Evaluation of Mix Time on Concrete Consistency and Consolidation

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In an effort to look at ways to improve the quality of the finished concrete pavement product, the Iowa Department of Transportation and ISU conducted research on two existing highway projects in 1997. The objectives of that research included evaluation of two alternative types of central mixers, the effect of the type of hauling equipment, the mix design, and the mixing time employed to produce the mix on the consistency, consolidation and air matrix in the concrete pavement. The concrete was tested at the plant site and at the grade by standard methods employed in the testing of ready mixed concrete delivery. The results of that research have provided some insight into the consistency and consolidation of the concrete produced and placed. In addition, core analysis of the hardened concrete by the Scanning Electron Microscope (SEM) have given more information relative to the impact of the paving operation on the air matrix on the finished product. This paper will report some of those results and indicate how they may be shaping the future mix design and construction of concrete pavements. Key words: mix design, concrete, pavements, mix time.

INTRODUCTION

In an effort to evaluate ways to continuously improve the paving products delivered to the public, the Iowa Department of Transportation (DOT) in conjunction with the Iowa Highway Research Board (IHRB) and the Civil and Construction Engineering (CCE) Department of Iowa State University entered into Project HR-1066. "Effect of Mix times on Portland Cement Concrete (PCC) Properties" was an effort to look at the concrete quality from mixing to consolidation at the paving site.

RESEARCH OBJECTIVES

The research effort was directed at collection and evaluation of data relating mixing time to:
a. Hardened air content and distribution
b. Potential segregation in the hauling units
c. Concrete consolidation quality at the paving site
d. Workability of the concrete at the paving site.

The long term goal of the Iowa DOT in this work was the development of a performance based specification for Portland cement concrete pavement construction that measures quality, consistency, hardened air content and pavement strength at the construction site.

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DATA COLLECTION METHODS

Data was collected at two separate construction sites (Carlisle and Carroll, Iowa) under contract to the same contractor by the Iowa DOT. At the Carlisle site, a conventional central drum mix plant was employed to produce the concrete. A horizontal drum mixer with blades that moved within the drum was employed at the Carroll site. The research staff chose to employ the plastic concrete tests outlined in ASTM, C-94 specification that pertains to measuring consistency and quality of concrete in a ready mix truck or agitor. In the case of the mix design, the contractor was also allowed to use a second mix design of their choosing in separate tests at the Carlisle site. All testing was done at the field concrete plant site with the cooperation of the contractor and the Iowa DOT staff. Samples were obtained from the concrete hauling units, selected at random, as they left the plant site and at the paver when the same load was consolidated.

Mixing time was measured visually at the plant site as the time elapsed between the introduction of all the materials into the mixer and the initial mix delivery into the hauling unit. Nominal mixing times chosen for each site were as follows:

Carroll (Iowa DOT mix) - 30 and 45 seconds
Carlisle (Iowa DOT mix) - 45, 60 and 90 seconds
Carlisle (Contractor mix) - 45, 60 and 90 seconds

Tests were conducted on the plastic concrete samples in accordance with ASTM C-94 specification, on samples collected at the plant site from the center and side of the hauling unit load and in the field directly in front of the paver. Concrete parameters tested included:
a. Slump, as per ASTM standard C143
b. Unit Weight as per ASTM standard C138
c. Air content as per ASTM standard C231
d. Retained Course Aggregate as per ASTM standard C94.

Compressive cylinders were constructed from samples from each of the truck load used in the plastic concrete tests. Cores were also extracted from the hardened concrete in the areas where the test truck loads of concrete were placed and compressive strengths were determined in accordance with ASTM C42 test procedures.

ANALYSIS RESULTS

The field data was summarized in terms of the information gathered from each of the hauling unit loads selected in the sample. This means that at each of the construction sites, test results were collected for randomly selected truck loads of concrete at the plant site. Material in these units were tested at the plant site and at the paver when the material was deposited on the grade. The results of physical tests at both sites, cylinders constructed at the plant and

cores extracted from the pavement in the area where the load was placed, were compared statistically relative to mix type and time of mixing. The detailed results of that work are contained in the project report for HR-1066.

A summary of the statistical analysis of variance (ANOVA) for the physical tests of slump, unit weight, air content and retained coarse aggregate yielded the following information:

1. The 30-45 second mixing times for the Carroll DOT mix and alternative mixer indicate no significant differences in slump, unit weight, air content and retained coarse aggregate.

2. The selected mixing times for the Carlisle DOT mix and the conventional drum mixer indicate that increasing the mixing time from 45 to 60, 45 to 90 and 60 to 90 seconds lead to a significant increase in the air content retained in the final product. There were no significant changes noted in any of the other physical test results.

3. The Carlisle contractor mix results indicate a significant increase in unit weight and a reduction in air content when the mixing time was increased from 45 to 60 seconds. However, increasing the mixing time from 60 to 90 seconds indicated a significant difference in the concrete unit weight and retained coarse aggregate test results.

In terms of sampling location the ANOVA tests provided the following answers:

1. For all mix types and mixing times, sampling at the center or side of the truck provided no significant difference in the dependent variables.

2. The Carroll DOT mix did show significant differences in the retained coarse aggregate between side and center of the truck and the grade samples. The same result was also shown when the test for the Carlisle contractor design mix was evaluated.

3. The tests indicate that longer mixing times led to significantly different air contents in the samples taken from the center and side of the truck and at the grade.

ANOVA analysis of the cylinders and cores from each of the test sampling areas at the plant and behind the paver resulted in the following information:

1. The effect of mixing time for the Carroll Iowa DOT mix and the Carlisle contractor designed mix do indicate that longer mixing time did create significantly increase compressive strengths for in both the cylinders and cores.

2. The Carlisle Iowa DOT mix cylinders and core compressive strengths decreased as the mixing time increased from 45 to 60 and 60 to 90 seconds.

An ANOVA in the results of the SEM analysis for the cores and cylinders identified the following results:

1. The Carlisle Iowa DOT mix and the Carroll Iowa DOT mix show no significant difference in average air content for the mixing times compared.

2. The Carlisle contractor designed mix does indicate a significant difference in the average air content for all mixing times compared. The average air content across the test specimen increases as the time of mixing increases from 45 to 90 and 60 to 90 seconds, but decreases when the mixing time is changed from 45 to 60 seconds.

Field visual evaluation of the mix at both the plant site and the grade did yield some information that is difficult to identify in the test results at the Carroll construction site. Mixing at the 30 and 45 seconds yielded visible sand seams (uncoated sand particles) in the discharged materials. Some of this phenomenon was visually present in the truck at the plant testing site. These sand seams were still present in the truck when the material was discharged into the paver. The concrete produced under this set of mixing conditions was difficult to place and finish.

CONCLUSIONS

This research was directed at evaluating the effect of mixing time on the physical characteristics of the finished Portland cement concrete pavement. It considered three mix designs, two difference concrete mixers and four mixing times. The results of the research, compared to the research objectives, indicate the following conclusions:

1. Potential segregation in the hauling units: Dump truck type hauling units do not significantly change or decrease the quality of the material being delivered to the paver and should continue to be allowed in addition to agitor type hauling vehicles for transport of Portland cement concrete paving materials.

2. Concrete consolidation and workability quality at the paving site: The results of the ANOVA indicate that mixing times of 60 seconds or greater do have a positive influence on the physical characteristics of the concrete product. It is recommended that the 60 second minimum mixing time be retained for all mixer types at this time.

3. Hardened air content and distribution: The data from this set of tests indicates that for Iowa DOT designed mixes the mixing time did not effect the physical attributes of the concrete significantly. The results did show a conflicting ideas for the contractor designed mix. We suggest that this is the result of both a different matrix of coarse and fine aggregate in the contractor mix as related to previous Iowa DOT mixes. It does open a new set of parameters for mix approval when coupled with the impact of mix admixtures being used or considered. It is recommended that contractor mix designs be thoroughly laboratory tested prior to construction to determine the impact of admixtures and the differences in aggregate/cement matrix on the desired physical performance factors desired by the agency.

4. Concrete mixer type and mixing times: Visual and physical test data indicate that reduced mixing times for alternative type mixers should only be allowed when steps have been taken to change the mixing process to eliminate any particles of aggregate that are not coated upon discharge into the hauling unit.

ACKNOWLEDGMENTS

REFERENCES

1. Cable, J.K. and L.L.McDaniel. *Effect of Mix Times on PCC Properties, HR-1066,* Iowa Department of Transportation, Ames, Iowa, May 1998.

Evaluation of Glass Fiber Reinforced Plastic Dowels as Load Transfer Devices in Highway Pavement Slabs

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The use of dowel bars, fabricated from glass fiber reinforced plastic (GFRP), as load transfer devices in highway pavement slabs is a possible solution to the corrosion problems related to the current use of steel dowels. The material properties of GFRP are considerably different from those of steel. Therefore, to keep material stresses within permissible limits, the diameter and spacing used for steel dowels is no longer valid for GFRP dowels. This paper presents a design procedure for determining the required diameter and spacing for GFRP dowels based on the load transferred through the critical dowel. Essentially, the diameter and spacing requirements for GFRP dowels is based on an equivalent deflection for a joint containing steel dowels spaced at the standard 300 mm (12 in.). GFRP dowels appear to be a feasible solution as long as the diameter of the dowel is increased, spacing decreased, or a combination of both. Key words: concrete pavements, glass fiber reinforced plastics, dowels, doweled joints.

INTRODUCTION

A considerable amount of the nation's transportation infrastructure is in need of repair or replacement because of deterioration resulting from pavement reinforcement corrosion. New construction methods and new materials are needed to protect the infrastructure in order to avoid this type of deterioration. An obvious method of controlling this deterioration is to use a material that is naturally resistant to corrosive environments such as glass fiber reinforced plastic (GFRP).

Load transfer devices are structural members placed at locations of transverse joints in highway pavements that act to transfer shear across the joint. Since these devices are placed along the length of the joint, they are susceptible to de-icing salts. The steel dowels which are currently used as load transfer devices corrode when exposed to these salts and bind or lock the joint, resulting in undesirable stresses. Therefore, the non-corrosive properties of GFRP make it an ideal material for use as a load transfer device in concrete highway pavement slabs.

Since the material properties of GFRP are different from those of steel, the diameter and spacing commonly used for steel dowels is no longer valid for GFRP dowels. This paper presents a design

procedure for determining the required diameter and spacing for GFRP dowels based on the load transferred through the critical dowel.

DESIGN PROCEDURE

The diameter and spacing required for GFRP dowels can be determined by equating the relative deflection of a joint doweled with steel dowels to that of a joint containing GFRP dowels. For a specific diameter and spacing, the relative deflection between adjacent slabs can be determined. The dowel bar diameter and spacing which results in a deflection equivalent to that for a joint containing steel dowels spaced at the standard 300 mm (12 in.) is the desired diameter and spacing for GFRP dowels.

As shown in Figure 1, the relative deflection between adjacent pavement slabs, Δ, consists of two components: the deflection of the dowel bar within the pavement at the face of the joint, y_o, and the shear deflection of the dowel bar across the joint, δ (*1*). The relative joint deflection is given in Equation (1):

$$\Delta = 2y_o + \delta$$

The deflection of the dowel relative to the concrete, at the face of the joint, was developed by Friberg (*2*) for design purposes and is given in Equation (2):

$$y_o = \frac{P_t}{4\beta^3 EI}\left(2 + \beta z\right)$$

where:

$$b = \sqrt[4]{\frac{Kb}{4EI}}$$

K = modulus of dowel support
b = dowel bar diameter
E = modulus of elasticity of the dowel bar
I = moment of inertia of the dowel bar
P_t = load transferred by critical dowel
z = joint width

Friberg's equation is based upon the theoretical model developed by Timoshenko and Lessells (*3*) for the analysis of beams on elastic foundations. Friberg's equation was derived assuming a dowel bar of semi-infinite length. Dowel bars used in practice are of finite length, therefore, this equation would not apply. However, Albertson (*4*) has shown that this equation can be applied to dowel bars with a βL value greater than or equal to 2 with little or

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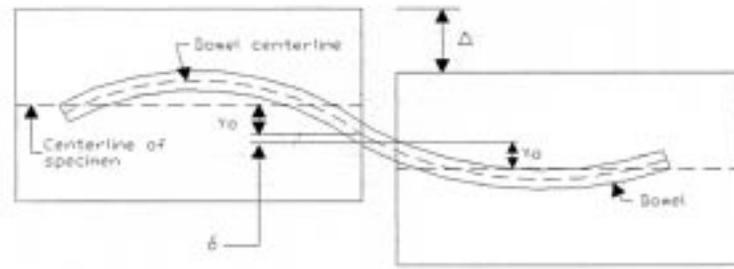
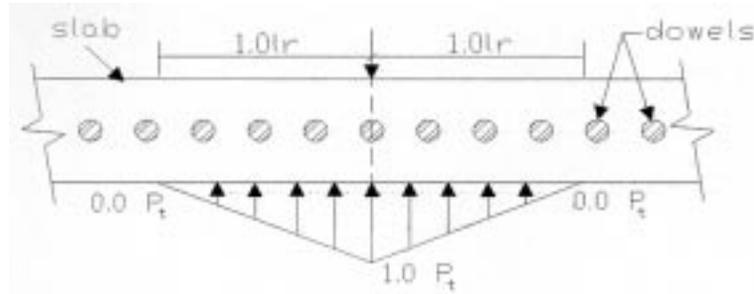**FIGURE 1 Relative deflection between pavement slabs.**

FIGURE 2 Load transfer distribution.

no error. The length of the dowel bar embedded in one side of the slab is denoted as L.

The shear deflection of the dowel across the joint is given in Equation (3):

$$\delta = \frac{\lambda P_t z}{A G}$$

where:

λ = form factor, equal to 10/9 for solid circular section
A = cross-sectional area of the dowel bar
G = shear modulus
P_t = load transferred by critical dowel
z = joint width

Particular attention should be paid to how the value of the shear modulus is obtained for GFRP dowels. Since FRP materials are anisotropic, the shear modulus for a GFRP dowel must be determined by composite materials theory. The procedure for determining the shear modulus is quite involved, however, this value can usually be obtained from the manufacturer.

Modulus of Dowel Support

The modulus of dowel support, K, is the reaction per unit area causing a unit deflection. The value of K must be determined empirically due to the difficulty in establishing a value theoretically. Due to the lack of experimentally determined values of K, a value of 407 Gpa/m (1,500,000 pci) was adopted by the authors as suggested by Yoder and Witczak (*5*).

Load Transferred by Critical Dowel

When a load is applied to the edge of a slab, a portion of that load is transferred to the adjacent slab through the dowels by shear. Tabatabie et al. (*6*) suggested that only the dowels contained within a distance of $1.0\ell_r$ from the load are active in transferring the load where ℓ_r is the radius of relative stiffness, defined by Westergaard (*7*) as follows:

$$\ell_r = \sqrt[4]{\frac{E_c h^3}{12(1-\mu^2)k}}$$

where:

E_c = modulus of elasticity of the pavement concrete
h = pavement thickness
μ = Poisson's ratio for the pavement concrete
k = modulus of subgrade reaction

Tabatabie also proposed a linear distribution of the load transferred across the joint as shown in Figure 2.

If 100 percent efficiency is achieved in load transfer by the dowel bars, 50 percent of the wheel load would be transferred to the subgrade while the other 50 percent would be transferred through the dowels to the adjacent slab. Repetitive loading of the joint
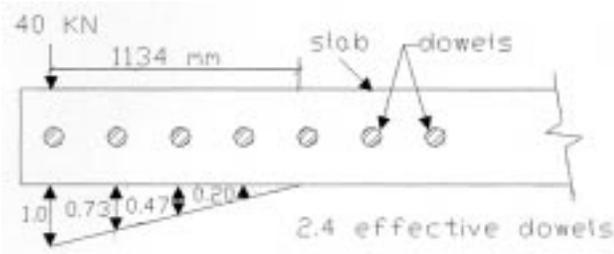
FIGURE 3 Effective dowels for 300 mm dowel bar spacing.

results in the creation of a void directly beneath the dowel at the face of the joint. According to Yoder and Witczak (*5*), a 5 to 10 percent reduction in load transfer occurs upon formation of this void; therefore, a design load transfer of 45 percent of the applied wheel load is recommended.

In their book, *Principles of Pavement Design*, Yoder and Witczak present a method for determining the load transferred by the critical dowel. In determining the load transferred by the critical dowel, Yoder and Witczak assumed that the deflection under a corner load would be greater than the deflection of the interior slab due to the same applied load. Thus, the corner dowel would be the critical dowel for edge loads (*5*). The load transferred by the critical dowel is given in Equation (5):

$$P_t = \frac{Design\ Load\ Transfer}{Number\ of\ Effective\ Dowels}$$

DESIGN EXAMPLE

Consider a 40 KN (9000 lbf) wheel load applied to a 250 mm (10 in.) thick concrete pavement slab with a compressive strength of 48 MPa (7000 psi). The pavement slab rests on a subbase having a modulus of subgrade reaction equal to 27 MPa/m (100 pci). Assuming a joint width of 6 mm (0.25 in.), determine the required spacing and diameter for GFRP dowels with the following properties:

  modulus of elasticity = 41 GPa (6 x 10⁶ psi)
  shear modulus = 3.3 GPa (476,000 psi)
  dowel bar length = 460 mm (18 in.)

Solution

1. Determine the Load Transferred by the Critical Dowel

$$\ell_r = \sqrt[4]{\frac{E_c h^3}{12(1-\mu^2)k}} = \sqrt[4]{\frac{(32.9)0.250^3}{12(1-0.2^2)0.027}}$$

$$= 1.134\ m\ (45\ in.)$$

The load transferred by the critical dowel is maximum when the wheel load is positioned directly over the dowel. For this loading

condition and with the standard 300 mm (12 in.) spacing of dowels, 2.4 dowels are effectively active in transferring the load as shown in Figure 3. (The number of effective dowels was arrived at using U.S. customary units.)

Design load transfer = 0.45(40) = 18 KN (4045 lbf)

$$P_t = \frac{Design\ Load\ Transfer}{Number\ of\ Effective\ Dowels} = \frac{18}{2.4}$$

$$= 7.5\ KN\ (1685\ lbf)$$

2. Determine the Relative Deflection for a Joint Containing Steel Dowels

Assume the following properties for the steel dowels:
  modulus of elasticity = 200 GPa (29 x 10⁶ psi)
  shear modulus = 77.5 GPa (11.24 x 10⁶ psi)
  dowel bar length = 460 mm (18 in.)

The recommended dowel bar diameter should be equal to 1/8 the slab thickness (*8*).

$$b = \frac{250}{8} = 31.25\ mm$$

Use a value of 31.75 mm for b since a 1.25 in. diameter bar will be used in the field.

$$I = \frac{\pi b^4}{64} = \frac{\pi(0.03175)^4}{64} = 5.0\ x\ 10^{-8}\ m^4\ (0.12\ in^4)$$

$$\beta = \sqrt[4]{\frac{Kb}{4EI}} = \sqrt[4]{\frac{(407)0.03175}{4(200)5.0x10^{-8}}} = 24\ m^{-1}\ (0.61\ in^{-1})$$

$$\beta L = \frac{24(0.46-0.006)}{2} = 5.45$$

Since βL is greater than 2, Equation (2) can be used to determine the deflection of the dowel relative to the concrete.

$$y_o = \frac{P_t}{4\beta^3 EI}(2+\beta z) =$$

$$\frac{0.0000075}{4(24)^3(200)5.0\ x\ 10^{-8}}(2+(24)0.006) = 2.91\ x$$

$$10^{-5}\ m\ (0.0011\ in.)$$

$$\delta = \frac{\lambda P_t z}{AG} = \frac{(10/9)0.0000075(0.006)}{7.92\ x\ 10^{-4}(77.5)} =$$

$$8.15\ x\ 10^{-7}\ m\ (3.21\ x\ 10^{-5}\ in.)$$

$$\Delta = 2y_o + \delta = 2(0.0291) + 0.000815 = 0.06\ mm\ (0.0024\ in)$$

3. Determine the Relative Deflection for a Joint Containing GFRP Dowels

  b = 31.75 mm (1.25 in.)

$$I = \frac{\pi b^4}{64} = \frac{\pi(0.03175)^4}{64} = 5.0 \times 10^{-8} \text{ m}^4 \ (0.12 \text{ in}^4)$$

$$\beta = \sqrt[4]{\frac{Kb}{4EI}} = \sqrt[4]{\frac{(407)0.03175}{4(41)5.0 \times 10^{-8}}} = 35 \text{ m}^{-1} \ (0.90 \text{ in}^{-1})$$

$$\beta L = \frac{35(0.46 - 0.006)}{2} = 7.95$$

Since βL is greater than 2, Equation (2) can be used to determine the deflection of the dowel relative to the concrete.

$$y_o = \frac{P_t}{4\beta^3 EI}\left(2 + \beta z\right) =$$

$$\frac{0.0000075}{4(35)^3(41)5.0 \times 10^{-8}}\left(2 + (35)0.006\right) =$$

4.71×10^{-5} m (0.0018 in.)

$$\delta = \frac{\lambda P_t z}{AG} = \frac{(10/9)0.0000075(0.006)}{7.92 \times 10^{-4}(3.3)} =$$

1.91×10^{-5} m (0.0008 in.)

$$\Delta = 2y_o + \delta = 2(0.0471) + 0.0191 = 0.1133 \text{ mm } (0.0044 \text{ in})$$

4. Determine the Required Diameter and Spacing for GFRP Dowels

Steps 1 and 3 were repeated for various diameters and spacings. The results of these calculations are presented in Table 1. The correct diameter and spacing for GFRP dowels is that which results in a relative deflection of approximately 0.06 mm (0.0025 in.). Table 2 lists the various combinations of diameter and spacing that work for this particular problem. Although this procedure typically results in material stresses within permissible limits, the authors recommend that the bearing stress in the concrete along with the flexural and shear stresses within the critical dowel be checked. The authors refer the reader to Friberg's paper, "Design of Dowels in Transverse Joints of Concrete Pavements," for equations to determine maximum bearing stress in the concrete and maximum shear and moment within the dowel (*2*).

CONCLUSIONS AND RECOMMENDATIONS

Typically, bearing stress in the concrete is the controlling factor in the design of doweled joints. If current design procedures were followed in determining the diameter and spacing for GFRP dowels, the resulting deflection of the dowel relative to the concrete would have been approximately 1.6 times that of an equivalent joint containing steel dowels. Since the bearing stress in the concrete is directly proportional to the deflection of the dowel relative to the concrete (Equation [6]), the concrete bearing stress also would have increased by a factor of 1.6:

$$\delta_b = K y_o$$

TABLE 1 Relative Joint Deflections (mm)

Dowel Bar Diameter (mm)	Dowel Bar Spacing (mm)			
	300	250	200	150
31.75	0.11	0.10	0.08	0.06
38.10	0.09	0.07	0.06	0.05
44.45	0.06	0.05	0.04	0.03

* 1 in. = 25.4 mm

TABLE 2 Solution to Design Example

Dowel Bar Diameter (mm)	Dowel Bar Spacing (mm)
31.75	150
38.10	200
44.45	300

* 1 in. = 25.4 mm

In order to keep the bearing stresses in the concrete comparable to those for a steel doweled joint, the dowel bar diameter must be increased, spacing decreased, or a combination of both. Additional experimental evidence is needed to verify these predictions. Currently, Iowa State University is undergoing experimental investigations in the laboratory and field to verify these somewhat theoretical postulations mentioned in this paper.

GFRP dowel bars appear to be a feasible solution to the deterioration of the transverse joints of highway pavement slabs as long as the diameter of the dowel is increased, spacing decreased, or a combination of both. This adjustment is necessary in order to keep the deflection of the joint and thus the bearing stresses in the concrete equivalent to those experienced by their steel counterparts.

REFERENCES

1. Porter, M.L., E.A. Lorenz, K.P. Viswanath, B.A. Barnes, and M.D. Albertson. *Thermoset Composite Concrete Reinforcement*. Engineering Research Institute, Iowa State University, May 1992.
2. Friberg, B.F. Design of Dowels in Transverse Joints of Concrete Pavements. *Transactions, American Society of Civil Engineers*. Vol. 105, No. 2081, 1940.
3. Timoshenko, S. and J.M. Lessels. *Applied Elasticity*. Westinghouse Technical Night School Press, Pennsylvania, 1925.
4. Albertson, M.D. Fibercomposite and Steel Pavement Dowels. *Masters Thesis*. Iowa State University, 1992.
5. Yoder, E.J., and M.W. Witczak. *Principles of Pavement Design*. 2nd ed. John Wiley & Sons, Inc., New York, 1975.
6. Tabatabie, A.M., E.J. Barenberg, and R.E. Smith. *Longitudinal Joint Systems in Slip-formed Rigid Pavements: Vol. II-Analysis of Load Transfer Systems for Concrete Pavements*. Report No. DOT/FAA.RD-79/4, Federal Aviation Administration, U.S. Department of Transportation, 1979.
7. Westergaard, H.M. Computation of Stresses in Concrete Roads. *Proceedings of the 5th Annual Meeting of the Highway Research Board*, Washington, D.C., 1925.
8. American Association of State Highway and Transportation Officials (AASHTO). AASHTO Guide for Design of Pavement Structures. AASHTO, Washington, D.C., 1993.