Wheel Load Equivalency Based on Flexural Fatigue of Asphaltic Concrete

R. A. JIMENEZ, Arizona Transportation and Traffic Institute, University of Arizona

Wheel load equivalencies have been used in the design of pavements to account for the varieties of load magnitude and configuration. This presentation is concerned with an approach for estimating wheel load equivalencies based on a particular flexure fatigue characteristic of asphaltic concrete. The equivalencies are referred to as destructive ratios, DRs, and are related to the number of repetitions of a particular stress that an asphaltic-concrete surface course can endure in a specified pavement structure. The approach for determining the destructive ratios is described for single-wheel applications of variable loads and tire pressures on pavement structures of different strengths. Comparisons of the calculated destructive ratios were made with wheel load equivalencies established by the AASHO Road Test engineers. These comparisons showed that there was not a consistent relationship between the two equivalencies for the four pavements chosen. However, note is made that in one case results of loads are considered for the surface course only, whereas for the AASHO condition the total pavement structure was involved.

•TRAFFIC on pavements is made up of a variety of wheel loads and gear arrangements. As a consequence, in pavement design, different means (1-6) have been used for obtaining "design wheel loads" or for determining the accumulative damaging effects of different vehicles using the road. It is not the purpose of this report to discuss the various ways of treating mixed traffic for determining wheel load equivalencies but rather to present the results of an approach toward relating the effects of different wheel loads on the fatigue life of asphaltic-concrete surface courses.

FATIGUE OF ASPHALTIC CONCRETE

In recent years there has been great interest in searching for and defining the flexure fatigue characteristics of asphaltic concrete (7-13). A review of the literature on fatigue of asphaltic concrete indicates that the relation between bending tensile stress (S) and number of stress repetitions to cause failure (N) may be expressed as follows:

$$S = I_0 N^{-b} \tag{1}$$

where I_0 and b are constants. Jimenez (13) reports on fatigue studies of different asphaltic-concrete mixtures and suggests that the value for the exponent, b, in Eq. 1 may vary slightly from -0.2. However, the coefficient, I_0, may vary over a wide range depending on the stiffness or static tensile strength of the mixture. If the slopes of all S-N curves are considered to be the same, then the relative effect on fatigue life of any stress as compared to that of a reference stress, would be constant for asphaltic concretes of different static tensile strengths or I_0's. In this report measure of the relative destructive effect of a stress will be termed destructive ratio, DR, which is the number of load repetitions to cause failure N_1, of the reference stress, S_1, divided by

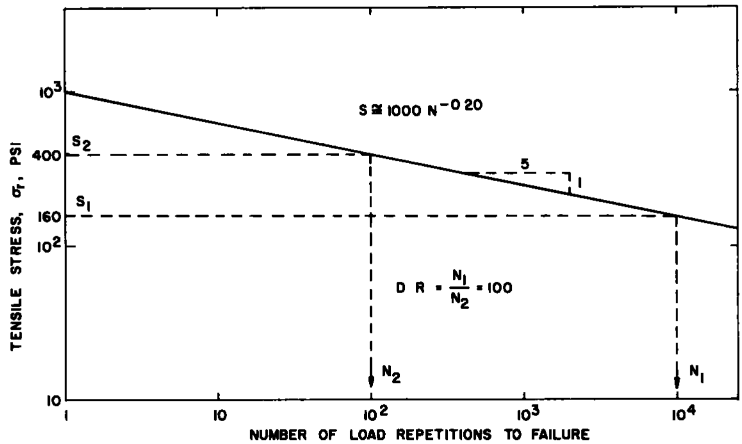

Figure 1. Relationship between tensile stress and number of repetitions to failure.

the number of load repetitions corresponding to failure at the other stress. As an example, consider the following:

From Eq. 1:

$$S = I_0 N^{-b}$$

and

$$N_1 = (S_1)^{-1/b} \ (1/I_0)^{-1/b}$$

$$N_2 = (S_2)^{-1/b} \ (1/I_0)^{-1/b}$$

Then, the DR = $(N_1/N_2) = (S_1/N_2) = (S_1/S_2)^{-1/b}$ which shows that the strength of the material does not influence the value of destructive ratio. Figure 1 shows the above concept where S_1 is the reference stress.

The calculations for stresses given in Table 1 are based on asphaltic concrete having a static bending strength value, I_0, of 1,000 psi.

STRESSES AND PAVEMENT STRUCTURES

Asphalt pavements may be considered as three-layered systems, and the stresses at certain locations can be calculated by use of Jones' tables (14). The stresses of concern in this report are the central radial stresses at the bottom of the surface course.

The structural systems examined for this presentation are shown in Figure 2 and are listed as follows:

1. Surface course of asphaltic concrete
   (a) Modulus E_1 = 50,000, 100,000, and 125,000 psi.
   (b) Thickness h_1 = 1, 2, 4, and 8 in.
2. Base
   (a) Modulus E_2 = 5,000 psi.
   (b) Thickness h_2 = 8 in.
3. Subgrade
   (a) Modulus E_3 = 2,500 psi.

The selections of E_1 were somewhat arbitrary but appear to be reasonable in comparison with such values as previously given (13). The values of K_1 or E_1/E_2 were selected to yield ratios of 10, 20, and 25. This then fixed the value of 5,000 psi for E_2

TABLE 1

STRESSES AND DESTRUCTIVE RATIOS, DR, FOR VARIOUS SINGLE WHEEL LOADS AND PAVEMENTS
(h_2 = 8 in., E_2 = 5,000 psi, and E_3 = 2,500 psi)
$S = 1000\ N^{-0.2}$

Load and Pres. (kips - psi)		h_1 (in.)	$K_1 = 10$				$K_1 = 20$				$K_1 = 25$			
			S_{r1} (psi)	N ($\times 10^3$)	DR N_1	DR 820	S_{r1} (psi)	N ($\times 10^3$)	DR N_1	DR 820	S_{r1} (psi)	N ($\times 10^3$)	DR N_1	DR 820
4	60	1					221	2.4	6.14	0.34				
6	60						174	8.1	1.80	0.10				
8	75						162	11.7	1.24	0.07				
9	75						155	14.6*	1.00	0.06				
10	80						150	17.0	0.86	0.05				
12	90						141	24.0	0.61	0.03				
4	60	2	118	58.5	0.12	0.01	243	1.4	0.14	0.58	300	0.5	0.15	1.69
6	60		140	24.5	0.29	0.03	288	0.6	0.33	1.36	353	0 2	0.35	3.81
8	75		166	10.8	0.66	0.08	333	0.3	0.69	2.83	406	0.1	0.73	8.05
9	75		178	7.1*	1.00	0.11	357	0.2*	1.00	4.10	432	0.075*	1.00	10.91
10	80		190	5.1	1.40	0.16	378	0.1	1.33	5.46	459	0.05	1.44	15.73
12	90		216	2.6	2.73	0.31	423	0.08	2.41	9 88	511	0.03	2.38	26.21
4	60	4	106	102.4	0 10	0.01	160	12.2		0.07	179	7.0	0.05	0.12
6	60		130	36.1	0.29	0.02	205	3.5		0.24	233	1.8	0.21	0.46
8	75		154	15.1	0.69	0.05	250	1.3		0.65	287	0.6	0.62	1.34
9	75		166	10.4*	1.00	0.08	271	0.82*		1.00	314	0.39*	1.00	2.10
10	80		178	7.1	1.45	0.11	293	0.5		1.51	341	0.3	1.49	3.21
12	90		203	3.7	2.81	0.22	337	0.3		3 06	395	0.1	3 19	6.89
4	60	8					56	1860.0	0.02					
6	60						84	316.0	0 14					
8	75						112	78.2	0.55	0.01				
9	75						127	42.8*	1.00	0.02				
10	80						141	24.0	1.79	0 03				
12	90						169	9.3	4.60	0.09				

*Reference repetitions (N_1)

which will be considered to represent an unbound base course material. According to Peattie (15), "... for unbound granular materials the effective value of E_2/E_3 invariably lies between 2 and 5." The selection of $E_2/E_3 = 2$, thus sets our value for E_3 equal to 2,500 psi. It is apparent that the absolute values of E's are not a primary factor for stress computations; but the modular ratios are.

The use of Jones' tables for stress calculations required that circular and uniformly loaded contact areas be assumed. With respect to the larger wheel loads that would normally be carried on duals, it was assumed that the area of contact with the pavement surface was circular and equal to the load divided by the tire inflation pressure. Additionally, it was considered reasonable to increase the tire inflation pressure as the wheel load increased. A review of truck tire ratings given by the Tire and Rim Association (16) suggested the grouping for tire pressures and loads given in Table 2.

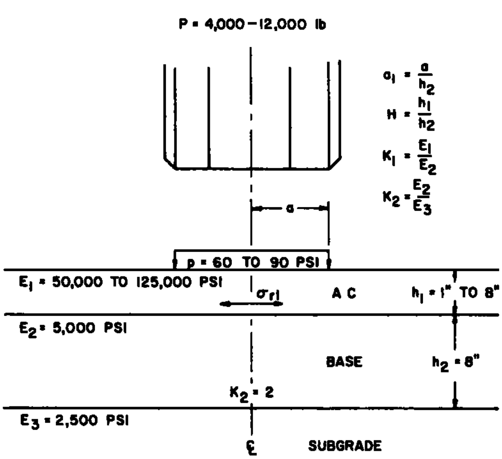

Figure 2. Variables and symbols for three-layered systems.

Typical calculated tensile stresses resulting from the selected wheel loads are shown in Figure 3. The data points do not lie on a straight line; however, for practical purposes and especially in consideration of the assumed contact areas, a linear relationship between the tensile stress and single wheel load was accepted as shown by the solid lines. As expected, the higher the K_1 value, the higher was the

TABLE 2

TIRE PRESSURE AND LOAD GROUPING

Total Load (lb)	Inflation Pressure (psi)
4,000	60
6,000	60
8,000	75
9,000	75
10,000	80
12,000	90

stress for other conditions fixed. Figure 3 also shows that the rate of stress increase with increasing load is greatest for the highest K_1 plot.

In Figure 4, effects of surface thickness on the relationship between tensile stress and load are presented. The relative position of the h = 1-in. curve is interesting. From the low stresses associated with this curve it would seem that the maximum curvature of the deflected layer does not occur directly below the center of the loaded area and/or that a greater portion of the load is transmitted to the base course.

DESTRUCTIVE RATIO

Stresses and destructive ratios for the different pavement structures and also reference stresses are listed in Table 1. Typical relationships between destructive ratio and wheel load are shown in the semi-log plot of Figure 5. The reference condition is a 9,000-lb wheel load on a pavement with a surface course thickness of 4 in. and a K_1 value of 20. The relative positions of these curves indicate the changes in the damaging effects of different wheel loads as the base loses stiffness in comparison to the surface course (E_1/E_2 increases), such as may occur during a spring thaw or when the asphaltic concrete increases in stiffness due to temperature changes or aging of the asphalt.

In order to check this approach for establishing wheel load equivalencies, comparisons were made with comparable values determined at the AASHO Test Road (4). Such a comparison is shown in Figure 6 for a pavement with a common structural number of 3.0. The SN of 3.0 was obtained using a_1 and a_2 values of 0.44 and 0.14, respectively. The plot of fatigue equivalency vs. AASHO equivalency shows almost a perfect agreement. It should be remembered that equivalencies from the AASHO data were related to the total pavement structure and not to the surface course only as is the case for the fatigue equivalencies.

Further comparisons of equivalencies with AASHO values are shown in Figure 7. There is not a consistent relationship between the AASHO and fatigue equivalencies for

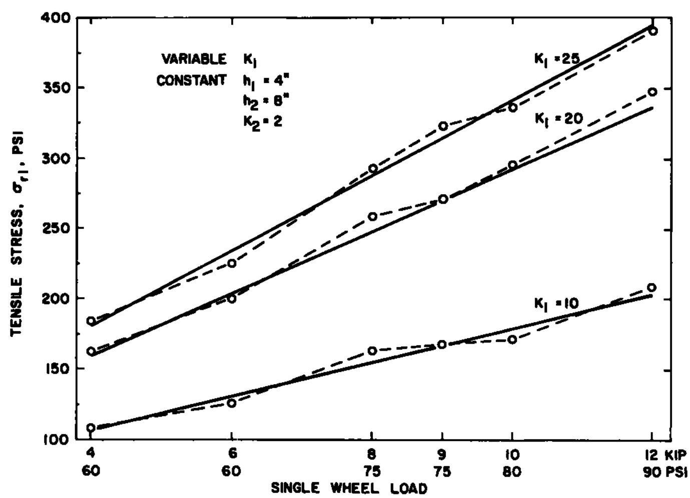

Figure 3. Relationship between tensile stress and wheel load.

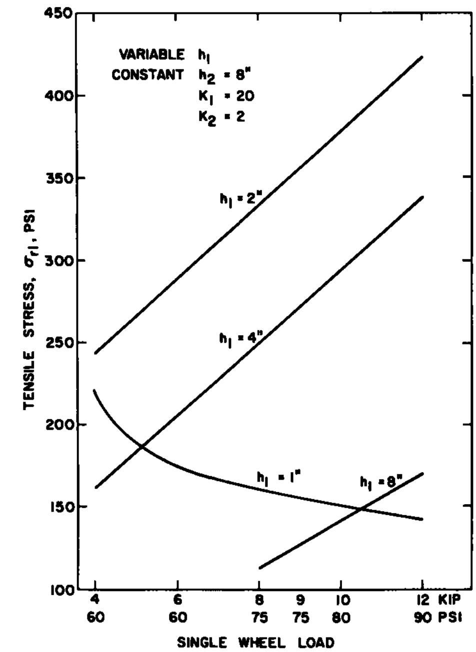

Figure 4. Relationship between load and tensile stress at 1st interface.

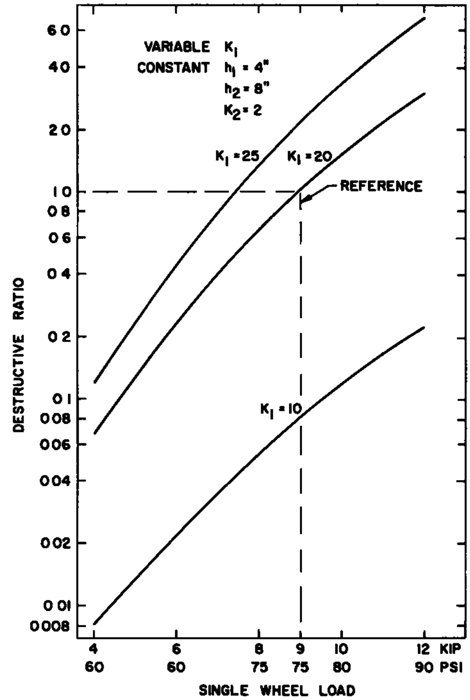

Figure 5. Relationship between wheel load and destructive ratio.

the pavements with surface course of different thicknesses. From Figure 7 and considering the assumed conditions of pavements and wheel loads, the following conclusions are reached:

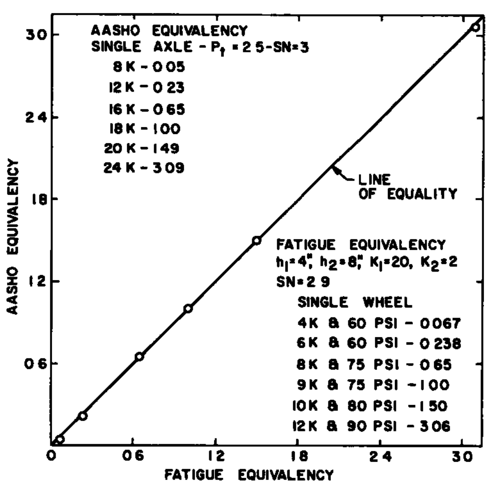

Figure 6. Relationship between AASHO and fatigue wheel load equivalencies.

1. For the pavement with the 1-in. thick surface course, the larger wheel loads are less destructive with respect to flexure fatigue of the surface; however, these loads would have more damaging effects to the subsoils.

2. For the pavement with the 2-in. surface course, single wheel loads up to 9,000 lb are more damaging to the surface than to its foundation and then as the load increases it contributes more to subsoil failure.

3. For the pavement with the 4-in. surface course, the wheel loads are equally damaging to the surface course and to the subsoils.

4. For the pavement with the 8-in. surface course, single wheel loads up to 9,000 lb are slightly less damaging to the surface course than to its foundation and then as the load increases it contributes more to flexure fatigue.

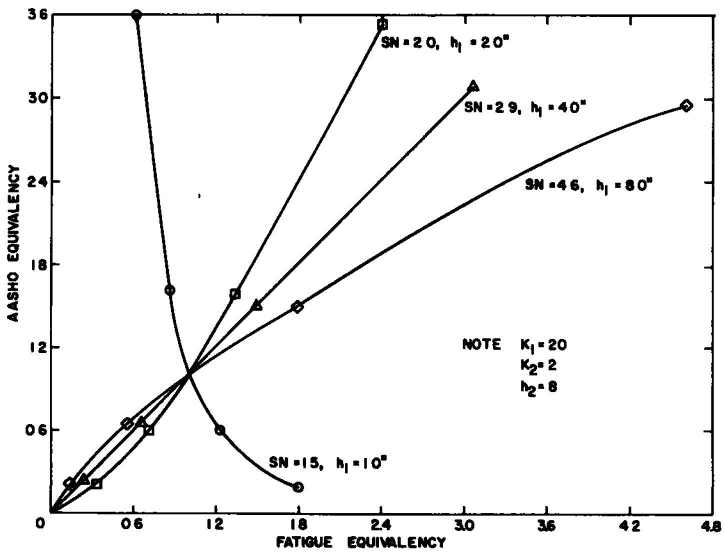

Figure 7. Relationship between AASHO and fatigue wheel load equivalencies.

SUMMARY

This discussion has been quite limited and perhaps too much liberty has been taken for the conditions assumed. Nevertheless, the approach presented for determining wheel load equivalencies appears reasonable and with the comparisons of these values with the equivalencies established by AASHO serve to warrant the following:

1. Flexural fatigue characteristics of asphaltic concrete are a factor to consider in determining wheel load equivalencies.
2. The changes that occur in relative stiffness (E_1/E_2) between a surface course and a base will affect the damaging effects of a wheel load.
3. For thin surface courses (< 1.5 in.), the smaller wheel loads can be more destructive than the larger ones.
4. The destructiveness of different wheel loads may be greater with respect to flexure fatigue strength of the asphaltic concrete than with respect ot the strength of foundation soils.

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