ANALYSIS OF BENDING STIFFNESS VARIATION AT CRACKS IN CONTINUOUS PAVEMENTS

By

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SUMMARY REPORT 56-22 (S)

SUMMARY OF
RESEARCH REPORT 56-22

PROJECT 3-5-63-56

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SUMMARY REPORT 56-22 (S)

Foreword

Research Report 56-22 describes an analytical evaluation of the effect of transverse cracks on the longitudinal bending rigidity of continuously reinforced concrete pavements. It also presents a sensitivity study of the variables affecting the design of such pavements using the discrete-element method of slab analysis.

This is the twenty-second in a series of reports that describe the work done in Research Project 3-5-63-56, "Development of Methods for Computer Simulation of Beam-Columns and Grid-Beam and Slab Systems." This is the seventh report in the series that deals primarily with pavement slabs.

Introduction

A general discrete-element method for solution of discontinuous plates and slabs has been developed by Hudson and Matlock (Ref 1) and Stelzer and Hudson (Ref 2) based on a physical model representation of the plate or slab by bars, springs, and torsion bars which are grouped in a system of orthogonal beams. Computer programs developed for this method are designated by the acronym SLAB. This report describes the application of SLAB methods in a study of continuously reinforced concrete pavement.

Problem and Approach

Continuously reinforced concrete pavement (CRCP) can be defined as a concrete pavement in which the longitudinal reinforcing steel acts continuously for its length and no transverse joints other than occasional construction joints are present. In practice, the continuity is sometimes interrupted by expansion joints at structures, but except for these, there is technically no limit to the possible length of CRCP.

Transverse contraction joints were long considered essential to preventing pavement damage from volume-change stresses, but CRCP takes care of these stresses by allowing the pavement to develop a random pattern of very fine transverse cracks (Fig 1). Because of volume-change stresses, crack formation in a continuously reinforced pavement slab is inevitable until expansive materials are perfected and therefore a thorough understanding of the behavior of a pavement structure with such discontinuities is needed. The real pavement system, including the cracks, must be analyzed, and this can be approximated with reasonable confidence using SLAB programs.

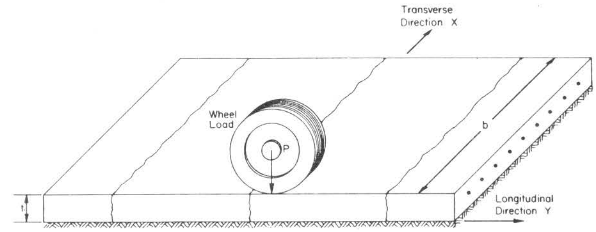


Fig 1. Continuously reinforced concrete pavement (CRCP).

Figure 2a shows a cracked portion of CRCP and Fig 2b shows a schematic variation in the moment of inertia in the cracked region. The shape of this curve is not known exactly because of the complexity of the problem. For applying the discrete-element method to the discretized continuously reinforced concrete pavement, a method was developed using basic moment-curvature relationships in which an average moment of inertia, which simulates the effect of cracks on slab bending stiffness, was determined. Furthermore, the development length bond idea (Ref 3) was used to specify the slab portion over which the average intertia could realistically be applied.

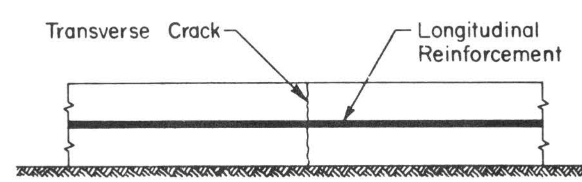
Besides the discontinuity analysis, the use of other slab input variables to model real effects was investigated, including

(1) partitioning of the slab and use of the effect of boundary restraints to represent continuity,

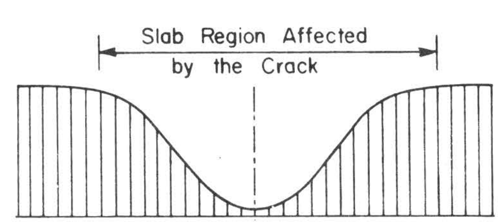
(2) determination of the value of the tension in the longitudinal reinforcement and its effect of deflections and principal stresses, and

(3) determination of the value of Poisson's ratio which should be used and its sensitivity.

After the SLAB method was evaluated for its applicability to CRCP, the second objective was ap-



(a) Cracked portion of CRCP.



(b) Schematic variation in moment of inertia in the region of the crack.

Fig 2. Effect of a discontinuity on the bending rigidity of the slab.

TABLE 1. FACTORIAL VARIABLES

Modulus of subgrade reaction, lb/in²/in	Crack Spacing, ft	Slab bending stiffness, (lb-in²)/in: 20×10^6	150×10^6	1125×10^6
40	4	1	13	25
	6	2	14	26
	8	3	15	27
	10	4	16	28
200	4	5	17	29
	6	6	18	30
	8	7	19	31
	10	8	20	32
1000	4	9	21	33
	6	10	22	34
	8	11	23	35
	10	12	24	36

proached; this was a sensitivity study of the rigid pavement design structural variables, namely slab bending stiffness, subgrade modulus, and crack spacing. A full factorial of these variables (Table 1) was evaluated and solutions were made (1) for loads on the crack and (2) loads between cracks. An analysis of variance was performed on calculated values of maximum deflection and principal moment.

Crack Effect

Discontinuities exert significant influence on the bending rigidity of structural members. Based on basic moment-curvature relationships, an expression was developed for the average moment of inertia due to the discontinuity in terms of slab geometrical characteristics and material properties. Figure 3 shows

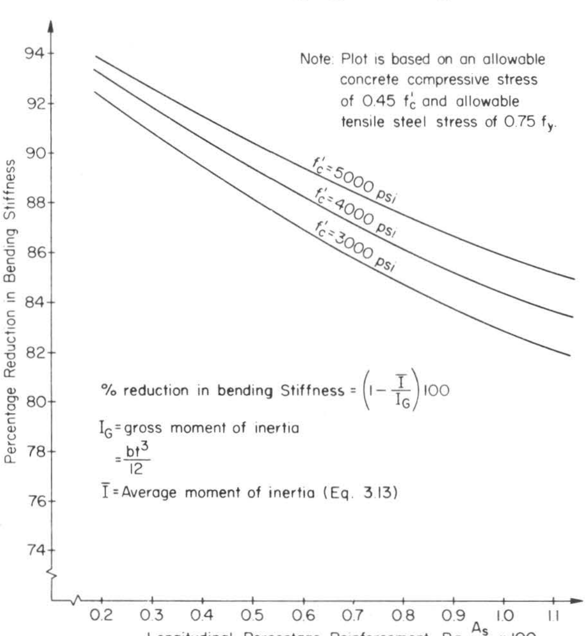


Fig 3. Variation of the percentage reduction in bending stiffness at crack location with longitudinal percentage reinforcement.

the variation of the percentage reduction in bending stiffness with the longitudinal percentage reinforcement. Bending stiffness reduction ranged from 80 to 90 percent for the change encountered in the percentage reinforcement.

Example Problem

The influence of cracks on the behavior of the pavement is illustrated in Fig 4. A 24-by-40-foot slab loaded with two 9,000-pound wheel loads located at 2 and 3 feet from the edge was considered, and the percentage reduction in bending stiffness determined was 90 percent over a length of 12 inches.

Besides the condition with 90 percent stiffness reduction at the crack location, two other conditions were studied: the hinged condition, in which there is zero stiffness at the discontinuity; and the uncracked condition, in which the full slab is treated as one piece. The variation in deflections for each of these cases is shown in Fig 4. The effect of the hairline cracks is clearly illustrated by the 30 percent increase in deflection of the 90 percent reduction case over the uncracked case. Likewise, the percentage deflection increase was doubled (60 percent) for the hinged and the uncracked cases.

Results of the Analysis of Variance

To determine the sensitivity of the rigid pavement design variables, an analysis of variance was made on the maximum values of deflections and principal moments for the factorial combination of variables shown in Table 1. The results indicated that the most significant variables, accounting for around 90 percent of the variation in deflection and principal moment (stress) responses, were slab bending stiffness and modulus of subgrade reaction. The latter variable showed a higher contribution to deflections than to principal moments, and slab bending stiffness produced an opposite effect. Crack spacing has a minor effect on slab behavior.

The orthogonal polynomial breakdown indicated

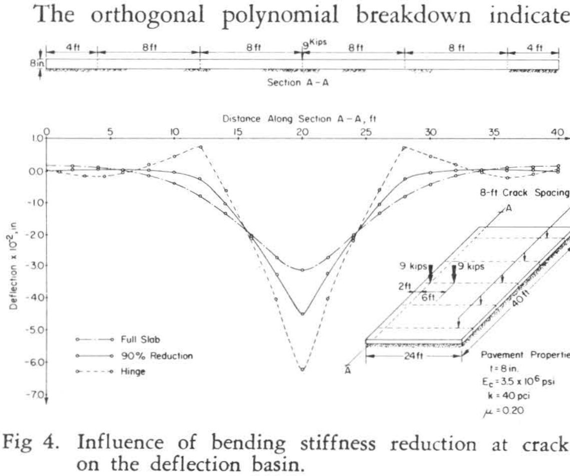


Fig 4. Influence of bending stiffness reduction at cracks on the deflection basin.

that the linear effect in the log of both subgrade modulus and slab bending stiffness is highly significant. Furthermore, interactions between these two design variables do occur, indicating that variations in deflections and principal moments are not defined by the main effects of the design variables alone.

Conclusions

This investigation was conducted to determine, by use of the discrete-element slab model, the sensitivity of pavement deflection and principal moments to changes in design parameters. The findings, however, can provide reasonable information for selecting those variables which require the most consideration in design.

Based on calculated changes in deflections and principal moments, the following conclusions can be drawn from this study.

(1) The effect of transverse cracks in CRCP on the longitudinal bending rigidity of the slab is important.

(2) The effect of variations in Poisson's ratio is negligible.

(3) When a CRC pavement is analyzed (considering no loss in subgrade support), it is reasonable to consider only the partition or area extending 15 to 2 feet on each side of the loaded area. No boundary restraints are needed at the edges of such a partition (free edges).

(4) The modulus of subgrade reaction is important in determining the amount of deflection.

(5) Principal moments or stresses are mainly dependent on, first, the stiffness of the slab and, second, the subgrade modulus.

(6) For the increments given to subgrade modulus, slab bending stiffness, and crack spacing, the analysis of variance and its orthogonal polynominal breakdown showed that

  (a) A definite logarithmic linear trend of subgrade modulus with deflection is observed, as well as a tendency toward a logarithmic quadratic relationship.

  (b) The linear effect of the log of bending stiffness on principal moments and deflections is quite significant.

(7) The width of the crack has a strong influence on the performance of continuously reinforced concrete pavements. The reduction of the bending rigidity of the slab and the consequent increase in the lab deflection as a result of an increase in crack width are important. Perhaps the requirement most necessary for the successful performance of continuously reinforced concrete pavement is that the steel reinforcement hold any transverse cracks to a narrow width.

Recommendations

Based on this investigation, it is recommended that

(1) pavement design procedures include greater consideration of the modulus of subgrade reaction, because of its influence on deflections and stresses;

(2) stress criteria in present design procedures be coupled with deflection criteria to help to insure a pavement deflection less than the desired maximum; and

(3) transverse cracks be kept very narrow in order to

  (a) prevent progressive infiltration of incompressible materials,

  (b) prevent appreciable amounts of surface water from reaching the subgrade, and

  (c) maintain effective aggregate interlock between crack surfaces.

References

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KEY WORDS: discrete-element analysis, cracks, pavement slab, continuously reinforced concrete pavement, sensitivity analysis, deflection, principal moment, boundary restraints, program SLAB.

The full text of Research Report 56-22 can be obtained from R. L. Lewis, Chairman, Research and Development Committee, Texas Highway Department, File D-8 Research, 11th and Brazos Streets, Austin, Texas 78701 (512/475-2971).