CONTINUOUSLY REINFORCED CONCRETE PAVEMENT: STRUCTURAL PERFORMANCE AND DESIGN/CONSTRUCTION VARIABLES

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SUMMARY OF

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Foreword

Research Report 177-7 describes the evaluation of the structural performance of a continuously reinforced concrete pavement with emphasis on the relative effect of design, construction and environmental variables. The applications of the results in designing new pavement structures as well as its application in maintenance and rehabilitation are discussed.

This report is part of a project which aims at the analysis of maintenance and rehabilitation of continuously reinforced concrete pavements and is the first report on the actual structural performance of pavements of this kind in the rural area of Texas.

Problem and Approach

The design and construction of continuously reinforced concrete pavements (CRCP) does not incorporate transverse joints for construction or expansion; instead a random pattern of transverse cracks is allowed to develop as a result of shrinkage and temperature changes. Longitudinal steel reinforcement is placed in the slab to ensure a narrow crack width thus preventing the intrusion of surface water and foreign matter. Hence, good load transfer at cracks is retained for a great part of the pavement life and better structural performance is provided. Since transverse joints are non-existent, a major source of rigid pavement maintenance is excluded from CRCP. Thus, theoretically, CRCP can be considered maintenance free over a good part of the design life.

However in practice it was found that maintenance was required on certain pavement sections much sooner than expected. Furthermore, there was a considerable variation in structural performance of the pavements, not only from district to district but also from section to section. In order to quantify this variation objectively, a project was initiated to measure the condition of the pavement in a relatively rapid and inexpensive way (Ref 1). This survey provided the basis for a study into the relative importance of design, construction and environmental variables on the structural performance of a CRCP.

Some 56 sections each 600 feet (197 meters) long, were selected on the Interstate Highway System for a detailed study. Design and construction information were retrieved from construction plans and files which together with field measurements of deflection, road roughness, cracking pattern and crack width could be used in an analysis of structural performance. Instead of employing an elaborate program of sampling and laboratory testing of specimens, it is intended to engage the Surface Dynamics Profilometer for road roughness measurements and the Dynaflect for deflection and surface curvature measurements from which slab and subgrade stiffness values can be derived. Thus it is intended to evaluate the structural capacity of a CRCP by utilizing rapid methods of measurement and by incorporating pavement characteristics that are known from construction information.

The basis of the analysis procedure has to be theoretical models in order to incorporate variables that may not show enough variation on the sections that were selected. These variables include slab thickness, vehicle loading, temperature movements, types of aggregate and load transfer characteristics. Unfortunately no single theoretical model exists which can be applied in this report so that a regression technique is used to tie together as many theoretical models as possible.

Theoretical Models

Measureable structural failure in a pavement, which can be considered as a progressive phenomenon occurring with time or with an increase in loading, is associated with the probability of failure at a specific point in the pavement due to a variation in pavement characteristics. The probability of failure can be illustrated as in Fig 1 which shows probability of failure, or the actual measured amount of distress on an in-service pavement, as a function of the variance of pavement characteristics. This relation is denoted by a value Z , the standard normal variable, which can be derived from the ratio area failed to total area surveyed as shown in Fig 2.

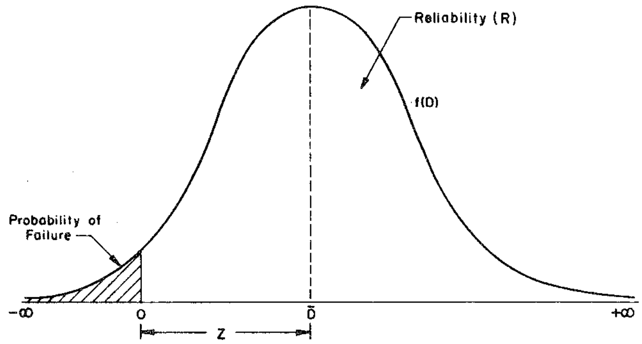

Fig 1. Probability of failure and the effect of a variation in pavement characteristics.

The area that has structurally failed can then be written in terms of Z which relates to the number of load applications experienced on the pavement, n , and the maximum number of load applications designed for, N :

$$Z = \frac{\log n - \log N}{S^2}$$

where S^2 denotes the variance of pavement characteristics and number of load applications combined.

The value of n can be determined from the actual number of equivalent loads experienced on an old pavement or expected on a new pavement. The variance S^2 can be determined from past experience with similar construction or can be calculated and the maximum number of loads designed for can be calculated from a stress analysis if the fatigue characteristics of CRCP are known.

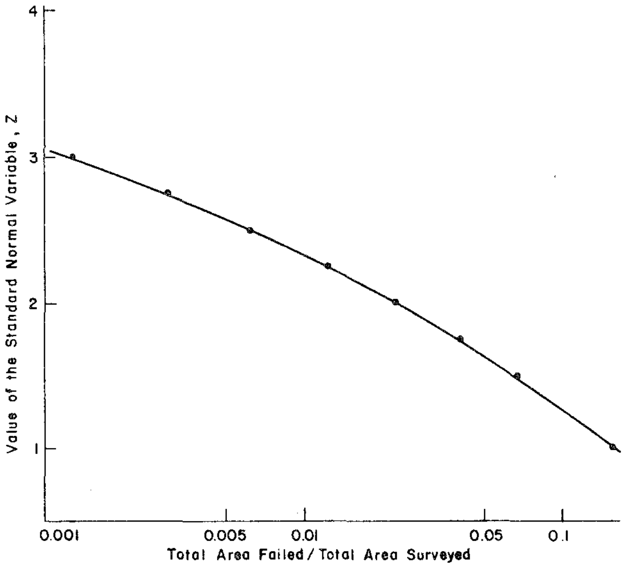

Fig 2. The standard normal variable Z as a function of area failed/area surveyed.

The value of N can therefore be calculated from

$$N = C\left(\frac{f_c}{\sigma_c}\right)^d$$

where

N = maximum number of load applications,

f_c = strength of the material,

σ_c = maximum stress in the pavement due to one load application, and

C and d = fatigue constants to be determined for CRCP.

Since σ_c, the stress in the pavement, depends on pavement stiffness values, magnitude of loading and load transfer characteristics which vary with time, a single theoretical model has to be developed by using several existing models. Equations for load transfer through granular interlock and dowel action of the longitudinal steel reinforcement are tied to a pavement stress model through regression techniques which at the same time provide means of deriving values for C and d, the fatigue constants.

Implications of the Results

The resulting equation that relates the area that has failed structurally, or will fail in the future, to number of load applications and variance in pavement characteristics can be used in predicting future structural failures on existing pavements. The equation is equally applicable in the design of new pavements in terms of the amount of failures that can be tolerated at specific levels of service in terms of number of load applications per day for example.

The greatest benefit of the analysis is in the enhancement of a better understanding of the structural performance of a CRCP. The final equation for example can be written in terms of the assumption that a CRCP behaves as a beam of infinite length. This allows the interpretation of the manifestation of distress as follows: "beam action occurs in a longitudinal direction, that is, in the direction of traffic, on a new pavement. As the cumulative load applications increase, transverse cracks occur first in between existing shrinkage cracks. At the same time crack deterioration increases with time and traffic and a gradual loss of load transfer eventually leads to transverse cracks closer to existing cracks. The result is a closer transverse crack spacing, about 2 to 3 feet (0.6 to 0.9 meters). The penetration of water through the deteriorating cracks causes pumping and leads to a loss of subgrade support of the 2 to 3-foot (0.6 to 0.9-meter) wide transverse beams and eventually these small beams crack due to traffic loading. This cracking can be defined as a minor punch out and represents a structural failure that needs to be repaired in the end."

The manifestation of distress as described above warrants the consideration of preventive maintenance in the form of maintaining apparent minor types of distress. The design of new pavements to prevent a loss of load transfer by improved crack width and dowel steel design needs attention too.

Conclusions

The investigation has shown that the variance of pavement structure characteristics is an important contributor to the poor structural performance of some CRCP sections. Some definite conclusions from the study can be summarized:

(1) The simulation of CRCP as a beam on an elastic subgrade renders accurate enough results if it is compared to the results of the Westergaard equations. The mechanism of distress in CRCP can then be described in a sequence:

- (a) transverse cracking occurs midway between shrinkage cracks in the CRCP due to wheel loads and as a result of longitudinal beam action of the pavement,
- (b) because of a decrease in load transfer at the cracks with time, the CRCP begins to act as an end loaded beam with subsequent closely spaced, 2 to 3-foot (0.6 to 0.9-meter) transverse cracking, and
- (c) a total loss of load transfer at the cracks eventually leads to narrow transverse beams which break up to form punch-outs.

(2) Load transfer at the transverse cracks, either through aggregate interlock or through dowel action of the steel reinforcement, plays a significant role. Factors that have an effect on improved load transfer include

- (a) the use of crushed aggregates as the largest sized particles in the concrete mix, which enhances load transfer through aggregate interlock,
- (b) proper design and mixing of concrete for increased uniformity and workability, which improves compaction and thus the strength of the concrete around the steel,
- (c) the use of concrete mixes with small thermal movements to decrease variation of crack width and thus variation in load transfer, and
- (d) the use of proper construction methods and equipment to improve the densification of concrete especially around the steel reinforcement.

(3) The significance of the effect of load transfer on structural performance emphasizes the importance of sound maintenance techniques. This specifically has a bearing on the size and the construction of repair patches. Additional analysis is necessary to determine the optimum size of a repair patch by which the effect of load transfer is minimized since the restoration of load transfer from the patch to the existing concrete can be achieved only by great effort.

(4) The most important distress manifestations to be considered at the design stage include the mean crack spacing since a big crack spacing is synonymous with a wide crack and thus a loss in load transfer. A small crack spacing on the other hand negatively affects the slab stiffness as well as road roughness. Therefore an initial optimum crack spacing needs to be determined for design purposes. Other important distress types that warrant prevention at a design or maintenance stage are spalling, which has a possible influence on permeability and load transfer, pumping and the resulting loss of subgrade support, and minor punch-outs, which eventually may be the forerunner of structural failure in the form of a severe punch-out.

(5) Variation in concrete properties could not be measured accurately and can be blamed for a low correlation coefficient for repair patches. The same can be said for the correlation coefficients for punch-outs.

Reference

1. McCullough, B. F., and P. J. Strauss, "A Performance Survey of Continuously Reinforced Concrete Pavements in Texas," Research Report 21-1F, Center for Highway Research, The University of Texas at Austin, November 1974.

KEY WORDS: continuously reinforced concrete pavement, regression, pavement distress, prediction of distress, load transfer, stress, dynamic loading.

The full text of Research Report 177-7 can be obtained from Mr. Phillip L. Wilson, State Planning Engineer, Transportation Planning Division, File D-10R, State Department of Highways and Public Transportation, P.O. Box 5051, Austin, Texas 78763.