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Rigid Pavement Performance Influenced by Slab Strength and Thickness

A staff (NCHRP) digest of the essential findings from the final report on NCHRP Project 1-4(1)A, "Extension of Road Test Performance Concepts", by A. S. Vesic, Professor of Civil Engineering, and S. K. Saxena, Research Assistant, Duke University

THE PROBLEM AND ITS SOLUTION

The present state of the art in the area of rigid pavement design is to a large degree based on experience gained by trial and error and empirical relationships developed during field experiments such as the AASHO Road Test. As long as the designer is dealing with foundation soils, environmental factors, material properties, construction techniques, and traffic loading conditions that are similar to those for which the relationships have been determined, the performance can be reasonably well predicted. However, as design parameters change a need exists for a more rational approach to pavement design.

The objective of this study was to examine existing theories for structural behavior of rigid pavements in view of the large amount of controlled field performance data collected during the Road Test. A most significant contribution of the study toward the ultimate solution to the problem is the development of a relationship between tensile stress in the pavement slab caused by moving loads and portland cement concrete pavement performance. This lends support to most existing theoretical methods of rigid pavement design. It will be of particular value to highway engineers faced with the problem of designing rigid pavements for rapidly increasing traffic, heavier wheel loads, and new or modified materials and construction techniques.

The evidence of the relationship between traffic loadings and concrete slab strength and thickness is so strong--based on pavement slabs of 2.5- to

11-in. thickness and single-axle loadings of 6,000 to 30,000 lb---that the findings should have some direct practical application without the need for confirmation by further research or translation into specifications or standards. The equation expressing the relationship provides an opportunity for quantitative evaluation of the effect of variations in strength and slab thickness on pavement performance and thus strongly supports the need for quality control during construction. The expression also offers an adequate rational basis for evaluation of an equivalent number of axle load applications for rigid pavements subjected to mixed traffic. In addition to the previously described potential for practical application, the research findings contribute substantially to the progress being made in the area of more rational approaches to structural design of pavements. Using existing mechanistic theories, designers responsible for specialized problems not easily solved by normal procedures should be able to predict with more certainty the potential life of a rigid pavement utilizing the results of this study.

FINDINGS

The principal design criterion of most theories for structural design of rigid pavements is based on consideration of tensile stress, σ, in the slab. The slab thickness, h, is selected so as to keep this stress within certain limits set by the ultimate tensile strength, f_c, of the slab in bending. Such an approach is not entirely satisfactory because it does not take into account the effect of load repetitions on pavement performance. A major development resulting from the AASHO Road Test was the introduction of an index of performance known as present serviceability index, PSI. During this study, a complete stress analysis was performed for all rigid pavement slabs of the AASHO Road Test for which serviceability data were available. The critical stresses for each loading case and slab were plotted versus the number of load repetitions, $N_{2.5}$, needed to reduce the present serviceability index to 2.5. Each tandem-axle load was considered as two single-axle load repetitions. It was found that for conditions at the Road Test a unique relationship results regardless of slab thickness and axle loading. This most significant finding confirms the soundness of a rational, mechanistic approach to design of rigid pavements.

It can be shown that the data in Figure 31 can be fitted by the expression:

$$N_{2.5} = 225{,}000(f_c/\sigma)^{11} \tag{17}$$

in which f_c represents tensile strength of the pavement slab material in bending (for AASHO Road Test slabs f_c = 790 psi), and σ represents the maximum combined tensile stress in the pavement slab caused by traffic load, Q, moving in the anticipated average wheel path position. (In existing design procedures σ is computed as the absolute maximum stress caused by loads placed in some extreme positions such as the slab edge or the slab corner.)

By use of Eq. 17 and consideration of the fact that the pavement stress, σ, for AASHO Road Test conditions is found to be proportional to wheel load, Q, and inversely proportional approximately to the 1.25 power of the slab thickness, h, the following general relationship between principal variables in the AASHO Road Test can be established:

$$N_{2.5} = C\, f_c^{4}\, h^{5}\, Q^{-4} \tag{18}$$

where C is a constant.

APPLICATIONS

Eq. 18 suggests that slab thickness should be increased as the fifth root of the anticipated number of load applications. This means that under otherwise equal circumstances the pavement life may be increased 1.8 times by adopting a 9-in. instead of an 8-in. slab thickness, and 3 times by adopting a 10-in. instead of an 8-in. slab thickness. At the same time, the pavement life may be reduced to one-half by adopting a 7-in. instead of an 8-in. slab thickness.

It also follows from Eq. 18 that the pavement life varies as the fourth power of the concrete strength. This points out the importance of quality of materials in pavement construction--a 10% increase in strength may mean a 50% increase in pavement life; a 20% increase in strength may mean doubling the pavement life. At the same time, a 10% reduction in concrete strength may mean reducing the pavement life to 65% of the normal expectation; a 20% reduction in strength may mean reducing the life to 40% of the normal expectation.

Eq. 18 may provide a rational basis for evaluation of effects of over load and mixed traffic on pavement life. A consistent 20% overload may reduce the pavement life to one-half that normally expected. One application of double load is equivalent to 16 applications of normal load; at the same time, 16 applications of the half-load in mixed traffic should be equivalent to one application of normal load. Many (6,500) applications of a 2-kip axle load should be equivalent to one application of an 18-kip load.

The analyses leading to Eq. 18 furnish a rational basis for evaluation of equivalency of single and tandem loads under much more general conditions than possible in the past. With such an expression it becomes possible to predict in a rational way what would be the effect of using, on a certain pavement, tandem-axle loads with different axle spacing or with a different distance between extreme wheels. Moreover, it becomes possible to predict with somewhat greater certainty the potential life of a rigid pavement subjected to traffic by a new vehicle, which may be of entirely different characteristics than any other vehicle used in the past on similar pavements.

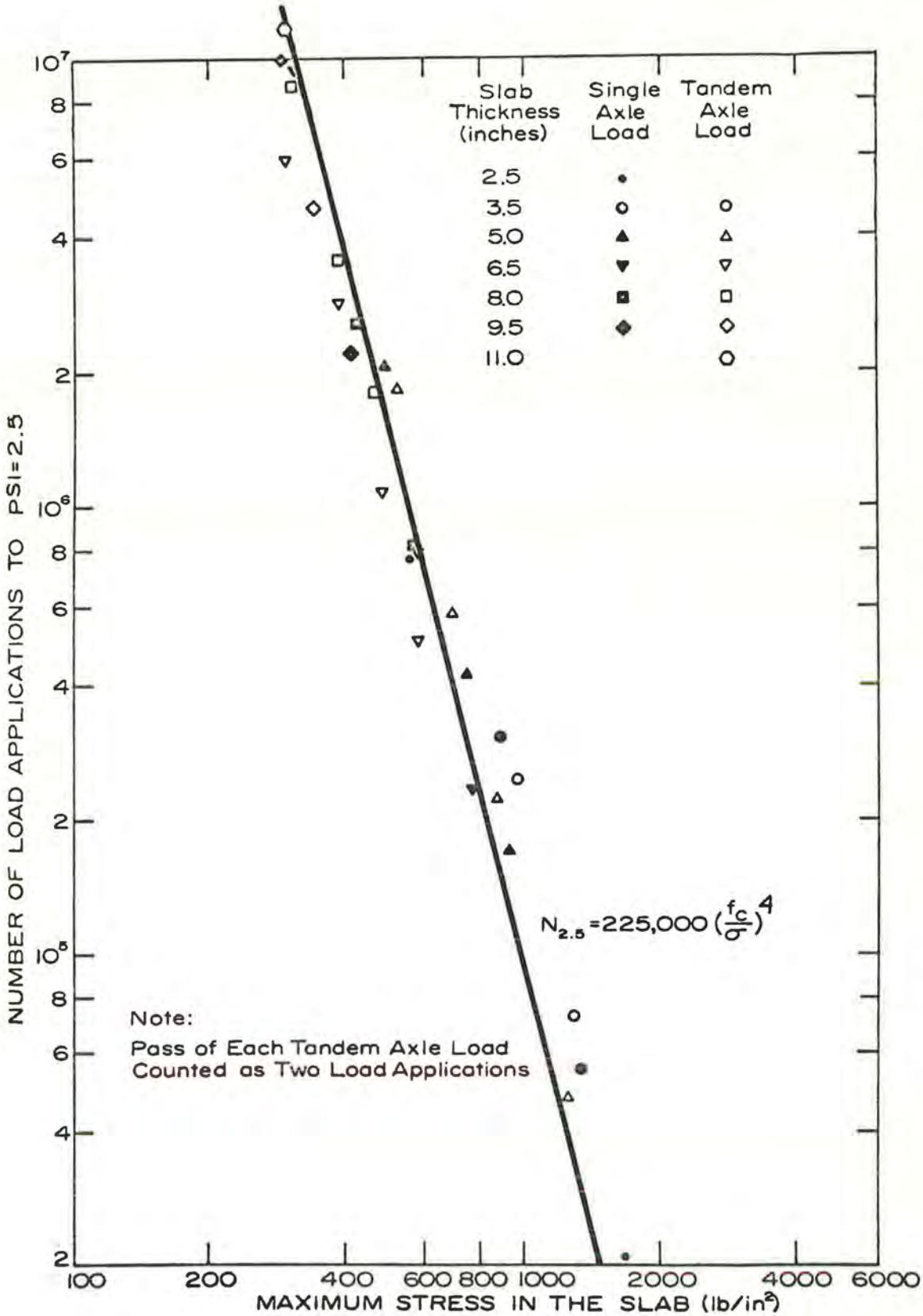

Fig. 31. Relationship of performance to maximum combined tensile stress in slab.