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DISCUSSION OF M.W. WITCZAK's

A COMPARISON OF LAYERED THEORY DESIGN APPROACHES TO OBSERVED ASPHALT AIRFIELD PAVEMENT PERFORMANCE

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DISCUSSION OF

A COMPARISON OF LAYERED THEORY DESIGN APPROACHES TO OBSERVED ASPHALT AIRFIELD PAVEMENT PERFORMANCE

by
M. W. Witczak

The author is to be complimented for his paper and for illustrating the difficulties and hazards to be encountered when attempting to utilize different pavement design methods and to compare resultant thicknesses.

The author correctly emphasizes that the conversion of CBR to a subgrade modulus requires prudent judgment. The multiplicative conversion factor of 1500 is thought to be applicable to soils having a fairly high clay content and is so used in the Kentucky schema. The use of "1500" as the appropriate value for gravelly subgrades is questionable.

The E_1 - temperature relationship used by Kentucky was developed from analyses of the AASHO Road Test data *(28)* and reported elsewhere *(29)*. That relationship is shown in Figure 20 in comparison with the $|E^*|$ - temperature curves for three frequencies as reported by Witczak *(23)* and in Figure 21 in comparison with data presented by Kallas and Riley *(30)*. The Kentucky relationship very nearly matches the 1-Hz curve (Figure 20) and is expressed by the equation

$$\log E_1 = (A/T_A) + B$$

where T_A = absolute temperature, $^\circ R = ^\circ F + 460^\circ (^\circ K = 273 + ^\circ C)$,

E_1 = average modulus of elasticity of asphaltic concrete at T_A, and

A and B are constants.

The Kentucky E_1 - temperature curve has the approximate relative position of the 0.5-Hz curve in the Kallas and Riley set (Figure 21). This is an appropriate position because the Kentucky curve was based upon data from the creep-speed Benkelman beam test method wherein the truck travels at approximately 2 to 3 mph (0.9 to 1.3 m/s). Witczak chose 2 Hz as the appropriate frequency for taxiing aircraft traveling at 10 to 20 mph (4.5 to 8.9 m/s). Witczak states that the average air temperature was 55 F (14.4 C) for the Baltimore-Washington International Airport (BWIA). The 10-inch (25.4-cm) depth had a mean monthly pavement temperature of 65 F (20 C). The intersection of 65 F (20 C) and the 2-Hz curve in Figure 20 gives Witczak's $|E^*|$ of 600 ksi (4.14 GPa). However, an $|E^*|$ of 600 ksi (4.14 GPa) at 2 Hz (Kallas and Riley) matches a pavement temperature of approximately 72 F, as shown in Figure 21. Therefore, the modulus-temperature relationship also depends on the specific mix. For 2 Hz and 600 ksi (4.14 GPa), the Kentucky moduli values would be approximately 480 ksi (3.31 GPa) and 375 ksi (2.59 GPa) from Figures 20 and 21, respectively. The Kentucky E_1 - temperature relationship was based upon a pavement temperature defined as the average of the temperatures at the top, middle, and bottom of the asphaltic concrete layer. Witczak used the temperature at the 10-inch (25.4-cm) depth as an indication of the mean monthly pavement temperature (Figure 3, Reference 23).

The relationship between tensile stress, repetitions, and $|E^*|$ moduli shown in Figure 13 indicates that, for a given tensile strain, a change in repetitions has a corresponding change in $|E^*|$ moduli. Likewise, for a constant $|E^*|$ in Figure 13, a change in repetitions has a corresponding change in tensile strain. The tensile strain of 4.05×10^{-4} for 600 ksi (4.14 GPa) corresponds to Witczak's N_{fo} = 13,239 repetitions for taxiway TW A-6 at BWIA. However, in Figure 21, an $|E^*|$ of 600 ksi (4.14 GPa) intersects the 2-Hz line at an approximate mean pavement temperature of 72 F (22 C). The Kentucky E_1 - temperature relationship shows a correspondence of 72 F (22 C) and an $|E^*|$ of 375 ksi (2.59 GPa). In Figure 13, a tensile strain of 4.05×10^{-4} intersects the $|E^*|$ of 375 ksi (2.59 GPa) at 38,000 repetitions -- the predicted repetitions (N_{fp}) obtained by Witczak. Thus, when the changes in moduli and test frequency conditions are respected and properly equated, the observed and predicted number of repetitions are essentially the same.

Kingham's criteria *(12)* is predicated upon the equation $N = K(1/\epsilon_a)^C$, where C has a value of 4.215 and produces the parallel lines shown in Figure 12. The Kentucky strain-fatigue relationship, shown in Figure 13, can also be expressed by the same equation; however, K and C vary according to the average pavement temperature as shown in Figure 22.

The same type of comparisons can be made through equivalent loads. This discusser used the conditions shown in Figure 5 for input data to the Chevron computer program *(31)*. The Kentucky system is predicated upon repetitions of equivalent 18-kip (80-kN) axleloads, or 9-kip (40-kN) wheel loads. The DC 8 63F aircraft strut load of 172.1 kips (765 kN) *(17)* is supported equally by four tires, yielding a wheel load of 43 kips (191 kN). The Chevron program produced for a 9-kip (40-kN) wheel load a tensile strain of 8.89×10^{-5} at the bottom of a 10-inch (25.4-cm) thick layer of asphaltic concrete having a Young's modulus of 600 ksi (4.14 GPa) and a vertical compressive subgrade strain of 2.18×10^{-4}. Figure 5 shows that the 43-kip (191-kN) wheel load at 600 ksi (4.14 GPa) yields a tensile strain of 3.85×10^{-4} and a vertical compressive subgrade strain of 9.2×10^{-4}. The ratio of tensile strains, due to differences in loads and computer programs, gives a value of 4.33 = (3.85/0.889). Likewise, the vertical compressive subgrade strain ratio is 4.22 = (9.2/2.18). Figure 23 shows that the Kentucky (Chevron computer analysis) ratio of vertical compressive subgrade strains produced by a 43-kip (191-kN) wheel load to those produced by a 9-kip (40-kN) wheel load is 4.14. The Kentucky (Figure 4, Reference 32) axleload equivalency relationship shows that a 43-kip (191-kN) wheel load has a damage factor of approximately 2,000 compared to a 9-kip (40-kN) wheel load. Therefore, 13,239 repetitions of a 43-kip (191-kN) wheel load has the equivalent number of 26,478,000 repetitions of a 9-kip (40-kN) wheel load. Extrapolating in Figure 13, this corresponds to a tensile strain of 1.08×10^{-4} for the Kentucky modulus of 600 ksi (4.14 GPa). Using the Kentucky wheel load damage factor of 4.14 would yield a predicted strain value of $(4.14)(1.08 \times 10^{-4}) = 4.47 \times 10^{-4}$; the corresponding predicted number of repetitions would be 8,200 for 600 ksi (4.14 GPa). If Witczak's modulus was adjusted to the Kentucky equivalent modulus of 375 ksi (2.59 GPa) according to Figure 21, a tensile strain of 4.47×10^{-4} has an approximate corresponding value of 14,000 repetitions as shown on Figure 13. Therefore, the discusser has shown by two more or less independent procedures that Witczak's observed number of repetitions and the Kentucky predicted number of repetitions are essentially the same.

The E_1 - temperature relationship used to obtain basic criteria applied in the development of the Kentucky design schema was derived from extensive field experience in Kentucky. Thus, the use of other E_1 - temperature relationships with the design system would seem to be inappropriate.

In summary, when the appropriate modulus-temperature-frequency relationship is chosen, the Kentucky system produces the same number of repetitions as observed for TW A-6; Witczak's "factor of safety" for Kentucky's $|E^*|$ in his Table 10 would thus be approximately 1.0. This is true whether the moduli adjustment is predicated upon test frequency or determined by wheel load damage factor equivalencies. Kingham's criteria can be applied, at temperatures involved in this study, to Kentucky's strain-fatigue criteria when Figure 22 is used to obtain appropriate K and C values.

The discusser has shown that the Witczak's and Kentucky's design systems do produce essentially the same results provided the proper equivalency conditions are respected between the systems. Equal moduli do not necessarily produce equal designs unless all other conditions are properly equated.

ADDITIONAL REFERENCES

28. *The AASHO Road Test Report 5, Pavement Research,* **Special Report 61** E, Highway Research Board, 1962.
29. Southgate, H. F. and Deen, R. C., *Temperature Distribution within Asphalt Pavements and Its Relationship to Pavement Deflection,* **Research Record 291**, Highway Research Board, 1969.
30. Kallas, B. F. and Riley, J. C., *Mechanical Properties of Asphalt Pavement Materials,* **Second International Conference of the Structural Design of Asphalt Pavements,** University of Michigan, 1967.
31. Michelow, J., *Analysis of Stresses and Displacements in an N-Layered Elastic System under a Load Uniformly Distributed on a Circular Area,* unpublished, September 24, 1963.
32. Southgate, H. F.; Deen, R. C.; and Havens, J. H.; *Adaptation of AASHO Interim Guide To Fundamental Concepts,* The Association of Asphalt Paving Technologists Annual Meeting, Phoenix, Arizona, February 10-12, 1975.

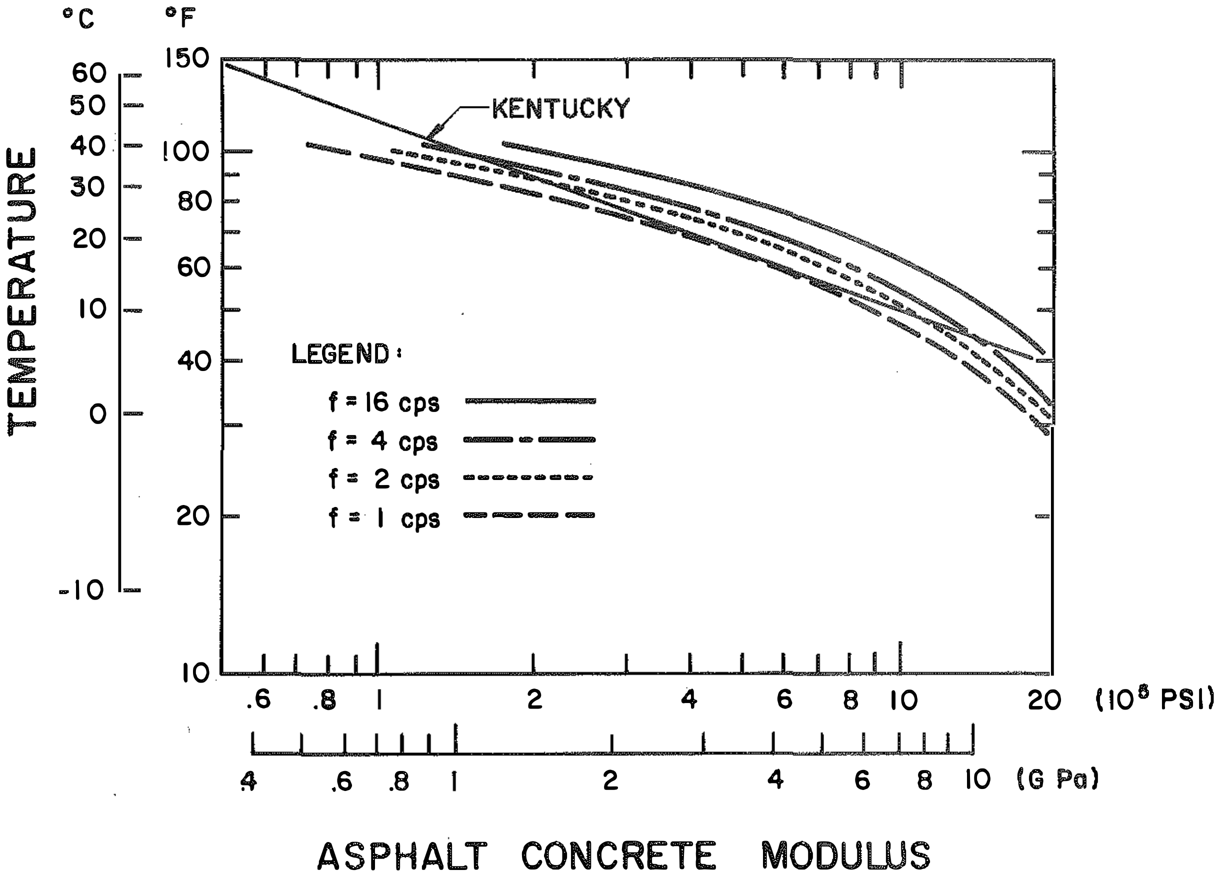

Figure 20. Effect of Temperature and Frequency upon Typical Asphaltic Concrete Dynamic Modulus (after 23, Figure 1).

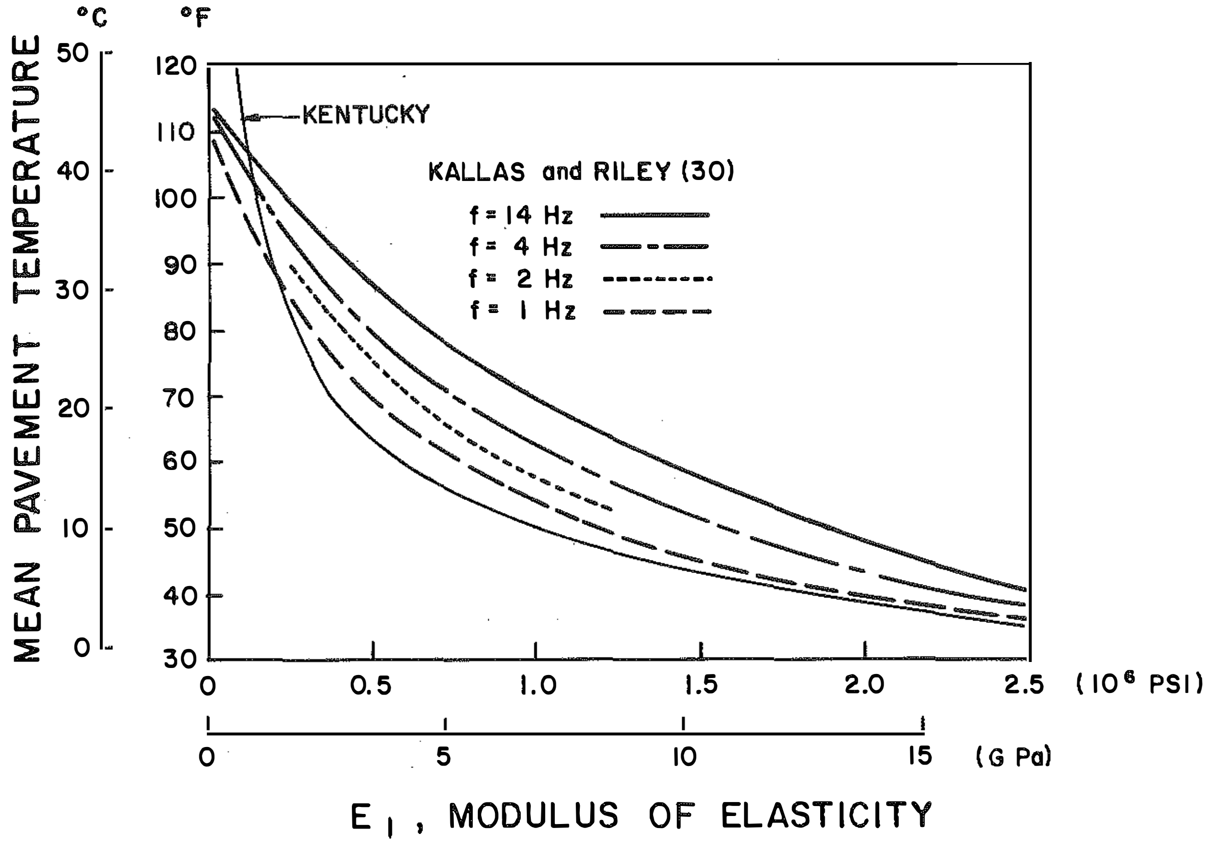

Figure 21. Effect of Test Frequency upon Modulus of Elasticity - Mean Pavement Temperature Relationship (after 30, Figure 3b).

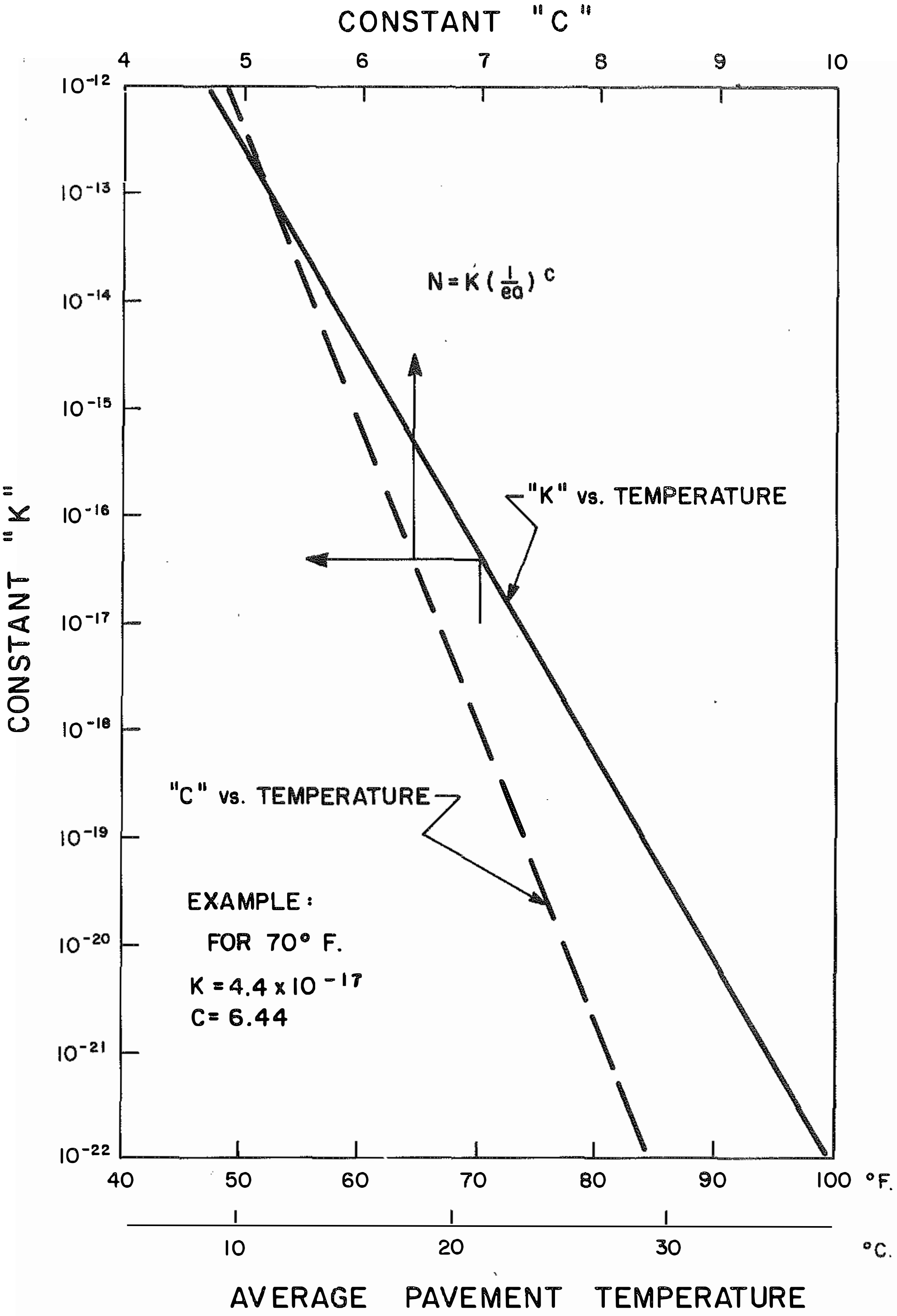

Figure 22. Effects of Average Pavement Temperature upon Values of "K" and "C" in the Equation $N = K(1/\epsilon_a)^C$.

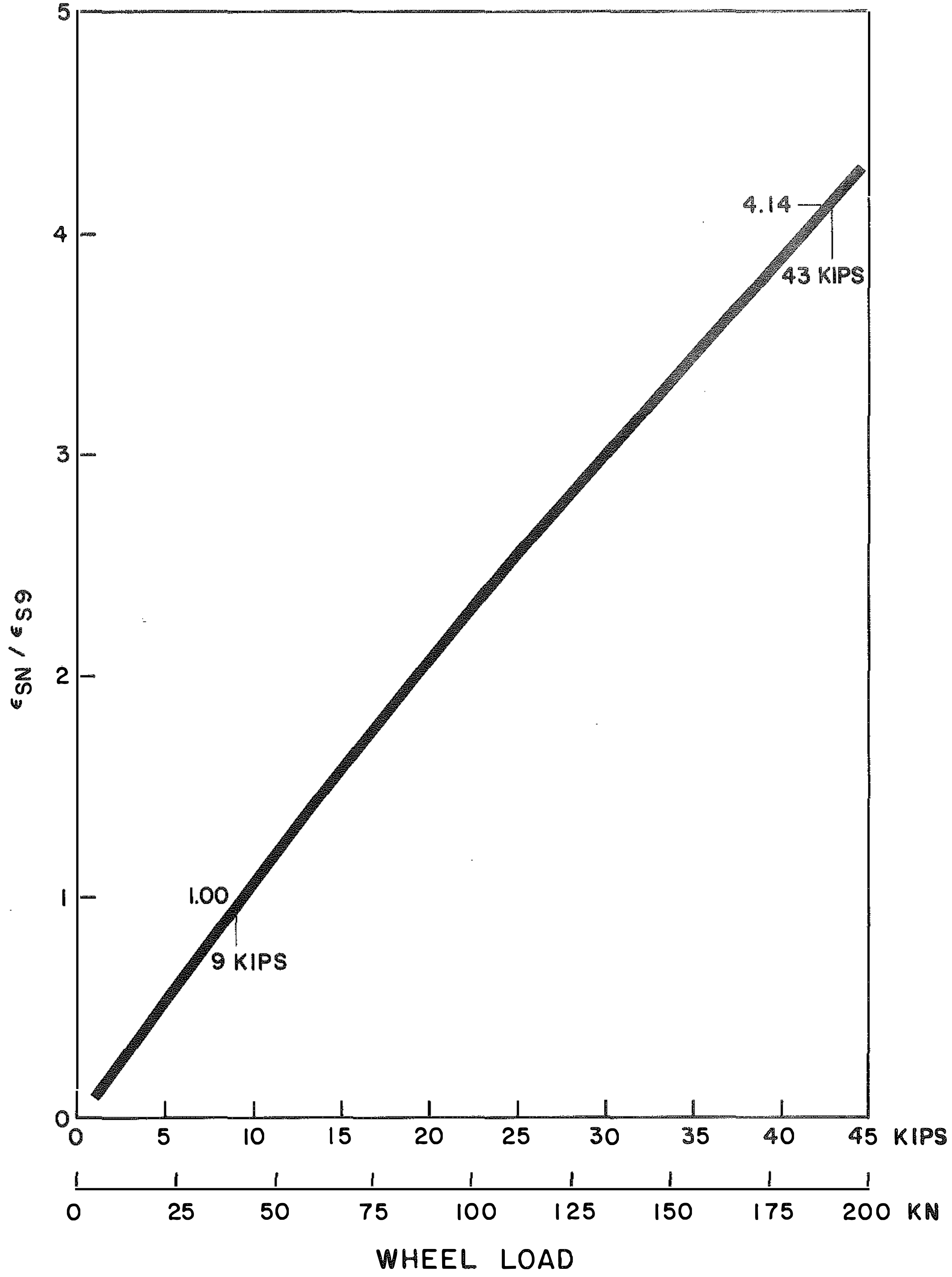

Figure 23. Ratio of Vertical Compressive Subgrade Strain to Strain under a 9-kip Wheel Load as a Function of Equivalent, Hypothetical Wheel Load.