STRUCTURAL BEHAVIOR OF BITUMINOUS CONCRETE OVERLAY ON CEMENT CONCRETE PAVEMENT

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The use of bituminous concrete overlays on cement concrete pavement is gaining considerable popularity. No rational approach is yet available to define the structural behavior of this composite section. In this investigation, pressure-deformation and load-transmission characteristics of bituminous concrete overlays on uncracked rigid pavements were studied by testing model slabs of 4 ft (1.2 m) square size. The base slabs of cement concrete were 2 and 3 in. (5 and 7.5 cm) thick, and each one was separately overlaid with 1, 2, and 3 in. (2.5, 5, and 7.5 cm) of bituminous concrete. The testing was carried out by static load tests at the interior by using rigid circular plates 6, 8, and 10 in. (15, 20, and 25 cm) in diameter. The surface deformations were observed with deflection dial gages, and the stresses developed in the base slab were measured by the use of electrical strain gages fixed underneath the base slab at the interior region. An equation was established to calculate the stress in the base slab. This equation has been used to determine the overlay thickness on existing uncracked rigid pavements.

Thousands of miles of bituminous concrete overlays have been placed on rigid highway pavements through stage-construction techniques. The Corps of Engineers has carried out full-scale traffic testing on airfield pavements and has proposed a method for overlay design. This method has recently been modified for use on highway pavements (1, 2). However, this procedure is based on wheel loads of far greater magnitude than those encountered on highways.

In the present investigation, pressure-deformation and load-transmission characteristics of a bituminous concrete layer over rigid base slabs were studied by conducting plate-bearing tests at the interior of model slabs. Because the failure starts in the cement concrete base slab and progresses to the surface of the overlay, a relation has been established to calculate the stress developed in the base slab. This relation can be employed for designing overlay thickness.

TEST PROGRAM

The dimensions of the model slabs were 4 ft (1.2 m) square. The base slabs of cement concrete were 2 and 3 in. (5 and 7.5 cm) thick, and each one was separately overlaid with 1-, 2-, and 3-in. (2.5, 5, and 7.5 cm) thick bituminous concrete layers. The bituminous concrete layers 1-, 2-, and 3-in. (2.5, 5, and 7.5 cm) thick were also

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directly laid on the subgrade and tested. The depth of subgrade soil in the test pit was kept at 5 ft (1.5 m) so that no boundary effects of the foundation were provided for the loading frame.

A cement concrete mix of 1:2.5:5 with a water-cement ratio of 0.45 was selected. The slabs were precast and cured for 28 days. The physical properties of the mix, as determined after 28 days, were as follows:

Compressive strength = 3,070 lb/in^2 (215 kg/cm^2)
Modulus of elasticity = 3.15×10^6 lb/in^2 (2.2×10^5 kg/cm^2)
Flexural strength = 510 lb/in^2 (35.6 kg/cm^2)

A coarse-graded type of mix for the bituminous concrete was selected. The designed gradation shown in Figure 1 satisfies the requirements of ASTM Designation D 1753-60 T. There is a lot of controversy regarding the grade of bitumen to be used for some regions in India. Griffith (3) recommends a somewhat harder grade of bitumen so that deflections may be less. In the present study, 80 to 100 penetration grade was selected because this is mostly used for road construction in India. The binder content of 6.25 percent as obtained from the Marshall stability test was adopted. Temperatures at mixing and compaction considerably affect the strength characteristics of bituminous concrete mixes (4). The following temperature combinations, which are found to give optimum results, were selected for paving mix.

Mixing temperature = 350 F (175 C)
Compaction temperature = 300 F (150 C)

The designed bituminous mixer (5) had a capacity of 7 ft^3 (0.2 m^3). The paving mix obtained from the mixer was rolled at desired compaction temperature with a laboratory roller. The rolling was done by covering the mix with a wooden plank so as to obtain uniform thickness.

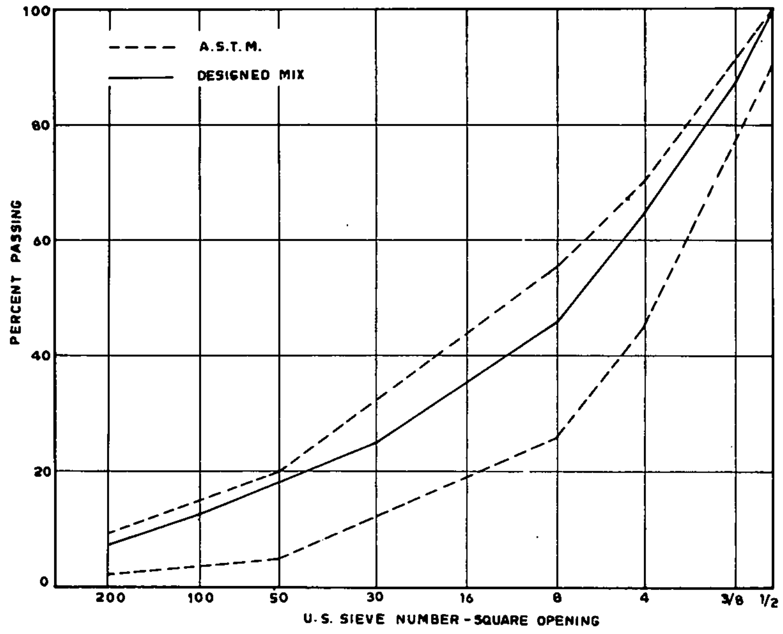

Figure 1. Aggregate gradation used for bituminous mix.

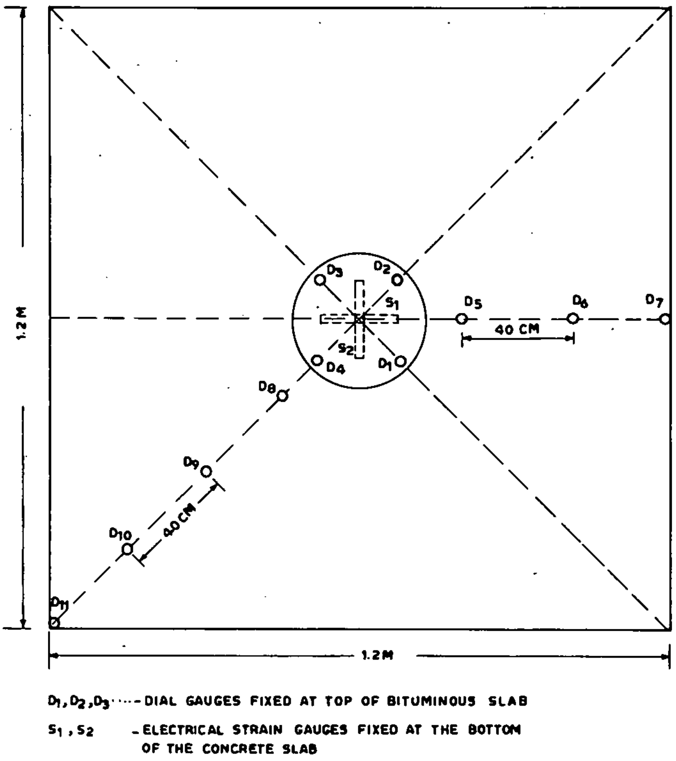

Figure 2. Positions of strain and deflection dial gages.

The subgrade soil was type A_4, (U.S.P.R.A. classification) and had a modulus of subgrade reaction of 140 lb/in.^{3} (9.0 kg/cm^3). The cement concrete slab with 2 electrical strain gages fixed at the interior on the bottom side was placed on the prepared subgrade. To attain interface conditions, a seating load of 1 lb/in^2 (0.07 kg/cm^2) was applied and released 10 times by using a 24-in. (60 cm) diameter plate. The bituminous concrete mold assembly was pushed on the cement concrete slab and the wooden base was pulled out. The bituminous concrete layer was covered with a wooden plank, and a seating load of 1 lb/in^2 (0.07 kg/cm^2) was applied and released 10 times by using a 24-in. (60 cm) diameter plate to attain proper interface conditions.

The plate-bearing test is comparatively the best method for determining the strength characteristics of pavement layers. This method effectively measures the pressure-deformation characteristics in the presence of lateral confinement and underlying subgrade support. In this study also, the static load tests were carried out at the interior of the slab by using rigid circular plates of varying diameters of 6, 8, and 10 in. (15, 20, and 25 cm). The positions of the electrical strain gages and deflection dial gages are shown in Figure 2. The testing was done under no warping conditions of the base slab (6).

ANALYSIS OF TEST RESULTS

Pressure-Deformation Characteristics

Figures 3 and 4 show typical plots of surface pressure versus plate deformations for different variables considered in this investigation. For a constant surface pressure, the deformations increase with increasing plate diameter as the pavement section is stressed with a greater load. Increased overlay thickness improves the load-supporting

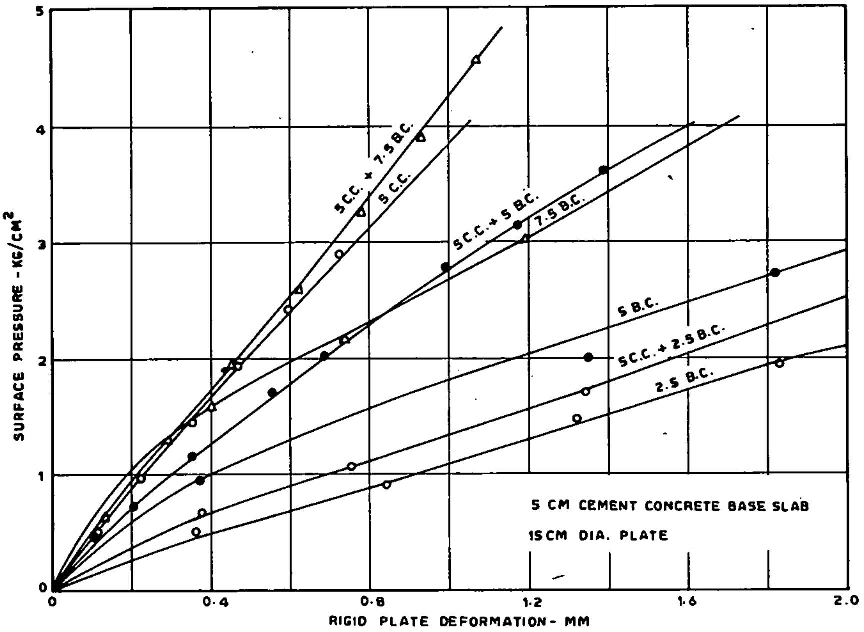

Figure 3. Relation between surface pressure and rigid plate deformation—2-in. base slab and 6-in. plate.

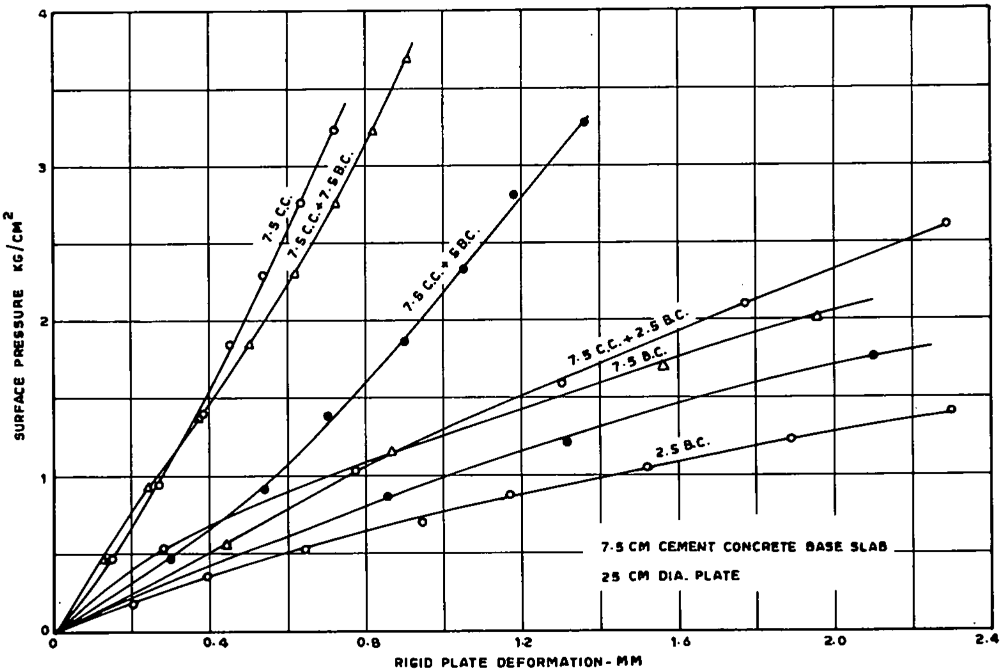

Figure 4. Relation between surface pressure and rigid plate deformation—3-in. base slab and 10-in. plate.

ability and thereby causes decreased surface deformations. It is further observed that, for a constant surface pressure, the deflections on the base slab with no overlay are less than in the case when a thin overlay is employed, though in the latter system load-carrying capacity is obviously higher. This indicates the distinct variation in the deformation characteristics of flexible and rigid pavements. Therefore, pressure deformation characteristics alone are not sufficient for design criteria of bituminous overlays on rigid pavements; load-transmission characteristics must also be studied along with them.

Load-Transmission Characteristics

Figures 5 and 6 show that, for a constant load, the stress developed in the base slab increases with decreased plate diameter. Figure 7 shows that, for a constant surface pressure, the stress in the base slab increases with increasing plate diameter. The curves are curvilinear, and the increase in stress value is maximum between plate sizes 8 and 10 in. (20 and 25 cm) for all values of surface pressures employed in the study.

Figure 8 shows the reduction in stress value with varying overlay thicknesses. The rate of stress reduction is observed to decrease as the overlay thickness is increased. The maximum reduction is observed between overlay thicknesses of 1 and 2 in. (2.5 and 5 cm). Further, the net reduction is more with decreased plate diameter. Thus, the

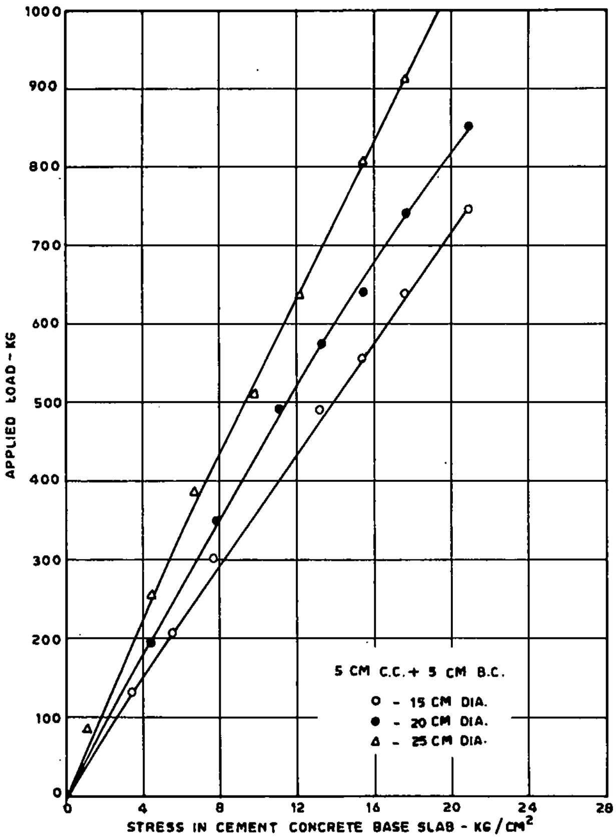

Figure 5. Relation between applied load and stress in cement concrete base slab—2-in. base slab and 2-in. overlay.

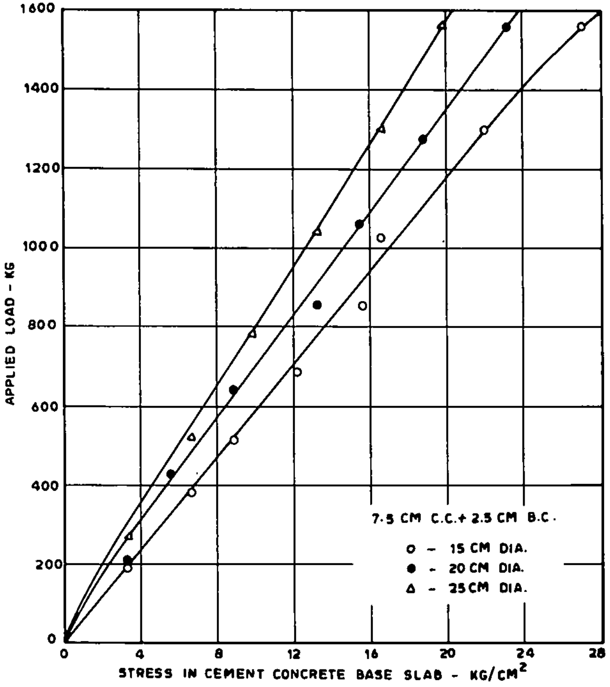

Figure 6. Relation between applied load and stress in cement concrete base slab—3-in. base slab and 1-in. overlay.

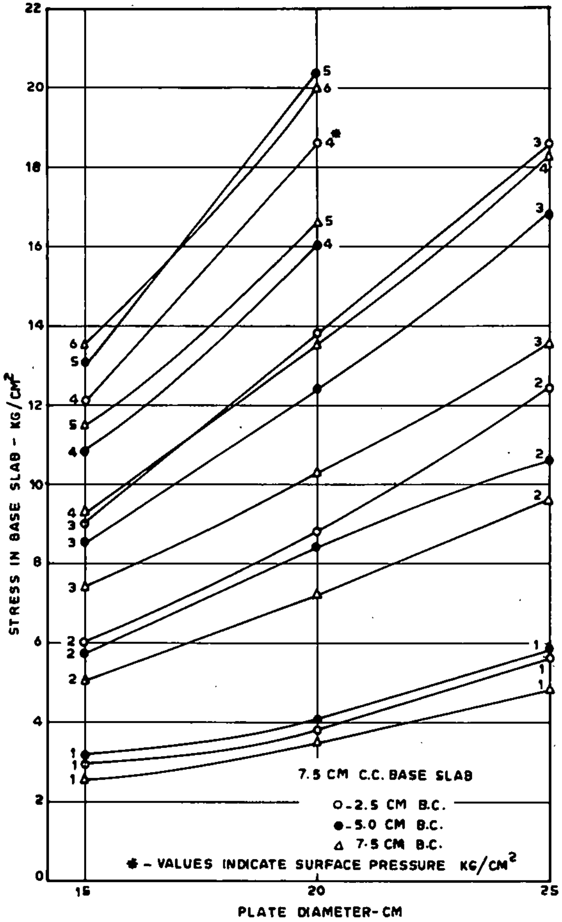

Figure 7. Effect of size of loaded area on stress in 3-in. base slab.

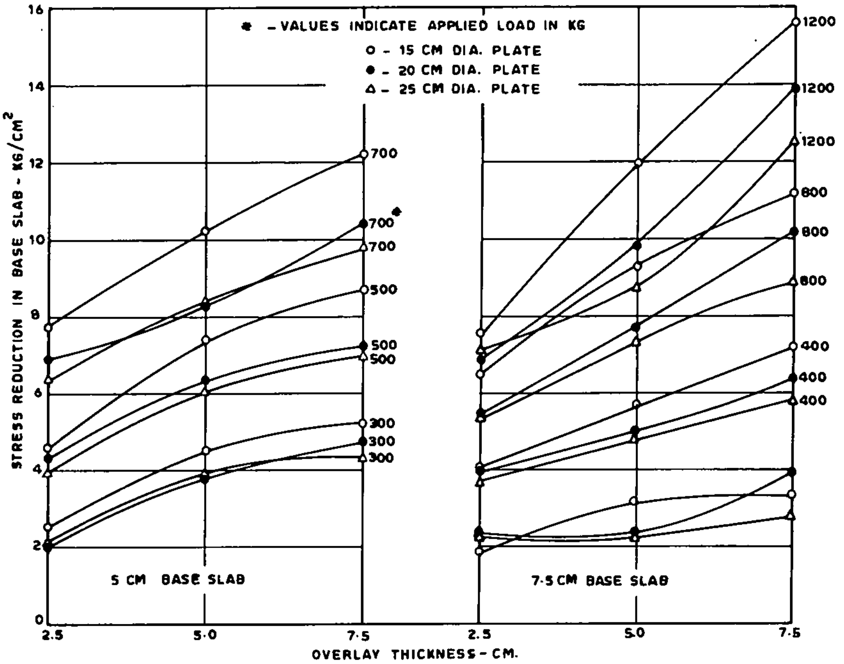

Figure 8. Effect of overlay thickness on stress reduction in base slab.

overlay reduces the stress in the base slab, and this reduction is inversely proportional to plate diameter.

Stress Equations for Base Slabs

The structural capacity of the bituminous concrete overlay over rigid pavements depends on the surface deflections and the stress developed in the base slab. The failure of the composite section will occur when either the surface deflections exceed 0.15 in. (0.38 cm) or the stress developed in the base slab exceeds the ultimate fiber stress. The stress, σ, developed in the base slab of the composite section can be represented by

$$\sigma = \sigma_1 - \sigma_2 \tag{1}$$

where

σ_1' = stress in base slab when no overlay is provided; and
σ_2 = reduction in stress value due to overlay.

The stress, σ_1, depends on the base slab thickness, h_1; whereas, stress reduction, σ_2, is a function of both the base slab thickness, h_1, and the overlay thickness, h_2. Thus, separate relations have been established for σ_1 and σ_2.

The relation for σ_1 can be expressed in the following form:

$$\sigma_1 = \left(AP/h_1^2\right)\left[X \log_{10} (\ell/a) + 1\right] \tag{2}$$

where

P = wheel load;
ℓ = radius of relative stiffness; and
a = radius of contact area.

The values of coefficients A and X are found to be 0.35 and 3.78 respectively from the experimental data. Equation 2 thus reduces to

$$\sigma_1 = \left(0.35P/h_1^2\right)\left[3.78 \log_{10} (\ell/a) + 1\right] \tag{3}$$

The relation for σ_2 can be expressed in the following form:

$$\sigma_2 = \left[BP/(h_1)^D\right] (h_2)^C \left[Y \log_{10} (\ell/a) + 1\right] \tag{4}$$

where B, C, D, and Y are the coefficients. The observed values of stress reduction, σ_2, are obtained by subtracting calculated values of σ_1 (by using Eq. 3) from measured stress.

To find the coefficient C, multipliers of stress values are calculated from data shown in Figure 8 when overlay thickness changes from 1 to 2 in. (2.5 to 5 cm) and 1 to 3 in. (2.5 to 7.5 cm). The mean values of multipliers are obtained in these cases for varying values of load and plate diameter. The value of coefficient C is thus found to be 0.5. The value of coefficient D is obtained from data shown in Figure 9 by calculating the multiplier on changing base slab thickness from 2 to 3 in. (5 to 7.5 cm) with ratio $(\ell/a) = 1$ and 10. The mean value of the coefficient is thus found to be 2.0. Equation 4 thus reduces to

$$\sigma_2 = \left(BP/h_1^2\right) \sqrt{h_2} \left[Y \log_{10} (\ell/a) + 1\right] \tag{5}$$

To determine the value of coefficients B and Y, plots are drawn for varying values of P, h_1, and h_2 between stress reduction σ_2 and ratio (ℓ/a). Lines are extended both ways to meet ratios $(\ell/a) = 1$ and 10. A typical plot is shown in Figure 10.

When $(\ell/a) = 1$, Eq. 5 reduces to

$$\sigma_2 = \left(BP/h_1^2\right)\sqrt{h_2}. \tag{6}$$

Points are plotted as shown in Figure 11 between P versus $\left(\sigma_2 h_1^2\right)/\sqrt{h_2}$ for $(\ell/a) = 1$. The best line of fit gives the value of coefficient B as 0.09.

When $(\ell/a) = 10$, Eq. 5 reduces to

$$\sigma_2 = \left(BP/h_1^2\right) \sqrt{h_2} \; (Y + 1) \tag{7}$$

with $B = 0.09$.

The values of multiplier $(Y + 1)$ is calculated for varying values of P, h_1, and h_2 by noting the ratio of stress reduction σ_2 at $(\ell/a) = 1$ and $(\ell/a) = 10$. The mean of multiplier $(Y + 1)$ is obtained as 2.5, thereby giving $Y = 1.5$. Equation 4 thus takes the following final form:

$$\sigma_2 = \left(0.09P/h_1^2\right)\sqrt{h_2} \left[1.5 \log_{10} (\ell/a) + 1\right] \tag{8}$$

The stress developed in the base slab due to an overlay of thickness h_2 can thus be given by

$$\sigma = \left(0.35P/h_1^2\right) \left[3.78 \log_{10} (\ell/a) + 1\right] - \left(0.09P/h_1^2\right) \sqrt{h_2} \left[1.5 \log_{10} (\ell/a) + 1\right] \tag{9}$$

Figure 12 shows the comparison between computed and measured values of stress for a wide range of values of different parameters. The comparison reveals that computed values are lower than those observed by a maximum of 11.5 percent and higher by a maximum of 14.0 percent, thereby showing a good agreement.

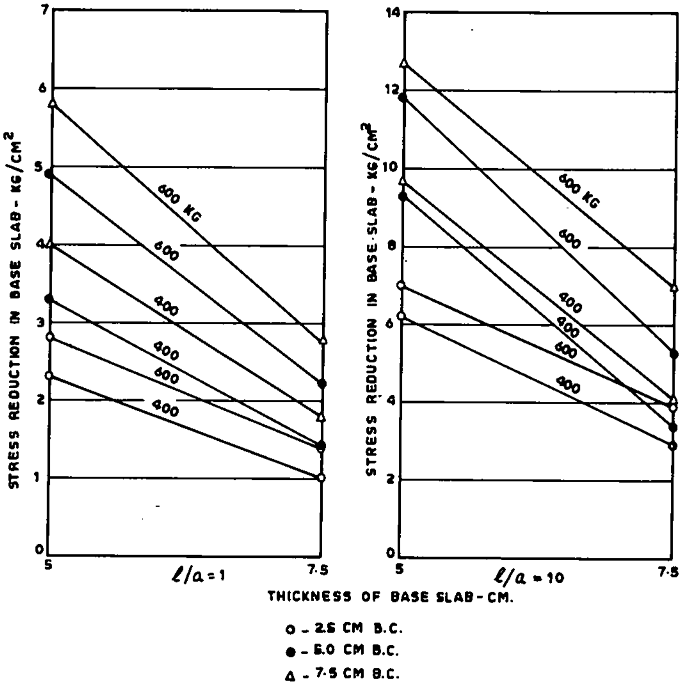

Figure 9. Effect of base slab thickness on stress reduction.

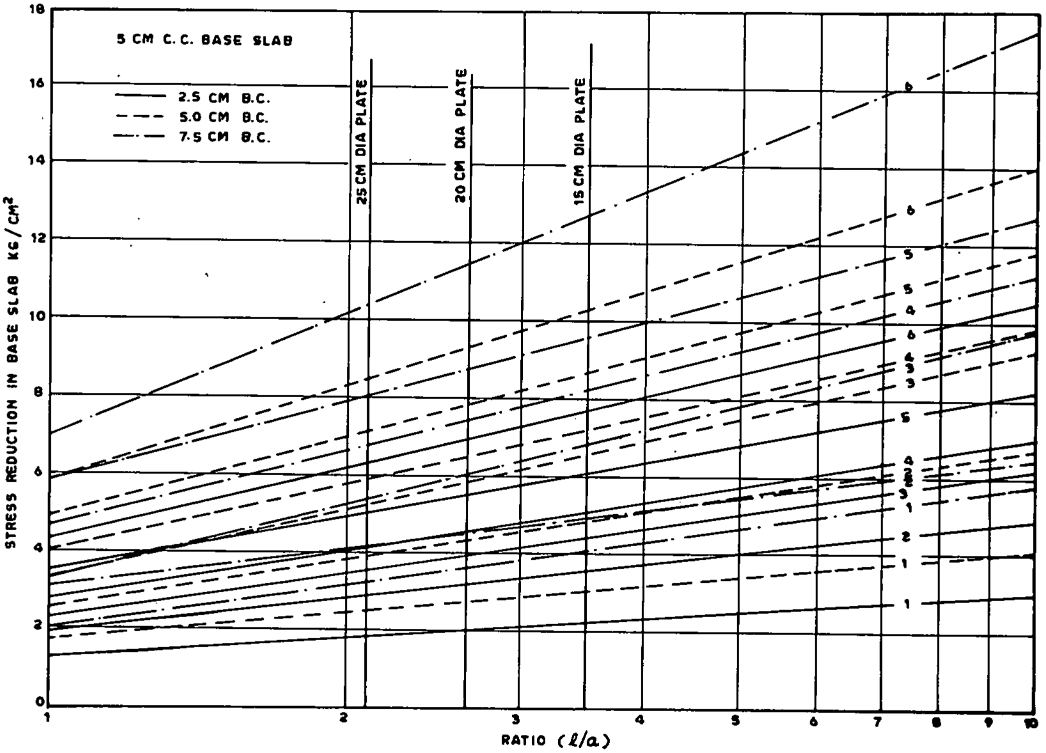

Figure 10. Relation between (ℓ/a) and stress reduction in base slab.

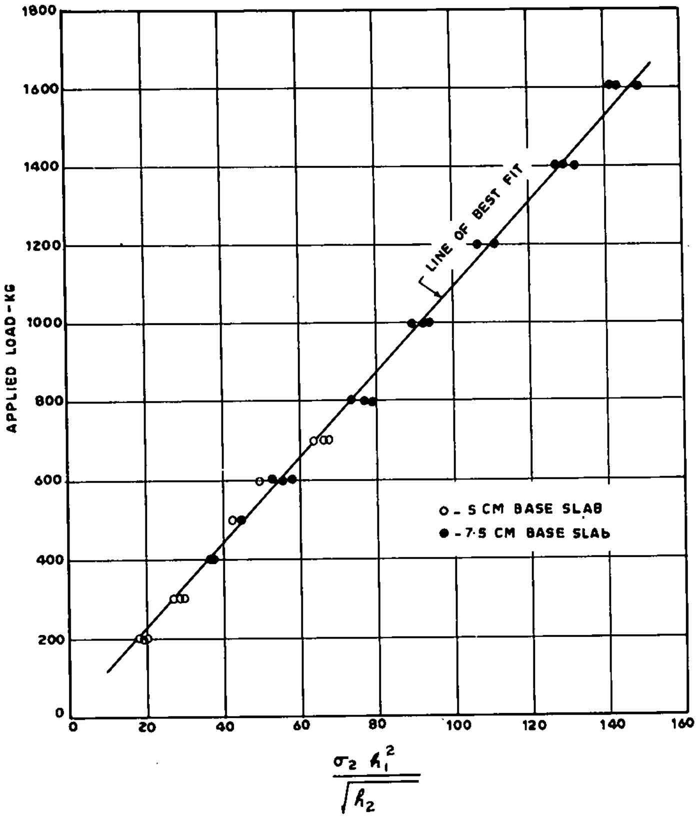

Figure 11. Load versus stress reduction in base slab when (ℓ/a) = 1.

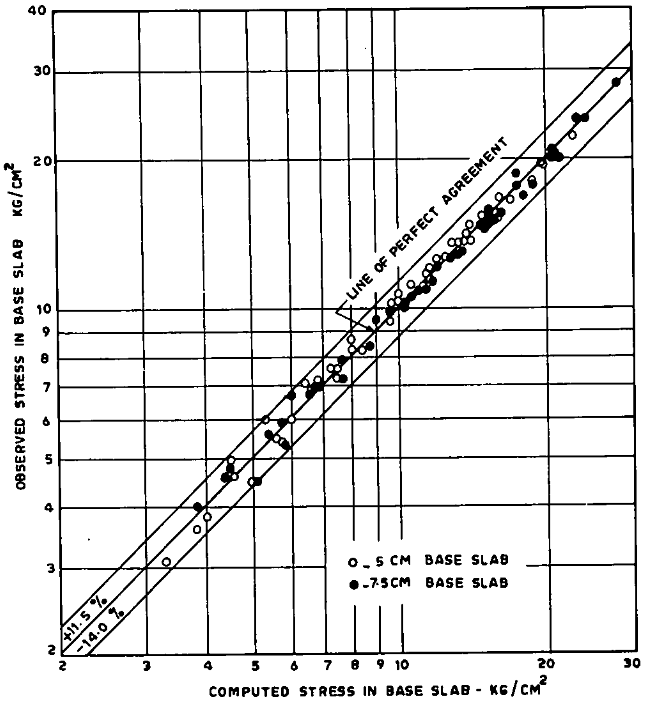

Figure 12. Comparison of computed and measured values of stress in base slab.

TABLE 1

COMPARISON OF OVERLAY THICKNESS DESIGNED BY CORPS OF ENGINEERS METHOD AND BY DEVELOPED EQUATION

Design Traffic Index	Design Thickness h_d		Existing Thickness of Rigid Pavement h_1		Overlay Thickness			
					Corps of Engineers Method		Development Equation	
	In.	Cm	In.	Cm	In.	Cm	In.	Cm
4	8	20	5	12.5	5.5	13.75	4.8	12.0
4	8	20	6	15.0	3.0	7.5	2.5	6.25
2	6.5	16.25	4.0	10.0	-0.9	-2.25	3.5	8.75

Note: Wheel load = 9,000 lb (4,050 kg); tire pressure = 75 lb/in.^{2} (5.25 kg/cm^2); and subgrade reaction = 150 lb/in.^{3} (4.2 kg/in.^{3}).

Thickness Determination

The developed equation can be used for designing overlay thickness. Table 1 gives a comparison of the overlay thickness designed by the Corps of Engineers method and by the developed equations. The design thickness, h_d, of rigid pavement has been calculated by the Corps of Engineers method. The stress developed at the interior of a rigid slab of thickness h_d is found from Eq. 3. The overlay thickness, h_2, over an existing base slab thickness, h_1, is found from Eq. 9 in such a way that in the composite section the same value of stress in the base slab occurs as in thickness h_d with no overlay.

The results given in Table 1 show that for an h_d of 8 in. (20 cm), the overlay thicknesses designed by both the methods are in good agreement; the maximum variation is 17 percent. For a design thickness of 6.5 in. (16.25 cm), the overlay thickness designed from the developed equation appears to be reasonable, but the Corps of Engineers method gives erroneous results. This shows that the Corps of Engineers method is inadequate for designing bituminous overlays over rigid pavements especially when traffic volume is low.

SUMMARY

Load-deformation criteria cannot by themselves be employed to define the structural behavior of composite sections; load-transmission characteristics must also be studied.

The magnitude of the stress developed at the interior of the base slab is expressed by Eq. 9. The Corps of Engineers method to design overlay thickness for highway pavements seems to be inadequate. In some cases, especially when traffic volume is low, this method gives erroneous results. For the remaining conditions, a comparison of the overlay thickness designed by the Corps of Engineers method and by the developed equation shows a good agreement.

It may be noted that the developed procedure and the resultant overlay thicknesses are dependent on the reliability of the procedure selected for determining the total slab thickness requirements. Full-scale field tests with thicknesses and loads typical of pavements in regular service are needed to verify the equations for application.

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