Abridgment

System for Summation of Load-Induced Pavement Strains to Produce a Rut Profile

M. S. Snaith and R. W. Kirwan, Trinity College, University of Dublin

Investigations during the past nine years on various facets of the road design problem by the Soil Mechanics Laboratory of Trinity College, Dublin, are now fitting together to produce a means of predicting pavement rutting that may be incorporated into a pavement design system.

This paper seeks to show that it is possible to characterize the permanent deformation behavior of pavement materials, and that a simple computer program may be used to predict the amount of rutting that will occur in a pavement.

The advantages of the computer program DEFPAV, which is central to this system, are as follows:

1. The recoverable and irrecoverable components of pavement deformation are produced at the same time;
2. Stress-dependent moduli may be used in all layers;
3. Tension relaxation may be applied in the granular pavement layers;
4. A complete rut profile is computed; and
5. There is a wide choice of creep laws that may be used in all layers.

CREEP CHARACTERIZATION

The most promising method of rut prediction is that from the direct interpolation of laboratory strain behavior (1), although this requires laboratory creep characterizations of a subgrade material and a bituminous-bound pavement material. The former is available from the analysis of tests previously carried out at Trinity College (2); the latter is available from the analysis of tests at the University of Nottingham on a dense bitumen macadam road-base material (3).

A number of Irish glacial tills have been tested in a repeated load triaxial machine to determine their resilient characteristics (2, 4, 5), and a more detailed study of the permanent deformation behavior of a glacial till, known locally as Dublin boulder clay, was made. The results of this investigation were used to produce the relation between strain and load applications for the subgrade material (a well-graded till, PI 14, PL 17, with 90, 57, and 42 percent passing 19-mm (¾-in), No. 36, and No. 200 BS sieves respectively).

Both the AASHO load equivalency factors (6) and Pell's strain-life law for bitumens (7) incorporate the concept that the amount of damage induced in a material is proportional to a power of the imposed stress or strain. Consequently, a creep law of the following form was investigated.

$$\epsilon_n = A\nabla^b \quad (1)$$

where A is a function of the elapsed time and the material and b is a constant for the material. From this relation it is possible to obtain, for the Dublin boulder clay, the equation

$$\epsilon_n(\%) = [0.01042\ (\log_{10}N)^{1/2}\ \nabla]^{1.75} \quad (2)$$

where ∇ is the stress in kPa. Within the time limits of the laboratory tests there is a good agreement between the permanent strain calculated by equation 2 and the observed behavior of the clay.

A similar approach was used to characterize the dense bitumen macadam. It is possible to describe the strain as a function of the vertical stress and the number of load repetitions by the equation

$$\epsilon_n(\%) = [0.00015\ (\log_{10}N)^{1.9}\nabla]^{1.75} \quad (3)$$

Thus, the damaging power of the stress is the same for the bituminous material as for the glacial till. However, since bitumen is a temperature-sensitive material, a modification to the time factor (log N) in the above equation is necessary.

$$\epsilon_n(\%) = [0.00015\ (\overline{0.68 + 0.0008T^2}\ \log_{10}N)^{1.9}\nabla]^{1.75} \quad (4)$$

where T is the temperature in °C. This method provides an adequate representation for both of these ma-

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

terials and could be used for the creep characterization of other materials. However, many potential users of such a system do not have sophisticated dynamic testing equipment. One method of avoiding the complex dynamic creep test is to find a simple relation between it and the easily performed static creep test. One set of tests from which such a relation may be derived has been carried out at the University of Nottingham; the details of these experiments may be found elsewhere (8).

Stated simply, the procedure of these tests was as follows. A dense bitumen macadam was made into cylindrical specimens suitable for triaxial compression tests. A number of them were subjected to dynamic vertical stress pulses of a sinusoidal pattern, while others were tested at a static vertical stress. Since the relation that was most promising appeared to be one that contained a function that included the power of the dynamic wave, the root mean square level of the dynamic stress pulse

Figure 1. Comparison of predicted permanent deformation with measured values for a bituminous-bound material.

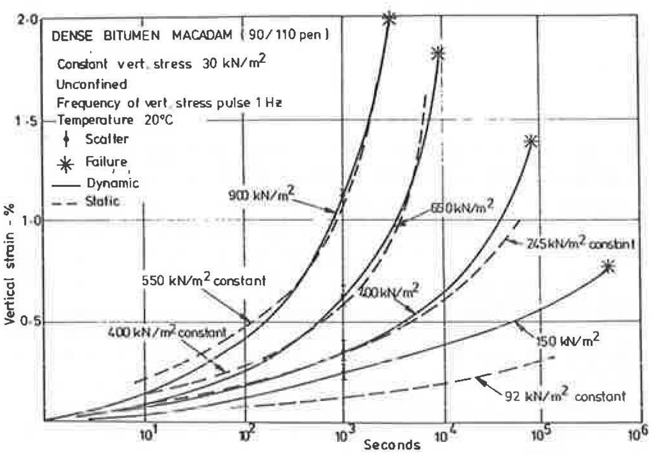


Figure 2. Finite-element representation of the bituminous base course study.

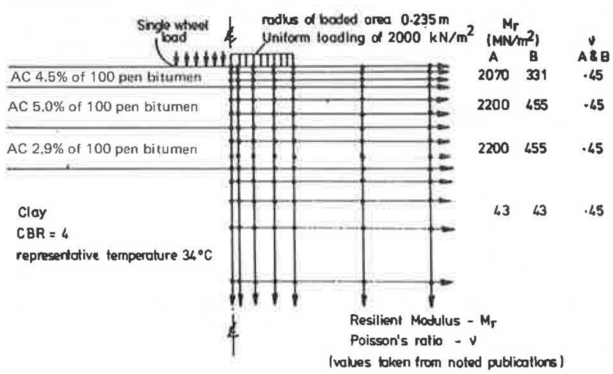
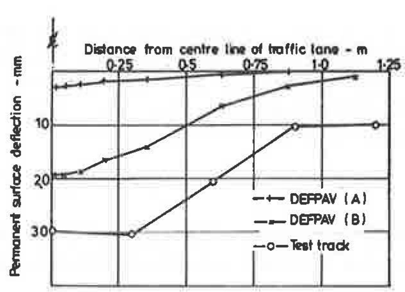


Figure 3. Comparison of observed and predicted surface profiles after eight passes of a 340-kN wheel load.



was investigated as the equivalent static stress. For one full cycle, the rms value W_r of the sinusoidal stress pulse W_D is given by the relation

$$W_r = (3/8)^{1/2}\, W_D$$

That is, the equivalent static stress level is 61 percent of the peak-to-peak dynamic (sinusoidal) stress, independent of its frequency.

This hypothesis was tested by determining the rms values of the four dynamic stress levels used in the Nottingham tests: 550, 400, 245, and 92 kPa, corresponding to dynamic levels of 900, 650, 400, and 150 kPa respectively. The interpolated strain-time values of the static tests were plotted with the dynamic test results (Figure 1) to show that this procedure gives a good correlation between the static and dynamic tests.

RUT DEPTH PREDICTION

After assuming that the materials in a road pavement may be characterized in the manner described above, some method of using these data to produce the surface profile of a road pavement after any number of load applications is necessary.

In 1967 work was begun on a finite-element program, DYNASTCO, that would be capable of predicting the stresses and elastic strains in a four-layer pavement beneath a single wheel load (4). This program has now been developed so that both the predicted stresses and elastic deformations compare favorably with the values derived from test tracks and from similar programs.

This program is incorporated into the first four cycles of the program DEFPAV, in which the stress field is calculated by the iterative procedure used for the rigorous finite-element solution of the elastic problem. The program then takes the stresses in each element of the original finite-element mesh, and calculates, for that element (independent of its neighbors), the vertical strain according to the specified creep law for its layer. When this procedure is complete the permanent strain values of each column of elements are summed to give the overall surface deformation. This means that, for one program run, the stresses, elastic and permanent strains, and change in surface profile are all calculated. Eight creep laws similar to those described above may be stored in the program at any one time. Any particular law may be assigned to any layer on external command, which makes the use of the program as a research tool extremely easy.

SYSTEM PROVING

To verify that the program was giving a realistic solution, a comparison was made between the results of a repeated load test and a finite-element model of a triaxial specimen of glacial till by applying various vertical stresses to the specimen model in DEFPAV and observing its behavior. Elastic strains were computed for given applied stresses, and the moduli and Poisson's ratio thus obtained were checked against those values originally entered.

To verify the solution to the creep problem, a prescribed stress was applied to the computer model, and the creep at various times was computed. These results were compared with actual test results and with the results calculated manually using the creep law programmed into DEFPAV. The following example is given to illustrate the procedure.

The permanent deformation over a gauge length of 100 mm of a 100-mm diameter triaxial specimen of Dublin boulder clay after 10 000 load repetitions was

Method of Determination	Deformation (mm)
Experimental	0.78
Direct calculation from creep law (equation 2)	0.77
DEFPAV	0.78

After completion of these trials the program was tested on full-scale test results from other research centers (9). However, the importance of engineering judgment when considering a material characterization for a full-scale trial section is apparent from the analysis of the pavement reported by Burns and others (10). Figure 2 shows the test section as reported and the finite-element model of the pavement. Two moduli values were taken for each of the bituminous layers: A represents undamaged material and B represents damaged material. The undamaged values are typical of those that might be expected of such a material subjected to normal traffic loads. However, this pavement was required to carry a 340-kN rolling wheel load, which caused complete structural failure within eight passes. For this reason, the lower values of moduli B were used as an estimation of the moduli of the damaged layers.

Figure 3 shows the observed and predicted deformations of this test section. There is a large difference between the levels of deformation predicted using A and B, with the latter a much better approximation to the levels of deformation observed.

It is therefore seen that, given adequate material characterization, the DEFPAV program can be used to compute the stresses, elastic strains, and pavement deformations in a pavement due to a moving wheel load.

CONCLUSIONS

1. The creep behavior of a glacial till (Dublin boulder clay) and a road-base material (dense bitumen macadam) was studied. The increase of strain with stress and number of load applications for the two materials followed the form $\epsilon(\%) = [A(\log_{10}N)^c \nabla]^{1.75}$, where A and C are constants dependent on the material.

2. A relation linking the permanent strain behavior of a dense bitumen macadam in dynamic and static laboratory creep tests is suggested. It is shown that the permanent deformation results of dynamic tests may be predicted by static tests in which the stress levels are set at the rms values of the stress pulse of the dynamic tests.

3. A finite-element program has been adapted to give the stresses, elastic strains, and permanent change in surface profile in a four-layer road pavement due to the passage of rolling wheel loads. The program (DEFPAV) may incorporate up to eight creep laws, any one of which may be used to describe the creep behavior of a certain layer.

ACKNOWLEDGMENTS

The research described in this paper is part of a project sponsored by the U.S. Army European Research Office, the National Science Council of Ireland, and An Foras Forbartha. We would like to thank W. Wright of the Engineering School, Trinity College, for his support, and T. E. Glynn and M. Maher for their assistance with certain facets of this work.

REFERENCES

1. R. D. Barksdale. Laboratory Evaluation of Rutting in Base Course Materials. Proc., 3rd International Conference on the Structural Design of Asphalt Pavements, London, 1972, pp. 161-174.
2. M. S. Snaith. Repeated Load Testing of Boulder Clay Subgrades. Univ. of Dublin, MSc thesis, 1969.
3. S. F. Brown and M. S. Snaith. The Permanent Deformation Characteristics of a Dense Bitumen Macadam Subjected to Repeated Loading. Proc., AAPT, Vol. 43, 1974, pp. 224-248.
4. R. W. Kirwan and T. E. Glynn. Investigation of Soils Subjected to Dynamic Loading. U.S. Army European Research Office, internal rept., Dec. 1968.
5. T. L. Casey. A Laboratory Pavement Simulator and an Investigation to Relate Dynamic and Ordinary Soil Properties. Univ. of Dublin, MSc thesis, 1973.
6. W. J. Liddle. Application of AASHO Road Test Results to the Design of Flexible Pavement Structures. Proc., 1st International Conference on the Structural Design of Asphalt Pavements, Ann Arbor, 1962, pp. 42-51.
7. P. S. Pell. Fatigue Characteristics of Bitumen and Bituminous Mixes. Proc., 1st International Conference on the Structural Design of Asphalt Pavements, Ann Arbor, 1962, pp. 310-323.
8. M. S. Snaith. Deformation Characteristics of Dense Bitumen Macadam Subjected to Dynamic Loading. Univ. of Nottingham, PhD thesis, 1973.
9. R. W. Kirwan and M. S. Snaith. Further Investigation Towards a Rational Method of Design for Flexible Pavements, Part II. U.S. Army European Research Office, internal rept., April 1975.
10. C. D. Burns, R. H. Ledbetter, and R. W. Grau. Study of Behavior of Bituminous-Stabilized Pavement Layers. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., Miscellaneous Paper S-73-4, 1973.
11. S. F. Brown, C. A. Bell, and B. V. Brodrick. Permanent Deformation of Flexible Pavements. U.S. Army European Research Office, internal rept., Nov. 1974.