Procedure for Predicting Rut Depths in Flexible Pavements

Frank Meyer and Ralph Haas, Department of Civil Engineering, University of Waterloo, Ontario
M. W. W. Dharmawardene, Colombo, Sri Lanka

The basic concept of the simulative, statistically based approach to rut prediction includes characterization of the materials under simulated field conditions. It involves testing in a specially designed apparatus (1) consisting of a high-pressure triaxial chamber with temperature controls, electrohydraulic systems for independent control of vertical and horizontal stresses, and a variety of ancillary measuring equipment.

Factorially designed experiments were used to evaluate the permanent deformation characteristics of both asphalt concrete and unbound base materials.

MATHEMATICAL MODELS

One of the many advantages of statistical designs (2) is their ability to determine the importance of the interactions of the variables in explaining the behavior of materials. This advantage is a necessity for asphalt and unbound materials.

The statistical analysis of the data provided simple mathematical models that explain the rate of permanent deformation as a function of several significant variables and interactions. The initial models were developed for the compression and tension zones in an 85/100 penetration asphalt layer. However, since the tension zone contributed three to four times as much rutting at the surface as did the compression zone, attempts to reduce the high tensile stresses by the use of a 300/400 penetration asphalt were also made. The effect of air voids was studied in the tension phase and led to a modified model for the tension mode of the 85/100 penetration asphalt.

The models developed are described in detail by Morris (3), Morris and others (4), Meyer (5), and Haas and Meyer (6) for asphalt and by Dharmawardene (7) for the unbound base course.

All are of the following form:

$$\epsilon_p = f(\sigma_1, \sigma_3, T, D, AV, N) \pm E \qquad (1)$$

where

ϵ_p = permanent deformation (percent),
σ_1 = vertical stress,
σ_3 = lateral stress,
T = temperature,
D = density (for unbound base materials),
AV = air voids (for asphalt concrete),
N = number of load applications, and
E = error of estimate.

VERIFICATION OF THE MODELS

The models were verified by comparison of the predicted values with rut depths measured on various sections of the Brampton Test Road. The predictions were developed by analyzing the traffic, the temperatures, and the materials used for a selected time period. These results were used for a stress analysis to obtain input for the models, and, finally, the rut predictions for many sublayers were calculated and summed over the entire depth to obtain the total rut depth at the surface. The agreement between the measured and predicted values is outlined by Morris (3) and Dharmawardene (7).

USES AND CAPABILITIES OF THE MODELS

A predictive technique should be capable of being incorporated into design procedures, as well as being simple and concise. At present, most design systems use limiting values of riding comfort or serviceability but do not consider the problems resulting from excessive rutting. If the actual magnitudes of expected rut depths were known, an additional, new limiting design criterion for this factor could be developed. [For example, a terminal level of 1.3 cm (0.5 in) rut depth might be appropriate for certain classes of highways.]

Because many structures are designed on an equivalency basis, the question arises as to whether the pre-

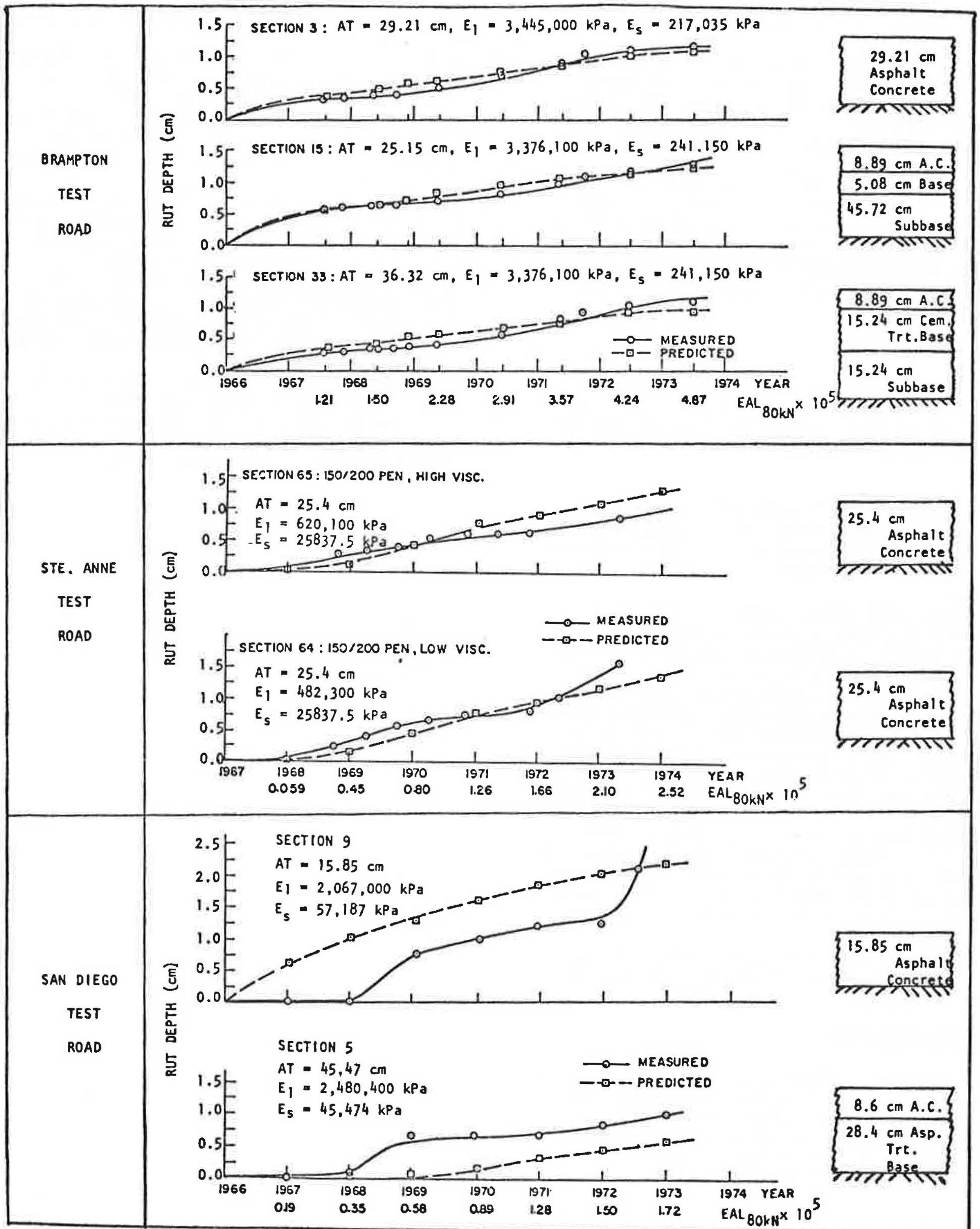
Publication of this paper sponsored by Committee on Strength and Deformation Characteristics of Pavement Sections.

dictive method will work under these conditions.

After a sensitivity analysis was performed for all of the variables subjectively determined to be significant in rutting, a simplified regression equation was developed from data obtained from the laboratory-based mathematical models (equation 1). This final model has the following form:

$$D = -1.0318 + 1.2067AT + 0.0803N - 2.3684 \ln AT + 0.1896 \ln (AT\ N) + 1.1639E_1 \ln AT - 0.0216E_sN - 0.4114E_1 N \ln AT + 0.0456E_sN \ln AT \qquad (2)$$

Figure 1. Comparison of measured and predicted rut depths on three test roads.



Note: 1 cm = 0.39 in; 1 kPa = 0.15 lb/in²; 1 kN = 0.23 kip.

where

D = permanent deformation in inches,
AT = 0.25 equivalent asphalt thickness (cm),
E_1 = 0.69 modulus E_1 (kPa),
E_s = 0.69 modulus E_s (kPa), and
N = number of 80-kN load applications/10^5.

This equation has statistical values of $R^2 = 0.966$, $F = 515.01$, and $SE = 0.28$ cm. Typical correlations for the Brampton, Ste. Anne, and San Diego test roads are illustrated in Figure 1 (8).

A variety of situations and factors can be evaluated by using this simple rut depth prediction model to provide guidelines with respect to optimum properties such as thicknesses and composition. An example is given by Meyer and others (8) in which rut depths were calculated for various thicknesses of equivalent full-depth asphalt, with all other variables constant. The results showed an optimum thickness for each level of traffic, which was verified to some degree by AASHO (9) and San Diego test roads (10) results. This simple model can also be incorporated into design procedures to check the rut depths of alternative strategies and compare them to limiting criteria.

CONCLUSIONS

This paper has presented a procedure for calculating rut depths in flexible pavements, based on models developed from laboratory experiments that simulate field conditions. The principal points may be summarized as follows:

1. The simulation of field conditions in dynamic triaxial tests is a reliable means for measuring the permanent deformation characteristics of both asphalt-bound and unbound granular base materials under a variety of conditions.
2. A statistically based experimental program that used these testing procedures has provided the basis for the development of rut depth prediction models. These models have been verified by comparison with actual field measurements at the Brampton Test Road. Layer equivalencies can also be used in the models to convert sections to either equivalent full-depth or equivalent granular base. From these results, a simple regression equation was developed that predicts rut depths at the Brampton, Ste. Anne, and San Diego test roads with good agreement.
3. The models have been used to evaluate the effects of a wide range of equivalent full-depth thicknesses and in full-depth layer moduli. The results suggest that, for given levels of traffic, there may be an optimum thickness, but a wide range of the modulus has little effect on the rut depth.
4. The simple regression equation can be incorporated into design procedures to analyze rut depths of possible alternatives.

ACKNOWLEDGMENTS

The investigations on which this paper is based have been supported by Gulf Oil Canada, Ltd., whose assistance is gratefully acknowledged. The Ontario Ministry of Transportation and Communications provided cooperation and support with test samples and data, and this assistance is also gratefully acknowledged.

REFERENCES

1. J. Morris and R. C. G. Haas. Characterization of Bituminous Mixtures for Permanent Deformation Predictions. ASTM Special Technical Publ. 561, Philadelphia, 1973.
2. O. L. Davies. Design and Analysis of Industrial Experiments. Oliver and Boyd, London, 1967.
3. J. Morris. The Prediction of Permanent Deformation in Asphalt Concrete Pavements. Univ. of Waterloo, Ontario, PhD thesis, 1973.
4. J. Morris, R. C. G. Haas, P. Reilly, and E. Hignell. Permanent Deformation in Asphalt Pavements Can Be Predicted. Proc., AAPT, Vol. 43, 1974, pp. 41-76.
5. F. R. P. Meyer. Permanent Deformation Prediction of Asphalt Concrete Pavements. Univ. of Waterloo, Ontario, MASc thesis, 1974.
6. R. C. G. Haas and F. R. P. Meyer. Cyclic Creep of Bituminous Materials Under Transient, High-Volume Loads. TRB, Transportation Research Record 549, Jan. 1975, pp. 1-14.
7. M. W. W. Dharmawardene. Permanent Deformation Characteristics of Granular Base Course Materials Subjected to Highway Loading. Univ. of Waterloo, Ontario, MASc thesis, 1975.
8. F. R. P. Meyer, A. Cheetham, and R. C. G. Haas. A Preliminary Design Subsystem for Permanent Deformation in Asphalt Pavements. Ontario Ministry of Transportation and Communications, OJTCRP Project W-34, April 1976.
9. The AASHO Road Test: Report 5—Pavement Research. HRB, Special Rept. 61E, 1962.
10. J. F. Shook. Analysis of Performance on the San Diego County Experimental Base Project. Univ. of Waterloo, Ontario, MASc thesis, 1975.