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16. Abstract

CRCP-2 is an extension and revision of the CRCP-1 computer solution for the analysis of continuously reinforced concrete pavement (reported in Research Report NCHRP 1-15). It improves the proficiency and extends the capability of the original model. Small errors in CRCP-1 for extreme values of variable combinations, such as a high-friction value and a high steel percentage, were remedied by extending the original steel stress model to cover situations where development length under the influence of high frictional resistance might exceed half the crack spacing. The stress-strength interaction model in CRCP-1 has been revised such that the maximum concrete stress under minimum temperature is compared with the concrete strength at the time of minimum temperature occurrence, thus allowing for additional strength gain in the concrete. Wheel load and wheel-load stress are included in CRCP-1 as new design variables for when the combined effect of the bending stress under wheel load and the in-plane stress under environmental load are considered. Some minor changes were made in the computer program. In order to be compatible with the mathematical model, which requires at least one increment be contained in the bond slip zone, the initial slab length was adjusted inside the program to ensure that the increment length is within tolerance limits while maintaining the dimensional array for the slab length to one hundred increments. Thus, the computation time was substantially reduced, and errors at high-level studies were eliminated. The revision of the CRCP-1 model and the inclusion of wheel load, provide better predictions of the behavior of CRC pavement. However, to fully portray the state-of-stress in a slab, fatigue due to repetitions of load and warping stress due to temperature differential need to be considered.

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by

James Ma
B. Frank McCullough

Research Report Number 177-9

Development and Implementation of the Design, Construction and Rehabilitation of Rigid Pavements

Research Project 3-8-75-177

conducted for

Texas
State Department of Highways and Public Transportation

in cooperation with the
U. S. Department of Transportation
Federal Highway Administration

by the

CENTER FOR HIGHWAY RESEARCH

THE UNIVERSITY OF TEXAS AT AUSTIN

August 1977

PREFACE

This is the ninth report in the series of reports that describes the work done in the project entitled, "Development and Implementation of the Design, Construction, and Rehabilitation of Rigid Pavements," The project is conducted at the Center for Highway Research, The University of Texas at Austin as part of the Cooperative Highway Research Program sponsored by the State Department of Highways and Public Transportation and the Federal Highway Administration.

This report presents the results of an analytical study undertaken to improve the method, CRCP-1, for the computer solution of continuously reinforced concrete pavement.

Our thanks are extended to Dr. W. R. Hudson, member of my graduate supervising committee, who reviewed this report. Special thanks to Mrs. Patricia Henninger for typing the drafts of the manuscript, Charlie Copeland and Randy Wallin concerning the analysis of the computer program. Thanks are also due to Mrs. Marie Fisher and Mr. Art Frakes for their efforts in editing and coordinating the reports preparation.

James C. M. Ma
B. Frank McCullough

August 1977

LIST OF REPORTS

Report No. 177-1, "Drying Shrinkage and Temperature Drop Stresses in Jointed Reinforced Concrete Pavement," by Felipe R. Vallejo, B. Frank McCullough, and W. Ronald Hudson, describes the development of a computerized system capable of analysis and design of a concrete pavement slab for drying shrinkage and temperature drop. August 1975.

Report No. 177-2, "A Sensitivity Analysis of Continuously Reinforced Concrete Pavement Model CRCP-1 for Highways," by Chypin Chiang, B. Frank McCullough, and W. Ronald Hudson, describes the overall importance of this model, the relative importance of the input variables of the model, and recommendations for efficient use of the computer system. August 1975.

Report No. 177-3, "A Study of the Performance of the Mays Ride Meter," by Yi Chin Hu, Hugh J. Williamson, B. Frank McCullough, and W. Ronald Hudson, discusses the accuracy of measurements made by the Mays Ride Meter and their relationship to roughness measurements made with the Surface Dynamics Profilometer. January 1977.

Report No. 177-4, "Laboratory Study of the Effect of Non-Uniform Foundation Support on CRC Pavements," by Enrique Jimenez, W. Ronald Hudson, and B. Frank McCullough, describes the laboratory tests of CRC slab models with voids beneath them. Deflection, crack width, load transfer, spalling, and cracking are considered. Also used is the SLAB 49 computer program that models the CRC laboratory slab as a theoretical approach. The physical laboratory results and the theoretical solutions are compared and analyzed and the accuracy is determined. (Being prepared for submission)

Report No. 177-5, "A Comparison of Two Inertial Reference Profilometers Used to Evaluate Airfield and Highway Pavements," by Chris Edward Doepke, B. Frank McCullough, and W. Ronald Hudson, describes a United States Air Force owned profilometer developed for measuring airfield runway roughness and compares it with the Surface Dynamics Profilometer using plotted profiles and mean roughness amplitude data from each profilometer. Preliminary, March 1976.

Report No. 177-6, "Sixteenth Year Progress Report on Experimental Continuously Reinforced Concrete Pavement in Walker County," by Thomas P. Chesney and B. Frank McCullough, presents a summary of data collection and analysis over a 16-year period. During that period, numerous findings resulted in changes in specifications and design standards. These data will be valuable for shaping guidelines for future construction. April 1976.

Report No. 177-7, "Continuously Reinforced Concrete Pavement: Structural Performance and Design/Construction Variables," by Pieter J. Strauss, B. Frank McCullough, and W. Ronald Hudson, describes a detailed analysis of design, construction, and environmental variables that may have an effect on the structural performance of a CRCP. May 1977.

Report No. 177-8, "Continuously Reinforced Concrete Pavement: Prediction of Distress Quantities," by John P. Machado, B. Frank McCullough, and Hugh J. Williamson, presents a general analysis of environmental, design, construction and historic pavement behavior conditions and their effects on future performance. (Being prepared for submission)

Report No. 177-9, "CRCP-2, An Improved Computer Program for the Analysis of Continuously Reinforced Concrete Pavements," by James Ma and B. Frank McCullough, describes the modification of a computerized system capable of analysis of a continuously reinforced concrete pavement based on drying shrinkage and temperature drop. Preliminary, August 1977.

ABSTRACT

CRCP-2 is an extension and revision of the CRCP-1 computer solution for the analysis of continuously reinforced concrete pavement (reported in Research Report NCHP 1-15). It improves the proficiency and extends the capability of the original model. Small errors in CRCP-1 for extreme values of variable combinations, such as a high-friction value and a high steel percentage, were remedied by extending the original steel stress model to cover situations where development length under the influence of high frictional resistance might exceed half the crack spacing. The stress-strength interaction model in CRCP-1 has been revised such that the maximum concrete stress under minimum temperature is compared with the concrete strength at the time of minimum temperature occurrence, thus allowing for additional strength gain in the concrete. Wheel load and wheel-load stress are included in CRCP-1 as new design variables for when the combined effect of the bending stress under wheel load and the in-plane stress under environmental load are considered.

Some minor changes were made in the computer program. In order to be compatible with the mathematical model, which requires at least one increment be contained in the bond slip zone, the initial slab length was adjusted inside the program to ensure that the increment length is within tolerance limits while maintaining the dimensional array for the slab length to one hundred increments. Thus, the computation time was substantially reduced, and errors at high-level studies were eliminated.

The revision of the CRCP-1 model and the inclusion of wheel load, provide better predictions of the behavior of CRC pavement. However, to fully portray the state-of-stress in a slab, fatigue due to repetitions of load and warping stress due to temperature differential need to be considered.

KEY WORDS: continuously reinforced concrete pavement, external load, internal load, CRCP-1 program, CRCP-2 program, development length, steel stress model

SUMMARY

The CRCP-1 method, developed in Ref 5, provides a useful tool for the analysis of temperature and shrinkage effects on continuously reinforced concrete pavements. Certain modifications of the CRCP-1 method were made in this study to increase the proficiency and to extend the capability of this method. The age-tensile strength model was extended to cover conditions in which the drop to minimum temperature was delayed. For high frictional subbase, the steel stress model was extended to cover conditions in which the bond length exceeds one-half the crack spacing. The wheel-load stress was combined with the internal load caused by temperature drop and drying shrinkage to obtain a better prediction of crack spacing in field conditions.

The inclusion of wheel-load stress with internal stress was accomplished by superimposing the tensile stress at the bottom fibre, computed by the Westergaard equation for a single-concentrated vertical load, an the airplane tensile stress across the depth of the slab, computed by the CRCP-1 method.

IMPLEMENTATION STATEMENT

The CRCP-2 computer program developed in this study can be used to determine the combined effect of external loads and internal loads on a continuously reinforced concrete pavement. In addition, the modification of the mathematical model, as well as the computer program, makes it possible to analyze a CRC slab under the influence of high-level parameters; the new program should be used in lieu of the original CRCP-1 program for extreme values of variable combinations. For instance, the analysis of a CRC pavement laid over a treated base with high frictional resistance, the analysis of high percentage steel, the analysis of high temperature drop, or any combination of the above conditions can be made only by the revised, CRCP-2, program.

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NOMENCLATURE

Symbol	Units	Definition
a	inch	Radius of the tire contact area
Ac	in^2	Area of concrete
As	in^2	Area of steel
b	in	Development length
D	in	Slab thickness
Ec	psi	Modulus of elasticity of concrete
Es	psi	Modulus of elasticity of steel
F_{cm}	lbs	Concrete force between cracks
F_i	lb/in^2	Friction force for a dx element
F_{sc}	lbs	Steel force at the crack
F_{sm}	lbs	Steel force between cracks
f'_{cx}	psi	Compressive strength of concrete at x days
$f'_{28th\ day}$	psi	Compressive strength of concrete at 28th day
f'_{tx}	psi	Tensile strength of concrete at x days
k	$lb/in^2/in$	Modulus of subgrade
ℓ	in	Radius of relative stiffness
L	in	Half the slab length
p	percent	Percentage steel
P	lbs	Applied wheel load
μ	lb/in^2	Nominal bond stress
U	lb/in	Bond force per unit length

Symbol	Units	Definition
x	days	Number of days in between from the time when pavement was built to the time when minimum temperature was reached
Z	in/in	Total shrinkage strain
α_c	in/in/°F	Thermal coefficient of concrete
α_s	in/in/°F	Thermal coefficient of steel
Y	in	Movement of concrete slab
ΔT	°F	Change in temperature
ΔX	in	Crack width
ϕ	in	Steel bar diameter
ε_{cz}	in/in	Shrinkage strain of concrete due to restraint of steel
$\varepsilon_{c\Delta t}$	in/in	Concrete strain due to temperature drop
ε_{sz}	in/in	Shrinkage strain of steel due to contraction of concrete
$\varepsilon_{s\Delta t}$	in/in	Steel strain due to temperature drop
ε_o	in	Steel bar perimeter
σ_{cm}	psi	Concrete stress between the cracks
σ_{cz}	psi	Shrinkage stress of concrete
$\sigma_{c\Delta t}$	psi	Concrete stress due to temperature drop
σ_i	psi	Interior wheel-load stress
σ_{sc}	psi	Steel stress at the crack
σ_{sm}	psi	Steel stress between the crack
σ_{sz}	psi	Shrinkage stress of steel
$\sigma_{s\Delta t}$	psi	Steel stress due to temperature drop
μ		Poissons ratio

CHAPTER 1. INTRODUCTION

BACKGROUND

The rational approach to pavement design is based on the use of the mechanics of the materials and the structural equilibrium of the system to predict the behavior of the pavement. The rational approaches developed for rigid pavements can be categorized into three groups: first, the theory that deals with the stress in the slab under wheel load; second, the stress in the slab induced by environmental factors; and, third, fatigue or repeated load effects.

Stress in the Slab Under Wheel Load

The earliest attempt to predict the behavior of rigid pavement was made in 1920. By assuming zero support near the corner, Goldbeck approximated the stress in the slab under wheel load in his corner formula (Ref 1). In 1926, H. M. Westergaard (Ref 2) used Timoshenko's plate equations to develop a slab on foundation solution for edge, interior, and corner loading conditions. In 1956, Turner et al introduced the finite element method and started a new trend in structural analysis which is characterized by its heavy reliance on high-speed computers (Ref 3). Most recently, Hudson and Matlock introduced the discrete element method, which is a very powerful method for the analysis of stress on rigid pavements (Ref 4). The slab in the discrete element model was beams, to represent bending stiffness, and torsional bars, to represent torsional stiffness. The support media was represented by the spring constant k equal to the modulus of subgrade described in Westergaard's equations.

Stress Induced by Environmental Factors

In the area of environmental design, a continuously reinforced concrete pavement (CRCP) model was developed which can be used to predict the in-plane stress in the slab caused by drying shrinkage and temperature drop (Ref 5).

In that model, CRCP-1, the movement, or the summation of concrete strains along the slab, is fitted to a friction-movement curve of a particular type of supporting soil to determine the frictional force acting on the pavement. The concrete stress then is the equilibrium force needed to balance the frictional resistance of the soil, plus the steel restraint of the reinforcement. One unique feature in the CRCP design method is that the age-strength function of the concrete slab is used in the model to follow-through the formation of cracks each time the internal stress exceeds the tensile strength of the concrete.

In addition to the change in average temperature along the slab, the warping stress cuased by the temperature differential across the depth of the slab should also be considered. In 1940, Thomlinson extended Westergaard's equation to predict the warping stress of rigid pavements (Ref 6). Both Westergaard and Thomlinson assumed full support beneath each slab, and their analysis was later modified by Teller and Sutherland (Ref 7) to account for the loss in support along the edges. Also, computer programs to compute stress, deflection, and loss in support caused by this warping effect were written by Harr and Leonards (Ref 8).

Repeated Load Effects

In fatigue design, the progressive structural damage in the concrete slab caused by repeated loads is emphasized. Due to the difference in material behavior between the slab and the subgrade, where one may be elastic while the other may be plastic under repeated load, the rational approach to fatigue design is quite complex. Very limited research has been done in this area, and fatigue design still has to rely heavily on other empirical solutions.

THE PROBLEM AND THE STUDY OBJECTIVES

There are two major advantages to the development of rational theories. Different modes of failures and different types of pavement behavior can be studied more closely with these theories. Second, due to tremendous cost involved, only limited road tests can be performed. To cover other environments and other conditions, rational analysis can be used to extend the findings indicated in these road test for pavement design.

In earlier discussions, several rational techniques, each dealing with specific problems, were briefly reviewed. Although the severity of distress due to any particular cause can be analyzed using these theories, pavement behavior under the combined effect of all factors is not known.

The objectives in this study were three-fold:

(1) To extend the CRCP-1 design method, which considered only the effect of temperature drop and drying shrinkage, to include wheel-load stress at the mid-slab, which will lead to better prediction of the stress development and crack spacing of continuously reinforced concrete pavment under field conditions.

(2) To modify the steel-stress model used in CRCP-1 to cover conditions in which the development length of the steel bar exceeds one-half the crack spacing. When high friction values are used in the analysis, the crack spacings may be reduced to such short lengths that the distance required for the bond between steel and concrete to fully develop may exceed them. When such a case arises, computer program CRCP-1 and the theoretical models are no longer valid. To cover such conditions, a new set of equations must be developed and added to the CRCP-1 program.

(3) To compare the stress caused by the minimum temperature drop with the tensile strength of the concrete at the time when the minimum temperature occurs and not with the earlier 28th day strength, since concrete strength continues to increase after it reaches its early strength. This is particularly significant when the pavement is built in summer and the temperature will not reach the minimum until a few months later. The CRCP-1 program needs to be revised to account for this increase in tensile strength before the occurrence of a severe cold temperature.

The inclusion of external load and the modifications of the mathematical models as well as the computer program resulted in a revised version of CRCP-1, which is designated as CRCP-2.

SCOPE OF THE STUDY

This study expands and modifies computer solution CRCP-1. The addition of new equations to acheive the objectives resulted in the addition of several new variables to the CRCP-1 design method. The variables used in the CRCP-1 program and the additional variables used in the CRCP-2 are listed in Tables 1.1 and 1.2, respectively.

The report covers the development of the equations for inclusion in the design method. Chapter 2 discusses the theoretical model used in CRCP-1 design method and the wheel-load stress and the combined effect of external and internal loads. Chapter 3 discusses the modification of the age-concrete

TABLE 1.1. DESIGN VARIABLES USED IN CRCP-1 PROGRAM

Symbol	Definition	Units
ITPYER	Types of reinforcement either deformed bar or deformed wire fabric	
p	Percent reinforcement	percent
∅	Bar diameter	inches
fy	Steel yield stress	lb/in^2
E_s	Steel modulus	lb/in^2
α_s	Thermal coefficient for steel	in/in/°F
BHIGH	Transverse wire spacing	inches
D	Slab thickness	inches
α_c	Thermal coefficient for concrete	in/in/°F
Z	Drying shrinkage strain	in/in
UNWT	Unit weight of concrete	lb/in^3
FPC	28th day compressive strength	lb/in^2
F(I), Y(I)	Friction-movement relationship between the slab and the subbase	lb/in^2, in
CURT	Curing temperature	°F
TD	Minimum daily temperature	°F
DTMAX	Minimum temperature expected after concrete gain full strength	°F
MAXITE	Maximum number of interactions	
TOL	Relative closure tolerance	percent

TABLE 1.2. ADDITIONAL VARIABLES IN CRCP-2 PROGRAM

Symbol	Definition	Units
WHLSTR	Wheel load stress	lb/in^2
WHLOAD	Wheel load	lb
WHBASE	Wheel base radius	inches
SOILK	Modulus of subgrade	$lb/in^2/in$
TMLOD	Number of days after concrete is set before wheel load is applied	days
COLDTM	Number of days after concrete is set before minimum temperature occurs	days
COLDSTN	Concrete strength at the time when minimum temperature occurs	psi

strength model in CRCP-1 to account for the gain in strength between the 28th day and the occurrence of the minimum temperature. Modification of the steel-stress model to cover the condition in which development length exceeds one-half the crack spacing is discussed in Chapter 4. Chapter 5 describes sample problems used to demonstrate the application of the new design variables in CRCP-2. Chapter 6 summarizes the report and presents recommendations for implementation and additional development.

CHAPTER 2. DRYING SHRINKAGE, TEMPERATURE DROP, AND WHEEL-LOAD STRESS IN CONTINUOUSLY REINFORCED CONCRETE PAVEMENT

BACKGROUND

The dimensional changes in a continuously reinforced concrete pavement caused by drying shrinkage of the concrete and temperature variation after curing were investigated and design method CRCP-1 was developed in the study described in Ref 5. The theoretical model was based on the material properties, stress, strain interaction between steel, concrete, subgrade, and the internal forces caused by the temperature drop and shrinkage of the slab.

Figures 2.1 and 2.2 show the geometric model used to develop the basic equations for the CRCP-1 design method. Due to the accumulated friction and the terminal treatments used in the construction, the slab model assumes an anchorage at each end so that the pavement within the anchorages will maintain a fixed length.

The difference in the thermal coefficients of steel and concrete together with the drying shrinkage of concrete enable us to determine the internal stress in the reinforced slab. With the friction movement characteristic of the slab and the soil, the degree of restraint of the supporting medium can be estimated. By establishing equilibrium in the system, the stress of one material can be correlated to the stress of the adjacent materials. Finally, the crack spacing is determined by comparing concrete stress with concrete strength at each time interval.

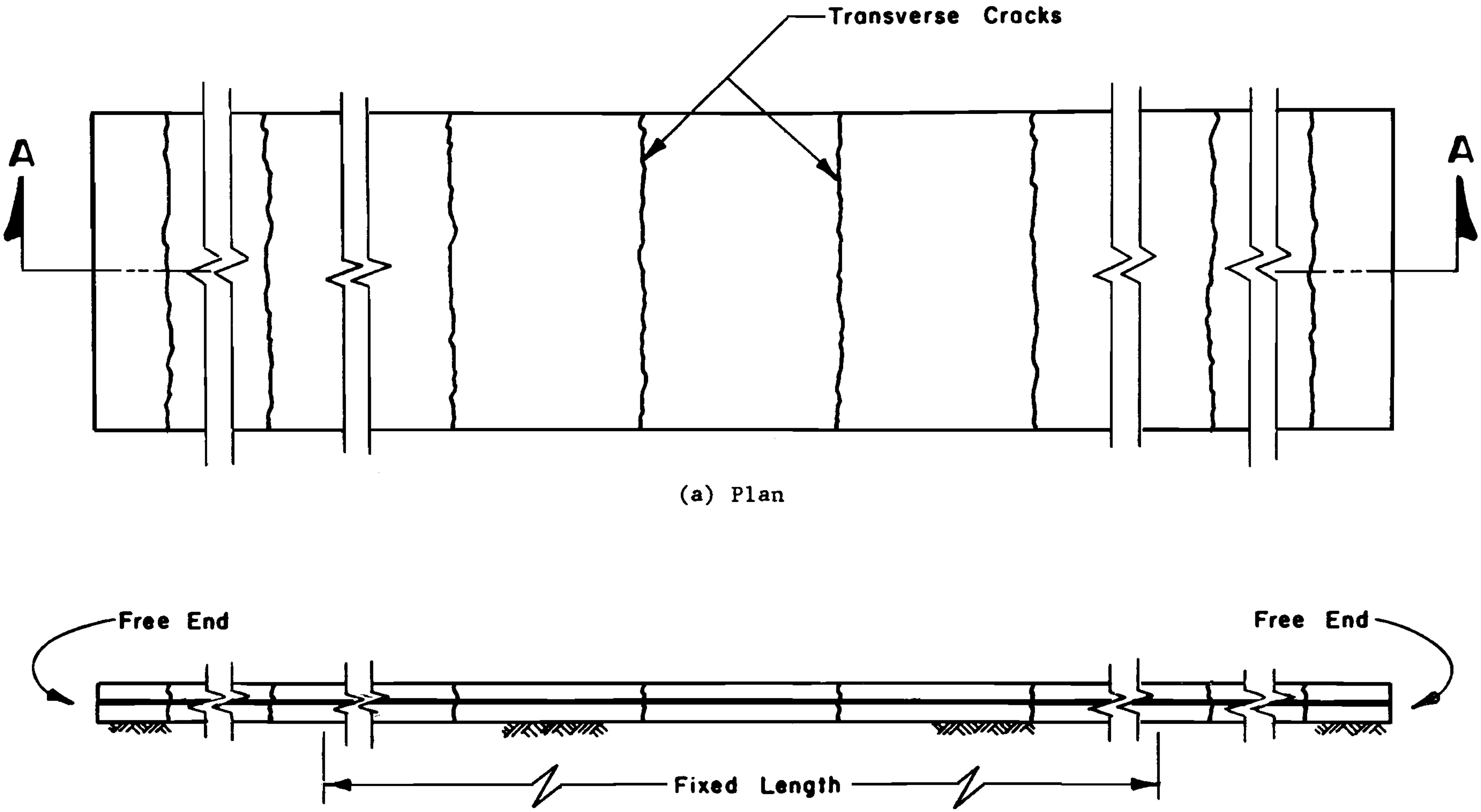
In the development of the model, the following assumptions were made:

(1) A crack occurs when the concrete stress exceeds the concrete strength, and, after cracking, the concrete stress at the location of the crack is zero.

(2) The concrete and steel properties are linearly elastic.

(3) In the fully bonded sections of the concrete slab, there is no relative movement between the steel and the concrete.

(4) The force displacement curve which characterizes the frictional resistance between the concrete slab and the underlying base is elastic.



(a) Plan

(b) Section AA

Fig 2.1. Full length of a continuously reinforced concrete pavement (Ref 5).

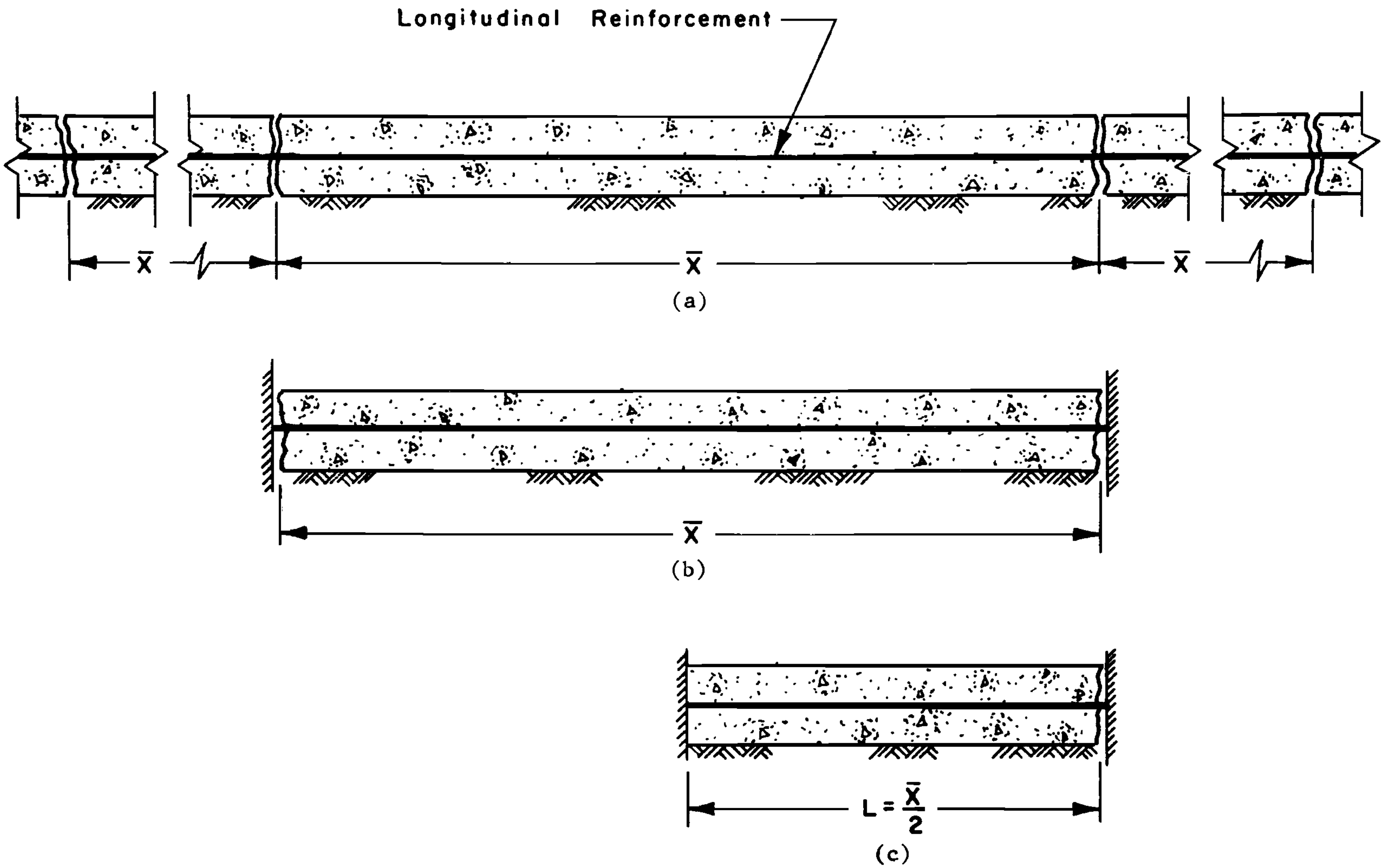


Fig 2.2. Continuously reinforced concrete pavement geometric model (Ref 5).

(5) Temperature variations and shrinkage due to drying are uniformly distributed throughout the slab, and hence, a one-dimensional axial structural model is adopted for the analysis of the problem.

(6) Material properties are independent of space.

(7) The effect of creep of concrete and slab warping are neglected.

PRIMARY CONCEPTS

The mechanistic behavior of the CRCP-1 can be summarized briefly in the following paragraphs...

Steel and Concrete Interaction

In the fully bonded section of a continuously reinforced concrete pavement, the total change in length in the concrete will be the same as the change in length of the steel. Thus, the difference in the thermal coefficients of expansion and contraction for the steel and the concrete plus the drying shrinkage of the concrete results in a steel and concrete strain history that may be modeled by a mathematical relationship. By converting strains into stress based on their individual modulus of elasticity, the stress history of the concrete can be written as the function of the stress history of the steel.

Steel Boundary Conditions

The total length of the pavement within the fictitious anchorages is fixed, which implies that the integrals of the steel strains along the slab or the sume of the area under the steel strain diagram will equal the pavements shortening. The steel stress at any point can be written as a function of the steel stress at any other location along the slab.

Equilibrium

Figures 2.3 and 2.4 show a free-body diagram for the CRCP-1 model. By summing all the forces, the steel and the concrete stresses between the cracks will be balanced by the sum of the steel stresses at the crack and the frictional resistance between the slab and the base.

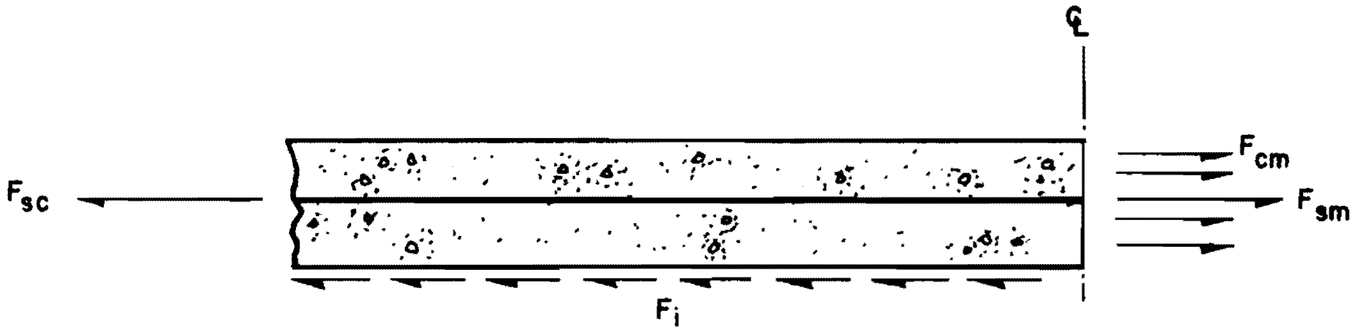


Fig 2.3. Forces in CRCP free-body diagram (Ref 1).

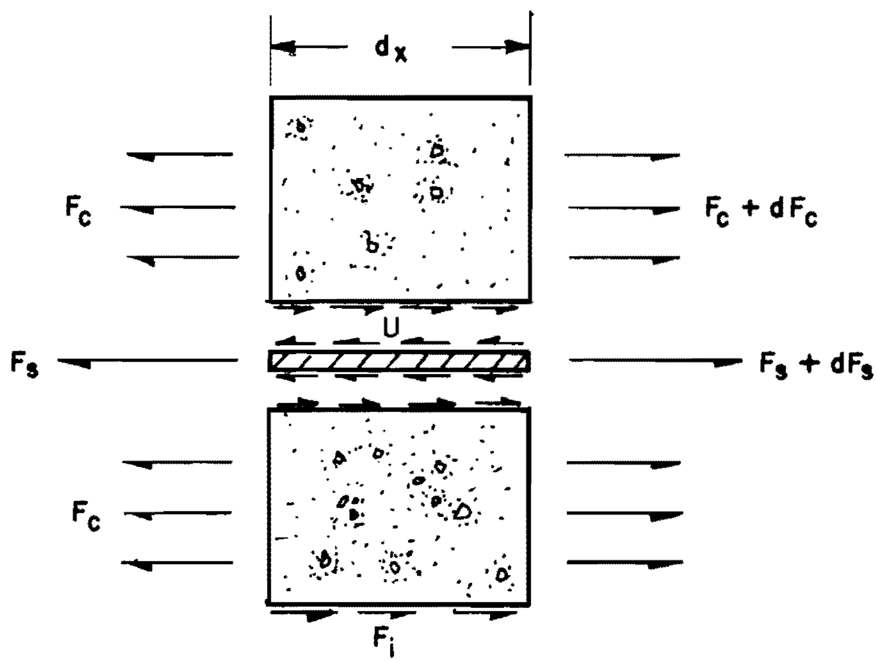


Fig 2.4. Free-body diagram of an element in CRCP-1 model (Ref 5).

By converting the concrete stresses between the cracks into functions of steel stress as described earlier, the steel stress and subsequently the concrete stress and slab movement can be readily calculated, provided that the frictional resistance is known. The frictional resistance, however, is not a constant force because it depends on the magnitude of the movement of the slab, and the larger the movement, the larger the resulting frictional force. Since the movement of the slab is its length times the total strain, and the stress of the concrete and steel must be solved in order for the strain to be known, an interactive process that involves the following steps (Fig 2.5) is therefore needed to solve the friction force and stresses in the slab:

(1) Assume zero friction and solve for the strain of concrete along the slab.

(2) Sum the strains and solve for the movement of the slab, Y_1 .

(3) Use a friction-movement curve, obtained through laboratory experiments, to locate the frictional force, F_2 , that corresponds to the movement found in step 2.

(4) Reenter the frictional force from step 3, F_2 , into the basic equations and solve for movement, Y_2 .

(5) Reenter Y_2 into the F-M curve and solve for F_3 .

(6) Use F_4 , the average of F_2 and F_3 , to solve for Y_{4c} with the basic equations and Y_{4e} by using the F-M curve.

(7) If Y_{4c} is greater than Y_{4e} , F_5 will be equal to $(F_2 + F_4)/2$, and if Y_{4c} is smaller than Y_{4e} , F_5 will be equal to $(F_3 + F_4)/2$.

(8) Returning to step 6, use the new frictional force until the movement solved from the equations falls within the tolerance range of the movement obtained from the F-M curve.

(9) Use the final frictional force to solve for the steel stress at the crack and the concrete stress at the mid-slab.

INCLUSION OF WHEEL-LOAD STRESS

When a crack occurs, the tension that was carried by the concrete will be taken up by the steel. The concrete stress will, therefore, be zero at the crack and increase to its maximum in tension at the mid-slab. This high tension stress at the mid-slab is the result of the accumulated frictional resistance of the base plus the restraint on concrete contraction by the steel.

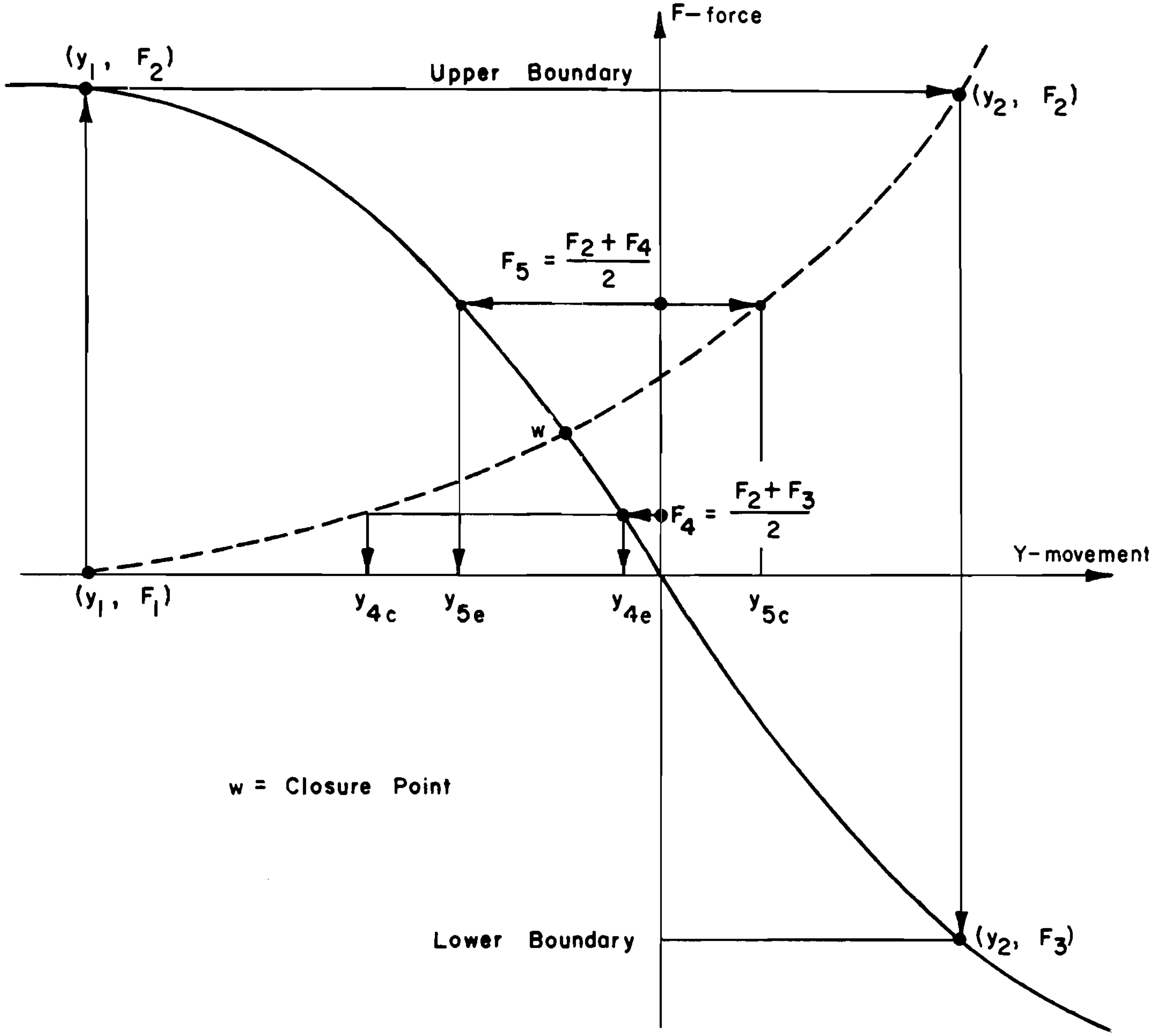


Fig 2.5. Binary search technique as applied to frictional resistance-movement curve (Ref 5).

If the warping effect due to the temperature variance is set aside, the tensile stress due to the internal forces will be uniformly distributed across the depth of the slab (Fig 2.6b). Maximum of this tensile stress will, theoretically, be near the mid-point between a pair of cracks where the highest frictional resistance is accumulated. The stress due to external force on the other hand will be in compression on the top fibre and in tension on the bottom fibre (Fig 2.6c). The highest combined stress due to both external and internal forces will then be at the bottom fibre of the slab and at the mid-point between two cracks. Figure 2.6d shows the stress diagram for the wheel load stress superimposed with the tensile stress at mid-slab caused by drying shrinkage and temperature drop, in which

$$\sigma_{TOT} = \sigma_{INT} + \sigma_{EXT}$$

where

σ_{TOT} = combined external and internal stresses,

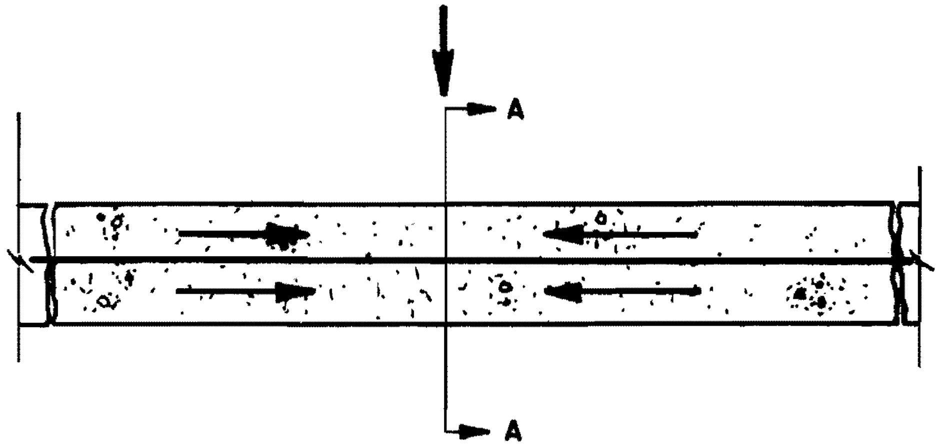
σ_{INT} = tensile stress caused by drying shrinkage and temperature drop, and

σ_{EXT} = tensile stress at the bottom fibre of the slab under wheel load.

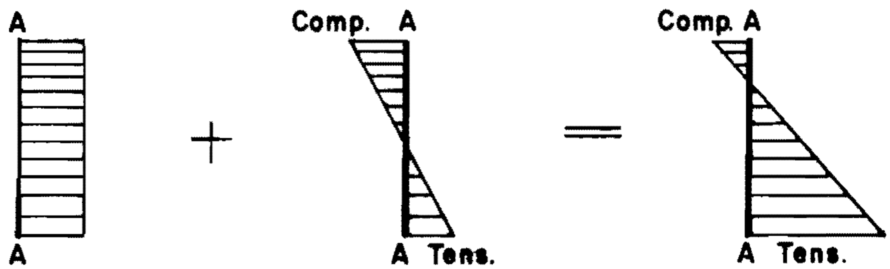
New cracks will form when σ_{TOT} exceeds the tensile strength of the concrete. After new cracks have developed, the external load will be moved to a new position, the mid-point between the newly developed crack and an adjacent crack. This process continues until equilibrium is established.

The inclusion of wheel-load stress in the CRCP-2 computer program is briefly summarized in the flow diagram in Fig 2.7.

The tensile stress due to the external load will be solved in the CRCP-2 computer program, using Westergaard's equation for interior loading. The user may choose, however, to solve the wheel-load stress by some other means. An option is available in the program in which either the wheel load in pounds or the wheel load stress in pound per square inch can be inputted.



(a) Side view of CRCP geometric model.

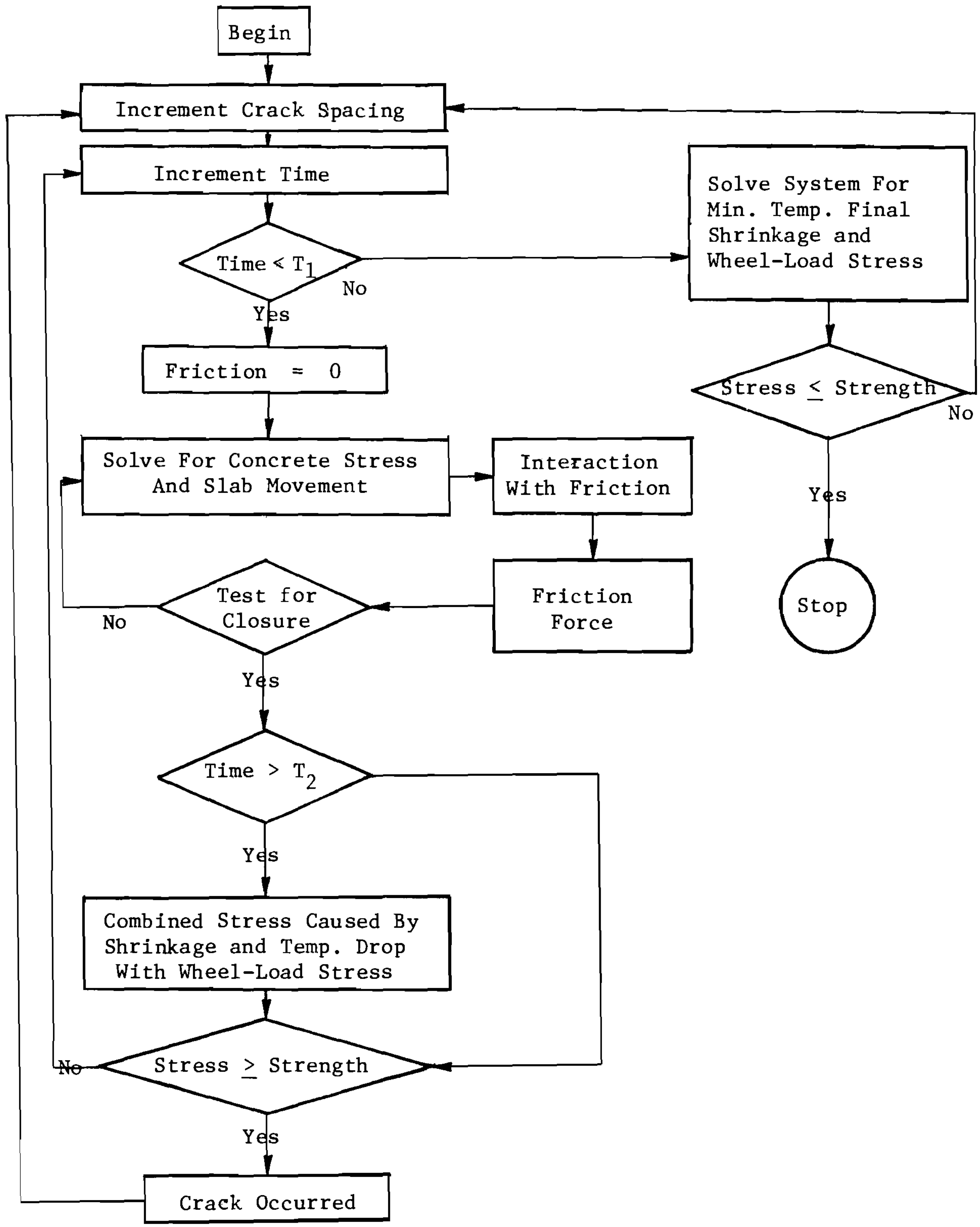


(b) Tensile stress of concrete at mid-slab due to temp. drop and shrinkage.

(c) Stress of concrete under wheel load.

(d) Combined shrinkage, temperature and wheel-load stress.

Fig 2.6. Stress diagram of concrete at the center of the slab due to wheel loads and volume changes.



T_1 = Time for concrete to gain full strength.

T_2 = Time when wheel load is applied.

Fig 2.7. Flow diagram for CRCP-2.

STRESS IN SLAB DUE TO WHEEL LOAD

Steel reinforcement in continuous pavements is not designed to carry tensile stress at the bottom when wheel load is applied. In fact, most steel bars in the existing rigid pavements are placed at the mid-depth of the slab to keep cracks tightly closed so that the time for the water to seep through is greater than the surface runoff time, thus preventing passage of water from the surface to the subgrade. When steel bars are placed at the neutral surface or mid-depth, the compression on the top fibre and the tension on the bottom fibre of a reinforced slab will be the same as for the nonreinforced slab. Several methods available for the analysis of a concrete slab under wheel load are discussed in the following sections.

Westergaard Interior Equation

The Westergaard equation for interior loading may be used here to predict the tensile stress at the bottom fibre of the slab (Ref 2). The resistance to deformation of the slab under wheel load depends upon the relative stiffness of the supporting media and the slab; the stiffer the slab and the weaker the subgrade, the greater is the stress. Westergaard defined the relative properties of these two materials as radius of relative stiffness, in which

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

where

E_c = modulus of elasticity of the concrete slab (lb/in^2),
D = thickness of the slab (inches),
μ = Poissons ratio, and
k = modulus of subgrade reaction ($lb/in^2/in$);

and tensile stress at the bottom of the slab for interior loading, in which

$$\sigma_i = 0.3162 \frac{P}{D^2} [\log_{10}(D^3) - 4 \log_{10} a - \log_{10} k + 6.478]$$

where

a = radius of the tire contact area (inches) and
P = applied load (pounds).

If the assumption is made that plane cross-sections remain plane and perpendicular to the neutral surface during loading, the theory of elasticity leads to the conclusion that the peak moment and, thus, the peak tensile stress at the bottom of the slab, are infinite. However, if we take into account the deformation due to local stress in the immediate neighborhood of a concentrated load, the above assumption cannot be made and the tensile stress at the bottom fibre of the slab will be rounded off. Computation according to Nadai's analysis (Ref 9), shows that the stress can be found using the special theory which considers local stress at the point of loading if the radius, a , of the above equation is replaced by an equivalent radius, b , in which

$$b = \sqrt{1.6a^2 + D^2} - 0.675D \quad \text{for } a \leq 1.724D$$

and

$$b = a \quad \text{for } a \geq 1.724D$$

The tensile stress at the bottom for interior loading when a is less than 1.724D becomes

$$\sigma_i = 0.3162 \frac{P}{D^2} [\log_{10} (D^3) - 4 \log_{10} (\sqrt{1.6a^2 + D^2} - 0.675D) - \log_{10} k + 6.478]$$

Discrete Element

Several computer programs were developed to solve the wheel-load stress of the slab. The discrete-element method developed by Hudson and Matlock is a very powerful analytical tool for prediction of stresses in concrete slab (Refs 4 and 11). This method was based on the biharmonic equation (Ref 12), which states that the fourth order differential of deflection times the stiffness is equal to the load applied. This fourth order differential was solved by the central-differential approximation in which the differential of deflection is the change of deflection between adjacent stations divided by the distance between those stations. To obtain the stiffness of the system, the slab was replaced by x-bars and y-bars to simulate bending stiffness, torsional bars to simulate torsional stiffnesses, and elastic joints to connect the whole system together. Due to the large number of simultaneous equations that relate the relative forces which acted on each element, a direct matrix manipulation technique (Ref 10) was employed to obtain the deflection at each joint.

Two approaches are recommenced to compute the wheel-load stress for the CRCP-2 computer program. First, to solve the wheel-load stress internally using Westergaard's equation for interior loading, the user needs only to input the magnitude of the wheel load, in pounds, wheel base radius, and modulus of subgrade. The selection of Westergaard's equation was made for the following reasons: (1) it is easy to apply, the solution obtained will be the tensile stress directly under the wheel load, (2) the computational time required is minimal, and (3) it is the most reliable closed form solution available. Tests were run on concrete slabs in the laboratory, and it was concluded that the values derived from Westergaard's theoretical formula correlate closely with the actual test values (Refs 15 and 16).

The second approach is to solve the wheel-load stress externally and input the maximum concrete tensile stress obtained into the CRCP-2 program. For edge loads, the tensile stress can be obtained using Westergaard's equation for edge loadings. For pavements that have nonuniform slab thicknesses or nonuniform soil supports, the tensile stress under wheel load can be solved by the discrete element method. This open form solution allows us to consider voids underneath the pavement. Also, cracks can be modeled by reducing bending stiffness along the crack (Ref 13). To use this method, it is necessary to investigate the load transfer between cracks, which includes (1) aggregate interlock, (2) shear resistance by steel reinforcement, and (3) moment transfer if the crack width is small enough for the slab on each side to make contact. Concepts for modeling the load transfer at the crack are still being developed and it is recommended they be considered for future studies (Chapter 6).

Note that neither approach mentioned above considered the fatigue of the concrete slab due to repetitive loadings. A safety factor is needed in these approaches when they are used for design.

EFFECT OF EXTERNAL LOAD

A series of problems with input parameters, listed in Table 2.1, was solved using the CRCP-2 program to investigate the combined effect of both the external and the internal forces on the performance of continuously reinforced concrete pavement. A series was developed to study the effect of wheel load stress on the crack spacings of a CRC pavement. The results are plotted in Fig 2.8. In the B series, the effects of wheel-load stress on crack width, crack spacing, and steel and concrete stress are examined and illustrated in Fig 2.9. With different steel percentages, the C series allows for individual examination of the crack spacing, the crack width, and the steel and the concrete stresses, with and without wheel-load stress. The results are plotted in Figs 2.10 to 2.13. The D series shows the effect of wheel load applied on slab with different thicknesses. The E series gives an indication of the effect of wheel load on CRC pavement applied at various ages after the placement of the slab.

Figure 2.8 shows the change of crack spacing with time for four different magnitudes of external loads. The loads were applied on the 28th day, and there is no effect on the behavior of the pavement before that time. The addition of bending stress in the slab under external load to the existing internal force from restrained pavement volume changes leads to higher tensile stress and cause new cracks to form. As shown in the figure, the final crack spacing decreases as the magnitude of the external load increases. The decrease in the final crack spacing will cause other variables in a CRC pavement to change, as is illustrated in the following problem series.

Figure 2.9 is a composite figure to show the effect of wheel-load stress on the behavior of various variables in a CRC pavement. As shown in the figure, the final crack spacing decreases when heavier external loads were applied. The reduction in crack spacing lessens the amount of frictional resistance between the slab and the subgrade because the contact area is reduced. Subsequently, the crack width and the forces transmitted to the

TABLE 2.1. INPUT PARAMETERS FOR TESTING THE COMBINED EFFECT OF EXTERNAL LOAD AND ENVIRONMENTAL STRESSES

	Problem Series																								
	1A	2A	3A	4A	1B	2B	3B	4B	5B	6B	1C	2C	3C	4C	5C	6C	7C	8C	1D	2D	3D	4D	1E	2E	3E
Steel Properties																									
P (percent)	1.0				0.5						0.5	0.7	0.9	1.2	0.5	0.7	0.9	1.2	0.7				1.0		
ϕ (in)	0.5				0.6						0.6								0.6				0.5		
$fy \times 10^4$ (psi)	6.0				6.0						6.0								6.0				6.0		
$E_s \times 10^7$ (psi)	2.9				2.9						2.9								2.9				2.9		
$\alpha_c \times 10^{-6}$ (in/in/°F)	5.0				5.0						5.0								5.0				5.0		
Concrete Properties																									
D (in)	10.0				10.0						10.0								6.0	8.0	10.0	12.0	10.0		
$\alpha_c \times 10^{-6}$ (in/in/°F)	5.0				5.0						5.0								5.0				5.0		
$Z \times 10^{-4}$ (in/in)	4.0				4.0						4.0								4.0				4.0		
$\gamma \times 10^2$ (pcf)	1.5				1.5						1.5								1.5				1.5		
$f'_c \times 10^3$ (psi)	6.0				6.0						6.0								5.0				6.0		
Temperature Data																									
Curing Temp (°F)	75.0°				75.0°						75.0°								70.0°				75.0°		
Minimum 1st - 10th	65.0°				50.0°						50.0°								65.0°				65.0°		
Daily 11th - 16th	50.0°				50.0°						50.0°								65.0°				65.0°		
Temp (°F) 17th - 28th	50.0°				50.0°						50.0°								55.0°				65.0°		
Minimum Temp (°F)	40.0°				40.0°						40.0°								30.0°				40.0°		
COLDTM (Days)	90.0				90.0						90.0°								90.0				90.0		
Friction																									
Fi (psi)	1.0				1.0						1.0								1.0				1.0		
Y (in)	-0.1				-0.1						-0.1								-0.1				-0.1		
External Load																									
Wheel Load $\times 10^3$ (lbs)	*	*	*	*	*	*	*	*	*	*	0	0	0	0	*	*	*	*	9.0	9.0	9.0	9.0	*	*	*
Wheel Load Stress (psi)	0	50	150	200	0	50	100	150	200	250	0	0	0	0	100	100	100	100	287.6	179.2	121.9	88.01	200	200	200
Time Applied (Days)		28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	7	15	28

*Option of inputting stress due to wheel load used.

1 inch = 2.54 cm

1 psi = .070454 kg/cm^2

1 pcf = .00001605 kg/cm^3

1°F = (9/5) × °C + 32°

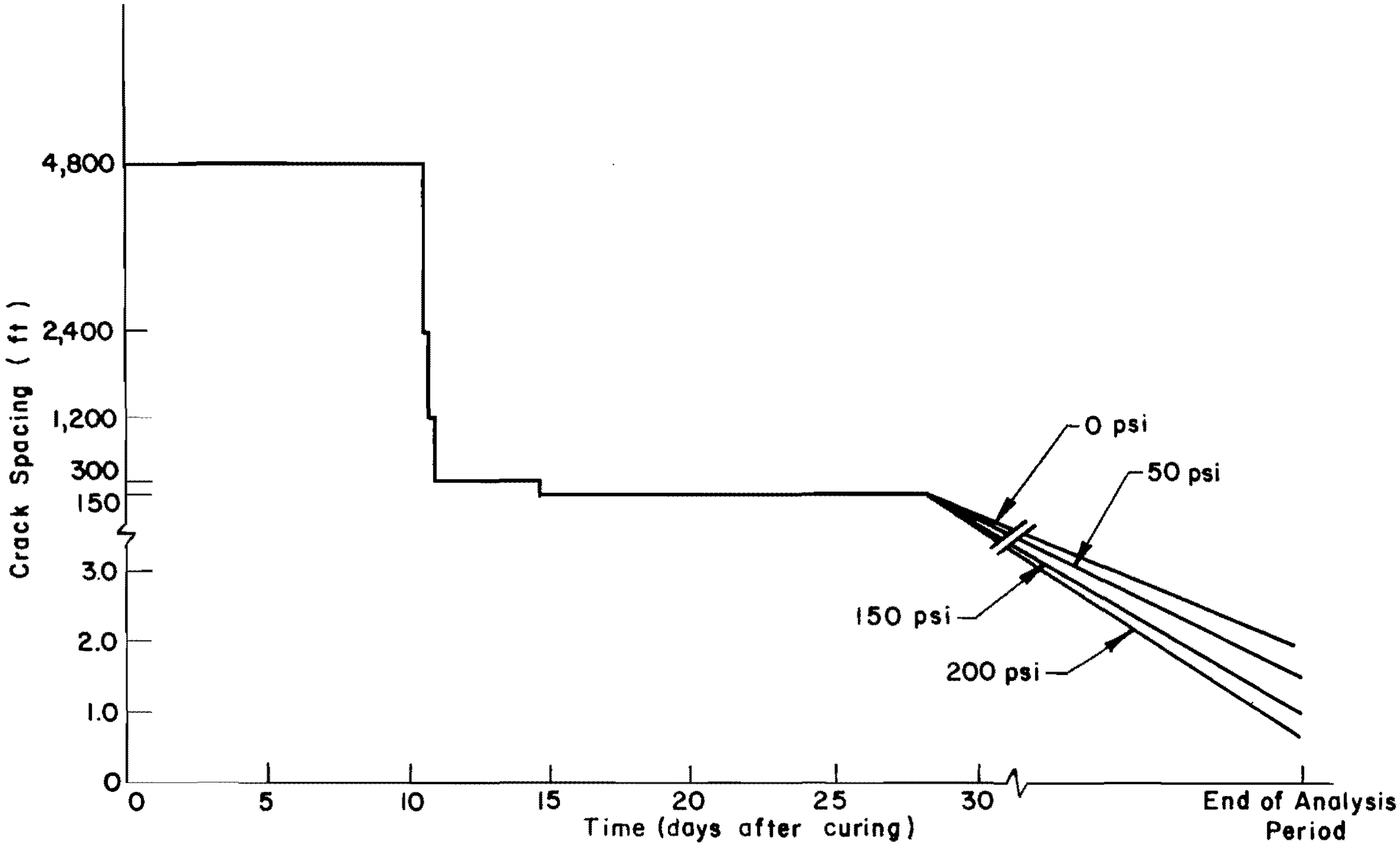


Fig 2.8. A-Series crack spacing under different wheel load stresses applied on 28th day versus time solved by CRCP-2 program.

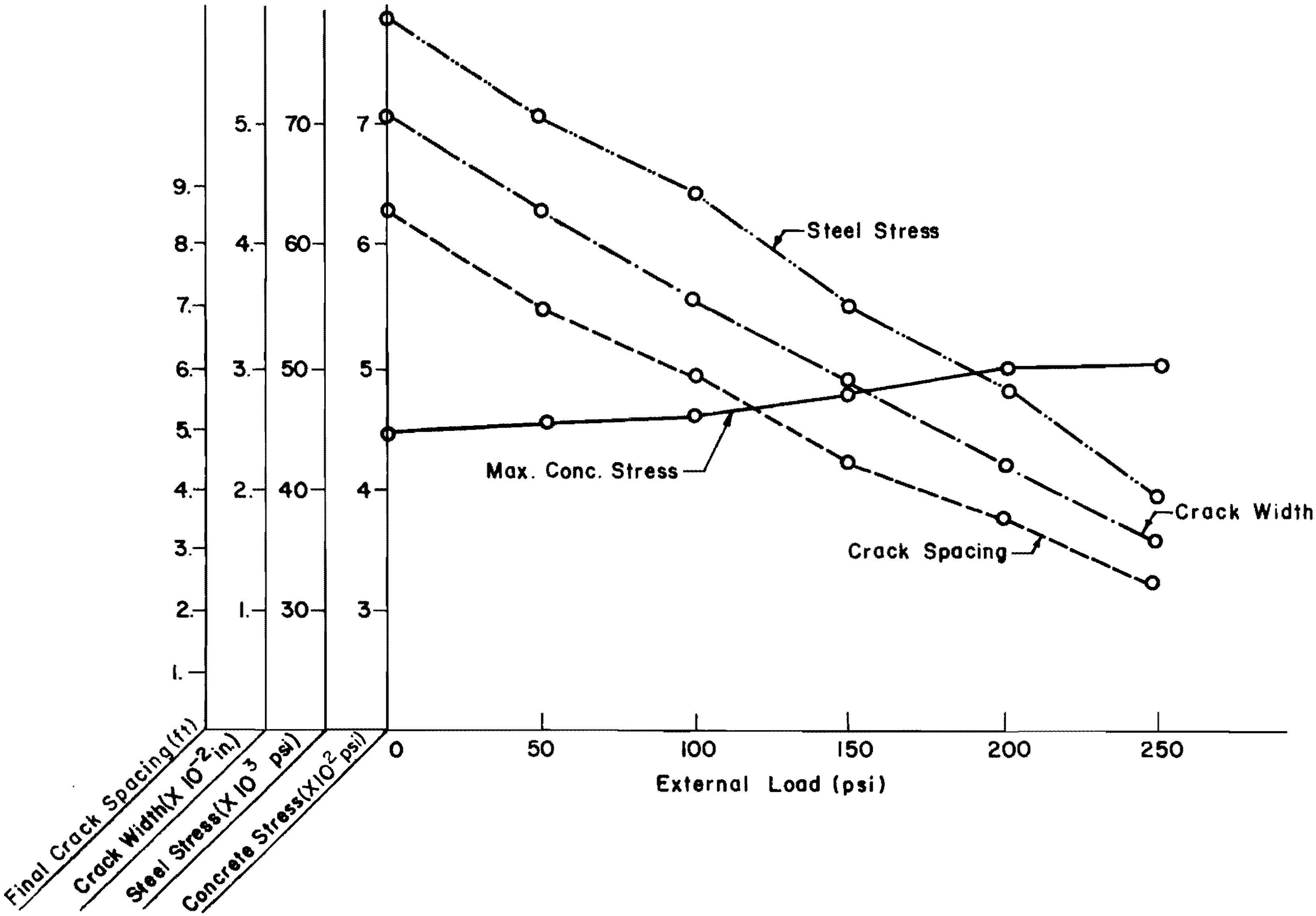


Fig 2.9. B-Series external load versus crack spacing, crack width, steel stress and maximum concrete stress at the end of analysis period, solved by CRCP-2 program.

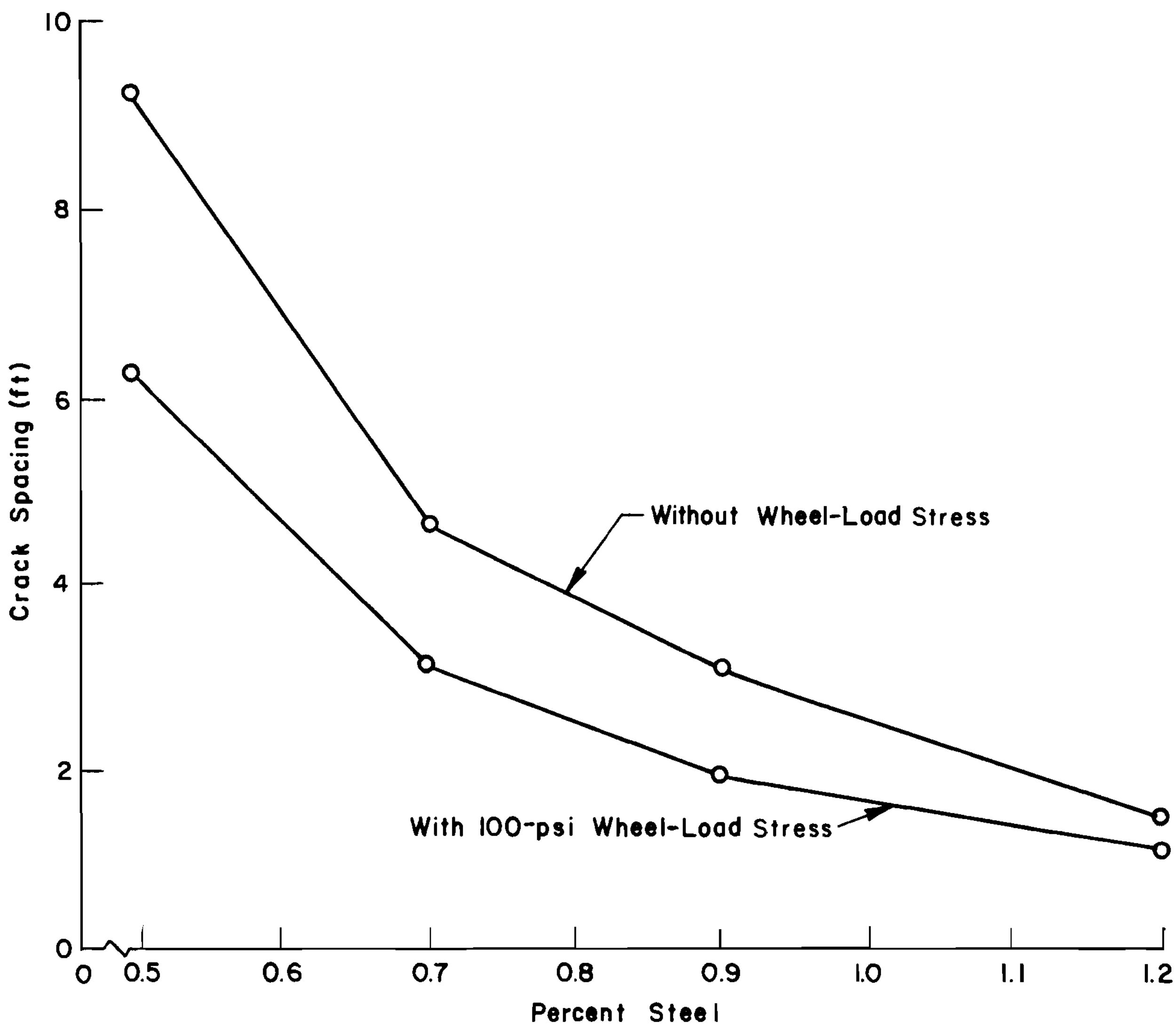


Fig 2.10. C-Series percent steel versus final crack spacing with and without external load solved by CRCP-2 program.

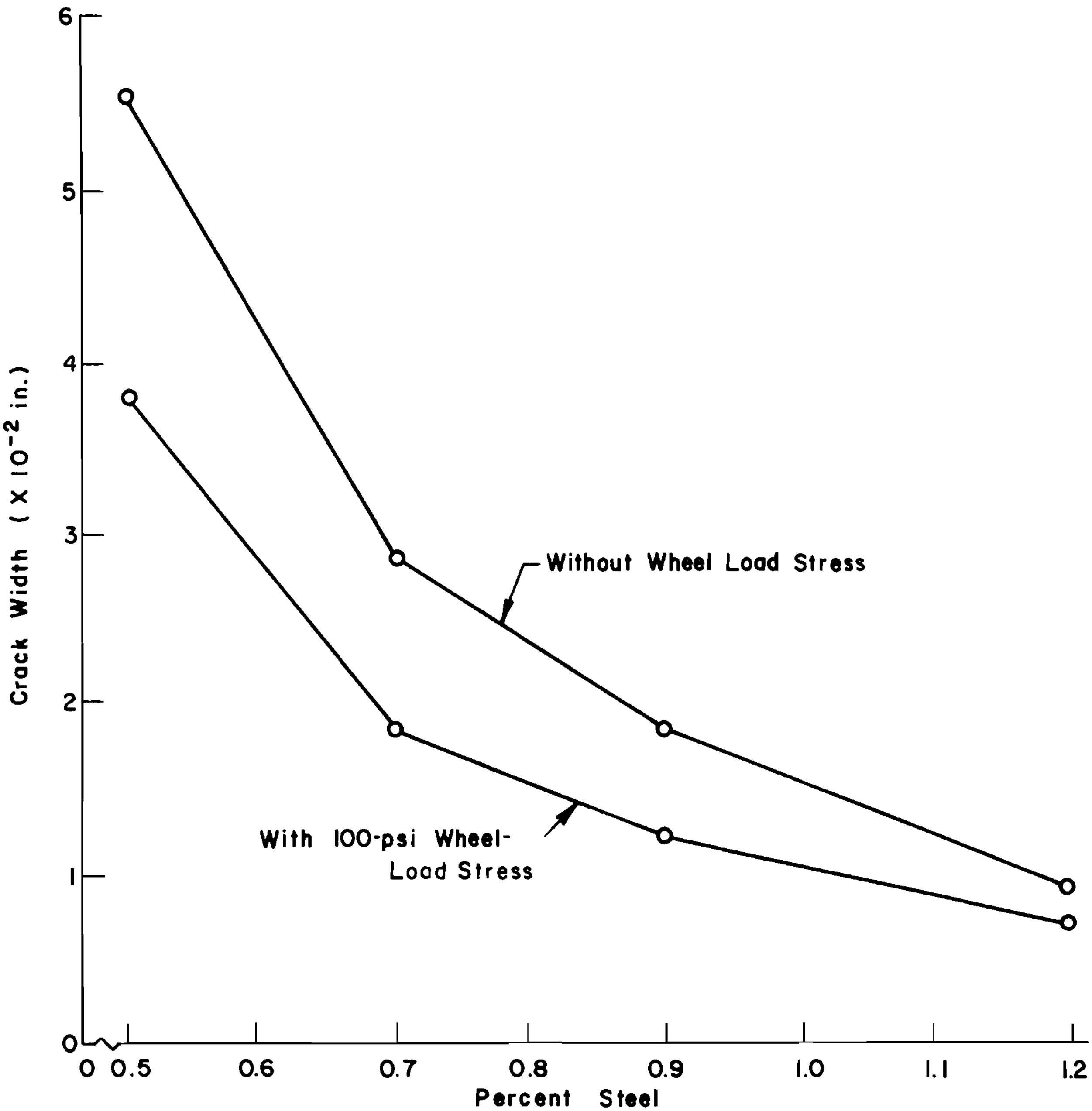


Fig 2.11. C-Series percent steel versus final crack width with and without external load solved by CRCP-2 program.

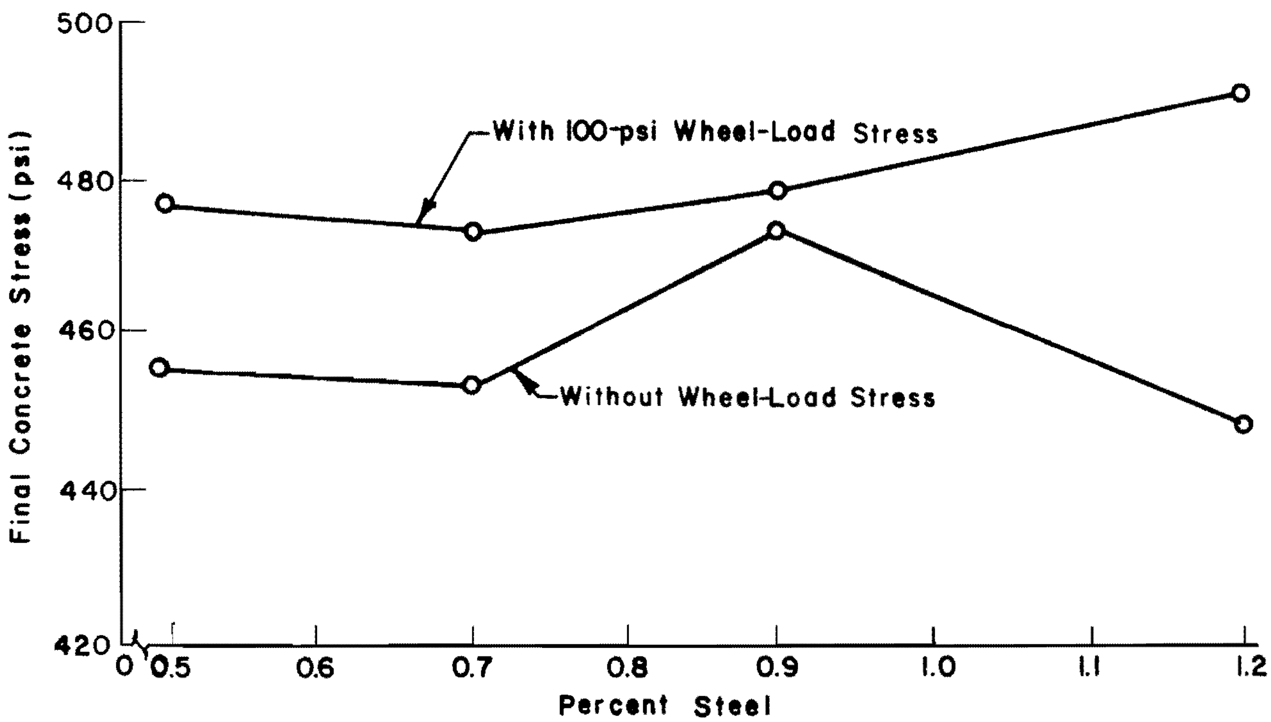


Fig 2.12. C-Series percent steel versus final concrete stress with and without external load solved by CRCP-2 program.

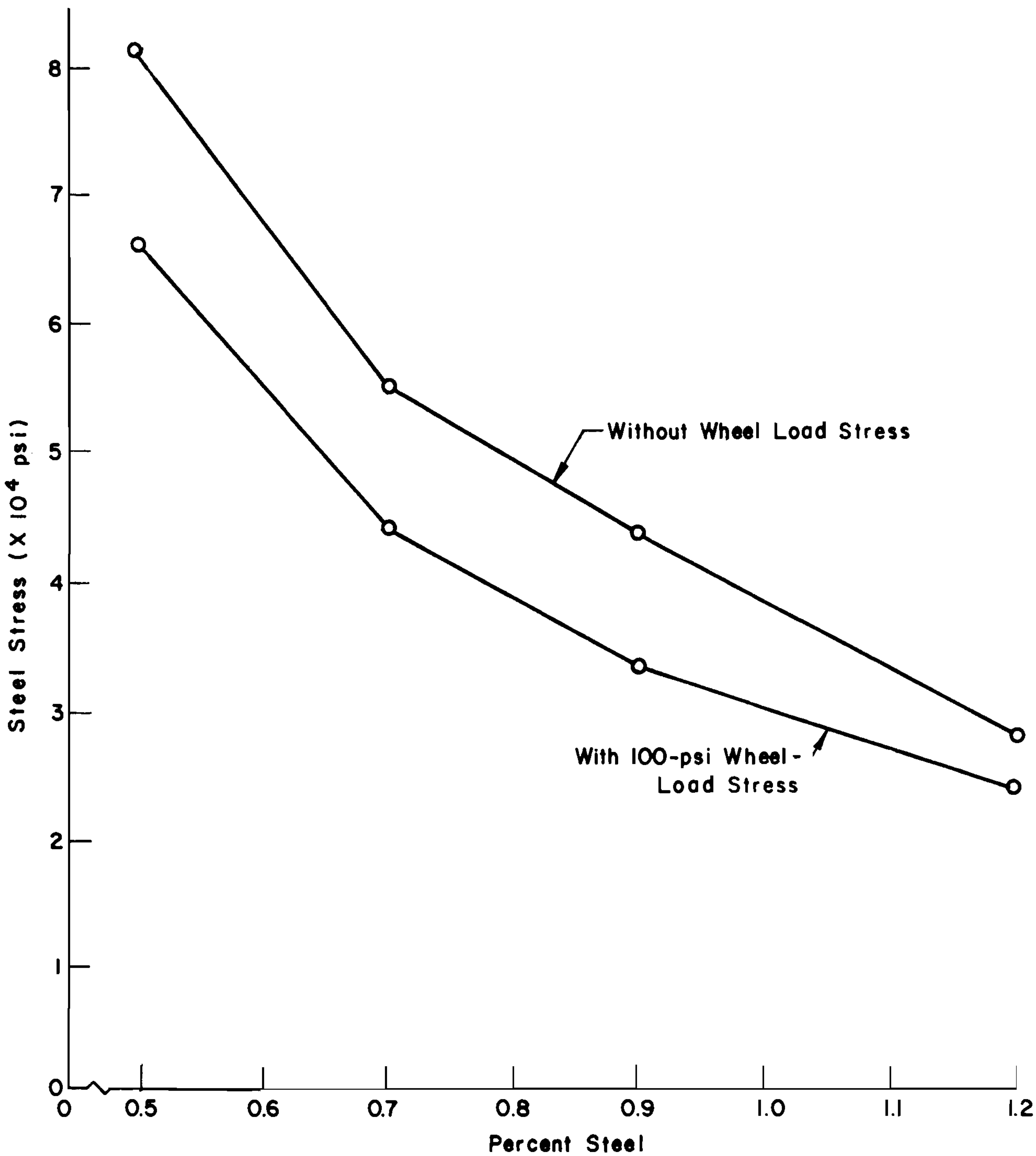


Fig 2.13. C-Series percent steel versus final steel stress with and without external load solved by CRCP-2 program.

steel from the reduced restraint also decrease. The final concrete stress is more or less a straight line for different magnitudes of external loads. This phenomenon will be disucssed further later on.

Results from this problem series show that the addition of external load reduces both the steel stress and the crack width in CRC pavement by forcing more cracks to develop. The reduction of these two variables can be favorable for the design as long as the crack spacing is maintained at an acceptable level.

The steel reinforcement in a continuously reinforced concrete pavmeent does not prevent cracking. On the contrary, it induces cracks because the volume change in the concrete is restrained by the steel bars and because of the subgrade friction. However, steel in the slab also keeps the cracks tightly closed. In Fig 2.10, increase in steel percentages in the slab was associated with decrease in crack spacing and with even smaller crack spacing when external load was applied. The reduction of crack spacing in turn caused the crack width and the steel stress to decrease, as shown in Fig 2.11 and 2.13.

The final concrete stresses plotted in Fig 2.12 do not show a trend. Increase in steel percentage caused the concrete stress to increase and then decrease. The difference in concrete stress between the slab that had wheel load applied to it and the slab without wheel load is large at one point and small at the other. This shows that the concrete stress does not depend solely on the steel percentage or the magnitude of wheel load. The final concrete stress is primarily controlled by the final state of stress in the slab and the crack spacing that the CRC pavement eventually stabilized with. If, for instance, before any external load is applied the internal forces caused by drying shrinkage and temperature drop alone have created enough tension in the slab for the concrete to be on the point of breaking, the addition of external load will result in an even larger tensiie stress in the concrete and cause new cracks to form. On the other hand, as new cracks develop, the crack spacing will be one half the length as before, which relieves some of the internal tensile stress present when the crack spacing was larger. The final concrete stress, therefore, may actually be the same as before any external load was applied.

The effect of slab thickness on the performance of CRC pavement under 9000-pound (4091-kg) wheel load is plotted in Fig 2.14. Since a greater slab thickness is accompanied by an increase in the slab's cross-sectional area the concrete stress per unit area due to external load decreases as slab thickness increases. For the external loads, the increase in slab thickness increases the stiffness of the slab, thus reducing the bending stress in the concrete. Consequently, in order to achieve equilibrium, the net reduction of concrete stress permits the crack spacing to be kept greater for thicker slabs. The increase in crack spacing causes both the steel stress and the crack width to increase, as shown in Fig 2.14.

The results of an application of external loads at various ages after the placement of the slab are plotted in Fig 2.15; note that cracks start to develop immediately when 200 psi of external load is applied. The final crack spacings however are not affected by the time of load application.

The input data for the above analysis are shown in Appendix 3.

SUMMARY

A series of problems are solved using CRCP-2 to test the effect of wheel load on continuously reinforced concrete pavement. Either the wheel loads are input in pounds and the stresses solved by Westergaard's equation within the program or the wheel-load stress is solved externally and input directly into the program.

The results from this study show that

(1) Increase in wheel-load stress will reduce crack width, crack spacing, and steel stress.

(2) Increase in steel percentage will reduce crack width, crack spacing, and steel stress with or without wheel-load stress.

(3) An increase in slab thickness will increase the crack width, the crack spacing, and the steel stress. This shows that the design for the slab thickness and the steel reinforcement as indicated in (2) counteract with each other, therefore must be balanced properly to ensure that the limiting criterias for the crack width, the crack spacing and the steel stress are satisfied.

(4) Cracks developed earlier when wheel loads were applied earlier, but developed into the same crack spacing at the end of the analytical period regardless to the time when the load was applied.

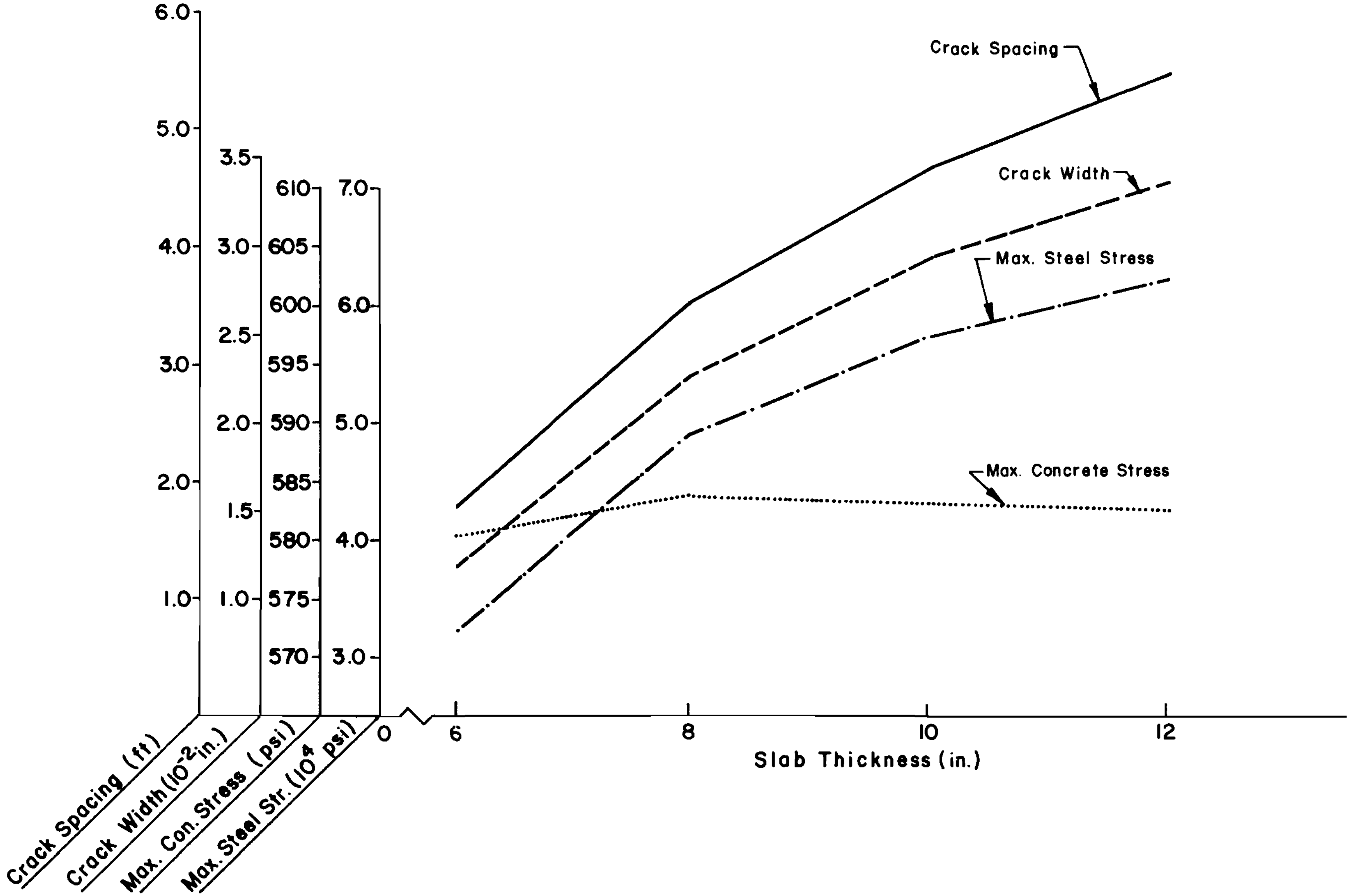


Fig 2.14. D-Series thickness of a slab under 4091 kg. external load versus crack spacing, crack width, steel stress and maximum concrete stress at the end of analysis period.

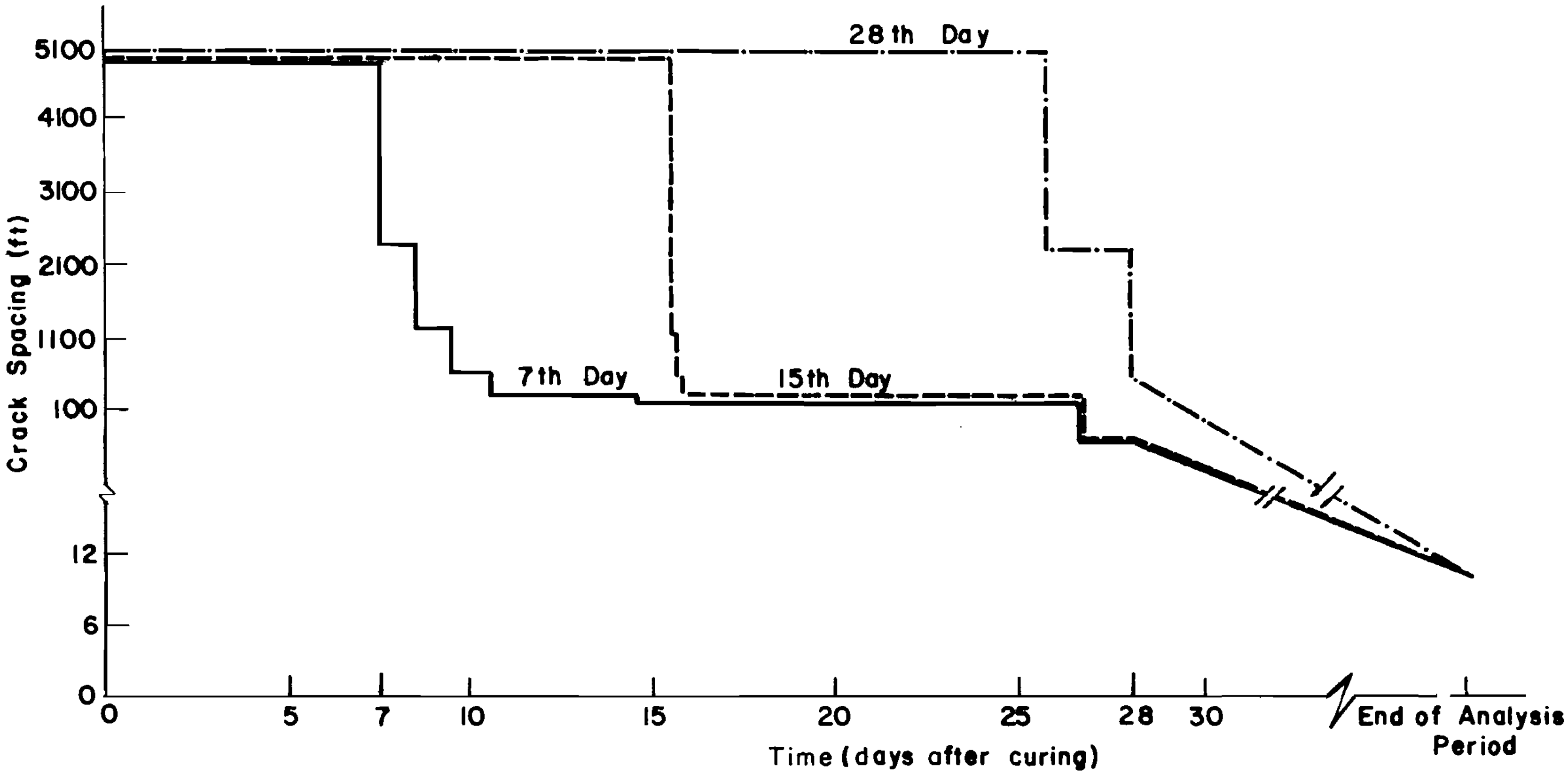


Fig 2.15. E-Series time of external load application solved by CRCP-2 program.

CHAPTER 3. AGE, STRENGTH-STRESS INTERACTION

BACKGROUND

The rate at which concrete gains strength depends on many factors, such as

(1) the concrete materials, the type of cement, and the size of aggregates,

(2) the proportions mix, the water/cement ratio, and the gel/space ratio, and

(3) the curing time, the temperature, and so on.

All these factors affect the time required for the concrete slab to develop adequate strength. In the past, the 28th day strength was used as a standard measure for the strength of concrete, although the 28th day strength is considerably lower than the long-term strength. This gain in strength after the 28th day was used by structural designers as an extra contribution to the safety factor.

In pavement design, the safety factor required is minimal because failure in pavement is not really a failure but a distress limit, such as Serviceability Index (SI), which poses no real danger to the safety of the users. Also, the fact that the maximum internal stress occurs when temperature drop is highest means that the ultimate strength of the slab, therefore, should be measured when the temperature is the lowest and not necessarily on the 28th day.

In the model in Ref 5, an interactive process was used to compare stress caused by shrinkage and daily temperature drop with the tensile strength of the slab at each time interval. Use of the strength-stress interaction model in CRCP-1 is illustrated by Fig 3.1a. The solid line in the figure represents the age-strength curve of the concrete, the dash line represents the concrete stress in the slab, and points 1 to 7 represent the steps in the interactive process. At point 1, the stress is higher than the strength, which causes cracks to form. The reduction of crack spacing relieve some of the internal forces in the slab and causes the concrete stress to drop to point 2. A further decrease in temperature or a higher shrinkage factor causes the

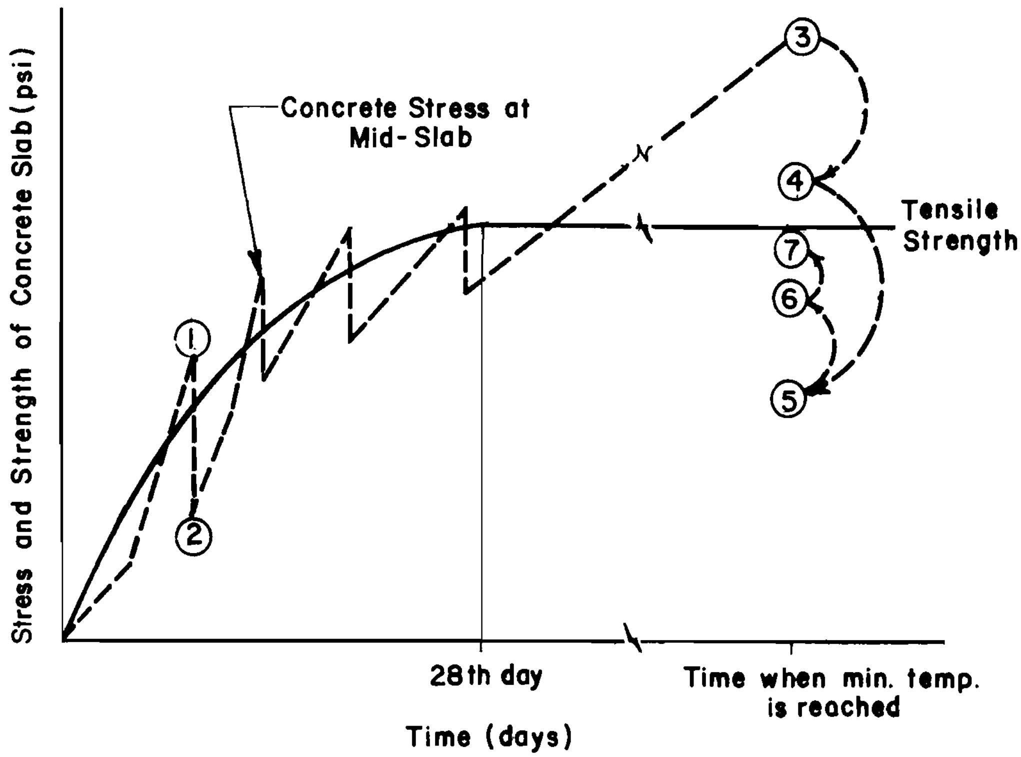


Fig 3.1a. Variation of concrete strength and maximum concrete stress with time in the CRCP-1 model.

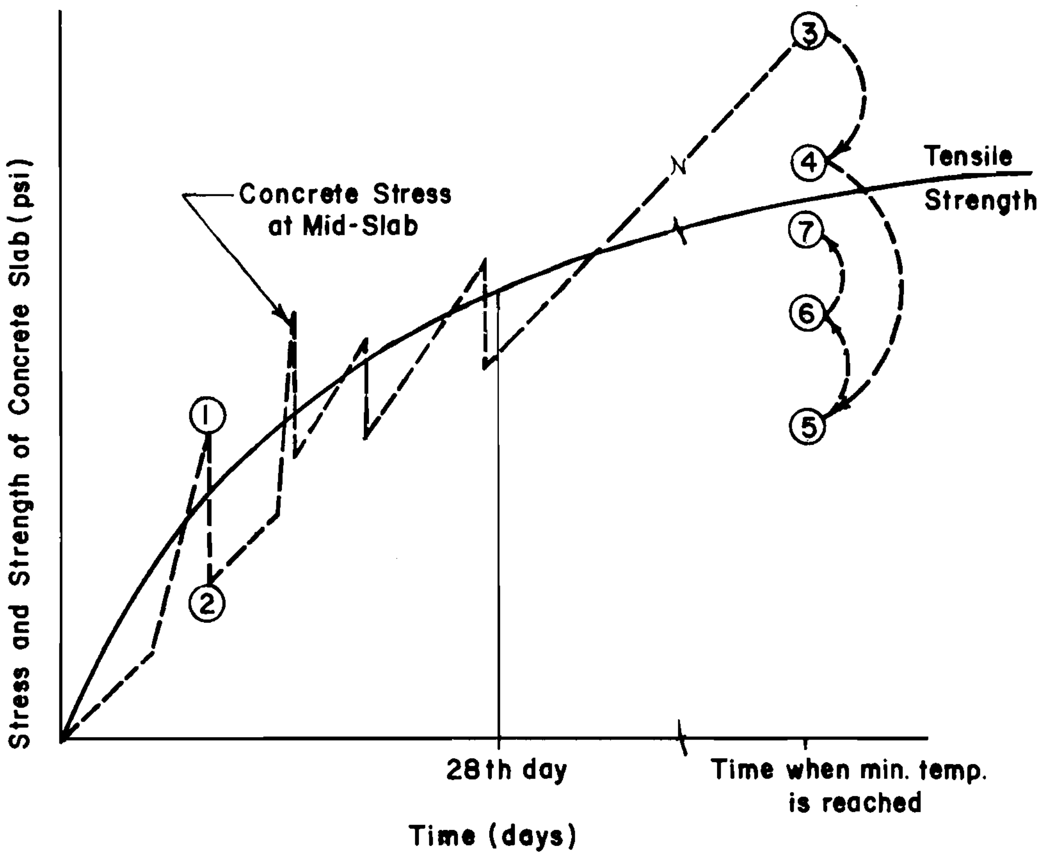


Fig 3.1b. Variation of concrete strength and maximum concrete stress with time accounting for the increase in strength after the 28th day in the CRCP-2 model.

concrete stress to increase again, which forces other cracks to develop. This interactive process continues until the concrete reaches the 28th-day strength. From then on, the strength of the concrete no longer increases with time and this is treated as the ultimate strength of the slab. The maximum concrete stress generated by the maximum temperature drop and maximum shrinkage factor is represented by point 3 in the figure. Since the stress is higher than the strength, the crack spacing is further reduced, which causes the concrete stress to drop to point 4 and then point 5, until the stress is insufficient to induce another crack. The final crack spacing is then adjusted higher or lower until the stress in the concrete is within the limit of tolerance, with the strength at point 7.

Comparing the maximum concrete stress in the CRCP-1 model to the 28th-day strength may be underestimating the actual strength in the concrete at that time. This underestimation, however, does not provide any safety factor in the design. On the contrary, the lower crack spacing predicted from this underestimation may mislead the designer into decreasing the steel reinforcement in the slab in seeking for an optimum crack spacing and crack width.

INCREASE IN STRENGTH AFTER 28TH DAY

Figure 3.1b shows the strength-stress interaction model in CRCP-2 program. This model projects the strength gain in the concrete beyond the 28th day. The age-strength curve represented by the solid line shows a further increase in concrete strength after the 28th-day strength. The initial steps in the strength-stress interaction in CRCP-2 are identical to the original model. However, after the 28th day, the maximum concrete stress at point 3 is compared to the strength of the concrete at the time minimum temperature occurs and not with the 28th-day strength. Since the stress at point 3 is higher than the strength, cracks will develop and the stress will drop to point 4 and then point 5. Once the concrete stress falls below the strength, the crack spacing is adjusted until the final concrete stress matches the ultimate concrete strength at the point 7. This higher tensile strength is now generated by the computer program, which is based on the age-strength curve from Ref 14. The equations used to predict the increase in tensile strength after 28th day are as follows:

compressive strength, f'_c

$$f'_{c_x} = f'_{c_{28th\ day}} \left[1 + 0.1972 \log\left(\frac{x}{28}\right)\right] \text{psi} \tag{3.1}$$

tensile strength, f'_t

$$f'_{t_x} = \frac{3000}{3 + \frac{12000}{f'_{cx}}} \text{ X constant psi} \tag{3.2}$$

where

x = number of days from the time the pavement was built to the time the minimum temperature was reached.

An option is provided in the computer program in which users can input the strength at the time of the minimum temperature drop. For users who specify neither the time nor the ultimate strength the program defaults to a 28-day concrete strength.

EFFECTS DUE TO THE STRENGTH INCREASE

A series of test problems, for which the input parameters are listed in Table 3.1, have been solved with the CRCP-2 program. By allowing various time periods for the concrete strength to build up before applying the minimum temperature, different final crack spacings are found. As shown in Fig 3.2, the final crack spacing increases with an increase of time before the occurrence of the minimum temperature. The solid line in the figure represents the final tensile strength in the concrete. The higher tensile strength sets a higher limit for the concrete stress to reach before cracks can be developed, which inturn increase the crack width and the steel stress in the slab, as shown in the figure.

The input data for the above analysis are printed in Appendix 3.

SUMMARY

A new strength-stress interaction model in the CRCP-2 program has replaced the original model in the CRCP-1 program to account for the concrete strength gain beyond the 28th day. If the lowest temperature is to occur after

TABLE 3.1. INPUT PARAMETERS FOR TESTING THE NEW STRENGTH-STRESS INTERACTION MODEL.

	1F	2F	3F	4F	5F
Steel Properties					
P (percent)			0.5		
ϕ (in)			0.6		
fy x 10^4 (psi)			6.0		
E_s x 10^7 (psi)			2.9		
α_c x 10^{-6} (in/in/°F)			5.0		
Concrete Properties					
D (in)			10.0		
α_c x 10^{-6} (in/in/°F)			5.0		
Z x 10^{-4} (in/in)			4.0		
γ x 10^2 (pcf)			1.5		
f'_c x 10^3 (psi)			6.0		
Temperature Data					
Curing Temp (°F)			75.0°		
Minimum 1st - 10th			65.0°		
Daily 11th - 16th			65.0°		
Temp (°F) 17th - 28th			50.0°		
Minimum Temp (°F)			0.0°		
COLDTM (Days)	28.0	60.0	90.0	120	150
Friction					
Fi (psi)			2.0		
Y (in)			-0.1		
External Load					
Wheel Load x 10^3 (lbs)			0		
Wheel Load Stress (psi)			0		
Time Applied (Days)			7		

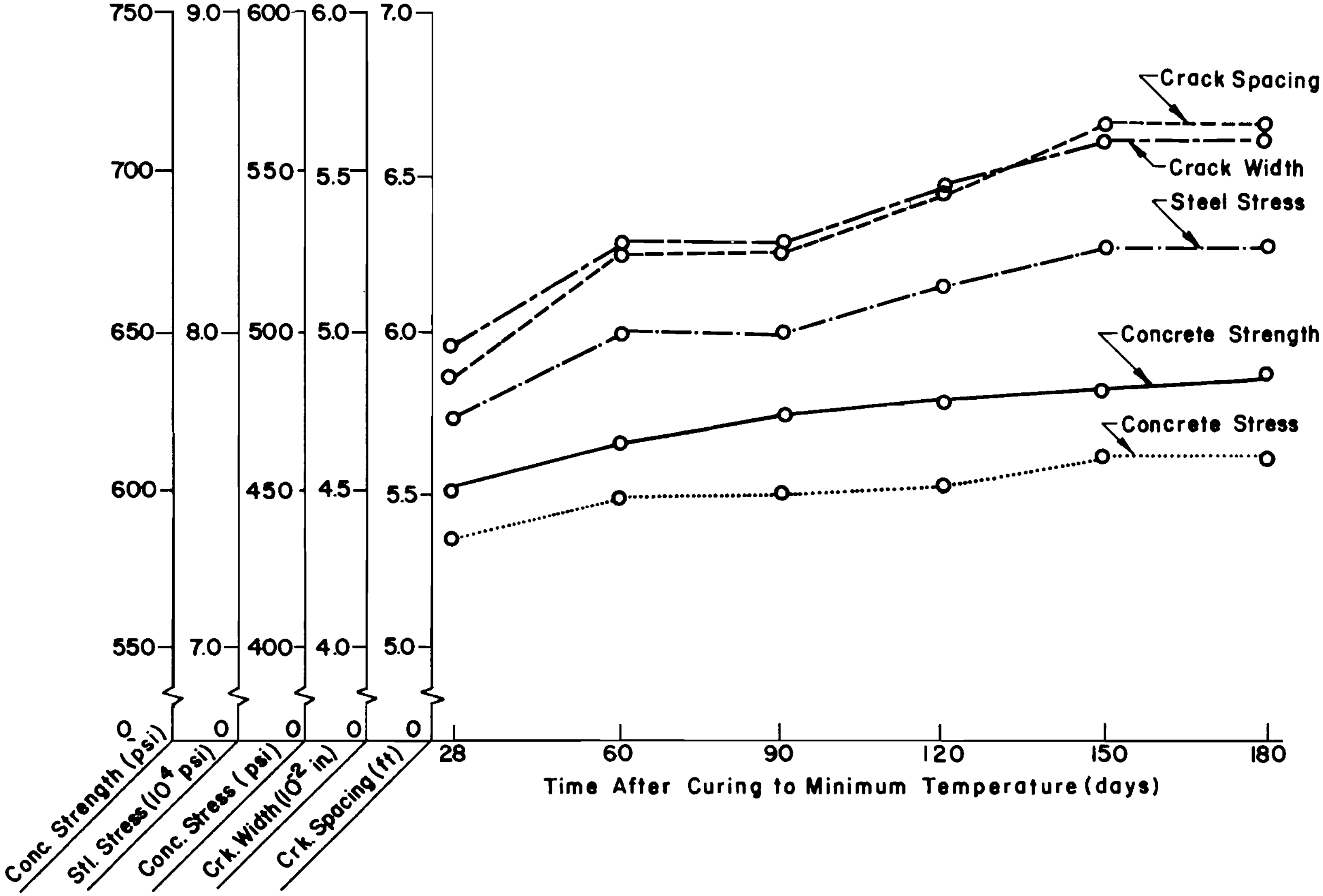


Fig 3.2. Number of days after curing before minimum temperature occurs versus crack spacing, crack width, concrete stress and steel stress.

a prolonged period of time after the pavement was built, it is important to consider the strength gain in the concrete during that time. The results obtained from a test problem solved with the CRCP-2 program indicate that, by considering certain strength gain after the 28th day, a higher crack spacing is predicted. This increase in crack spacing will affect other variables in the CRC pavement and possibly change the percentage steel needed for the design.

CHAPTER 4. MODIFICATION OF STEEL STRESS MODEL FOR DEVELOPMENT LENGTH EXCEEDS CRACK SPACING

BACKGROUND

When high friction values are used in the analysis, the crack spacing may become so small that the distance required for the bond between the steel and its surrounding concrete to fully develop, is greater than the spacing. When this happens, computer program CRCP-1 and the theoretical models are not applicable. To cover such conditions, a new set of equations has been developed and added to the CRCP-1 program. The change in the steel stress model after the development length exceeds half the crack spacing is shown in Fig 4.1.

DERIVATIONS OF BASIC EQUATIONS

For a fully bonded section, the basic equations are similar to the original equations. At the partially bonded zone, the average bond stress will determine the development length as well as the rate of stress transfer from the steel to the concrete. The mechanics of composite materials which lead to the derivation of basic equations are described below.

Interactions Between Steel and Concrete at Fully Bonded Zone

The interactions between steel and concrete caused by drying shrinkage and temperature drop are as follows:

Stress Caused by Shrinkage. As shown in Fig 4.2, the total concrete shrinkage strain, Z , is equal to the summation of the strain in concrete caused by the restraint of the fully bonded steel bar, ε_{cz} , and the strain in steel caused by the shortening of the concrete due to shrinkage, ε_{sz} , or

$$Z = \varepsilon_{cz} + \varepsilon_{sz} .$$

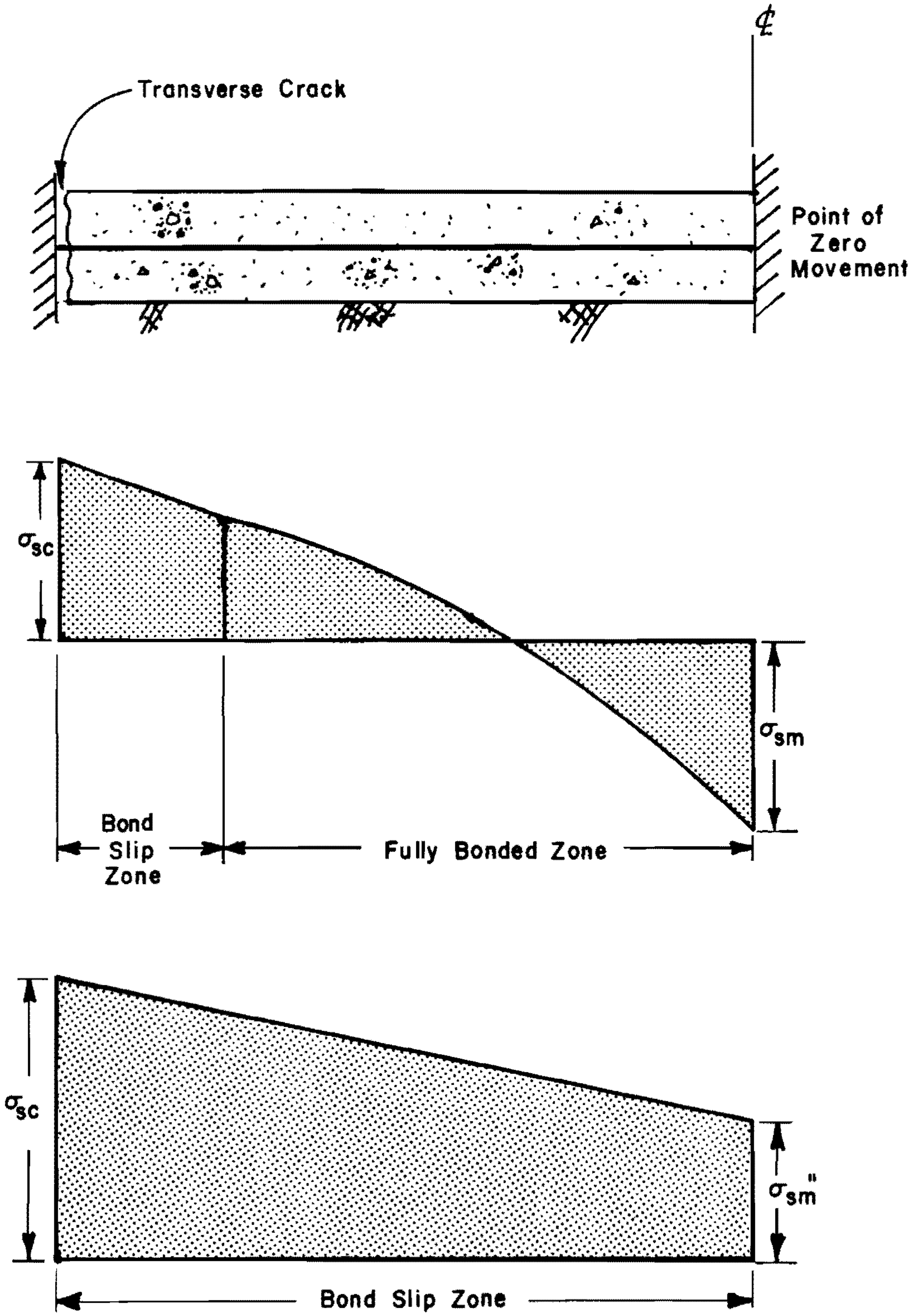
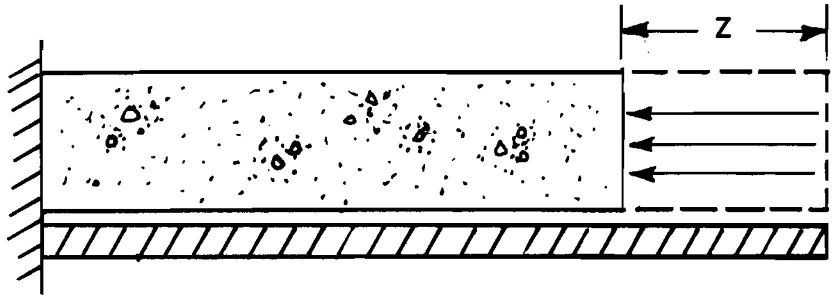
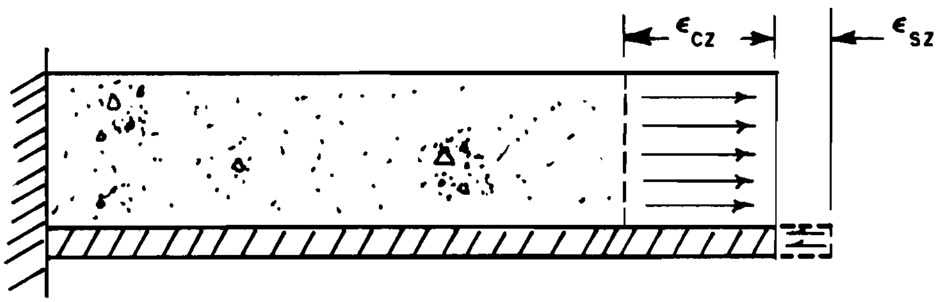


Fig 4.1. Change of steel stress model after development length exceeds half the crack spacing.



(a) Steel and concrete not bonded.



(b) Steel and concrete fully bonded.

Fig 4.2. Behavior of a reinforced slab subjected to shrinkage.

Replacing the above equation with stress and using a negative value to represent compression results in

$$Z = \frac{\sigma_{cz}}{E_c} + \left(-\frac{\sigma_{sz}}{E_s}\right)$$

or

$$\sigma_{cz} = ZE_c + \frac{\sigma_{sz}}{n} \tag{4.1}$$

where

σ_{sz} = steel stress due to shrinkage of concrete at fully bonded section,

σ_{cz} = concrete stress due to restraint of steel at fully bonded section, and

n = E_s/E_c .

<u>Stress Caused by Temperature Drop</u>. From Fig 4.3,

$$\varepsilon_c - \varepsilon_s = \varepsilon_{c\Delta t} + \varepsilon_{s\Delta t}$$

where

ε_c = concrete strain due to temperature drop with no restraint,

ε_s = steel strain due to temperature drop with no restraint,

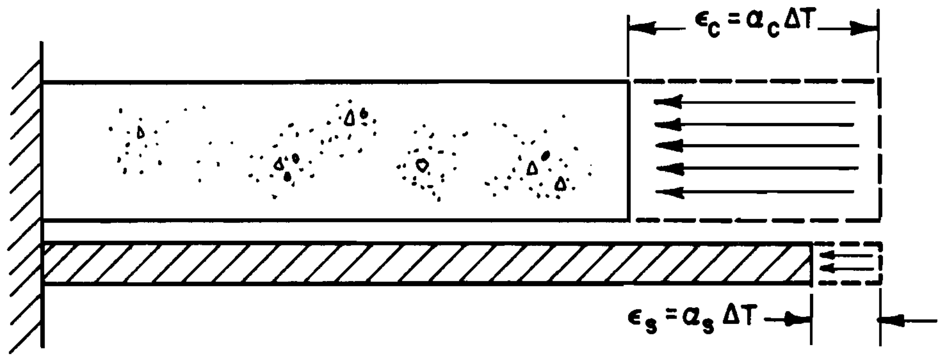
$\varepsilon_{s\Delta t}$ = steel strain caused by shortening of concrete during temperature drop at fully bonded section,

$\varepsilon_{c\Delta t}$ = concrete strain in tension caused by the restraint of steel bars at fully bonded section.

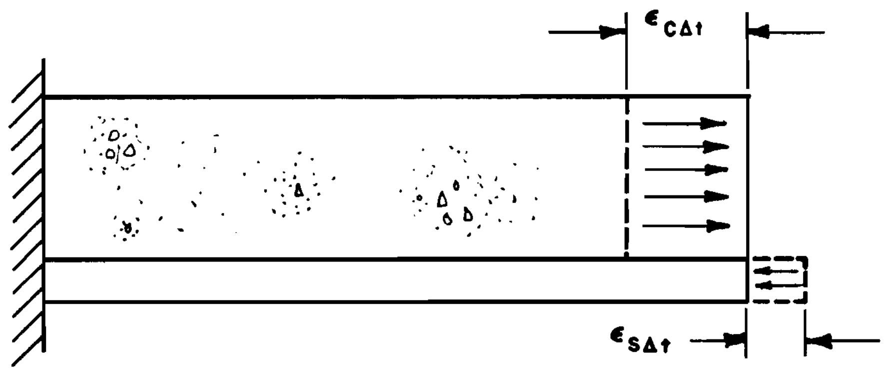
Replacing the above equation with stress and using a negative value for compression gives

$$\alpha_c \Delta T + \alpha_s \Delta T = \frac{\sigma_{c\Delta t}}{E_c} + \left(-\frac{\sigma_{s\Delta t}}{E_s}\right)$$

or



(a) Steel and concrete not bonded.



(b) Steel and concrete fully bonded.

Fig 4.3. Behavior of a reinforced slab subjected to temperature drop.

$$\sigma_{c\Delta t} = E_c \Delta T (\alpha_c - \alpha_s) + \frac{\sigma_{s\Delta t}}{n} \qquad (4.2)$$

where

$\sigma_{c\Delta t}$, $\sigma_{s\Delta t}$ = stresses due to temperature drop at fully bonded section, and

α_s, α_c = thermal coefficients of steel and concrete.

Combining stress due to drying shrinkage and temperature drop. Combining Eqs 4.1 and 4.2,

$$\sigma_{cm} = \sigma_{cz} + \sigma_{c\Delta t}$$

$$= (ZE_c + \frac{\alpha_{sz}}{n}) + \{E_c \Delta T(\alpha_c - \alpha_s) + \frac{\sigma_{s\Delta t}}{n}\}$$

$$= E_c \{Z + \Delta T(\alpha_c - \alpha_s)\} + \frac{1}{n} (\sigma_{sz} + \sigma_{s\Delta t})$$

$$\sigma_{cm} = E_c \{Z + \Delta T(\alpha_c - \alpha_s)\} + \frac{1}{n} (\sigma_{sm}) \qquad (4.3)$$

where

σ_{cm} = total concrete stress due to temperature drop and drying shrinkage at fully bonded region, and

σ_{sm} = total steel stress due to temperture drop and drying shrinkage of concrete at fully bonded region.

Overall Equilibrium

From Fig 2.3, the summation of all forces is

$$F_{sm} + F_{cm} = F_{sc} + \int_o^x F_i dx$$

where

F_{sm} = force of steel at mid-slab,

F_{cm} = force of concrete at mid-slab,

F_{sc} = force of steel at the crack, and
F_i = friction force between slab and support.

Converting the above equation into stresses

$$A_s\sigma_{sm} + A_c\sigma_{cm} = A_s\,\sigma_{sc} + \int_0^x F_i dx$$

$$\sigma_{sc} = \sigma_{sm} + \frac{\sigma_{cm}}{\frac{A_s}{A_c}} - \frac{\int_0^x F_i dx}{A_s}$$

where

A_s = area of steel and
A_c = area of concrete,

and, for a one-foot strip,

$$A_c = D \times 1' = D$$
$$A_s = pA_c = pD$$

where

P = percent reinforcement and
D = thickness of the slab

gives

$$\sigma_{sc} = \sigma_{sm} + \frac{\sigma_{cm}}{p} - \frac{\int_0^x F_i dx}{pD} \quad . \tag{4.4}$$

Movement of the Slab

The total movement of the slab will be the sum of the movement caused by temperature drop plus the movement caused by shrinkage. From Figs 4.2 and 4.3 we have

$$\frac{dY_{cz}}{dx} = \varepsilon_{cz} - Z$$

and

$$\frac{dY_{c\Delta t}}{dx} = \varepsilon_{c\Delta t} - \alpha_c \Delta T$$

where

Y_{cz} = slab movement caused by shrinkage and

$Y_{c\Delta T}$ = slab movement caused by temperature drop.

The total movement of the slab, Y_c , will be

$$Y_c = \int_0^L \varepsilon_{cz} dx + \int_0^L \varepsilon_{c\Delta t} - (Z + \alpha_c \Delta T)L$$

$$= \int_0^L \varepsilon_c dx - (Z + \alpha_c \Delta T)L \qquad (4.5)$$

where

ε_c = total strain of concrete and

L = slab length.

Crack Width

Crack width is simply the summation of the concrete movement from both sides of the crack:

$$\Delta x = 2 Y_c$$

$$= 2 \int_0^L \varepsilon_c dx - 2(Z + \alpha_c \Delta T)L$$

where

Δx = crack width.

Bond Stress and Bond Length

Bond stress can be considered as the chemical adhesion and the bearing of projections between concrete paste and the steel surface. It is the unit shear force acting parallel to the bar on the interface between bar and concrete. When cracks form, shrinkage and temperature decrease will shorten the adjacent concrete slabs, thus pulling on the steel bars at the crack and resulting in an increase in high-tension. This increase of tensile steel stress will transfer back to the concrete at a rate which is controlled by the bond stress. The real mechanism of stress transfer with deformed bars is quite complex; it involves three basic elements, which progress in the following sequence: first, the shearing resistance of the adhesion itself; then, the frictional resistance to sliding after adhesion is broken; and, finally, the bearing against the lugs. In Ref 5, the model, an average bond stress U was used in which

$$U = \mu\varepsilon_o$$

where

$$\mu = \frac{9.5\sqrt{f'c}}{\emptyset} \leq 800 \text{ lb/in}^2$$

ε_o = perimeter of steel bar, and

$\emptyset$ = bar diameter.

As stated above, the high tensile stress of the steel bars at the crack was transferred to the nearby concrete at a rate which is controlled by the shear resistance of the bond between steel and concrete. And, since this shear resistance was assumed to be an average value (bond stress) evenly spread along the bar from the crack to the fully bonded region, the change of steel stress is a linear curve sloping downward at the bond slip zone. Summing all the forces acting on the steel bar alone, shown in Fig 4.4b, we have

$$F_s + dF_s = F_s + Udx$$

$$A_s d\sigma_s = (\mu\varepsilon_o)dx$$

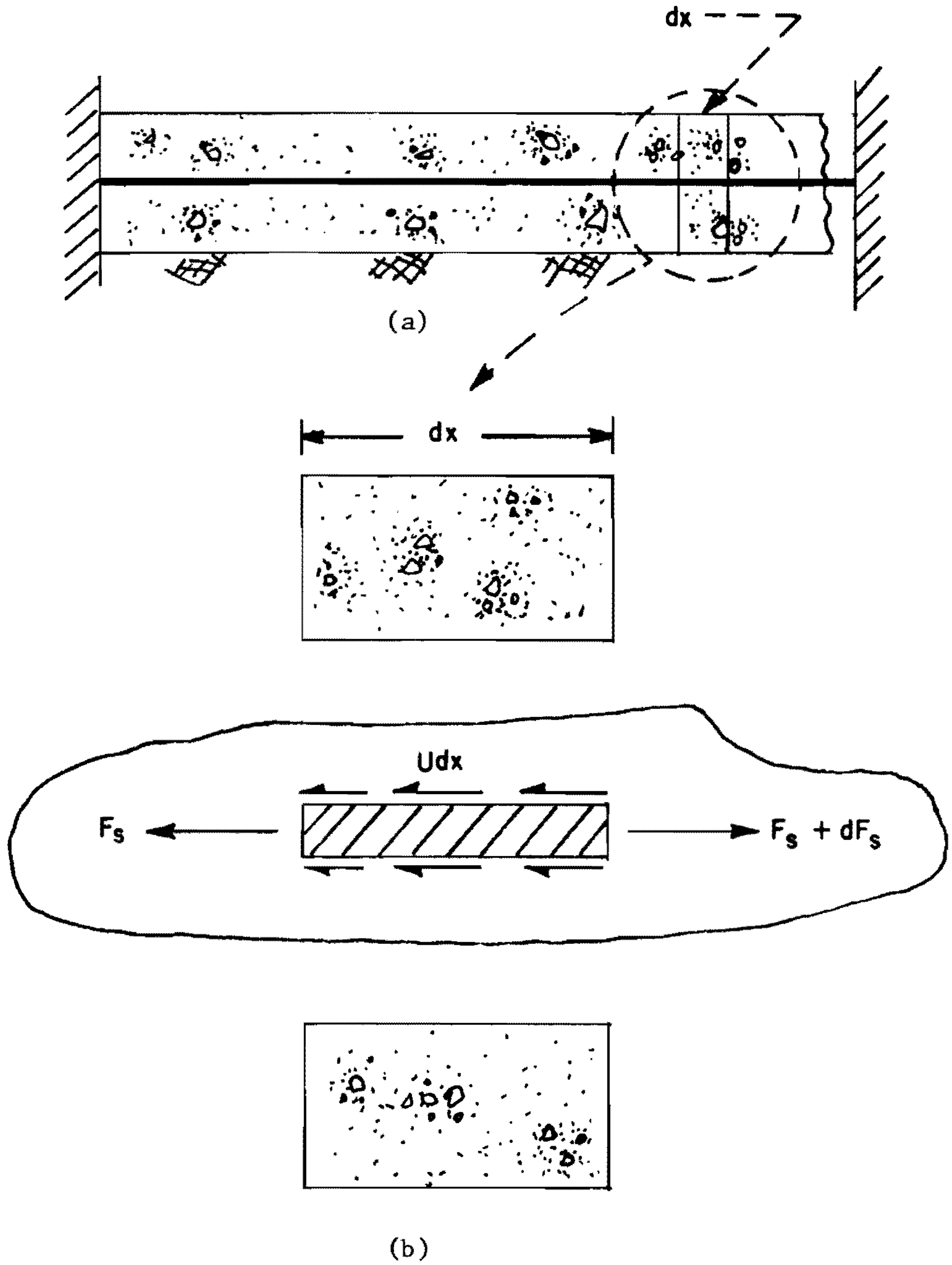


Fig 4.4. Free-body diagram to illustrate forces in the steel bar at bond-slip zone.

$$d\sigma_s = \frac{\mu\pi\phi}{\frac{\pi\phi^2}{4}} dx$$

$$= \frac{4\mu}{\phi} dx \tag{4.6}$$

By integration, the development length, b , required will be

$$\int_o^b d\sigma_s = \frac{4\mu}{\phi} \int_o^b dx$$

$$\sigma_{sc} - \sigma_{sm} = \frac{4\mu}{\phi} (b)$$

$$b = \frac{\phi}{4\mu} (\sigma_{sc} - \sigma_{sm}) \tag{4.7}$$

Steel Boundary Condition

Since the total length of the steel bar is fixed, the strain caused by the drying shrinkage and the temperature drop of the concrete minus the strain of steel due to thermal contraction should equal zero; therefore

$$\int_o^L \varepsilon_s dx - \alpha_s L\Delta T = 0$$

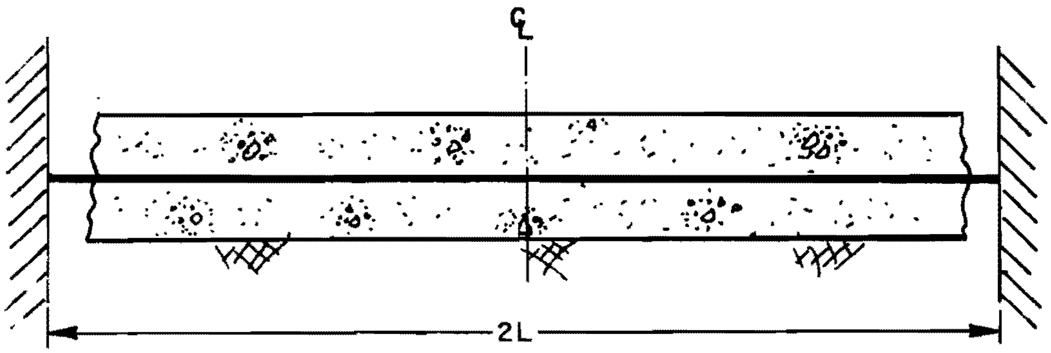
$$\frac{1}{E_s} \int_o^L \sigma_s dx - \alpha_s L\Delta T = 0 .$$

Integrating the steel stress from the crack to the mid-slab gives the area under the steel stress diagram, shown in Fig 4.5b, and yields

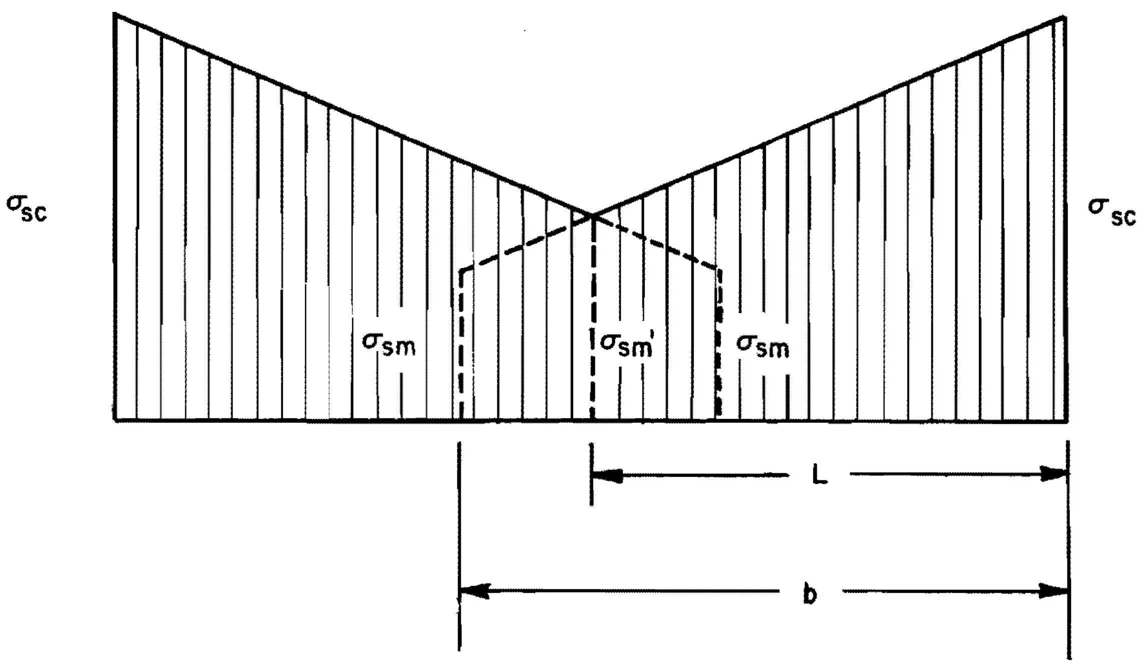
$$\frac{L}{2} (\sigma_{sm'} + \sigma_{sc}) = E_s \alpha_s \Delta T\ L \tag{4.8}$$

where

$\sigma_{sm'}$ = steel stress at the mid-slab for partially bonded condition which is higher than the steel stress σ_{sm} in fully bonded section.



(a) Free-body diagram of the CRCP model.



(b) Steel stress diagram.

Fig 4.5. Steel stress diagram showing development length exceeding half the crack spacing.

The slope for the steel stress diagram in Fig 4.5b, which can be obtained if the development length b is known,

$$s = \frac{\sigma_{sc} - \sigma_{sm}}{b}$$

and the steel stress $\sigma_{sm'}$, will be

$$\sigma_{sm'} = \sigma_{sm} + s(b-L)$$

$$= \sigma_{sm} + \left(\frac{\sigma_{sc} - \sigma_{sm}}{b}\right)(b - L)$$

$$= \sigma_{sc} - \frac{L}{b}\sigma_{sc} + \frac{L}{b}\sigma_{sm}$$

Substituting the above equation into Eq 4.8,

$$\frac{L}{2}\left[\sigma_{sc} + (\sigma_{sc} - \frac{L}{b}\sigma_{sc} + \frac{L}{b}\sigma_{sm})\right] = E_s\alpha_s L\Delta T$$

$$\sigma_{sc} - \frac{L}{2b}\sigma_{sc} + \frac{L}{2b}\sigma_{sm} = E_s\alpha_s\Delta T \qquad (4.9)$$

Summary of Equations

$$\sigma_{cm} = E_c\{Z + \Delta T(\alpha_c - \alpha_s)\} + \frac{1}{n}(\sigma_{sm}) \qquad (4.3)$$

$$\sigma_{sc} = \sigma_{sm} + \frac{\sigma_{cm}}{p} - \frac{\int_0^x F_i\,dx}{pD} \qquad (4.4)$$

$$E_s\alpha_s\Delta T = \sigma_{sc} - \frac{L}{2b}\sigma_{sc} + \frac{L}{2b}\sigma_{sm} \qquad (4.9)$$

where:

$$b = \frac{\phi}{4\mu}(\sigma_{sc} - \sigma_{sm}). \qquad (4.7)$$

From the above, we have four unknowns (σ_{sc}, σ_{sm}, σ_{cm}, F_i), but only three equations. To solve these equations, a binary search technique was used. By assuming zero friction, an estimate of slab movement can be made. By plotting this movement on the friction-movement curve provided by the user, an estimate of friction-force can be obtained. The slab will be analyzed again, but this time with the estimated frictional resistance. The interaction will continue until the friction obtained from the analytical procedure coincides with the friction obtained through the friction-movement curve. The interaction technique was shown in Chapter 6 of Ref 5.

Two models are needed, one without friction and the other with friction. They are as follows:

<u>Frictionless Model</u>. From Eq 4.4,

$$\sigma_{sc} = \sigma_{sm} + \frac{\sigma_{cm}}{p} - \cancelto{0}{\frac{\int_0^x F_i dx}{pD}}$$

$$\sigma_{cm} = p\sigma_{sc} - p\sigma_{sm}$$

Substituting into Eq 4.3,

$$\sigma_{sc} - \sigma_{sm} = E_c \left[Z + \Delta T(\alpha_c - \alpha_s)\right] + \frac{1}{n} (\sigma_{sm})$$

$$\sigma_{sc} - \sigma_{sm} = \frac{E_c}{p} \left[Z + \Delta T(\alpha_c - \alpha_s)\right] + \frac{1}{pn} (\sigma_{sm})$$

$$\sigma_{sm} (1 + \frac{1}{pn}) = \sigma_{sc} - \frac{E_c}{p} \left[Z + \Delta T(\alpha_c - \alpha_s)\right]$$

or

$$C_1 \ \sigma_{sm} = \sigma_{sc} - C_2 \qquad (4.10)$$

where

$$C_1 = 1 + \frac{1}{n}$$

$$C_2 = \frac{E_c}{p}\left[Z + \Delta T(\alpha_c - \alpha_s)\right]$$

By combining terms in Eq 4.9 and substituting b from Eq 4.7;

$$\sigma_{sc} - \frac{L}{2b}\sigma_{sc} + \frac{L}{2b}\sigma_{sm} = E_s\alpha_s\Delta T$$

$$\sigma_{sc} - \frac{L}{2b}(\sigma_{sc} - \sigma_{sm}) = E_s\alpha_s\Delta T$$

$$\sigma_{sc} - \frac{L(\sigma_{sc} - \sigma_{sm})}{2\{\frac{\phi}{4\mu}(\sigma_{sc} - \sigma_{sm})\}} = E_s\alpha_s\Delta T$$

$$\sigma_{sc} = \frac{L}{2k} + E_s\alpha_s\Delta T \qquad (4.11)$$

where

$$k = \frac{\phi}{4\mu}\ .$$

Equation 4.11 indicates that the concrete stress is no longer a function of the steel-stress at the crack in the frictionless model. This is obvious, because the theory assumes an average bond-stress which will dominate the rate of stress-transfer from steel to concrete at the bond-slip zone. Summing all the forces acting on the concrete element at the bond-slip zone in Fig 4.6 gives

$$F_c = F_i dx + U dx + F_c + dFc$$

$$A_c d\sigma_c = -F_i dx - U dx$$

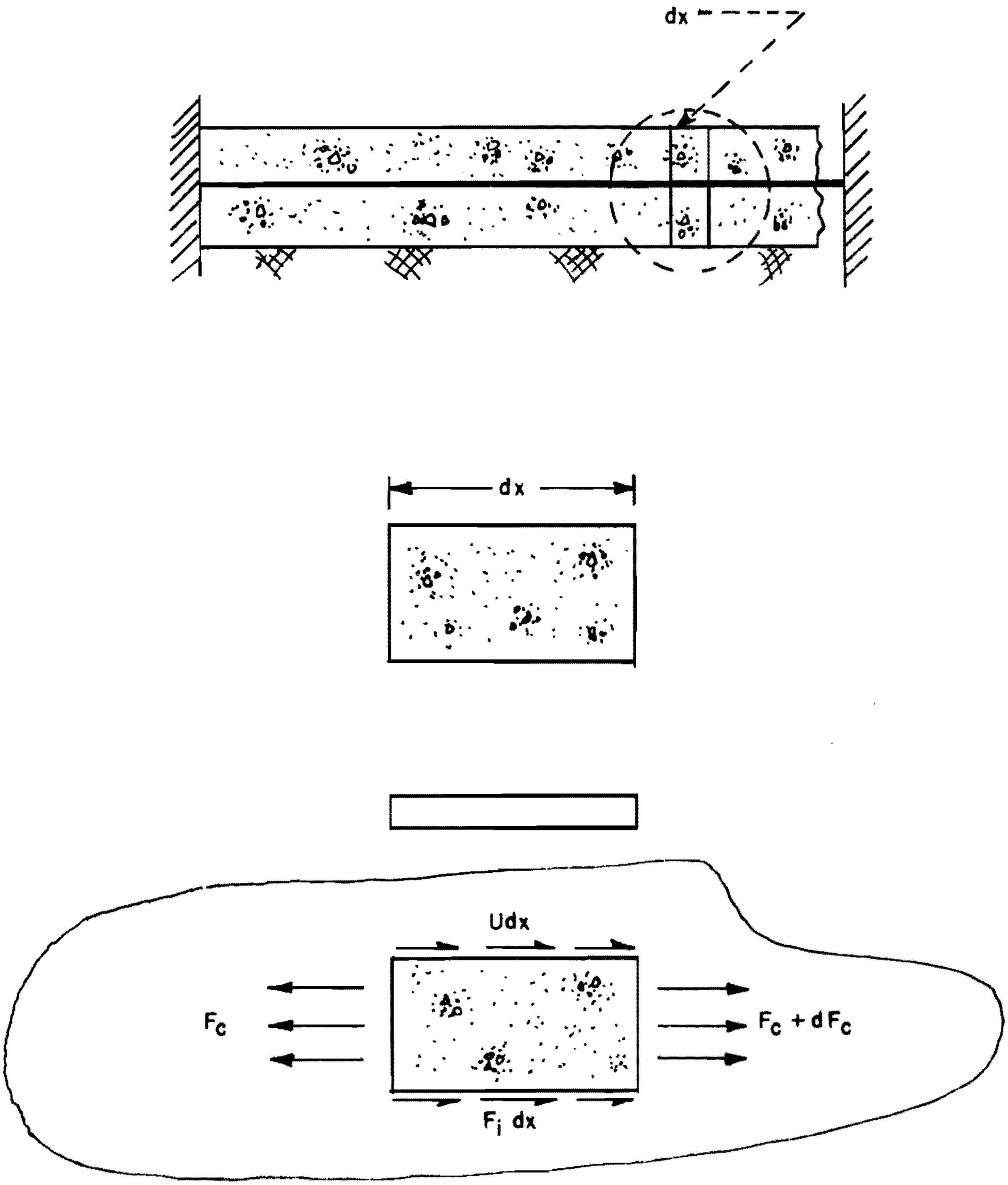


Fig 4.6. Free-body diagram to illustrate forces acting in the concrete at bond-slip zone.

For a one-foot strip,

$$d\sigma_c = -\frac{F_i dx}{D} - \frac{\mu\pi\phi}{\frac{\pi\phi^2}{4p}} dx$$

$$= -\frac{F_i}{D}dx - \frac{4\mu p}{\phi}dx \qquad (4.12)$$

By integration, the maximum concrete stress at the middle for a frictionless slab is

$$\int_o^L d\sigma_c = -\frac{\int_o^L F_i dx}{D} - \frac{4\mu p}{\phi}\int_o^L dx$$

(the first term on the right is struck through and marked O)

$$\sigma_{cm} = -\frac{4\mu p}{\phi} L \qquad (4.13)$$

Combining Eqs 4.10 and 4.11 gives

$$\sigma_{sm} = \frac{1}{C_1}\left(\frac{L}{2K} + E_s \alpha_s \Delta T\right) - \frac{C_2}{C_1} \qquad (4.14)$$

Friction Model.

Combining Eqs 4.3 and 4.4,

$$p\sigma_{sc} - p\sigma_{sm} + p\frac{\int_o^x F_i dx}{pD} = E_c\{Z + \Delta T(\alpha_c - \alpha_s)\} + \frac{1}{n}\sigma_{sm}$$

$$\sigma_{sc} - \sigma_{sm} + \frac{\int_o^x F_i dx}{pD} = \frac{E_c}{p}\{Z + \Delta T(\alpha_c - \alpha_s)\} + \frac{1}{np}\sigma_{sm}$$

$$\sigma_{sm}\left(1 + \frac{1}{np}\right) = \sigma_{sc} - C_2 + C_3$$

$$\sigma_{sm} C_1 = \sigma_{sc} - C_2 + C_3 \qquad (4.15)$$

Where

$$C_1 = 1 + \frac{1}{np}$$

$$C_2 = \frac{E_c}{p}\{Z + \Delta T(\alpha_c - \alpha_s)\}$$

$$C_3 = \frac{\int_0^L F_i dx}{pD}$$

By substituting b into Eq 4.9, the steel stress at the crack is

$$\sigma_{sc} = \frac{L}{2k} + E_s \alpha_s \Delta T$$

From Eq 4.12, the maximum concrete stress will be

$$\sigma_{cm} = -\frac{\int_0^L F_i dx}{D} - \frac{4\mu pL}{\phi} . \qquad (4.16)$$

SUMMARY

The basic equations derived in this chapter are an extension of the equations developed in the CRCP-1 model to cover conditions in which development length exceeds half the crack spacing and, thus, extend its capability for solving problems with more extreme parameters, such as higher friction value, abrupt temperature changes, heavy wheel-load stress, and so on.

While the mechanism of the load transfer in the bond-slip zone is quite complex and the state of art is still being developed an average bond strength value was used in this study to predict the rate of load transfer from steel bars to concrete.

CHAPTER 5. EXAMPLE PROBLEMS AND OBSERVATIONS

A series of example problems are presented in this chapter to demonstrate the application of the CRCP-2 program with the added design variables discussed in the previous chaters. Observations of the predicted behavior of CRC pavement with these new variables are also made.

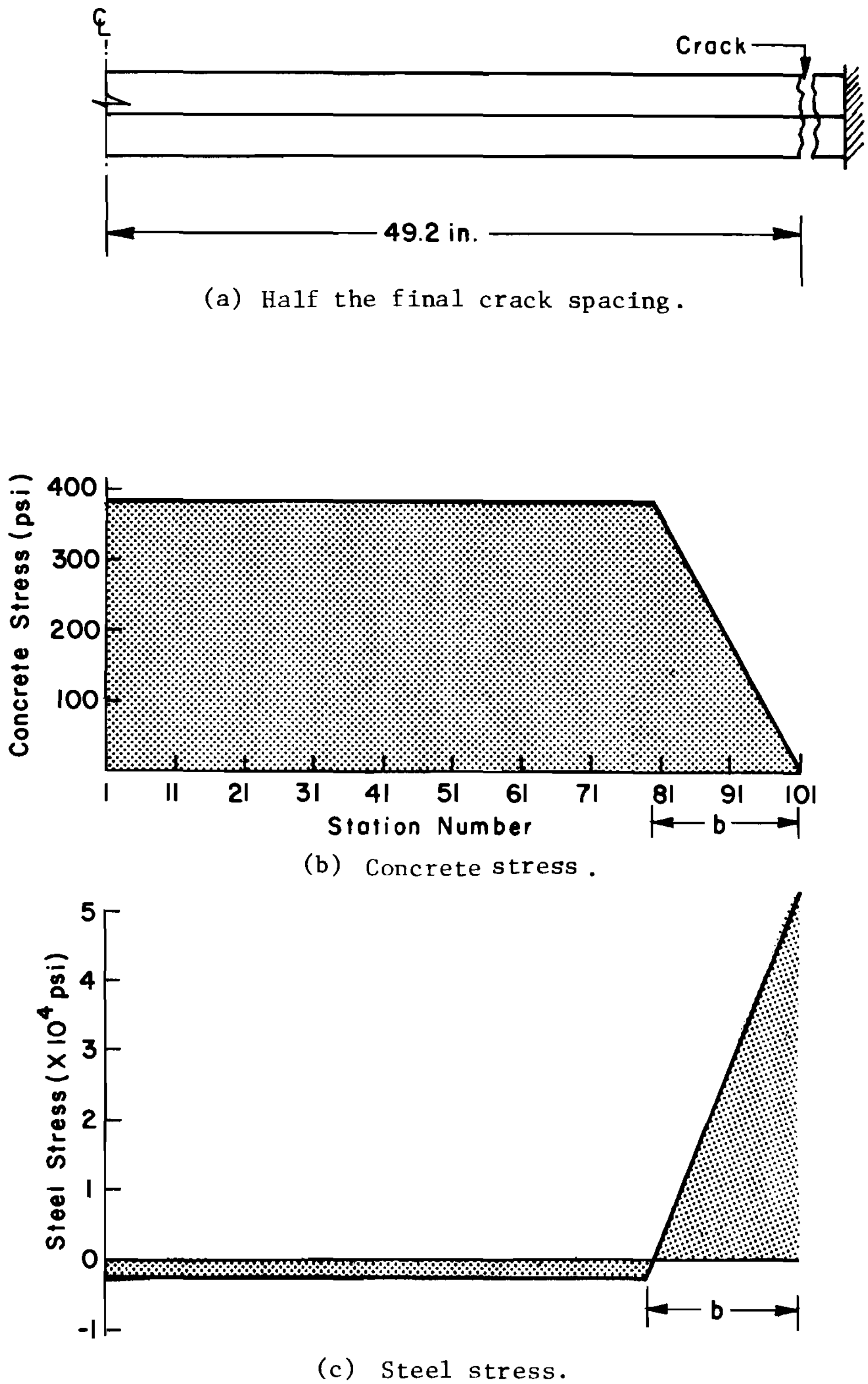
Problem A - Development Length Exceeds Crack Spacing

Two analysis are made of a continuously reinforced concrete pavement placed over two different kinds of subbases. The first problem, A-1, is a control problem with input data that can be solved by the original steel stress model in CRCP-1. The second problem, A-2, has exactly the same input data as Problem A-1, except that the steel reinforcement and the subbase friction are higher to force the crack spacing to fall below the development length in the slab. The CRCP-2 program with the revised steel stress model is used to solve this problem.

Problem A-1, deals with a 0.7 percent reinforced concrete pavement placed over a smooth subbase with maximum frictional resistance of 1.0 psi (70.45 gm/cm^2) per 0.1-inch (0.254-cm) movement. The concrete properties, the steel properties, and the daily temperature variations are tabulated in the computer output in Appendix 2.

The final crack spacing obtained from this analysis is 8.2 feet (2.499 m). The maximum steel stress found was 52,580 psi (3704.5 Kg/cm^2), which is slightly below the yeilding stress for steel. The difference between the maximum concrete stress and the maximum tensile strength for the concrete is within 1.0 percent, which is the closure tolerance assigned to this problem.

The changes in steel and concrete stresses are plotted along the horizontal stations of the slab in Fig 5.1. Station 1 is at the mid-slab and station 101 is at the crack. In Figs 5.1b and 5.1c, the steel stress is the highest, while concrete carries no load at the crack. From station 101 towards the mid-slab, the steel stress decreases as it transfers its load to concrete along the bond-slip zone. The total development length required for the load transfer in this problem is 9.84 inches (24.99 cm).



Note: 1 inch = 2.54 centimeters
1 psi = 70.454 gm/cm^2

Fig 5.1. Variation of steel stress and concrete stress along the CRCP-1 model.

In Problem A-2, the steel percentage and the bar diameters are higher, and a maximum frictional resistance of 7.5 psi (.528 kg/cm^2) per 0.2-inch (0.508-cm) movement was used. The increase in frictional resistance reduces the crack spacing further, while the increase in steel percentage and bar diameter increase the devleopment length. The result will be such that the development length exceeds one half the crack spacing an the problem can no longer be solved using the CRCP-1 program. The solutions obtained by the CRCP-2 program are plotted in Fig 5.2. The final crack spacing is shorter than the result obtained from Problem A-1 and the new development length for the load transfer occupies the entire slab. The steel stress diagram in Fig 5.2c is consistant with the steel stress model developed in Chapter 4.

Problem B - Increase in Tensile Strength Before Minimum Temperature Occurs

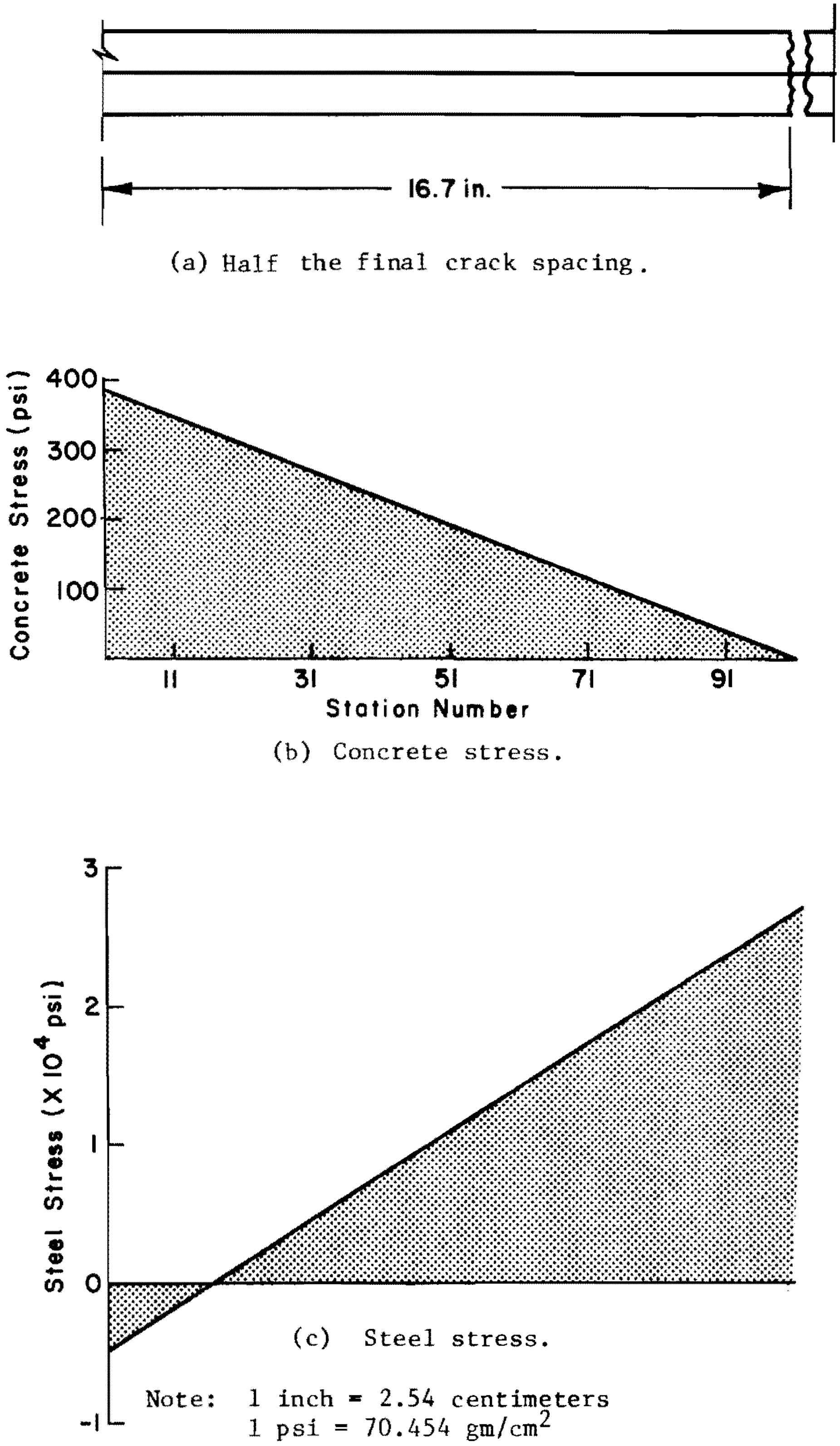
For this comparison it is assumed that a continuously reinforced concete pavement is built in midsummer, and the minimum, winter, temperature is not anticipated for at least 3 months. The daily temperature variations recorded during the first 28 days are tabulated in the computer output in Appendix 2.

Two analyses were made on this pavement. Problem B-1 considered the strength increase of concrete only up to the 28th day, as was done in the CRCP-1 program. In Problem B-2, all input parameters remained the same, except that an allowance of 90 days was given for the concrete to gain additional strength before the occurrence of the minimum winter temperatures.

The variations of concrete strength, concrete stress, and the changes of crack spacing with time are plotted in Figs 5.3 and 5.4 for the alternative solutions. Figure 5.3 represents the original CRCP-1 model, where increase in tensile strength after the 28th day is not accounted for. Figure 5.4 shows an increase in tensile strength after the 28th day and an increase in the crack spacing is found when it is compared to Problem B-1.

Problem C - Environmental Stresses as Combined with External Load Stresses

To demonstrate the combined effect of environmental and wheel-load stresses, a 12-inch (30.48-cm) thick pavement with 1.2 percent steel reinforcement is placed over a polyethylene sheeting with maximum frictional resistance 1.0 psi with 0.1 inch (0.254 cm) of movement at sliding. The subgrade modulus



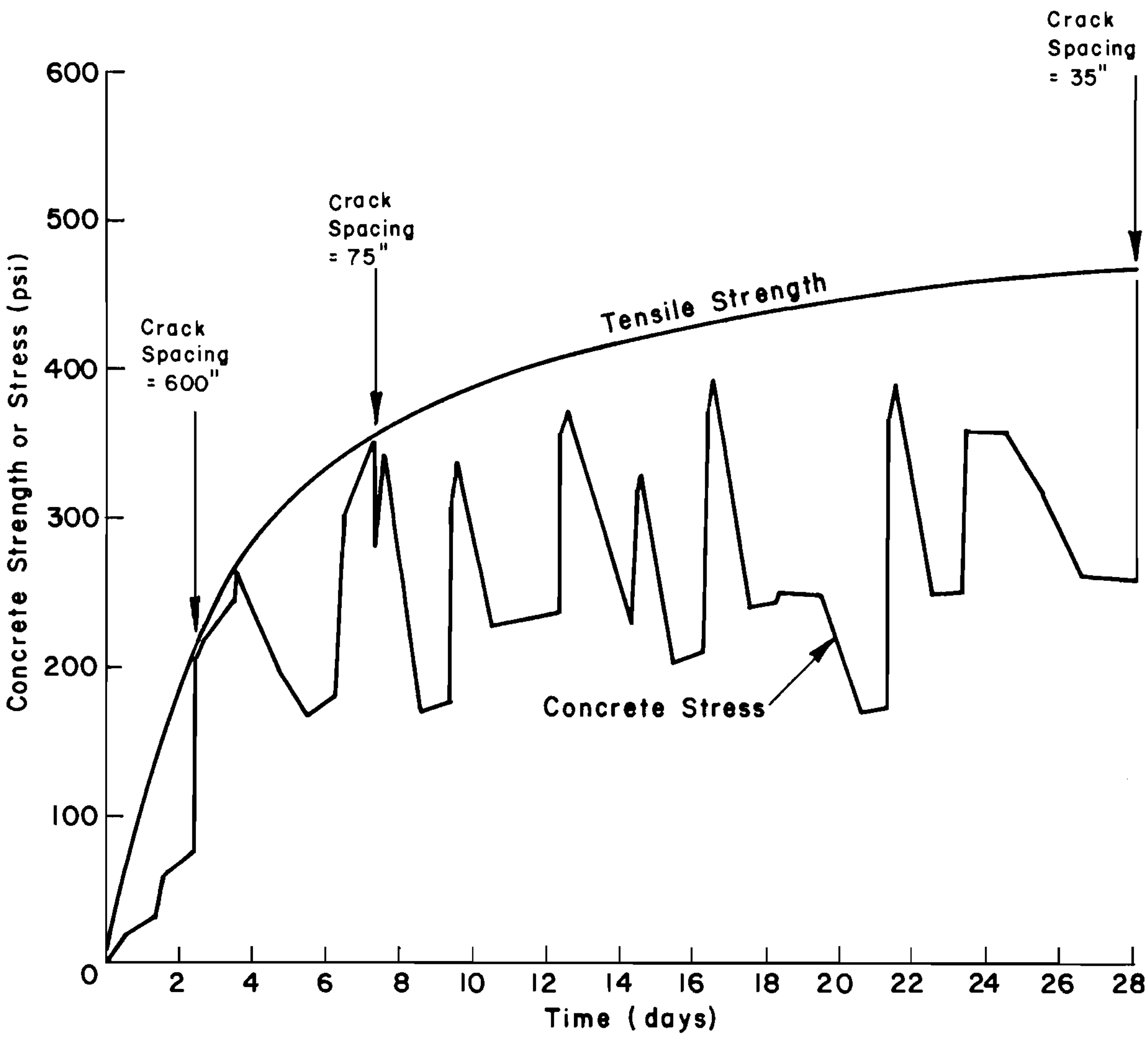
(a) Half the final crack spacing.

(b) Concrete stress.

(c) Steel stress.

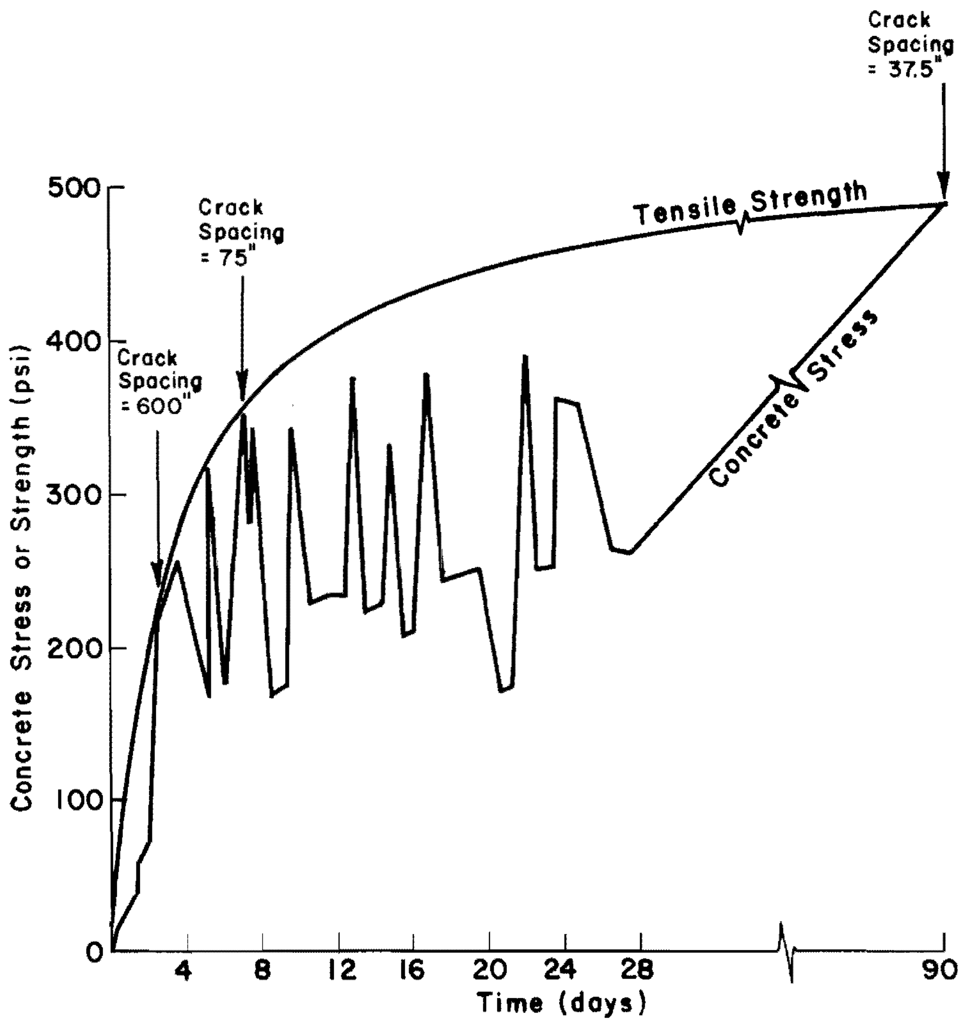
Note: 1 inch = 2.54 centimeters
1 psi = 70.454 gm/cm^2

Fig 5.2. Variation of steel stress and concrete stress along the CRCP-2 model.



Note: 1 inch = 2.54 centimeters; 1 psi = 0.0704 kg/cm^2.

Fig 5.3. Variation of concrete strength and maximum concrete stress with time for CRCP-1 model.



Note: 1 inch = 2.54 centimeters; 1 psi = 0.0704 kg/cm^2.

Fig 5.4. Variation of concrete strength and maximum concrete stress with time for CRCP-2 model.

is estimated to be 150 pci (4.157 kg/cc). The steel and concrete properties are tabulated in the computer output in Appendix 2.

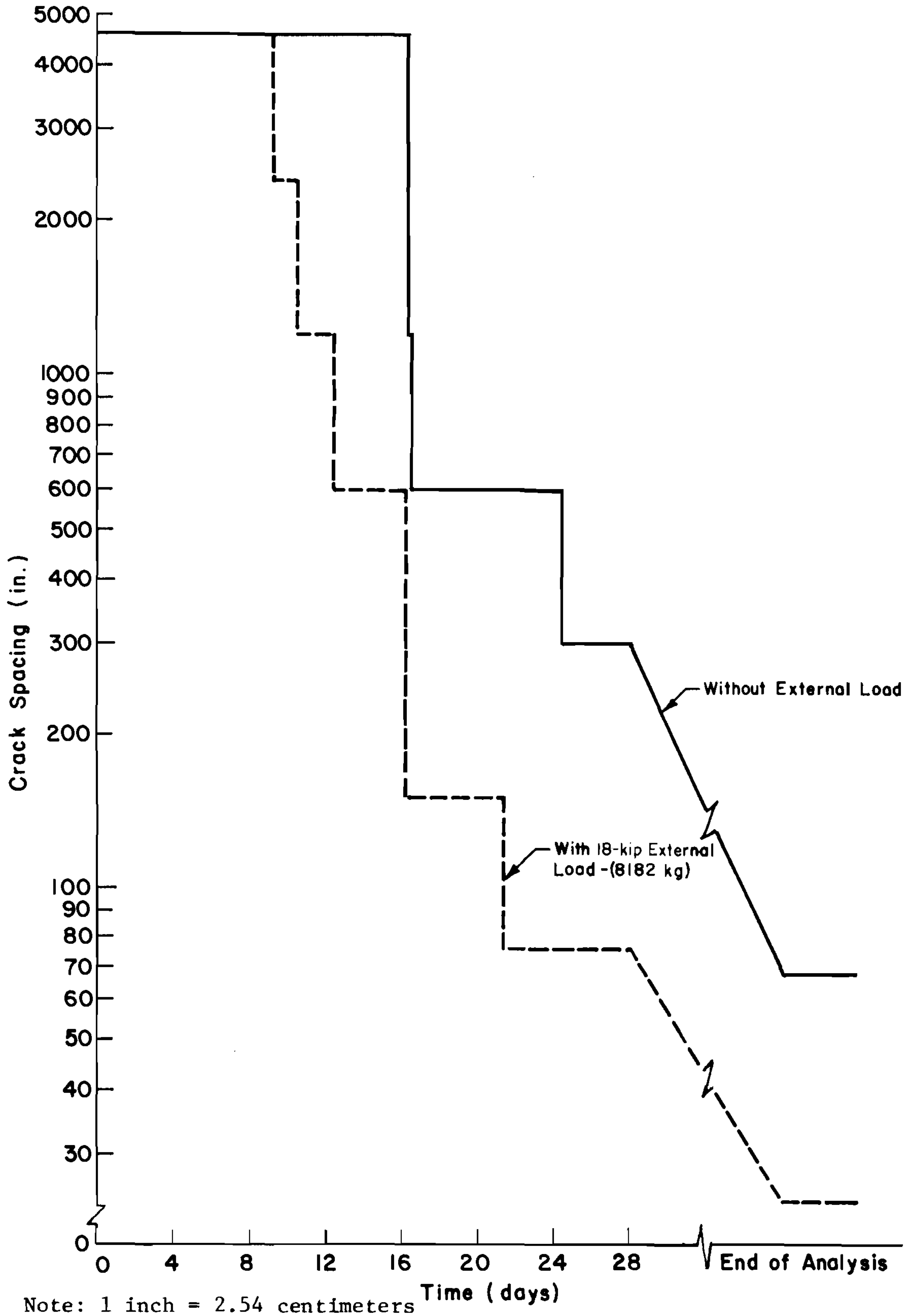
In Problem C-1, the slab described above was analyzed with only the internal stress caused by the change in temperature and drying shrinkage. In Problem C-2, in addition to the environmental stresses, an 18-kip (8182.0-kg) external load was applied to the slab on the seventh day after the placement of the slab. The results from both analyses are plotted in Figs 5.5 and 5.6.

In Fig 5.5, the effect on crack spacings of CRC pavement due to the external load is demonstrated by the sudden drop in the crack spacing, where the combined external and internal stresses exceeded the tensile strength of concrete. At the end of the analysis period, the final crack spacing for the loaded pavement was less than one-half the value for the unloaded pavement.

Figure 5.6 shows the change in steel stress with time for both Problems C-1 and C-2. Arrows are used in the figure to indicate the time cracks occurred.

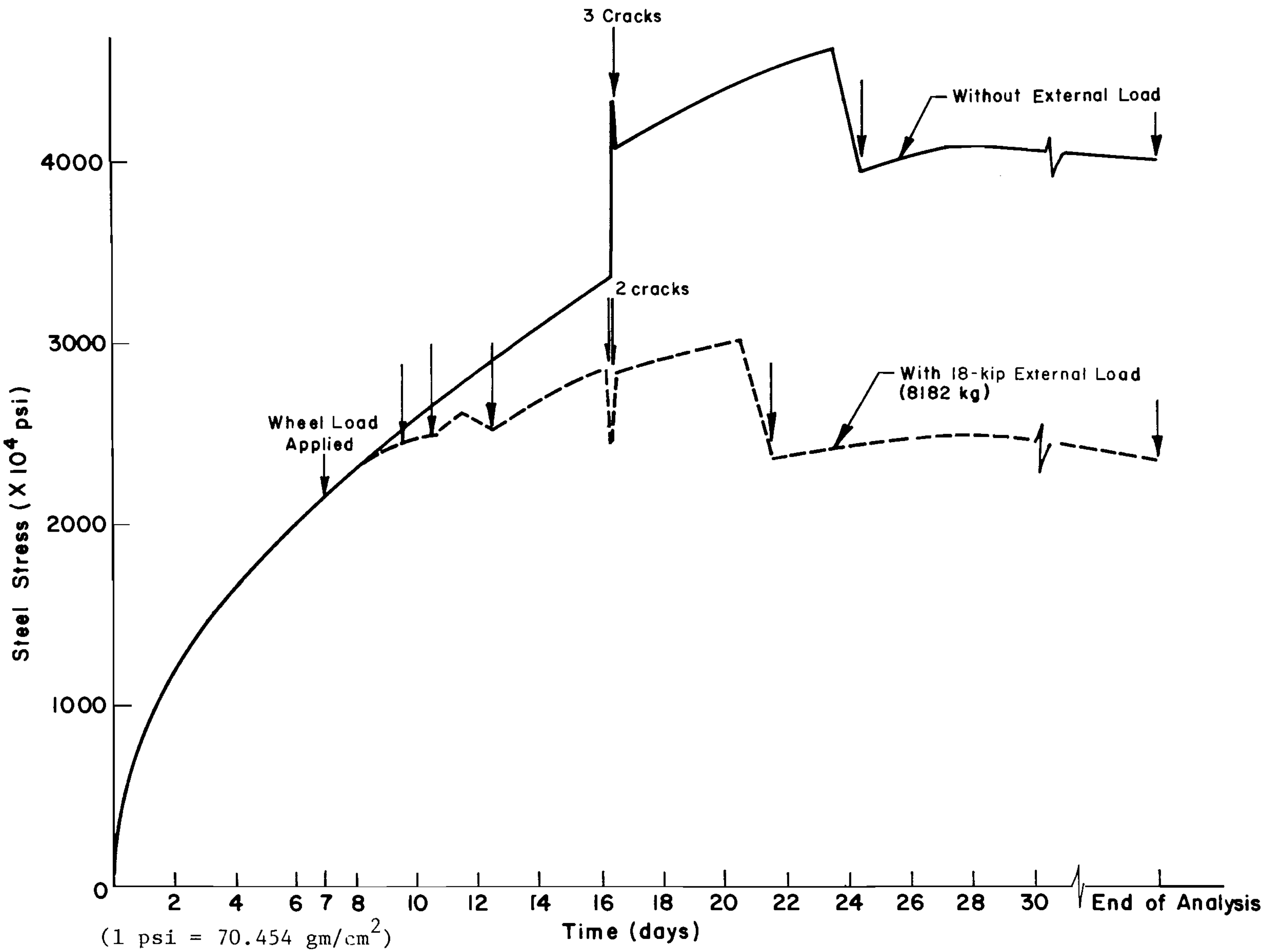
For a given slab length and for a nearly constant drop in temperature, the stress in concrete will increase with time. However, each time a crack occurs, the slab length will be reduced. The cumulative frictional resistance for that shorter slab will be lessened, which in turn lowers the stress in the concrete as well as the steel stress. For the concrete strength, which increases steadily with time, the maximum concrete stress required for the crack to form increases with time also. Notice that, in Fig 5.6, the general trend for the steel stress curves is to increase with time but plunge downward everytime a crack occurs.

When an external load is applied to the pavement, the combination of both the external load and the internal load stresses induces more cracks in the CRC pavement, which explains the decrease in steel stress for the loaded curve in Fig 5.6.



Note: 1 inch = 2.54 centimeters

Fig 5.5. Change in crack spacing with time; with and without external load solved by CRCP-2 program.



(1 psi = 70.454 gm/cm^2)

Fig 5.6. Change in steel stress with time; with and without external load solved by CRCP-2 program.

CHAPTER 6. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

SUMMARY

The CRCP-1 method, developed in Ref 5, provides a useful tool for the analysis of temperature and shrinkage effects on cintinuously reinforced concrete pavements. Certain modifications of the CRCP-1 method were made in this study to increase the proficiency and to extend the capability of this method. The age-tensile strength model was extended to cover conditions in which the drop to minimum temperature was delayed. For high frictional subbase, the steel stress model was extended to cover conditions in which the bond length exceeds one-half the crack spacing. The wheel-load stress was combined with the internal load caused by temperature drop and drying shrinkage to obtain a better prediction of crack spacing in field conditions.

The inclusion of wheel-load stress with internal stress was accomplished by superimposing the tensile stress at the bottom fibre, computed by the Westergaard equation for a single-concentrated vertical load, an the inplane tensile stress across the depth of the slab, computed by the CRCP-1 method.

The computer program was written in FORTRAN IV computer language for the Control Data Corporation 6600 digital computer. The program can be adapted for use with the IBM 360/370 computer by some minor changes.

CONCLUSIONS

Based on this study, the following conclusions are made.

(1) The forces acting on the continuously reinforced concrete pavement can be modeled more realistically using the CRCP-2 computer program, which allows for analysis of a CRC pavement under both wheel-load stress and environmental stress. The inclusion of wheel load helps to gain more insights into the real behavior of CRC pavmeent. Warping effect and the fatigue in the slab under repetitive loadings, however, are not considered.

(2) From a limited number of test problems, it was found that the addition of wheel load on continuously reinforced concrete pavement has the same effect as increasing the steel percentage in the pavement; they both force more cracks to develop. Variation in crack spacing changes the magnitudes of other variables in the pavement, such as steel stress and crack width; lower crack spacing results in lower steel stress and lower crack width. Decrease in slab thickness, on the other hand has an adverse effect on the behavior of CRC pavement. Increasing the slab thickness, can prevent excessive cracking. For the design of CRC pavement it is important to have a proper correlation on the steel percentage and the slab thickness. The final crack spacing should be adjusted to keep cracks at an optimum width.

(3) Comparing the concrete stress under the minimum temperature with the 28th-day strength will sometimes cause underestimation of the crack spacing and, thus, the steel stress in the CRC pavement and mislead the designer in to decreasing the steel reinforcement in the slab. The strength-stress interaction model used in the CRCP-2 program enables us to project the strength gain in the concrete beyond the 28th day and predict the final crack spacing more accurately.

(4) The modified steel stress model in the CRCP-2 program can cover conditions where development length exceeds half the crack spacing, thus extending its capability for solving problems with more extreme parameters, such as high friction values, abrupt temperature changes, heavy wheel load, and so on.

(5) Computer program CRCP-2 can be used to develop charts or nomographs for the design of continuously reinforced concrete pavement.

RECOMMENDATIONS

Stress induced by different types of loadings have been treated in the past separately by various methods. To realistically analyze the complete state-of-stress, further research is needed to combine these theories and models into a more complete design. In addition, more effort should be directed toward better understanding of various design variables, such as the frictional resistance of treated base, the air of concrete temperature of the slab, and the load transfer at cracks. Recommendation for future research are listed as follows.

Environmental Load Plus Traffic Loads

The environmental influence on rigid pavements can be seperated into two categories. The first is the difference in temperature throughout the depth of the slab, which, in accordance with the thermal conductivity of the concrete, has a slab-surface temperature different from the mid-depth temperature. The strain differential due to this temperature variation causes the slab to curl up and at the same time, the weight of the slab adds pressure in the opposite direction. The loss of support near the crack due to this warping effect poses a serious problem when the wheel load is added. Either Teller's closed form solution or Leonard's computer program (Refs 7 and 8) can be used here to solve for the tensile stress on the top fibre of the slab near the crack. The second category of environmental influence is the change of temperature after curing, which, in accordance with the thermal coefficient of contraction, will build up a magnitude of in-plane stress when the temperature reduces to below curing temperature. The CRCP-1 method was developed to solve this tensile stress along the slab.

The bending of a slab due to traffic load contributes another type of stress on the pavement. Although the values derived from Westergaard's equation correlate closely with the laboratory results and have been widely used for the prediction of wheel-load stress (Refs 15 and 16), the method is limited to uniform slab thickness, uniform foundation support, and a single, concentrated loading. The discrete-element method on the other hand allows considerable freedom for the configuration of the pavement, the loading patterns patterns, the flexural stiffness of the slab and various combinations of support median. The finite approximation method not only offers major advantages over the Westergaard equation, but since the slab in the discrete-element model was decided into discrete elements, such as beams, torsional rods, and springs, it can be suited to couple various types of loading into a more complete analytical tool for the design of rigid pavements. Valuable research would be to include the environmental stress into the discrete element model as a uniaxial thrust acting longitudinally on the beams. In a similar manner, the strain differential across the depth due to the temperature gradient also can be included with additional efforts.

Load Transfer at the Crack

To fully portray a continuously reinforced concrete pavement, the slab as well as the transverse cracks that occur every few feet need to be considered. Work done by Abou-Ayyash (Ref 13) suggested a reduced stiffness at the crack to account for the moment transfer when each end of the slab at the crack come in contact with each other. The amount of stiffness needs to be reduced and the length of hte slab under influence can be determined by using the basic-moment curvature relationship. A study done by Strauss found that, unless the crack width is very narrow, as in the case of early-age, the probability of slabs' coming in contact at the crack is very small (Ref 17). Other forms of load transfer are aggregate interlock and dowel action of the steel bars. By simulating aggregates as circular particles and by simple geometry, the shear stress carried by the bearing of the aggregate particles can be obtained if the crack width is known. By using the pile theory (Ref 17), the amount of shear load acting on the concrete due to the dowel action of the steel bars can be found. It would be highly desirable to model the cracks as related to these three types of load transfer and incorporate them into other analytical models mentioned in previous paragraphs.

Frictional-Resistance of Treated Base

In the CRCP-1 design method, the friction-movement relationship between the slab and its support must be known before the amount of frictional force acting on the slab can be estimated. Past studies were made to determine the friction-movement relationship between the slab and the granular materials; however, little was known about the frictional force developed on the slab for treated base. Therefore, a study to determine the friction-movement curve for cement-stabilized, asphalt-stabilized, and lime-stabilized bases is highly desirable.

Air and Concrete Temperature

Assessment of pavement temperature at mid-depth for the input data in the CRCP-1 design method, as well as the temperature variation across the depth of the slab, for the prediction of strain differential requires a correlation to link air temperature with pavement temperature at any time and depth.

A pavement temperature simulation model was developed for simulating bituminous pavement temperatures, as related to air temperature, wind velocity, solar radiation, and the thermal properties of the concrete (Ref 18), and based on the same conception, the temperature simulation model for rigid pavement can be developed. Future research should be conducted to incorporate this model into other non-traffic-associated slab design models for the prediction of environmental stresses.

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APPENDIX 1

LISTING OF COMPUTER PROGRAM CRCP-2

```
      PROGRAM CRCP2(INPUT,OUTPUT,TAPE5=INPUT)
CCC*************************************************************************
C
C
C
C                              C R C P
C
C                           - VERSION 2.1 -
C
C
C                    LATEST REVISON - 29 MARCH 1977
C
C
C
C*************************************************************************
C
C
C
C                    THE INPUTS ARE AS FOLLOWS:
C          ALL CARD TYPES MUST BE PRESENT FOR EACH PROBLEM UNLESS
C        OTHERWISE STATED EXCEPT TYPE 1, WHICH MUST BE PRESENT ONCE
C                          AND ONLY ONCE.
C
C
C                              TYPE 1
C                        DESCRIPTION OF RUN
C
C  AN1       ANY COMBINATION OF LETTERS AND/OR NUMBERS.
C            ( 2 CARDS ARE REQUIRED )
C
C
C                              TYPE 2
C                       DESCRIPTION OF PROBLEM
C
C  NPROB     COLS. 1-5 : PROBLEM NUMBER
C                   (ANY COMBINATION OF LETTERS AND/OR NUMBERS)
C  AN2       COLS. 11-80 : DESCRIPTION OF PROBLEM
C                   (ANY COMBINATION OF LETTERS AND/OR NUMBERS)
C
C
C                              TYPE 3
C                          STEEL PROPERTIES
C
C  ITYPER    COL. 5 : TYPE OF REINFORCEMENT
C                   = 1 FOR DEFORMED BARS
C                   = 2 FOR DEFORMED WIRE FABRIC
C  P         COLS. 11-20 : PERCENT STEEL REINFORCEMENT
C  DIA       COLS. 21-30 : REINFORCING BAR DIAMETER
C                   (INCHES)
C  FY        COLS. 31-40 : YIELD STRESS
C                   (PSI)
C  ES        COLS. 41-50 : ELASTIC MODULUS
C                   (PSI)
C  ALPHAS    COLS. 51-60 : THERMAL COEFFICIENT OF STEEL
C  BHIGH     COLS. 61-70 : TRANSVERSE WIRE SPACING
C                   (INCHES)
C                   (OMIT IF DEFORMED BARS ARE USED)
C
C
C                              TYPE 4
C                        CONCRETE PROPERTIES
C
C  THICK     COLS. 11-20 : CONCRETE SLAB THICKNESS
C                   (INCHES)
C  ALPHAC    COLS. 21-30 : THERMAL COEFFICIENT OF CONCRETE
C  ZTOT      COLS. 31-40 : DRYING SHRINKAGE STRAIN
C                   (IN./IN.)
C  UNWT      COLS. 41-50 : UNIT WEIGHT OF CONCRETE
C                   (PCF)
C  FPC       COLS. 51-60 : 28-DAY COMPRESSIVE STRENGTH
C                   (PSI)
C                   (OMIT IF USER PROVIDES AGE-TENSILE DATA,
C                    E.G.,IF NSTRN GT 0)
C  STRNMUL   COLS. 61-64 : USED WITH FPC BY PROGRAM TO GENERATE THE
C                   AGE-TENSILE RELATIONSHIP.
C                   (OMIT IF USER PROVIDES AGE-TENSILE DATA,
C                    E.G.,IF NSTRN GT 0)
C                   (STRNMUL MUST BE LE 1.0)
C                   (DEFAULT VALUE IS 1.0)
C  NSTRN     COLS. 65-66 : NUMBER OF POINTS IN THE AGE-TENSILE RELAT.
C                 = 0 IF PROGRAM GENERATES RELATIONSHIP
C                    ( 0 LE NSTRN LE 20 )
C  IFY       COLS. 69-70 : NUMBER OF POINTS IN SLAB-BASE FRICTION CURVE
C                 = 1 - USER SUPPLIES ONE POINT, PROGRAM WILL
C                     GENERATE A STRAIGHT LINE CURVE
C                 = 2 - USER SUPPLIES ONE POINT, PROGRAM WILL
C                     GENERATE A PARABOLIC CURVE
C                  (IN THE ABOVE CASES, THE POINT SUPPLIED
C                   SHOULD BE WHEN SLIDING OCCURS)
C                 > 2 - USER DEFINES THE CURVE WITH IFY POINTS
C                  (THE FIRST POINT MUST BE (0.0,0.0))
C                     ( 0 LT IFY LE 10 )
C                    (DEFAULT VALUE IS 2)
C
C
C                              TYPE 5
C                        ENVIRONMENTAL INPUTS
C
C  CURTEMP   COLS. 1-10 : CURING TEMPERATURE
C                   (DEGREES FAHRENHEIT)
C  NTEMP     COLS. 11-15 : NUMBER OF DAYS BEFORE CONCRETE GAINS FULL
C                   STRENGTH, NTEMP SHOULD EQUAL AGEU(NSTRN) IF
C                   NSTRN > 0, OTHERWISE NTEMP = 28.
C                    ( 0 LT NTEMP LE 50 )
C  DELTATM   COLS. 21-30 : MINIMUM TEMPERTURE EXPECTED AFTER CONCRETE
C                   GAINS FULL STRENGTH
C                   (DEGREES FAHRENHEIT)
C  COLDTM    COLS.  36-40 : NUMBER OF DAYS AFTER CONCRETE IS SET
C                    BEFORE MINIMUM TEMPERATURE DELTATM OCCURS
C                    (E.G.FIRST COLD SEASON)
C                    (OMIT IF RUN IS PROGROM CRCP1)
C                    (COLDTM.GE.28.0)
C                    (DEFAULT VALUE IS 28.0)
C
C
C                              TYPE 6
C                     MINIMUM DAILY TEMPERATURE
C        (IF NTEMP > 16, THEN ADDITIONAL CARDS ARE REQUIRED)
C
C  DT        COLS. 1-5,6-10,11-15,ETC. : (DEGREES FAHRENHEIT)
```

```
C
C
C                          TYPE 7
C                 EXTERNAL LOAD OR STRESS
C            (OMIT THIS CARD IF RUN IS PROGRAM CRCP1)
C
C  TMLOD      COLS. 6-10 : NUMBER OF DAYS AFTER CONCRETE IS SET
C                          BEFORE WHEEL LOAD IS APPLIED
C                          (DEFAULT VALUE IS 0.0)
C  WHLOAD     COLS.11-20 : WHEEL LOAD (LBS)
C                          (BLANK IF USER SUPPLIES WHLSTR)
C                          (DEFAULT VALUE IS 0.0)
C  WHBASE     COLS.21-30 : WHEEL BASE RADIUS (IN.)
C                          (BLANK IF USER SUPPIES WHLSTR)
C
C  SOILK      COLS.31-40 : MODULUS OF SUBGRADE (PSI)
C                          (BLANK IF USER SUPPLIES WHLSTR)
C  WHLSTR     COLS.41-50 : WHEEL LOAD STRESS (PSI)
C                          (BLANK IF USER SUPPLIES WHLOAD)
C
C
C
C                          TYPE 8
C                  PRINT AND PLOT OPTIONS
C
C  TOL      COLS. 1-5 : RELATIVE CLOSURE TOLERANCE
C                       (PERCENT)
C                       (DEFAULT VALUE IS 5.0)
C  LONGPR   COLS. 6-10 : FLAG TO PRINT RESULTS FROM EACH ITERATION
C                      = YES IF DESIRED
C                      = BLANK IF NOT DESIRED
C  NPRINT   COLS. 11-15 : RATE OF SUBSAMPLING USED IN PRINTING RESULTS
C                         FOR EACH ITERATION
C                         (E.G., 101 POINTS ARE CALCULATED IN EACH
C                         ITERATION, IF NPRINT = 20 AND LONGPR = YES THEN
C                         FOR EACH ITERATION VALUES AT POINTS 1, 21, 41,
C                         61, 81, AND 101 WILL BE PRINTED)
C                         (DEFAULT VALUE IS 20)
C  IPLOT    COLS. 16-20 : FLAG FOR PLOT OF TEMPERTURE DROP VS. TIME
C                       = YES IF PLOT IS DESIRED
C                       = BLANK IF NOT DESIRED
C  TMSCALE  COLS. 21-35 : NUMBER OF INCHES PER DAY TO BE PLOTTED
C  FINAL    COLS. 36-40 : NUMBER OF DAYS TO BE PLOTTED
C
C
C                          TYPE 9
C              AGE TENSILE-STRENGTH RELATIONSHIP
C            (THIS CARD MUST BE OMITTED IF NSTRN = 0)
C       (IF NSTRN > 8, THEN ADDITIONAL CARDS ARE REQUIRED)
C
C  AGEU     COLS. 1-5,11-15,21-25,ETC. : AGE OF THE CONCRETE
C                                        (DAYS)
C  TENSION  COLS. 6-10,16-20,26,30,ETC. : TENSILE STRENGTH
C                                        (PSI)
C
C
C                          TYPE 10
C              SLAB-BASE FRICTION RELATIONSHIP
C                  (FORCE-DISPLACEMENT)
C           (IF IFY > 4 ADDITIONAL CARDS ARE REQUIRED)
C
```

```
C  FEXP     COLS. 1-10,21-30,ETC. : FRICTIONAL FORCE PER UNIT LENGTH
C                                   (PSI)
C  YEXP     COLS. 11-20,31-40,ETC. : SLAB MOVEMENT
C                                   (INCHES)
C
C
C
C*********************************************************************
C
      COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
      COMMON /BLOCK2/ SS(101),AAA,WS(101),LONGPR,NPRINT,MAXITE,CRACKW
      COMMON /BLOCK3/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB,NEWBAR
      COMMON /BLOCK4/ AL(101),STRAIN(101),CONSTR(101),STRESSS(101)
      COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
      COMMON /BLOCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
      COMMON /BLOCK8/ Y(101),REFF(101),YP(101),H,ICLOSEB,YPITE(101)
      COMMON /BLOCK9/ STX,STY,PSX,PSY,ITE
      COMMON /BLOCK10/ NSTRN,VOS,AGEU(20),TENSION(20),STRNMUL
      COMMON /BLOCK12/ DT(50),NTEMP,NTIFLAG,UPINC,DOWNINC
      COMMON /BLOCK13/ AGE(8),PERCENT(8),COLDTM,ANTEMP,IBXBAR,COLDSTN
      COMMON /BLOCK14/ F(101),BONDL,Z,DELTAT,STRMAX,WHLSTR,TMLOD,IBECK
C
      DIMENSION SUM(101),AN1(16),AN2(7)
      DATA AGE/0.,1.,3.,5.,7.,14.,21.,28./
      DATA PERCENT/0.,15.,36.,53.,63.,82.,94.,100./
      DATA EP/ 1.0E-09 /,NTP1/ 101 /,VDS/ 4.0 /,MAXITE/ 30 /
      INTEGER AAA
C
C     PROGRAM AND PROBLEM IDENTIFICATION
C
      READ 510, (AN1(N),N=1,16)
   10 READ 520, NPROB,(AN2(N),N=1,7)
        IF(EOF,5) 470,11
   11 PRINT 530
      PRINT 540, (AN1(N),N=1,16)
      PRINT 550, NPROB,(AN2(N),N=1,7)
C
C     INPUT STEEL PROPERTIES
C
      READ 560, ITYPER,P,DIA,FY,ES,ALPHAS,BHIGH
      PRINT 580
      PRINT 570
      PRINT 580
         IF (ITYPER.EQ.1) PRINT 590
         IF (ITYPER.EQ.2) PRINT 600
         IF (ITYPER.LT.1.OR.ITYPER.GT.2) GO TO 450
      PRINT 610, P,DIA,FY,ES,ALPHAS
C
C     INPUT CONCRETE PROPERTIES
C
      READ 620, THICK,ALPHAC,ZTOT,UNWT,FPC,STRNMUL,NSTRN,IFY
      PRINT 580
      PRINT 630
      PRINT 580
      PRINT 640, THICK,ALPHAC,ZTOT,UNWT,FPC
C
C     INPUT ENVIROMENTAL FACTORS
C
      READ 650, CURTEMP,NTEMP,DELTATM,COLDTM,COLDSTN
C
```

```
C       INPUT MINIMUM DAILY TEMPERTURE
C
      READ 655, (DT(I),I=1,NTEMP)
C
C     INPUT EXTERNAL LOAD
C
      READ 660,TMLOD,WHLOAD,WHBASE,SOILK,WHLSTR
      READ 665, TOL,LONGPR,NPRINT,IPLOT,TMSCALE,FINAL
C
C       MAKE DEFAULT SETTINGS
C
          IF(LONGPR.EQ.3HYES.AND.NPRINT.LE.0) NPRINT = 20
          IF(IFY.LE.0) IFY = 2
          IF(TOL.LE.0.0) TOL = 5.0
          IF(ITYPER.EQ.2.AND.BHIGH.LE.0.0) BHIGH = 18.0
          IF (STRNMUL.EQ.0.0) STRNMUL = 1.0
          IF (COLDTM.LT.NTEMP) COLDTM = NTEMP
          IF (TMLOD.GE.NTEMP) TMLOD = NTEMP
C
         IF (NSTRN.EQ.0) GO TO 30
C
C     INPUT AGE-TENSILE STRENGTH RELATIONSHIP
C
      READ 668, (AGEU(I),TENSION(I),I=1,NSTRN)
              TENS=TENSION(NSTRN)
      PRINT 670, ((AGEU(I),TENSION(I)),I=1,NSTRN)
         GO TO 60
   30 PRINT 680
      PRINT 690
      DO 50 I=1,8
              DUMDUM=FPC*PERCENT(I)*0.01
         IF (DUMDUM.EQ.0.) GO TO 40
              DUMDUM=STRNMUL*3000./(3.+12000./DUMDUM)
   40 PRINT 700, AGE(I),DUMDUM
   50 CONTINUE
              TENS=STRNMUL*3000./(3.+12000./FPC)
C
C     INPUT SLAB-BASE FRICTION RELATIONSHIP **(FORCE-DISPLACEMENT**)
C
   60 PRINT 710
      READ 730, (FEXP(I),YEXP(I),I=1,IFY)
         IF (IFY.EQ.2) GO TO 80
         IF (IFY.GT.2) GO TO 90
              FRICMUL=FEXP(1)/YEXP(1)
              FU=FEXP(1)
         PRINT 740, FEXP(1),YEXP(1)
         GO TO 100
   80          FRICMUL=SQRT(ABS(1/YEXP(1)))*FEXP(1)
              FU=FEXP(1)
         PRINT 750, FEXP(1),YEXP(1)
         GO TO 100
   90      IF (FEXP(1).NE.0.OR.YEXP(1).NE.0.) GO TO 440
         PRINT 760, ((FEXP(I),YEXP(I)),I=1,IFY)
  100 PRINT 800
      PRINT 790, CURTEMP
      PRINT 810
      DO 110 I=1,NTEMP
              TEMPT=DT(I)
              DT(I)=CURTEMP-DT(I)
          IF (DT(I).LT.0) DT(I)=0.
      PRINT 820, I,TEMPT,DT(I)
  110 CONTINUE
C
      PRINT 840, DELTATM,COLDTM
                DELTATM=CURTEMP-DELTATM
C
C        CALCULATE WHEEL STRESS
C
      IF (NSTRN.EQ.0) GO TO 111
         DUMA=TENS/STRNMUL
         DUMB=(12000.*DUMA)/(3000.-3.*DUMA)
         ECON=33.*(UNWT**1.5)*SQRT(DUMB)
      GO TO 112
  111    ECON=33.*(UNWT**1.5)*SQRT(FPC)
  112 IF (WHLOAD.EQ.0.) GO TO 116
      Q1=1.724*THICK
      IF (WHBASE.GE.Q1) GO TO 113
      B=SQRT(1.6*(WHBASE**2.)+(THICK**2.))-(.675*THICK)
      GO TO 114
  113 B=WHBASE
  114 Q2=ECON*(THICK**3.)
      Q3=11.73*SOILK
      STIF=(Q2/Q3)**.25
      Q4=(.316*WHLOAD)/(THICK**2.)
      Q5=ALOG10(STIF/B)
      WHLSTR=Q4*(4*Q5+1.069)
  116 CONTINUE
      PRINT 845
      PRINT 850
      PRINT 846
      IF (WHLOAD.EQ.0.0) GO TO 852
      PRINT 851,WHLOAD,WHBASE,SOILK,ECON,TMLOD,WHLSTR
      GO TO 854
  852 PRINT 853,WHLSTR,TMLOD
  854 PRINT 860
      PRINT 870, MAXITE,TOL
          IF (IPLOT.EQ.3HYES) CALL PLOTEMP (TMSCALE,FINAL)
C     ***********************************
C          INITIALIZE PARAMETERS         *
C     ***********************************
        IF(LONGPR.EQ.3HYES) PRINT 500
               XBAR = 4800.0
               IFINISH=0
               TOL=0.01*TOL
               P=0.01*P
  130        IF (ITYPER.EQ.2) ICLOSEB=1
               NEWBAR = 0
               ANTEMP=NTEMP
               IBABY=0
               IBECK=0
               IBXBAR=0
               IENDONE=0
               ITEB=0
               NT=NTP1-1
               H=XBAR/(2.0*NT)
               IB=1
               AAA=1
               BLOW=0.5*BHIGH
  140           NTIFLAG=1
               TIME=0.
```

```
            DOWNINC=2.
            UPINC=10.
            DELTAT=0.
            Z=0.
C      *****************************************************************
C         THIS SECTION OF THE PROGRAM HAS THE ALGORITHIUM FOR THE
C         INCREMENTAL APPROACH BEFORE THE TENSILE STRENGTH REACHES
C         A MAXIMUM CONSTANT LEVEL.
C      *****************************************************************
          IF (ITYPER.EQ.2.) BONDL=BLOW+(BHIGH-BLOW)*RANB(0.)
  150            ITTIME=0
  160    CALL DELTEMP (TIME,DELTAT)
         IF (TIME.GE.ANTEMP) GO TO 260
      CALL FORWARD (TENSTRN,ZTOT,Z)
      CALL PACKAGE (SUM,INDEX)
         IF (NEWBAR.EQ.1) GO TO 130
         IF (STRMAX.LT.TENSTRN) GO TO 170
            NTIFLAG=-1
            ITTIME=ITTIME+1
         IF (ITTIME.GT.MAXITE) GO TO 410
         GO TO 160
 170  CONTINUE
         IF (ABS(STRMAX).LT.0.001) GO TO 150
            PFLS=TENSTRN
            PSTRMAX=STRMAX
            NTIFLAG=1
      IF (IFINISH.EQ.1) PRINT 490, TIME,DELTAT,Z,TENSTRN,XBAR,CRACKW,
     1      STRMAX,STRESSS(NTP1)
C
C         LOCATE POINT 2
C
  180       ITE=1
      CALL DELTEMP (TIME,DELTAT)
         IF (TIME.GE.ANTEMP) GO TO 260
      CALL FORWARD (TENSTRN,ZTOT,Z)
      CALL PACKAGE (SUM,INDEX)
         IF (NEWBAR.EQ.1) GO TO 130
            DUMMY=(STRMAX-TENSTRN)/TENSTRN
         IF (ABS(DUMMY).LT.TOL) GO TO 220
         IF ((STRMAX-TENSTRN).GE.0.) GO TO 200
            PFLS=TENSTRN
            PSTRMAX=STRMAX
      IF (IFINISH.EQ.1) PRINT 490, TIME,DELTAT,Z,TENSTRN,XBAR,CRACKW,
     1      STRMAX,STRESSS(NTP1)
         GO TO 180
 200  CONTINUE
            IBXBAR=1
 210  CONTINUE
            ITE=ITE+1
         IF (ITE.GT.MAXITE) GO TO 460
      CALL GETME (PFLS,PSTRMAX,TENSTRN,STRMAX,FOUT)
            TENSTRN=FOUT
            NTIFLAG=0
      CALL BACKWAR (FOUT,ZTOT,Z)
      CALL DELTEMP (TIME,DELTAT)
      CALL PACKAGE (SUM,INDEX)
         IF (NEWBAR.EQ.1) GO TO 130
            DUMMY=(STRMAX-TENSTRN)/TENSTRN
         IF (ABS(DUMMY).GE.TOL) GO TO 210
 220  CONTINUE
            IBXBAR=1
            ICRLOC=0
            RESPONS=TIME
         IF (IENDONE.EQ.1) GO TO 230
            XBAR=0.5*XBAR
            H=XBAR/(2.*NT)
         GO TO 240
 230  CONTINUE
            BOUNDU=XBAR
            XBAR=(BOUNDL+BOUNDU)*0.5
            H=XBAR/(2.*NT)
 240      TRY1=2.*XBAR
 241  CONTINUE
          IF (ITYPER.EQ.2.) BONDL=BLOW+(BHIGH-BLOW)*RANB(0.)
      CALL PACKAGE (SUM,INDEX)
         IF (NEWBAR.EQ.1) GO TO 130
         IF (IBABY.EQ.0) GO TO 250
      CALL BABY (IENDONE,BOUNDL,BOUNDU)
          TRY2=ABS(TRY1-XBAR)
      IF (TRY2.LT.1.0) GO TO 250
         GO TO 241
 250  CONTINUE
      IF (IFINISH.EQ.1) PRINT 490, TIME,DELTAT,Z,TENSTRN,XBAR,CRACKW,
     1      STRMAX,STRESSS(NTP1)
            PFLS=TENSTRN
            PSTRMAX=STRMAX
            NTIFLAG=1
         GO TO 180
C     *****************************************************************
C     THIS SECTION OF PROGRAM HAS THE ALGORITHM FOR THE INCREMENTAL
C     APPROACH AFTER THE TENSILE STRENGTH REACHED MAXIMUM VALUE.
C     *****************************************************************
 260        TIME=ANTEMP
      CALL FORWARD (TENSTRN,ZTOT,Z)
            DELTAT=DELTATM
          IF (ITYPER.EQ.2.) BONDL=BLOW+(BHIGH-BLOW)*RANB(0.)
 270        Z=ZTOT
      CALL PACKAGE (SUM,INDEX)
         IF (NEWBAR.EQ.1) GO TO 130
 290  CONTINUE
            DUMMY=(STRMAX-TENSTRN)/TENSTRN
         IF (ABS(DUMMY).LT.TOL) GO TO 360
         IF (STRMAX.LT.TENSTRN) GO TO 320
            IBXBAR=1
            ICRLOC=1
         IF (IENDONE.EQ.1) GO TO 300
            XBAR=0.5*XBAR
            H=XBAR/(2.*NT)
         GO TO 270
 300  CONTINUE
            BOUNDU=XBAR
            XBAR=(BOUNDL+BOUNDU)*0.5
            H=XBAR/(2.*NT)
          GO TO 270
 320  CONTINUE
         IF (ICRLOC.EQ.0.AND.IFINISH.EQ.1) GO TO 370
            NTIFLAG=1
         IF (IENDONE.NE.1) BOUNDU = 2.0 * XBAR
            BOUNDL=XBAR
            XBAR=(BOUNDU+BOUNDL)*0.5
```

```
            H=XBAR/(2.*NT)
        IF (IBXBAR.EQ.0) GO TO 140
            IENDONE=1
            DUMMY=(BOUNDU-BOUNDL)/BOUNDU
        IF (DUMMY.LT.0) GO TO 420
        IF (DUMMY.LT.TOL) GO TO 360
        IF (ICRLOC.NE.0) GO TO 270
            TIME=RESPONS
            IBECK=0
        GO TO 150
 360  CONTINUE
        IF (IFINISH.EQ.0) GO TO 380
 370  CONTINUE
      CALL PACKAGE (SUM,INDEX)
            XBAR=XBAR/12.
      PRINT 880, XBAR,CRACKW,STRMAX,STRESSS(NTP1),TENSTRN
      PRINT 890
      PRINT 900, (I,AL(I),Y(I),F(I),CONSTR(I),STRESSS(I),I=1,NTP1)
 380  CONTINUE
        IF (IFINISH.EQ.1) GO TO 10
            TEMXBAR=XBAR
            XBAR=4800.0
            IFINISH=1
      PRINT 530
      PRINT 540, (AN1(N),N=1,16)
      PRINT 550, NPROB,(AN2(N),N=1,7)
      PRINT 480
        GO TO 130
C
  410 PRINT 910
        GO TO 10
 420  CONTINUE
      PRINT 920
        GO TO 470
 440  CONTINUE
      PRINT 940
        GO TO 470
  445 CONTINUE
      PRINT 475,STRMAX,TENSTRN,BOUNDU,BOUNDL
        GO TO 10
 450  CONTINUE
      PRINT 950, ITYPER
        GO TO 470
 460  CONTINUE
      PRINT 960, ITE
 470  CONTINUE
C
  475 FORMAT (//,10X,*ERROR IS DETECTED*,/,10X,*STRMAX =*,E10.3,/,
     1           10X,*TENSTRN =*,E10.3,/,10X,*BOUNOU =*,E10.3,/,
     2           10X,*BOUNDL =*,E10.3)
 480  FORMAT (62X,9H MAXIMUM ,/, 2X,23H TIME   TEMP    DRYING ,
     1      53H  TENSILE  CRACK     CRACK     CONCRETE    STRESS IN ,/,
     2      1X,51H (DAYS)  DROP   SHRINKAGE  STRGTH  SPACING   WIDTH ,
     3      4X,22H STRESS      THE STEEL ,/)
 490  FORMAT ( 2X,F5.2,2X,F5.1,2X,E10.3,2X,F5.1,3X,F6.1,
     1      1X,E10.3,2(2X,E10.3))
 500  FORMAT ( 1H1 )
 510  FORMAT (8A10)
 520  FORMAT (A5,5X,7A10)
 530  FORMAT (5H1    ,76X,10HI-----TRIM)
```

```
540  FORMAT (1X,8A10)
550  FORMAT (//,5H PROB,/,A5,5X,7A10,//)
560  FORMAT (I5,5X,6(E10.3))
570  FORMAT (10X,1H*,46X,1H*,/,
   1      10X,48H*                STEEL PROPERTIES              *,/,
   2      10X,1H*,46X,1H*)
580  FORMAT (10X,48(1H*))
590  FORMAT (//,15X,39H TYPE OF LONGITUDINAL REINFORCEMENT IS ,/,
   1            26X,14H DEFORMEO BARS)
600  FORMAT (//,15X,39H TYPE OF LONGITUDINAL REINFORCEMENT IS ,/,
   1            23X,21H DEFORMED WIRE FABRIC)
610  FORMAT (//,15X,24H PERCENT REINFORCEMENT =,E10.3,/,
   1            15X,24H BAR DIAMETER          =,E10.3,/,
   2            15X,24H YIELD STRESS          =,E10.3,/,
   3            15X,24H ELASTIC MODULUS       =,E10.3,/,
   4            15X,24H THERMAL COEFFICIENT   =,E10.3,///)
 620 FORMAT (10X,5E10.3,F4.1,I2,2X,I2)
630  FORMAT (10X,1H*,46X,1H*,/,
   1      10X,48H*              CONCRETE PROPERTIES             *,/,
   2      10X,1H*,46X,1H*)
640  FORMAT (//,15X,22H SLAB THICKNESS      =,E10.3,/,
   1            15X,22H THERMAL COEFFICIENT =,E10.3,/,
   2            15X,22H TOTAL SHRINKAGE     =,E10.3,/,
   3            15X,22H UNIT WEIGHT CONCRETE=,E10.3,/,
   4            15X,22H COMPRESSIVE STRENGTH=,E10.3,//)
 650 FORMAT (E10.3,I5,5X,E10.3,5X,F5.1,F10.1)
 655 FORMAT ((16F5.1))
 660 FORMAT (5E10.2)
 665 FORMAT (F5.1,2X,A3,I5,2X,A3,F15.10,F5.0)
 668 FORMAT ((16F5.0))
670  FORMAT (//,15X,40H TENSILE STRENGTH DATA AS INPUT BY USER ,//,
   1            14X,16H AGE,   TENSILE ,/,
   2            13X,18H (DAYS)  STRENGTH ,/,
   3           (15X,F5.1,2X,F5.1))
680  FORMAT (14X,22H TENSILE STRENGTH DATA,/,15X,21(1H*))
690  FORMAT ( /,15X,43H NO TENSILE STRENGTH DATA IS INPUT BY USER ,/,
   1          15X,49H THE FOLLOWING AGE-TENSILE STRENGTH RELATIONSHIP ,/
   2,         15X,46H IS USED WHICH IS BASED ON THE RECOMMENDATION ,/,
   3          15X,37H GIVEN BY U.S. BUREAU OF RECLAMATION ,//,
   4          15X,15H AGE,  TENSILE ,/,
   5          14X,17H (DAYS) STRENGTH ,/)
700  FORMAT (13X, 2(2X,F5.1))
710  FORMAT ( /,10X,48(1H*),/,10X,1H*,46X,1H*,/,
   1      10X,1H*,5X,35H SLAB-BASE FRICTION CHARACTERISTICS,6X,1H*,/,
   2      10X,1H*,14X,17H F-Y RELATIONSHIP,15X,1H*,/,10X,1H*,46X,1H*,/,
   3      10X,48(1H*),//)
730  FORMAT ((8F10.4))
740  FORMAT (15X,41HTYPE OF FRICTION CURVE IS A STRAIGHT LINE,//,
   1     15X,24H MAXIMUM FRICTION FORCE=,F10.4,/,
   2     15X,24H MOVEMENT AT SLIDING   =,F10.4)
750  FORMAT (15X,36HTYPE OF FRICTION CURVE IS A PARABOLA,//,
   1     15X,24H MAXIMUM FRICTION FORCE=,F10.4,/,
   2     15X,24H MOVEMENT AT SLIDING   =,F10.4)
760  FORMAT (11X,45HTYPE OF FRICTION CURVE IS A MULTILINEAR CURVE,//,
   1      17X,5H F(I),5X,5H Y(I),//,(13X,2F10.4),//)
790  FORMAT (   14X,20H CURING TEMPERATURE=,F5.1,//)
800  FORMAT (///,10X,30(1H*),/,
   1      10X,1H*,28X,1H*,/,
   2      10X,30H*      TEMPERATURE DATA      *,/,10X,1H*,28X,1H*,/,
   3      10X,30(1H*),//)
```

```
810  FORMAT (20X,7HMINIMUM,6X,7HDROP IN,/,
    1      10X,3HDAY,5X,11HTEMPERATURE,2X,11HTEMPERATURE,/)
820  FORMAT (10X,(I3,8X,F5.1,8X,F5.1))
 840 FORMAT (/,12X,36H MINIMUM TEMPERATURE EXPECTED AFTER ,/,
    1          12X,37H CONCRETE GAINS FULL STRENGTH       =,F5.1,
    2          22H DEGREES FAHRENHEIT   ,/,13X,*DAYS BEFORE*
    3          * REACHING MIN. TEMP.    =*F5.1,X,*DAYS*)
 845 FORMAT (1H1,//,10X,48(1H*))
 846 FORMAT (10X,48(1H*))
 850 FORMAT (10X,1H*,46X,1H*,/,
    1      10X,48H*                EXTERNAL LOAD                *,/,
    2      10X,1H*,46X,1H*)
 851 FORMAT (//,15X,25H WHEEL LOAD (LBS)        =,E10.3,/,
    1           15X,25H WHEEL BASE RADIUS (IN) =,E10.3,/,
    2           15X,25H SUBGRADE MODULUS (PSI) =,E10.3,/,
    3           15X,25H CONCRETE MODULUS (PSI) =,E10.3,/,
    4           15X,25H LOAD APPLIED AT        =,X,F2.0,* TH DAY*,/,
    5           15X,25H CALC.LOAD STRESS (PSI) =,E10.3,///)
 853 FORMAT (//,15X,25H WHEEL LOAD STRESS (PSI)=,E10.3,/,
    1           15X,25H LOAD APPLIED AT        =,X,F2.0,* TH DAY*,///)
860  FORMAT (//,10X,48(1H*),/,10X,1H*,46X,1H*,/,10X,1H*,6X,
    1        33H ITERATION AND TOLERANCE CONTROL ,7X,1H*,/,
    2        10X,1H*,46X,1H*,/,10X,48(1H*),///)
870  FORMAT (10X,40H MAXIMUM ALLOWABLE NUMBER OF ITERATIONS=,I5  ,//
    1         10X,28H RELATIVE CLOSURE TOLERANCE=,F5.1, 8H PERCENT,//)
880  FORMAT (1H1,10X,34H AT THE END OF THE ANALYSIS PERIOD,/,
    1     /,10X,21H CRACK SPACING       =,E10.3,6H FEET ,
    2     /,10X,21H CRACK WIDTH         =,E10.3,8H INCHES ,
    3     /,10X,21H MAX CONCRETE STRESS=,E10.3,5H PSI ,
    4     /,10X,21H MAX STEEL STRESS   =,E10.3,5H PSI,
    5     /,10X,21H CONC.TENS.STRENGTH =,E10.3,5H PSI )
890  FORMAT (//,10X,48H STA-   DIS-   CONCRETE    FRICTION   CONCRETE
    1,        4X,7H STEEL ,/,10X,24H TION  TANCE   MOVEMENT ,
    2         4X,31H FORCE       STRESS      STRESS ,/)
900  FORMAT (10X,I5,2X,F5.1,2X,4(E10.3,2X,))
910  FORMAT (//,10X,37H FOR ALLOWABLE NUMBER OF ITERATIONS, ,/,
    1           10X,36H THE SOLUTION DOES NOT CLOSE ON THE ,
    2           10X,24H STRESS STRENGTH CURVE. ,/,
    3         13X,29HCURRENT PROBLEM IS TERMINATED,/,
    4           19X,18H PROGRAM CONTINUES)
920  FORMAT (//,10X,41H ERROR IS DETECTED BY ITERATING ON CRACK ,/,
    1           10X,41H SPACING.  PROGRAM IS TERMINATED.         ,)
930  FORMAT (//,15X,3H** ,*CURRENT PROBLEM IS TERMINATED*3H **,//,
    1           15X,*THE BOND LENGTH IS GREATER THAN THE*,/,
    2           15X,*CRCP MODEL. UNFORTUNATELY, FOR THIS*,/,
    3           15X,*CONDITION, THE THEORETICAL EQUATIONS*,/,
    4           15X,*DO NOT HOLD TRUE.*,/,23X,*PROGRAM CONTINUES*)
940  FORMAT  (//,10X,* ERROR IS DETECTED *,/,
    1       10X,* FRICTION-MOVEMENT CURVE INPUT IS WRONG *,/,
    2       10X,* F(1) AND Y(1) SHOULD BE ZEROS *,/,
    3       10X,* PROGRAM IS TERMINATED *)
950  FORMAT  (//,10X,* ERROR IS DETECTED *,/,
    1   10X,*TYPE OF PERCENT REINFORCEMENT OPTION IS NOT RIGHT*,/,
    2   10X,*ITYPER=*,I5)
960  FORMAT (//,10X,* PROGRAM IS TERMINATED , ITE = *,I5)
              END
```

```
      SUBROUTINE PACKAGE (SUM,INDEX)
CC
      COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
      COMMON /BLOCK2/ SS(101),AAA,WS(101),LONGPR,NPRINT,MAXITE,CRACKW
      COMMON /BLOCK3/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB,NEWBAR
      COMMON /BLOCK4/ AL(101),STRAIN(101),CONSTR(101),STRESSS(101)
      COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
      COMMON /BLOCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
      COMMON /BLOCK8/ Y(101),REFF(101),YP(101),H,ICLOSEB,YPITE(101)
      COMMON /BLOCK9/ STX,STY,PSX,PSY,ITE
      COMMON /BLOCK14/ F(101),BONDL,Z,DELTAT,STRMAX,WHLSTR,THLOD,IBECK
      DIMENSION SUM(101)
      REAL L
      INTEGER AAA
C
            L=0.5*XBAR
      DO 10 I=1,NTP1
            Y(I)=REFF(I)=YP(I)=AL(I)=F(I)=0.
            SS(I)=STRAIN(I)=CONSTR(I)=STRESSS(I)=0.
 10   CONTINUE
         IF (ITYPER.EQ.1) CALL DFBAR(THLOD,WHLSTR)
         IF (NEWBAR.EQ.1) RETURN
         IF (ITYPER.EQ.2) CALL DFWIRE
        IF (BONDL.GT.L) IBABY=1
        IF (BONDL.LE.L) IBABY=0
            STRAINC=STRMAX/EC
      CALL STRGENE (BONDL)
      CALL SIMPSPE (STRAIN,NTP1,H,SUM)
      CALL CONMOV (SUM,Z,DELTAT)
      CALL FRIC (F)
      DO 20 J=1,NTP1
   20       REFF(J)=F(J)
         IF (ITYPER.EQ.1) CALL DFBARF(THLOD,WHLSTR)
         IF (ITYPER.EQ.2) CALL DFWIREF
      CALL SIMPSPE (STRAIN,NTP1,H,SUM)
      CALL CONMOV (SUM,Z,DELTAT)
      CALL FRIC (F)
      DO 30 J=1,NTP1
   30       F(J)=(REFF(J)+F(J))*0.5
C
   40 CALL SIMPSPE (F,NTP1,H,SUM)
            FF=SUM(NTP1)
        IF (AAA.LT.MAXITE) GO TO 50
      PRINT 90, AAA
      PRINT 100
      PRINT 110, (I,AL(I),REFF(I),YP(I),Y(I),F(I),I=1,NTP1)
   50 IF(FRICMUL.NE.0.0) CALL BAKFRIC(F)
         IF (ITYPER.EQ.1) CALL DFBARF(THLOD,WHLSTR)
         IF (ITYPER.EQ.2) CALL DFWIREF
        IF (LONGPR.NE.3HYES) GO TO 60
      PRINT 120
      PRINT 140, TIME,Z,DELTAT
      PRINT 130, STRMAX
   60 CALL SIMPSPE (STRAIN,NTP1,H,SUM)
      CALL CONMOV (SUM,Z,DELTAT)
      CALL CLOSE (NTP1,INDEX,F)
        IF (INDEX.EQ.1.AND.ICLOSEB.EQ.1) RETURN
      DO 200 I=1,NTP1
        IF (YP(I).GT.Y(I)) GO TO 250
            TEMP=REFF(I)
```

```
             REFF(I)=F(I)
             F(I)=(3.0*F(I)-TEMP)*0.5
      GO TO 200
250   CONTINUE
             F(I)=(REFF(I)+F(I))*0.5
200   CONTINUE
      GO TO 40
C
 90   FORMAT (//,10X,*RESULTS FOR ITERATION *, I5,/)
100   FORMAT (/,12X,*I*,7X,*AL(I)*,7X,*REFF*,9X,*YP*,11X,*Y*,11X,*F*,/)
110   FORMAT (10X,I5,5(2X,E10.3))
120   FORMAT (//,20X,*IN THE PACKAGE ROUTINE*,/)
130   FORMAT (  19X,* STRMAX =*,E10.3)
140   FORMAT ( 19X,* FOR TIME OF * ,E10.3,/,
     1   20X,*SHRINKAGE=*,E10.3,/,
     2   20X,*DELTAT   =*,E10.3)
      END
```

```
      SUBROUTINE CONMOV (SUM,Z,DELTAT)
CC
C     ******************************************************************
C         THIS SUBROUTINE COMPUTES THE MOVEMENT OF THE CONCRETE AT
C         EVERY STATION . THE MOVEMENT IS COMPUTED FROM THE DEVELOPPED
C         DIFFERENTIAL EQUATION .
C     ******************************************************************
C
      COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
      COMMON /BLOCK2/ SS(101),AAA,WS(101),LONGPR,NPRINT,MAXITE,CRACKW
      COMMON /BLOCK3/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB,NEWBAR
      COMMON /BLOCK4/ AL(101),STRAIN(101),CONSTR(101),STRESSS(101)
      COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
      COMMON /BLOCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
      COMMON /BLOCK8/ Y(101),REFF(101),YP(101),H,ICLOSEB,YPITE(101)
      DIMENSION SUM(101)
      INTEGER AAA
C
      DO 10 I=1,NTP1
               Y(I)=SUM(I)-AL(I)*(ALPHAC*DELTAT+Z)+Y(1)
   10   IF (ABS(Y(I)).GT.1.) GO TO 20
               CRACKW=ABS(Y(NTP1))*2.
        IF (LONGPR.EQ.3HYES) PRINT 30,((I,AL(I),STRAIN(I),SUM(I),Y(I)),
     1                        I=1,NTP1,NPRINT)
      RETURN
C
   20 PRINT 50, (Y(I),I=1,NTP1)
   30 FORMAT( //,25X,*IN SUBROUTINE CONMOV*,
     1           //,10X,* INDEX  DISTANCE    CON STR      SUM        CO
     2N MOV *,//,(10X,I5,4(2X,E10.3)))
 50   FORMAT (/,10X,47H MOVEMENTS GREATER THAN 1 INCH ARE ENCOUNTERED ,/
     1,      10X,8(2X,E10.3))
      END
```

```
      SUBROUTINE CLOSE (N,INDEX,F)
CC
C     ****************************************************************
C           THIS SUBROUTINE IS USED WITH THE BINARY TECHNIQUE
C           OF MOVEMENT CLOSURE
C     ****************************************************************
C
      COMMON /BLOCK2/ SS(101),AAA,WS(101),LONGPR,NPRINT,MAXITE,CRACKW
      COMMON /BLOCK4/ AL(101),STRAIN(101),CONSTR(101),STRESSS(101)
      COMMON /BLOCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
      COMMON /BLOCK8/ Y(101),REFF(101),YP(101),H,ICLOSEB,YPITE(101)
      DIMENSION DIF(101),F(101)
      INTEGER AAA
C
               INDEX=0
               BAD=1.
      IF(LONGPR.EQ.3HYES) PRINT 140
         IF (AAA.EQ.1) GO TO 50
      DO 20 I=2,N
         IF (Y(I).EQ.0.) GO TO 20
         IF (ABS(Y(I)).LT.1.E-06) GO TO 20
               DIF(I)=(Y(I)-YPITE(I))/Y(I)
          IF (ABS(DIF(I)).GT.TOL) BAD=BAD+1.
 20   CONTINUE
         IF (LONGPR.NE.3HYES) GO TO 30
      PRINT 80
      PRINT 90, ((I,Y(I),YPITE(I),DIF(I)),I=1,N,NPRINT)
 30   CONTINUE
         IF (BAD.GT.1.) GO TO 50
           INDEX = 1
           AAA = 1
         IF (LONGPR.EQ.3HYES) PRINT 100
      RETURN
 50   CONTINUE
               AAA=AAA+1
         IF (AAA.GT.MAXITE) GO TO 70
               MA1=AAA-1
      DO 60 I=1,N
   60          YPITE(I)=Y(I)
          IF (LONGPR.EQ.3HYES) PRINT 110,MA1,BAD,AAA
      RETURN
C
 70   CONTINUE
      PRINT 120
      PRINT 110, MA1,BAD,AAA
      PRINT 80
      PRINT 130, ((I,Y(I),YPITE(I),DIF(I),SS(I),STRESSS(I),STRAIN(I),
     1      CONSTR(I),F(I)),I=1,N)
C
 80   FORMAT ( 20X,*      Y         YPITE        DIF      *,/)
 90   FORMAT ( 20X,I5,3(2X,E10.3))
 100  FORMAT (10X,3H** ,*SOLUTION CLOSES WITHIN THE SPECIFIED NUMBER OF
     1ITERATIONS *,2H**,6/ )
 110  FORMAT ( /,10X,* SOLUTION DID NOT CLOSE FOR ITERATION*,I5,/,
     1    10X,*THE NUMBER OF POINTS THAT DID NOT CLOSE ARE*,F10.0,/,
     2     1H1,//,10X,* RESULTS FOR ITERATION *,I5,//)
 120  FORMAT (//,10X,* BAD LUCK, SOLUTION DID NOT CLOSE *,//)
 130  FORMAT ( 20X,I5,8(2X,E10.3))
  140 FORMAT(//,30X,*IN SUBROUTINE CLOSE*,/)
      END
```

```
      SUBROUTINE BAKFRIC (F)
CC
      COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
      COMMON /BLOCK2/ SS(101),AAA,WS(101),LONGPR,NPRINT,MAXITE,CRACKW
      COMMON /BLOCK3/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB,NEWBAR
      COMMON /BLOCK4/ AL(101),STRAIN(101),CONSTR(101),STRESSS(101)
      COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
      COMMON /BLOCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
      COMMON /BLOCK8/ Y(101),REFF(101),YP(101),H,ICLOSEB,YPITE(101)
      DIMENSION F(101)
      INTEGER AAA
C
         IF (IFY.EQ.1) GO TO 40
         IF (IFY.EQ.2) GO TO 60
      DO 30 I=1,NTP1
      DO 10 J=1,IFY
         IF (ABS(F(I)).LT.ABS(FEXP(J))) GO TO 20
 10   CONTINUE
               YP(I)=YEXP(IFY)
         GO TO 30
 20   CONTINUE
               DUMDUM=(FEXP(J)-FEXP(J-1))/(ABS(YEXP(J))-ABS(YEXP(J-1)))
               YP(I)=ABS(YEXP(J-1))+(ABS(F(I))-FEXP(J-1))/DUMDUM
          IF (F(I).GT.0) YP(I)=-YP(I)
 30   CONTINUE
      RETURN
 40   CONTINUE
      DO 50 I=1,NTP1
               YP(I)=F(I)/FRICMUL
          IF (ABS(F(I)).GE.FU) YP(I)=YEXP(1)
 50   CONTINUE
      RETURN
 60   CONTINUE
      DO 70 I=1,NTP1
               YP(I)=(F(I)/FRICMUL)**2
          IF (ABS(F(I)).GE.FU) YP(I)=YEXP(1)
          IF (F(I).GT.0) YP(I)=-YP(I)
 70   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE BABY (IENDONE,BOUNDL,BOUNDU)
CC
      COMMON /BLOCK3/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB,NEWBAR
      COMMON /BLOCK4/ AL(101),STRAIN(101),CONSTR(101),STRESSS(101)
      COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
      COMMON /BLOCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
      COMMON /BLOCK8/ Y(101),REFF(101),YP(101),H,ICLOSEB,YPITE(101)
C
           IBABY = 0
                BOUNDL=XBAR
         IF (IENDONE.EQ.1) GO TO 10
                BOUNDU=2.*XBAR
                XBAR=(BOUNDL+BOUNDU)*0.5
                H=XBAR/(2.*NT)
                IENDONE=1
      RETURN
   10           XBAR=(BOUNDL+BOUNDU)*0.5
                H=XBAR/(2.*NT)
      RETURN
      END
```

```
      SUBROUTINE DFBARF
CC
C     ******************************************************************
C         THIS SUBROUTINE SOLVES FOR THE STRESS IN THE STEEL AT THE CRAC
C         AND BETWEEN CRACKS.  IT IS USED IN THE CASE OF DEFORMED BARS S
C         THE DEVELOPMENT LENGTH CRITERIA OR BOUNDARY CONDITION IS IMPOS
C         IN THE SOLUTION OF THE BASIC EQUATIONS.
C     ******************************************************************
C
      COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
      COMMON /BLOCK2/ SS(101),AAA,WS(101),LONGPR,NPRINT,MAXITE,CRACKW
      COMMON /BLOCK3/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB,NEWBAR
      COMMON /BLOCK4/ AL(101),STRAIN(101),CONSTR(101),STRESSS(101)
      COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
      COMMON /BLOCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
      COMMON /BLOCK7/ SIGMASC,SIGMASB,NA,NAP1,E,A,S,DENO,NAP2
      COMMON /BLOCK8/ Y(101),REFF(101),YP(101),H,ICLOSEB,YPITE(101)
      COMMON /BLOCK14/ F(101),BONDL,Z,DELTAT,STRMAX,WHLSTR,THLOD,IBECK
      DIMENSION SUM(101)
      INTEGER AAA
C
                ICLOSEB=0
                A=AL(NTP1)-BONDL
         IF (A.LE.0.) GO TO 15
                NA=A/H+1+EP
                E=A-AL(NA)
         IF (NA.GT.NT) GO TO 50
                NAP1=NA+1
                NAP2=NA+2
                NAM1=NA-1
                DENO=THICK*(P+1./RATIO)
                SUM1=0.
                SUM2=0.
      DO 10 I=1,NAM1
                SUM1=SUM1+(2*NA-(2.*I+1))*(-F(I)/DENO)
   10           SUM2=SUM2+(-F(I)/DENO)
C
C     DEFINE CONSTANTS
C
                S=-F(NAP1)/DENO
                ANA=NA
   15     CONTINUE
                BONDCON=DIA/(4.*U)
                C1=1.+1./(RATIO*P)
                C2=EC*(Z+DELTAT*(ALPHAC-ALPHAS))/P
                C3=FF/(P*THICK)
          IF (A.LE.0.AND.IBECK.EQ.1) GO TO 16
                C4=C2-C3
                C5=H*SUM2+S*E
                C6=H*H*SUM1*0.5
                C7=(ANA-1.)*H
                C8=H*SUM2*E+S*E*E*0.5
                C9=-C4/C1+C5
C
C     DEFINE QUADRATIC EQUATION CONSTANTS
C
                AA=BONDCON*(1.-1./(C1*C1))*0.5
                BB=(C7+E)/C1-BONDCON*C9/C1
       CC=-ALPHAS*AL(NTP1)*DELTAT*ES-C4*(C7+E)
     1      /C1+C6+C8-BONDCON*C9*C9*0.5
```

```
C
                DELTA=BB*BB-4.*AA*CC
          IF (DELTA.LT.0.) GO TO 60
C
                ROOT1=(-BB+SQRT(DELTA))/(2.*AA)
                ROOT2=(-BB-SQRT(DELTA))/(2.*AA)
          IF (ROOT2.GT.0.) GO TO 40
                SIGMASC=ROOT1
                SIGMASB=(SIGMASC-C4)/C1
                BONDLC=(SIGMASC-(SIGMASB+C5))*BONDCON
           IF (A.GT.0.AND.IBECK.EQ.0) GO TO 17
   16           SIGMASC=AL(NTP1)/(2.*BONDCON)+ES*ALPHAS*DELTAT
                SIGMASB=(SIGMASC-C2+C3)/C1
                BONDLC=(SIGMASC-SIGMASB)*BONDCON
   17           DUM=(BONDLC-BONDL)/BONDLC
           IF (ABS(DUM).LE.TOL) ICLOSEB=1
           IF (ICLOSEB.EQ.1) ITEB=0
                ITEB=ITEB+1
          IF (ITEB.GT.MAXITE) GO TO 20
                BONDL=BONDLC
C
C     COMPUTE AREAS FOR SUMMATION CHECK
C
                A1=H*((2.*ANA-2.)*SIGMASB+H*SUM1)*0.5
                A2=SIGMASB*E+H*SUM2*E+S*E*E*0.5
                A3=(SIGMASB+C5+SIGMASC)*BONDL*0.5
                AAAA=A1+A2+A3
           IF (IBECK.EQ.1) AAAA=AL(NTP1)*(SIGMASC-(AL(NTP1)*
     1                          (SIGMASC-SIGMASB))/(2.*BONDL))
C
                DUM2=ALPHAS*AL(NTP1)*DELTAT*ES
          IF (ABS(AAAA-DUM2).GT.1.E-5) GO TO 70
      CALL POIRES (LOCMAX)
      RETURN
C
 20   CONTINUE
      PRINT 90, ITEB
          GO TO 80
 30   CONTINUE
      PRINT 100, A
          GO TO 80
 40   CONTINUE
      PRINT 110, DELTA,ROOT1,ROOT2
          GO TO 80
 50   CONTINUE
      PRINT 120,NA,NT,BONDL,AL(NTP1),H,A
          GO TO 80
 60   CONTINUE
      PRINT 130, DELTA
      GO TO 80
 70   CONTINUE
      PRINT 140, DUM2,AAAA
 80   CONTINUE
C
 90   FORMAT (//,10X,* SOLUTION DID NOT CLOSE BY ITERATING ON BOND *,
     1       *LENGTH IN SUBROUTINE DFBARF*,/,10X,*PROGRAM IS TERMINATED*,
     2       /,10X,* ITEB=*,I5)
 100  FORMAT (//,10X,*ERROR IS DETECTED IN DFBARF*,/,
     1       10X,*A IS NEGATIVE AND=*,E10.3)
 110  FORMAT (//,10X,*DELTA=*,E10.3,/,
     1                10X,*ROOT1=*,E10.3,/,
     2                10X,*ROOT2=*,E10.3,/,
     3          10X,* ERROR IS DETECTED IN SUBROUTINE DFBARF,ROOT2 IS POS.*)
 120  FORMAT (/,20X,* ERROR IS DETECTED *,/,
     1                10X,* NA = *,I5,10X,* NT = *,I5,/,
     2                10X,* B  = *,F10.3,5X,* AL = *,F10.5,/,
     3                10X,* H  = *,F10.3,5X,* A  = *,F10.5)
 130  FORMAT (/,10X,*ERROR IS DETECTED*,/,
     1            10X,* DELTA IS NEGATIVE AND=*,E10.3)
 140  FORMAT (/,10X,* ERROR IS DETECTED IN SUBROUTINE DFBARF*,/,
     1      10X,* DUM2 IS NOT EQUAL TO AAAA*,/,
     2      10X,* DUM2=*,E15.7,2X,* AAAA=*,E15.7)
      END
```

```
      FUNCTION RANB (ARG)
CC
      DATA PY,RANB/3.0576752,.379845342/
C
          IF (ARG.LT.0.0) RETURN
          IF (ARG.GT.0.0) GO TO 20
   10          TEMP=RANB
               RANB=RANB*PY*1.2357863E+5
               N=RANB
               RANB=ABS(RANB-N)
               PY=TEMP
      RETURN
   20          N=ARG
               PY=ABS(ARG-N)*6.0585548
         GO TO 10
      END
```

```
      SUBROUTINE DFBAR
CC
C     THIS SUBROUTINE COMPUTES THE STRESSES AND STRAINS IN THE CONCRETE
C     STEEL DUE TO A TEMPERATURE DROP AND/OR SHRINKAGE .
C     THE EQUATIONS ARE WRITTEN FOR A FRICTIONLESS SYSTEM
C
      COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
      COMMON /BLOCK2/ SS(101),AAA,WS(101),LONGPR,NPRINT,MAXITE,CRACKW
      COMMON /BLOCK3/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB,NEWBAR
      COMMON /BLOCK4/ AL(101),STRAIN(101),CONSTR(101),STRESSS(101)
      COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
      COMMON /BLOCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
      COMMON /BLOCK8/ Y(101),REFF(101),YP(101),H,ICLOSEB,YPITE(101)
      COMMON /BLOCK14/ F(101),BONDL,Z,DELTAT,STRMAX,WHLSTR,THLOD,IBECK
      INTEGER AAA
C
        HXBAR = 0.5 * XBAR
         IF (Z.LT.0.OR.DELTAT.LT.0.) GO TO 40
         IF (IBECK.EQ.1) GO TO 20
C
C         COMPUTE CONSTANTS
C
               C1=(RATIO*P)/(1.+RATIO*P)
               C2=(ES*Z)/(1.+RATIO*P)
               C3=(1.-C1)*DIA/(4.*U)
               C4=C2*DIA/(4.*U)
               AA=C3-C1*C3
               BB=XBAR*C1-C1*C4+C2*C3+C4
               DD=-ES*XBAR*DELTAT*ALPHAS-XBAR*C2+C2*C4
               DELTA=BB*BB-4.*AA*DD
         IF (DELTA.LT.0.) GO TO 90
C
C       STRSC= STRESS IN THE STEEL AT THE CRACK
C       STRSB= STRESS IN THE STEEL BETWEEN CRACKS
C       STRC= STRESS IN CONCRETE
C
               STRSC=(-BB+(DELTA**0.5))/(2.*AA)
               STRSB=C1*STRSC-C2
               STRC=STRSB/RATIO+EC*Z
               B=(STRSC-STRSB)*DIA/(4.0*U)
         IF (B.LE.0.) GO TO 30
         IF (B.GT.H) GO TO 10
         XBAR=100.*B
         NEWBAR=1
         RETURN
   10    IF (B.GE.HXBAR) GO TO 20
      CRAW=(ALPHAC*DELTAT+Z)*HXBAR-(STRC*(HXBAR-B))/EC-STRC*B/(EC*2.)
               CHE=(XBAR-2.*B)*STRSB+(STRSC+STRSB)*B
               CHECK=CHE-ES*XBAR*DELTAT*ALPHAS
         IF (ABS(CHECK).GT.1.E-2) GO TO 70
C
C     *   CHECKING THE SOLUTION BY SOLVING FOR CONCRETE STRESS FIRST
               C11=DIA/(4.*U*P*P)
               C12=XBAR*RATIO
               C13=XBAR*ES*Z
               C14=ALPHAS*XBAR*ES*DELTAT
               DEL=C12*C12+4.*C11*(C13+C14)
               CONCRES=(-C12+SQRT(DEL))/(2.*C11)
               R2=(-BB-SQRT(DELTA))/(2.*AA)
               R4=C1*R2-C2
```

```
         R6=R4/RATIO+EC*Z
      IF (R6.GT.0) GO TO 50
      IF (R2.GT.0) GO TO 50
      IF (LONGPR.EQ.3HYES) PRINT 130, C1,C2,C3,C4,AA,BB,DD,
     1                    DELTA,DEL,CONCRES
      IF (ABS(STRC-CONCRES).GT.1.E-7) GO TO 80
C
C     *   END OF ABOVE CHECK
C
       GO TO 25
 20        IBECK=1
           C1=1.+(1./RATIO)
           C2=(EC/P)*(DELTAT*(ALPHAC-ALPHAS)+Z)
       STRSB=(1./C1)*((HXBAR*4.*U)/(2.*DIA)+ES*ALPHAS*DELTAT)-(C2/C1)
       STRSC=(HXBAR*4.*U)/(2.*DIA)+ES*ALPHAS*DELTAT
       STRC=(4.*U*HXBAR*P)/DIA
       B=(STRSC-STRSB)*DIA/(4.*U)
     IF (B.LT.HXBAR) GO TO 105
       CRAW=(ALPHAC*DELTAT+Z)*HXBAR-(STRC*HXBAR)/(2.*EC)
       STRAREA=HXBAR*(2.*STRSC-(HXBAR*STRSC)/B+(HXBAR*STRSB)/B)/
     1          (2.*ES)
     IF (ABS(STRAREA-ALPHAS*DELTAT*HXBAR).GT.1.E-7) GO TO 100
       STRMAX=STRC
       STRAINC=STRC/EC
       BONDL=B
 25    IF (LONGPR.EQ.3HYES) PRINT 120,P,DELTAT,Z,XBAR,STRSC,STRSB
     1                   ,STRC,EC,B,CRAW
       IF(ISECK.EQ.1) GO TO 28
C
C      COMPUTE AREA UNDER STEEL STRAIN DIAGRAM FOR THE ASSUMED
C      FRICTIONLESS SYSTEM
C
C
           DUM1=HXBAR-B
           STRAREA=DUM1*STRSB/ES+(STRSB+STRSC)*B/(2.*ES)
      IF (ABS(STRAREA-ALPHAS*DELTAT*HXBAR).GT.1.E-7) GO TO 100
           STRMAX=STRC
C
           STRAINC=STRC/EC
           BONDL=B
C
C      COMPUTE CRACK WIDTH BY USING D.E. CONCEPT
C
         CRWIDTH=Z*BONDL+((STRSC+STRSB)/ES-STRAINC)*BONDL*0.5
         DUM1=(CRAW-CRWIDTH)/CRAW
      IF (ABS(DUM1).GT.0.01) GO TO 60
 28   CONTINUE
      RETURN
C
 30   CONTINUE
      PRINT 140, B
         GO TO 110
 40   CONTINUE
      PRINT 150, Z,DELTAT
         GO TO 110
 50   CONTINUE
      PRINT 160, R2,R4,R6
         GO TO 110
 60   CONTINUE
      PRINT 170, CRAW,CRWIDTH
         GO TO 110
 70   CONTINUE
      PRINT 120, P,DELTAT,Z,XBAR,STRSC,STRSB,STRC,EC,B,CRAW
      PRINT 180, CHECK
         GO TO 110
 80   CONTINUE
      PRINT 120, P,DELTAT,Z,XBAR,STRSC,STRSB,STRC,EC,B,CRAW
      PRINT 190
         GO TO 110
 90   CONTINUE
      PRINT 200
C
 100  CONTINUE
      PRINT 210
      PRINT 220, STRAREA
 105     CONTINUE
         PRINT 115
         PRINT 116,B,HXBAR
 110  CONTINUE
C
 115  FORMAT (//,10X,*IN SUBROUTINE DFBAR, BOND LENGTTH IS*/,
     1          10X,* NOT GREATER THAN HALF THE CRACK SPCING *)
 116  FORMAT (//,10X,*BONDL          =*,E10.3,/,
     1          10X,*HALF XBAR      =*,E10.3,//)
 120  FORMAT (//,10X,* PERCENT REINFORCEMENT         =*,E10.3,/,
     1          10X,* TEMPERATURE DROP              =*,E10.3,/,
     2          10X,* SHRINKAGE                     =*,E10.3,/,
     3          10X,* CRACK SPACING                 =*,E10.3,/,
     4          10X,* STEEL STRESS AT CRACK         =*,E10.3,/,
     5          10X,* STEEL STRESS BETWEEN CRACKS   =*,E10.3,/,
     6          10X,* CONCRETE STRESS               =*,E10.3,/,
     7          10X,* CONCRETE MODULUS              =*,E10.3,/,
     8          10X,* DEVELOPMENT LENGTH            =*,E10.3,/,
     9          10X,* CRACK WIDTH                   =*,E10.3,//)
 130  FORMAT( //,20X,*IN SUBROUTINE DFBAR*,
     1        //,10X,  *  C1 = *,E10.3 ,
     2                 *  C2 = *,E10.3 ,
     3                 *  C3 = *,E10.3 ,
     4                 *  C4 = *,E10.3 ,/,10X,
     5                 *  AA = *,E10.3 ,
     6                 *  BB = *,E10.3 ,
     7                 *  DD = *,E10.3 ,//,10X,
     8                 *  DELTA= *,E10.3 ,
     9                 *  DEL = *,E10.3 ,
     A                 *  CONCRES =*,E10.3, )
 140  FORMAT (//,10X,*ERROR IS DETECTED IN SUBROUTINE DFBAR*,/,
     1      10X,*BOND LENGTH IS NEGATIVE AND=*,E10.3,/,
     2      10X,*PROGRAM IS TERMINATED*)
 150  FORMAT (//,10X,* ERROR IS DETECTED IN SUBROUTINE TEMPSHR *,
     1          10X,*       Z = *,E10.3,/,
     2          10X,* DELTAT = *,E10.3)
 160  FORMAT (//,10X,*ERROR IS DETECTED IN SUBROUTINE TEMPSHR *
     1          10X,* STEEL STRESS AT CRACK       =*,E10.3,/,
     2          10X,* STEEL STRESS BETWEEN CRACK =*,E10.3,/,
     3          10X,* CONCRETE STRESS             =*,E10.3)
 170  FORMAT (//,10X,*ERROR IS DETECTED IN THE COMPUTATION OF CRACK*,/,
     1  10X,* WIDTH FOR THE FRICTIONLESS SYSTEM*,2(5X,E10.3))
 180  FORMAT (///, 10X,* ROOTS DO NOT SATISFY EQUATION 1 *,/, 10X,
     1 * CHECK= *, E10.3)
 190  FORMAT (//,10X,* SOLUTION ONE DOES NOT MATCH SOLUTION TWO *)
 200  FORMAT (///,30X,*DELTA IS NEGATIVE*)
```

```
210  FORMAT  (/,10X,*SOMETHING IS WRONG, THE AREA UNDER STEEL STRAIN DI
    1AGRAM IS NOT EQUAL TO ALPHAS *,1H*,* DELTAT *,1H*,* XBAR / 2*,/)
220  FORMAT (//,10X,* AREA UNDER STEEL STRAIN DIAGRAM FOR FRICTIONLESS
    1SLAB = *,E10.3,//)
     END
```

```
      SUBROUTINE FRIC (F)
CC
      COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
      COMMON /BLOCK2/ SS(101),AAA,WS(101),LONGPR,NPRINT,MAXITE,CRACKW
      COMMON /BLOCK3/ XBAR,STRSC,STRSS,STRC,ISABY,ITES,NEWBAR
      COMMON /BLOCK4/ AL(101),STRAIN(101),CONSTR(101),STRESSS(101)
      COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
      COMMON /BLOCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
      COMMON /BLOCK8/ Y(101),REFF(101),YP(101),H,ICLOSEB,YPITE(101)
      DIMENSION F(101)
      INTEGER AAA
C
               BEYOND = 0.0
      IF(LONGPR.EQ.3HYES) PRINT 160
         IF (IFY.EQ.2) GO TO 40
         IF (IFY.GT.2) GO TO 90
               SLOPE=FRICMUL
C
C     COMPUTE FRICTION FORCES FROM STRAIGHT LINE GRAPH
C
      DO 30 I=1,NTP1
               F(I)=Y(I)*SLOPE
         IF (ABS(F(I)).LE.FU) GO TO 30
          IF (F(I).GT.0.0) F(I)=FU
          IF (F(I).LT.0.0) F(I)=-FU
 30   CONTINUE
         GO TO 135
C
C     COMPUTE FRICTION FORCES FROM PARABOLA
C
   40 DO 80 I=1,NTP1
C
         IF (Y(I).GT.0.) GO TO 50
               F(I)=FRICMUL*SQRT(ABS(Y(I)))
         GO TO 60
 50   CONTINUE
               F(I)=-FRICMUL*SQRT(Y(I))
 60   CONTINUE
         IF (ABS(F(I)).LE.FU) GO TO 80
          IF (F(I).GT.0.0) F(I)=FU
          IF (F(I).LT.0.0) F(I)=-FU
   80 CONTINUE
         IF (LONGPR.EQ.3HYES) PRINT 180
         GO TO 135
C
 90   CONTINUE
C     COMPUTE FRICTION FORCES FROM INPUT POINT CURVE
      DO 130 I=1,NTP1
      DO 100 J=1,IFY
         IF (ABS(Y(I)).LT.ABS(YEXP(J))) GO TO 110
 100  CONTINUE
               BEYOND=BEYOND+1.
               F(I)=FEXP(IFY)
         GO TO 120
 110  CONTINUE
               DUMDUM=(FEXP(J)-FEXP(J-1))/(ABS(YEXP(J))-ABS(YEXP(J-1)))
               F(I)=FEXP(J-1)+DUMDUM*(ABS(Y(I))-ABS(YEXP(J-1)))
 120  CONTINUE
          IF (Y(I).GT.0.0) F(I)=-F(I)
 130  CONTINUE
```

```
  135  IF(LONGPR.EQ.3HYES) PRINT 170,(I,AL(I),Y(I),F(I),I=1,NTP1,NPRINT)
C
C           COMPUTE THE TOTAL FRICTION FORCE
C
          IF (BEYOND.GT.0.) PRINT 190, BEYOND
              FF = 0.0
      DO 150 I=1,NT,2
                FF=FF+(F(I)+4.*F(I+1)+F(I+2))*H/3.
 150  CONTINUE
          IF (LONGPR.EQ.3HYES) PRINT 200, FF
      RETURN
C
  160 FORMAT( //,20X,*IN SUBROUTINE FRIC*,/)
 170  FORMAT ( 11X,*I*,6X,*AL(I)*,7X,*Y(I)*,8X,*F(I)*,//,
     1          (8X,I5,3(2X,E10.3)))
 180  FORMAT ( /,10X,*FRICTION MOVEMENT CURVE IS A PARABOLA*,/)
 190  FORMAT (//,10X,*IN COMPUTING THE FRICTION FORCES FROM MOVEMENTS*,/
     1,   10X,F5.0,* POINTS EXCEEDED THE MAX MOV ON F-Y CURVE*)
 200  FORMAT (/,10X,* TOTAL FRICTION FORCE  =*,E10.3)
      END
```

```
      SUBROUTINE DFWIREF
CC
      COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
      COMMON /BLOCK2/ SS(101),AAA,WS(101),LONGPR,NPRINT,MAXITE,CRACKW
      COMMON /BLOCK3/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB,NEWBAR
      COMMON /BLOCK4/ AL(101),STRAIN(101),CONSTR(101),STRESSS(101)
      COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
      COMMON /BLOCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
      COMMON /BLOCK7/ SIGMASC,SIGMASB,NA,NAP1,E,A,S,DENO,NAP2
      COMMON /BLOCK8/ Y(101),REFF(101),YP(101),H,ICLOSEB,YPITE(101)
      COMMON /BLOCK14/ F(101),BONDL,Z,DELTAT,STRMAX,WHLSTR,TMLOD,IBECK
      DIMENSION SUM(101)
      INTEGER AAA
C
C
C         COMPUTE THE STRAINS DUE TO FRICTION FORCES DEVELOPED
C         DUE TO SLAB MOVEMENT
C
                A=AL(NTP1)-BONDL
         IF (A.LE.0.) GO TO 50
                NA=A/H+1+EP
                E=A-AL(NA)
         IF (NA.GT.NT) GO TO 60
         IF (LONGPR.EQ.3HYES) PRINT 90, H,BONDL,A,NA,E
                NAP1=NA+1
                NAP2=NA+2
                NAM1=NA-1
                NAM2=NA-2
                DENO=THICK*(P+1./RATIO)
C         COMPUTE THE SLOPE TO THE STEEL STRAIN DISTRIBUTION CURVE BY
C
C         DIVIDING THE FRICTION FORCE BY DENO AND CONSIDERING THE
C         SIGN CONVENTION ADOPTED IN THIS STUDY
C
C                         SLOPE(I) = -  F(I) / DENO
                SUM1=0.
                SUM2=0.
      DO 20 I=1,NAM1
                SUM1=SUM1+(2*NA-(2.*I+1))*(-F(I)/DENO)
                SUM2=SUM2+(-F(I)/DENO)
 20   CONTINUE
         IF (LONGPR.NE.3HYES) GO TO 30
      PRINT 100
      PRINT 110, SUM1,SUM2
 30   CONTINUE
C
C         DEFINE  CONSTANTS FOR SOLUTION OF EQUATIONS
C
                C1=1.+1./(P*RATIO)
                C2=((Z+DELTAT*(ALPHAC-ALPHAS))*EC)/P
                C3=FF/(P*THICK)
                S=-F(NAP1)/DENO
C
C         SOLVE FOR STRESS IN STEEL BETWEEN CRACKS AND AT CRACK
C
      DUM1=ALPHAS*AL(NTP1)*DELTAT*ES-H*H*SUM1*0.5-E*H*SUM2-
     1      S*E*E*0.5-(H*SUM2+S*E+C2-C3)*BONDL*0.5
                ANA=NA
                DUM2=H*(2.*ANA-2.)*0.5+E+((1.+C1)*BONDL)*0.5
C
```

```
            SIGMASB=DUM1/DUM2
            SIGMASC=C1*SIGMASB+C2-C3
C
C       CHECK FOR THE SUMMATION OF STEEL STRESSES UNDER THE
C       STEEL DIAGRAM
C
            A1=(((2.*ANA-2.)*SIGMASB+H*SUM1)*H)*0.5
            A2=(2.*SIGMASB+2.*H*SUM2+S*E)*E*0.5
            A3=(SIGMASB+H*SUM2+S*E+SIGMASC)*BONDL*0.5
            DUM1=A1+A2+A3
            DUM2=ALPHAS*AL(NTP1)*DELTAT*ES
            DUM3=DUM1-DUM2
         IF (ABS(DUM3).GT.1.E-4) GO TO 70
C
C
C       COMPUTE THE STEEL AND CONCRETE STRAIN AT EVERY INCREMENT
C       THE STRAIN IS COMPUTED IN THE BONDED AND UNBONDED SECTIONS
C
      CALL POIRES (LOCMAX)
         IF (LONGPR.EQ.3HYES) PRINT 120, SIGMASB,SIGMASC,STRMAX,LOCMAX
      RETURN
C
 50   CONTINUE
      PRINT 130, A
         GO TO 80
 60   CONTINUE
      PRINT 140, NA,NT
         GO TO 80
 70   CONTINUE
      PRINT 150, SIGMASC,SIGMASB,DUM1,DUM2,DUM3
 80   CONTINUE
C
   90 FORMAT( //,20X,*IN SUBROUTINE DFWIREF*,
     A        //,10X,* INCREMENT LENGTH     =*,E14.7,/,
     1           10X,* BOND LENGTH          =*,E14.7,/,
     2           10X,* NO SLIPPAGE LENGTH   =*,E14.7,/,
     3           10X,* NO OF INCREMENTS ,NA =*,I5    ,/,
     4           10X,* E                          =*,E14.7,//)
 100  FORMAT (//,10X,* INDEX    SLOPE       SUM1        SUM2 *,/)
 110  FORMAT (/,10X,* SUM1 =*,E10.3,10X,* SUM2 =*,E10.3,/)
 120  FORMAT (//,10X,* STEEL  STRESS AT MIDSPAN   =*,E10.3,/,
     1          10X,* STEEL  STRESS AT CRACK      =*,E10.3,/,
     2          10X,* MAXIMUM CONCRETE STRESS     =*,E10.3,/,
     3          10X,*STATION OF MAXIMUN STRESS IS *,I5,/)
 130  FORMAT (//,10X,*ERROR IS DETECTED IN DFWIREF*,/,
     1     10X,*A IS NEGATIVE AND =*,E10.3)
 140  FORMAT (/,20X,* ERROR IS DETECTED *,/,
     1        10X,* NA = *,I5,10X,* NT = *,I5)
 150  FORMAT (//,20X, * ERROR IS DETECTED * ,/,
     1          10X, * STEEL STRESS AT CRACK        =*,E10.3,/,
     2          10X, * STEEL STRESS BETWEEN CRACKS =*,E10.3,/,
     3          10X, * SUMMATION OF A1,A2,AND A3   =*,E10.3,/,
     4          10X, * ALPHA  L  DELTAT  ES        =*,E10.3,/,
     5          10X, * ABSOLUTE DIFFERENCE         =*,E10.3)
      END
```

```
      SUBROUTINE DFWIRE
CC
C     ******************************************************************
C         THIS SUBROUTINE SOLVES FOR THE STRESS IN THE STEEL AND
C         CONCRETE FOR DEFORMED WIRE FABRIC -NO FRICTION FORCES
C         ARE CONSIDERED IN THE SOLUTION
C     ******************************************************************
      COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
      COMMON /BLOCK2/ SS(101),AAA,WS(101),LONGPR,NPRINT,MAXITE,CRACKW
      COMMON /BLOCK3/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB,NEWBAR
      COMMON /BLOCK4/ AL(101),STRAIN(101),CONSTR(101),STRESSS(101)
      COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
      COMMON /BLOCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
      COMMON /BLOCK7/ SIGMASC,SIGMASB,NA,NAP1,E,A,S,DENO,NAP2
      COMMON /BLOCK8/ Y(101),REFF(101),YP(101),H,ICLOSEB,YPITE(101)
      COMMON /BLOCK14/ F(101),BONDL,Z,DELTAT,STRMAX,WHLSTR,TMLOD,IBECK
      REAL L
C
C     DEFINE CONSTANTS
C
              L=0.5*XBAR
              C1=EC*Z+EC*DELTAT*(ALPHAC-ALPHAS)
              C2=ALPHAS*L*DELTAT*ES
              C3=BONDL/(2.*RATIO)+P*L
C
C             SOLVE FOR STRESSES
              STRC=(C1*P*L+C2*P/RATIO)/C3
              STRSB=(-C1*BONDL/2.+P*C2)/C3
              STRSC=(C2/RATIO+C1*(L-BONDL/2.)+P*C2)/C3
              STRMAX=STRC
C
C     CHECK EQUILIBRIUM - EQUATION 1
C
              DUM1=STRC+P*STRSB
              DUM2=P*STRSC
         IF (ABS(DUM1-DUM2).GT.1.E-5) GO TO 10
              SRAINC=STRC/EC
      RETURN
C
   10 PRINT 20, STRC,STRSB,STRSC,DUM1,DUM2
 20   FORMAT (//,10X,* ERROR IS DETECTED *,/,
     1        10X,* EQUILIBRIUM IS NOT SATISFIED *,/,
     2        10X,* STRC = *,E10.3,5X,* STRSB = *,E10.3,5X,* STRSC =*,
     3        E10.3,/,10X,* DUM1 = *,E10.3,5X,* DUM2 = *,E10.3)
      END
```

```
      SUBROUTINE FORWARD (TENSTRN,ZTOT,Z)
CC
C     ******************************************************************
C         THIS SUBROUTINE CALCULATES THE TIME DEPENDENT VARIABLES FROM
C         WHICH THE SLAB RESPONSES ARE COMPUTED. LINEAR INTERPOLATION
C         IS USED TO GET FLEXURAL STRENGTH FROM AGE OF CONCRETE .
C     ******************************************************************
C
      COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
      COMMON /BLOCK2/ SS(101),AAA,WB(101),LONGPR,NPRINT,MAXITE,CRACKW
      COMMON /BLOCK3/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB,NEWBAR
      COMMON /BLOCK4/ AL(101),STRAIN(101),CONSTR(101),STRESSS(101)
      COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
      COMMON /BLOCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
      COMMON /BLOCK8/ Y(101),REFF(101),YP(101),H,ICLOSEB,YPITE(101)
      COMMON /BLOCK10/ NSTRN,VDS,AGEU(20),TENSION(20),STRNMUL
      COMMON /BLOCK13/ AGE(8),PERCENT(8),COLDTM,ANTEMP,IBXBAR,COLDSTN
      INTEGER AAA
C
         IF (NSTRN.GT.0.) GO TO 30
      DO 10 I=1,8
               J=I
   10    IF (TIME.LE.AGE(I)) GO TO 20
         GO TO 70
   20    IF (TIME.EQ.ANTEMP.AND.IBXBAR.EQ.1) GO TO 21
              PERCOM=(PERCENT(J)-PERCENT(J-1))/(AGE(J)-AGE(J-1))
               PERCOM=PERCENT(J-1)+PERCOM*(TIME-AGE(J-1))
               COMSTR=PERCOM*FPC/100
               FLESTRN=3000./(3.+12000./COMSTR)
               TENSTRN=FLESTRN*STRNMUL
         GO TO 60
   21    IF (COLDSTN.LE.0) GO TO 22
               TENSTRN=COLDSTN
               FLESTRN=TENSTRN/STRNMUL
               COMSTR=(12000.*FLESTRN)/(3000.-3.*FLESTRN)
         GO TO 60
   22          COMSTR=FPC*(1.+0.1972*(ALOG10(COLDTM/ANTEMP)))
               FLESTRN=3000./(3.+12000./COMSTR)
               TENSTRN=FLESTRN*STRNMUL
         GO TO 60
 30   CONTINUE
      DO 40 I=1,NSTRN
               J=I
         IF (TIME.LE.AGEU(I)) GO TO 50
 40   CONTINUE
         GO TO 70
 50      IF(TIME.EQ.ANTEMP.AND.IBXBAR.EQ.1) GO TO 23
C
C     COMPUTE SLOPE BY LINEAR INTERPOLATION
C
               SLOPE=(TENSION(J)-TENSION(J-1))/(AGEU(J)-AGEU(J-1))
               TENSTRN=TENSION(J-1)+SLOPE*(TIME-AGEU(J-1))
               FLESTRN=TENSTRN/STRNMUL
               COMSTR=(12000.*FLESTRN)/(3000.-3.*FLESTRN)
          GO TO 60
   23 IF (COLDSTN.LE.0) GO TO 24
        TENSTRN=COLDSTN
          GO TO 25
 24     TENSTRN=TENSION(NSTRN)*(1.+0.1972*(ALOG10(COLDTM/ANTEMP)))
   25   FLESTRN=TENSTRN/STRNMUL
          COMSTR=(12000.*FLESTRN)/(3000.-3.*FLESTRN)
C
 60   CONTINUE
C
              EC=33.*(UNWT**1.5)*SQRT(COMSTR)
              RATIO=ES/EC
              U=9.5*SQRT(COMSTR)/DIA
         IF (U.GT.800.) U=800.
              SHRN=26.*EXP(0.36*VDS)
              Z=(TIME/(SHRN+TIME))*ZTOT
        IF (LONGPR.NE.3HYES) RETURN
      PRINT 100, TIME,Z,FLESTRN,COMSTR,EC,RATIO,U
      PRINT 90, J,PERCENT(J),AGE(J),PERCOM,PERCENT(J-1),AGE(J-1),FPC
      RETURN
 70   PRINT 80, TIME
C
 80   FORMAT (//,10X,*ERROR IS DETECTED IN SUBROUTINE FORWARD*,/,10X,
     1 *TIME ENCOUNTERED IS GREATER THAN MAXIMUM AGE PROVIDED BY THE USE
     2R*/,      10X,*TIME =*,E10.3,/,
     3          10X,*PROGRAM IS TERMINATED*)
  90  FORMAT( 40X,*J =*I2,/10X,*PERCENT(J) =*F5.1,7X,
     1        *AGE(J) =*F5.1,7X,*PERCOM =*F10.3,/10X,
     2        *PERCENT(J-1) =*F5.1,5X,*AGE(J-1) =*F5.1,5X,
     3        *FPC =*F14.3)
 100  FORMAT (     //,15X,*IN SUBROUTINE FORWARD*,//,
     1           10X,* TIME              *,E10.3,/,
     2           10X,* SHRINKAGE         *,E10.3,/,
     3           10X,* FLEXURAL STRENGTH*,E10.3,/,
     4           10X,* COMPRESSIVE STRN *,E10.3,/,
     5           10X,* CON MODULUS       *,E10.3,/,
     6           10X,* RATIO             *,E10.3,/,
     7           10X,* BOND STRENTH      *,E10.3,/)
             END
```

```
      SUBROUTINE BACKWAR (TENSTRN,ZTOT,Z)
CC
C     ******************************************************************
C           THIS SUBROUTINE CALCULATES THE TIME DEPENDENT VARIABLES FROM
C           THE COMPUTED STRENGTH ON THE LINE OF EQUALITY OF STRESS -
C           STRENGTH CURVE .
C     ******************************************************************
C
      COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
      COMMON /BLOCK2/ SS(101),AAA,WS(101),LONGPR,NPRINT,MAXITE,CRACKW
      COMMON /BLOCK3/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB,NEWBAR
      COMMON /BLOCK4/ AL(101),STRAIN(101),CONSTR(101),STRESSS(101)
      COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
      COMMON /BLOCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
      COMMON /BLOCK8/ Y(101),REFF(101),YP(101),H,ICLOSEB,YPITE(101)
      COMMON /BLOCK10/ NSTRN,VOS,AGEU(20),TENSION(20),STRNMUL
      COMMON /BLOCK13/ AGE(8),PERCENT(8),COLDTM,ANTEMP,IBXBAR,COLDSTN
      INTEGER AAA
C
      IF (NSTRN.GT.0.) GO TO 30
              FLESTRN=TENSTRN/STRNMUL
              COMSTR=(12000.*FLESTRN)/(3000.-3.*FLESTRN)
              PERCOM=(COMSTR/FPC)*100.
              EC=33.*(UNWT**1.5)*SQRT(COMSTR)
              RATIO=ES/EC
              U=9.5*SQRT(COMSTR)/DIA
         IF (U.GT.800.) U=800.
      DO 10 I=1,8
              J=I
   10    IF (PERCOM.LE.PERCENT(I)) GO TO 20
      PRINT 80, PERCOM
         GO TO 70
   20         TIME=(PERCENT(J)-PERCENT(J-1))/(AGE(J)-AGE(J-1))
              TIME=AGE(J-1)+(PERCOM-PERCENT(J-1))/TIME
         GO TO 60
C
C     COMPUTE THE TIME CORRESPONDING
C     TO TENSILE STRENGTH
C
   30 DO 40 I=1,NSTRN
              J=I
   40    IF (TENSTRN.LE.TENSION(I)) GO TO 50
      PRINT 90, TENSTRN
         GO TO 70
C
C     COMPUTE SLOPE BY LINEAR INTERPOLATION
C
   50         TIME=(TENSION(J)-TENSION(J-1))/(AGEU(J)-AGEU(J-1))
              TIME=AGEU(J-1)+(TENSTRN-TENSION(J-1))/TIME
C
   60         SHRN=26.*EXP(0.36*VOS)
              Z=(TIME/(SHRN+TIME))*ZTOT
         IF (LONGPR.EQ.3HYES) PRINT 100, FLESTRN,COMSTR,EC,TIME,Z
      RETURN
 70   CONTINUE
C
 80   FORMAT (//,10X,*ERROR IS DETECTED IN SUBROUTINE BACKWARD*,/,
     1           10X,*THE COMPUTED PERCENT COMPRESSION IS GREATER THAN TH
     2E MAXIMUM PERCENT AVAILABLE*,/,
     3           10X,*PERCOM =*E10.3,/,
     4           10X,*PROGRAM IS TERMINATED*)
 90   FORMAT (//,10X,*ERROR IS DETECTED IN SUBROUTINE BACKWARD*,/,
     1           10X,*THE COMPUTED TENSILE STRENGTH IS GREATER THAN THE M
     2AXIMUM STRENGTH PROVIDED BY THE USER*,/,
     3           10X,*TENSTRN=*,E10.3,/,
     4           10X,*PROGRAM IS TERMINATED*)
  100 FORMAT( //,15X,*IN SUBROUTINE BACKWAR*,
     A            //,10X,* FLESTRN             *,E10.3,/,
     1           10X,* COMPRESSIVE STR  *,E10.3,/ ,
     2           10X,* CON MODULUS      *,E10.3,/,
     3           10X,* TIME             *,E10.3,/,
     4            10X,* SHRINKAGE        *,E10.3,//)
        END
```

```
      SUBROUTINE DELTEMP (TIME,DELTAT)
CC
C     ******************************************************************
C         THIS SUBROUTINE CONTAINS THE INCREMENTAL TECHNIQUE
C         FOR TEMPERATURE TIME DATA.   A SINE WAVE IS FIT
C         THROUGH EACH DAY,   THE ROUTINE HAS THREE OPTIONS.
C
C         DELTEMP INCREMENTS UP BY UPINC IF NTIFLAG = 1
C         INCREMENTS DOWN BY DOWNINC IF NTIFLAG = -1
C         IT GIVES THE TEMPERATURE DROP AT TIME IF NTIFLAG = 0
C     ******************************************************************
C
      COMMON /BLOCK2/ SS(101),AAA,WS(101),LONGPR,NPRINT,MAXITE,CRACKW
      COMMON /BLOCK12/ DT(50),NTEMP,NTIFLAG,UPINC,DOWNINC
      DATA PI / 3.14159265359 /
C
      DO 10 ITIME=1,NTEMP
            REALTI=FLOAT(ITIME)
   10   IF (REALTI.GT.TIME) GO TO 20
      PRINT 130, DELTAT,TIME
      STOP 66
   20 CONTINUE
        IF (TIME.GT.REALTI-.75.A.TIME.LT.REALTI-.25) GO TO 30
            DELTAT=0.
      IF(NTIFLAG) 120,80,50
   30 CONTINUE
            DELTAT=DT(ITIME)*SIN((TIME-REALTI+.75)*2.*PI)
        IF (NTIFLAG) 120,80,50
   50 CONTINUE
            DELTAT=DELTAT+UPINC
        IF (TIME.GT.REALTI-.5) GO TO 90
        IF (DELTAT.GE.DT(ITIME)+UPINC-1.E-7) GO TO 90
        IF (DELTAT.LE.DT(ITIME)) GO TO 100
   60 CONTINUE
            DELTAT=DT(ITIME)
   70 CONTINUE
            TIME=REALTI-.5
   80 CONTINUE
      RETURN
   90       REALTI=REALTI+1.
            ITIME=ITIME+1
            DELTAT=DELTAT-UPINC
        IF (ITIME.GT.NTEMP) GO TO 70
        IF (DELTAT.GE.DT(ITIME)) GO TO 60
  100 CONTINUE
            TPLUS=ABS(ASIN(DELTAT/DT(ITIME))/(2.*PI)-.25)
         IF (TIME.LE.REALTI-.5) TPLUS=-TPLUS
            TIME=REALTI+TPLUS-.5
      RETURN
  120 CONTINUE
            DELTAT=DELTAT-DOWNINC
        IF (DELTAT.GT.0.0) GO TO 100
            DELTAT=0.
         IF (TIME.LE.REALTI-.5) TIME=REALTI-.75
         IF (TIME.GT.REALTI-.5) TIME=REALTI+.25
      RETURN
  130 FORMAT (* END OF TEMPERATURE ARRAY ENCOUNTERED*,/,* DELTAT =*,F6.3
     1,* TIME =*,F6.3)
       END
```

```
      SUBROUTINE PLOTEMP (TMSCALE,FINAL)
CC
C     ******************************************************************
C       THIS SUBROUTINE IS CALLED AT THE USERS OPTION TO PLOT
C       TEMPERTURE DROP VS. TIME (DAYS).
C     ******************************************************************
C
      COMMON /BLOCK12/ DT(50),NTEMP,NTIFLAG,UPINC,DOWNINC
C
      CALL BGNPLT (4LPLOT,FINAL*TMSCALE+10.,28,1)
      CALL PLT (2.,.75,-3)
            TEMP=0.
      DO 10 I=1,NTEMP
         IF (DT(I).GT.TEMP) TEMP=DT(I)
   10 CONTINUE
            TEMP=TEMP+10.-AMOD(TEMP,10.)
            YSCALE=0.1*TEMP
         IF (TMSCALE.GT.5.O.TMSCALE.LE.0) TMSCALE=2.
      CALL PLT (0.,10.,2)
   20 CONTINUE
      CALL PLT (-.15,TEMP/YSCALE,2)
      CALL NUMBER (-.6,TEMP/YSCALE-.1,.15,TEMP,0.,-1)
            TEMP=TEMP-YSCALE
      CALL PLT (0.,TEMP/YSCALE,3)
         IF (TEMP.GE.0) GO TO 20
      CALL PLT (0.,0.,3)
            TIME=FINAL-AMOD(FINAL,1.)
      CALL PLT (TIME*TMSCALE,0.,2)
   30 CONTINUE
      CALL PLT (TIME*TMSCALE,-.15,2)
         IF (AMOD(TIME,1.).GT.1.E-6) GO TO 40
      CALL NUMBER (TIME*TMSCALE-.1,-.3,.15,TIME,0.,-1)
   40 CONTINUE
            TIME=TIME-.5
      CALL PLT (TIME*TMSCALE,0.,3)
         IF (TIME.GE.0) GO TO 30
      CALL SYMBOL (5.,6.,.3,33HPLOT OF TEMPERATURE DROP VS. TIME,0.,33)
      CALL SYMBOL (6.15,5.,.3,23HAS USED IN CRCP PROGRAM,0.,23)
      CALL SYMBOL (5.,-.6,.2,15HTIME  (IN DAYS),0.,15)
      CALL SYMBOL (-1.,1.,.2,38HTEMPERATURE DROP  (DEGREES FAHRENHEIT),
     1      90.,38)
      CALL PLT (0.,0.,3)
            TIME=0.
            NTIFLAG=0
      CALL PLT ((TIME+.25)*TMSCALE,0.,2)
            TIME=TIME+.275
   50 CONTINUE
      CALL DELTEMP (TIME,D)
      CALL PLT (TIME*TMSCALE,D/YSCALE,2)
            TIME=TIME+.025
         IF (AMOD(TIME,1.).LT..75) GO TO 50
         IF (TIME.GE.FINAL-AMOD(FINAL,1.)-.25) TIME=TIME-.2476
      CALL PLT ((TIME+.475)*TMSCALE,0.,2)
            TIME=TIME+.475
         IF (TIME.LT.FINAL-AMOD(FINAL,1.)) GO TO 50
      CALL ENDPLT
      RETURN
      END
```

```
      SUBROUTINE POIRES (LOCMAX)
CC
      COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
      COMMON /BLOCK2/ SS(101),AAA,WS(101),LONGPR,NPRINT,MAXITE,CRACKW
      COMMON /BLOCK3/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB,NEWBAR
      COMMON /BLOCK4/ AL(101),STRAIN(101),CONSTR(101),STRESSS(101)
      COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
      COMMON /BLOCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
      COMMON /BLOCK7/ SIGMASC,SIGMASB,NA,NAP1,E,A,S,DENO,NAP2
      COMMON /BLOCK8/ Y(101),REFF(101),YP(101),H,ICLOSEB,YPITE(101)
      COMMON /BLOCK14/ F(101),BONDL,Z,DELTAT,STRMAX,WHLSTR,TMLOD,IBECK
      DIMENSION SUM(101)
      INTEGER AAA
C
                HH = 0.5 * H
                II=NAP2
                SUM3=0.
                SUM4=0.
         IF (IBECK.EQ.1) GO TO 55
                STRESSS(1)=SIGMASB
                SS(1)=STRESSS(1)/ES
                STRAIN(1)=SS(1)+Z+DELTAT*(ALPHAC-ALPHAS)
                CONSTR(1)=STRAIN(1)*EC
                LOCMAX=1
                STRMAX=CONSTR(1)
      DO 20 I=2,NA
                STRESSS(I)=STRESSS(I-1)+H*(-F(I)/DENO)
                SS(I)=STRESSS(I)/ES
                STRAIN(I)=SS(I)+Z+DELTAT*(ALPHAC-ALPHAS)
                CONSTR(I)=STRAIN(I)*EC
         IF (CONSTR(I).LT.STRMAX) GO TO 10
                STRMAX=CONSTR(I)
                LOCMAX=I
  10  CONTINUE
                SUM3=SUM3+(SS(I)+SS(I-1))*HH
                SUM4=SUM4+(STRESSS(I)+STRESSS(I-1))*HH
  20  CONTINUE
                ADDI=STRESSS(NA)+S*E
                ADDIAR=(STRESSS(NA)+ADDI)*E*0.5
                SUM3=SUM3+(ADDIAR)/ES
                SUM4=SUM4+ADDIAR
                SLOPE2=(SIGMASC-ADDI)/BONDL
                ADDIC=ADDI/ES+Z+DELTAT*(ALPHAC-ALPHAS)
                SLOPECC=-ADDI/BONDL
                STRESSS(NAP1)=ADDI+(AL(NAP1)-A)*SLOPE2
                SS(NAP1)=STRESSS(NAP1)/ES
      STRAIN(NAP1)=ADDIC-F(NAP1)*H/(THICK*EC)-(STRESSS(NAP1)-ADDI)*P/EC
                CONSTR(NAP1)=STRAIN(NAP1)*EC
         IF (CONSTR(NAP1).LT.STRMAX) GO TO 30
                STRMAX=CONSTR(NAP1)
                LOCMAX=NAP1
  30  CONTINUE
                SUM4=SUM4+(STRESSS(NAP1)+ADDI)*(AL(NAP1)-A)*0.5
                SUM3=SUM3+(STRESSS(NAP1)+ADDI)*(AL(NAP1)-A)/(2.*ES)
         IF (NA.EQ.NT) II=NAP1
      DO 50 I=II,NTP1
                STRESSS(I)=ADDI+(AL(I)-A)*SLOPE2
                SS(I)=STRESSS(I)/ES
      STRAIN(I)=STRAIN(I-1)-F(I)*H/(THICK*EC)-(STRESSS(I)-STRESSS(I-1))*
     1          P/EC
```

```
                CONSTR(I)=STRAIN(I)*EC
         IF (CONSTR(I).LT.STRMAX) GO TO 40
                STRMAX=CONSTR(I)
                LOCMAX=I
  40  CONTINUE
                SUM3=SUM3+(SS(I)+SS(I-1))*HH
                SUM4=SUM4+(STRESSS(I)+STRESSS(I-1))*HH
  50  CONTINUE
         GO TO 58
  55            SBPIN=SIGMASC-(AL(NTP1)*(SIGMASC-SIGMASB))/BONDL
                SLOP=(SIGMASC-SIGMASB)/BONDL
                SLOPK=(SIGMASC-SBPIN)/AL(NTP1)
                DUMP=ABS(SLOPK-SLOP)
         IF (DUMP.GT.1.E-5) GO TO 65
                STRESSS(1)=SBPIN
                SS(1)=STRESSS(1)/ES
                SIGMACM=FF/THICK+(4.*AL(NTP1)*U*P)/DIA
                CONSTR(1)=SIGMACM
                STRAIN(1)=CONSTR(1)/EC
                LOCMAX=1
                STRMAX=CONSTR(1)
         DO 57 I=2,NTP1
                STRESSS(I)=AL(I)*SLOP+STRESSS(1)
                SS(I)=STRESSS(I)/ES
                STRAIN(I)=STRAIN(1)*(1.-AL(I)/AL(NTP1))
                CONSTR(I)=STRAIN(I)*EC
         IF (CONSTR(I).LT.STRMAX) GO TO 56
                STRMAX=CONSTR(I)
                LOCMAX=I
  56     CONTINUE
                SUM3=SUM3+(SS(I)+SS(I-1))*HH
                SUM4=SUM4+(STRESSS(I)+STRESSS(I-1))*HH
  57     CONTINUE
  58  IF(ICLOSEB.EQ.1.AND.TIME.GE.TMLOD) STRMAX=STRMAX+WHLSTR
          IF (LONGPR.NE.3HYES) RETURN
      PRINT 70, ADDI,ADDIC
      PRINT 80
      PRINT 90, ((I,AL(I),STRESSS(I),SS(I),CONSTR(I),STRAIN(I)),I=1,
     1      NTP1,NPRINT)
            RIGHTQ=ALPHAS*DELTAT*AL(NTP1)*ES
      PRINT 100, SUM3,SUM4,RIGHTQ
      PRINT 110
C
      CALL SIMPSPE (SS,NTP1,H,SUM)
C
      DO 60 I=1,NTP1
            WS(I)=SUM(I)-(ALPHAS*DELTAT)*AL(I)
  60  CONTINUE
      PRINT 120, ((I,AL(I),SS(I),SUM(I),WS(I)),I=1,NTP1,NPRINT)
      RETURN
C
  65  PRINT 68,DUMP
  67  CONTINUE
  68  FORMAT(//,10X,*ERROR IN POIRES,DUMP=*,E10.3)
  70  FORMAT(//,30X,*IN SUBROUTINE POIRES*,
     1       //,20X,*ADDI =*,E10.3,10X,*ADDIC =*,E10.3 )
  80  FORMAT (//,10X, * INDEX  DISTANCE  STEEL STRESS  STEEL STRAIN  CON
     1 STRESS   CON STRAIN  *,/)
  90  FORMAT (10X, I5 ,5(2X,E10.3))
 100  FORMAT (//,10X,*SUM OF AREA UNDER STEEL STRAIN DIAGRAM =*,E10.3,/,
```

```
    1           10X,*SUM OF AREA UNDER STEEL STRESS DIAGRAM =*,E10.3,/,
    2           10X,*RIGHT QUANTITY                          =*,E10.3//)
110  FORMAT (///,15X,* MOVEMENT OF STEEL BEFORE CONCRETE CRACKS *,//,
    1      10X,* INDEX  DISTANCE    STE.STRAIN    SUM       STEEL MOVE*/
    2)
120  FORMAT (10X,I5,4(2X,E10.3))
     END
```

```
      SUBROUTINE SIMPSPE (Y,N,H,SUM)
CC
C          THIS SUBROUTINE COMPUTES THE AREA UNDER A DISTRIBUTION USING
C          SIMPSONS RULE WITH A SPECIAL MODIFICATION
C
      DIMENSION Y(N),SUM(N)
C
      DO 10 I=1,N
   10     SUM(I) = 0.0
              A1=(Y(1)+Y(2))*H*0.5
              AOLD=A1
              SUM(2)=AOLD
              NM1=N-1
C
      DO 20 I=2,NM1
              AS=(Y(I-1)+4.*Y(I)+Y(I+1))*H/3
              A=AS-AOLD
              SUM(I+1)=SUM(I)+A
              AOLD=A
 20   CONTINUE
      RETURN
       END
```

```
      SUBROUTINE GETME (X1,Y1,X2,Y2,FOUT)
CC
C     ******************************************************************
C          THIS SUBROUTINE SOLVES FOR THE POINT OF INTERSECTION OF TWO
C          STRAIGHT LINES , WHERE ONE OF THE LINES IS Y=X .
C          THIS VERSION OF THE PROGRAM JOINS THE NEW POINT TO THE POINT
C          ON THE OTHER SIDE OF THE  Y=X LINE .
C     ******************************************************************
C
C          PSX AND PSY ARE STORED VALUES
C          BELOW THE EQUALITY LINE
C          STX AND STY ARE STORED VALUES
C          ABOVE THE EQUALITY LINE
C
      COMMON /BLOCK2/ SS(101),AAA,WS(101),LONGPR,NPRINT,MAXITE,CRACKW
      COMMON /BLOCK9/ STX,STY,PSX,PSY,ITE
C
         IF (ITE.EQ.2) GO TO 10
         IF (X2-Y2) 20,20,40
 10   CONTINUE
                 DUMX2=PSX=X1
                 DUMY2=PSY=Y1
         GO TO 30
 20   CONTINUE
                 DUMX2=PSX
                 DUMY2=PSY
 30   CONTINUE
                 DUMX1=STX=X2
                 DUMY1=STY=Y2
         GO TO 50
 40   CONTINUE
                 DUMX1=STX
                 DUMY1=STY
                 DUMX2=PSX=X2
                 DUMY2=PSY=Y2
 50   CONTINUE
      FOUT=(DUMX2*DUMY1-DUMX1*DUMY2)/((DUMX2-DUMX1)-(DUMY2-DUMY1))
         IF(LONGPR.EQ.3HYES) PRINT 60, ITE,DUMX1,DUMY1,DUMX2,DUMY2,FOUT
      RETURN
C
 60   FORMAT (//,10X,* IN SUBROUTINE GETME *,/,
     1            10X,* ITE =*,I5,/,
     2            10X,* DUMX1 =*,E10.3,10X,* DUMY1 =*,E10.3,/,
     3            10X,* DUMX2 =*,E10.3,10X,* DUMY2 =*,E10.3,/,
     4            10X,* FOUT =*,E10.3,/)
      END
```

```
      SUBROUTINE STRGENE (BONDL)
CC
C     ******************************************************************
C          THIS SUBROUTINE GENERATES THE STRAIN IN THE CONCRETE AT
C          EVERY STATION IN THE FRICTIONLESS SLAB .
C          RESULTS OF SUBROUTINE TEMPSHR ARE USED -( NO FRICTION )
C     ******************************************************************
C
      COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
      COMMON /BLOCK2/ SS(101),AAA,WS(101),LONGPR,NPRINT,MAXITE,CRACKW
      COMMON /BLOCK3/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB,NEWBAR
      COMMON /BLOCK4/ AL(101),STRAIN(101),CONSTR(101),STRESSS(101)
      COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
      COMMON /BLOCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
      COMMON /BLOCK8/ Y(101),REFF(101),YP(101),H,ICLOSEB,YPITE(101)
      INTEGER AAA
C
                A=0.5*XBAR-BONDL
                HH=-H
      DO 20 I=1,NTP1
                STRAIN(I)=STRAINC
                AL(I)=HH+H
                HH=AL(I)
           IF (AL(I).GT.A) STRAIN(I)=STRAINC - STRAINC*(AL(I)-A)/BONDL
           IF (A.LE.0.) STRAIN(I)=STRAINC-(STRAINC*AL(I)*2.)/XBAR
                CONSTR(I)=STRAIN(I)*EC
 20   CONTINUE
          IF (LONGPR.NE.3HYES) RETURN
      PRINT 30
      PRINT 40, ((I,AL(I),STRAIN(I),CONSTR(I)),I=1,NTP1,NPRINT)
      PRINT 50, NTP1,A,H
      RETURN
C
   30 FORMAT( //,20X,*IN SUBROUTINE STRGENE*,
     1            //,10X,* INDEX  DISTANCE   CON STRAIN  CON STRESS *,/)
 40   FORMAT (10X,I5 , 3(2X,E10.3))
 50   FORMAT (/,20X,* NO. OF POINTS *,I5,/,20X,* BONDED LENGTH =*,
     1            E10.3,/,20X,* INCREMENT LENGTH =*,E10.3)
      END
```

APPENDIX 2

EXAMPLE PROBLEMS

```
          CRCP-2 TESTING
       EXAMPLE PROBLEM FOR CRCP-2 TESTING

PROB
A-1        BOND LENGTH > 1/2 XBAR. FIRST WITH LOW F-M CURVE

           ***********************************************
           *                                             *
           *              STEEL PROPERTIES               *
           *                                             *
           ***********************************************


              TYPE OF LONGITUDINAL REINFORCEMENT IS
                         DEFORMED BARS


              PERCENT REINFORCEMENT = 7.000E-01
              BAR DIAMETER          = 6.000E-01
              YIELD STRESS          = 6.000E+04
              ELASTIC MODULUS       = 9.000E+06
              THERMAL COEFFICIENT   = 5.000E-06


           ***********************************************
           *                                             *
           *            CONCRETE PROPERTIES              *
           *                                             *
           ***********************************************


              SLAB THICKNESS       = 1.000E+01
              THERMAL COEFFICIENT = 5.000E-06
              TOTAL SHRINKAGE      = 4.000E-04
              UNIT WEIGHT CONCRETE= 1.500E+02
              COMPRESSIVE STRENGTH= 2.500E+03


             TENSILE STRENGTH DATA
             *********************

              NO TENSILE STRENGTH DATA IS INPUT BY USER
              THE FOLLOWING AGE-TENSILE STRENGTH RELATIONSHIP
              IS USED WHICH IS BASED ON THE RECOMMENDATION
              GIVEN BY U.S. BUREAU OF RECLAMATION

              AGE,   TENSILE
             (DAYS)  STRENGTH

               0.0      0.0
               1.0     85.7
               3.0    191.9
               5.0    248.8
               7.0    282.5
              14.0    338.8
              21.0    370.1
              28.0    384.6
```

```
*********************************************************
*                                                       *
*       SLAB-BASE FRICTION CHARACTERISTICS              *
*               F-Y RELATIONSHIP                        *
*                                                       *
*********************************************************
```

TYPE OF FRICTION CURVE IS A STRAIGHT LINE

MAXIMUM FRICTION FORCE=   1.0000
MOVEMENT AT SLIDING   =   -.1000

```
****************************
*                          *
*     TEMPERATURE DATA     *
*                          *
****************************
```

CURING TEMPERATURE= 75.0

DAY	MINIMUM TEMPERATURE	DROP IN TEMPERATURE
1	72.0	3.0
2	69.0	6.0
3	53.0	22.0
4	53.0	22.0
5	60.0	15.0
6	65.0	10.0
7	54.0	21.0
8	15.0	60.0
9	59.0	16.0
10	20.0	55.0
11	50.0	25.0
12	50.0	25.0
13	15.0	60.0
14	54.0	21.0
15	30.0	45.0
16	59.0	16.0
17	15.0	60.0
18	54.0	21.0
19	53.0	22.0
20	54.0	21.0
21	69.0	6.0
22	22.0	53.0
23	56.0	19.0
24	30.0	45.0
25	32.0	43.0
26	43.0	32.0
27	56.0	19.0
28	57.0	18.0

MINIMUM TEMPERATURE EXPECTED AFTER
CONCRETE GAINS FULL STRENGTH   = 0.0 DEGREES FAHRENHEIT
DAYS BEFORE REACHING MIN. TEMP.   = 28.0 DAYS

```
**************************************************
*                                                *
*                 EXTERNAL LOAD                  *
*                                                *
**************************************************

      WHEEL LOAD STRESS (PSI)= 0.
      LOAD APPLIED AT        = 28 TH DAY


**************************************************
*                                                *
*        ITERATION AND TOLERANCE CONTROL         *
*                                                *
**************************************************

 MAXIMUM ALLOWABLE NUMBER OF ITERATIONS=   30

 RELATIVE CLOSURE TOLERANCE=  1.0 PERCENT
```

CRCP-2 TESTING
EXAMPLE PROBLEM FOR CRCP-2 TESTING

PROB
A-I   BOND LENGTH > 1/2 XBAR, FIRST WITH LOW F-M CURVE

TIME (DAYS)	TEMP DROP	DRYING SHRINKAGE	TENSILE STRGTH	CRACK SPACING	CRACK WIDTH	MAXIMUM CONCRETE STRESS	MAXIMUM STRESS IN THE STEEL
.50	3.0	1.814E-06	44.8	4800.0	5.727E-04	1.394E+01	2.108E+03
1.33	3.0	4.802E-06	105.3	4800.0	9.747E-04	2.595E+01	3.799E+03
1.50	6.0	5.394E-06	114.8	4800.0	2.720E-03	4.853E+01	7.059E+03
2.29	6.0	8.190E-06	157.4	4800.0	3.584E-03	6.266E+01	9.016E+03
2.38	16.0	8.490E-06	161.7	4800.0	1.644E-02	1.458E+02	2.051E+04
2.40	18.2	8.576E-06	163.0	2400.0	1.861E-02	1.571E+02	2.246E+04
2.42	19.0	8.617E-06	163.6	1200.0	1.784E-02	1.522E+02	2.211E+04
2.45	21.1	8.753E-06	165.5	600.0	1.719E-02	1.486E+02	2.175E+04
2.50	22.0	8.910E-06	167.8	600.0	1.838E-02	1.543E+02	2.258E+04
3.50	22.0	1.236E-05	206.9	600.0	2.065E-02	1.749E+02	2.546E+04
4.50	15.0	1.576E-05	235.4	600.0	1.346E-02	1.470E+02	2.135E+04
5.50	10.0	1.909E-05	257.5	600.0	8.956E-03	1.235E+02	1.787E+04
6.33	10.0	2.181E-05	271.6	600.0	9.758E-03	1.313E+02	1.897E+04
6.45	20.0	2.221E-05	273.6	600.0	2.271E-02	2.014E+02	2.911E+04
6.50	21.0	2.237E-05	274.4	600.0	2.421E-02	2.083E+02	3.009E+04
7.31	21.0	2.497E-05	285.2	600.0	2.536E-02	2.159E+02	3.115E+04
7.34	31.0	2.507E-05	285.4	600.0	4.102E-02	2.758E+02	3.976E+04
7.34	32.9	2.509E-05	285.5	300.0	2.911E-02	2.308E+02	3.346E+04
7.38	42.9	2.520E-05	285.8	300.0	3.965E-02	2.697E+02	3.909E+04
7.40	48.0	2.526E-05	286.0	150.0	2.681E-02	2.211E+02	3.211E+04
7.46	58.0	2.546E-05	286.5	150.0	3.300E-02	2.456E+02	3.567E+04
7.50	60.0	2.559E-05	286.9	150.0	3.427E-02	2.504E+02	3.637E+04
8.50	16.0	2.876E-05	295.4	150.0	8.798E-03	1.280E+02	1.847E+04
9.30	16.0	3.124E-05	302.0	150.0	9.103E-03	1.313E+02	1.892E+04
9.33	26.0	3.134E-05	302.3	150.0	1.465E-02	1.667E+02	2.409E+04
9.36	36.0	3.145E-05	302.6	150.0	2.050E-02	1.973E+02	2.856E+04
9.41	46.0	3.158E-05	302.9	150.0	2.656E-02	2.247E+02	3.255E+04
9.50	55.0	3.187E-05	303.7	150.0	3.216E-02	2.476E+02	3.588E+04
10.50	25.0	3.493E-05	311.8	150.0	1.457E-02	1.681E+02	2.425E+04
11.50	25.0	3.794E-05	319.8	150.0	1.498E-02	1.721E+02	2.479E+04
12.32	25.0	4.037E-05	326.1	150.0	1.531E-02	1.753E+02	2.523E+04
12.35	35.0	4.046E-05	326.4	150.0	2.121E-02	2.065E+02	2.977E+04
12.38	45.0	4.057E-05	326.6	150.0	2.731E-02	2.344E+02	3.384E+04
12.43	55.0	4.071E-05	327.0	150.0	3.355E-02	2.600E+02	3.756E+04
12.50	60.0	4.090E-05	327.5	150.0	3.673E-02	2.722E+02	3.934E+04
13.50	21.0	4.382E-05	335.1	150.0	1.348E-02	1.662E+02	2.386E+04
14.33	21.0	4.619E-05	340.4	150.0	1.378E-02	1.691E+02	2.425E+04
14.37	31.0	4.632E-05	340.6	150.0	1.965E-02	2.020E+02	2.904E+04
14.43	41.0	4.649E-05	340.9	150.0	2.573E-02	2.312E+02	3.330E+04
14.50	45.0	4.668E-05	341.2	150.0	2.822E-02	2.423E+02	3.491E+04
15.50	16.0	4.951E-05	345.8	150.0	1.137E-02	1.545E+02	2.209E+04
16.29	16.0	5.171E-05	349.4	150.0	1.164E-02	1.569E+02	2.242E+04
16.32	26.0	5.179E-05	349.5	150.0	1.741E-02	1.920E+02	2.753E+04
16.35	36.0	5.188E-05	349.7	150.0	2.342E-02	2.228E+02	3.201E+04
16.39	46.0	5.198E-05	349.8	150.0	2.959E-02	2.505E+02	3.605E+04
16.44	56.0	5.212E-05	350.1	150.0	3.590E-02	2.761E+02	3.976E+04
16.50	60.0	5.228E-05	350.3	150.0	3.846E-02	2.859E+02	4.119E+04
17.50	21.0	5.501E-05	354.8	150.0	1.490E-02	1.787E+02	2.556E+04
18.45	21.0	5.758E-05	359.1	150.0	1.523E-02	1.815E+02	2.594E+04

18.50	22.0	5.771E-05	359.3	150.0	1.583E-02	1.851E+02	2.646E+04
19.50	21.0	6.035E-05	363.6	150.0	1.559E-02	1.845E+02	2.635E+04
20.50	6.0	6.296E-05	367.9	150.0	7.509E-03	1.286E+02	1.819E+04
21.27	6.0	6.494E-05	370.6	150.0	7.730E-03	1.309E+02	1.850E+04
21.30	16.0	6.502E-05	370.7	150.0	1.329E-02	1.717E+02	2.443E+04
21.33	26.0	6.510E-05	370.8	150.0	1.916E-02	2.063E+02	2.946E+04
21.37	36.0	6.520E-05	370.9	150.0	2.525E-02	2.368E+02	3.390E+04
21.42	46.0	6.532E-05	371.0	150.0	3.149E-02	2.646E+02	3.793E+04
21.50	53.0	6.553E-05	371.1	150.0	3.594E-02	2.828E+02	4.058E+04
22.50	19.0	6.806E-05	373.3	150.0	1.539E-02	1.853E+02	2.638E+04
23.32	19.0	7.010E-05	375.0	150.0	1.564E-02	1.872E+02	2.663E+04
23.36	29.0	7.021E-05	375.1	150.0	2.162E-02	2.201E+02	3.143E+04
23.42	39.0	7.034E-05	375.2	150.0	2.778E-02	2.496E+02	3.571E+04
23.50	45.0	7.055E-05	375.3	150.0	3.157E-02	2.662E+02	3.811E+04
24.50	43.0	7.300E-05	377.4	150.0	3.064E-02	2.628E+02	3.760E+04
25.50	32.0	7.542E-05	379.5	150.0	2.413E-02	2.337E+02	3.334E+04
26.50	19.0	7.780E-05	381.6	150.0	1.659E-02	1.942E+02	2.758E+04
27.50	18.0	8.015E-05	383.6	150.0	1.629E-02	1.928E+02	2.736E+04

AT THE END OF THE ANALYSIS PERIOD

CRACK SPACING = 8.203E+00 FEET
CRACK WIDTH = 6.509E-02 INCHES
MAX CONCRETE STRESS= 3.860E+02 PSI
MAX STEEL STRESS = 5.258E+04 PSI,
CONC.TENS.STRENGTH = 3.846E+02 PSI

STA-TION	DIS-TANCE	CONCRETE MOVEMENT	FRICTION FORCE	CONCRETE STRESS	STEEL STRESS
1	0.0	0.	0.	3.860E+02	-2.454E+03
2	.5	-3.188E-04	3.188E-03	3.860E+02	-2.454E+03
3	1.0	-6.375E-04	6.376E-03	3.860E+02	-2.454E+03
4	1.5	-9.563E-04	9.564E-03	3.860E+02	-2.454E+03
5	2.0	-1.275E-03	1.275E-02	3.860E+02	-2.454E+03
6	2.5	-1.594E-03	1.594E-02	3.860E+02	-2.454E+03
7	3.0	-1.913E-03	1.913E-02	3.860E+02	-2.454E+03
8	3.4	-2.231E-03	2.232E-02	3.860E+02	-2.454E+03
9	3.9	-2.550E-03	2.550E-02	3.860E+02	-2.454E+03
10	4.4	-2.869E-03	2.869E-02	3.860E+02	-2.454E+03
11	4.9	-3.188E-03	3.188E-02	3.860E+02	-2.454E+03
12	5.4	-3.506E-03	3.507E-02	3.860E+02	-2.454E+03
13	5.9	-3.825E-03	3.826E-02	3.860E+02	-2.454E+03
14	6.4	-4.144E-03	4.144E-02	3.860E+02	-2.454E+03
15	6.9	-4.463E-03	4.463E-02	3.860E+02	-2.454E+03
16	7.4	-4.782E-03	4.782E-02	3.860E+02	-2.454E+03
17	7.9	-5.100E-03	5.101E-02	3.860E+02	-2.454E+03
18	8.4	-5.419E-03	5.420E-02	3.860E+02	-2.454E+03
19	8.9	-5.738E-03	5.738E-02	3.860E+02	-2.454E+03
20	9.4	-6.057E-03	6.057E-02	3.860E+02	-2.454E+03
21	9.8	-6.375E-03	6.376E-02	3.860E+02	-2.454E+03
22	10.3	-6.694E-03	6.695E-02	3.860E+02	-2.454E+03
23	10.8	-7.013E-03	7.014E-02	3.860E+02	-2.454E+03
24	11.3	-7.332E-03	7.332E-02	3.860E+02	-2.454E+03
25	11.8	-7.651E-03	7.651E-02	3.860E+02	-2.454E+03
26	12.3	-7.969E-03	7.970E-02	3.860E+02	-2.454E+03
27	12.8	-8.288E-03	8.289E-02	3.860E+02	-2.454E+03
28	13.3	-8.607E-03	8.608E-02	3.860E+02	-2.454E+03
29	13.8	-8.926E-03	8.926E-02	3.859E+02	-2.454E+03
30	14.3	-9.244E-03	9.245E-02	3.859E+02	-2.454E+03
31	14.8	-9.563E-03	9.564E-02	3.859E+02	-2.454E+03
32	15.3	-9.882E-03	9.883E-02	3.859E+02	-2.454E+03
33	15.7	-1.020E-02	1.020E-01	3.859E+02	-2.454E+03
34	16.2	-1.052E-02	1.052E-01	3.859E+02	-2.454E+03
35	16.7	-1.084E-02	1.084E-01	3.859E+02	-2.454E+03
36	17.2	-1.116E-02	1.116E-01	3.859E+02	-2.454E+03
37	17.7	-1.148E-02	1.148E-01	3.859E+02	-2.454E+03
38	18.2	-1.179E-02	1.180E-01	3.859E+02	-2.454E+03
39	18.7	-1.211E-02	1.211E-01	3.859E+02	-2.454E+03
40	19.2	-1.243E-02	1.243E-01	3.859E+02	-2.454E+03
41	19.7	-1.275E-02	1.275E-01	3.859E+02	-2.454E+03
42	20.2	-1.307E-02	1.307E-01	3.859E+02	-2.454E+03
43	20.7	-1.339E-02	1.339E-01	3.859E+02	-2.454E+03
44	21.2	-1.371E-02	1.371E-01	3.859E+02	-2.454E+03
45	21.7	-1.403E-02	1.403E-01	3.859E+02	-2.454E+03
46	22.1	-1.434E-02	1.435E-01	3.858E+02	-2.454E+03
47	22.6	-1.466E-02	1.467E-01	3.858E+02	-2.454E+03
48	23.1	-1.498E-02	1.498E-01	3.858E+02	-2.454E+03
49	23.6	-1.530E-02	1.530E-01	3.858E+02	-2.454E+03
50	24.1	-1.562E-02	1.562E-01	3.858E+02	-2.454E+03

51	24.6	-1.594E-02	1.594E-01	3.858E+02	-2.454E+03
52	25.1	-1.626E-02	1.626E-01	3.858E+02	-2.455E+03
53	25.6	-1.658E-02	1.658E-01	3.858E+02	-2.455E+03
54	26.1	-1.690E-02	1.690E-01	3.858E+02	-2.455E+03
55	26.6	-1.721E-02	1.722E-01	3.858E+02	-2.455E+03
56	27.1	-1.753E-02	1.753E-01	3.858E+02	-2.455E+03
57	27.6	-1.785E-02	1.785E-01	3.858E+02	-2.455E+03
58	28.1	-1.817E-02	1.817E-01	3.858E+02	-2.455E+03
59	28.5	-1.849E-02	1.849E-01	3.857E+02	-2.455E+03
60	29.0	-1.881E-02	1.881E-01	3.857E+02	-2.455E+03
61	29.5	-1.913E-02	1.913E-01	3.857E+02	-2.455E+03
62	30.0	-1.945E-02	1.945E-01	3.857E+02	-2.455E+03
63	30.5	-1.976E-02	1.977E-01	3.857E+02	-2.455E+03
64	31.0	-2.008E-02	2.009E-01	3.857E+02	-2.455E+03
65	31.5	-2.040E-02	2.040E-01	3.857E+02	-2.455E+03
66	32.0	-2.072E-02	2.072E-01	3.857E+02	-2.455E+03
67	32.5	-2.104E-02	2.104E-01	3.857E+02	-2.455E+03
68	33.0	-2.136E-02	2.136E-01	3.857E+02	-2.455E+03
69	33.5	-2.168E-02	2.168E-01	3.856E+02	-2.455E+03
70	34.0	-2.200E-02	2.200E-01	3.856E+02	-2.455E+03
71	34.5	-2.232E-02	2.232E-01	3.856E+02	-2.455E+03
72	34.9	-2.263E-02	2.264E-01	3.856E+02	-2.455E+03
73	35.4	-2.295E-02	2.295E-01	3.856E+02	-2.455E+03
74	35.9	-2.327E-02	2.327E-01	3.856E+02	-2.455E+03
75	36.4	-2.359E-02	2.359E-01	3.856E+02	-2.455E+03
76	36.9	-2.391E-02	2.391E-01	3.856E+02	-2.455E+03
77	37.4	-2.423E-02	2.423E-01	3.856E+02	-2.455E+03
78	37.9	-2.455E-02	2.455E-01	3.855E+02	-2.455E+03
79	38.4	-2.487E-02	2.487E-01	3.855E+02	-2.455E+03
80	38.9	-2.518E-02	2.519E-01	3.821E+02	-1.973E+03
81	39.4	-2.551E-02	2.551E-01	3.639E+02	6.247E+02
82	39.9	-2.583E-02	2.583E-01	3.457E+02	3.222E+03
83	40.4	-2.616E-02	2.616E-01	3.275E+02	5.820E+03
84	40.9	-2.649E-02	2.649E-01	3.094E+02	8.418E+03
85	41.3	-2.682E-02	2.682E-01	2.912E+02	1.102E+04
86	41.8	-2.715E-02	2.716E-01	2.730E+02	1.361E+04
87	42.3	-2.749E-02	2.749E-01	2.548E+02	1.621E+04
88	42.8	-2.783E-02	2.784E-01	2.366E+02	1.881E+04
89	43.3	-2.818E-02	2.818E-01	2.184E+02	2.141E+04
90	43.8	-2.853E-02	2.853E-01	2.002E+02	2.400E+04
91	44.3	-2.888E-02	2.888E-01	1.820E+02	2.660E+04
92	44.8	-2.923E-02	2.923E-01	1.638E+02	2.920E+04
93	45.3	-2.959E-02	2.959E-01	1.456E+02	3.180E+04
94	45.8	-2.995E-02	2.995E-01	1.274E+02	3.439E+04
95	46.3	-3.031E-02	3.031E-01	1.092E+02	3.699E+04
96	46.8	-3.067E-02	3.068E-01	9.098E+01	3.959E+04
97	47.2	-3.104E-02	3.104E-01	7.278E+01	4.219E+04
98	47.7	-3.141E-02	3.141E-01	5.458E+01	4.478E+04
99	48.2	-3.179E-02	3.179E-01	3.638E+01	4.738E+04
100	48.7	-3.216E-02	3.217E-01	1.818E+01	4.998E+04
101	49.2	-3.254E-02	3.255E-01	-1.820E-02	5.258E+04

```
        CRCP-2 TESTING
 EXAMPLE PROBLEM FOR CRCP-2 TESTING
```

PROB
A-2

```
BOND LENGTH > 1/2 XBAR, WITH HIGH F-M CURVE

**********************************************
*                                            *
*              STEEL PROPERTIES              *
*                                            *
**********************************************

     TYPE OF LONGITUDINAL REINFORCEMENT IS
                DEFORMED BARS

     PERCENT REINFORCEMENT = 1.200E+00
     BAR DIAMETER          = 1.000E+00
     YIELD STRESS          = 6.000E+04
     ELASTIC MODULUS       = 2.900E+07
     THERMAL COEFFICIENT   = 5.000E-06

**********************************************
*                                            *
*            CONCRETE PROPERTIES             *
*                                            *
**********************************************

     SLAB THICKNESS        = 1.000F+01
     THERMAL COEFFICIENT = 5.000F-06
     TOTAL SHRINKAGE       = 4.000F-04
     UNIT WEIGHT CONCRETE= 1.500F+02
     COMPRESSIVE STRENGTH= 2.500F+03

    TENSILE STRENGTH DATA
    *********************

     NO TENSILE STRENGTH DATA IS INPUT BY USER
     THE FOLLOWING AGE-TENSILE STRENGTH RELATIONSHIP
     IS USED WHICH IS BASED ON THE RECOMMENDATION
     GIVEN BY U.S. BUREAU OF RECLAMATION

     AGE,  TENSILE
    (DAYS) STRENGTH

      0.0     0.0
      1.0    85.7
      3.0   191.9
      5.0   248.8
      7.0   282.5
     14.0   338.8
     21.0   370.1
     28.0   384.6
```

```
*********************************************
*                                           *
*     SLAB-BASE FRICTION CHARACTERISTICS    *
*            F-Y RELATIONSHIP               *
*                                           *
*********************************************
```

TYPE OF FRICTION CURVE IS A PARABOLA

MAXIMUM FRICTION FORCE=   7.5000
MOVEMENT AT SLIDING   =   -.2000

```
****************************
*                          *
*     TEMPERATURE DATA     *
*                          *
****************************
```

CURING TEMPERATURE= 75.0

DAY	MINIMUM TEMPERATURE	DROP IN TEMPERATURE
1	72.0	3.0
2	69.0	6.0
3	53.0	22.0
4	53.0	22.0
5	60.0	15.0
6	65.0	10.0
7	54.0	21.0
8	15.0	60.0
9	59.0	16.0
10	20.0	55.0
11	50.0	25.0
12	50.0	25.0
13	15.0	60.0
14	54.0	21.0
15	30.0	45.0
16	59.0	16.0
17	15.0	60.0
18	54.0	21.0
19	53.0	22.0
20	54.0	21.0
21	69.0	6.0
22	22.0	53.0
23	56.0	19.0
24	30.0	45.0
25	32.0	43.0
26	43.0	32.0
27	56.0	19.0
28	57.0	18.0

MINIMUM TEMPERATURE EXPECTED AFTER
CONCRETE GAINS FULL STRENGTH   = 0.0 DEGREES FAHRENHEIT
DAYS BEFORE REACHING MIN. TEMP.   = 28.0 DAYS

```
*************************************************
*                                               *
*                 EXTERNAL LOAD                 *
*                                               *
*************************************************

      WHEEL LOAD STRESS (PSI)= 0.
      LOAD APPLIED AT        = 28 TH DAY


*************************************************
*                                               *
*      ITERATION AND TOLERANCE CONTROL          *
*                                               *
*************************************************

 MAXIMUM ALLOWABLE NUMBER OF ITERATIONS=   30

 RELATIVE CLOSURE TOLERANCE=  1.0 PERCENT
```

CRCP-2 TESTING
EXAMPLE PROBLEM FOR CRCP-2 TESTING

PROB
A-2 BOND LENGTH > 1/2 XBAR. WITH HIGH F-M CURVE

TIME (DAYS)	TEMP DROP	DRYING SHRINKAGE	TENSILE STRGTH	CRACK SPACING	CRACK WIDTH	MAXIMUM CONCRETE STRESS	STRESS IN THE STEEL
.50	3.0	1.814E-06	44.8	4800.0	3.776E-04	1.417E+01	1.417E+03
1.33	3.0	4.802E-06	105.3	4800.0	5.321E-04	2.634E+01	2.368E+03
1.50	6.0	5.394E-06	114.8	4800.0	1.250E-03	5.013E+01	4.480E+03
2.29	6.0	8.190E-06	157.4	4800.0	1.474E-03	6.345E+01	5.600E+03
2.38	16.0	8.490E-06	161.7	4800.0	5.621E-03	1.500E+02	1.297E+04
2.40	17.5	8.548E-06	162.6	2400.0	5.585E-03	1.625E+02	1.416E+04
2.40	17.5	8.549E-06	162.6	1200.0	5.741E-03	1.617E+02	1.415E+04
2.40	17.7	8.557E-06	162.7	600.0	5.657E-03	1.557E+02	1.417E+04
2.41	18.7	8.604E-06	163.4	300.0	5.581E-03	1.498E+02	1.413E+04
2.46	21.1	8.753E-06	165.5	150.0	5.431E-03	1.454E+02	1.400E+04
2.50	22.0	8.910E-06	167.8	150.0	5.791E-03	1.508E+02	1.450E+04
3.50	22.0	1.236E-05	206.9	150.0	6.379E-03	1.704E+02	1.600E+04
4.50	15.0	1.576E-05	235.4	150.0	4.141E-03	1.438E+02	1.319E+04
5.50	10.0	1.909E-05	257.5	150.0	2.749E-03	1.212E+02	1.086E+04
6.33	10.0	2.181E-05	271.6	150.0	2.980E-03	1.287E+02	1.143E+04
6.45	20.0	2.221E-05	273.6	150.0	6.844E-03	1.956E+02	1.769E+04
6.50	21.0	2.237E-05	274.4	150.0	7.287E-03	2.021E+02	1.829E+04
7.31	21.0	2.497E-05	285.2	150.0	7.587E-03	2.094E+02	1.882E+04
7.34	31.0	2.507E-05	285.4	150.0	1.222E-02	2.658E+02	2.410E+04
7.35	35.1	2.511E-05	285.5	75.0	9.168E-03	2.280E+02	2.077E+04
7.39	45.1	2.522E-05	285.9	75.0	1.222E-02	2.634E+02	2.411E+04
7.42	52.7	2.533E-05	286.2	37.5	8.518E-03	2.188E+02	2.000E+04
7.50	60.0	2.559E-05	286.9	37.5	9.82[illegible]E-03	2.352E+02	2.154E+04
8.50	16.0	2.876E-05	295.4	37.5	2.562E-03	1.215E+02	1.065E+04
9.30	16.0	3.124E-05	302.0	37.5	2.645E-03	1.245E+02	1.084E+04
9.33	26.0	3.134E-05	302.3	37.5	4.227E-03	1.575E+02	1.395E+04
9.36	36.0	3.145E-05	302.6	37.5	5.887E-03	1.859E+02	1.663E+04
9.41	46.0	3.158E-05	302.9	37.5	7.600E-03	2.114E+02	1.902E+04
9.50	55.0	3.187E-05	303.7	37.5	9.18[illegible]E-03	2.326E+02	2.101E+04
10.50	25.0	3.493E-05	311.8	37.5	4.193E-03	1.588E+02	1.393E+04
11.50	25.0	3.794E-05	319.8	37.5	4.300E-03	1.625E+02	1.416E+04
12.32	25.0	4.037E-05	326.1	37.5	4.386E-03	1.655E+02	1.434E+04
12.35	35.0	4.046E-05	326.4	37.5	6.052E-03	1.944E+02	1.705E+04
12.38	45.0	4.057E-05	326.6	37.5	7.767E-03	2.203E+02	1.947E+04
12.43	55.0	4.071E-05	327.0	37.5	9.519E-03	2.440E+02	2.169E+04
12.50	60.0	4.090E-05	327.5	37.5	1.041E-02	2.554E+02	2.274E+04
13.50	21.0	4.382E-05	335.1	37.5	3.860E-03	1.570E+02	1.341E+04
14.33	21.0	4.619E-05	340.4	37.5	3.942E-03	1.597E+02	1.357E+04
14.37	31.0	4.632E-05	340.6	37.5	5.593E-03	1.902E+02	1.642E+04
14.43	41.0	4.649E-05	340.9	37.5	7.298E-03	2.174E+02	1.895E+04
14.50	45.0	4.668E-05	341.2	37.5	7.996E-03	2.276E+02	1.990E+04
15.50	16.0	4.951E-05	345.8	37.5	3.257E-03	1.461E+02	1.219E+04
16.29	16.0	5.171E-05	349.4	37.5	3.330E-03	1.484E+02	1.233E+04
16.32	26.0	5.179E-05	349.5	37.5	4.953E-03	1.810E+02	1.536E+04
16.35	36.0	5.188E-05	349.7	37.5	6.637E-03	2.096E+02	1.802E+04
16.39	46.0	5.198E-05	349.8	37.5	8.364E-03	2.353E+02	2.042E+04
16.44	56.0	5.212E-05	350.1	37.5	1.012E-02	2.590E+02	2.262E+04
16.50	60.0	5.228E-05	350.3	37.5	1.084E-02	2.681E+02	2.346E+04
17.50	21.0	5.501E-05	354.8	37.5	4.244E-03	1.686E+02	1.410E+04

18.45	21.0	5.758E-05	359.1	37.5	4.332E-03	1.712E+02	1.425E+04
18.50	22.0	5.771E-05	359.3	37.5	4.500E-03	1.746E+02	1.456E+04
19.50	21.0	6.035E-05	363.6	37.5	4.428E-03	1.741E+02	1.442E+04
20.50	6.0	6.296E-05	367.9	37.5	2.154E-03	1.220E+02	9.497E+03
21.27	6.0	6.494E-05	370.6	37.5	2.216E-03	1.241E+02	9.630E+03
21.30	16.0	6.502E-05	370.7	37.5	3.776E-03	1.621E+02	1.315E+04
21.33	26.0	6.510E-05	370.8	37.5	5.42[illegible]E-03	1.942E+02	1.612E+04
21.37	36.0	6.520E-05	370.9	37.5	7.117E-03	2.226E+02	1.875E+04
21.42	46.0	6.532E-05	371.0	37.5	8.854E-03	2.483E+02	2.113E+04
21.50	53.0	6.553E-05	371.1	37.5	1.009E-02	2.651E+02	2.269E+04
22.50	19.0	6.806E-05	373.3	37.5	4.363E-03	1.748E+02	1.422E+04
23.32	19.0	7.010E-05	375.0	37.5	4.432E-03	1.765E+02	1.432E+04
23.36	29.0	7.021E-05	375.1	37.5	6.101E-03	2.071E+02	1.715E+04
23.42	39.0	7.034E-05	375.2	37.5	7.817E-03	2.344E+02	1.968E+04
23.50	45.0	7.055E-05	375.3	37.5	8.867E-03	2.498E+02	2.109E+04
24.50	43.0	7.300E-05	377.4	37.5	8.606E-03	2.467E+02	2.072E+04
25.50	32.0	7.542E-05	379.5	37.5	6.793E-03	2.197E+02	1.814E+04
26.50	19.0	7.780E-05	381.6	37.5	4.692E-03	1.830E+02	1.467E+04
27.50	18.0	8.015E-05	383.6	37.5	4.607E-03	1.818E+02	1.448E+04

AT THE END OF THE ANALYSIS PERIOD

CRACK SPACING = 2.783E+00 FEET
CRACK WIDTH = 2.378E-02 INCHES
MAX CONCRETE STRESS= 3.827E+02 PSI
MAX STEEL STRESS = 2.674E+04 PSI,
CONC.TENS.STRENGTH = 3.846E+02 PSI

STA- TION	DIS- TANCE	CONCRETE MOVEMENT	FRICTION FORCE	CONCRETE STRESS	STEEL STRESS
1	0.0	0.	0.	3.827E+02	-4.989E+03
2	.2	-1.084E-04	1.747E-01	3.789E+02	-4.672E+03
3	.3	-2.171E-04	2.471E-01	3.751E+02	-4.355E+03
4	.5	-3.259E-04	3.028E-01	3.713E+02	-4.037E+03
5	.7	-4.350E-04	3.498E-01	3.674E+02	-3.720E+03
6	.8	-5.443E-04	3.913E-01	3.636E+02	-3.403E+03
7	1.0	-6.538E-04	4.289E-01	3.598E+02	-3.086E+03
8	1.2	-7.635E-04	4.635E-01	3.559E+02	-2.768E+03
9	1.3	-8.734E-04	4.957E-01	3.521E+02	-2.451E+03
10	1.5	-9.835E-04	5.260E-01	3.483E+02	-2.134E+03
11	1.7	-1.094E-03	5.547E-01	3.445E+02	-1.816E+03
12	1.8	-1.204E-03	5.821E-01	3.406E+02	-1.499E+03
13	2.0	-1.315E-03	6.083E-01	3.368E+02	-1.182E+03
14	2.2	-1.426E-03	6.334E-01	3.330E+02	-8.646E+02
15	2.3	-1.537E-03	6.576E-01	3.292E+02	-5.473E+02
16	2.5	-1.649E-03	6.810E-01	3.253E+02	-2.300E+02
17	2.7	-1.760E-03	7.037E-01	3.215E+02	8.730E+01
18	2.8	-1.872E-03	7.257E-01	3.177E+02	4.046E+02
19	3.0	-1.984E-03	7.471E-01	3.138E+02	7.219E+02
20	3.2	-2.096E-03	7.679E-01	3.100E+02	1.039E+03
21	3.3	-2.209E-03	7.883E-01	3.062E+02	1.356E+03
22	3.5	-2.321E-03	8.081E-01	3.024E+02	1.674E+03
23	3.7	-2.434E-03	8.275E-01	2.985E+02	1.991E+03
24	3.8	-2.547E-03	8.465E-01	2.947E+02	2.308E+03
25	4.0	-2.661E-03	8.652E-01	2.909E+02	2.626E+03
26	4.2	-2.774E-03	8.834E-01	2.871E+02	2.943E+03
27	4.3	-2.888E-03	9.013E-01	2.832E+02	3.260E+03
28	4.5	-3.002E-03	9.189E-01	2.794E+02	3.577E+03
29	4.7	-3.116E-03	9.362E-01	2.756E+02	3.895E+03
30	4.8	-3.230E-03	9.533E-01	2.717E+02	4.212E+03
31	5.0	-3.345E-03	9.700E-01	2.679E+02	4.529E+03
32	5.2	-3.460E-03	9.865E-01	2.641E+02	4.847E+03
33	5.3	-3.575E-03	1.003E+00	2.603E+02	5.164E+03
34	5.5	-3.690E-03	1.019E+00	2.564E+02	5.481E+03
35	5.7	-3.805E-03	1.035E+00	2.526E+02	5.798E+03
36	5.8	-3.921E-03	1.050E+00	2.488E+02	6.116E+03
37	6.0	-4.037E-03	1.066E+00	2.450E+02	6.433E+03
38	6.2	-4.153E-03	1.081E+00	2.411E+02	6.750E+03
39	6.3	-4.269E-03	1.096E+00	2.373E+02	7.068E+03
40	6.5	-4.385E-03	1.111E+00	2.335E+02	7.385E+03
41	6.7	-4.502E-03	1.125E+00	2.296E+02	7.702E+03
42	6.8	-4.619E-03	1.140E+00	2.258E+02	8.019E+03
43	7.0	-4.736E-03	1.154E+00	2.220E+02	8.337E+03
44	7.2	-4.853E-03	1.168E+00	2.182E+02	8.654E+03
45	7.3	-4.971E-03	1.182E+00	2.143E+02	8.971E+03
46	7.5	-5.089E-03	1.196E+00	2.105E+02	9.289E+03
47	7.7	-5.206E-03	1.210E+00	2.067E+02	9.606E+03
48	7.8	-5.325E-03	1.224E+00	2.029E+02	9.923E+03
49	8.0	-5.443E-03	1.237E+00	1.990E+02	1.024E+04
50	8.2	-5.561E-03	1.251E+00	1.952E+02	1.056E+04

51	8.3	-5.680E-03	1.264E+00	1.914E+02	1.088E+04
52	8.5	-5.799E-03	1.277E+00	1.875E+02	1.119E+04
53	8.7	-5.918E-03	1.290E+00	1.837E+02	1.151E+04
54	8.9	-6.038E-03	1.303E+00	1.799E+02	1.183E+04
55	9.0	-6.157E-03	1.316E+00	1.761E+02	1.214E+04
56	9.2	-6.277E-03	1.329E+00	1.722E+02	1.246E+04
57	9.4	-6.397E-03	1.341E+00	1.684E+02	1.278E+04
58	9.5	-6.518E-03	1.354E+00	1.646E+02	1.310E+04
59	9.7	-6.638E-03	1.366E+00	1.608E+02	1.341E+04
60	9.9	-6.759E-03	1.379E+00	1.569E+02	1.373E+04
61	10.0	-6.880E-03	1.391E+00	1.531E+02	1.405E+04
62	10.2	-7.001E-03	1.403E+00	1.493E+02	1.437E+04
63	10.4	-7.122E-03	1.415E+00	1.454E+02	1.468E+04
64	10.5	-7.243E-03	1.427E+00	1.416E+02	1.500E+04
65	10.7	-7.365E-03	1.439E+00	1.378E+02	1.532E+04
66	10.9	-7.487E-03	1.451E+00	1.340E+02	1.563E+04
67	11.0	-7.609E-03	1.463E+00	1.301E+02	1.595E+04
68	11.2	-7.732E-03	1.475E+00	1.263E+02	1.627E+04
69	11.4	-7.854E-03	1.486E+00	1.225E+02	1.659E+04
70	11.5	-7.977E-03	1.498E+00	1.186E+02	1.690E+04
71	11.7	-8.100E-03	1.509E+00	1.148E+02	1.722E+04
72	11.9	-8.223E-03	1.521E+00	1.110E+02	1.754E+04
73	12.0	-8.347E-03	1.532E+00	1.072E+02	1.786E+04
74	12.2	-8.470E-03	1.544E+00	1.033E+02	1.817E+04
75	12.4	-8.594E-03	1.555E+00	9.951E+01	1.849E+04
76	12.5	-8.718E-03	1.566E+00	9.569E+01	1.881E+04
77	12.7	-8.842E-03	1.577E+00	9.186E+01	1.912E+04
78	12.9	-8.967E-03	1.588E+00	8.803E+01	1.944E+04
79	13.0	-9.091E-03	1.599E+00	8.420E+01	1.976E+04
80	13.2	-9.216E-03	1.610E+00	8.038E+01	2.008E+04
81	13.4	-9.341E-03	1.621E+00	7.655E+01	2.039E+04
82	13.5	-9.467E-03	1.632E+00	7.272E+01	2.071E+04
83	13.7	-9.592E-03	1.643E+00	6.889E+01	2.103E+04
84	13.9	-9.718E-03	1.653E+00	6.507E+01	2.135E+04
85	14.0	-9.844E-03	1.664E+00	6.124E+01	2.166E+04
86	14.2	-9.970E-03	1.675E+00	5.741E+01	2.198E+04
87	14.4	-1.010E-02	1.685E+00	5.358E+01	2.230E+04
88	14.5	-1.022E-02	1.696E+00	4.976E+01	2.261E+04
89	14.7	-1.035E-02	1.706E+00	4.593E+01	2.293E+04
90	14.9	-1.048E-02	1.717E+00	4.210E+01	2.325E+04
91	15.0	-1.060E-02	1.727E+00	3.827E+01	2.357E+04
92	15.2	-1.073E-02	1.737E+00	3.445E+01	2.388E+04
93	15.4	-1.086E-02	1.748E+00	3.062E+01	2.420E+04
94	15.5	-1.099E-02	1.758E+00	2.679E+01	2.452E+04
95	15.7	-1.111E-02	1.768E+00	2.296E+01	2.484E+04
96	15.9	-1.124E-02	1.778E+00	1.914E+01	2.515E+04
97	16.0	-1.137E-02	1.788E+00	1.531E+01	2.547E+04
98	16.2	-1.150E-02	1.799E+00	1.148E+01	2.579E+04
99	16.4	-1.163E-02	1.809E+00	7.655E+00	2.610E+04
100	16.5	-1.176E-02	1.819E+00	3.827E+00	2.642E+04
101	16.7	-1.189E-02	1.829E+00	0.	2.674E+04

```
            CRCP-2 TESTING
      EXAMPLE PROBLEM FOR CRCP-2 TESTING


PROB
B-1      NO INCREASE IN TENSILE STRENGTH AFTER 28 TH DAY

         ***********************************************
         *                                             *
         *               STEEL PROPERTIES              *
         *                                             *
         ***********************************************


               TYPE OF LONGITUDINAL REINFORCEMENT IS
                         DEFORMED BARS


               PERCENT REINFORCEMENT = 1.200E+00
               BAR DIAMETER          = 1.000E+00
               YIELD STRESS          = 6.000E+04
               ELASTIC MODULUS       = 2.900E+07
               THERMAL COEFFICIENT   = 5.000E-06


         ***********************************************
         *                                             *
         *             CONCRETE PROPERTIES             *
         *                                             *
         ***********************************************


               SLAB THICKNESS      = 1.000E+01
               THERMAL COEFFICIENT = 5.000E-06
               TOTAL SHRINKAGE     = 4.000E-04
               UNIT WEIGHT CONCRETE= 1.500E+02
               COMPRESSIVE STRENGTH= 3.500E+03


              TENSILE STRENGTH DATA
              ********************

               NO TENSILE STRENGTH DATA IS INPUT BY USER
               THE FOLLOWING AGE-TENSILE STRENGTH RELATIONSHIP
               IS USED WHICH IS BASED ON THE RECOMMENDATION
               GIVEN BY U.S. BUREAU OF RECLAMATION

               AGE,  TENSILE
              (DAYS) STRENGTH

                0.0     0.0
                1.0   116.0
                3.0   249.5
                5.0   316.8
                7.0   355.4
               14.0   417.8
               21.0   451.3
               28.0   466.7
```

```
*********************************************
*                                           *
*      SLAB-BASE FRICTION CHARACTERISTICS   *
*              F-Y RELATIONSHIP             *
*                                           *
*********************************************
```

TYPE OF FRICTION CURVE IS A STRAIGHT LINE

MAXIMUM FRICTION FORCE= 3.0000
MOVEMENT AT SLIDING = -.1000

```
****************************
*                          *
*     TEMPERATURE DATA     *
*                          *
****************************
```

CURING TEMPERATURE= 75.0

DAY	MINIMUM TEMPERATURE	DROP IN TEMPERATURE
1	72.0	3.0
2	69.0	6.0
3	53.0	22.0
4	51.0	24.0
5	60.0	15.0
6	65.0	10.0
7	54.0	21.0
8	15.0	60.0
9	59.0	16.0
10	20.0	55.0
11	50.0	25.0
12	50.0	25.0
13	15.0	60.0
14	54.0	21.0
15	30.0	45.0
16	59.0	16.0
17	15.0	60.0
18	54.0	21.0
19	53.0	22.0
20	54.0	21.0
21	69.0	6.0
22	22.0	53.0
23	56.0	19.0
24	30.0	45.0
25	32.0	43.0
26	43.0	32.0
27	56.0	19.0
28	57.0	18.0

MINIMUM TEMPERATURE EXPECTED AFTER
CONCRETE GAINS FULL STRENGTH = 0.0 DEGREES FAHRENHEIT
DAYS BEFORE REACHING MIN. TEMP. = 28.0 DAYS

```
**************************************************
*                                                *
*                 EXTERNAL LOAD                  *
*                                                *
**************************************************

      WHEEL LOAD STRESS (PSI)= 0.
      LOAD APPLIED AT        = 28 TH DAY



**************************************************
*                                                *
*        ITERATION AND TOLERANCE CONTROL         *
*                                                *
**************************************************

 MAXIMUM ALLOWABLE NUMBER OF ITERATIONS=   30

 RELATIVE CLOSURE TOLERANCE=  1.0 PERCENT
```

CRCP-2 TESTING
EXAMPLE PROBLEM FOR CRCP-2 TESTING

PROB
B-1 NO INCREASE IN TENSILE STRENGTH AFTER 28 TH DAY

TIME (DAYS)	TEMP DROP	DRYING SHRINKAGE	TENSILE STRGTH	CRACK SPACING	CRACK WIDTH	MAXIMUM CONCRETE STRESS	STRESS IN THE STEEL
.50	3.0	1.814E-06	61.6	4800.0	3.764E-04	1.651E+01	1.802E+03
1.33	3.0	4.802E-06	141.5	4800.0	5.504E-04	3.080E+01	2.980E+03
1.50	6.0	5.394E-06	153.7	4800.0	1.340E-03	5.774E+01	5.609E+03
2.29	6.0	8.190E-06	207.3	4800.0	1.684E-03	7.472E+01	6.990E+03
2.38	16.0	8.490E-06	212.6	4800.0	7.031E-03	1.755E+02	1.638E+04
2.43	20.0	8.669E-06	215.8	2400.0	9.480E-03	2.130E+02	2.003E+04
2.44	20.3	8.688E-06	216.2	1200.0	9.492E-03	2.091E+02	1.988E+04
2.46	21.2	8.759E-06	217.4	600.0	9.258E-03	2.058E+02	1.970E+04
2.50	22.0	8.910E-06	220.1	600.0	9.911E-03	2.140E+02	2.046E+04
3.43	22.0	1.214E-05	265.3	600.0	1.124E-02	2.445E+02	2.292E+04
3.50	24.0	1.236E-05	267.6	600.0	1.296E-02	2.639E+02	2.472E+04
4.50	15.0	1.576E-05	301.2	600.0	7.038E-03	2.029E+02	1.868E+04
5.50	10.0	1.909E-05	326.9	600.0	4.474E-03	1.672E+02	1.512E+04
6.33	10.0	2.181E-05	342.9	600.0	4.917E-03	1.790E+02	1.608E+04
6.45	20.0	2.221E-05	345.2	600.0	1.268E-02	2.887E+02	2.621E+04
6.50	21.0	2.237E-05	346.1	600.0	1.362E-02	2.998E+02	2.722E+04
7.31	21.0	2.497E-05	358.4	600.0	1.433E-02	3.122E+02	2.821E+04
7.32	25.7	2.502E-05	358.5	300.0	1.475E-02	3.155E+02	2.863E+04
7.34	31.5	2.507E-05	358.7	150.0	1.325E-02	2.984E+02	2.711E+04
7.37	41.5	2.518E-05	359.0	150.0	1.850E-02	3.529E+02	3.217E+04
7.38	43.0	2.520E-05	359.1	75.0	1.190E-02	2.826E+02	2.565E+04
7.42	53.0	2.534E-05	359.5	75.0	1.508E-02	3.184E+02	2.898E+04
7.50	60.0	2.559E-05	360.3	75.0	1.738E-02	3.421E+02	3.118E+04
8.50	16.0	2.876E-05	369.8	75.0	4.244E-03	1.709E+02	1.509E+04
9.30	16.0	3.124E-05	377.3	75.0	4.394E-03	1.754E+02	1.541E+04
9.33	26.0	3.134E-05	377.5	75.0	7.208E-03	2.248E+02	1.999E+04
9.36	36.0	3.145E-05	377.9	75.0	1.021E-02	2.677E+02	2.397E+04
9.41	46.0	3.158E-05	378.3	75.0	1.333E-02	3.061E+02	2.753E+04
9.50	55.0	3.187E-05	379.1	75.0	1.624E-02	3.382E+02	3.050E+04
10.50	25.0	3.493E-05	388.1	75.0	7.158E-03	2.268E+02	2.003E+04
11.50	25.0	3.794E-05	396.9	75.0	7.361E-03	2.323E+02	2.041E+04
12.32	25.0	4.037E-05	403.9	75.0	7.524E-03	2.368E+02	2.072E+04
12.35	35.0	4.046E-05	404.2	75.0	1.055E-02	2.805E+02	2.475E+04
12.38	45.0	4.057E-05	404.5	75.0	1.369E-02	3.197E+02	2.837E+04
12.43	55.0	4.071E-05	404.9	75.0	1.692E-02	3.557E+02	3.168E+04
12.50	60.0	4.090E-05	405.4	75.0	1.858E-02	3.729E+02	3.326E+04
13.50	21.0	4.382E-05	413.7	75.0	6.588E-03	2.240E+02	1.940E+04
14.33	21.0	4.619E-05	419.4	75.0	6.741E-03	2.281E+02	1.968E+04
14.37	31.0	4.632E-05	419.6	75.0	9.732E-03	2.742E+02	2.392E+04
14.43	41.0	4.649E-05	419.9	75.0	1.286E-02	3.153E+02	2.770E+04
14.50	45.0	4.668E-05	420.3	75.0	1.414E-02	3.308E+02	2.912E+04
15.50	16.0	4.951E-05	425.3	75.0	5.518E-03	2.077E+02	1.769E+04
16.29	16.0	5.171E-05	429.2	75.0	5.652E-03	2.111E+02	1.793E+04
16.32	26.0	5.179E-05	429.3	75.0	8.580E-03	2.602E+02	2.243E+04
16.35	36.0	5.188E-05	429.5	75.0	1.166E-02	3.034E+02	2.640E+04
16.39	46.0	5.198E-05	429.7	75.0	1.484E-02	3.424E+02	2.998E+04
16.44	56.0	5.212E-05	429.9	75.0	1.810E-02	3.784E+02	3.328E+04
16.50	60.0	5.228E-05	430.2	75.0	1.943E-02	3.922E+02	3.454E+04
17.50	21.0	5.501E-05	435.0	75.0	7.302E-03	2.416E+02	2.060E+04

18.45	21.0	5.758E-05	439.5	75.0	7.466E-03	2.455E+02	2.087E+04
18.50	22.0	5.771E-05	439.8	75.0	7.770E-03	2.505E+02	2.133E+04
19.50	21.0	6.035E-05	444.4	75.0	7.645E-03	2.498E+02	2.116E+04
20.50	6.0	6.296E-05	449.0	75.0	3.579E-03	1.717E+02	1.392E+04
21.27	6.0	6.494E-05	451.9	75.0	3.689E-03	1.749E+02	1.414E+04
21.30	16.0	6.502E-05	452.0	75.0	6.474E-03	2.318E+02	1.934E+04
21.33	26.0	6.510E-05	452.1	75.0	9.459E-03	2.802E+02	2.378E+04
21.37	36.0	6.520E-05	452.1	75.0	1.258E-02	3.232E+02	2.770E+04
21.42	46.0	6.532E-05	452.2	75.0	1.579E-02	3.622E+02	3.127E+04
21.50	53.0	6.553E-05	452.4	75.0	1.809E-02	3.878E+02	3.360E+04
22.50	19.0	6.806E-05	454.7	75.0	7.538E-03	2.509E+02	2.099E+04
23.32	19.0	7.010E-05	456.5	75.0	7.665E-03	2.535E+02	2.116E+04
23.36	29.0	7.021E-05	456.6	75.0	1.071E-02	2.997E+02	2.539E+04
23.42	39.0	7.034E-05	456.7	75.0	1.387E-02	3.412E+02	2.918E+04
23.50	45.0	7.055E-05	456.9	75.0	1.582E-02	3.644E+02	3.129E+04
24.50	43.0	7.300E-05	459.1	75.0	1.534E-02	3.597E+02	3.078E+04
25.50	32.0	7.542E-05	461.3	75.0	1.199E-02	3.188E+02	2.696E+04
26.50	19.0	7.780E-05	463.4	75.0	8.145E-03	2.633E+02	2.181E+04
27.50	18.0	8.015E-05	465.6	75.0	7.993E-03	2.614E+02	2.156E+04

AT THE END OF THE ANALYSIS PERIOD

CRACK SPACING = 2.881E+00 FEET
CRACK WIDTH = 2.454E-02 INCHES
MAX CONCRETE STRESS= 4.666E+02 PSI
MAX STEEL STRESS = 3.030E+04 PSI,
CONC.TENS.STRENGTH = 4.667E+02 PSI

STA-TION	DIS-TANCE	CONCRETE MOVEMENT	FRICTION FORCE	CONCRETE STRESS	STEEL STRESS
1	0.0	0.	0.	4.666E+02	-8.554E+03
2	.2	-1.116E-04	3.348E-03	4.619E+02	-8.166E+03
3	.3	-2.234E-04	6.702E-03	4.573E+02	-7.777E+03
4	.5	-3.354E-04	1.006E-02	4.526E+02	-7.389E+03
5	.7	-4.477E-04	1.343E-02	4.480E+02	-7.000E+03
6	.9	-5.602E-04	1.681E-02	4.433E+02	-6.612E+03
7	1.0	-6.729E-04	2.019E-02	4.386E+02	-6.223E+03
8	1.2	-7.858E-04	2.358E-02	4.340E+02	-5.834E+03
9	1.4	-8.990E-04	2.697E-02	4.293E+02	-5.446E+03
10	1.6	-1.012E-03	3.037E-02	4.246E+02	-5.057E+03
11	1.7	-1.126E-03	3.378E-02	4.200E+02	-4.669E+03
12	1.9	-1.240E-03	3.720E-02	4.153E+02	-4.280E+03
13	2.1	-1.354E-03	4.062E-02	4.106E+02	-3.891E+03
14	2.2	-1.468E-03	4.405E-02	4.060E+02	-3.503E+03
15	2.4	-1.583E-03	4.748E-02	4.013E+02	-3.114E+03
16	2.6	-1.697E-03	5.092E-02	3.966E+02	-2.726E+03
17	2.8	-1.812E-03	5.437E-02	3.920E+02	-2.337E+03
18	2.9	-1.928E-03	5.783E-02	3.873E+02	-1.948E+03
19	3.1	-2.043E-03	6.129E-02	3.826E+02	-1.560E+03
20	3.3	-2.159E-03	6.476E-02	3.780E+02	-1.171E+03
21	3.5	-2.274E-03	6.823E-02	3.733E+02	-7.827E+02
22	3.6	-2.391E-03	7.172E-02	3.686E+02	-3.941E+02
23	3.8	-2.507E-03	7.521E-02	3.640E+02	-5.503E+00
24	4.0	-2.623E-03	7.870E-02	3.593E+02	3.831E+02
25	4.1	-2.740E-03	8.221E-02	3.546E+02	7.717E+02
26	4.3	-2.857E-03	8.571E-02	3.500E+02	1.160E+03
27	4.5	-2.974E-03	8.923E-02	3.453E+02	1.549E+03
28	4.7	-3.092E-03	9.275E-02	3.406E+02	1.937E+03
29	4.8	-3.209E-03	9.628E-02	3.360E+02	2.326E+03
30	5.0	-3.327E-03	9.982E-02	3.313E+02	2.715E+03
31	5.2	-3.445E-03	1.034E-01	3.266E+02	3.103E+03
32	5.4	-3.564E-03	1.069E-01	3.220E+02	3.492E+03
33	5.5	-3.682E-03	1.105E-01	3.173E+02	3.880E+03
34	5.7	-3.801E-03	1.140E-01	3.126E+02	4.269E+03
35	5.9	-3.920E-03	1.176E-01	3.080E+02	4.658E+03
36	6.0	-4.039E-03	1.212E-01	3.033E+02	5.046E+03
37	6.2	-4.159E-03	1.248E-01	2.986E+02	5.435E+03
38	6.4	-4.278E-03	1.284E-01	2.940E+02	5.823E+03
39	6.6	-4.398E-03	1.320E-01	2.893E+02	6.212E+03
40	6.7	-4.518E-03	1.356E-01	2.846E+02	6.601E+03
41	6.9	-4.639E-03	1.392E-01	2.800E+02	6.989E+03
42	7.1	-4.759E-03	1.428E-01	2.753E+02	7.378E+03
43	7.3	-4.880E-03	1.464E-01	2.706E+02	7.766E+03
44	7.4	-5.001E-03	1.500E-01	2.660E+02	8.155E+03
45	7.6	-5.122E-03	1.537E-01	2.613E+02	8.543E+03
46	7.8	-5.244E-03	1.573E-01	2.566E+02	8.932E+03
47	8.0	-5.366E-03	1.610E-01	2.520E+02	9.321E+03
48	8.1	-5.488E-03	1.646E-01	2.473E+02	9.709E+03
49	8.3	-5.610E-03	1.683E-01	2.426E+02	1.010E+04
50	8.5	-5.732E-03	1.720E-01	2.380E+02	1.049E+04

51	8.6	-5.855E-03	1.756E-01	2.333E+02	1.087E+04
52	8.8	-5.978E-03	1.793E-01	2.286E+02	1.126E+04
53	9.0	-6.101E-03	1.830E-01	2.240E+02	1.165E+04
54	9.2	-6.224E-03	1.867E-01	2.193E+02	1.204E+04
55	9.3	-6.347E-03	1.904E-01	2.146E+02	1.243E+04
56	9.5	-6.471E-03	1.941E-01	2.100E+02	1.282E+04
57	9.7	-6.595E-03	1.979E-01	2.053E+02	1.321E+04
58	9.9	-6.719E-03	2.016E-01	2.006E+02	1.360E+04
59	10.0	-6.844E-03	2.053E-01	1.960E+02	1.398E+04
60	10.2	-6.968E-03	2.091E-01	1.913E+02	1.437E+04
61	10.4	-7.093E-03	2.128E-01	1.866E+02	1.476E+04
62	10.5	-7.218E-03	2.166E-01	1.820E+02	1.515E+04
63	10.7	-7.343E-03	2.203E-01	1.773E+02	1.554E+04
64	10.9	-7.469E-03	2.241E-01	1.726E+02	1.593E+04
65	11.1	-7.595E-03	2.278E-01	1.680E+02	1.632E+04
66	11.2	-7.721E-03	2.316E-01	1.633E+02	1.670E+04
67	11.4	-7.847E-03	2.354E-01	1.586E+02	1.709E+04
68	11.6	-7.973E-03	2.392E-01	1.540E+02	1.748E+04
69	11.8	-8.100E-03	2.430E-01	1.493E+02	1.787E+04
70	11.9	-8.227E-03	2.468E-01	1.447E+02	1.826E+04
71	12.1	-8.354E-03	2.506E-01	1.400E+02	1.865E+04
72	12.3	-8.481E-03	2.544E-01	1.353E+02	1.904E+04
73	12.4	-8.609E-03	2.583E-01	1.307E+02	1.942E+04
74	12.6	-8.737E-03	2.621E-01	1.260E+02	1.981E+04
75	12.8	-8.865E-03	2.659E-01	1.213E+02	2.020E+04
76	13.0	-8.993E-03	2.698E-01	1.167E+02	2.059E+04
77	13.1	-9.121E-03	2.736E-01	1.120E+02	2.098E+04
78	13.3	-9.250E-03	2.775E-01	1.073E+02	2.137E+04
79	13.5	-9.379E-03	2.814E-01	1.027E+02	2.176E+04
80	13.7	-9.508E-03	2.852E-01	9.799E+01	2.214E+04
81	13.8	-9.637E-03	2.891E-01	9.332E+01	2.253E+04
82	14.0	-9.767E-03	2.930E-01	8.866E+01	2.292E+04
83	14.2	-9.897E-03	2.969E-01	8.399E+01	2.331E+04
84	14.3	-1.003E-02	3.008E-01	7.932E+01	2.370E+04
85	14.5	-1.016E-02	3.047E-01	7.466E+01	2.409E+04
86	14.7	-1.029E-02	3.086E-01	6.999E+01	2.448E+04
87	14.9	-1.042E-02	3.126E-01	6.533E+01	2.486E+04
88	15.0	-1.055E-02	3.165E-01	6.066E+01	2.525E+04
89	15.2	-1.068E-02	3.204E-01	5.599E+01	2.564E+04
90	15.4	-1.081E-02	3.244E-01	5.133E+01	2.603E+04
91	15.6	-1.094E-02	3.283E-01	4.666E+01	2.642E+04
92	15.7	-1.108E-02	3.323E-01	4.200E+01	2.681E+04
93	15.9	-1.121E-02	3.362E-01	3.733E+01	2.720E+04
94	16.1	-1.134E-02	3.402E-01	3.266E+01	2.758E+04
95	16.2	-1.147E-02	3.442E-01	2.800E+01	2.797E+04
96	16.4	-1.160E-02	3.481E-01	2.333E+01	2.836E+04
97	16.6	-1.174E-02	3.521E-01	1.866E+01	2.875E+04
98	16.8	-1.187E-02	3.561E-01	1.400E+01	2.914E+04
99	16.9	-1.200E-02	3.601E-01	9.332E+00	2.953E+04
100	17.1	-1.214E-02	3.641E-01	4.666E+00	2.992E+04
101	17.3	-1.227E-02	3.682E-01	0.	3.030E+04

```
CRCP-2 TESTING
EXAMPLE PROBLEM FOR CRCP-2 TESTING
```

PROB
B-2 ALLOW STRENGTH BUILD UP FOR 90 DAYS

```
*****************************************
*                                       *
*          STEEL PROPERTIES             *
*                                       *
*****************************************


     TYPE OF LONGITUDINAL REINFORCEMENT IS
              DEFORMED BARS


     PERCENT REINFORCEMENT = 1.200E+00
     BAR DIAMETER          = 1.000E+00
     YIELD STRESS          = 6.000E+04
     ELASTIC MODULUS       = 2.900E+07
     THERMAL COEFFICIENT   = 5.000E-06


*****************************************
*                                       *
*         CONCRETE PROPERTIES           *
*                                       *
*****************************************


     SLAB THICKNESS      = 1.000E+01
     THERMAL COEFFICIENT = 5.000E-06
     TOTAL SHRINKAGE     = 4.000E-04
     UNIT WEIGHT CONCRETE= 1.500E+02
     COMPRESSIVE STRENGTH= 3.500E+03


    TENSILE STRENGTH DATA
    ********************

     NO TENSILE STRENGTH DATA IS INPUT BY USER
     THE FOLLOWING AGE-TENSILE STRENGTH RELATIONSHIP
     IS USED WHICH IS BASED ON THE RECOMMENDATION
     GIVEN BY U.S. BUREAU OF RECLAMATION

     AGE,  TENSILE
    (DAYS) STRENGTH

      0.0    0.0
      1.0  116.0
      3.0  249.5
      5.0  316.8
      7.0  355.4
     14.0  417.8
     21.0  451.3
     28.0  466.7
```

```
********************************************
*                                          *
*     SLAB-BASE FRICTION CHARACTERISTICS   *
*            F-Y RELATIONSHIP              *
*                                          *
********************************************
```

TYPE OF FRICTION CURVE IS A STRAIGHT LINE

MAXIMUM FRICTION FORCE=   3.0000
MOVEMENT AT SLIDING   =   -.1000

```
***************************
*                         *
*     TEMPERATURE DATA    *
*                         *
***************************
```

CURING TEMPERATURE= 75.0

DAY	MINIMUM TEMPERATURE	DROP IN TEMPERATURE
1	72.0	3.0
2	69.0	6.0
3	53.0	22.0
4	51.0	24.0
5	60.0	15.0
6	65.0	10.0
7	54.0	21.0
8	15.0	60.0
9	59.0	16.0
10	20.0	55.0
11	50.0	25.0
12	50.0	25.0
13	15.0	60.0
14	54.0	21.0
15	30.0	45.0
16	59.0	16.0
17	15.0	60.0
18	54.0	21.0
19	53.0	22.0
20	54.0	21.0
21	69.0	6.0
22	22.0	53.0
23	56.0	19.0
24	30.0	45.0
25	32.0	43.0
26	43.0	32.0
27	56.0	19.0
28	57.0	18.0

MINIMUM TEMPERATURE EXPECTED AFTER
CONCRETE GAINS FULL STRENGTH   = 0.0 DEGREES FAHRENHEIT
DAYS BEFORE REACHING MIN. TEMP.   = 90.0 DAYS

```
*********************************************
*                                           *
*               EXTERNAL LOAD               *
*                                           *
*********************************************

      WHEEL LOAD STRESS (PSI)= 0.
      LOAD APPLIED AT        = 28 TH DAY


*********************************************
*                                           *
*     ITERATION AND TOLERANCE CONTROL       *
*                                           *
*********************************************

 MAXIMUM ALLOWABLE NUMBER OF ITERATIONS=   30

 RELATIVE CLOSURE TOLERANCE=  1.0 PERCENT
```

CRCP-2 TESTING
EXAMPLE PROBLEM FOR CRCP-2 TESTING

PROB
B-2 ALLOW STRENGTH BUILD UP FOR 90 DAYS

TIME (DAYS)	TEMP DROP	DRYING SHRINKAGE	TENSILE STRGTH	CRACK SPACING	CRACK WIDTH	MAXIMUM CONCRETE STRESS	STRESS IN THE STEEL
.50	3.0	1.814E-06	61.6	4800.0	3.764E-04	1.651E+01	1.802E+03
1.33	3.0	4.802E-06	141.5	4800.0	5.504E-04	3.080E+01	2.980E+03
1.50	6.0	5.394E-06	153.7	4800.0	1.340E-03	5.774E+01	5.609E+03
2.29	6.0	8.190E-06	207.3	4800.0	1.684E-03	7.472E+01	6.990E+03
2.38	16.0	8.490E-06	212.6	4800.0	7.031E-03	1.755E+02	1.638E+04
2.43	20.0	8.669E-06	215.8	2400.0	9.480E-03	2.130E+02	2.003E+04
2.44	20.3	8.688E-06	216.2	1200.0	9.492E-03	2.091E+02	1.988E+04
2.46	21.2	8.759E-06	217.4	600.0	9.258E-03	2.058E+02	1.970E+04
2.50	22.0	8.910E-06	220.1	600.0	9.911E-03	2.140E+02	2.046E+04
3.43	22.0	1.214E-05	265.3	600.0	1.124E-02	2.445E+02	2.292E+04
3.50	24.0	1.236E-05	267.6	600.0	1.296E-02	2.639E+02	2.472E+04
4.50	15.0	1.576E-05	301.2	600.0	7.038E-03	2.029E+02	1.868E+04
5.50	10.0	1.909E-05	326.9	600.0	4.474E-03	1.672E+02	1.512E+04
6.33	10.0	2.181E-05	342.9	600.0	4.917E-03	1.790E+02	1.608E+04
6.45	20.0	2.221E-05	345.2	600.0	1.268E-02	2.887E+02	2.621E+04
6.50	21.0	2.237E-05	346.1	600.0	1.362E-02	2.998E+02	2.722E+04
7.31	21.0	2.497E-05	358.4	600.0	1.433E-02	3.122E+02	2.821E+04
7.32	25.7	2.502E-05	358.5	300.0	1.475E-02	3.155E+02	2.863E+04
7.34	31.5	2.507E-05	358.7	150.0	1.325E-02	2.984E+02	2.711E+04
7.37	41.5	2.518E-05	359.0	150.0	1.850E-02	3.529E+02	3.217E+04
7.38	43.0	2.520E-05	359.1	75.0	1.190E-02	2.826E+02	2.565E+04
7.42	53.0	2.534E-05	359.5	75.0	1.508E-02	3.184E+02	2.898E+04
7.50	60.0	2.559E-05	360.3	75.0	1.738E-02	3.421E+02	3.118E+04
8.50	16.0	2.876E-05	369.8	75.0	4.244E-03	1.709E+02	1.509E+04
9.30	16.0	3.124E-05	377.3	75.0	4.394E-03	1.754E+02	1.541E+04
9.33	26.0	3.134E-05	377.5	75.0	7.208E-03	2.248E+02	1.999E+04
9.36	36.0	3.145E-05	377.9	75.0	1.021E-02	2.677E+02	2.397E+04
9.41	46.0	3.158E-05	378.3	75.0	1.333E-02	3.061E+02	2.753E+04
9.50	55.0	3.187E-05	379.1	75.0	1.624E-02	3.382E+02	3.050E+04
10.50	25.0	3.493E-05	388.1	75.0	7.158E-03	2.268E+02	2.003E+04
11.50	25.0	3.794E-05	396.9	75.0	7.361E-03	2.323E+02	2.041E+04
12.32	25.0	4.037E-05	403.9	75.0	7.524E-03	2.368E+02	2.072E+04
12.35	35.0	4.046E-05	404.2	75.0	1.055E-02	2.805E+02	2.475E+04
12.38	45.0	4.057E-05	404.5	75.0	1.369E-02	3.197E+02	2.837E+04
12.43	55.0	4.071E-05	404.9	75.0	1.692E-02	3.557E+02	3.168E+04
12.50	60.0	4.090E-05	405.4	75.0	1.858E-02	3.729E+02	3.326E+04
13.50	21.0	4.382E-05	413.7	75.0	6.588E-03	2.240E+02	1.940E+04
14.33	21.0	4.619E-05	419.4	75.0	6.741E-03	2.281E+02	1.968E+04
14.37	31.0	4.632E-05	419.6	75.0	9.732E-03	2.742E+02	2.392E+04
14.43	41.0	4.649E-05	419.9	75.0	1.286E-02	3.153E+02	2.770E+04
14.50	45.0	4.668E-05	420.3	75.0	1.414E-02	3.308E+02	2.912E+04
15.50	16.0	4.951E-05	425.3	75.0	5.518E-03	2.077E+02	1.769E+04
16.29	16.0	5.171E-05	429.2	75.0	5.652E-03	2.111E+02	1.793E+04
16.32	26.0	5.179E-05	429.3	75.0	8.580E-03	2.602E+02	2.243E+04
16.35	36.0	5.188E-05	429.5	75.0	1.166E-02	3.034E+02	2.640E+04
16.39	46.0	5.198E-05	429.7	75.0	1.484E-02	3.424E+02	2.998E+04
16.44	56.0	5.212E-05	429.9	75.0	1.810E-02	3.784E+02	3.328E+04
16.50	60.0	5.228E-05	430.2	75.0	1.943E-02	3.922E+02	3.454E+04
17.50	21.0	5.501E-05	435.0	75.0	7.302E-03	2.416E+02	2.060E+04

18.45	21.0	5.758E-05	439.5	75.0	7.466E-03	2.455E+02	2.087E+04
18.50	22.0	5.771E-05	439.8	75.0	7.770E-03	2.505E+02	2.133E+04
19.50	21.0	6.035E-05	444.4	75.0	7.645E-03	2.498E+02	2.116E+04
20.50	6.0	6.296E-05	449.0	75.0	3.579E-03	1.717E+02	1.392E+04
21.27	6.0	6.494E-05	451.9	75.0	3.689E-03	1.749E+02	1.414E+04
21.30	16.0	6.502E-05	452.0	75.0	6.474E-03	2.318E+02	1.934E+04
21.33	26.0	6.510E-05	452.1	75.0	9.459E-03	2.802E+02	2.378E+04
21.37	36.0	6.520E-05	452.1	75.0	1.258E-02	3.232E+02	2.770E+04
21.42	46.0	6.532E-05	452.2	75.0	1.579E-02	3.622E+02	3.127E+04
21.50	53.0	6.553E-05	452.4	75.0	1.809E-02	3.878E+02	3.360E+04
22.50	19.0	6.806E-05	454.7	75.0	7.538E-03	2.509E+02	2.099E+04
23.32	19.0	7.010E-05	456.5	75.0	7.665E-03	2.535E+02	2.116E+04
23.36	29.0	7.021E-05	456.6	75.0	1.071E-02	2.997E+02	2.539E+04
23.42	39.0	7.034E-05	456.7	75.0	1.387E-02	3.412E+02	2.918E+04
23.50	45.0	7.055E-05	456.9	75.0	1.582E-02	3.644E+02	3.129E+04
24.50	43.0	7.300E-05	459.1	75.0	1.534E-02	3.597E+02	3.078E+04
25.50	32.0	7.542E-05	461.3	75.0	1.199E-02	3.188E+02	2.696E+04
26.50	19.0	7.780E-05	463.4	75.0	8.145E-03	2.633E+02	2.181E+04
27.50	18.0	8.015E-05	465.6	75.0	7.993E-03	2.614E+02	2.156E+04

AT THE END OF THE ANALYSIS PERIOD

CRACK SPACING = 3.125E+00 FEET
CRACK WIDTH = 2.643E-02 INCHES
MAX CONCRETE STRESS= 4.884E+02 PSI
MAX STEEL STRESS = 3.284E+04 PSI,
CONC.TENS.STRENGTH = 4.904E+02 PSI

STA-TION	DIS-TANCE	CONCRETE MOVEMENT	FRICTION FORCE	CONCRETE STRESS	STEEL STRESS
1	0.0	0.	0.	4.884E+02	-7.835E+03
2	.2	-1.210E-04	3.629E-03	4.884E+02	-7.835E+03
3	.4	-2.419E-04	7.258E-03	4.884E+02	-7.835E+03
4	.6	-3.629E-04	1.089E-02	4.884E+02	-7.835E+03
5	.8	-4.839E-04	1.452E-02	4.884E+02	-7.835E+03
6	.9	-6.048E-04	1.815E-02	4.884E+02	-7.835E+03
7	1.1	-7.258E-04	2.177E-02	4.884E+02	-7.835E+03
8	1.3	-8.468E-04	2.540E-02	4.884E+02	-7.835E+03
9	1.5	-9.677E-04	2.903E-02	4.884E+02	-7.834E+03
10	1.7	-1.089E-03	3.266E-02	4.831E+02	-7.392E+03
11	1.9	-1.210E-03	3.631E-02	4.778E+02	-6.950E+03
12	2.1	-1.332E-03	3.996E-02	4.725E+02	-6.508E+03
13	2.3	-1.454E-03	4.361E-02	4.672E+02	-6.066E+03
14	2.4	-1.576E-03	4.728E-02	4.619E+02	-5.624E+03
15	2.6	-1.698E-03	5.095E-02	4.566E+02	-5.182E+03
16	2.8	-1.821E-03	5.463E-02	4.513E+02	-4.740E+03
17	3.0	-1.944E-03	5.832E-02	4.460E+02	-4.298E+03
18	3.2	-2.067E-03	6.202E-02	4.407E+02	-3.855E+03
19	3.4	-2.191E-03	6.572E-02	4.354E+02	-3.413E+03
20	3.6	-2.314E-03	6.943E-02	4.301E+02	-2.971E+03
21	3.8	-2.438E-03	7.315E-02	4.248E+02	-2.529E+03
22	3.9	-2.563E-03	7.688E-02	4.194E+02	-2.087E+03
23	4.1	-2.687E-03	8.062E-02	4.141E+02	-1.645E+03
24	4.3	-2.812E-03	8.436E-02	4.088E+02	-1.203E+03
25	4.5	-2.937E-03	8.812E-02	4.035E+02	-7.608E+02
26	4.7	-3.062E-03	9.187E-02	3.982E+02	-3.187E+02
27	4.9	-3.188E-03	9.564E-02	3.929E+02	1.234E+02
28	5.1	-3.314E-03	9.942E-02	3.876E+02	5.655E+02
29	5.3	-3.440E-03	1.032E-01	3.823E+02	1.008E+03
30	5.4	-3.566E-03	1.070E-01	3.770E+02	1.450E+03
31	5.6	-3.693E-03	1.108E-01	3.717E+02	1.892E+03
32	5.8	-3.820E-03	1.146E-01	3.664E+02	2.334E+03
33	6.0	-3.947E-03	1.184E-01	3.611E+02	2.776E+03
34	6.2	-4.075E-03	1.222E-01	3.558E+02	3.218E+03
35	6.4	-4.202E-03	1.261E-01	3.505E+02	3.660E+03
36	6.6	-4.330E-03	1.299E-01	3.451E+02	4.102E+03
37	6.8	-4.458E-03	1.338E-01	3.398E+02	4.544E+03
38	6.9	-4.587E-03	1.376E-01	3.345E+02	4.986E+03
39	7.1	-4.716E-03	1.415E-01	3.292E+02	5.429E+03
40	7.3	-4.845E-03	1.453E-01	3.239E+02	5.871E+03
41	7.5	-4.974E-03	1.492E-01	3.186E+02	6.313E+03
42	7.7	-5.104E-03	1.531E-01	3.133E+02	6.755E+03
43	7.9	-5.233E-03	1.570E-01	3.080E+02	7.197E+03
44	8.1	-5.364E-03	1.609E-01	3.027E+02	7.639E+03
45	8.3	-5.494E-03	1.648E-01	2.974E+02	8.081E+03
46	8.4	-5.625E-03	1.687E-01	2.921E+02	8.523E+03
47	8.6	-5.755E-03	1.727E-01	2.868E+02	8.965E+03
48	8.8	-5.887E-03	1.766E-01	2.815E+02	9.407E+03
49	9.0	-6.018E-03	1.805E-01	2.761E+02	9.849E+03
50	9.2	-6.150E-03	1.845E-01	2.708E+02	1.029E+04

51	9.4	-6.282E-03	1.885E-01	2.655E+02	1.073E+04
52	9.6	-6.414E-03	1.924E-01	2.602E+02	1.118E+04
53	9.8	-6.546E-03	1.964E-01	2.549E+02	1.162E+04
54	9.9	-6.679E-03	2.004E-01	2.496E+02	1.206E+04
55	10.1	-6.812E-03	2.044E-01	2.443E+02	1.250E+04
56	10.3	-6.945E-03	2.084E-01	2.390E+02	1.294E+04
57	10.5	-7.079E-03	2.124E-01	2.337E+02	1.339E+04
58	10.7	-7.213E-03	2.164E-01	2.284E+02	1.383E+04
59	10.9	-7.347E-03	2.204E-01	2.231E+02	1.427E+04
60	11.1	-7.481E-03	2.244E-01	2.177E+02	1.471E+04
61	11.3	-7.616E-03	2.285E-01	2.124E+02	1.515E+04
62	11.4	-7.750E-03	2.325E-01	2.071E+02	1.560E+04
63	11.6	-7.886E-03	2.366E-01	2.018E+02	1.604E+04
64	11.8	-8.021E-03	2.406E-01	1.965E+02	1.648E+04
65	12.0	-8.157E-03	2.447E-01	1.912E+02	1.692E+04
66	12.2	-8.293E-03	2.488E-01	1.859E+02	1.737E+04
67	12.4	-8.429E-03	2.529E-01	1.806E+02	1.781E+04
68	12.6	-8.565E-03	2.570E-01	1.753E+02	1.825E+04
69	12.7	-8.702E-03	2.611E-01	1.700E+02	1.869E+04
70	12.9	-8.839E-03	2.652E-01	1.646E+02	1.913E+04
71	13.1	-8.976E-03	2.693E-01	1.593E+02	1.958E+04
72	13.3	-9.114E-03	2.734E-01	1.540E+02	2.002E+04
73	13.5	-9.251E-03	2.776E-01	1.487E+02	2.046E+04
74	13.7	-9.389E-03	2.817E-01	1.434E+02	2.090E+04
75	13.9	-9.528E-03	2.858E-01	1.381E+02	2.134E+04
76	14.1	-9.666E-03	2.900E-01	1.328E+02	2.179E+04
77	14.2	-9.805E-03	2.942E-01	1.275E+02	2.223E+04
78	14.4	-9.944E-03	2.983E-01	1.222E+02	2.267E+04
79	14.6	-1.008E-02	3.025E-01	1.169E+02	2.311E+04
80	14.8	-1.022E-02	3.067E-01	1.115E+02	2.355E+04
81	15.0	-1.036E-02	3.109E-01	1.062E+02	2.400E+04
82	15.2	-1.050E-02	3.151E-01	1.009E+02	2.444E+04
83	15.4	-1.064E-02	3.193E-01	9.561E+01	2.488E+04
84	15.6	-1.078E-02	3.235E-01	9.030E+01	2.532E+04
85	15.7	-1.093E-02	3.278E-01	8.499E+01	2.576E+04
86	15.9	-1.107E-02	3.320E-01	7.967E+01	2.621E+04
87	16.1	-1.121E-02	3.362E-01	7.436E+01	2.665E+04
88	16.3	-1.135E-02	3.405E-01	6.905E+01	2.709E+04
89	16.5	-1.149E-02	3.448E-01	6.374E+01	2.753E+04
90	16.7	-1.163E-02	3.490E-01	5.843E+01	2.798E+04
91	16.9	-1.178E-02	3.533E-01	5.312E+01	2.842E+04
92	17.1	-1.192E-02	3.576E-01	4.780E+01	2.886E+04
93	17.2	-1.206E-02	3.619E-01	4.249E+01	2.930E+04
94	17.4	-1.221E-02	3.662E-01	3.718E+01	2.974E+04
95	17.6	-1.235E-02	3.705E-01	3.187E+01	3.019E+04
96	17.8	-1.249E-02	3.748E-01	2.656E+01	3.063E+04
97	18.0	-1.264E-02	3.791E-01	2.124E+01	3.107E+04
98	18.2	-1.278E-02	3.835E-01	1.593E+01	3.151E+04
99	18.4	-1.293E-02	3.878E-01	1.062E+01	3.195E+04
100	18.6	-1.307E-02	3.921E-01	5.307E+00	3.240E+04
101	18.7	-1.322E-02	3.965E-01	-6.037E-03	3.284E+04

CRCP-2 TESTING
EFFECT OF EXTERNAL LOAD

PROB
C-1 ZERO EXTERNAL LOAD

```
**************************************************
*                                                *
*               STEEL PROPERTIES                 *
*                                                *
**************************************************
```

TYPE OF LONGITUDINAL REINFORCEMENT IS
DEFORMED BARS

```
PERCENT REINFORCEMENT = 1.200E+00
BAR DIAMETER          = 1.000E+00
YIELD STRESS          = 6.000E+04
ELASTIC MODULUS       = 2.900E+07
THERMAL COEFFICIENT   = 5.000E-06
```

```
**************************************************
*                                                *
*             CONCRETE PROPERTIES                *
*                                                *
**************************************************
```

```
SLAB THICKNESS       = 1.200E+01
THERMAL COEFFICIENT  = 5.000E-06
TOTAL SHRINKAGE      = 4.000E-04
UNIT WEIGHT CONCRETE= 1.500E+02
COMPRESSIVE STRENGTH= 5.000E+03
```

TENSILE STRENGTH DATA
****

NO TENSILE STRENGTH DATA IS INPUT BY USER
THE FOLLOWING AGE-TENSILE STRENGTH RELATIONSHIP
IS USED WHICH IS BASED ON THE RECOMMENDATION
GIVEN BY U.S. BUREAU OF RECLAMATION

AGE, (DAYS)	TENSILE STRENGTH
0.0	0.0
1.0	157.9
3.0	322.0
5.0	398.5
7.0	440.6
14.0	506.2
21.0	540.2
28.0	555.6

```
*************************************************
*                                               *
*      SLAB-BASE FRICTION CHARACTERISTICS       *
*             F-Y RELATIONSHIP                  *
*                                               *
*************************************************
```

TYPE OF FRICTION CURVE IS A STRAIGHT LINE

MAXIMUM FRICTION FORCE=   1.0000
MOVEMENT AT SLIDING   =   -.1000

```
******************************
*                            *
*      TEMPERATURE DATA      *
*                            *
******************************
```

CURING TEMPERATURE= 75.0

DAY	MINIMUM TEMPERATURE	DROP IN TEMPERATURE
1	65.0	10.0
2	65.0	10.0
3	65.0	10.0
4	65.0	10.0
5	65.0	10.0
6	65.0	10.0
7	65.0	10.0
8	65.0	10.0
9	65.0	10.0
10	65.0	10.0
11	65.0	10.0
12	65.0	10.0
13	65.0	10.0
14	65.0	10.0
15	65.0	10.0
16	65.0	10.0
17	55.0	20.0
18	55.0	20.0
19	55.0	20.0
20	55.0	20.0
21	55.0	20.0
22	55.0	20.0
23	55.0	20.0
24	55.0	20.0
25	55.0	20.0
26	55.0	20.0
27	55.0	20.0
28	55.0	20.0

MINIMUM TEMPERATURE EXPECTED AFTER
CONCRETE GAINS FULL STRENGTH   = 30.0 DEGREES FAHRENHEIT
DAYS BEFORE REACHING MIN. TEMP.   = 90.0 DAYS

```
***********************************************
*                                             *
*               EXTERNAL LOAD                 *
*                                             *
***********************************************

      WHEEL LOAD STRESS (PSI)= 0.
      LOAD APPLIED AT        = 28 TH DAY


***********************************************
*                                             *
*      ITERATION AND TOLERANCE CONTROL        *
*                                             *
***********************************************

 MAXIMUM ALLOWABLE NUMBER OF ITERATIONS=   30

 RELATIVE CLOSURE TOLERANCE=  1.0 PERCENT
```

CRCP-2 TESTING
EFFECT OF EXTERNAL LOAD

PROB
C-1 ZERO EXTERNAL LOAD

TIME (DAYS)	TEMP DROP	DRYING SHRINKAGE	TENSILE STRGTH	CRACK SPACING	CRACK WIDTH	MAXIMUM CONCRETE STRESS	MAXIMUM STRESS IN THE STEEL
.50	10.0	1.814E-06	85.7	4800.0	2.019E-03	6.065E+01	6.460E+03
1.50	10.0	5.394E-06	206.0	4800.0	3.121E-03	1.075E+02	1.032E+04
2.50	10.0	8.910E-06	287.3	4800.0	4.070E-03	1.422E+02	1.317E+04
3.50	10.0	1.236E-05	342.9	4800.0	4.962E-03	1.709E+02	1.553E+04
4.50	10.0	1.576E-05	381.0	4800.0	5.815E-03	1.954E+02	1.753E+04
5.50	10.0	1.909E-05	409.6	4800.0	6.663E-03	2.177E+02	1.935E+04
6.50	10.0	2.237E-05	430.6	4800.0	7.499E-03	2.377E+02	2.099E+04
7.50	10.0	2.559E-05	445.8	4800.0	8.319E-03	2.558E+02	2.246E+04
8.50	10.0	2.876E-05	456.0	4800.0	9.114E-03	2.718E+02	2.376E+04
9.50	10.0	3.187E-05	465.9	4800.0	9.940E-03	2.879E+02	2.507E+04
10.50	10.0	3.493E-05	475.4	4800.0	1.079E-02	3.041E+02	2.637E+04
11.50	10.0	3.794E-05	484.6	4800.0	1.168E-02	3.204E+02	2.769E+04
12.50	10.0	4.090E-05	493.4	4800.0	1.259E-02	3.367E+02	2.902E+04
13.50	10.0	4.382E-05	502.0	4800.0	1.353E-02	3.532E+02	3.034E+04
14.50	10.0	4.668E-05	508.8	4800.0	1.446E-02	3.685E+02	3.159E+04
15.50	10.0	4.951E-05	513.9	4800.0	1.537E-02	3.829E+02	3.274E+04
16.33	10.0	5.182E-05	518.1	4800.0	1.614E-02	3.948E+02	3.370E+04
16.41	16.7	5.203E-05	518.4	2400.0	2.578E-02	5.016E+02	4.346E+04
16.42	17.7	5.207E-05	518.5	1200.0	2.442E-02	4.862E+02	4.231E+04
16.50	20.0	5.228E-05	518.9	600.0	2.273E-02	4.680E+02	4.079E+04
17.50	20.0	5.501E-05	523.8	600.0	2.352E-02	4.787E+02	4.163E+04
18.50	20.0	5.771E-05	528.6	600.0	2.432E-02	4.892E+02	4.247E+04
19.50	20.0	6.035E-05	533.3	600.0	2.511E-02	4.996E+02	4.330E+04
20.50	20.0	6.296E-05	538.0	600.0	2.590E-02	5.100E+02	4.412E+04
21.50	20.0	6.553E-05	541.4	600.0	2.666E-02	5.193E+02	4.486E+04
22.50	20.0	6.806E-05	543.6	600.0	2.738E-02	5.275E+02	4.551E+04
23.50	20.0	7.055E-05	545.8	600.0	2.809E-02	5.357E+02	4.615E+04
24.50	20.0	7.300E-05	548.0	300.0	2.075E-02	4.608E+02	3.940E+04
25.50	20.0	7.542E-05	550.2	300.0	2.121E-02	4.670E+02	3.987E+04
26.50	20.0	7.780E-05	552.4	300.0	2.167E-02	4.731E+02	4.034E+04
27.50	20.0	8.015E-05	554.5	300.0	2.212E-02	4.792E+02	4.080E+04

AT THE END OF THE ANALYSIS PERIOD

CRACK SPACING = 4.688E+00 FEET
CRACK WIDTH = 3.014E-02 INCHES
MAX CONCRETE STRESS= 5.740E+02 PSI
MAX STEEL STRESS = 3.992E+04 PSI,
CONC.TENS.STRENGTH = 5.789E+02 PSI

STA-TION	DIS-TANCE	CONCRETE MOVEMENT	FRICTION FORCE	CONCRETE STRESS	STEEL STRESS
1	0.0	0.	0.	5.740E+02	-7.898E+03
2	.3	-1.399E-04	1.399E-03	5.740E+02	-7.898E+03
3	.6	-2.798E-04	2.798E-03	5.740E+02	-7.898E+03
4	.8	-4.196E-04	4.196E-03	5.740E+02	-7.898E+03
5	1.1	-5.595E-04	5.595E-03	5.740E+02	-7.898E+03
6	1.4	-6.994E-04	6.994E-03	5.740E+02	-7.898E+03
7	1.7	-8.393E-04	8.393E-03	5.740E+02	-7.898E+03
8	2.0	-9.791E-04	9.792E-03	5.740E+02	-7.898E+03
9	2.3	-1.119E-03	1.119E-02	5.740E+02	-7.898E+03
10	2.5	-1.259E-03	1.259E-02	5.740E+02	-7.898E+03
11	2.8	-1.399E-03	1.399E-02	5.740E+02	-7.898E+03
12	3.1	-1.539E-03	1.539E-02	5.740E+02	-7.898E+03
13	3.4	-1.679E-03	1.679E-02	5.740E+02	-7.898E+03
14	3.7	-1.818E-03	1.818E-02	5.740E+02	-7.898E+03
15	3.9	-1.958E-03	1.958E-02	5.740E+02	-7.898E+03
16	4.2	-2.098E-03	2.098E-02	5.740E+02	-7.898E+03
17	4.5	-2.238E-03	2.238E-02	5.740E+02	-7.898E+03
18	4.8	-2.378E-03	2.378E-02	5.740E+02	-7.898E+03
19	5.1	-2.518E-03	2.518E-02	5.740E+02	-7.898E+03
20	5.3	-2.658E-03	2.658E-02	5.740E+02	-7.898E+03
21	5.6	-2.798E-03	2.798E-02	5.740E+02	-7.898E+03
22	5.9	-2.937E-03	2.937E-02	5.740E+02	-7.898E+03
23	6.2	-3.077E-03	3.077E-02	5.739E+02	-7.898E+03
24	6.5	-3.217E-03	3.217E-02	5.739E+02	-7.898E+03
25	6.8	-3.357E-03	3.357E-02	5.739E+02	-7.898E+03
26	7.0	-3.497E-03	3.497E-02	5.739E+02	-7.898E+03
27	7.3	-3.637E-03	3.637E-02	5.739E+02	-7.898E+03
28	7.6	-3.777E-03	3.777E-02	5.739E+02	-7.898E+03
29	7.9	-3.917E-03	3.917E-02	5.739E+02	-7.898E+03
30	8.2	-4.056E-03	4.057E-02	5.739E+02	-7.898E+03
31	8.4	-4.196E-03	4.196E-02	5.739E+02	-7.898E+03
32	8.7	-4.336E-03	4.336E-02	5.739E+02	-7.898E+03
33	9.0	-4.476E-03	4.476E-02	5.739E+02	-7.898E+03
34	9.3	-4.616E-03	4.616E-02	5.739E+02	-7.898E+03
35	9.6	-4.756E-03	4.756E-02	5.739E+02	-7.898E+03
36	9.8	-4.896E-03	4.896E-02	5.739E+02	-7.898E+03
37	10.1	-5.036E-03	5.036E-02	5.739E+02	-7.898E+03
38	10.4	-5.175E-03	5.176E-02	5.739E+02	-7.898E+03
39	10.7	-5.315E-03	5.315E-02	5.739E+02	-7.898E+03
40	11.0	-5.455E-03	5.455E-02	5.739E+02	-7.898E+03
41	11.3	-5.595E-03	5.595E-02	5.708E+02	-7.639E+03
42	11.5	-5.736E-03	5.736E-02	5.613E+02	-6.846E+03
43	11.8	-5.877E-03	5.877E-02	5.518E+02	-6.053E+03
44	12.1	-6.018E-03	6.018E-02	5.423E+02	-5.261E+03
45	12.4	-6.160E-03	6.160E-02	5.328E+02	-4.468E+03
46	12.7	-6.303E-03	6.303E-02	5.233E+02	-3.675E+03
47	12.9	-6.446E-03	6.446E-02	5.137E+02	-2.883E+03
48	13.2	-6.590E-03	6.590E-02	5.042E+02	-2.090E+03
49	13.5	-6.735E-03	6.735E-02	4.947E+02	-1.298E+03
50	13.8	-6.880E-03	6.880E-02	4.852E+02	-5.051E+02

51	14,1	-7,026E-03	7,026E-02	4,757E+02	2,875E+02
52	14,3	-7,172E-03	7,172E-02	4,662E+02	1,080E+03
53	14,6	-7,319E-03	7,319E-02	4,567E+02	1,873E+03
54	14,9	-7,466E-03	7,467E-02	4,471E+02	2,665E+03
55	15,2	-7,615E-03	7,615E-02	4,376E+02	3,458E+03
56	15,5	-7,763E-03	7,763E-02	4,281E+02	4,251E+03
57	15,7	-7,913E-03	7,913E-02	4,186E+02	5,043E+03
58	16,0	-8,062E-03	8,063E-02	4,091E+02	5,836E+03
59	16,3	-8,213E-03	8,213E-02	3,996E+02	6,628E+03
60	16,6	-8,364E-03	8,364E-02	3,901E+02	7,421E+03
61	16,9	-8,516E-03	8,516E-02	3,806E+02	8,214E+03
62	17,2	-8,668E-03	8,668E-02	3,710E+02	9,006E+03
63	17,4	-8,821E-03	8,821E-02	3,615E+02	9,799E+03
64	17,7	-8,974E-03	8,974E-02	3,520E+02	1,059E+04
65	18,0	-9,128E-03	9,129E-02	3,425E+02	1,138E+04
66	18,3	-9,283E-03	9,283E-02	3,330E+02	1,218E+04
67	18,6	-9,438E-03	9,438E-02	3,235E+02	1,297E+04
68	18,8	-9,594E-03	9,594E-02	3,140E+02	1,376E+04
69	19,1	-9,751E-03	9,751E-02	3,045E+02	1,455E+04
70	19,4	-9,908E-03	9,908E-02	2,949E+02	1,535E+04
71	19,7	-1,007E-02	1,007E-01	2,854E+02	1,614E+04
72	20,0	-1,022E-02	1,022E-01	2,759E+02	1,693E+04
73	20,2	-1,038E-02	1,038E-01	2,664E+02	1,772E+04
74	20,5	-1,054E-02	1,054E-01	2,569E+02	1,852E+04
75	20,8	-1,070E-02	1,070E-01	2,474E+02	1,931E+04
76	21,1	-1,086E-02	1,086E-01	2,379E+02	2,010E+04
77	21,4	-1,102E-02	1,102E-01	2,283E+02	2,090E+04
78	21,7	-1,119E-02	1,119E-01	2,188E+02	2,169E+04
79	21,9	-1,135E-02	1,135E-01	2,093E+02	2,248E+04
80	22,2	-1,151E-02	1,151E-01	1,998E+02	2,327E+04
81	22,5	-1,167E-02	1,167E-01	1,903E+02	2,407E+04
82	22,8	-1,184E-02	1,184E-01	1,808E+02	2,486E+04
83	23,1	-1,200E-02	1,200E-01	1,713E+02	2,565E+04
84	23,3	-1,217E-02	1,217E-01	1,617E+02	2,644E+04
85	23,6	-1,233E-02	1,233E-01	1,522E+02	2,724E+04
86	23,9	-1,250E-02	1,250E-01	1,427E+02	2,803E+04
87	24,2	-1,267E-02	1,267E-01	1,332E+02	2,882E+04
88	24,5	-1,284E-02	1,284E-01	1,237E+02	2,961E+04
89	24,7	-1,300E-02	1,300E-01	1,142E+02	3,041E+04
90	25,0	-1,317E-02	1,317E-01	1,047E+02	3,120E+04
91	25,3	-1,334E-02	1,334E-01	9,514E+01	3,199E+04
92	25,6	-1,351E-02	1,351E-01	8,563E+01	3,278E+04
93	25,9	-1,368E-02	1,368E-01	7,611E+01	3,358E+04
94	26,2	-1,385E-02	1,386E-01	6,660E+01	3,437E+04
95	26,4	-1,403E-02	1,403E-01	5,708E+01	3,516E+04
96	26,7	-1,420E-02	1,420E-01	4,757E+01	3,595E+04
97	27,0	-1,437E-02	1,437E-01	3,806E+01	3,675E+04
98	27,3	-1,455E-02	1,455E-01	2,854E+01	3,754E+04
99	27,6	-1,472E-02	1,472E-01	1,903E+01	3,833E+04
100	27,8	-1,490E-02	1,490E-01	9,512E+00	3,913E+04
101	28,1	-1,507E-02	1,507E-01	-3,237E-03	3,992E+04

CRCP-2 TESTING
EFFECT OF EXTERNAL LOAD

PROB
C-2

EXTERNAL LOAD = 18000.0 LB.

```
*******************************************************
*                                                     *
*                  STEEL PROPERTIES                   *
*                                                     *
*******************************************************
```

TYPE OF LONGITUDINAL REINFORCEMENT IS
DEFORMED BARS

```
PERCENT REINFORCEMENT = 1.200E+00
BAR DIAMETER          = 1.000E+00
YIELD STRESS          = 6.000E+04
ELASTIC MODULUS       = 2.900E+07
THERMAL COEFFICIENT   = 5.000E-06
```

```
*******************************************************
*                                                     *
*                CONCRETE PROPERTIES                  *
*                                                     *
*******************************************************
```

```
SLAB THICKNESS       = 1.200E+01
THERMAL COEFFICIENT  = 5.000E-06
TOTAL SHRINKAGE      = 4.000E-04
UNIT WEIGHT CONCRETE= 1.500E+02
COMPRESSIVE STRENGTH= 5.000E+03
```

TENSILE STRENGTH DATA
****

NO TENSILE STRENGTH DATA IS INPUT BY USER
THE FOLLOWING AGE-TENSILE STRENGTH RELATIONSHIP
IS USED WHICH IS BASED ON THE RECOMMENDATION
GIVEN BY U.S. BUREAU OF RECLAMATION

AGE, (DAYS)	TENSILE STRENGTH
0.0	0.0
1.0	157.9
3.0	322.0
5.0	398.5
7.0	440.6
14.0	506.2
21.0	540.2
28.0	555.6

```
*****************************************************
*                                                   *
*      SLAB-BASE FRICTION CHARACTERISTICS           *
*              F-Y RELATIONSHIP                     *
*                                                   *
*****************************************************
```

TYPE OF FRICTION CURVE IS A STRAIGHT LINE

MAXIMUM FRICTION FORCE=   1.0000
MOVEMENT AT SLIDING   =   -.1000

```
******************************
*                            *
*      TEMPERATURE DATA      *
*                            *
******************************
```

CURING TEMPERATURE= 75.0

DAY	MINIMUM TEMPERATURE	DROP IN TEMPERATURE
1	65.0	10.0
2	65.0	10.0
3	65.0	10.0
4	65.0	10.0
5	65.0	10.0
6	65.0	10.0
7	65.0	10.0
8	65.0	10.0
9	65.0	10.0
10	65.0	10.0
11	65.0	10.0
12	65.0	10.0
13	65.0	10.0
14	65.0	10.0
15	65.0	10.0
16	65.0	10.0
17	55.0	20.0
18	55.0	20.0
19	55.0	20.0
20	55.0	20.0
21	55.0	20.0
22	55.0	20.0
23	55.0	20.0
24	55.0	20.0
25	55.0	20.0
26	55.0	20.0
27	55.0	20.0
28	55.0	20.0

MINIMUM TEMPERATURE EXPECTED AFTER
CONCRETE GAINS FULL STRENGTH   = 30.0 DEGREES FAHRENHEIT
DAYS BEFORE REACHING MIN. TEMP.   = 90.0 DAYS

```
*************************************************
*                                               *
*                 EXTERNAL LOAD                 *
*                                               *
*************************************************

      WHEEL LOAD (LBS)         = 1.800E+04
      WHEEL BASE RADIUS (IN)   = 6.500E+00
      SUBGRADE MODULUS (PSI)   = 1.500E+02
      CONCRETE MODULUS (PSI)   = 4.287E+06
      LOAD APPLIED AT          =  7 TH DAY
      CALC.LOAD STRESS (PSI)   = 1.760E+02


*************************************************
*                                               *
*        ITERATION AND TOLERANCE CONTROL        *
*                                               *
*************************************************

 MAXIMUM ALLOWABLE NUMBER OF ITERATIONS=   30

 RELATIVE CLOSURE TOLERANCE=  1.0 PERCENT
```

CRCP-2 TESTING
EFFECT OF EXTERNAL LOAD

PROB C-2 EXTERNAL LOAD = 18000.0 LB.

TIME (DAYS)	TEMP DROP	DRYING SHRINKAGE	TENSILE STRGTH	CRACK SPACING	CRACK WIDTH	MAXIMUM CONCRETE STRESS	MAXIMUM STRESS IN THE STEEL
.50	10.0	1.814E-06	85.7	4800.0	2.019E-03	6.065E+01	6.460E+03
1.50	10.0	5.394E-06	206.0	4800.0	3.121E-03	1.075E+02	1.032E+04
2.50	10.0	8.910E-06	287.3	4800.0	4.070E-03	1.422E+02	1.317E+04
3.50	10.0	1.236E-05	342.9	4800.0	4.962E-03	1.709E+02	1.553E+04
4.50	10.0	1.576E-05	381.0	4800.0	5.815E-03	1.954E+02	1.753E+04
5.50	10.0	1.909E-05	409.6	4800.0	6.663E-03	2.177E+02	1.935E+04
6.50	10.0	2.237E-05	430.6	4800.0	7.499E-03	2.377E+02	2.099E+04
7.50	10.0	2.559E-05	445.8	4800.0	8.319E-03	4.318E+02	2.246E+04
8.50	10.0	2.876E-05	456.0	4800.0	9.114E-03	4.478E+02	2.376E+04
9.50	10.0	3.187E-05	465.9	2400.0	8.970E-03	4.574E+02	2.463E+04
10.50	10.0	3.493E-05	475.4	1200.0	9.261E-03	4.607E+02	2.489E+04
11.50	10.0	3.794E-05	484.6	1200.0	1.001E-02	4.750E+02	2.606E+04
12.50	10.0	4.090E-05	493.4	600.0	9.280E-03	4.666E+02	2.521E+04
13.50	10.0	4.382E-05	502.0	600.0	9.910E-03	4.791E+02	2.622E+04
14.50	10.0	4.668E-05	508.8	600.0	1.053E-02	4.907E+02	2.715E+04
15.50	10.0	4.951E-05	513.9	600.0	1.113E-02	5.013E+02	2.801E+04
16.33	10.0	5.182E-05	518.1	600.0	1.163E-02	5.102E+02	2.873E+04
16.34	10.6	5.184E-05	518.1	300.0	9.457E-03	4.771E+02	2.576E+04
16.38	14.6	5.195E-05	518.3	150.0	8.630E-03	4.636E+02	2.454E+04
16.50	20.0	5.228E-05	518.9	150.0	1.133E-02	5.058E+02	2.835E+04
17.50	20.0	5.501E-05	523.8	150.0	1.165E-02	5.121E+02	2.882E+04
18.50	20.0	5.771E-05	528.6	150.0	1.196E-02	5.183E+02	2.928E+04
19.50	20.0	6.035E-05	533.3	150.0	1.226E-02	5.244E+02	2.974E+04
20.50	20.0	6.296E-05	538.0	150.0	1.257E-02	5.305E+02	3.019E+04
21.50	20.0	6.553E-05	541.4	75.0	7.938E-03	4.587E+02	2.362E+04
22.50	20.0	6.806E-05	543.6	75.0	8.097E-03	4.622E+02	2.385E+04
23.50	20.0	7.055E-05	545.8	75.0	8.254E-03	4.657E+02	2.409E+04
24.50	20.0	7.300E-05	548.0	75.0	8.410E-03	4.691E+02	2.431E+04
25.50	20.0	7.542E-05	550.2	75.0	8.563E-03	4.725E+02	2.454E+04
26.50	20.0	7.780E-05	552.4	75.0	8.715E-03	4.758E+02	2.476E+04
27.50	20.0	8.015E-05	554.5	75.0	8.865E-03	4.791E+02	2.498E+04

AT THE END OF THE ANALYSIS PERIOD

CRACK SPACING = 2.002E+00 FEET
CRACK WIDTH = 1.393E-02 INCHES
MAX CONCRETE STRESS= 5.823E+02 PSI
MAX STEEL STRESS = 2.345E+04 PSI.
CONC.TENS.STRENGTH = 5.789E+02 PSI

STA-TION	DIS-TANCE	CONCRETE MOVEMENT	FRICTION FORCE	CONCRETE STRESS	STEEL STRESS
1	0.0	0.	0.	4.062E+02	-1.040E+04
2	.1	-6.427E-05	6.427E-04	4.022E+02	-1.006E+04
3	.2	-1.287E-04	1.287E-03	3.981E+02	-9.723E+03
4	.4	-1.931E-04	1.931E-03	3.941E+02	-9.385E+03
5	.5	-2.577E-04	2.577E-03	3.900E+02	-9.046E+03
6	.6	-3.225E-04	3.225E-03	3.859E+02	-8.708E+03
7	.7	-3.873E-04	3.873E-03	3.819E+02	-8.369E+03
8	.8	-4.522E-04	4.522E-03	3.778E+02	-8.031E+03
9	1.0	-5.172E-04	5.172E-03	3.737E+02	-7.692E+03
10	1.1	-5.824E-04	5.824E-03	3.697E+02	-7.354E+03
11	1.2	-6.476E-04	6.476E-03	3.656E+02	-7.015E+03
12	1.3	-7.130E-04	7.130E-03	3.616E+02	-6.677E+03
13	1.4	-7.785E-04	7.785E-03	3.575E+02	-6.338E+03
14	1.6	-8.440E-04	8.440E-03	3.534E+02	-6.000E+03
15	1.7	-9.097E-04	9.097E-03	3.494E+02	-5.661E+03
16	1.8	-9.755E-04	9.755E-03	3.453E+02	-5.323E+03
17	1.9	-1.041E-03	1.041E-02	3.412E+02	-4.984E+03
18	2.0	-1.107E-03	1.107E-02	3.372E+02	-4.646E+03
19	2.2	-1.174E-03	1.174E-02	3.331E+02	-4.307E+03
20	2.3	-1.240E-03	1.240E-02	3.291E+02	-3.969E+03
21	2.4	-1.306E-03	1.306E-02	3.250E+02	-3.630E+03
22	2.5	-1.373E-03	1.373E-02	3.209E+02	-3.292E+03
23	2.6	-1.439E-03	1.439E-02	3.169E+02	-2.953E+03
24	2.8	-1.506E-03	1.506E-02	3.128E+02	-2.615E+03
25	2.9	-1.573E-03	1.573E-02	3.087E+02	-2.276E+03
26	3.0	-1.639E-03	1.639E-02	3.047E+02	-1.938E+03
27	3.1	-1.706E-03	1.706E-02	3.006E+02	-1.599E+03
28	3.2	-1.773E-03	1.774E-02	2.966E+02	-1.261E+03
29	3.4	-1.841E-03	1.841E-02	2.925E+02	-9.222E+02
30	3.5	-1.908E-03	1.908E-02	2.884E+02	-5.837E+02
31	3.6	-1.975E-03	1.975E-02	2.844E+02	-2.452E+02
32	3.7	-2.043E-03	2.043E-02	2.803E+02	9.334E+01
33	3.8	-2.111E-03	2.111E-02	2.762E+02	4.318E+02
34	4.0	-2.178E-03	2.178E-02	2.722E+02	7.704E+02
35	4.1	-2.246E-03	2.246E-02	2.681E+02	1.109E+03
36	4.2	-2.314E-03	2.314E-02	2.641E+02	1.447E+03
37	4.3	-2.382E-03	2.382E-02	2.600E+02	1.786E+03
38	4.4	-2.450E-03	2.450E-02	2.559E+02	2.124E+03
39	4.6	-2.519E-03	2.519E-02	2.519E+02	2.463E+03
40	4.7	-2.587E-03	2.587E-02	2.478E+02	2.801E+03
41	4.8	-2.656E-03	2.656E-02	2.437E+02	3.140E+03
42	4.9	-2.724E-03	2.724E-02	2.397E+02	3.478E+03
43	5.0	-2.793E-03	2.793E-02	2.356E+02	3.817E+03
44	5.2	-2.862E-03	2.862E-02	2.316E+02	4.155E+03
45	5.3	-2.931E-03	2.931E-02	2.275E+02	4.494E+03
46	5.4	-3.000E-03	3.000E-02	2.234E+02	4.832E+03
47	5.5	-3.069E-03	3.069E-02	2.194E+02	5.171E+03
48	5.6	-3.138E-03	3.138E-02	2.153E+02	5.509E+03
49	5.8	-3.208E-03	3.208E-02	2.112E+02	5.848E+03
50	5.9	-3.277E-03	3.277E-02	2.072E+02	6.186E+03

51	6.0	-3.347E-03	3.347E-02	2.031E+02	6.525E+03
52	6.1	-3.416E-03	3.416E-02	1.991E+02	6.864E+03
53	6.2	-3.486E-03	3.486E-02	1.950E+02	7.202E+03
54	6.4	-3.556E-03	3.556E-02	1.909E+02	7.541E+03
55	6.5	-3.626E-03	3.626E-02	1.869E+02	7.879E+03
56	6.6	-3.696E-03	3.696E-02	1.828E+02	8.218E+03
57	6.7	-3.766E-03	3.767E-02	1.787E+02	8.556E+03
58	6.8	-3.837E-03	3.837E-02	1.747E+02	8.895E+03
59	7.0	-3.907E-03	3.907E-02	1.706E+02	9.233E+03
60	7.1	-3.978E-03	3.978E-02	1.666E+02	9.572E+03
61	7.2	-4.049E-03	4.049E-02	1.625E+02	9.910E+03
62	7.3	-4.119E-03	4.119E-02	1.584E+02	1.025E+04
63	7.4	-4.190E-03	4.190E-02	1.544E+02	1.059E+04
64	7.6	-4.261E-03	4.261E-02	1.503E+02	1.093E+04
65	7.7	-4.332E-03	4.332E-02	1.462E+02	1.126E+04
66	7.8	-4.404E-03	4.404E-02	1.422E+02	1.160E+04
67	7.9	-4.475E-03	4.475E-02	1.381E+02	1.194E+04
68	8.0	-4.546E-03	4.546E-02	1.341E+02	1.228E+04
69	8.2	-4.618E-03	4.618E-02	1.300E+02	1.262E+04
70	8.3	-4.690E-03	4.690E-02	1.259E+02	1.296E+04
71	8.4	-4.761E-03	4.761E-02	1.219E+02	1.330E+04
72	8.5	-4.833E-03	4.833E-02	1.178E+02	1.363E+04
73	8.6	-4.905E-03	4.905E-02	1.137E+02	1.397E+04
74	8.8	-4.977E-03	4.977E-02	1.097E+02	1.431E+04
75	8.9	-5.049E-03	5.049E-02	1.056E+02	1.465E+04
76	9.0	-5.122E-03	5.122E-02	1.016E+02	1.499E+04
77	9.1	-5.194E-03	5.194E-02	9.750E+01	1.533E+04
78	9.2	-5.267E-03	5.267E-02	9.344E+01	1.566E+04
79	9.4	-5.339E-03	5.339E-02	8.937E+01	1.600E+04
80	9.5	-5.412E-03	5.412E-02	8.531E+01	1.634E+04
81	9.6	-5.485E-03	5.485E-02	8.125E+01	1.668E+04
82	9.7	-5.558E-03	5.558E-02	7.719E+01	1.702E+04
83	9.8	-5.631E-03	5.631E-02	7.312E+01	1.736E+04
84	10.0	-5.704E-03	5.704E-02	6.906E+01	1.770E+04
85	10.1	-5.777E-03	5.777E-02	6.500E+01	1.803E+04
86	10.2	-5.851E-03	5.851E-02	6.094E+01	1.837E+04
87	10.3	-5.924E-03	5.924E-02	5.687E+01	1.871E+04
88	10.5	-5.998E-03	5.998E-02	5.281E+01	1.905E+04
89	10.6	-6.072E-03	6.072E-02	4.875E+01	1.939E+04
90	10.7	-6.145E-03	6.145E-02	4.469E+01	1.973E+04
91	10.8	-6.219E-03	6.219E-02	4.062E+01	2.007E+04
92	10.9	-6.293E-03	6.293E-02	3.656E+01	2.040E+04
93	11.1	-6.368E-03	6.368E-02	3.250E+01	2.074E+04
94	11.2	-6.442E-03	6.442E-02	2.844E+01	2.108E+04
95	11.3	-6.516E-03	6.516E-02	2.437E+01	2.142E+04
96	11.4	-6.591E-03	6.591E-02	2.031E+01	2.176E+04
97	11.5	-6.665E-03	6.665E-02	1.625E+01	2.210E+04
98	11.7	-6.740E-03	6.740E-02	1.219E+01	2.243E+04
99	11.8	-6.815E-03	6.815E-02	8.125E+00	2.277E+04
100	11.9	-6.890E-03	6.890E-02	4.062E+00	2.311E+04
101	12.0	-6.965E-03	6.965E-02	0.	2.345E+04

APPENDIX 3

INPUT VARIABLES FOR SOLUTIONS IN CHAPTER 2 AND CHAPTER 3

```
              CRCP-2 TESTING
         EXTERNAL LOAD VS. STL STRESS, CK SPCING, CK WIDTH
 1A      EXTERNAL LOAD = 0.0 LB.
 1               1.0        0.5    60000.029000000.0    .000005       0.00
                 10.   .000005      .0004      150.0     6000.0   1.     1
    75.   28              40.       90.
65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  50.  50.  50.  50.  50.  50.
50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.
   28.0          0.0        6.5    150.00        0.00
 1.        1
    1.0          -.1

 2A      EXTERNAL LOAD = 50.0 LB.
 1               1.0        0.5    60000.029000000.0    .000005       0.0
                 10.   .000005      .0004      150.0     6000.0   1.     1
    75.   28              40.       90.
65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  50.  50.  50.  50.  50.  50.
50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.
   28.0          0.0        6.5    150.00        50.0
 1.        1
    1.0          -.1

 3A      EXTERNAL LOAD = 150. LB.
 1               1.0        0.5    60000.029000000.0    .000005       0.00
                 10.   .000005      .0004      150.0     6000.0   1.     1
    75.   28              40.       90.
65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  50.  50.  50.  50.  50.  50.
50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.
   28.0          0.0        6.5    150.0         150.
 1.        1
    1.0          -.1

 4A      EXTERNAL LOAD = 200.0 LB.
 1               1.0        0.5    60000.029000000.0    .000005       0.00
                 10.   .000005      .0004      150.0     6000.0   1.     1
    75.   28              40.       90.
65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  50.  50.  50.  50.  50.  50.
50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.
   28.0          0.0        6.5    150.00        200.
 1.        1
    1.0          -.1
```

```
 1B      EXTERNAL LOAD = 0.0 LB.
 1               0.5        0.6    60000.029000000.0    .000005       0.00
                 10.    .000005       .0004      150.0    6000.0   1.      1
    75.   28               40.        90.
50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.
50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.
   28.0          0.0        6.5     150.00       0.00
 1.         1
    1.0          -.1

 2B      EXTERNAL LOAD = 50.0 LB.
 1               0.5        0.6    60000.029000000.0    .000005       0.00
                 10.    .000005       .0004      150.0    6000.0   1.      1
    75.   28               40.        90.
50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.
50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.
   28.0          0.0        6.5     150.000      50.0
 1.         1
    1.0          -.1

 3B      EXTERNAL LOAD = 100.0 LB.
 1               0.5        0.6    60000.029000000.0    .000005       0.00
                 10.    .000005       .0004      150.0    6000.0   1.      1
    75.   28               40.        90.
50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.
50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.
   28.0          0.0        6.5     150.00       100.
 1.         1
    1.0          -.1

 4B      EXTERNAL LOAD = 150.0 LB.
 1               0.5        0.6    60000.029000000.0    .000005       0.00
                 10.    .000005       .0004      150.0    6000.0   1.      1
    75.   28               40.        90.
50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.
50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.
   28.0          0.0        6.5     150.00       150.
 1.         1
    1.0          -.1

 5B      EXTERNAL LOAD = 200.0 LB.
 1               0.5        0.6    60000.029000000.0    .000005       0.00
                 10.    .000005       .0004      150.0    6000.0   1.      1
    75.   28               40.        90.
50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.
50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.
   28.0          0.0        6.5     150.00       200.
 1.         1
    1.0          -.1
```

```
              CRCP-2 TESTING
          EXTERNAL VS. PERCENTAGE STEEL
 1C       PERCENTAGE STEEL = 0.5
 1                  0.5         0.6     60000.029000000.0     .000005        1.     0.00
                    10.     .000005        .0004       150.0     6000.0     1.       1
     75.     28                 40.         90.
50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.
50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.
    28.0           0.0          6.5      150.0       0.00
 1.           1
     1.0           -.1

 2C       PERCENTAGE STEEL = 0.7
 1                  0.7         0.6     60000.029000000.0     .000005              0.00
                    10.     .000005        .0004       150.0     6000.0     1.       1
     75.     28                 40.         90.
50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.
50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.
    28.0           0.0          6.5      150.00      0.00
 1.           1
     1.0           -.1

 3C       PERCENTAGE STEEL = 0.9
 1                  0.9         0.6     60000.029000000.0     .000005              0.00
                    10.     .000005        .0004       150.0     6000.0     1.       1
     75.     28                 40.         90.
50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.
50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.
    28.0           0.0          6.5      150.00      0.00
 1.           1
     1.0           -.1

 4C       PENCENTAGE STEEL = 1.2
 1                  1.2         0.6     60000.029000000.0     .000005              0.00
                    10.     .000005        .0004       150.0     6000.0     1.       1
     75.     28                 40.         90.
50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.
50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.  50.
    28.0           0.0          6.5      150.0       0.00
 1.           1
     1.0           -.1
```

```
5C      PENCENTAGE STEEL = 0.5
 1                 0.5       0.6    60000.029000000.0    .000005       0.00
                   10.    .000005      .0004      150.0    6000.0   1.     1
    75.   28                40.       90.
50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50.
50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50.
   28.0            0.0       6.5    150.00      100.
1.          1
    1.0            -.1

6C      PENCENTAGE STEEL = 0.7
 1                 0.7       0.6    60000.029000000.0    .000005       0.00
                   10.    .000005      .0004      150.0    6000.0   1.     1
    75.   28                40.       90.
50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50.
50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50.
   28.0            0.0       6.5    150.00      100.
1.          1
    1.0            -.1

7C      PERCENTAGE STEEL = 0.9
 1                 0.9       0.6    60000.029000000.0    .000005       0.00
                   10.    .000005      .0004      150.0    6000.0   1.     1
    75.   28                40.       90.
50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50.
50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50.
   28.0            0.0       6.5    150.00      100.
1.          1
    1.0            -.1

8C      PERCENTAGE STEEL = 1.2
 1                 1.2       0.6    60000.029000000.0    .000005       0.00
                   10.    .000005      .0004      150.0    6000.0   1.     1
    75.   28                40.       90.
50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50.
50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50. 50.
   28.0            0.0       6.5    150.00      100.
1.          1
    1.0            -.1
```

```
               CRCP-2 TESTING
            EFFECT OF EXTERNAL LOAD AND SLAB THICKNESS
  1D        SLAB THICKNESS = 6.0 IN.
  1                0.7       0.6    60000.029000000.0   .000005      0.00
                   6.0   .000005      .0004     150.0    5000.0  1.    2
     70.   28              30.       90.
65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.
55.  55.  55.  55.  55.  55.  55.  55.  55.  55.  55.  55.
     28.    9000.0         6.5    150.00       0.00
 1.         1
     1.0        -.1

  2D        SLAB THICKNESS = 8.0 IN.
  1                0.7       0.6    60000.029000000.0   .000005      0.00
                   8.0   .000005      .0004     150.0    5000.0  1.    2
     70.   28              30.       90.
65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.
55.  55.  55.  55.  55.  55.  55.  55.  55.  55.  55.  55.
     28.    9000.0         6.5    150.0        0.00
 1.         1
     1.0        -.1

  3D        SLAB THICKNESS = 10.0 IN.
  1                0.7       0.6    60000.029000000.0   .000005      0.00
                   10.   .000005      .0004     150.0    5000.0  1.    2
     70.   28              30.       90.
65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.
55.  55.  55.  55.  55.  55.  55.  55.  55.  55.  55.  55.
     28.    9000.0         6.5    150.00       0.00
 1.         1
     1.0        -.1

  4D        SLAB THICKNESS = 12.0 IN.
  1                0.7       0.6    60000.029000000.0   .000005      0.00
                   12.   .000005      .0004     150.0    5000.0  1.    2
     70.   28              30.       90.
65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.
55.  55.  55.  55.  55.  55.  55.  55.  55.  55.  55.  55.
     28.    9000.0         6.5    150.0        0.00
 1.         1
     1.0        -.1
```

```
          CRCP-2 TESTING
        TIME OF LOAD APPLICATION
 1E     EXTERNAL LOAD APPLIED AT THE 7-TH DAY
 1              0.5       0.6    60000.029000000.0   .000005      0.00
                10.    .000005     .0004     150.0     6000.0  1.    1
    75.   28              40.       90.
65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.
65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.
    7.0         0.0       6.5    150.0        200.
 1.       1
    1.0         -.1

 2E     EXTERNAL LOAD APPLIED AT THE 15-TH DAY
 1              0.5       0.6    60000.029000000.0   .000005      0.00
                10.    .000005     .0004     150.0     6000.0  1.    1
    75.   28              40.       90.
65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.
65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.
   15.0         0.0       6.5    150.00       200.
 1.       1
    1.0         -.1

 3E     EXTERNAL LOAD APPLIED AT THE 28-TH DAY
 1              0.5       0.6    60000.029000000.0   .000005      0.00
                10.    .000005     .0004     150.0     6000.0  1.    1
    75.   28              40.       90.
65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.
65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.  65.
   28.0         0.0       6.5    150.0        200.
 1.       1
    1.0         -.1
```

```
            CRCP-2 TESTING
         TIME OF MIN. TEMP. VS. STL. STRESS, CK. WIDTH, CK. SPCING
 1F     COLDTM = 28.0
 1               0.5         0.6     60000.029000000.0    .000005        0.00
                 10.     .000005       .0004       150.0     6000.0  1.     1
    75.   28                 0.0       28.
65.  65.  65.   65.  65.  65.   65.  65.  65.  65.   65.  65.  65.  65.  65.  65.
50.  50.  50.   50.  50.  50.   50.  50.  50.  50.   50.  50.
   28.0          0.0         6.5     150.00
 1.         1
    2.0          -.1


 2F     COLDTM = 60.0
 1               0.5         0.6     60000.029000000.0    .000005        0.00
                 10.     .000005       .0004       150.0     6000.0  1.     1
    75.   28                 0.0       60.
65.  65.  65.   65.  65.  65.   65.  65.  65.  65.   65.  65.  65.  65.  65.  65.
50.  50.  50.   50.  50.  50.   50.  50.  50.  50.   50.  50.
   28.0          0.0         6.5     150.00
 1.         1
    2.0          -.1


 3F     COLDTM = 90.0
 1               0.5         0.6     60000.029000000.0    .000005        0.00
                 10.     .000005       .0004       150.0     6000.0  1.     1
    75.   28                 0.0       90.
65.  65.  65.   65.  65.  65.   65.  65.  65.  65.   65.  65.  65.  65.  65.  65.
50.  50.  50.   50.  50.  50.   50.  50.  50.  50.   50.  50.
   28.0          0.0         6.5     150.00
 1.         1
    2.0          -.1


 4F     COLDTM = 120.0
 1               0.5         0.6     60000.029000000.0    .000005        0.00
                 10.     .000005       .0004       150.0     6000.0  1.     1
    75.   28                 0.0      120.
65.  65.  65.   65.  65.  65.   65.  65.  65.  65.   65.  65.  65.  65.  65.  65.
50.  50.  50.   50.  50.  50.   50.  50.  50.  50.   50.  50.
   28.0          0.0         6.5     150.00
 1.         1
    2.0          -.1


 5F     COLDTM = 150.0
 1               0.5         0.6     60000.029000000.0    .000005        0.00
                 10.     .000005       .0004       150.0     6000.0  1.     1
    75.   28                 0.0      150.
65.  65.  65.   65.  65.  65.   65.  65.  65.  65.   65.  65.  65.  65.  65.  65.
50.  50.  50.   50.  50.  50.   50.  50.  50.  50.   50.  50.
   28.0          0.0         6.5     150.00
 1.         1
    2.0          -.1
```

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