FOREWORD

Highway administrators and engineers must select among alternative pavement investment and maintenance strategies. These decisions should be based upon economic analyses of the impacts expected for each pavement management strategy. Prestressed pavements offer an alternative type of strategy because of thinner slabs, fewer joints, and an expected reduction in maintenance costs.

In Volume 2, a computerized procedure for thickness design of prestressed pavements is presented. The other volumes are:

- FHWA/RD-82/090, Volume 1, "Joint Designs"
- FHWA/RD-82/092, Volume 3, "Construction Manual"
- FHWA/RD-82/115, Volume 4, "Prestressed Pavement Accelerated Testing Program" (available only from NTIS)
- FHWA/RD-82/114, Volume 5, "Evaluation of Innovative Concepts Relating to Prestressed Concrete Pavements" (available only from NTIS).

Richard E. Hay, Director
Office of Engineering and Highway Operations
Research and Development

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The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein only because they are considered essential to the object of this document.
A computerized procedure for the thickness design of "zero-maintenance" prestressed pavements is presented. Factors considered in developing the design procedure include traffic loading, temperature and moisture variations in concrete slab, loss of subbase support, properties of concrete, subbase and subgrade, and effective mid-slab prestress. The procedure is based on flexural stress analysis and prevention of bottom transverse cracking that may initiate from the longitudinal edge of the slab in the vicinity of mid-slab.

Input for the computer program include axle load distribution, wheel placement, traffic distribution during the day, temperature data, load transfer effectiveness, and effective prestress at mid-slab. Program output is in terms of total fatigue consumption at the end of design life. If the fatigue consumption is less than 100 percent, then the thickness meets design criteria.

A design example is presented for a rural four-lane highway in Illinois.
# Metric Conversion Factors

## Approximate Conversions from Metric Measures

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PREFACE

This report has been prepared as part of a contract between FHWA and the Construction Technology Laboratories, Division of the Portland Cement Association.

It is the second of a five-volume series concerning design of prestressed concrete pavements. The series consists of the following reports.

1. Prestressed Pavement Joint Designs
2. Prestressed Pavement Thickness Design
4. Prestressed Pavement Accelerated Testing Program
5. Evaluation of Innovative Concepts Relating to Prestressed Concrete Pavements
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<td>3.</td>
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<td>DESIGN EXAMPLE</td>
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<td>SUMMARY</td>
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INTRODUCTION

The objective of Federal Highway Administration's Research Project 5E, Premium Pavements for "Zero Maintenance" is to exploit modern materials and technology in developing "Zero Maintenance" pavements for warranted use.

As a portion of this research project, an investigation has been conducted by the Construction Technology Laboratories, a Division of the Portland Cement Association, to develop design and construction techniques for prestressed concrete pavements. This work will be co-presented in reports covering the following:

(1) Transverse joint design
(2) Thickness design procedure
(3) Construction techniques
(4) Accelerated testing program
(5) Laboratory studies

Conventional concrete pavements are designed on the basis of concrete's relatively low modulus of rupture without effectively utilizing the natural advantage of its high compressive strength. In prestressed pavements, precompression in the concrete due to prestressing increases the allowable stress in the flexural zone. This permits a reduction or elimination of cracking and a large decrease in the number of transverse joints. Consequently, a more comfortable riding surface, and a reduction in maintenance costs results.

Prestressed pavement design includes determination of required pavement thickness and joint hardware selection based on anticipated slab movement and length. Figure 1 shows the basic steps involved in prestressed pavement design.

As shown in Figure 1, the design process is iterative and involves interaction of many factors. The process starts with selection of an initial slab thickness. Then, under joint design, trial main slab length and prestress tendon size, spacing, and force are selected. Effective mid-slab prestress is computed. A minimum of about 50 psi mid-slab prestress should
Figure 1 - Prestressed Pavement Design Process
be obtained. If not obtained, slab length, tendon size, spacing, or force is varied until the desired mid-slab prestress is obtained.

Once the mid-slab prestress criteria is met, anticipated maximum joint movement is computed. The selection of an infiltration prevention device such as a strip seal, compression seal, or steel cover plate depends on the magnitude of joint movement. Slab length is varied until the computed joint movement can be accommodated by the device selected. At this time a decision is made regarding use of a single active joint or two active joints between adjacent main slabs.

After an acceptable slab length, midslab prestress level, and joint hardware arrangement are established, a structural analysis is performed. The analysis requires the value of effective mid-slab prestress as an input. Alternatively, a minimum level of mid-slab prestress value may be assumed in the structural analysis. The structural analysis computes fatigue consumption due to edge stresses at mid-slab. If fatigue consumption is more than 100 percent, the design process is repeated using a larger slab thickness.

This report presents a thickness design procedure for prestressed concrete pavements. Factors considered in developing the procedure include traffic loading, temperature and moisture variations in concrete slab, loss of subbase support, properties of concrete, subbase and subgrade, and effective mid-slab prestress.

**DESIGN PROCEDURE**

A computerized program for thickness design of prestressed pavements is presented. Required pavement thickness is a function of stresses resulting from traffic loads, temperature and moisture variations, loss of subbase support, and mid-slab effective prestress. Summation of these stresses is balanced against fatigue consumed to obtain a pavement designed to resist bottom flexural cracking.
An acceptable criterion for design based on deflection is not available. Therefore, deflections are not computed. However, it is recognized that prestressed concrete pavements are thinner than conventional concrete pavements. For this reason, it is recommended that high quality stabilized subbases be specified for use with prestressed pavements.

Procedures used for computing stresses and decisions regarding inputs are discussed. A program users manual and program listing are presented in the Appendix.

Traffic Load Stresses

A finite element computer program for analysis of slabs on a Winkler (liquid) foundation was used to compute moments for the case of edge loading. These moments expressed as a function of the radius of relative stiffness ($\lambda$) are stored in this computer program. They are used together with a coefficient to determine edge stresses resulting from loads located at or inward from the pavement edge. The program also considers optional use of a tied concrete shoulder with a variable input for load transfer efficiency at the longitudinal joint.

Slab width is 12 ft (3.66 m) and length is sufficient to represent a very long slab. Either a single or a tandem axle load configuration may be selected as input. However, wheel imprint dimensions and wheel and axle spacings are constant. Dimensions selected for tandem axle loading are shown in Fig. 2. For single axle loading, wheel imprint size and spacings are the same.

Moments at the pavement edge due to loads at the edge are given by the following equations.

For a single-axle load,

$$M = 483.34 \frac{P}{18,000} (\lambda)^{0.5711} \text{ in}-\text{lb} \quad (1)$$

where: $M =$ bending moment at edge

$$\lambda = \frac{4 \sqrt{\frac{Eh^3}{12 (1-\mu^2)}}}{k} \quad (2)$$

$$P = \text{load}$$

$E =$ modulus of elasticity of concrete

$\mu =$ Poisson's ratio

$h =$ thickness of slab
Dimensions in Inches

Figure 2 - Tandem Axle Load Configuration
where:  
\[ E = \text{Modulus of elasticity of concrete, psi} \]
\[ h = \text{slab thickness, in} \]
\[ \mu = \text{Poisson's ratio} = 0.15 \]
\[ k = \text{modulus of subgrade reaction, psi} \]

For a tandem-axle load:

\[ M = 185.14 \frac{P}{36,000} (l)^{0.8197} \text{ in-lb} \tag{3} \]

Moment equations are based on the assumption of loss of subbase support for a 20-in (508 mm) distance inward from the pavement edge. This adjustment is made to recognize upward slab warping due to moisture differentials.

Load stress, \( \sigma_L \), is determined by the equation:

\[ \sigma_L = \frac{6M}{h^2} \left( \frac{P}{18,000} \right) C_e \text{ psi} \tag{4} \]

where:  
\[ P = \text{single-axle or tandem-axle load, lb} \]
\[ n = 1 \text{ for single-axle load} \]
\[ n = 2 \text{ for tandem-axle load} \]
\[ C_e = \text{load placement coefficient} \]

Load placement coefficients shown in Fig. 3 are provided as program input. These coefficients are used to reduce stress at the pavement edge when loads are applied in wheel paths located inward from the edge.

Equation 4 for load stress, \( \sigma_L \), can be further modified to incorporate the contribution of a tied-shoulder. This is done by using the following equation:

\[ \sigma_L = \frac{6M}{h^2} \left( \frac{P}{18,000} \right) C_e \left( \frac{1}{1 + JE} \right) \text{ psi} \tag{4a} \]

where:  
\[ JE = \text{joint efficiency} \]
\[ JE = \frac{\text{deflection at shoulder side of joint}}{\text{deflection at main pavement side of joint}} \]

Traffic Characteristics

Axle-loads and lateral placement of loads across the pavement during different periods of the day are program inputs.
Figure 3 - Load Placement Coefficient, $C_e$
Curling stresses vary during the day and maximum curling stresses exist for only short durations. Therefore, traffic distribution during the day is required to equate maximum stresses to number of load applications during selected time periods. Time periods and traffic during the selected periods are program inputs.

States accumulate traffic loadometer data in the format used in Federal Highway Administration W4 loadometer tables. These tables tabulate number of axles observed within load groups, and are generally reported for 2,000 lb (18 kN) increments. Traffic projections are made for design periods that usually range from 20 to 40 years for concrete pavements.

A recommended lateral distribution of traffic is shown in Table 1. These values were selected based on information obtained by Emery. (1) Traffic volume is subdivided with respect to time of day. A recommended distribution is given in the users manual.

### TABLE 1 - LATERAL LOAD DISTRIBUTION

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<tr>
<th>Distance from Outside Wheel to Pavement Edge, in</th>
<th>Truck Traffic, %</th>
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<tbody>
<tr>
<td>0-6</td>
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<tr>
<td>6-12</td>
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<td>30-36</td>
<td>5</td>
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</table>

**Temperature Effects**

Curling stresses develop in a slab when temperatures vary with depth. During daytime, when the top surface is warmer than the bottom, tensile stresses develop at the slab bottom. During nighttime, when temperature gradients are reversed, tensile stresses develop at slab top. For stress calculations, it is generally assumed that the temperature gradient is linear. Maximum gradient is assumed about 3 F/in (0.07 C/mm) during
daytime and about 1 F/in (0.02 C/mm) during nighttime. In practice, the temperature distribution is usually non-linear and constantly changing. Also, maximum daytime and nighttime temperature differentials exist for short time durations. Temperature distributions measured at the AASHTO Road Test (2) are shown in Fig. 4.

Since daily variation of air temperature follows an approximate sinusoidal cycle, temperature variations at the slab surface can be assumed sinusoidal. This variation can be represented as (3, 4)

\[ \theta_T = \theta_o \sin \left( \frac{2\pi t}{T} \right) \] (5)

where:  
- \( \theta_T \) = temperature at surface of slab  
- \( \theta_o \) = constant = amplitude of the temperature cycle at slab surface  
- \( t \) = time of day (24-hour clock)  
- \( T = 24 \) hr

This equation represents daytime conditions well but gives an incorrect distribution for nighttime conditions. For nighttime, the amplitude is about one-third of that computed using this equation. Therefore, for nighttime conditions, \( \theta_o \) is replaced by \( \theta'_o \) which is equal to \( \theta_o / 3 \). Accuracy of night-time temperature distribution is not as critical because these stresses are subtracted from load stresses.

For homogeneous semi-infinite solids whose surface temperature varies sinusoidally, the temperature, \( \theta_z \), at any time \( t \) on a plane at depth \( z \) below the surface is given by

\[ \theta_z = \theta_o e^{-\beta} \sin \left( \frac{2\pi t}{T} - \beta \right) \] (6)

where:  
- \( \beta = \frac{z}{\psi} \sqrt{\frac{\pi}{T}} \)  
- \( \psi^2 = \text{diffusivity of the material, in } \text{ft}^2/\text{hr} \)  
- \( \psi = \frac{\lambda}{\gamma c} \)
Figure 4 - Measured Changes in Temperature Distribution
\[ \lambda = \text{thermal conductivity of the material, Btu/hr-ft-F} \]
\[ \gamma = \text{weight per unit volume of the material, lb/ft} \]
\[ c = \text{specific heat of the material, Btu/lb-F} \]

For a concrete slab resting on earth or subbase, Eq. 6 is applicable, as diffusivities of the materials are similar.

For concrete:
\[ \lambda = 1.20 \text{ Btu/hr-ft-F} \]
\[ \gamma = 145 \text{ lb/ft}^3 \]
\[ c = 0.22 \text{ Btu/lb-F} \]
\[ \psi^2 = 5.4168 \text{ in}^2/\text{hr} \]

Using this procedure, calculated variations in temperature distribution with time for concrete pavement thicknesses of as much as 10 in (254 mm) are shown in Fig. 5. These data are more representative of measured field data than the assumption of a linear temperature distribution.

Average slab temperature, \( \theta_M' \), at time \( t \) is obtained by integrating Eq. 6 for \( \theta_z \) between 0 and slab thickness, \( H \), and dividing by \( H \). The difference, \( \theta_D' \), between average slab temperature and slab bottom temperature, \( \theta_B' \), is given by:

\[ \theta_D' = \theta_M' - \theta_B' \]  \( \text{(7)} \)

Curling stress at the bottom of the edge of a long slab is given by:

\[ \sigma_c = \alpha E \theta_D \]  \( \text{(8)} \)

where: \( \alpha = \text{coefficient of thermal expansion.} \)

This non-linear temperature distribution formulation is used in the computerized design procedure to calculate curling stresses.

Its use requires an input value for \( \theta_0 \) shown in Eq. 5. For United States conditions a recommended value is 30 F; however, other values may be substituted where local information is available and conditions are substantially different.
Figure 5 - Calculated Changes in Temperature Distribution
Moisture Effects

Top to bottom variations in pavement moisture content result in bottom fiber compressive stresses. Ideally, these stresses would be calculated for cyclical seasonal changes in moisture content. Calculated stresses would then be used in the thickness design procedure in the same manner as temperature stresses. However, only limited data are available regarding top to bottom moisture distribution, seasonal moisture variation, or stress magnitude. Friberg\(^5\) and Nagataki\(^6\) report that restrained warping strain at slab bottom may be about 150 millionths. These data are valuable and serve to direct future research. However, for the present it is being assumed that warping stresses for 7- and 8-in (178 and 203 mm) thick pavements are 190 and 220 psi (1,310 and 1,517 kPa), respectively.

Warping also results in a loss of support along the pavement edge. Loss of support causes an increase in edge stress due to traffic loading. Effects of upward warping on load stress calculations are included in Eqs. 1 and 3.

Subbase Support

Pavement performance is related to the quality of subbase and subgrade support. Ideally, as shown in Figure 1, the thickness design procedure should also incorporate allowable subbase and subgrade deformations as limiting criteria. However, sufficient data are not available to develop such criteria for concrete pavements. Measured concrete pavement deformations are influenced by the temperature gradient in the concrete at time of testing. Therefore, concrete pavement deformation data have to be correlated with pavement temperatures.

Prestressed concrete pavements are thinner than conventional concrete pavements. Thus, subbase support requirements are more critical. For zero-maintenance projects it is recommended that high quality subbase be used with prestressed pavements. Modulus of subgrade reaction at the top of the subbase should be about 500 psi (3.57 kPa/cm).
Fatigue of Concrete

Flexural fatigue research on concrete has shown that as the ratio of flexural stress to modulus of rupture decreases, the number of stress repetitions to failure increases. (7) Allowable load repetitions for stress ratios between 0.50 and 0.85 are shown in Table 2. (8) These values are used in the program fatigue model. However, at the designer's option other fatigue models may be used as program input.

Mid-Slab Prestress

Mid-slab prestress is computed by accounting for prestress losses due to tendon friction, concrete shrinkage, concrete creep, steel relaxation, and subbase friction restraint.

Tendon Friction

Tendon friction results from curvature and wobble. Curvature is due to intentional and wobble to unintentional tendon profile variations. Tendon friction, \( \sigma_t \), is determined from the equation:

\[
\sigma_t = \sigma_{pe} \left( 1 - e^{-\left(ux + \frac{KL}{2}\right)} \right) \text{psi}
\]

where:
- \( \sigma_{pe} \) = end prestress, psi,
- \( u \) = curvature friction coefficient
- \( x \) = angular change of tendon from jacking end to mid-slab, radians
- \( K \) = wobble friction coefficient per foot
- \( L \) = slab length, ft

For straight portions of pavements, intentional angular changes are negligible. Therefore, tendon friction can be obtained from

\[
\sigma_t = \sigma_{pe} \left( 1 - e^{-\frac{KL}{2}} \right) \text{psi}
\]
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<th>Allowable repetition</th>
<th>Stress* ratio</th>
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</tr>
<tr>
<td>0.68</td>
<td>3,500</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Load stress divided by modulus of rupture.
** Unlimited repetitions for stress ratios of 0.50 or less.
Concrete Shrinkage

Prestress loss due to concrete shrinkage, $\sigma_s$, is given by the following equation:

$$\sigma_s = \varepsilon_s E_s \frac{A_s}{A_c} \text{ psi} \quad (11)$$

where:
- $\varepsilon_s$ = concrete shrinkage strain
- $E_s$ = modulus of elasticity of tendon steel, psi
- $A_s$ = area of tendon per unit width of slab, in$^2$
- $A_c$ = area of slab per unit width of slab, in$^2$

Concrete Creep

Prestress loss due to concrete creep, $\sigma_{cr}$, is given by the following equation:

$$\sigma_{cr} = C_u \frac{E_s}{E_c} \sigma_{pe} \frac{A_s}{A_c} \text{ psi} \quad (12)$$

where:
- $C_u$ = ultimate creep coefficient
- $E_c$ = modulus of elasticity of concrete, psi

Steel Relaxation

Prestress loss due to steel relaxation, $\sigma_r$, is given by the following equation:

$$\sigma_r = \rho \sigma_{pe} \text{ psi} \quad (13)$$

where:
- $\rho$ = relaxation coefficient for appropriate stress level

Subbase Friction

Prestress loss due to subbase friction, $\sigma_f$, is given by the following equation:

$$\sigma_f = \frac{\mu s L}{288} \text{ psi} \quad (14)$$
where:  \( \mu_s \) = slab to subbase friction factor  
\( \gamma \) = concrete unit weight, lb/ft\(^3\)  
\( L \) = slab length, ft

Effective mid-slab prestress, \( \sigma_p' \), is given by the following equation:

\[
\sigma_p' = \sigma_{pe} - \sigma_t - \sigma_{cr} - \sigma_r - \sigma_f \tag{15}
\]

Example calculations for computing prestress losses and mid-slab prestress are given in Table 3. Coefficients and other values used for the computations are listed in Table 4.

**PROGRAM FORMULATION**

Total flexural stress at mid-slab edge is computed using the following equation.

\[
\sigma_{Tijkl} = \sigma_{Lijkl} + \sigma_{Cjkl} - \sigma_p - \sigma_{Wkl} \tag{16}
\]

where:  \( \sigma_{Tijkl} \) = total flexural stress for the ith axle group at the jth period of the day of kth month of lth year,

\( \sigma_{Lijkl} \) = traffic load stress due to the ith axle group at the jth period of day of kth month of lth year,

\( \sigma_{Cjkl} \) = curling stress at the jth period of day of kth month of lth year,

\( \sigma_p \) = effective prestress at mid-slab at the jth period of day of kth month of lth year,

\( \sigma_{Wkl} \) = warping stress during kth month of lth year.
TABLE 3 - PRESTRESS CALCULATIONS

<table>
<thead>
<tr>
<th>Slab Thickness, in</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slab Length, ft</td>
<td>250</td>
<td>350</td>
</tr>
<tr>
<td>Strand Diameter, in</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Strand Force, kip</td>
<td>41</td>
<td>41</td>
</tr>
<tr>
<td>Strand Spacing, in</td>
<td>24</td>
<td>18</td>
</tr>
<tr>
<td>End of Slab Prestress, psi</td>
<td>244</td>
<td>285</td>
</tr>
</tbody>
</table>

**Prestress Losses**

| Shrinkage, psi | 6   | 6   |
| Creep, psi     | 4   | 6   |
| Relaxation, psi | 20  | 23  |
| Strand Friction, psi | 39  | 62  |
| Subbase Friction, psi | 100 | 140 |
| **Total Losses, psi** | 169 | 237 |
| Mid-Slab Prestress, psi | 75  | 48  |

1 in = 25.4 mm  
1 ft = 0.30 m  
1 kip = 4.448 kN  
1 psi = 6.894 kPa
<table>
<thead>
<tr>
<th>Item</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tendon Ultimate Strength, psi</td>
<td>270,000</td>
</tr>
<tr>
<td>Area 0.6 in diameter tendon, in (^2)</td>
<td>0.217</td>
</tr>
<tr>
<td>Concrete Creep Coefficient</td>
<td>2.5</td>
</tr>
<tr>
<td>Concrete Shrinkage Strain, millionths</td>
<td>150</td>
</tr>
<tr>
<td>Strand Relaxation Coefficient</td>
<td></td>
</tr>
<tr>
<td>70 percent of Ultimate Stress</td>
<td>0.08</td>
</tr>
<tr>
<td>75 percent of Ultimate Stress</td>
<td>0.10</td>
</tr>
<tr>
<td>Wobble Friction Coefficient per foot</td>
<td>0.0014</td>
</tr>
<tr>
<td>Subbase Friction Factor</td>
<td>0.8</td>
</tr>
<tr>
<td>Modulus of Elasticity of Steel, million psi</td>
<td>28</td>
</tr>
<tr>
<td>Modulus of Elasticity of Concrete, million psi</td>
<td>5</td>
</tr>
</tbody>
</table>

1 psi = 6.894 kPa
1 in = 25.4 mm
1 ft = 0.30 m
Anticipated number of repetitions, $N_i$, of stress of magnitude $\sigma_{Tijkl}$ is determined. Then, the allowable number of stress repetitions, $NN_i$, of magnitude $\sigma_{Tijkl}$ is calculated using the fatigue model. Fatigue consumption, $F_i$, due to repeated stress applications of magnitude $\sigma_{Tijkl}$ is obtained as follows:

$$F_i = \frac{N_i}{NN_i}$$

(17)

Total fatigue consumption, $F_{TOT}$, during the design period is obtained by summing fatigue consumed by load repetitions for each stress level, and is given by

$$F_{TOT} = \sum F_i$$

(18)

If total fatigue consumption at the end of the design period is less than 100 percent, the thickness obtained meets design criteria.

**DESIGN EXAMPLE**

Thickness design of a prestressed pavement for a heavily trafficked highway in central Illinois is presented. The high volume of heavy loads used is representative of traffic at locations where the concept of zero-maintenance pavements is applicable. The concept of "zero-maintenance" implies use of a premium pavement at locations where higher first costs is justified by a reduction in future costs due to repairs, user travel delays, and accidents.

The design procedure may be used to determine pavement thickness for any traffic mix. However, use of a thickness less than 6-in (152 mm) may not be practical as the space necessary for placing joint hardware such as anchors, seal holders, load transfer devices, reinforcement, and positioning bars may not be available.
Project Traffic Data

Traffic distribution used was determined from data obtained from field surveys and interviews by Darter and Barenberg. (9) Average daily traffic for the design period was selected as 6000 vehicles per day.

Design life = 20 years

Single axle load distribution during design period:

<table>
<thead>
<tr>
<th>Axle load, kips</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-20</td>
<td>80,422</td>
</tr>
<tr>
<td>20-22</td>
<td>62,144</td>
</tr>
<tr>
<td>22-24</td>
<td>25,589</td>
</tr>
<tr>
<td>24-26</td>
<td>8,530</td>
</tr>
<tr>
<td>26-28</td>
<td>3,656</td>
</tr>
<tr>
<td>28-30</td>
<td>1,219</td>
</tr>
<tr>
<td>30-32</td>
<td>609</td>
</tr>
<tr>
<td>32-34</td>
<td>183</td>
</tr>
</tbody>
</table>

Tandem axle load distribution during design period:

<table>
<thead>
<tr>
<th>Axle load, kips</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>38-40</td>
<td>29,244</td>
</tr>
<tr>
<td>40-42</td>
<td>11,576</td>
</tr>
<tr>
<td>42-44</td>
<td>4,874</td>
</tr>
<tr>
<td>44-46</td>
<td>3,656</td>
</tr>
<tr>
<td>46-48</td>
<td>1,828</td>
</tr>
<tr>
<td>48-50</td>
<td>1,219</td>
</tr>
<tr>
<td>50-52</td>
<td>1,219</td>
</tr>
<tr>
<td>52-54</td>
<td>609</td>
</tr>
<tr>
<td>54-56</td>
<td>183</td>
</tr>
</tbody>
</table>

Material Properties

Concrete modulus of elasticity = 5,000,000 psi
Concrete modulus of rupture = 700 psi
Modulus of subbase reaction = 500 pci
Diffusivity of concrete = 5.24 in$^2$/hr
Coefficient of thermal expansion of concrete = 0.000005 in/in/°F

Prestress

Effective mid-slab prestress = 50 psi
Warping Restraint Stress

<table>
<thead>
<tr>
<th>Slab Thickness, in.</th>
<th>Joint Efficiency, percent</th>
<th>Fatigue Consumed, percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>0</td>
<td>2,070</td>
</tr>
<tr>
<td>7</td>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>36</td>
</tr>
</tbody>
</table>

Based on above results a 7-in (178 mm) thick concrete pavement with a tied concrete shoulder or an 8-in (203 mm) thick pavement without a tied concrete shoulder may be used.

**SUMMARY**

A computerized design procedure for prestressed concrete pavement is presented. The procedure is based on flexural stress analysis and prevention of bottom transverse cracking at slab edge. At present, only limited data are available to determine values for temperature cycle amplitude, $\theta_0$, and warping restraint stress. Therefore, recommended design values may be used. The design procedure is simple to use and can be implemented immediately.
REFERENCES


3. Thomlinson, J., "Temperature Variations and Consequent Stresses Produced by Daily and Seasonal Temperature Cycles in Concrete Slabs," Concrete and Construction Engineering, June, 1940.


APPENDIX

USER'S MANUAL AND PROGRAM LISTING

PROGRAM PCP (Prestressed Concrete Pavement)

USER'S MANUAL

Data Card 1

<table>
<thead>
<tr>
<th>NPROB</th>
<th>I5</th>
</tr>
</thead>
</table>

NPROB = number of problems

The following set of cards are repeated NPROB times.

Data Card 2

<table>
<thead>
<tr>
<th>TITLE (20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20A4</td>
</tr>
</tbody>
</table>

TITLE (1) to TITLE (20) = problem title

Data Card 3

<table>
<thead>
<tr>
<th>AL</th>
<th>ALPHA</th>
<th>H</th>
<th>U</th>
<th>DIFUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>F10.2</td>
<td>F10.2</td>
<td>F10.2</td>
<td>F10.2</td>
<td>F10.2</td>
</tr>
</tbody>
</table>

AL = slab length, ft
ALPHA = coefficient of thermal expansion, in /in /F
H = initial slab thickness. If NSUBPR (data card 10) is greater than one, slab thickness is incremented by 1.0 inch.
U = Poisson's ratio for concrete
DIFUS = diffusivity of concrete, in ²/hour (see text for explanation)

Data Card 4

<table>
<thead>
<tr>
<th>TRAFFIC</th>
<th>GROWTH</th>
<th>NYEARS</th>
<th>NAXLE</th>
<th>NTAXLE</th>
<th>NPOS</th>
<th>NPROP</th>
<th>NTEMP</th>
<th>NLOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>F10.2</td>
<td>F10.2</td>
<td>I5</td>
<td>I5</td>
<td>I5</td>
<td>I5</td>
<td>I5</td>
<td>I5</td>
<td>I5</td>
</tr>
</tbody>
</table>

TRAFFIC = 1.0
GROWTH = percent traffic growth per year
NYEARS = design period, years. NYEARS equals one if NPROP = 1
NAXLE = number of single axle load types
NTAXLE = number of tandem axle load types
NPOS = number of lateral positions for wheel loads
NPROP = 0 if different material properties and temperature values are used for each month of the year
= 1 if material properties and temperature values are same for each month of the year
NTEMP = number of periods during the day. If each period is 4 hours, then NTEMP equals 6. This option is used to compute the appropriate curling stress for each period.

NLOC = 0 (zero)

Data Card 5 (Repeat for I=1 to NPOS times)

<table>
<thead>
<tr>
<th>PPP(I)</th>
<th>COEFF(I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F10.2</td>
<td>F10.2</td>
</tr>
</tbody>
</table>

PPP(I) = fraction of traffic along lateral position I. For example, if first lateral position between edge and 6 in inward from edge has 20 percent of traffic, then PPP(1) equals 0.20.

COEFF(I) = coefficient to compute edge stress for wheel position inward from edge. For example, for first lateral position between edge and 6 in inward from edge, coefficient equals 1. For the second lateral position between 6 in and 12 in inward from edge, coefficient equals 0.75. See text for more details.

Data Card 6 (Repeat for I=1 to NAXLE times)

<table>
<thead>
<tr>
<th>P(I)</th>
<th>PP(I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F10.2</td>
<td>F10.2</td>
</tr>
</tbody>
</table>

P(I) = single axle load type I, lb

PP(I) = total number of axle loads of type I per year

= total number of axle loads of type I for the design period if NYEARS equals 1.

Data Card 7 (Repeat for I=1 to NTAXLE times)

<table>
<thead>
<tr>
<th>T(I)</th>
<th>TT(I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F10.2</td>
<td>F10.2</td>
</tr>
</tbody>
</table>

T(I) = tandem axle load type I, lb

II(I) = total number of axle loads of type I per year

= total number of axle loads of type I for the design period if NYEARS equals 1.
Data Card 8 (If NTEMP (data card 4) is greater than eight, continue on second card)

TRTEMP(I) to TRTEMP (NTEMP)

8F10.2

TRTEMP(I) = fraction of truck traffic during period I of the day. If each period is 4 hours long, then the first period would be from mid-night to 4 hours (on the 24-hour clock). TRTEMP(1) is the fraction of traffic that is on the road during that period. TRTEMP(2) is the fraction of traffic on the road between 4 hours and 8 hours. An example of the traffic breakdown during a day is given below.

<table>
<thead>
<tr>
<th>Period, I</th>
<th>Time (24-hour clock)</th>
<th>TRTEMP(I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 to 4</td>
<td>0.05</td>
</tr>
<tr>
<td>2</td>
<td>4 to 8</td>
<td>0.20</td>
</tr>
<tr>
<td>3</td>
<td>8 to 12</td>
<td>0.25</td>
</tr>
<tr>
<td>4</td>
<td>12 to 16</td>
<td>0.25</td>
</tr>
<tr>
<td>5</td>
<td>16 to 20</td>
<td>0.20</td>
</tr>
<tr>
<td>6</td>
<td>20 to 24</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Data Card 9 (Repeat for each month of the year if NPROP (data card 4) is equal to 0. If NPROP equals 1, only one card is needed.)

<table>
<thead>
<tr>
<th>RM(I)</th>
<th>E(I)</th>
<th>AK(I)</th>
<th>SIGW(I)</th>
<th>THETA(I)</th>
<th>TMAX(I)</th>
<th>DTEMP(1,I)</th>
<th>DTEMP(2,I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F10.2</td>
<td>F10.2</td>
<td>F10.2</td>
<td>F10.2</td>
<td>F10.2</td>
<td>F10.2</td>
<td>F10.2</td>
<td>F10.2</td>
</tr>
</tbody>
</table>

RM(I) = modulus of rupture of concrete, psi
E(I) = modulus of elasticity of concrete, psi
AK(I) = modulus of subgrade reaction for the Ith month, psi
SIGW(I) = warping restraint stress for the Ith month, psi
THETA(I) = amplitude of temperature cycle at slab surface in degrees Fahrenheit if non-linear temperature distribution is used. See text for details.
TMAX(I) = time on 24-hour clock when maximum temperature occurs at slab top for month I. If maximum temperature occurs at 2 p.m., then TMAX(I) equals 14.0.
DTEMP(1,I) = Maximum daytime temperature difference in degrees Fahrenheit between slab top and slab bottom during month I of the year if linear temperature distribution is used.
DTEMP(2,I) = Maximum nighttime temperature difference in degrees Fahrenheit between slab top and slab bottom during month I of the year if linear temperature distribution is used. DTEMP(2,I) is a negative value.

NOTE: If linear temperature distribution is considered, then NSUBR (data card 10) should equal 1. The solution is found individually for each slab thickness as DTEMP(1,I) and DTEMP(2,I) would vary with thickness.
Data Card 10

<table>
<thead>
<tr>
<th>PRESTR</th>
<th>FATIGE</th>
<th>AA</th>
<th>BB</th>
<th>NSUBPR</th>
<th>NFAT</th>
<th>NPST</th>
<th>NLNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>F10.2</td>
<td>F10.2</td>
<td>I5</td>
<td>I5</td>
<td>I5</td>
<td>I5</td>
<td>I5</td>
<td>I5</td>
</tr>
</tbody>
</table>

PRESTR = initial value of effective prestress at mid-slab, psi.
If NPST is greater than 1, the prestress value is incremented by 10 psi.
FATIGE = 1.0 if a fatigue model is input (see Note 1 below)
= 2.0 if program dependent fatigue model is used (see Note 2 below)
AA = constant described below
BB = constant described below
NSUBPR = number of different slab thickness values to be considered. Thickness value is incremented by 1.0 in each time if NSUBPR is greater than 1.
NFAT = 1.0
NPST = number of different mid-slab prestress values to be considered. Prestress value is incremented by 10 psi each time if NPST is greater than 1.
NLNR = 1 if non-linear temperature distribution in the slab is considered.
= 2 if linear temperature distribution is considered.

NOTES:
(1) The fatigue model is of the following form:
\[ \log N = AA + BB \]  
(Combined Stress/Modulus of Rupture)
where N = allowable number of stress applications equal in magnitude to the combined stress
AA, BB = constants determined from laboratory fatigue tests
(2) Program dependent fatigue model is as follows:
\[ \log N = 11.829 - 12.195 \]  
(Combined Stress/Modulus of Rupture)

Data Card 11

<table>
<thead>
<tr>
<th>YJE</th>
<th>DECYJE</th>
</tr>
</thead>
<tbody>
<tr>
<td>F10.2</td>
<td>F10.2</td>
</tr>
</tbody>
</table>

YJE = initial joint efficiency when tied-shoulder is considered
DECYJE = percent decrease in joint efficiency per year if NYEARS is greater than 1.

Typical input and output are given in the following pages. The output contains a listing of the input and fatigue consumption at end of each month for the design period. If NYEARS in the input equals one, then fatigue consumption is given at end of each month for one year. A satisfactory slab thickness is one that produces fatigue consumption which is less than 100%.
PRESTRESSED PAVEMENT DESIGN EXAMPLE

*****NON-LINEAR TEMPERATURE********

*****SLAB PROPERTIES*****
SLAB LENGTH, FT = 350.00  SLAB THICKNESS, IN = 8.00
ALPHA, IN/IN/OF = 0.000050  POISSON RATIO = 0.15
DIFFUSIVITY OF CONCRETE = 5.41680
NO. OF MATERIAL PROPERTIES = 1

*****TRAFFIC DATA*****
ANNUAL TRAFFIC OR FACTOR = 1.00  ANNUAL TRAFFIC GROWTH = 0
DESIGN PERIOD, YR = 1
NO. OF SAL TYPES = 8  NO. OF TAL TYPES = 9
LATERAL POSITIONS = 4  DAILY TRAFFIC PERIODS = 6

<table>
<thead>
<tr>
<th>LATERAL POSITION</th>
<th>FRACTION OF TRAFFIC</th>
<th>STRESS COEFFICIENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.20</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>0.20</td>
<td>0.75</td>
</tr>
<tr>
<td>3</td>
<td>0.25</td>
<td>0.50</td>
</tr>
<tr>
<td>4</td>
<td>0.15</td>
<td>0.40</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SAL, LBS</th>
<th>NO OF AXLES(FRACTION)</th>
</tr>
</thead>
<tbody>
<tr>
<td>34000.00</td>
<td>183.00</td>
</tr>
<tr>
<td>32000.00</td>
<td>609.00</td>
</tr>
<tr>
<td>-30000.00</td>
<td>1219.00</td>
</tr>
<tr>
<td>28000.00</td>
<td>3456.00</td>
</tr>
<tr>
<td>26000.00</td>
<td>8530.00</td>
</tr>
<tr>
<td>24000.00</td>
<td>25589.00</td>
</tr>
<tr>
<td>22000.00</td>
<td>62144.00</td>
</tr>
<tr>
<td>20000.00</td>
<td>80422.00</td>
</tr>
<tr>
<td>TAL, LBS</td>
<td>NO OF AXLES (FRACTION)</td>
</tr>
<tr>
<td>----------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>56000.00</td>
<td>183.00</td>
</tr>
<tr>
<td>54000.00</td>
<td>609.00</td>
</tr>
<tr>
<td>52000.00</td>
<td>1219.00</td>
</tr>
<tr>
<td>50000.00</td>
<td>1219.00</td>
</tr>
<tr>
<td>48000.00</td>
<td>1828.00</td>
</tr>
<tr>
<td>46000.00</td>
<td>3656.00</td>
</tr>
<tr>
<td>44000.00</td>
<td>4874.00</td>
</tr>
<tr>
<td>42000.00</td>
<td>11376.00</td>
</tr>
<tr>
<td>40000.00</td>
<td>29244.00</td>
</tr>
</tbody>
</table>

TRAFFIC DISTRIBUTION DURING DAY = 0.05 .20 .25 .25 .20 .05

J OINT EFFICIENCY ALONG LONG J OINT = 0
DECREASE IN JE ALONG LONG JNT / YEAR = 0

<table>
<thead>
<tr>
<th>MONTH</th>
<th>RM</th>
<th>E</th>
<th>K</th>
<th>SIGW</th>
<th>THETA</th>
<th>TMAX</th>
<th>DTEMP(DAY)</th>
<th>DTEMP(HGT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>700.0</td>
<td>500000.0</td>
<td>500.0</td>
<td>220.0</td>
<td>30.0</td>
<td>14.0</td>
<td>18.0</td>
<td>-6.0</td>
</tr>
</tbody>
</table>

**** FATIGUE CURVE DATA ****
FATIGUE MODEL = 2.0
CONSTANT AA = 11.82900
CONSTANT BB = -12.19500

LONGITUDINAL PRESTRESS AT MIDLENGTH = 50.00

**** WHEEL LOADS AT MIDSLAB ****

YEAR NUMBER = 1
ANNUAL TRAFFIC OR FACTOR = 1.0
PERCENT FATIGUE CONSUMED = 3.0 6.0 9.0 11.9 14.9 17.9 20.9 23.9 26.9 29.8 32.8 35.8

OK
PROGRAM PCP - LISTING

10 C PROGRAM THICK (KEYBRD,CONSOL,TAPE5=KEYBRD,TAPE6=CONSOL)
20 C PRESTRESSED PAVEMENT THICKNESS DESIGN
30 DIMENSION FF(12),TITLE(20),SIGW(12)
40 C
50 COMMON/DNE/AL(12),E(12),RM(12),H,U,P(10),COEFF(10),SIGL(12,10,10),
60 NAXLE,T(10),SIGH(12,10,10),NTAXLE,TT(10),NPOS,COEF2(10)
70 COMMON/TWO/SIGCC(12,12),NTEMP,DTEMP(2,12),ALPHA,DIFUS,THETA(12),
80 TMAX(12),NLHR
90 COMMON/FOUR/SIGDAY ,PP(10),TRAFFIC,GROWTH
100 COMMON/FIVE/PPP(10),FATIGE,AA,BB,TRAF,TRTEMP(12)
110 COMMON/SIX/NYEARS,NPROP
120 C
130 C READ(S,.) NPROB
140 READ(S,501) NPROB
150 501 FORMAT(I5)
160 DO 100 NPR=1,NPROB
170 READ(S,196) (TITLE(I),I=1,20)
180 196 FORMAT(20A4)
190 WRITE(6,35)
200 WRITE(6,101)
210 101 FORMAT(1",CONCRETE PAVEMENT DESIGN - BASED ON EDGE STRESS",/)
220 C READ(S,*) AL,ALPHA,H,U,DIFUS
230 READ(S,502) AL,ALPHA,H,U,DIFUS
240 502 FORMAT(8F10.2)
250 C READ(S,* ) TRAFFIC,GROWTH,NYEARS,NAXLE,NTAXLE,NPOS,NPROP,NTEMP,NLOC
260 READ(S,503) TRAFFIC,GROWTH,NYEARS,NAXLE,NTAXLE,NPOS,NPROP,NTEMP,NLOC
270 503 FORMAT(2F10.2,8I5)
280 DO 14 I=1,NPOS
290 C READ(S,*) PPP(I),COEFF(I),COEF2(I)
300 READ(S,502) PPP(I),COEFF(I),COEF2(I)
310 14 CONTINUE
320 DO 5 I=1,NAXLE
330 C READ(S,*) P(I),PP(I)
340 READ(S,502) P(I),PP(I)
350 5 CONTINUE
360 DO B I=1,NTAXLE
370 C READ(S,*) T(I),TT(I)
380 READ(S,502) T(I),TT(I)
390 B CONTINUE
400 C READ(S,*) TRTEMP(I),I=1,NTEMP
410 READ(S,502) TRTEMP(I),I=1,NTEMP
420 DO 10 I=1,12
430 IF(NPROP.EQ.1.AND.I.GT.1) GO TO 11
440 C READ(S,*) RM(I),E(I),AK(I),SIGW(I),THETA(I),TMAX(I),DTEMP(I,I),
(S,C OR RETURN)>

-30-
PROGRAM PCP - LISTING (CONTINUED)

450 C  *  DTEMP(2,I)
460   READ(5,502)RM(I),E(I),AK(I),SIGW(I),THETA(I),TMAX(I),DTEMP(1,I),
470   *  DTEMP(2,I)
480   GO TO 10
490 10  RM(I)=RM(I)
500   E(I)=E(I)
510   AK(I)=AK(I)
520   SIGW(I)=SIGW(I)
530   THETA(I)=THETA(I)
540   TMAX(I)=TMAX(I)
550   DTEMP(1,I)=DTEMP(1,1)
560   DTEMP(2,I)=DTEMP(2,1)
570 10  CONTINUE
580 C   READ(5,*),PRESTR,FATIGE,AA,BB,NSUBPR,NFAT,NPST,NLNR
590   READ(5,504)PRESTR,FATIGE,AA,BB,NSUBPR,FAT,NPST,NLNR
600 504 FORMAT(4F10.2,4I5)
610 C   READ(5,*)YJE,DECYJE,XJE,DECXJE
620   READ(5,502)YJE,DECYJE,XJE,DECXJE
630 C   WRITE(6,197)(TITLE(IK),IK=1,20)
640 197 FORMAT(‘ ’,20A4)
650 C   NONL=1
(S,C OR RETURN)
660 C   IF(NLNR.EQ.3) NONL=2
670 C   DO 410 NNLNR=1,NONL
680 C   IF(NNLNR.EQ.1.AND.NONL.EQ.2) NLNR=1
690 C   IF(NNLNR.EQ.2.AND.NONL.EQ.2) NLNR=2
700 C   IF(NLNR.EQ.1) WRITE(6,411)
710 411 FORMAT(’,’,’****NON-LINEAR TEMPERATURE************’/)
720 C   IF(NLNR.EQ.2) WRITE(6,412)
730 412 FORMAT(’,’,’****LINEAR TEMPERATURE************’/)
740 C   DO 311 NPS=1,NPST
750 C   DO 211 NFT=1,NFAT
760 C   DO 210 NSUB=1,NSUBPR
770 C   IF(NFT.EQ.1.AND.NPS.EQ.1)WRITE(6,3)AL,H,ALPHA,U,DIFUS,NPROP
780 3 FORMAT(’,’,’****SLAB PROPERTIES*****’/)
790 1 ’’,’’SLAB LENGTH,FT=’,F6.2,5X,’SLAB THICKNESS,IN=’,F5.2/
800 2 ’’,’’ALPHA,IN/IN/OF=’,F9.7,5X,’POISSON RATIO=’,F4.2/
810 3 ’’,’’DIFFUSIVITY OF CONCRETE=’,F8.5/
820 4 ’’,’’NO. OF MATERIAL PROPERTIES=’,I2/
830 C   IF(NSUB.EQ.1.AND.NFT.EQ.1.AND.NPS.EQ.1)GO TO 903
840 C   GO TO 901
850 903 WRITE(6,9) TRAFFIC,GROWTH,NYEARS,NAXLE,NTAXLE,NPOS,NTEMP
860 9 FORMAT(’,’,’****TRAFFIC DATA*****’/)
(S,C OR RETURN)>

-31-
PROGRAM PCP - LISTING (CONTINUED)

1 ` ', 'ANNUAL TRAFFIC OR FACTOR=',F10.2,5X,
2 'ANNUAL TRAFFIC GROW=',F4.1, '/ ', 'DESIGN PERIOD, YR=',I2/
3 'NO. OF SAL TYPES=',I2,5X, 'NO. OF TAL TYPES=',I2/
4 'LATERAL POSITIONS=',I2,5X, 'DAILY TRAFFIC PERIODS=',I2/
5 WRITE(6,16) (I,PPP(I),COEFF(I),I=1,NPOS)
6 16 FORMAT( ' ', 'LATERAL POSITION FRACTION OF TRAFFIC',3X,
7 1 'STRESS COEFFICIENT/', '(6X,I2,16X,F5.2,15X,F4.2))
8 WRITE(6,35)
9 35 FORMAT( ' ')
10 WRITE(6,4) (P(I),PP(I), I=1,NAXLE)
11 4 FORMAT( ' ', 'SAL,LBS',7X, 'NO. OF AXLES(FRACTION)', '/'
12 1 ' ', (F8.2,13X,F12.2))
13 WRITE(6,44) (T(I),IT(I), I=1,NTIME)
14 44 FORMAT( ' ', 'TAL,LBS',8X, 'NO. OF AXLES (FRACTION)', '/
15 1 ' ', (F8.2,13X,F12.2))
16 WRITE(6,622) (ITMPL(I),I=1,NTEMP)
17 622 FORMAT( ' ', 'TRAFFIC DISTRIBUTION DURING DAY=',10(F4.2,4X))
18 WRITE(6,231) YJE,DECYJE
19 231 FORMAT( ' ', 'DECREASE IN JE ALONG LONG JNT /YEAR=',F5.2/
20 1 ' ', 'DECREASE IN JE ALONG LONG JNT /YEAR=',F5.2/
21 CONTINUE
22 WRITE(6,35)
23 (S,C OR RETURN)>
24 II=12
25 IF(NPROP.EQ.1) II=1
26 IF(NFT.EQ.1.AND.NPS.EQ.1) WRITE(6,6)(I,RM(I),E(I),AK(I),SIGW(I),
27 * THETA(I),TMAX(I),DTEMP(I),I=1,II)
29 4 ' ', 'TMAX',5X, 'DTEMP(DAY)',3X, 'DTEMP(NGT)'/
30 2 ' ', (13,5X,8(F9.1,3X)))
31 IF(FATIGE.EQ.2.0) AA=11.829
32 IF(FATIGE.EQ.2.0) BB=-12.195
33 IF(FATIGE.EQ.3.0) AA=14.428
34 IF(FATIGE.EQ.3.0) BB=-14.286
35 IF(NSUBST.1) GO TO 902
36 IF(NSUBSP.EQ.1.AND.NPS.EQ.1)WRITE(6,107) FATIGE,AA,BB
37 107 FORMAT( ' ', '/ ', '*****FATIGUE CURVE DATA*****' )
38 1 ' ', 'FATIGUE MODEL=',F4.1/
39 2 ' ', 'CONSTANT AA=',F10.5,5X, 'CONSTANT BB=',F10.5/
40 WRITE(6,117) PRESTR
41 117 FORMAT( ' ', 'LONGITUDINAL PRESTRESS AT MIDLENGTH=',F6.2/
42 CONTINUE
43 WRITE(6,35)
44 (S,C OR RETURN)>

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PROGRAM PCP - LISTING (CONTINUED)

1330 DO 300 III=1,2
1340 FFF=0.0
1350 IF(III.EQ.1) PRES=PRESIR
1360 IF(III.EQ.1) WRITE(6,302)
1370 302 FORMAT(’/****WHEEL LOADS AT MIDSLAB****/’)
1380 IF(III.EQ.2.AND.NLOC.EQ.0) GO TO 300
1390 IF(III.EQ.2) PRES=0.0
1400 IF(III.EQ.2) WRITE(6,301)
1410 301 FORMAT(’/****WHEEL LOADS AT TRANSVERSE JOINT(Crack)**/’)
1420 IF(NPS.GT.1.OR.NFT.GT.1) GO TO 555
1430 CALL SIGLD(III)
1440 CALL SIGCRCL
1450 555 CONTINUE
1460 C
1470 DO 20 II=1,NYEARS
1480 XXJE=XJE*(1-DECXJE/100*(II-1))
1490 YYJE=YJE*(1-DECYJE/100*(II-1))
1500 IF(III.EQ.1) XYJE=YYJE
1510 IF(III.EQ.2) XYJE=XXJE
1520 IF(XYJE.LE.0.0) XYJE=0.0
1530 XYJE=1/(1.0+XYJE)
1540 TRAF=TRAFFIC*(1.0+GROWTH/100.0)**II
1550 WRITE(6,105) II, TRAF
1560 105 FORMAT(’/YEAR NUMBER=’,I3,5X,’ANNUAL TRAFFIC OR FACTOR=’,F9.1)
1570 TRAF=TRAF/12.0
1580 DO 21 I=1,12
1590 DO 621 TEMP=1,NTEMP
1600 C CALCULATE FOR SINGLE AXLE LOADS
1610 C
1620 DO 30 J=1,NAXLE
1630 DO 30 K=1,NPOS
1640 SIGDAY=SIGL(I,J,K)*XYJE+SIGCC(I,ITEMP)-PRES-SIGW(I)
1650 IF(SIGDAY.LT.1.0) SIGDAY=1.0
1660 C
1670 CALL MINER(II,I,J,K,F,1,ITEMP)
1680 FFF=FFF+F
1690 C
1700 30 CONTINUE
1710 C
1720 C CALCULATE FOR TANDEM AXLE LOADS
1730 C
1740 DO 31 J=1,NTAXLE
1750 DO 31 K=1,NPOS
1760 SIGDAY=SIGT(I,J,K)*XYJE+SIGCC(I,ITEMP)-PRES-SIGW(I)
1770 31 CONTINUE
1780 C
1790 CONTINUE
1800 C
1810 C
PROGRAM PCP - LISTING (CONTINUED)

1770 IF(SIGDAY.LT.1.0) SIGDAY=1.0
1780 C
1790 CALL MINER(II,I,J,K,F,2,ITEMP)
1800 FFF=FFF+F
1810 C
1820 31 CONTINUE
1830 C
1840 621 CONTINUE
1850 FF(I)=FFF*100.0
1860 C
1870 21 CONTINUE
1880 WRITE(6,110) (FF(MN),MN=1,12)
1890 110 FORMAT(12F7.1,1X)
1900 20 CONTINUE
1910 C
1920 WRITE(6,35)
1930 300 CONTINUE
1940 H=H+1.0
1950 DO 6211 IS56=1,12
1960 IF(NPROP.EQ.1.AND.IS56.GT.1) GO TO 6210
1970 IF(NLNR.EQ.2.AND.NSUB.LT.NSUBPR)READ(5,DTEMP(1,IS56),DTEMP(2,IS56)
1980 C IF(NLNR.EQ.2.AND.NSUB.LT.NSUBPR)READ(5,502)DTEMP(1,IS56),DTEMP(2,IS
1990 C OR RETURN)
2000 C *6)
2010 GO TO 6211
2020 6210 DTEMP(1,IS56)=DTEMP(1,1)
2030 6211 CONTINUE
2040 210 CONTINUE
2050 H=H-1.0*NSUBPR
2060 IF(NFT.EQ.1) FATIGE=2.0
2070 IF(NFT.EQ.2) FATIGE=3.0
2080 211 CONTINUE
2090 PRESTR=PRESTR+10.0
2100 311 CONTINUE
2110 PRESTR=PRESTR-10.0*NPST
2120 410 CONTINUE
2130 100 CONTINUE
2140 C
2150 END
2160 SUBROUTINE SIGLD(III)
2170 C
2180 C
2190 COMMON/DNE/AY(I2),E(I2),RM(I2),H,U,P(I10),COEFF(I10),SIGL(I2,10,10),
2200 NAXLE,T(I10),SIGT(I2,10,10),NTAXLE,TT(I10),NF05,COEF2(I10)
(S,C OR RETURN)
PROGRAM PCP - LISTING (CONTINUED)

2210 COMMON/SIX/NYEARS,NPROP
2220 C
2230 C WRITE(6,55)
2240 C 55 FORMAT(’,’,/’,’;MONTH’,2X,’AXLE LOAD’,2X,
2250 C ’STRESS DISTRIBUTION ACROSS PAVEMENT’;/)
2260 C
2270    DO 10 I=1,12
2280    RADL=(E(I)*(H**3.0)/(12.0*(1.0-U**2.0)*AK(I))) **0.25
2290 C EGN BELOW IS FOR EDGE STRESS, 20 IN. LOSS OF SUPPORT
2300 IF(III.EQ.1) BMOM=483.34*(RADL**0.5711)
2310 C EGN BELOW IS FOR JOINT STRESS, FLAT SLAB
2320 IF(III.EQ.2) BMOM=133.91*(RADL**0.8107)
2330 SIGMA=6.0*BMOM/(H**2.0)
2340 C
2350 C FOR TANDEM AXLES
2360 C EGN BELOW IS FOR EDGE STRESS, 20 IN. LOSS OF SUPPORT
2370 IF(III.EQ.1) BMOM=185.14*(RADL**0.8197)
2380 C EGN BELOW IS FOR JOINT STRESS, FLAT SLAB
2390 IF(III.EQ.2) BMOM=110.32*(RADL**0.9090)
2400 SIGMB=6.0*BMOM/(H**2.0)
2410 C
2420 C CALCULATE FOR SINGLE AXLES
2430   DO 11 J=1,NAXLE
2440    SIGJ=SIGMA*(P(J)/18000.0)
2450 C
2460    DO 30 K=1,NPOS
2470 IF(III.EQ.1) COEF=COEFF(K)
2480 IF(III.EQ.2) COEF=COEF2(K)
2490 30 SIGL(I,J,K)=COEF*SIGJ
2500 C
2510 C WRITE(6,20) I,P(J),SIGL(I,J,K),K=1,NPOS)
2520 C 20 FORMAT(’,’,15,5X,10F10.1)
2530 11 CONTINUE
2540 C
2550 C CALCULATE FOR TANDEM AXLES
2560    DO 12 J=1,NTAXLE
2570    SIGJ=SIGMB*(T(J)/36000.0)
2580    DO 31 K=1,NPOS
2590 IF(III.EQ.1) COEF=COEFF(K)
2600 IF(III.EQ.2) COEF=COEF2(K)
2610 31 SIGT(I,J,K)=COEF*SIGJ
2620 C
2630 C WRITE(6,20) I,T(J),SIGT(I,J,K),K=1,NPOS)
2640 12 CONTINUE
(S,C OR RETURN)}>
2650 C
2660 10 CONTINUE
2670 C WRITE(6,35)
2680 C
2690 RETURN
2700 END
2710 SUBROUTINE SIGCC
2720 C
2730 COMMON/ONE/AK(12),E(12),RH(12),H,U,P(10),CUEFF(10),SIG(12,10,10),
2740 NAXLE,T(10),SIGT(12,10,10),NAXLE,T(11),NPOS,COEF(10)
2750 COMMON/TWO/SIGCC(12,12),NTEMP,UTEMP(2,12),ALPHA,DIFUS,THE1A(12),
2760 1 TMX(12),NLNR
2770 C
2780 IF(NLNR.EQ.2) GO TO 900
2790 DO 500 I=1,12
2800 DO 500 ITEMP=1,NTEMP
2810 DIFS=DIFUS**0.5
2820 TPRIOD=(ITEMP-1)*24.0/NTEMP
2830 TIME=TPRIOD-(TMX(I)-6.0)
2840 IF(TIME.LT.0.0) TIME=TIME+24.0
2850 ALB=(H/DIFS)*0.361801
2860 THETDD=-100.0
(9,C OR RETURN>)
2870 NTIMES=24.0/NTEMP
2880 DO 20 NTIME=1,NTIMES
2890 A1=THETA(I)/(2.0+ALB)
2900 A2=EXP(-ALB)*(COS(0.2618*TIME-ALB)-SIN(0.2618*TIME-ALB))
2910 A3=COS(0.2618*TIME)-SIN(0.2618*TIME)
2920 THETAM=A1*(A2-A3)
2930 THETB=THETA(I)+EXP(-ALB)*SIN(0.2618*TIME-ALB)
2940 THETD=THETAM-THETAB
2950 IF(THETAB.GT.THETDD) THETDD=THETAB
2960 TIME=TIME+1.0
2970 IF(TIME.GT.24.0) TIME=TIME-24.0
2980 20 CONTINUE
2990 SIGCC(I,ITEMP)=ALPHA*E(I)*THETDD
3000 300 IF(TIME.GT.12.0) SIGCC(I,ITEMP)=SIGCC(I,ITEMP)/3.0
3010 GO TO 901
3020 900 CONTINUE
3030 DO 600 I=1,12
3040 DO 600 ITEMP=1,NTEMP
3050 DIFF=(UTEMP(I,1)-UTEMP(I,2))/(NTEMP/2.0)
3060 TEMP=UTEMP(I,2)+(ITEMP-1)*DIFF
3070 IF(ITEMP.GT.(NTEMP/2)) TEMP=UTEMP(I,1)-(ITEMP-(NTEMP/2)-1)*DIFF
3080 600 SIGCC(I,ITEMP)=ALPHA*E(I)*TEMP*0.5
(S,C OR RETURN)>
CONTINUE
WRITE(6,902)SIGCC(1,ITEMP),ITEMP=1,NTMP
C CURLING STRESS WITH TIME FOR FIRST MONTH,
* 12F10.1//)
RETURN
END
SUBROUTINE MINER(I1,I,J,K,F,NUM,ITEMP)
COMMON/ONE/AK(12),E(12),RM(12),H,J,F(10),COEFF(10),SIGL(12,10,10),
MAXLE,T(10),SIGT(12,10,10),NTAXLE,TT(10),HPOS,COEF2(10)
COMMON/FOUR/SIGDAY ,PP(10),TRAFFIC,GROWTH
COMMON/FIVE/PPP(10),FATIGE,AA,BB,TKAF,TRTEMP(10)
C IF(NUM.EQ.1) AN=TRAFF*PP*(K)*TRTEMP(ITEMP)
IF(NUM.EQ.2) AN=TRAFF*TT*(K)*TRTEMP(ITEMP)
C IF(SIGDAY.LE.0.5*RM(I)) F=0.0
IF(SIGDAY.LE.0.5*RM(I)) GO TO 10
IF(SIGDAY.GT.0.85*RM(I)) SIGDAY =0.85*RM(I)
ANNDAY= (AA + BB*(SIGDAY /RM(I)))
ANNDAY=10.0#ANNDAY
F=AN/ANNDAY
(S,C OR RETURN)
10 CONTINUE
RETURN
END
>