presented here will contribute to a better understanding of the mechanics of pavement blowups and will serve pavement engineers as guidelines for prescribing measures to reduce or totally eliminate the occurrence of blowups in concrete pavements.

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Overlay Thickness Design Using Rolling Wheel Deflection Ratio and CBR Thickness Formula

E. SHKLARSKY

The thickness design formula of the California bearing ratio method is used, in conjunction with the common inverse proportionality between pavement life and some power of the surface deflection recoverable under a rolling wheel, to determine the required overlay thickness for an existing flexible pavement. The proposed procedure is compared with other known methods. It has the advantage of including the effects of equivalent single-wheel load and tire inflation pressure as well as the important parameter of subgrade strength, which do not figure in the other methods.

In this paper, the thickness design formula of the California bearing ratio (CBR) method is used, in conjunction with the common inverse proportionality between pavement life and some power of the surface deflection recoverable under a rolling wheel, in determining the required overlay thickness for an existing flexible pavement.

CBR THICKNESS FORMULA

The design thickness (in millimeters) of a pavement on a subgrade soil with given CBR strength (up to 12 percent) for a given wheel load (P) (for highway pavements, usually 4000 kg on dual wheel) is given by the following equation:

$$t = 2.3 \log(4.5N) \sqrt{P[(1/0.582\text{CBR}) - (1/\pi p)]} \quad (1)$$

where p is the tire inflation pressure (kg/cm²) and N is the number of lifetime applications of the wheel load.

Equation 1 is fitted to the empirical curve of percentage design versus number of applications provided by the U.S. Army Corps of Engineers. A nomographic chart for approximating equivalent single-wheel load (ESWL) and total pavement thickness for a dual wheel, according to Equation 1, is shown in Figure 1. The CBR strength is usually obtainable in field and laboratory tests, or indirectly, in vibratory nondestructive tests that yield Young's modulus of the subgrade (E_s), by using the nonlinear dynamic theory relation--i.e., E_s = 100 CBR (kg/cm²) = 1500 CBR (psi) (1, Figure 10).

OVERLAY THICKNESS FORMULA

The overlay thickness formula, related to Equation 1, reads as follows:

$$t_o = t_2 - t_1 \quad (2)$$

Figure 1. Approximation of ESWL and pavement thickness as function of soil CBR for single dual wheel by using Equation 1.

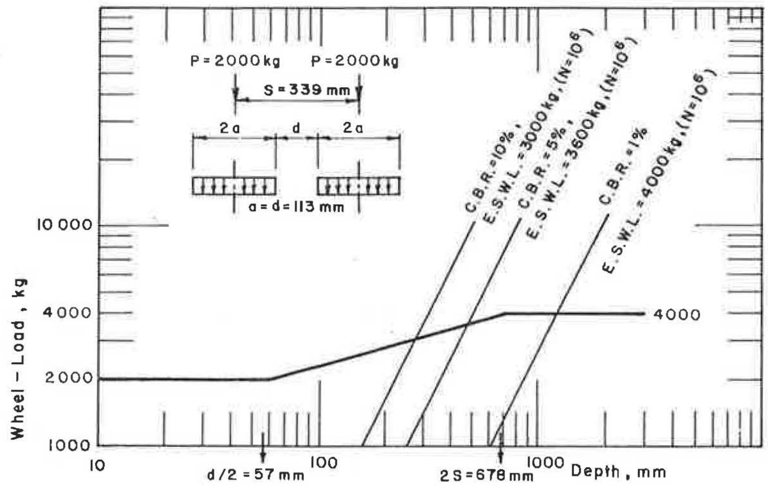
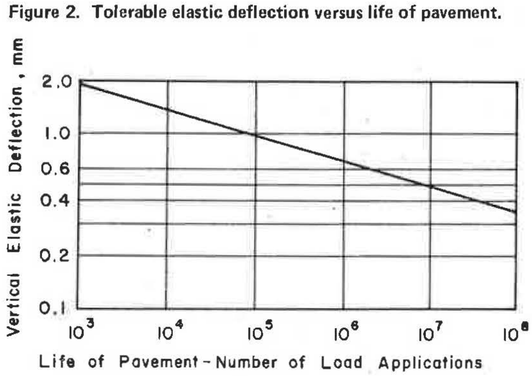


Figure 2. Tolerable elastic deflection versus life of pavement.



where

t_o = overlay design thickness required to reduce an existing (recoverable) deflection (d_e);
t_2 = total design thickness of a new pavement, intended to carry N_2 load applications, when built on the existing subgrade soil (with the same CBR strength) under the same load (P) and tire inflation pressure (p); and
t_1 = total design thickness of a new pavement, intended to carry N_1 load applications completing the life of the existing unoverlaid pavement of thickness t_e, under the same load (P) and tire inflation pressure (p).

It is assumed that the ESWL P is the same for t_1 and t_2. Thus,

$$t_2 = 2.3 \log(4.5N_2) \sqrt{P[(1/0.582CBR) - (1/\pi p)]} \quad (3)$$

$$t_1 = 2.3 \log(4.5N_1) \sqrt{P[(1/0.582CBR) - (1/\pi p)]} \quad (4)$$

from which

$$t_o = t_2 - t_1 = 2.3 \log(N_2/N_1) \sqrt{P[(1/Q582CBR) - (1/\pi p)]} \quad (5)$$

PROPORTIONALITY BETWEEN PAVEMENT LIFE AND SURFACE DEFLECTION

Research and experience point to a relation (shown in Figure 2) between the vertical elastic deflection of a flexible pavement under a rolling wheel and its life:

$$N = N\alpha 1/(d)^A \quad (6)$$

where

N = number of equivalent wheel loads,
d = elastic surface deflection, and
A = a constant exponent.

For the pavement types given by Lister (2), the value of A is 3.0, whereas in Figure 2 of the report by Widdup (3), it is 6.0 for equivalent 8000-kg axle loads.

The life ratio of the two pavements, referred to in the thickness formula, is seen to be

$$\text{Life of overlaid pavement/life of existing pavement} = N_2/N_1 = (d_e/d_o)^A \quad (7)$$

where d_e is the measured deflection of the existing unoverlaid pavement under the same ESWL and d_o is the tolerable predicted deflection of the existing overlaid pavement under the same ESWL.

Substituting the life ratio N_2/N_1 as in Lister's Equation 4 (2), one obtains the design thickness of the overlay that would reduce an existing recoverable deflection (d_e) to the required overlay deflection (d_o):

$$t_o = 2.3 \log(d_e/d_o)^A \sqrt{P[(1/0.582CBR) - (1/\pi p)]} \quad (8)$$

Existing pavement deflections are usually determined by using the Benkelman beam (or its automated forms); the required tolerable overlay deflections are predicted by previous experience, as shown in the work of Widdup (3, Figure 2) and Bushey, Baumeister, and Matthews (4, Figure 6), and are experimentally verified after completion of the overlay (4, Figure 9).

COMPARISON OF EQUATION 8 WITH OTHER METHODS

Scala proposed the following formula for the design of overlays (5,6):

$$h_o = B \log(d_e/d_o) \quad (9)$$

where

h_o = design thickness of the overlay (mm);
B = an empirical constant that ranges between 300 and 525 (for bituminous concrete, the lower bound corresponds to 10°C and the upper to 40°C);

d_e = measured recoverable deflection of the existing pavement; and
d_o = required design deflection of the overlay.

If one compares Equation 8 with Equation 9 as well as with Lister's chart (2, Figure 24) and the California asphalt concrete overlay design guide (4, Figure 10), the advantage of Equation 8 over all the others is obvious in that it alone contains all the design parameters--i.e., ESWL, tire inflation pressure, and soil strength. It should also be noted that, when the pressure factor is disregarded--i.e., $1/\pi p \rightarrow 0$--and the other parameters are kept constant, t_o is inversely proportional to the square root of the soil strength; in other words, the thickness of an overlay over a subgrade with a CBR of 4 or 9 percent is one-half or one-third, respectively, of that over a subgrade with a CBR of 1 percent.

NUMERICAL EXAMPLE

To illustrate the use of the procedure, assume the following:

Existing pavement with t_e = 485 mm (originally designed for 1 million load applications, where ESWL = 3600 kg).
Single-axle load = 8000 kg (4000 kg on each dual wheel).
$p = 5.0$ kg/cm².
Subgrade CBR = 5 percent.
Surface deflection according to Benkelman beam measurements = 1.0 mm.
Tolerable required surface deflection = 0.5 mm (3, Figure 2) (for 10-mm deflection N_1 = 1,000 load applications, and for 0.5-mm deflection N_2 = 1 million load applications).
A = 6.0 by the Scala and California methods and 3.0 by the Lister method.

From Equation 8,

$$t_o = 2.3 \log(1.0/0.5)^6 \sqrt{3{,}800\,[(1/0.582)(1/5) - (1/\pi 5.0)]} = 135 \text{ mm} \quad (10)$$

According to the Scala method, for 40°C, B = 500; therefore, from Equation 9,

$$h_o = 500 \log(1.0/0.50) = 150 \text{ mm} \quad (11)$$

The Lister method yields a minimum thickness of 40 mm, which, according to Equation 8, is comparable to 70 mm with A = 3.0 (ESWL = 3750 kg for CBR = 5 percent).

According to the California chart, the required asphalt concrete overlay thickness is 90 mm. For soil CBR of 1 and 10 percent, with other conditions kept constant, the respective overlay thicknesses according to Equation 8 are 340 mm (ESWL = 4000 kg) and 77 mm (ESWL = 3200 kg) for A = 6.0 and 170 mm (ESWL = 4000 kg) and 38 mm (ESWL = 3150 kg) for A = 3.0. With the other methods, the design thickness of the overlay remains unchanged.

SUMMARY

In this paper it has been shown how overlay thickness can be designed on the basis of the rolling-wheel deflection ratio by using the familiar CBR thickness formula. The proposed procedure has the advantage of including the effects of ESWL and tire inflation pressure as well as the important parameter of subgrade strength, which do not figure in the other methods.

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