Transition of Critical Fatigue Level from Road Surface to Lower Interface of Asphalt Layer

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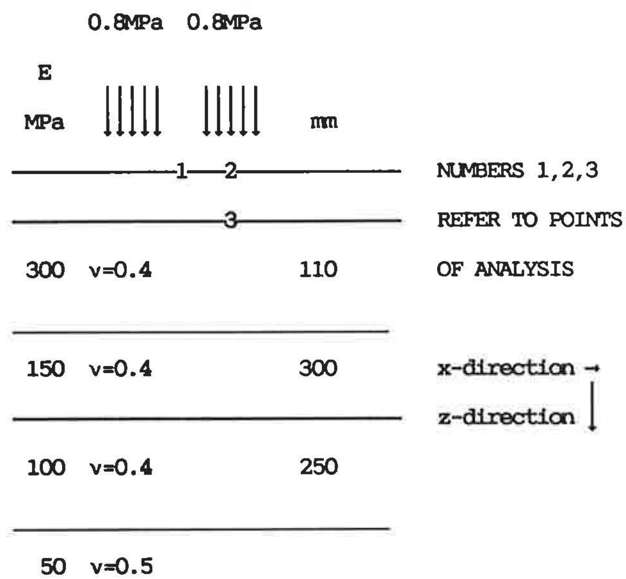
This paper deals with strains in thin asphalt surfacings on granular pavement layers, the purpose being to find whether highest tensile strains occur in the road surface or at the bottom interface of the asphalt layer. The study was based on an analysis by the BISAR program of an asphalt pavement loaded by a 10-ton axle dual-wheel load. The modulus of the asphalt layer was 1,000–5,000 MPa and of the granular road base 150 and 250 MPa, the thickness of the asphalt layer varying from 20 mm and up. Tensile and shear strains were calculated in the road surface and the asphalt interface at the point of load symmetry and at the center of one of the contact areas. Comparison was made with a crude tire tread pattern model. Thin asphalt surfacings showed the highest tensile strain in the road surface. At increasing thickness there was a transition of highest strain from the surface to the lower interface of the asphalt layer, the transition thickness varying with assumed modulus values. Considering tensile strain, the transition thickness varied between 30 and 40 mm, depending upon assumed modulus values, whereas on the basis of shear strain the transition thickness varied between 30 and 50 mm. The assumed tire tread pattern model showed no significant difference in this strain distribution.

In analytical design of asphalt pavements, the critical stresses or strains are usually allocated to the lower asphalt interface (horizontal tensile strain) or to the subgrade upper interface (vertical compressive strain). The latter will in the long run cause permanent deformation and contribute to rutting of the road surface. The fact that similar permanent deformation occurs in the adjacent granular layers is usually disregarded in pavement design.

Critical strain in the asphalt layer usually occurs in the lower interface and causes cracking after a large number of vehicle passes. Thin asphalt pavements, however, may be under compression in the lower interface, whereas the road surface may at the same time be under tensile strain. When either of the controlling variables attains a certain value, there must be a transition of critical level from one interface to the other (road surface to lower interface or vice versa). In the present paper the conditions for such transitions will be illuminated.

TRAFFIC LOAD

The following wheel load and pavement model was used:



The two circular loading areas have a radius of 100 mm, and the distance between loading centers is 300 mm. This pavement design is typical for rural roads in Sweden and contains a bituminous top layer, whereas the layers below are unbound granular. The thickness and stiffness modulus of the bitumen stabilized layer were varied, the Poisson's ratio being set at 0.35.

Influence of Top Layer Thickness

Strains calculated by the BISAR program are listed in Table 1, the asphalt modulus being set at 3,000 MPa.

Points 1 and 2 are located at the road surface and point 3 at the lower interface of the bitumen stabilized top layer. High thicknesses at the bottom of the table leave the road surface in a compressed state, whereas at lower thicknesses there are tensile strains in the road surface.

In the interval 20–150 mm, the highest tensile strain is vertical and appears under the center of the contact area. At the lower interface the horizontal strains are tensile (vertical is compressed and not shown). At low thickness these horizontal strains increase, thereafter passing a maximum, and then decreasing as the top layer grows in thickness. It may

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TABLE 1 TENSILE STRAINS XX, YY, AND ZZ AT POINTS 1, 2, AND 3

XX1	YY1	XX2	YY2	ZZ2	XX3	YY3	THICKN,mm
.359	-.429	-.422	-.525	.345	.156	.149	20
.349	-.464	-.476	-.587	.407	.297	.330	30
.267	-.479	-.459	-.584	.397	.335	.402	40
.176	-.474	-.415	-.551	.355	.327	.419	50
.100	-.456	-.368	-.508	.306	.305	.412	60
.042	-.431	-.326	-.464	.260	.281	.395	70
.001	-.404	-.291	-.423	.219	.259	.373	80
-.046	-.350	-.240	-.355	.155	.221	.327	100
-.065	-.303	-.205	-.303	.108	.190	.285	120
-.068	-.247	-.172	-.246	.060	.154	.231	150

Note: Directions are indicated in the diagram of the model given in the previous section. Values are in units of millistrain (1/1,000).

seem contradictory that vertical tensile strains (ZZ2) exist under the loaded surface. If, however, for simplicity the pavement layer is considered as a beam bent under load, it is obvious that a state of vertical tension exists in the upper surface, which may not be fully neutralized by the compressive action of the bending force.

At some points there is a tensile strain in one direction and compressive strains in other directions. Assessment of the significant state of strain at such a point requires further examination. Significant information will be provided by the strains in the direction of principal stress or the shear in the direction of principal shear stress. The maximum shear strains in these directions are listed by the BISAR program. Thus the highest shear strains are listed in Table 2. At point 1, all maximum shear strains are lower than in points 2 and 3.

The tensile strains are plotted against asphalt thickness in Figure 1 and the shear strains are plotted against asphalt thickness in Figure 2. According to Figure 1, the highest tensile strain is the horizontal tensile strain (XX1), which at an unrealistically low thickness is taken over by the vertical strain under the load center (ZZ2), which at a thickness of 39 mm is taken over by the horizontal tensile strain at point 3 (lower interface under the load center). If the vertical tensile strain is disregarded, the highest tensile strain at low thickness occurs at the point of symmetry between the loads in the road surface, this strain being taken over by the lower interface tensile strain YY3 at 31-mm thickness.

If the shear strains are considered (Fig. 2), it appears that at low thickness the highest strain γ_2 occurs in the road surface under the load center (position 2), but at higher thickness the shear strain γ_3 at the lower interface (position 3) is higher, the transition occurring at a thickness of 47 mm. Since 100 kg/m^2 of asphalt (40–45 mm) is a common surfacing thickness of rural roads in Sweden, this would mean that, under the assumptions made, the highest risk of fatigue cracking would exist in the road surface.

TABLE 2 MAXIMUM SHEAR STRAINS

THICKN	γ2	γ3
mm	microradians	
20	435	242
30	497	407
40	491	462
50	453	463
60	407	443
70	362	417
80	322	389
100	255	336
120	206	290
150	153	234

Influence of Asphalt Modulus

The relation between strains and moduli of the asphalt-bound layer is demonstrated in Figures 3–6. Figure 3, showing a typical thin 40-mm surfacing, makes the classical horizontal

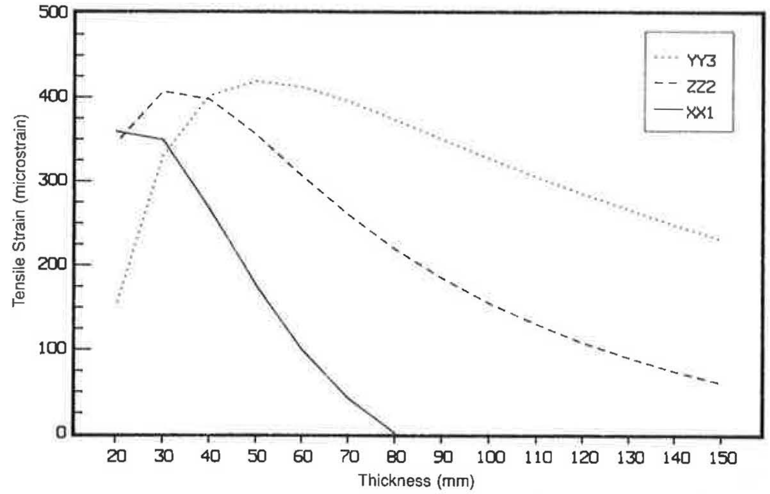


FIGURE 1 Tensile strains XX1, ZZ2, and YY3 as a function of thickness of asphalt-bound layer when asphalt layer modulus is 3,000 MPa (435 ksi).

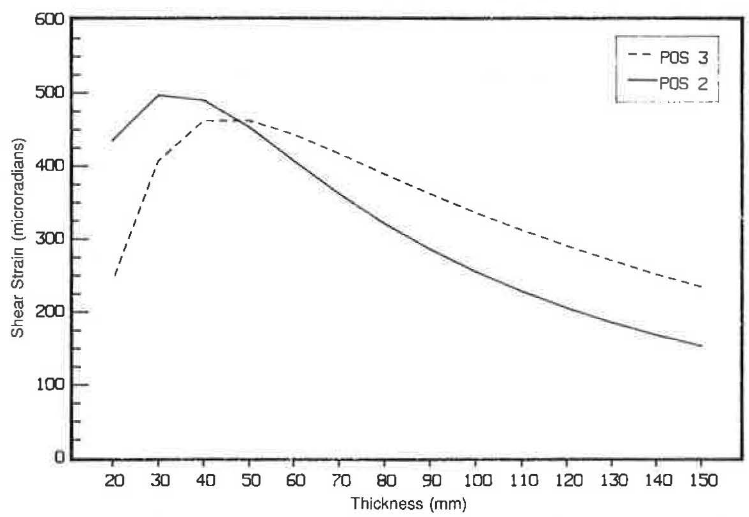


FIGURE 2 Shear strains at positions 2 and 3 when asphalt modulus is 3,000 MPa.

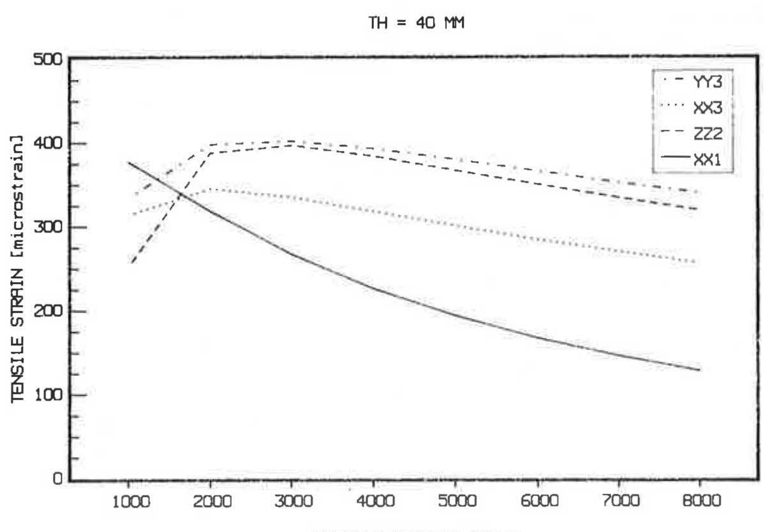


FIGURE 3 Tensile strains XX1, ZZ2, XX3, and YY3 as a function of asphalt-bound layer modulus, thickness 40 mm (1.6 in.).

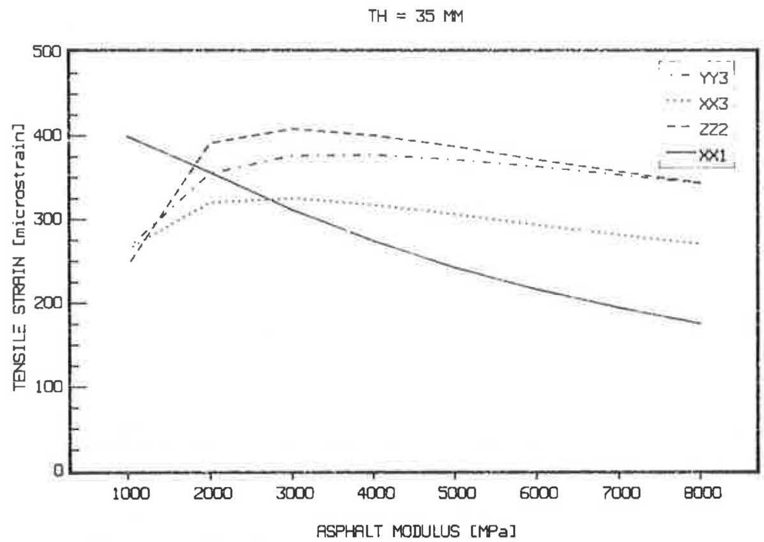


FIGURE 4 Tensile strains XX1, ZZ2, XX3, and YY3 as a function of asphalt-bound layer modulus, thickness 35 mm (1.4 in.).

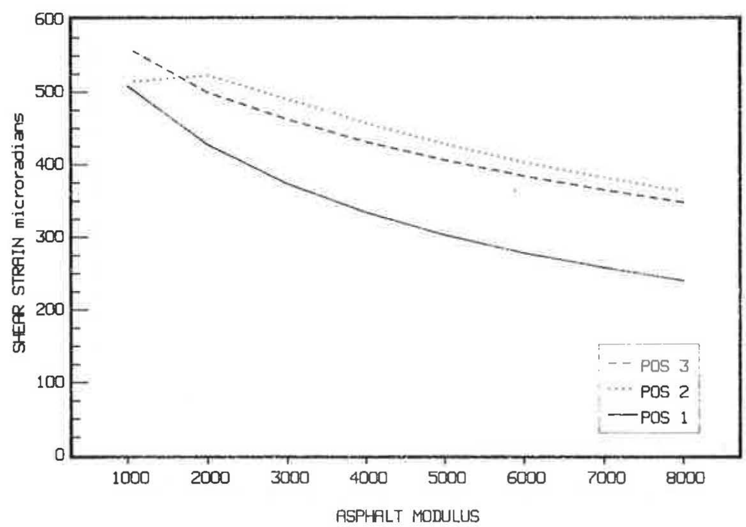


FIGURE 5 Shear strains at positions 1, 2, and 3 as a function of modulus of asphalt-bound layer thickness, 40 mm.

bottom strain critical at any modulus of reasonable value, whereas Figure 4 shows higher values for the vertical tensile strain in the road surface at the center of the contact area (position 2). On the other hand, if shear strains are considered (Figs. 5 and 6), position 2 is critical at both thicknesses at reasonable moduli levels.

Plots of the tensile and shear strains against asphalt thickness at 2,000 and 5,000 MPa asphalt moduli (Figs. 7–10) show a rather unwieldy picture, if tensile strains are considered, whereas the shear diagrams confirm a transition from critical surface to critical interface at an asphalt thickness between 40 and 50 mm.

Influence of Tire Tread Pattern

In a recent study, Roberts et al. (*1*) demonstrate quite an uneven distribution of contact pressure over the contact area; further, the contact pressure is considerably higher than expected from consideration of pneumatic pressure and load only. In the present study a contact pressure of 0.8 MPa was assumed, and the tire has so far been treated as giving a rectangular contact pressure distribution.

A simple approach to the influence of tire pattern has been made by considering a contact zone composed of several circular loads, together forming a contact area of approximately the same size as in the simple model used above. The pattern is outlined in Figure 11. For simplicity, the contact zone is assumed to carry a load of 25,000 N equally distributed over 32 circles. The contact pressure will then be 1.1 MPa in the interface between each circle and the road surface and nil between the circles.

Analysis of the strain distribution was made by assuming the pavement shown above, the surfacing having a thickness of 40 mm and an elastic modulus of 3,000 MPa. The result is listed in Table 3.

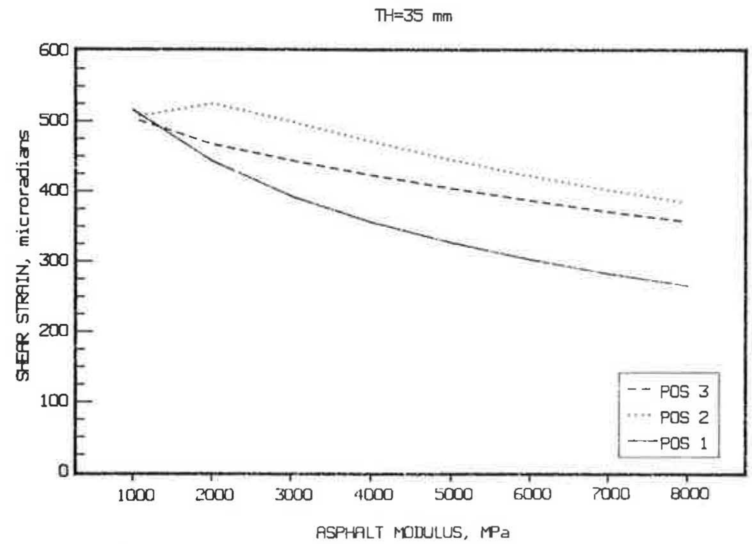


FIGURE 6 Shear strains at positions 1, 2, and 3 as a function of modulus of asphalt-bound layer thickness, 35 mm.

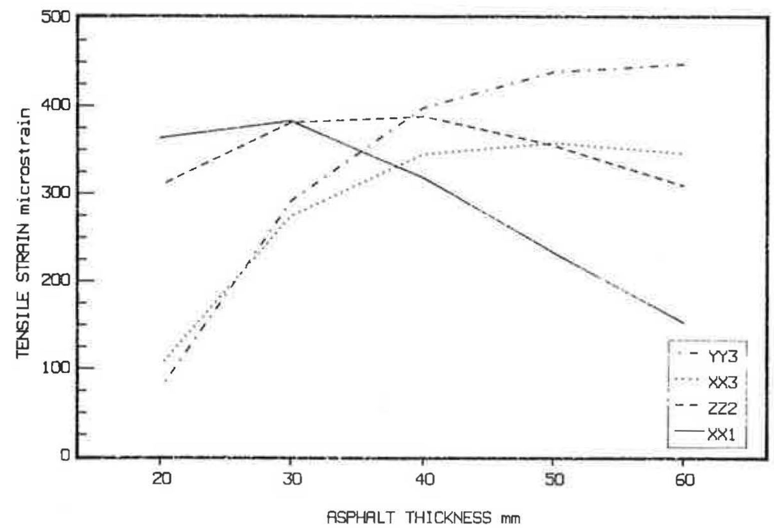


FIGURE 7 Tensile strains XX1, ZZ2, XX3, and YY3 as a function of thickness of asphalt-bound layer, when asphalt layer modulus is 2,000 MPa.

The table shows no dramatic differences between the two tire types. The differences between the subgrade values are negligible. The greatest difference occurs at the asphalt interface, showing horizontal tensile strains 309 and 396, respectively; the higher value appears at the center of the loading circle. This difference may correspond to a displacement of the transition curves found but will not change the general transition picture obtained from the simpler contact area model used.

Influence of Base Course Modulus

The variation with asphalt thickness of the horizontal strain in the direction of motion (YY3) at the asphalt interface at different values of the base course modulus is demonstrated in Figure 12, the pavement design being the same as in Table 3. The figure demonstrates the neutralizing effect of a thick asphalt layer at different modulus values of the base course.

The combined influence of asphalt modulus and granular base modulus on the transition of highest strain from the surface to the interface is shown in Table 4. The effect of increasing moduli of surfacing as well as granular base is obviously to slightly push the transition point to a greater asphalt thickness, confirming that critical road surface predominantly belongs to comparatively thin surfacings and low stiffness.

CONCLUSIONS

Highest tensile strains have been found to occur at the surface of the road in thin asphalt surfacings; however, the level of

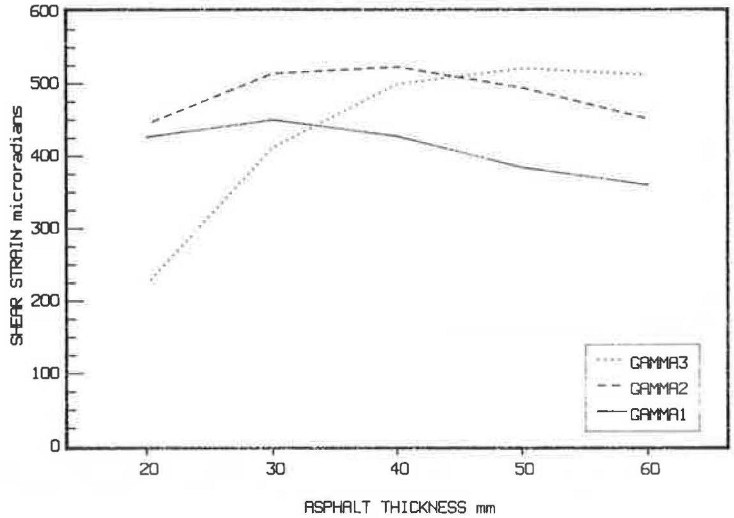


FIGURE 8 Shear strains at positions 1, 2, and 3 as a function of asphalt layer thickness when asphalt layer modulus is 2,000 MPa.

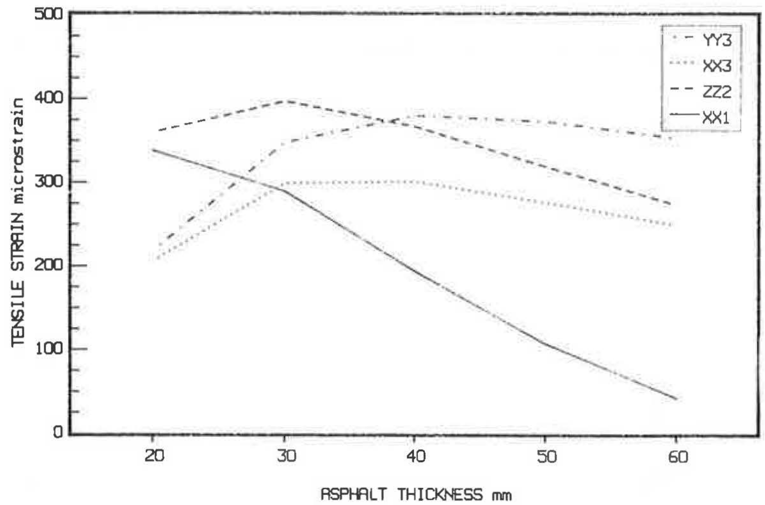


FIGURE 9 Tensile strains XX1, ZZ2, XX3, and YY3 as a function of thickness of asphalt-bound layer when asphalt layer modulus is 5,000 MPa.

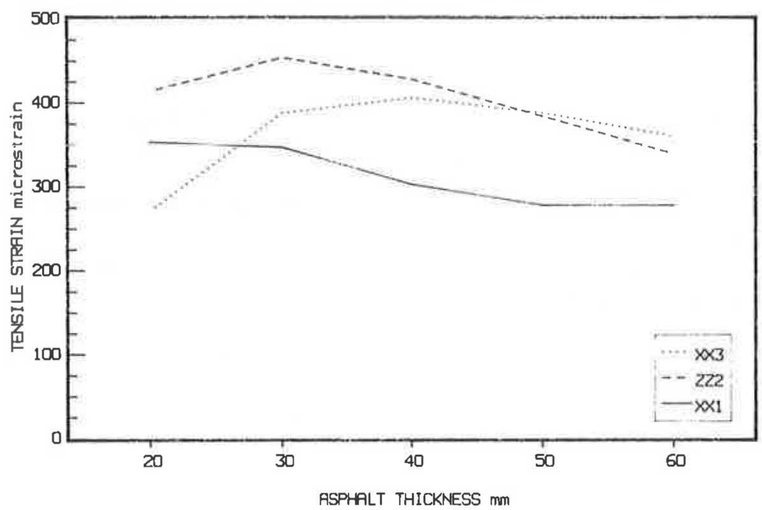
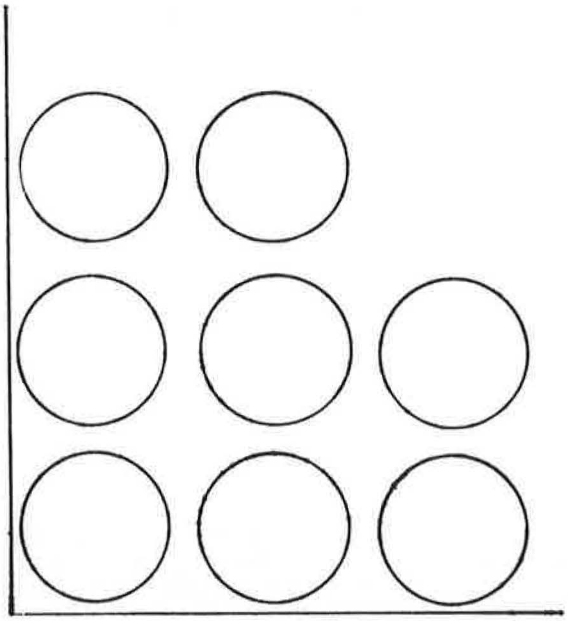


FIGURE 10 Shear strains at positions 1, 2, and 3 as a function of asphalt layer thickness when asphalt layer modulus is 5,000 MPa.



x	17.5	17.5	17.5	52.5	52.5	52.5	87.5	87.5
y	17.5	52.5	87.5	17.5	52.5	87.5	17.5	52.5

FIGURE 11 Assumed tire contact pattern under the following conditions: number of contact areas, 32; radius of contact areas, 15 mm; contact pressure, 1.11 MPa; total load, 25 kN. Coordinates of contact areas, in millimeters, are given at bottom of figure. One quadrant is shown.

highest strain is transferred to the lower asphalt interface at increasing thickness of the surfacing. The transition thickness varies moderately with asphalt modulus and with base course modulus. According to the present study, the absence of tread pattern does not influence the findings qualitatively, as long as only contact pressures are considered. The relation between inflation pressure and contact pressure is a different problem.

The three positions (1, 2, 3) considered above were analyzed only with respect to tensile and shear strains. The strength of the material will also be influenced by the current bulk strain ($\varepsilon_1 + \varepsilon_2 + \varepsilon_3$), i.e., the sum of the tensile strains in the three principal directions of stress. An analysis of the

TABLE 3 INFLUENCE OF MODEL TIRE PATTERN ON PARAMETERS STUDIED

Depth mm	XX microstrain	ZZ microstrain	UZ mm		MPa	mm
0	-387	417	0.61	between	3000	40
40	309	-438	0.61	pattern	300	110
700	122	-244	0.27	circles	150	300
					100	250
0	-387	417	0.61	centre	50	
40	309	-436	0.61	of pat-		
700	122	-244	0.24	tern circle	↑	
					pavement	
0	-515	389	0.64	tire of no	design	
40	396	-594	0.64	tread pat-		
700	123	-246	0.24	tern		

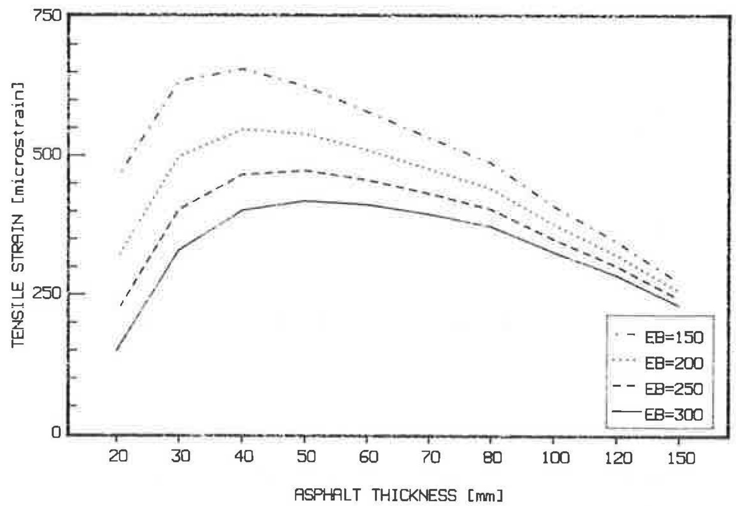


FIGURE 12 Variation of the horizontal strain at the bottom of the asphalt stabilized layer under one circular load as a function of thickness of the asphalt stabilized layer at different modulus values of the base course.

TABLE 4 COMBINED EFFECT OF DIFFERENT BASE AND SURFACING MODULI ON TRANSITION OF HIGHEST STRAIN FROM SURFACE TO INTERFACE

Easph MPa	Ebase MPa	Shear crit. Z (mm)	Shear crit. X (mm)	Strain crit. Z (mm)	Strain crit. X (mm)	Strain crit. change of dir.
1000	150	30	0	37	0→150	XX→YY
1000	250	42	150	39	0→150	ZZ→YY
3000	150	37	150	32	150	ZZ→YY
3000	250	47	150	39	150	ZZ→YY
5000	150	35	150	30	150	ZZ→YY
5000	250	53	150	36	150	ZZ→YY

influence of "continuously acting stresses" on the response to fluctuating stresses, given by Monismith et al. (*2*), is an approach to a solution of this very problem.

It is also reasonable that microcracks in the road surface develop into harmful road damage more quickly than similar cracks in the lower interface due to invasion of water and material particles. The transition thicknesses given in this paper may therefore not necessarily reflect transition with respect to fatigue only. These thicknesses probably are greater than those corresponding to transition with respect to highest tensile or shear strain.

The BISAR program used for analysis in the present paper describes a simplified model of real pavements. Therefore, the transition thicknesses reported in the paper cannot be taken as accurate to the millimeter but rather as an indication of the fact that the classical allocation of fatigue crack initiation is not necessarily applicable, especially to pavements with comparatively thin bituminous layers.

Crack initiation in the road surface was the subject of discussion at the recent Ann Arbor Conference, which took place after the present work was finished. However, there is difficulty in establishing by mere observation whether a fully developed crack was initiated at the surface or at the bottom of the pavement layer.

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2. C. L. Monismith, D. B. McLean, and R. Yuce. *Design Considerations for Asphalt Pavements.* Report TE 72-4. University of California, Berkeley, 1972.

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