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Abridgment

Pavement Evaluation With the Falling-Weight Deflectometer

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The falling-weight deflectometer (FWD) is a reliable, simple, and yet effective tool to determine the structural properties of pavements for roads and runways. Its characteristics of level of force (up to 60 kN) and loading time (approximately 30 ms) are more representative of heavy traffic than are those of most other deflection equipment. The deflection of the pavement and the deflection bowl are determined by geophones (velocity transducers) in the center of the loaded area and at certain distances from the center. The deflection levels are not affected adversely by the configuration of loading or the recording system, nor by possible influences of unstable reference points such as are encountered with some alternative systems.

A comprehensive description of the method has been published elsewhere (1). The principles are as follows:

The pavement structure is represented by a multilayer linear elastic system in which the materials are homogeneous and isotropic and are characterized by Young's modulus of elasticity (E) and Poisson's ratio (ν). In most cases, the structure can be regarded as a three-layer system (Figure 1) consisting of a bound top layer (E_1, ν_1, and thickness h_1), an unbound or cemented base layer (E_2, ν_2, and h_2), and a subgrade (E_3, ν_3, and infinite thickness). To simplify the system, fixed values are adopted for ν for all layers. The test load is assumed to be uniformly distributed over one or more circular areas.

The response of the pavement to a test load is characterized by the maximum deflection and the shape of the deflection bowl. The latter parameter is characterized by the ratio (Q_r) of the deflection at a distance r from the load (δ_r) to the deflection under the center of the test load (δ_0); i.e., $Q_r = \delta_r/\delta_0$. The ratio Q_r was chosen rather than the radius of curvature because Q_r can be measured more easily with existing equipment and provides equivalent information. The distance r can be fixed depending on the type of structure and is preferably such that Q_r is approximately 0.5 (2).

By using the BISAR program, graphs have been prepared giving the relations among E_1, δ_0, Q_r, and h_1 for predetermined values of E_2, h_2, E_3, and r for a given test load. From such graphs, with δ_0 and Q_r measured, two unknown structural parameters of the pavement can be determined if the other variables are known or can be estimated.

The pulse load is applied by a mass falling onto a set of springs that are mounted on a rigid circular plate resting on the pavement surface. Extensive tests with a prototype have shown the suitability of the method for determining the shape of the deflection bowl (1).

For routine measurements, a commercially available FWD was used. This FWD is mounted on a small trailer that can be towed by an automobile. The falling mass weighs 150 kg, and the maximum force developed is 60 kN at a drop height of 400 mm and a pulse width of 28 ms. These values were almost independent of type of pavement structure. The diameter of the foot plate is 300 mm.

The deflection of the pavement is measured by velocity transducers (geophones), one in the center of the loaded area and one or two at a fixed distance from the load. The transducers (50 mm in diameter and 55 mm in height) operate over a frequency range of 1 to 300 Hz. They are very rugged, which is advantageous in field conditions.

The FWD and the trailer were modified to permit quick operation with remote control from the towing car to enable measurements to be made in or between the wheel tracks without changing the line of drive. The trailer accommodates the power supply, and the recording instruments are in the automobile.

By using this equipment, surface deflections can be measured accurately and easily without the problems (such as the measuring reference points being located in the deflection bowl) that are encountered with some alternatives. The FWD is shown in Figure 2.

The transducer signals used to record the deflections are displayed on a screen to permit the operator to quickly verify the correct operation of the equipment and instruments. The maximum values of the deflections are digitized and stored on a tape recorder via a data unit or can be tabulated by a printer. The location of the points at which deflections are measured is recorded both longitudinally and transversely (in or between the wheel tracks or other position) with respect to the geometry of the road. A desk calculator facilitates the introduction of temperature data and is also used to calculate deflection ratios, mean values, variances, and other statistical data. A chart recorder is used to display the readings and calculated results.

Most pavement structures exhibit nonlinear behavior, particularly at low force levels, but generally, at force levels >30 kN, there is a straight line relation between deflection and force (Figure 3) (2). Thus, extrapolation of the deflection values to very heavy loads such as those under aircraft can be made with reasonable accuracy from measurements at, for example, 30 and 60 kN.

The residual life is the difference between the original design life of the pavement and the life already used. Because the initial decrease in asphalt modulus is relatively small, the design life of a pavement can be determined from the layer thicknesses and moduli derived from deflection measurements by using a Shell design chart (such as Figure 4) for the relevant subgrade modulus, weighted mean annual air temperature, and type of asphalt mix (3) (the same type of mix, of course, as anticipated with the interpretation) and deriving the number of standard axle-load applications for the given values of h_1 and h_2. Depending on the difference between the de-

Figure 1. Schematic representation of pavement structure under test load.

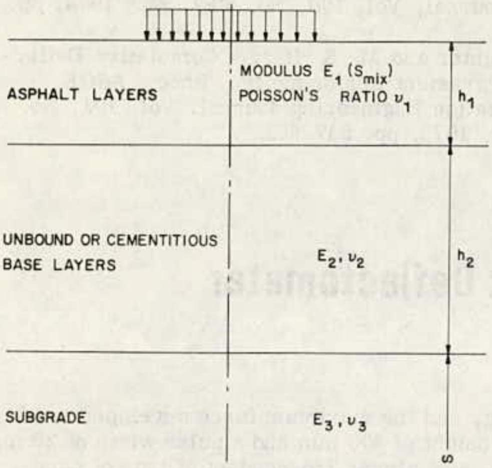


Figure 2. Falling-weight deflector.

Figure 3. Deflection as function of load.

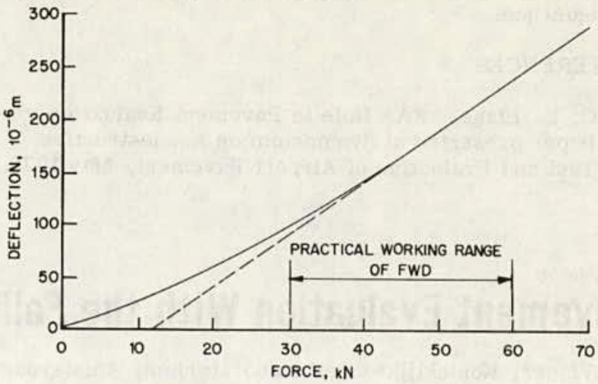
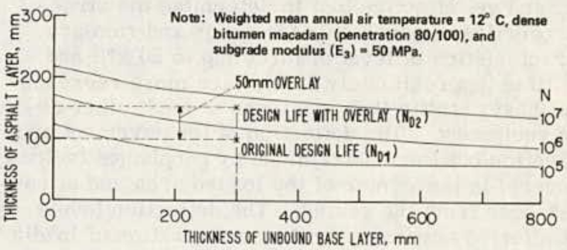


Figure 4. Use of Shell design chart to derive overlay thickness.



sign life found and the traffic carried to date, it can be decided whether or not strengthening is required.

The Shell design charts can also be used to determine the overlay thicknesses required for estimated future load applications. However, in many cases, the maximum asphalt strain occurs in the underside of the asphalt layer; thus after the strengthening of the pavement with an additional asphalt layer, strain will still be present in the original layer, although at a lower magnitude. In an overlay thickness design, this reduction in fatigue life of the original asphalt mix must be taken into account. When the asphalt mix used for the overlay is essentially the same as that of the original asphalt, the overlay thickness required for the design number (N_{02}) can be derived directly from the design chart used to determine the present design life (N_{01}), i.e., Figure 4.

The pavement evaluation and overlay design method described is regarded as a complete method that provides the engineer with structural pavement properties that can be used directly in a structural design method in which all relevant aspects (e.g., loading, climate, and use of materials) are incorporated.

The development of new design charts to replace the Shell design charts for flexible pavements published in 1963 and the pavement evaluation and overlay design procedures outlined above are described in detail elsewhere (3, 4).

Evaluation with the FWD has been used effectively on many roads and at three major airports (Zurich, Amsterdam, and Brussels) in Europe.

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