Abridgment

Possible Effect of Relative Plastic Behavior of Pavement Layers on Pavement Life

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The effect of the relative plastic behavior of the layers of three flexible pavements on the accuracy of their predicted pavement life (10 million standard axle passes) shown on a Shell design chart is investigated theoretically. The layers are treated by mechano-lattice stress analysis as elastoplastic materials. The analyses suggest that (a) when the asphaltic surface acts more plastically than the base and subgrade, lower-surface fatigue life becomes infinite but upper-surface fatigue life is reduced to less than that predicted by the Shell chart and (b) when the base and subgrade act more plastically than the asphaltic concrete surface, lower-surface fatigue life is drastically reduced. The rutting lives of pavements with upper layers that behave more plastically are shorter than those with upper layers that behave less plastically.

A number of flexible pavement design systems use the theory of linearized elasticity to determine those critical repeated stresses and strains that control rutting life and fatigue life. A question arises: What are the consequences of subjecting a pavement whose layers have different plastic behavior to the usual elastic analysis? The mechano-lattice stress-strain analysis is used in this paper to suggest some answers to this question.

The mechano-lattice, which is a type of mechanized finite-element analysis applied to multilayered elastoplastic flexible pavements, has been described fully elsewhere (1-4). It has also been used successfully to predict measured pavement performance (5,6) and to assess fabric reinforcement (7). Three points on a curve from Shell design chart HN84 (8), modified to a weighted mean air temperature (WMAAT) of 23°C (74°F), are examined to determine the theoretically possible changes in fatigue life and rutting life caused by variations in the plastic behavior of the pavement materials.

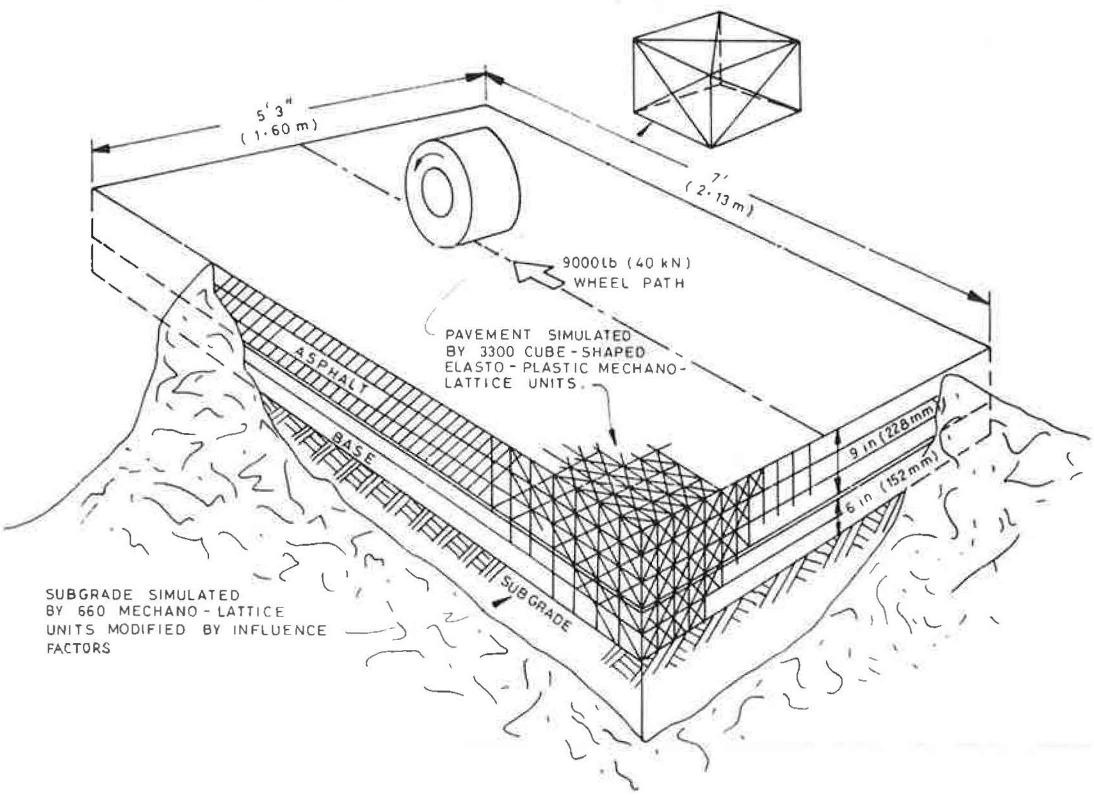
The elastoplastic mechano-lattice units are assembled as shown in Figure 1. The loaded wheel is assumed to move in one direction only so that one or more simulated passes leave behind residual rutting and stresses that accumulate with each additional simulated pass.

To illustrate the possible effects of variations in relative plastic behavior between layers, three hypothetical pavements with different relative plastic behavior were analyzed (see Figure 2) for each of the thickness designs represented by points A, B, and C on the Shell design chart shown in Figure 3. Thus, nine pavements were analyzed.

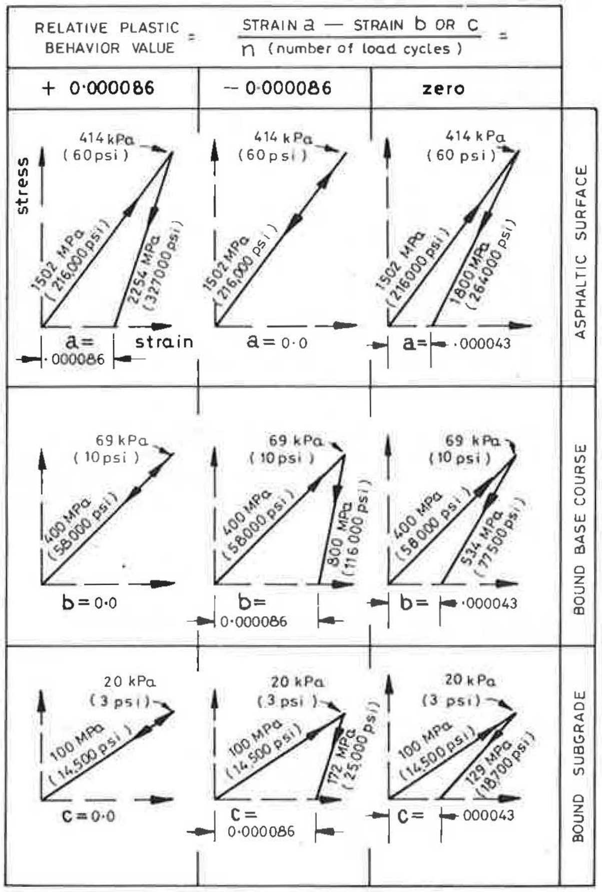
REPRESENTATION OF PLASTIC BEHAVIOR

The definition of relative plastic behavior is given in Figure 2, where the means of achieving the three relative plastic behavior values used in this investigation are illustrated by load-unload hysteresis loops. Thus, when the relative plastic behavior is positive (+0.000086), the asphaltic concrete (AC) in a triaxial test has a residual compressive strain of

Figure 1. Assembly of mechano-lattice units to simulate three-layered pavements.



Figuer 2. Hysteresis loops that characterize plastic behavior of each of three layers in pavements for different relative plastic behavior values.



0.000086 because the unloading modulus is greater than the loading modulus and the bound base and bound subgrade are assumed to be elastic (elastic moduli are taken from the particular Shell design chart). When the base and subgrade act more plastically than the elastic asphaltic concrete surface, the relative plastic behavior is negative (-0.000086 column in Figure 2). When all three layers have the same plastic behavior, the relative plastic behavior is zero, as in the third column in Figure 2.

The unloading moduli shown in Figure 2 are calculation expedients and only affect the relation between calculation passes and standard axle passes, as will be seen later.

COMPUTATION RESULTS

The two outputs from the computations studied here are (a) a 1.22-m (4-ft) straight-edge rutting ratio, defined as the rut depth under a 1.22-m straight edge, and (b) the transient and residual lateral stress (to determine fatigue behavior).

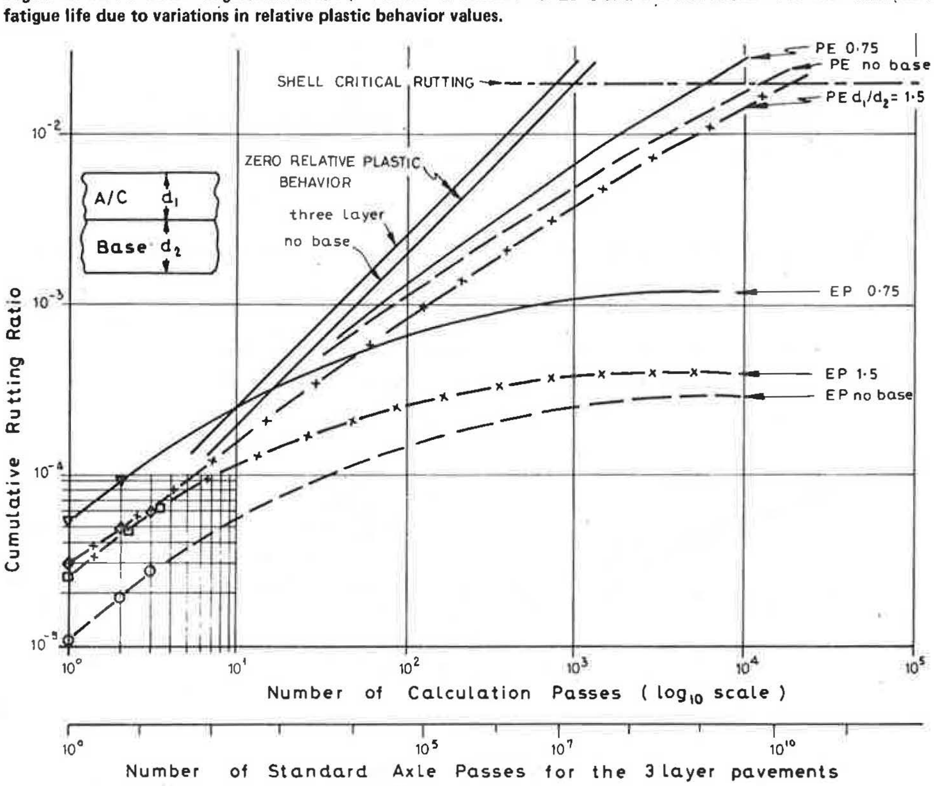
Rutting

Figure 4 shows the cumulative rutting ratio extrapolated over a range from one or two calculation passes to past the life of the pavement expected by the Shell chart. The extrapolations were assumed to be circular curves. Zero plastic behavior (PP) gave straight lines, positive relative plastic behavior (PE) gave a common large radius, and negative relative plastic behavior (EP) gave smaller radii.

The relation between calculation passes and standard axle passes is fixed by making the following assumptions:

1. The relative plastic behavior represented by the Shell design chart (last column of Figure 2) is zero (see plot D in Figure 4).

Figure 3. Part of Shell design chart HN84 (modified for WMMAT of 23°C and one base modulus of 0.4 million MPa) with calculated variations in rutting and fatigue life due to variations in relative plastic behavior values.



2. According to the Shell chart, Shell critical rutting is achieved at 10 million standard axle passes, which in Figure 4 is equivalent to about 800 calculation passes for points B and C in the Shell chart in Figure 3.

3. The first calculation pass is assumed to simulate the first standard axle pass.

The predicted rutting lives for the nine pavements are summarized in the lower plot in Figure 3.

Fatigue

Figure 5 shows how the transient lateral tensile stress at the bottom of the AC layer decreases with each calculation pass for pavement B with positive relative plastic behavior (PE). Thus, lower-surface fatigue life is likely to increase although upper-surface life may decrease. On the other hand, Figure 6 shows that the transient lateral stress at the bottom of the AC layer increases with each pass when the relative plastic behavior is negative (EP). This should reduce fatigue life in the lower surface. The rise, fall, and steady state of these fatigue stresses were converted to strains and extrapolated on a linear strain versus $\log_{10}$ (number of standard axle passes) plot. The fatigue lives were then determined on plots of log (tensile strain) versus log (number of standard axle passes). The Shell fatigue envelope and the same equivalency between calculation passes and standard axle passes as were determined from rutting were used (Figure 4).

CONCLUSIONS

Figure 3 summarizes the results of this study. Part of the Shell design chart, modified to a WMAAT of 23°C, is shown above the variations in fatigue and rutting life suggested as being the effects of varying relative plastic behavior. Thus, when the relative plastic behavior is positive--i.e., the asphaltic surface acts more plastically than the base and subgrade--then

1. Calculations indicate that fatigue life could be controlled by cracking in the upper surface and that it is shorter than that indicated by the Shell method. But the fatigue life of the lower AC surface is extended.

Figure 4. Cumulative rutting versus number of calculation passes extrapolated to Shell critical rutting on log-log plot, including some pavements with linearly elastic layers.

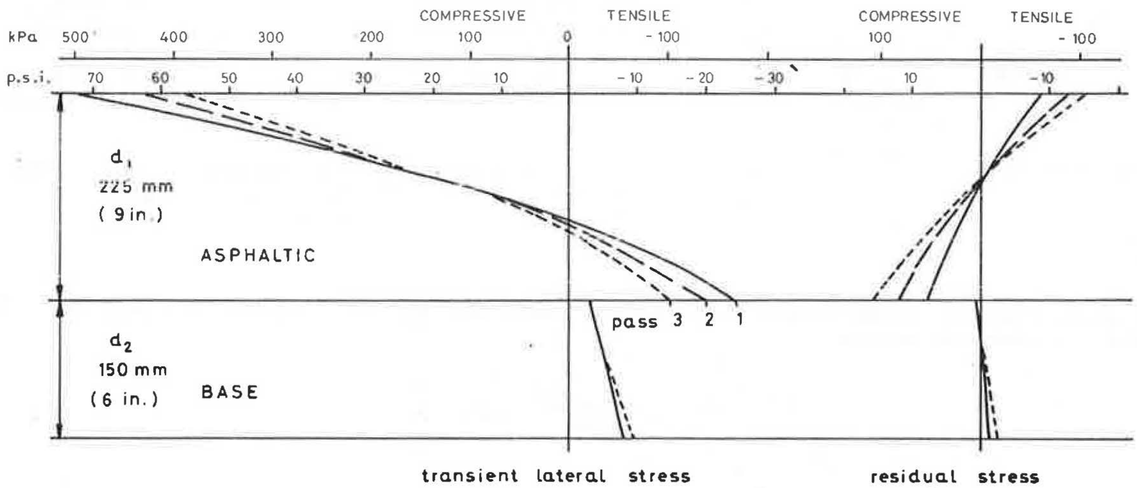


Figure 5. Stress results for three-layered pavement (B in Figure 3) for first three calculation passes: positive relative plastic behavior value and consequent reduction in transient tensile stresses in bottom of AC layer.

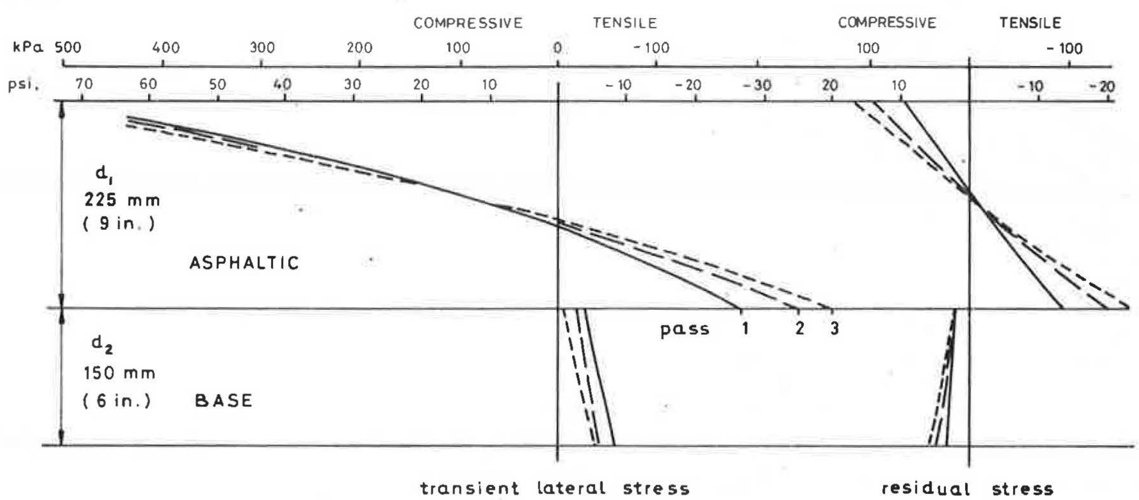
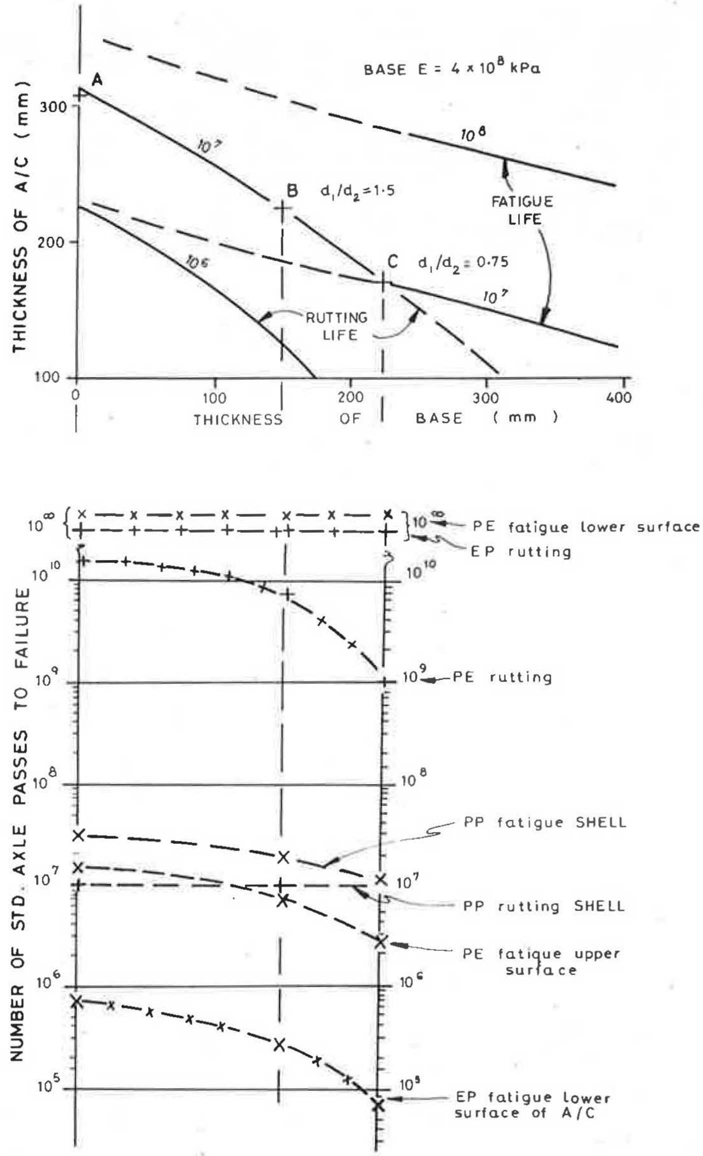


Figure 6. Stress results for three-layered pavement (B in Figure 3) for first three calculation passes: negative relative plastic behavior value and consequent increase in transient tensile stresses in bottom of AC layer.



2. Rutting life is longer than Shell rutting life due to the fact that in this study the base and subgrade are nonplastic.

When the relative plastic behavior is negative--i.e., the base and subgrade act more plastically than the asphaltic concrete--then

1. The fatigue life of the lower AC surface can decrease, in one case, to one-hundredth of the Shell fatigue life.
2. Rutting life is again longer than Shell rutting life because the AC is assumed to be elastic. The significant observation is that rutting is also less than it is when positive relative plastic behavior obtains. The absolute plasticity of all layers has the greatest effect on rutting.

ACKNOWLEDGMENT

I wish to thank I.K. Lee of the University of New South Wales and R.L. Lytton of the Texas Transportation Institute for their support and encouragement. This work has been supported since June 1981 by the Australian Research Grants Committee.

REFERENCES

1. W.O. Yandell. Prediction of the Behavior of Elastoplastic Roads During Repeated Rolling Using the Mechano-Lattice Analogy and the Results of Cyclic Load Material Tests. HRB, Highway Research Record 374, 1971, pp. 29-41.
2. W.O. Yandell and R.L. Lytton. The Effect of Residual Stress and Strain Buildup in a Flexible Pavement by Repeated Rolling of a Tire. Texas Transportation Institute, A&M Univ., College Station, Rept. RF 4087-1, Oct. 1979.
3. W.O. Yandell. Residual Stresses and Strains and Fatigue Cracking. Transportation Engineering Journal, ASCE, Vol. 108, No. TE1, Jan. 1982, pp. 103-116.
4. W.O. Yandell. The Use of the Mechano-Lattice Analysis to Investigate Relative Plastic Behavior. International Conference on Constitutive Laws for Engineering Materials, Tucson, Ariz., Jan. 8, 1983.

5. W.O. Yandell. Measurement and Prediction of Forward Movement and Rutting in Pavements Under Repetitive Wheel Loads. TRB, Transportation Research Record 888, 1982, pp. 77-84.
6. W.O. Yandell. Rutting and Cracking Prediction at P.S.U. Test Track Using Mechano-Lattice Analysis. Univ. of New South Wales, Kensington, Australia, Rept. UNICIV R-207, Nov. 1982.
7. W.O. Yandell and J.I. Curiskis. Fabric Reinforcement to Extend Pavement Life. Annual meeting, Assn. of Asphalt Paving Technologists, Atlanta, March 1983.
8. Shell Pavement Design Manual: Asphalt Pavements and Overlays for Road Traffic. Shell International Petroleum Co., Ltd., London, 1978.

Publication of this paper sponsored by Committee on Strength and Deformation Characteristics of Pavement Sections.