Engineering Journal of ASCE, Vol. 105, No. TE1, Jan. 1979, pp. 71-89.
8. A.E. Hoerl and R.W. Kennard. Ridge Regression: Application to Nonorthogonal Problems. Technometrics, Vol. 12, 1970, pp. 69-82.
9. A.T. Visser, C.A.V. Queiroz, and W.R. Hudson. Prediction of Tropical Roadbed Resilient Modulus from Standard Material Tests. Proc., Brazilian Symposium on Tropical Soils in Engineering, Federal Univ. of Rio de Janeiro, Brazil, Sept. 21-23, 1981, pp. 615-635.
10. A.T. Visser. An Evaluation of Unpaved Road Performance and Maintenance. Univ. of Texas at Austin, Ph.D. dissertation, May 1981.
11. F. Hsia and J. Padgett. Barry Creek Road Failure Investigation and Overlay Design. Region 5, Forest Service, U.S. Department of Agriculture, San Francisco, CA, Geotechnical and Materials Engineering Project 10521, Nov. 1978.
12. D.J. Van der Merwe. Summary of Information Related to the Characterization of Roadbed Materials During the Period 1978-1979. National Institute for Transport and Road Research, Council for Scientific and Industrial Research, Pretoria, South Africa, NITRR Tech. Note TP/25/80, March 1980 (in Afrikaans).
13. AASHO Road Test. HRB, Special Rept. 61G, 1962.
14. M.R. Thompson and Q.L. Robnett. Final Report--Data Summary: Resilient Properties of Subgrade Soils. Department of Civil Engineering, Univ. of Illinois, Urbana, Rept. UILU-ENG-76-2009, June 1976.

Aggregate Pavement Design: A Comparison of Two Models

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The U.S. Army Engineer Waterways Experiment Station (WES) model for Thickness Requirements for Unsurfaced Roads and Airfields is compared with the model developed from the Interim Guide for the Design of Flexible Pavement Structures of the American Association of State Highway and Transportation Officials (AASHTO). The WES model extends an earlier model for a single unsurfaced soil to include a more competent surfacing material overlying a subgrade soil. The AASHTO model for flexible pavements with a bituminous surface course is based primarily on the AASHO Road Test and associated studies. The paper demonstrates the adaptation of the WES model into the same parameters as the AASHTO model. These models, on three-dimensional drawings, show continuous curved surfaces from a minimum required pavement strength at low traffic and high subgrade strength, to progressively higher required pavement strengths at higher traffic and weaker subgrades. Of particular significance is the dramatic similarity of the two models, although one was developed for soil surfaces and the other for asphalt surfaces. The WES (soil surface) model indicates a required pavement strength 10-50 percent lower than the AASHTO (asphalt surface) model for the same traffic and subgrade strength. From this comparison, it is concluded that the WES model provides cost-effective aggregate pavement designs.

This paper compares the U.S. Army Engineer Waterways Experiment Station (WES) model for Thickness Requirements for Unsurfaced Roads and Airfields: Bare Base Support (1) with the model developed from the Interim Guide for the Design of Flexible Pavement Structures of the American Association of State Highway and Transportation Officials (AASHTO) (2). The procedure used here compares the models on a common-parameter basis for purposes of evaluation and discussion. The comparison gives an added perspective to both models and substantiates the application of the WES model in the design of aggregate-surfaced pavements for low-volume roads.

The WES model extends an earlier model for a single unsurfaced soil to include a more competent surfacing material overlying a subgrade soil. The model determines the thickness and minimum California bearing ratio (CBR) of surfacing material for a given number of coverages of a design wheel load and tire pressure in order to prevent failure of the subgrade soil. Failure was defined as a 3-in rut or elastic deformation of 1.5 in of the surface. The model is based on load tests of a variety of surfacing material strengths and depths over a variety of subgrade strengths by a variety of wheel loads and tire pressures to represent both truck and aircraft traffic.

The AASHTO model for flexible pavements with a bituminous surface course is based primarily on the AASHO Road Test and associated studies. The failure criterion on the AASHO Road Test was a terminal serviceability index (TSI) of 1.5 on a serviceability scale of zero (very bad) to 5 (very good). The AASHTO model relates the number of equivalent 18-kip axle loads (EALs) to subgrade strength (soil support) to determine pavement strength [structural number (SN)]. This SN may be adjusted by a regional factor. Pavement alternatives are developed by summing layer thicknesses times layer strength coefficients to total the required SN. The procedure relates a variety of strength measures, such as CBR and R-value, to soil support and layer coefficients. The resulting pavement model considered here is designed to reach a TSI of 2.0 (complete resurfacing needed) at the end of its design traffic volume. A similar model for TSI = 2.5 is included in the AASHTO Interim Guide (2).

PROCEDURE

It was first necessary to convert the WES model to the same parameters as the AASHTO model--that is, soil support, number of 18-kip EALs, and SN. Then the models could be compared on three-dimensional and two-dimensional graphical plots.

Correlation charts for CBR and soil support and layer coefficients are used here to compare the models. As the AASHTO Interim Guide (2) cautions, correlations will vary with local soils and test methods.

To calculate plotting points for the WES model, a 9000-lb wheel load with pressure of 80 lb/in² was assumed. "Coverage" was assumed to be equivalent to the number of passes. Soil support of the subgrade was determined from the correlation chart, static CBR, shown in Figure 1 (2). Surfacing thickness was determined by using the WES equation (1):

$$t = (0.176 \log C + 0.12) \sqrt{[P/8.1\,(CBR)] - (A/\pi)} \quad (1)$$

Figure 1. Soil support correlation.

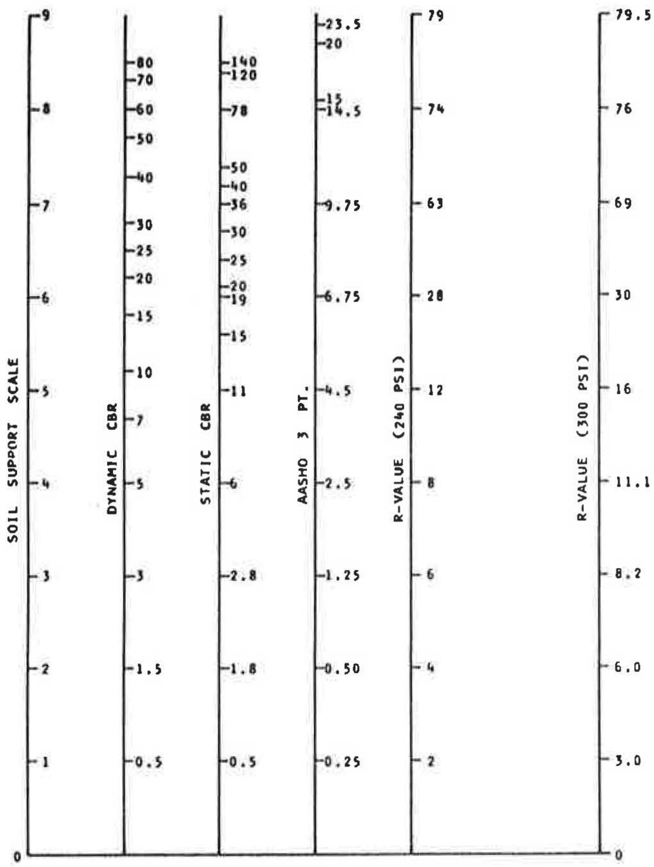
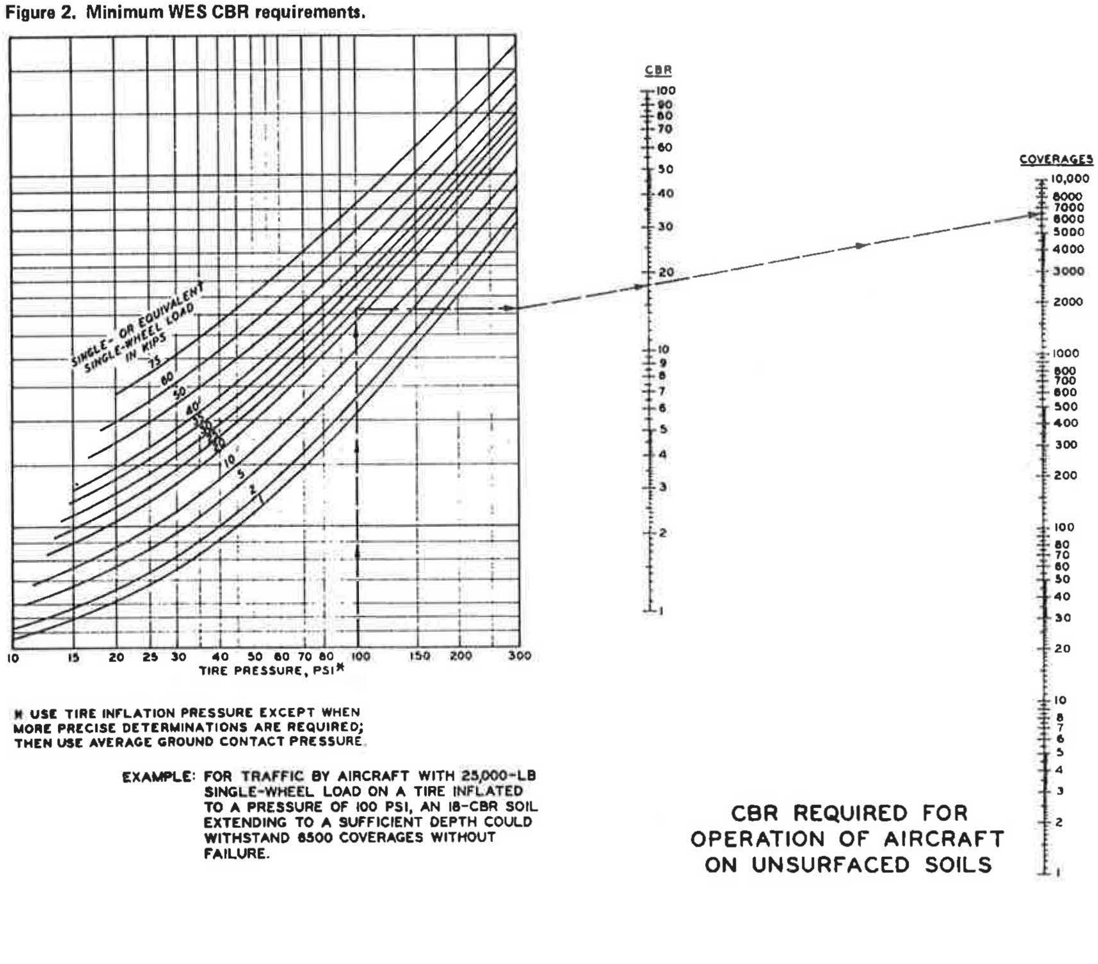


Figure 2. Minimum WES CBR requirements.



where

- t = design thickness (in),
- C = coverages,
- P = single or equivalent single wheel load (lb),
- A = tire contact area (in²) equal to load/tire contact pressure, and
- CBR = California bearing ratio of the subgrade soil.

The minimum surfacing CBR was determined from Figure 2 (1). Based on the surfacing thickness and minimum CBR, an equivalent SN was determined by using the a-layer strength coefficient determined from the correlation chart shown in Figure 3 for the surfacing CBR. The assumption, based on personal experience, to use the (a_3 - CBR) correlation was particularly significant and is discussed further later in this paper.

The following is a sample calculation for converting the WES model into AASHTO parameters for a subgrade CBR = 2.8 and 10 000 coverages:

Tire contact area A = 9000 lb/80 lb/in² = 112 in².

From the WES thickness equation, $t = [0.176 \log(10\,000) + 0.12] \sqrt{[9000/8.1\,(2.8)] - (112/\pi)}$ = 15.67 in.

From Figure 2, minimum surfacing CBR = 11.4.

From Figure 3, layer strength coefficient for CBR of 11.4, a = 0.084.

SN = at = 0.084 (15.67) = 1.32.

From Figure 1, for subgrade CBR = 2.8, soil support S = 3.

Therefore, for S = 3 and 10 000 18-kip EALs, SN = 1.32.

RESULTS

Figure 4 shows the three-dimensional plot of the AASHTO flexible pavement model. The plot shows the model as a surface curving upward from a minimum required SN at a low number of EALs and high soil support to progressively higher required SNs at higher numbers of EALs and lower soil support.

Figure 5 shows the three-dimensional plot of the WES model, including the plot of the sample calculated point. Figure 6 shows the WES model superimposed on the AASHTO model. The WES model closely shadows the AASHTO model, being essentially the same at S = 1 and giving increasingly lower SNs than the AASHTO model at higher traffic and soil support. Under 100 EALs, the AASHTO model goes to zero and the WES model gives slightly higher SNs. Figure 7 shows both models in two dimensions.

DISCUSSION OF RESULTS

That the WES model so similarly shadows the AASHTO flexible pavement model is striking, considering the widely different calculation format and the difference in test track surfacing materials. It is possible that the AASHTO model influenced development of the WES model or that the failure mechanisms are similar.

The WES model requires larger SNs than the AASHTO model for less than 100 coverages. This may be due

Figure 3. Layer coefficient correlation.

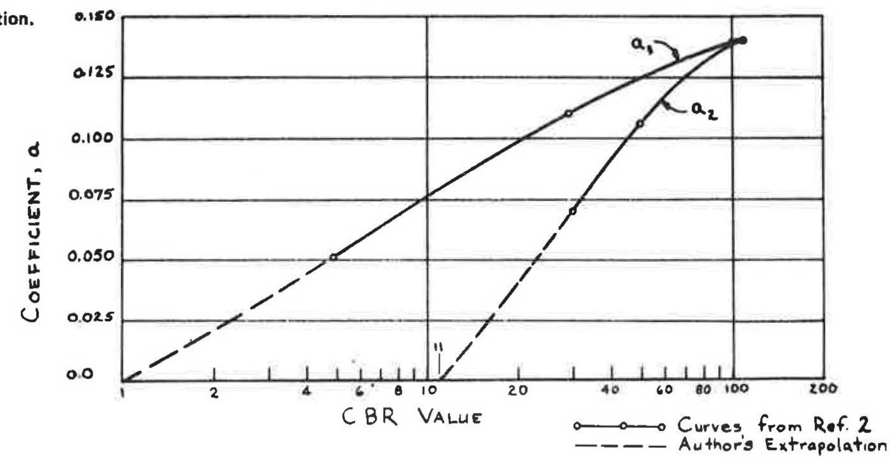


Figure 4. Three-dimensional plot of AASHTO model.

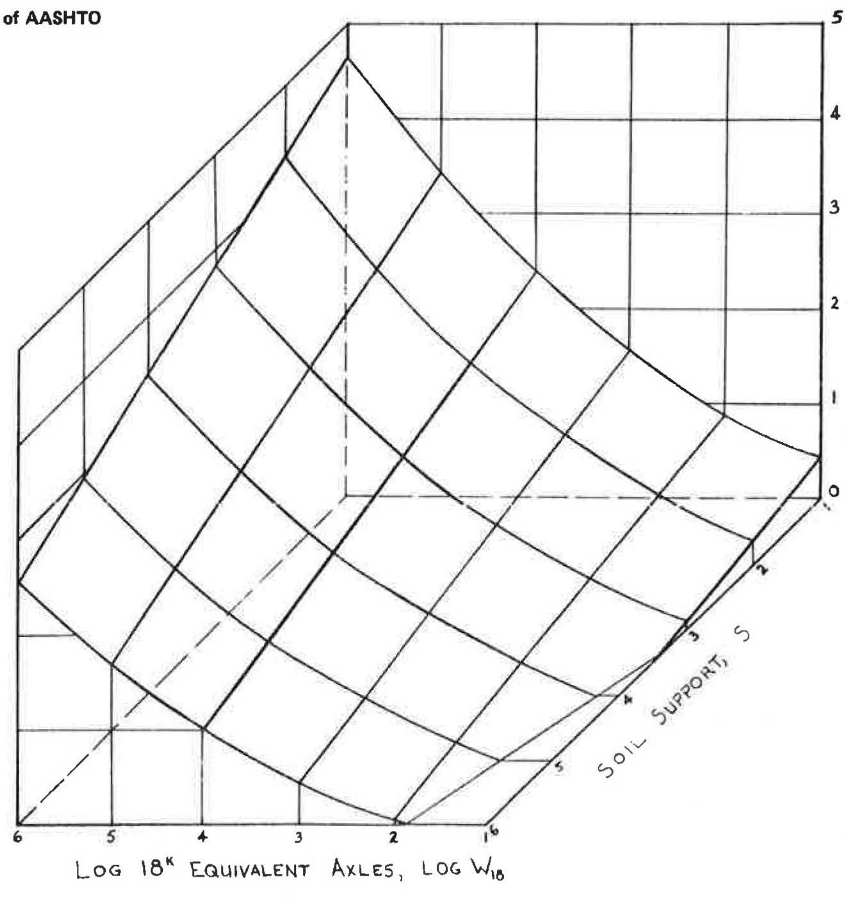


Figure 5. Three-dimensional plot of WES model.

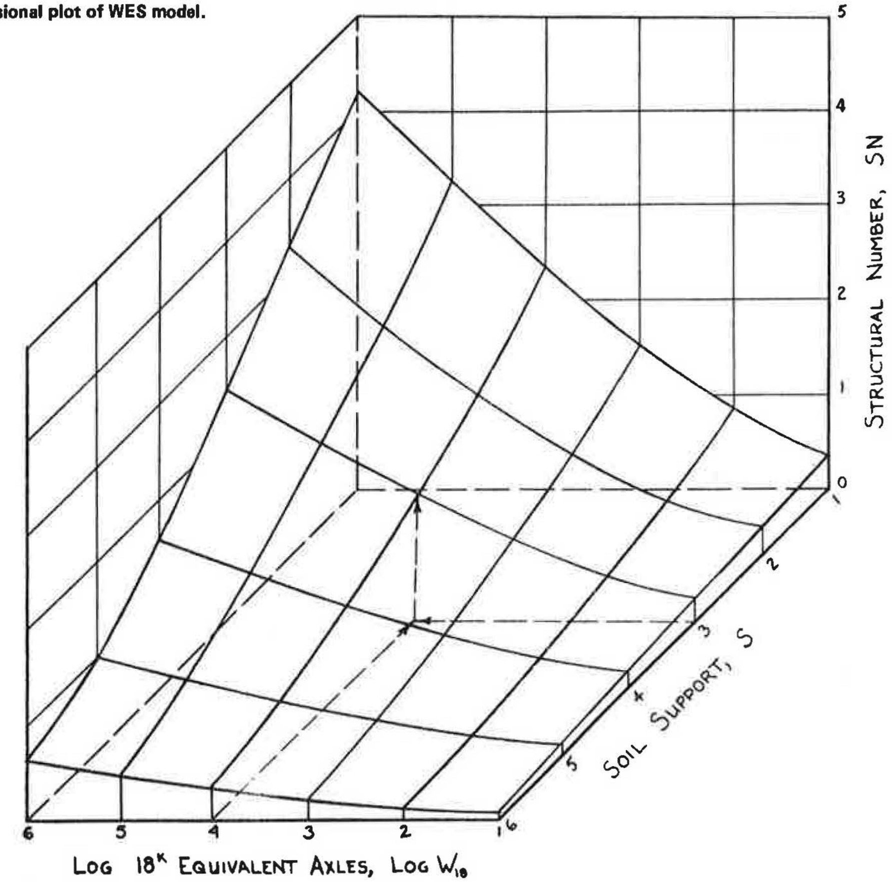


Figure 6. Three-dimensional plot of AASHTO and WES models.

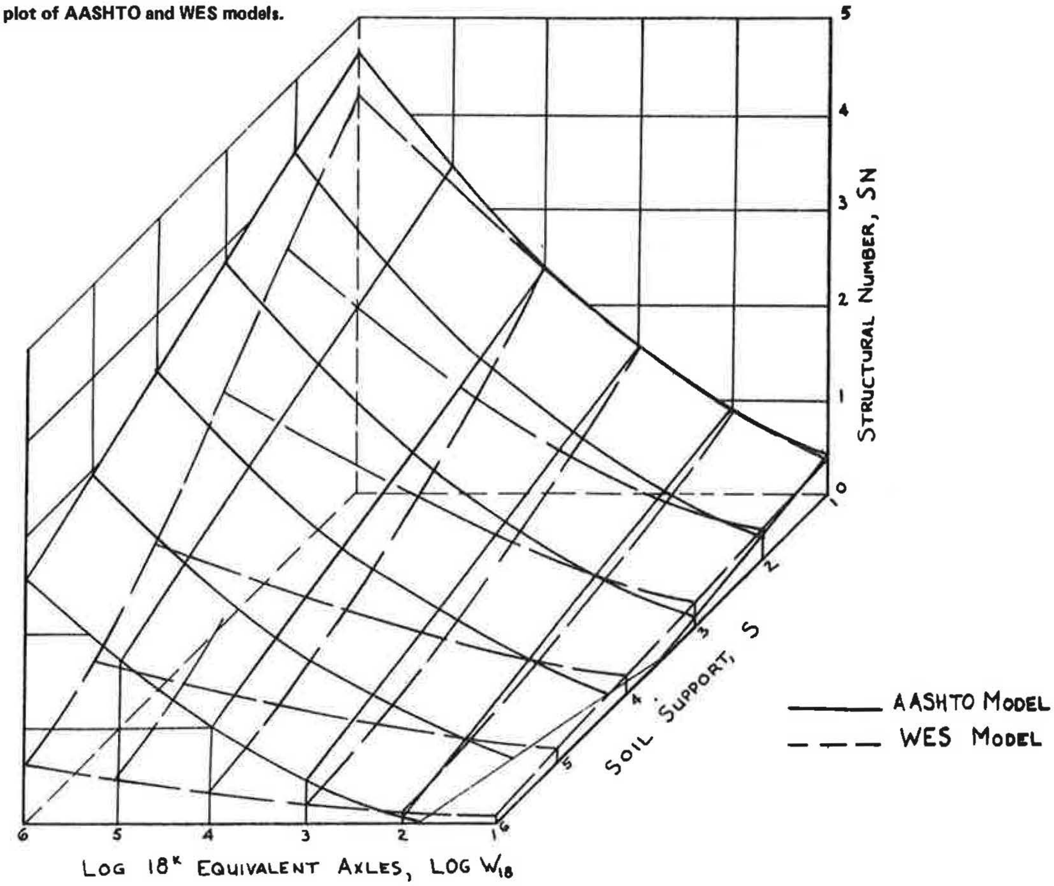
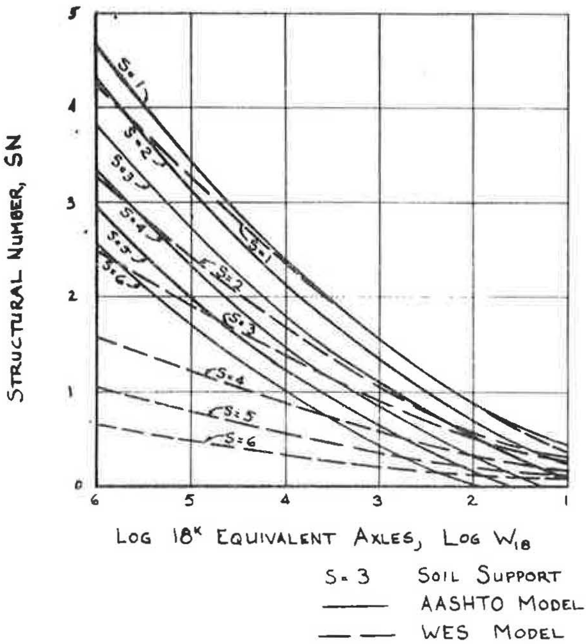


Figure 7. Two-dimensional plot of AASHTO and WES models.



to graphic extrapolation of the AASHTO model. Few roads are designed for less than 100 coverages, so this is not a significant inconsistency.

The portion of the WES model shown in this paper considers a very specific wheel load and tire pressure, whereas the total WES model considers the wide variety of loads and pressures necessary for the wide variety of aircraft. The more complex calculation procedures of the method are necessary to achieve this versatility. However, for the specialized use of road pavement design, a simpler procedure analogous to the AASHTO procedure could be used, as shown here.

It was noted in the procedure that the selection of the (a_3 - CBR) correlation for determining a strength coefficient for the surfacing layer was particularly significant. The AASHTO procedure would indicate that the layer coefficient should have been less for an upper layer, possibly as shown in Figure 3 for a_2. However, it can be seen from the sample calculations that a smaller layer coefficient would give an even lower design SN. For example, for the surfacing CBR of 11.4, a_2 would have been zero, even with a liberal extrapolation. Thus, the SN would have been zero also [SN = at = 0(15.08) = 0]. Thus, the whole WES model would be forced downward to give zero SNs for traffic less than 10 000 EALs. Different a correlations would similarly move the WES model upward or downward, but the shape would remain essentially as shown here.

When one looks at the layer coefficient qualitatively, even the weakest soils with CBRs of 1 or 2 must have some strength. Extrapolation of the a_3 correlation bears out this reasoning. Conversely, the a_2 correlation goes to zero at CBRs less than 11, which indicates that soils below CBR = 11 have no strength. This does not appear reasonable.

There are limitations to any pavement design model. The WES model was not developed specifically for truck loads and considered only relatively weak surfacing materials. There is some possibility that the model would be inaccurate, particularly for the higher-strength surfacing materials common in road construction. However, the AASHO road test was based on truck-type loads and strong surfacing materials. The fact that the WES model so closely shadows the AASHTO model derived from the AASHO road test offers significant verification of the WES model. This similarity in the models also points to the validity of the assumption that aggregate pavements react to strain in much the same way as asphalt pavements.

Another limitation of the WES model is that it does not consider maintenance. If the test ruts had been graded out at 2 in, how much longer would the surface have lasted? This would be an area for further research.

In addition, the WES model does not provide for different levels of service, nor is the 3-in rut criterion correlated to a level of service. Development of a serviceability rating criterion for soil-aggregate roads would put the 3-in rut in perspective. The WES data could be used to develop a similar model for 2-in ruts somewhat as done by the U.S. Forest Service (3). The Forest Service made a best fit of the 2-in WES rut data that resulted in an essentially parallel but raised model. Whereas the 3-in WES model is above and more conservative than the AASHTO model for less than 100 EALs, the Forest Service 2-in model became more conservative for less than 10 000 to 100 000 EALs. In fitting a 2-in model, it would perhaps be more reasonable to constrain it at the lower coverages, thus rotating rather than raising it.

The WES model does not include a regional or seasonal factor. Although the AASHTO model includes a regional factor, this factor was developed for asphalt-surfaced roads and was developed qualitatively rather than as the result of actual road testing. Environmental effects may be accounted for to some extent in the subgrade soil tests, such as soaking of the CBR specimens. A regional or seasonal factor for aggregate-surfaced roads needs further consideration.

CONCLUSIONS AND RECOMMENDATIONS

The WES model provides a workable design procedure for aggregate-surfaced roads that meets many tests of reasonableness. The model would be more workable and flexible for road design if it were restructured in terms of soil support, 18-kip EALs, and SNs. The WES model curves shown in Figure 6 can be used for aggregate surfacing design. The use of the (a_3 - CBR) correlation is more reasonable than the (a_2 - CBR) correlation.

Areas for further research include (a) studying the significance of maintenance, (b) developing serviceability rating criteria and applying service-level criteria to design models for aggregate-surfaced roads, and (c) evaluating regional or seasonal factors for aggregate surfacing design.

REFERENCES

1. Thickness Requirements for Unsurfaced Roads and Airfields: Bare Base Support. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, Tech. Rept. S-70-5, July 1970.
2. AASHTO Interim Guide for Design of Pavement Structures. AASHTO, Washington, DC, 1972.
3. Transportation Engineering Handbook. Forest Service, U.S. Department of Agriculture, FSH 7709.11, Jan. 1974.