TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.
CFHR 3-8-75-177-1

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
DRYING SHRINKAGE AND TEMPERATURE DROP STRESSES IN JOINTED REINFORCED CONCRETE PAVEMENT

5. Report Date
May 1976

6. Performing Organization Code

7. Author(s)
Felipe Rivero-Vallejo and B. Frank McCullough

8. Performing Organization Report No.
Research Report 177-1

9. Performing Organization Name and Address
Center for Highway Research
The University of Texas at Austin
Austin, Texas 78712

10. Work Unit No.

11. Contract or Grant No.
Research Study 3-8-75-177

12. Sponsoring Agency Name and Address
Texas State Department of Highways and Public Transportation - Transportation Planning Division
P. O. Box 5051
Austin, Texas 78763

13. Type of Report and Period Covered
Interim

14. Sponsoring Agency Code

15. Supplementary Notes
Study conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration. Research Study Title: "Development and Implementation of the Design, Construction and Rehabilitation of Rigid Pavements"

16. Abstract

This report deals with the development of a computerized system for analyzing and designing concrete pavement slabs subjected to drying, shrinkage, and drop in temperature stresses with time.

The system is capable of analyzing a given jointed reinforced concrete pavement slab design for crack occurrence. It is also capable of designing either a reinforced or a non-reinforced slab.

It has been found that the main factor acting in crack generation is the friction between the slab and the underlaying pavement course, with higher stresses in the slab occurring with higher friction values.

This work is a useful tool in the study of cracking in concrete pavement slabs because it is relatively simple to superimpose the stresses due to drying, shrinkage, and drop in temperature on the stresses generated by factors such as wheel load, warping, etc. in order to get a more realistic "state of stress" in the slab.

17. Key Words
jointed reinforced concrete pavement slabs, computer program JRCP-1, drying shrinkage and drop in temperature cracking, crack width, crack occurrence, subbase friction

18. Distribution Statement
No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	182	

Form DOT F 1700.7 (8-69)

DRYING SHRINKAGE AND TEMPERATURE DROP STRESSES IN JOINTED REINFORCED CONCRETE PAVEMENT

by

Felipe Rivero-Vallejo
B. Frank McCullough

Research Report Number 177-1

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

May 1976

PREFACE

This report summarizes the results of a study to determine the effects of a drop in temperature and of drying shrinkage on the occurrence of cracks in a jointed concrete pavement. The purpose of this work was to develop a computerized method to analyze, or design, either a reinforced or a non-reinforced pavement slab.

The project is being 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 would not have been possible without the help and assistance of many people. I also acknowledge Dr. W. R. Hudson, member of my graduate supervising committee. Special appreciation is extended to Mr. Thomas Hainze for his friendly help concerning the correction and analysis of the computer program. Thanks are also due to Mrs. Marie Fisher who has collaborated at different stages of this work.

Felipe Rivero-Vallejo
B. Frank McCullough

Austin, Texas
August 1975

LIST OF REPORTS

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

ABSTRACT

This report deals with the development of a computerized system for analyzing and designing concrete pavement slabs subjected to drying, shrinkage, and drop in temperature stresses with time.

The system is capable of analyzing a given jointed reinforced concrete pavement slab design for crack occurrence. It is also capable of designing either a reinforced or a non-reinforced slab.

It has been found that the main factor acting in crack generation is the friction between the slab and the underlaying pavement course, with higher stresses in the slab occurring with high friction values.

This work is a useful tool in the study of cracking in concrete pavement slabs because it is relatively simple to superimpose the stresses due to drying, shrinkage, and drop in temperature on the stresses generated by factors such as wheel load, warping, etc. in order to get a more realistic "state of stress" in the slab.

KEY WORDS: jointed reinforced concrete pavement slabs, computer program JRCP-1, drying shrinkage and drop in temperature cracking, crack width, crack width, crack occurrence, subbase friction.

SUMMARY

A computerized system to analyze a concrete pavement slab for drying shrinkage and drop in temperature stress with time has been developed.

The main purpose of developing the system was to search for possible cracking of the slab. The system was capable of

(a) analyzing a given slab design (length, width, thickness, steel percentage, etc.), checking the width of the cracks and the steel stresses against maximum values;

(b) designing the percent reinforcement for a concrete pavement slab, based on a maximum allowable crack width and stress in the steel; and

(c) designing a non-reinforced concrete slab.

This option will result in a slab length that will not give a cracked slab.

IMPLEMENTATION STATEMENT

This study resulted in a mathematical model that can be used to design more reliably the reinforcement steel for jointed reinforced concrete pavement. A computer program has been prepared that can be used now by the Highway Design Division of the State Department of Highways and Public Transportation. In order to obtain maximum utilization of this computer program, the following implementation steps are recommended.

(1) A range in temperature conditions should be selected on the basis of Texas geographic areas to be used for studying variations in performance with respect to temperature and shrinkage cracking. These geographic areas should be the same as those recommended for implementation of computer program CRCP-1.

(2) The wheel load stresses should be superimposed on those predicted by temperature changes and drying shrinkage. There is evidence from studies of concrete pavement that wheel load stresses may influence the formation of transverse cracks, especially during the early life of the pavement.

(3) A user's manual should be prepared for the State Department of Highways and Public Transportation, to permit field usage of the program. The operating manual in Appendix 1 of this report could be used as a guideline.

(4) The temperature data developed in connection with recommendation (2) should be used to develop a range of solutions, crack widths, crack spacings, and steel stresses for different material properties.

(5) The information from (4) should be used to develop a design manual for CRCP that would reflect more variables than are taken into account at the present time; in this way, the performance level of CRCP would be improved.

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION

CHAPTER 2. CONCEPT OF CRACKING

CHAPTER 3. THEORY

CHAPTER 4. GEOMETRIC MODELS

CHAPTER 5. REINFORCMENT ANALYSIS PACKAGE

CHAPTER 6. STUDY OF VARIABLES

CHAPTER 7. CONCLUSIONS, RECOMMENDATIONS AND IMPLEMENTATION GUIDELINES

APPENDICIES

CHAPTER 1. INTRODUCTION

In 1921 and 1922, the Pittsburg, California, Road Test was designed and performed to determine the efficiency of both reinforced and non-reinforced pavement of varying design. The results indicated that longitudinal joints were effective in preventing longitudinal cracks.

Although concrete pavements were first used in about 1900, uncontrolled cracking caused problems for many years. As a result, joints were introduced to control cracking. From 1930 through 1936, the Bureau of Public Roads conducted the Arlington Test Road at Arlington, Virginia. The results supplied much of the basis for modern pavement design criteria (Ref 1).

In the late 1930's, many highway engineers became concerned about the use of contraction joints where expansion joints were also used. The use of dowels in closely spaced contraction joints and other problems in the jointing of pavements were also studied in view of service records. To study these questions, the Bureau of Public Roads authorized the construction of long-range experimental road tests in California, Kentucky, Michigan, Minnesota, Missouri and Oregon. After World War II, research programs in several phases of pavement technology were intensified to meet the ever-increasing demand of postwar traffic; two of the more significant programs are the Maryland Road Test (HRB SR-21) and the AASHO Road Test (SR 61E).

At the present time, significant concrete pavement research is directed toward the study of transverse cracking, which is a major contributor to pavement deterioration. Cracking in jointed reinforced concrete pavement is a prime factor leading to a reduction in pavement performance, depending on crack width. Water percolation, spalling, loss in load-carrying capacity, and pumping are some of the distress manifestations which vary with cracking in a slab.

Extensive research has been done to determine causes of cracking. It has been found that cracks occur when the tensile strength of the concrete is exceeded by the stresses generated by internal and external forces. The external forces are basically due to wheel loads, and the internal forces are due to temperature changes (curling, shrinkage) and loss in moisture. Warping and curling have been studied at Purdue University and in many other places; the load effect has been studied at The University of Texas, but shrinkage in jointed pavements still has not been studied.

THE NEED

Concrete pavement is generally classified as either plain, continuously reinforced (CRCP), or jointed reinforced concrete pavement (JRCP). Reinforced concrete was recommended in 1914 to counteract cracking caused by thermally induced expansion and contraction. In 1916 it was recommended that all concrete roads be reinforced and specifications were written to cover several problems. In 1931, the common pavement slab was of the thickened edge design, and contained 30 to 69 pounds of steel, wire mesh, or bar mat per 100 square feet. Reinforcement design for rigid pavement is based on the concept that since it is often not economically possible to prevent the formation of cracks, it is necessary to control the opening of cracks in such a manner that the original load-carrying capacity of the slab is preserved. If the crack is permitted to open, contact between the faces of the crack is lost, with a corresponding loss in shearing resistance, and continued application of load results in progressive breakage. Since the main function of steel reinforcement in rigid pavement is to hold the interlock faces of the concrete at a crack in tight contact to provide for good load transfer, and to avoid water entering and washing out the subbase material, it is only necessary to furnish sufficient steel area to resist the forces tending to pull the crack faces apart. These forces develop when the slab tends to shorten as a result of a drop in temperature, concrete shrinkage, or moisture reduction. As the slab contracts, the movements are resisted by the friction between the slab and the underlying subgrade or subbase. The resistance to movement produces a direct tensile stress and may cause the concrete to crack. As soon as the concrete cracks, the tensile stress is transferred to the steel reinforcement.

In order to obtain the benefit of a better pavement design, reliable predictions of shrinkage and temperature stresses are required to complete the study of the pavement slab stresses. The reinforced slabs are designed to control random cracks; in other words, to minimize crack openings so that load transfer is provided by the aggregate interlock, thereby avoiding the distress manifestations tha could lead to total deterioration. Stresses in the manifestations that could lead to total deterioration. Stresses in the pavement are caused by different factors such as:

$$\sigma_{\text{concrete}} = \sigma_{\text{load}} + \sigma_{\text{curling}} + \sigma_{\text{moisture shrinkage}} + \sigma_{\text{drop in temperature}}$$

The crack formation mechanism is represented conceptually in Fig 1.1. Cracking of the concrete slabs occurs when the tensile stresses generated by external and internal forces exceed the concrete tensile strength. Obviously cracking will occur only with tension or contraction, with expansion not being a problem. Therefore, the concrete slab will experience cracking when at some time the tensile stresses are greater than the tensile strength of the concrete. If at some time the combination of tensile stresses due to load, curling, shrinkage, and drop in temperature exceeds the tensile strength cracking will occur. This can be represented in the following conceptual equation:

$$(\sigma_{\text{load}} + \sigma_{\text{curling}} + \sigma_{\text{shrinkage}} + \sigma_{\text{drop in temperature}}) > f_{\text{concrete}}$$

Temperature drop is defined as the daily drop in temperature from the curing temperature. As previously mentioned, stresses due to load and curling have been studied; remaining for study are the shrinkage and drop in temperature stresses. The need for studying shrinkage and drop in temperature became apparent when slabs at the Dallas-Fort Worth Regional Airport experienced a range of transverse cracking. From the study of such cracks (Ref 2), it can be seen that the combination of slab movement with subbase type is the cause of the cracks. Slab length or joint spacing was varied from 37.5 to 75 feet, and it was found that joint spacing of 37.5 feet gave a reduced cracking. Initially the construction engineers hypothesized that by changing the amount of steel, the problem would be solved, but in order for the steel to be effective, cracks must be present. Several subbase conditions were tried to study their effect on cracking. The studies confirmed the hypothesis that the stresses in the concrete would increase with increased sub-grade friction and joint spacing. For the low sub-grade friction, it can happen that no crack occurs, but, the movement of the slab still exists, leading to a joint width

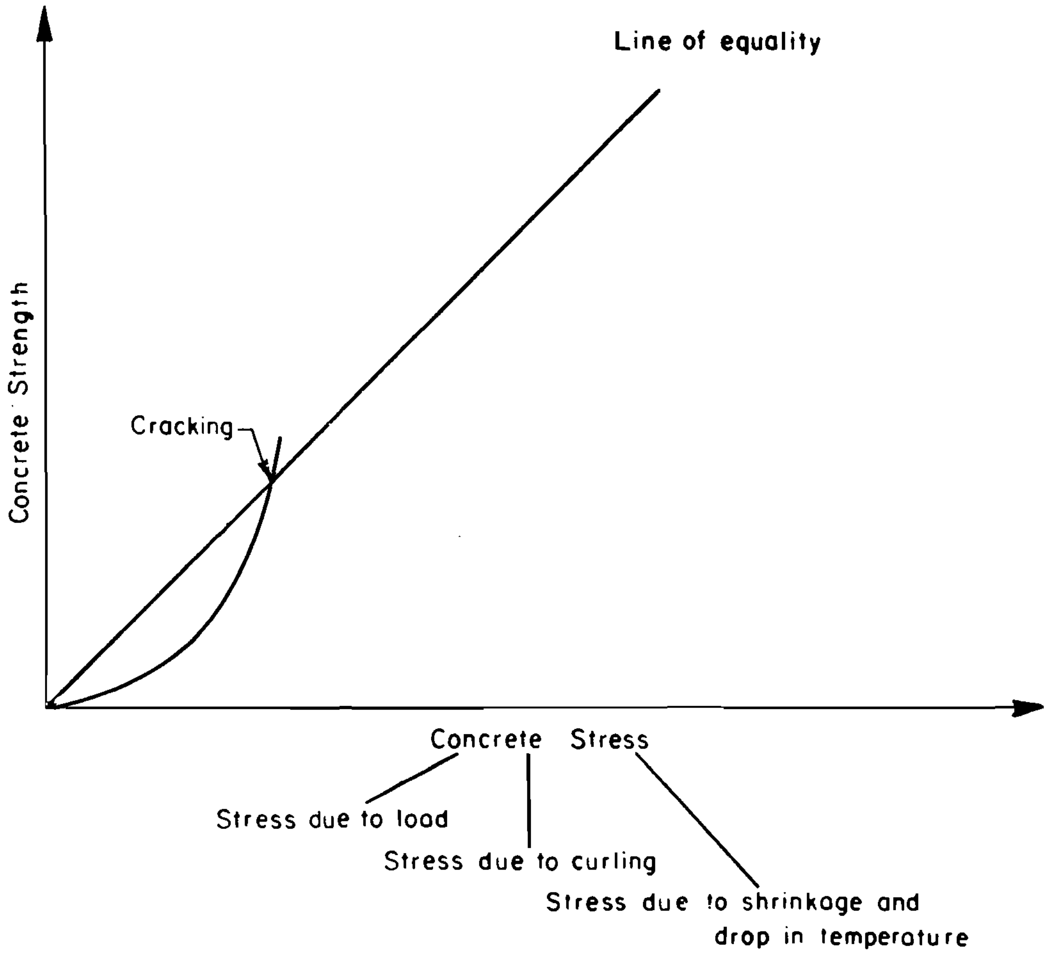


Fig 1.1. Graphical representation of a concrete pavement slab distress mechanism.

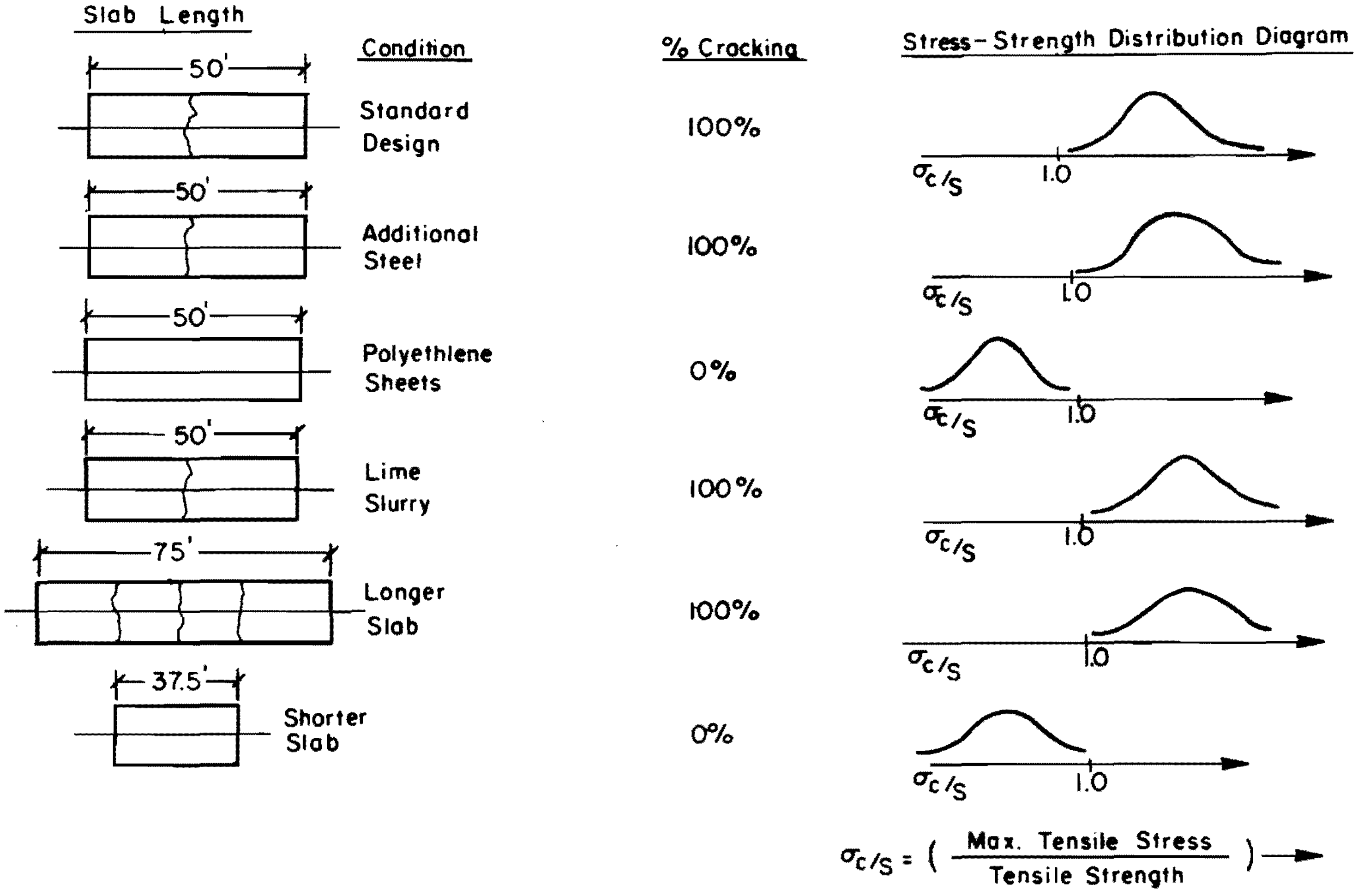


Fig 1.2. Summary of the findings of the Dallas-Ft. Worth study (Ref 1).

that can be harmful. In Fig 1.2, a brief graphic summary of the findings of Austin Research Engineers, is presented. In this figure, percent cracking is defined as the percent of slabs expressing one or more transverse cracks at or near mid-span. The distribution diagram shown on the right of the figure is a hypothetical condition based on percent cracking; thus, if one hundred percent cracking is reported, then the concrete tensile stress due to volume change must be greater than the concrete tensile strength for every slab, that is, the ratio must be greater than 1.0.

The restriction of slab movement will also be increased if the dowels at joints are not greased or have poor alignment as shown in Fig 1.3. This means that dowels hold the slab when it tends to contract, thus creating additional stresses that are very difficult to predict because of the infinite number of positions in which the dowels can be placed.

OBJECTIVES

This report describes studies of the stresses induced in the pavement due to shrinkage and drop in temperature in an effort to make a more complete and realistic study of the concrete stresses, and also to have a better feeling of how the stresses are going to be affected by the combination and interaction of shrinkage, drop in temperature, slab length, subbase friction, and concrete characteristics.

The concrete slab will experience contraction movements due to drying shrinkage and drop in temperature; those movements will be restrained by the reinforcing steel, and the subbase friction; the restraint provided by dowels and tie bars is not taken into account.

SCOPE OF THE STUDY

This study is focused on the effects of drying shrinkage and drop in temperature in the crack formation in a concrete pavement slab. The study is intended to provide a useful tool in the design and analysis of jointed concrete pavement. As previously discussed, the concrete contraction movement will be restrained by the reinforcing steel and the subbase friction, the last parameter being the most important one in the development of cracks. The goal of this study was to develop a computerized model capable of analyzing either a reinforced or a non-reinforced slab for temperature drop and drying shrinkage stresses.

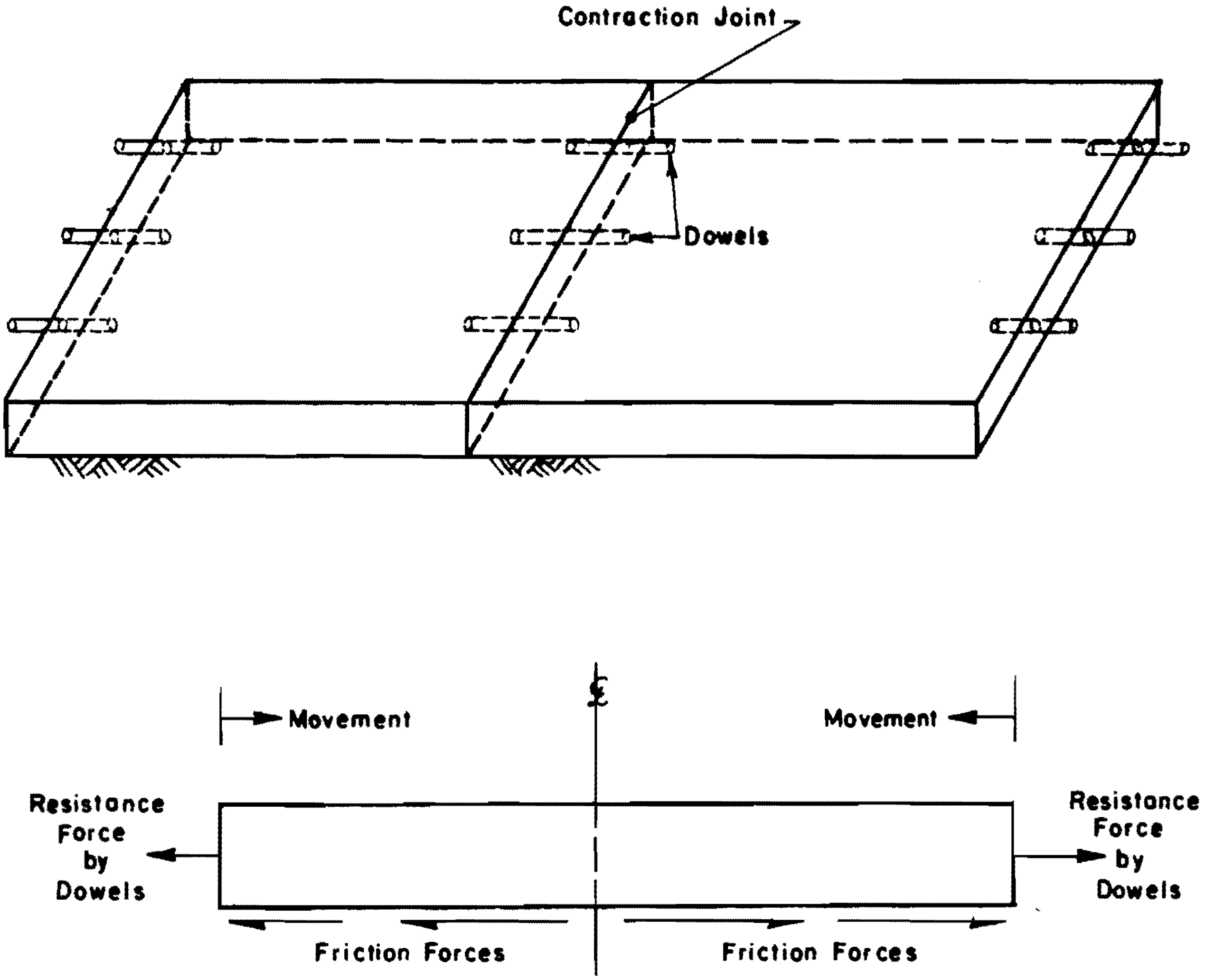


Fig 1.3. Forces generated by poorly placed dowels in a contracting slab.

This first chapter of the report is intended to introduce the reader to the subject. Chapter two gives a general view of the cracking mechanism in concrete. Chapter three deals with the theory and background on which the study is based, explaining in a comprehensive manner the shrinkage and drop in temperature phenomenona as well as concrete properties related to the study. Chapter four describes the mathematical approach used in the solution of our problem, including the geometric models as well as the solutions. Chapter five gives a description of the computer program and its usefulness.

CHAPTER 2. CONCEPT OF CRACKING

A brief conceptual explanation of why jointed reinforced concrete pavements crack is helpful to a better understanding of the problem. Cracking results when the concrete-tensile stress produced by contraction volume changes resulting from temperature drop, concrete shrinkage or both, exceeds the tensile-strength of the concrete which increases with time. The drying shrinkage is the reduction in length obtained when a saturated sample is dried under certain conditions; drying shrinkage depends on the cement and, in particular, certain conditions, including fineness, the richness of the mix, the water/cement ratio and the kind of curing, especially at early ages. The rate at which movement or shrinkage takes place depends on the permeability of the concrete. Drying shrinkage generally decreases as the strength of the aggregate increases (Ref 3).

It is fairly well established that shrinkage takes place over considerable time and the rate of increase of shrinkage decreases with time. The following figures have been given by Patten (Ref 3) to indicate the ranges of shrinkages at different times after placement:

after 2 weeks, 14-34 percent of the 20-year shrinkage;
after 3 months, 40-80 percent of the 20-year shrinkage; and
after 2 years, 66-85 percent of the 20-year shrinkage.

In Fig 2.1 approximatly average curves for the shrinkage strains for concrete made from ordinary portland cement, rapid hardening portland cement, and high alumina cement are given. It should be pointed out that the steepest portion of the curves occurs between time of placing and two months, emphasizing the importance of drying shrinkage in crack formation at an early concrete age (Ref 3). The volume changes alone do not produce stresses, but they occur as a result of the restriction provided by the friction between concrete and subbase. This may be seen in Fig 2.2 where two friction subbases, one low and the other high, are plotted (Ref 2). Stresses can be set up in rigid pavements as a result of uniform temperature changes which cause the slab to contract or expand. If a slab cools uniformly, a crack will generally occur at about the center of

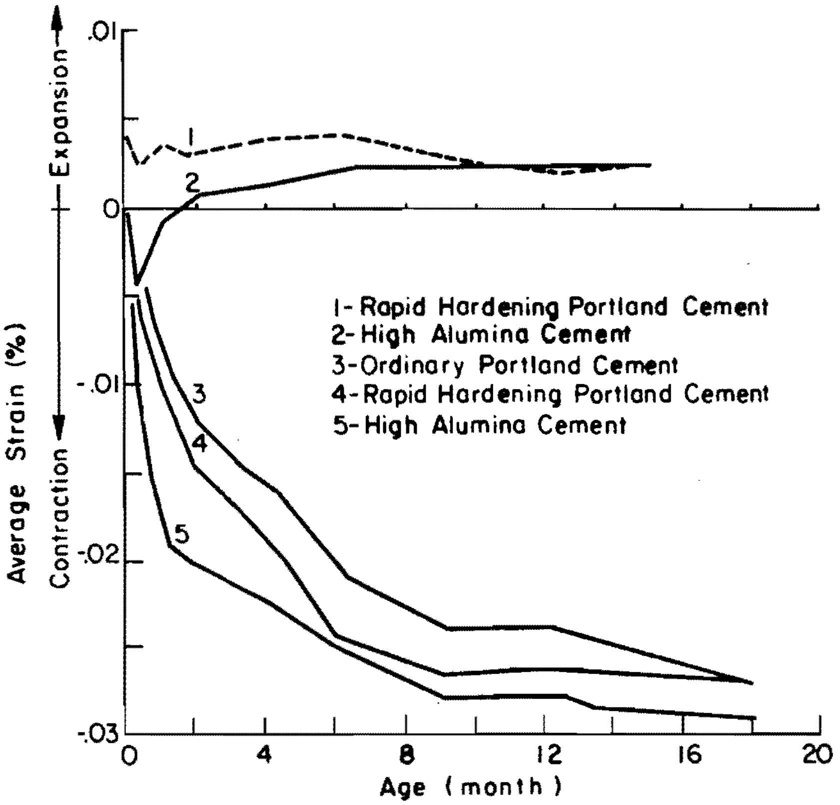
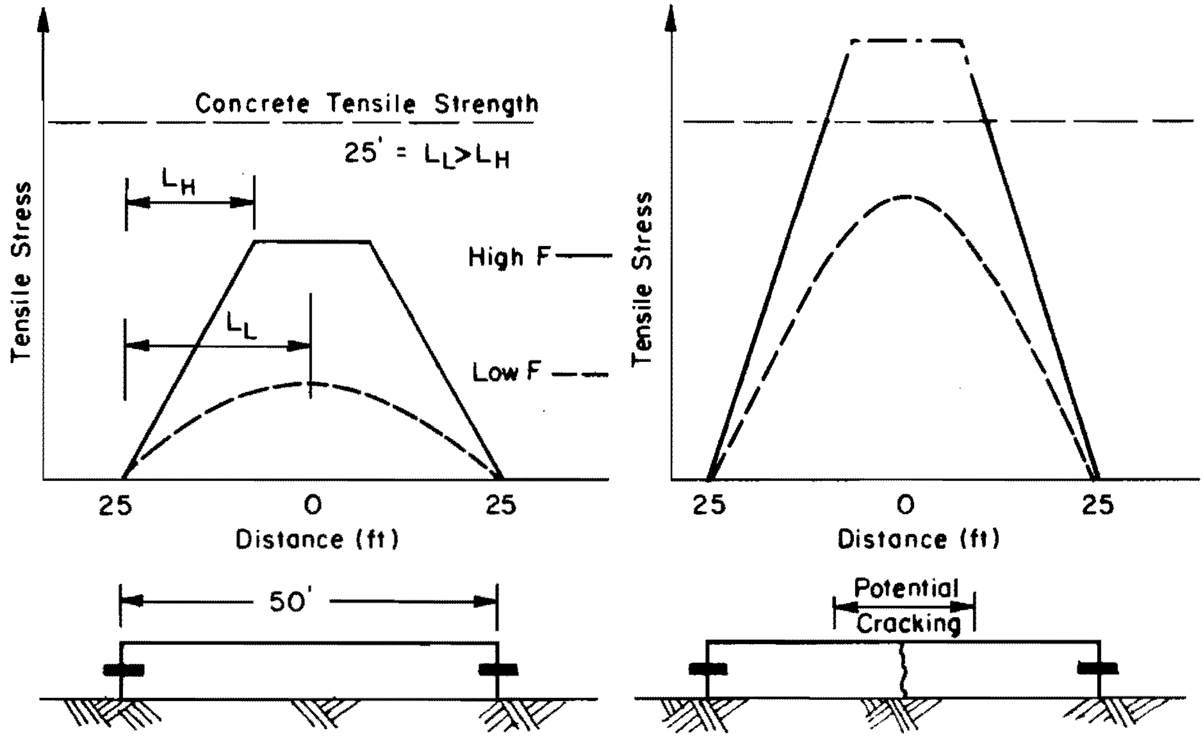


Fig 2.1. Shrinkage strains for three types of cement, after Glanville (Ref 3).



(a) Prior to cracking (b) At cracking

Fig 2.2. Longitudinal stress distribution in a concrete slab prior to and at cracking (Ref 2).

the slab. Shrinkage of the concrete also causes the same phenomenon to occur. In order to generate frictional resistance during contraction, movement between slab and subgrade must occur, which means the slab is going to slide when contracting. Research Studies indicate minimum displacement of 0.06-inches is need for friciton to be fully developed (Ref 4). The slab movement will be in a decreasing pattern going from a maximum at its free end to zero (no movement) at a point in the interior, where the maximum concrete tensile stress will develop. Kelly (Ref 4) has suggested, based on results of "tests", that fully mobilized frictional resistance is realized for the distance $\left(\frac{L}{2} - x\right)$ as shown in Fig 2.3, but from there to the geometric center of the slab, the shape of the stress distribution is parabolic. From this, it is obvious stresses due to frictional resistance in slabs will vary with slab length, but it is doubtful whether or not, on short slabs, sufficient friction will be developed to cause tensile stresses in the concrete that can lead to a distress manifestation (cracking).

THE PROBLEM

As discussed previously, the cracking occurrence in concrete slabs for pavements is a direct function of time, that is, the concrete slab will gain strength with time and also will contract due to temperature drop and drying shrinkage; both of which are also functions of time. The drop in temperature will be the difference between setting temperature and the lowest daily recorded temperature. This study is based on the early age of the concrete, from placement to 28 days, when concrete is approaching its full strength.

This study then is based on the need to find the stresses that the concrete is going to have with time and to determine if those stresses will produce a crack at or near maximum values. After knowing the concrete tensile stress distribution for a specific time and knowing the concrete tensile strength for that same time, it is fairly easy to predict a crack (Fig 2.4(a)); then, if a crack happens to occur, it is necessary to find the new concrete tensile stress distribution, which is going to be different from the previous one, because at the crack the concrete will have no stress, Fig 2.4(b); then by comparing this new stress pattern against concrete strength, more possible cracks can be detected, Fig 2.4(c).

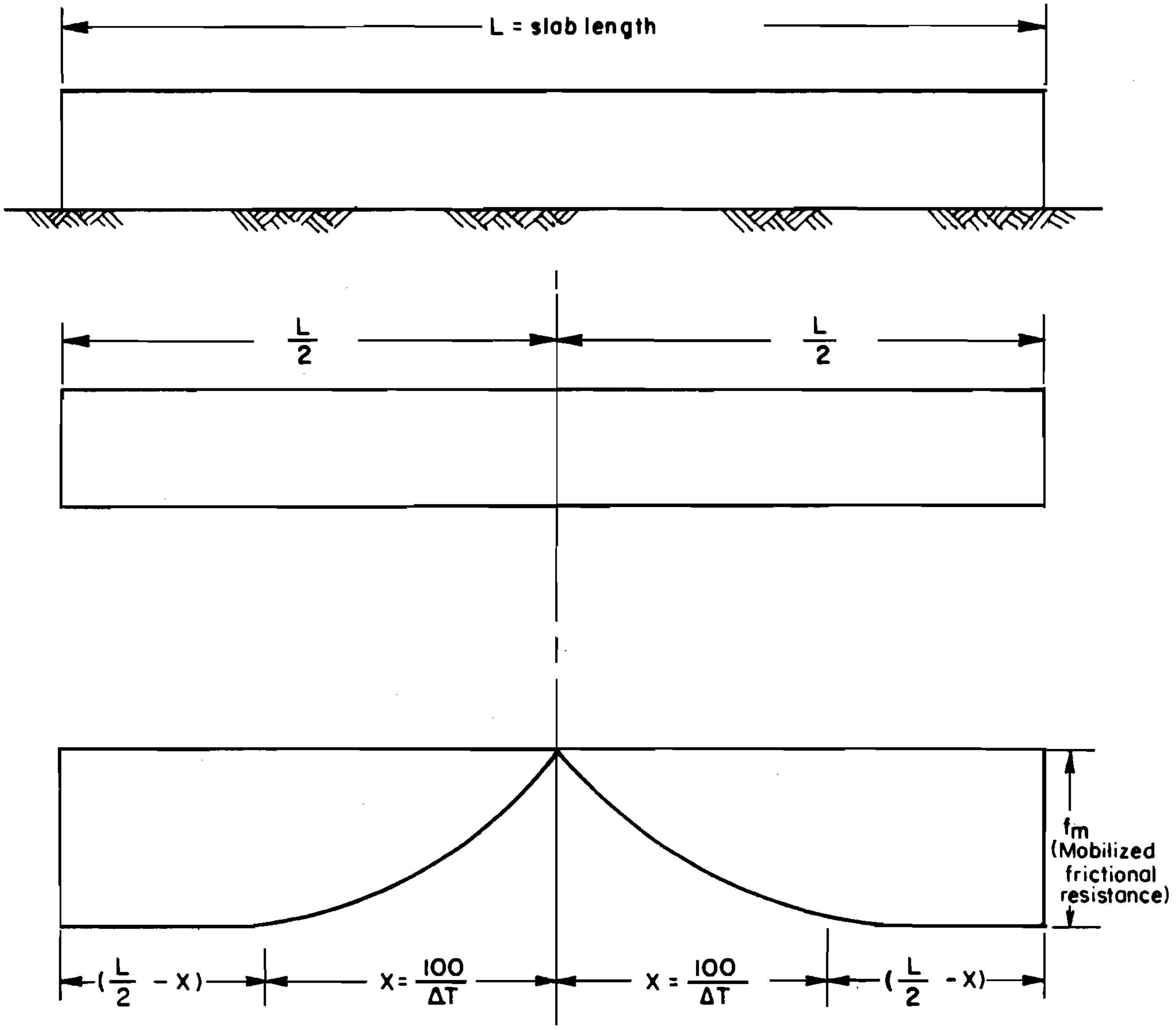
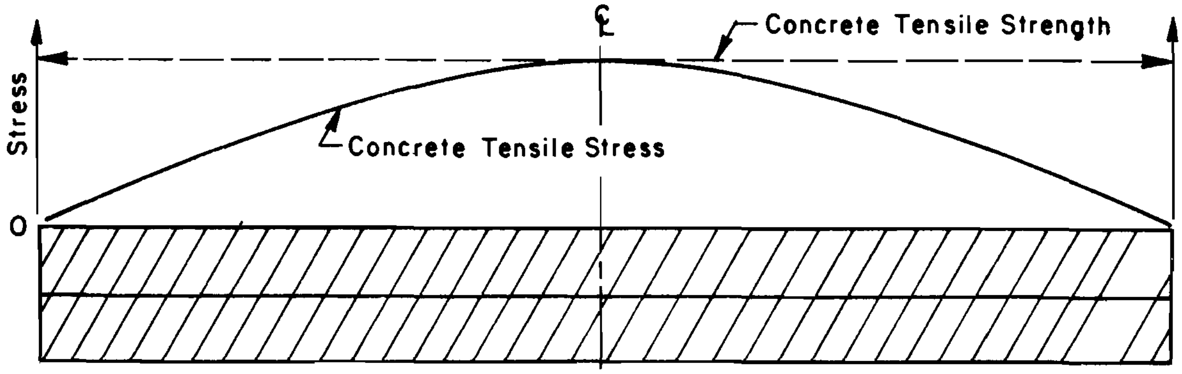
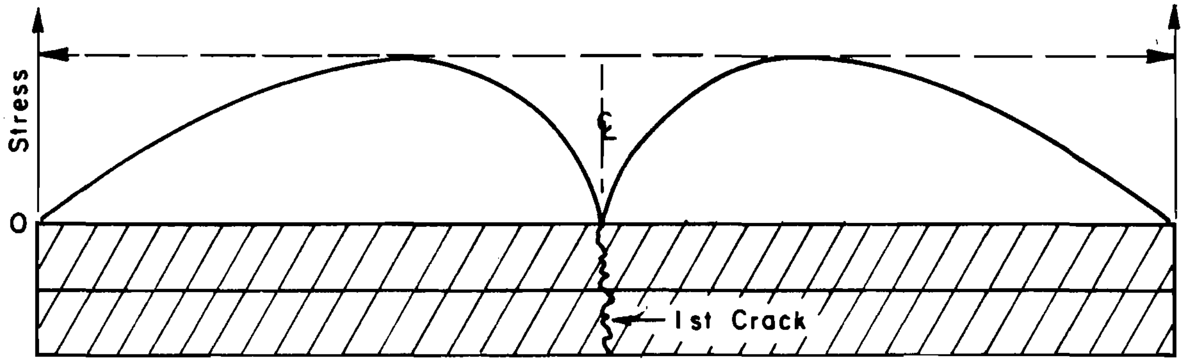


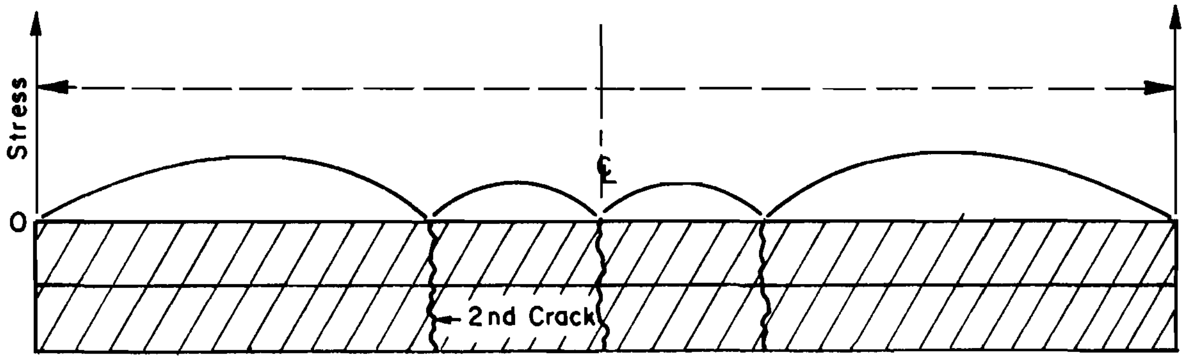
Fig 2.3. Mobilized frictional resistance distribution (Ref 4).



(a) Concrete slab prior to cracking



(b) Concrete slab after first crack



(c) Concrete slab after second crack

Fig 2.4. Crack occurrence in a concrete slab.

The present work will only analyze the possible occurrence of two cracks in the slab, because it is felt that the first crack will be the one with the worst conditions, namely excessive crack width.

Therefore, the first task is to find the concrete stresses at each time. To do this, it is necessary to remember that those stresses are going to be a direct function of frictional resistance, which is going to depend on the slab movement, and themovement depends on slab length, drying shrinkage and temperature drop. The task now is to relate all these factors and predict the concrete stress.

CHAPTER 3. THEORY

Temperature drop and shrinkage are variables with time, as is the concrete strength; therefore, the problem is to relate the state of stresses in the slab at every time, from the concrete placement until the concrete gains its full strength. The solution is to find the stress in the concrete due to shrinkage and temperature drop at several time increments, and then compare this stress with the concrete strength also at that time as illustrated in Fig 3.1. At times, shrinkage and temperature drop alone will not cause cracking, but, if we superimpose the stresses due to load, warping or curling, they can produce stresses higher than the concrete strength.

At an early age concrete, the cracking pattern is due basically to the external forces generated by restraint of contractional movements developed by shrinkage and drop in temperature. The restraint is provided by the type of subbase friction and the reinforcing steel and thus generates tensile stresses in the concrete. This phenomenon can be better understood by observing the concrete behavior information taken from Ref 4 which tells us that:

> "When cement is mixed with water to form a soft paste, it gradually stiffens until it becomes a solid. The cement is said to have set when it has gained sufficient rigidity to support an arbitararily defined pressure, after which it continues for a long time to harden. The water in the paste dissolves material at the surfaces of the cement grains and forms a gel which gradually increases in volume and stiffness. This leads to a rapid stiffening of the paste two to four hours after water has been added to the cement. Hydration continues to proceed deeper into the cement grains, at decreasing speed, with continued stiffening and hardening of the mass. In ordinary concrete the cement is probably never completely hydrated. The gel structure of the hardened paste seems to be the main reason for the volume changes which are caused in concrete by variations in moisture, such as the shrinkage of concrete as it dries. According to H. Rusch, for complete hydration of a given amount of cement, an amount of waterequal to about 25 percent of that of cement by weight, is needed chemically. An additional 10 to 15 percent must be present, however, to provide mobility for the water in the cement paste during the hydration process so that it can reach the cement particles, this makes for a total minimum water-cement ratio of 0.35 to 0.40 by weight and this ratio corresponds to 4 to gallons (15.14 - 17 lts) of water per sack of cement. Any amount of water above the 25 percent consumed in the chemical reaction produces pores in the cement paste. The strength of the hardened paste decreases

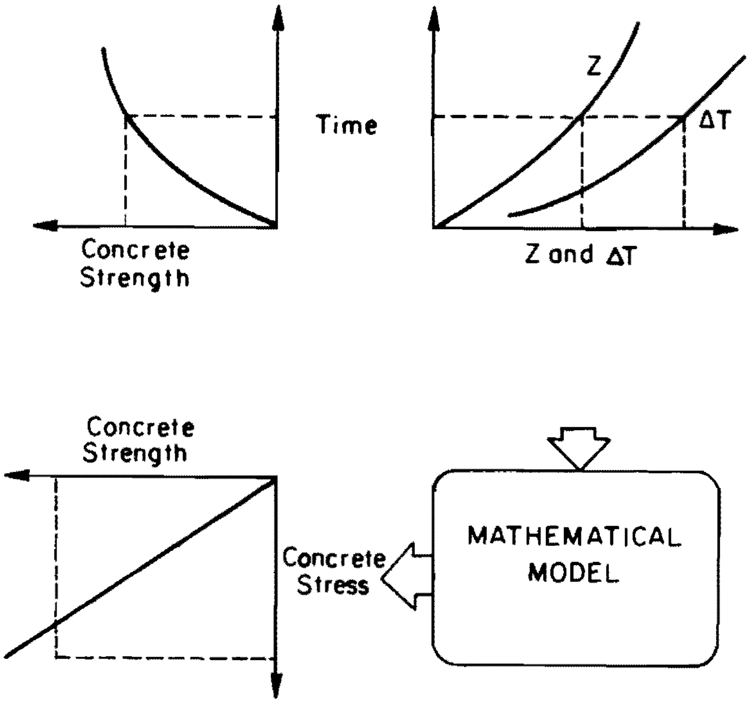


Fig 3.1. Flow chart to relate concrete strength and concrete stresses due to shrinkage (Z) and drop in temperature (ΔT) as a function of time.

> in inverse proportion of the fraction of the total volume occupied by pores. This is why the strength of the cement paste depends primarily on, and decreases directly with, increasing water cement ratio" (Fig 3.2).

SHRINKAGE

As discussed above, any workable concrete mix contains more water than is needed for hydration. If the concrete is exposed to air, the larger part of this free water evaporates in time, the rate and completeness of drying depending on ambient temperature and humidity conditions. As the concrete dries, it shrinks in volume, probably due to the capillary tension which develops in the water remaining in the concrete. Now, if dry concrete is immersed in water, it expands, regaining much of the volume loss from prior shrinkage. Shrinkage, which continues at a decreasing rate for several months, is a detrimental property of concrete in several aspects. When not adequately controlled, it will cause unsightly and often detrimental cracks. In structures which are statically indeterminate, it can cause large and harmful stresses. So, the chief factor which determines the amount of final shrinkage is the unit water content of the fresh concrete, as illustrated in Fig 3.3.

It is evident from this, that the chief means of reducing shrinkage is to reduce the water content of the fresh concrete to the minimum compatible with the required workability. In addition, careful and prolonged curing is helpful for shrinkage control (Ref 4). Values of final shrinkage for ordinary concretes are generally in the range of 0.0002 to 0.0007 inch per inch, depending on initial water content, ambient temperature and humidity conditions, and the nature of the aggregate (Ref 7). Highly absorptive aggregates, such as some sandstones and slates, result in shrinkage values twice those obtained with less absorptive materials such as granites and some limestones. Some lightweight aggregates, in view of their great porpsity, easily cause much larger shrinkage than ordinary concretes. Hansen and Matlick (Ref 6) made studies of the variability of shrinkage with time. According to them, this variation is a hyperbolic function of time, which can be expressed mathematically as follows:

$$\frac{Z_t}{Z_f} = \frac{t}{M + t} \qquad (3.1)$$

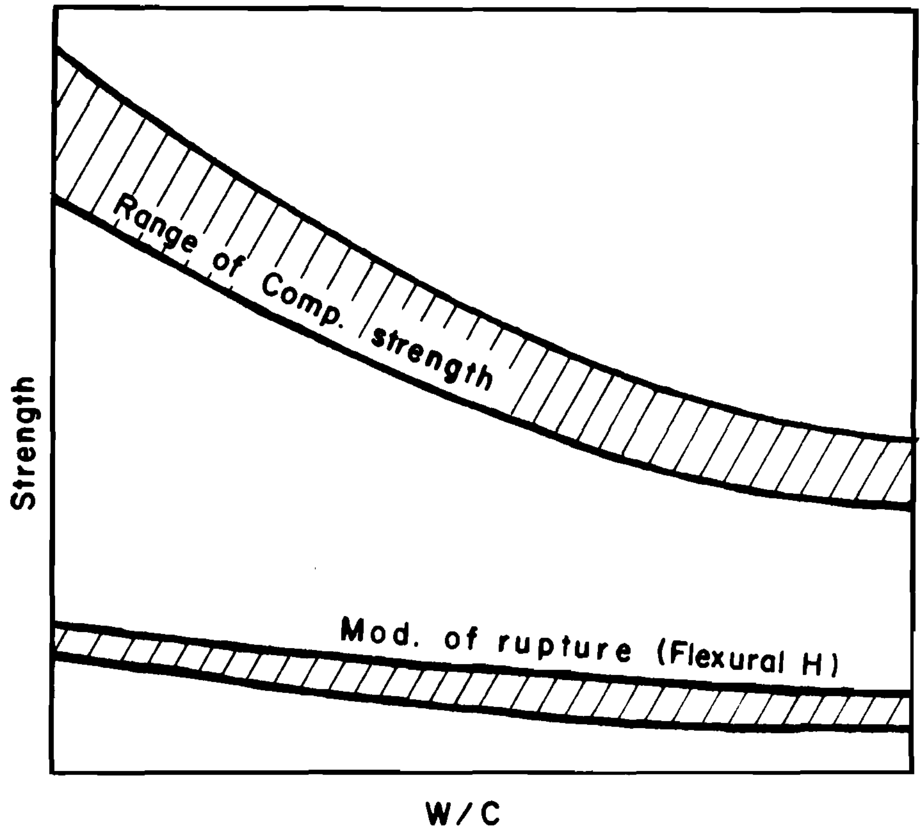


Fig. 3.2. Relationship between concrete strength and W/C ratio (Ref 4).

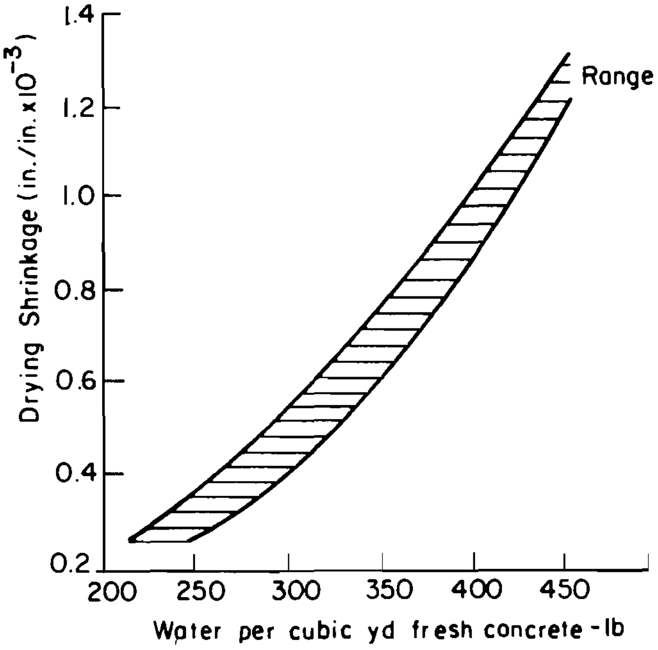


Fig. 3.3. Relationship between drying shrinkage and unit water content (Ref 4).

$$\frac{Z_t}{Z_f} = \frac{t}{M + t} \tag{3.1}$$

$$M = 26e^{0.36}\left(\frac{v}{s}\right) \tag{3.2}$$

e = base of Naperian log,
t = time in days after concrete setting
v = volume of the member (inches^3),
s = exposed surface area (inches^2),
Z_t = drying shrinkage at time t , nad
Z_f = final drying shrinkage.

For concrete slabs with dense graded and chemically stabilized sub-bases, the drying occurs from the top surface; thus the $\left(\frac{v}{s}\right)$ ratio equals to the concrete thickness D , resulting in the following relationship:

$$Z_t = \left(\frac{t}{26e^{0.36D} + t}\right) Z_f \tag{3.3}$$

Using the above equation and having the final drying shrinkage, the drying shrinkage for any time t can be obtained for a slab with D thickness. The slab thickness is a function of the loads that are going to act on the pavement.

TEMPERATURE CHANGES

Concrete expands with increasing temperature and contracts with decreasing temperature. The effects of such volume changes are similar to those caused by shrinkage. That is, temperature contraction can lead to undue cracking particularily when superimposed with shrinkage; in indeterminate structures, deformations due to temperature changes can cause large and occasionally harmful stresses. The coefficient of expansion varies somewhat, depending on the type of aggregate and richness of mix. It is generally within the range of 0.000004 to 0.000006 inch per inch per degree Fahrenheit (Ref 8). A value of 5.5×10^{-6} is generally accepted as satisfactory for calculating stresses and deformations caused by temperature changes. Other factors besides type of aggregate and richness of the mix that cause the coefficient of expansion of thermal coefficient to vary are temperature range, water-cement ratio, concrete age, and relative humidity.

That work assumes that the temperature distribution in the concrete slab is constant, with depth as an approximation. Tomlinson's work demonstrates that this assumption is not true in reality. Tomlinson's theory assumes the temperature varies according to a simple harmonic law. The temperature (θ) at any given depth (x) below the surface at any time (t) is obtained by means of the following relationships:

$$\theta = \theta o e - \frac{x}{h}\sqrt{\frac{\pi}{T}} \sin\left(\frac{2\pi}{T} t - \frac{x}{h}\sqrt{\frac{\pi}{T}}\right) \tag{3.4}$$

and

$$\theta o^{*} = \frac{1.5\,\theta_{a\ max} - \theta_{a\ min}}{2} \tag{3.5}$$

where

θo = amplitude of the temperature cycle at the free surface of the slab,

e = base of Naperian log,

h = diffusiveness of the concrete in inches^2/hour,

= $\dfrac{\text{thermal conductivity}}{\text{heat capacity per unit volume}}$

T = periodic time of the temperature cycle (24 hours for the daily cycle),

$\theta_{a\ max}$ = maximum air temperature on a particular day, and

$\theta_{a\ min}$ = minimum air temperature.

---

*Valid only for a six inch slab

CONCRETE PROPERTIES

Besides shrinkage, other concrete properties in which we are interested for the scope of this work are: thermal coefficient, strength, modulus of elasticity and bond.

Thermal Coefficient. The thermal properties of concrete are primarily a heat transfer process, extracting the excess heat from the concrete keeping the differential volume change at a minimum.

The mineralogical composition of the aggregate is the chief factor affecting the thermal properties of the concrete. From Ref 6, Table 3.1 can be used for recommended values for the thermal coefficient. Other factors are richness of the mix, relative humidity, water-cement ratio, concrete age, and temperature range.

Strength, Modulus of Elasticity and Bond. These three properties are related, and are functions of time. Knowing the tensile strength-time relationship, the flexural strength, the compressive strength, the bond stress, and the modulus of elasticity can be obtained as follows (Ref 7).

The split-tensile strength has a relation with the flexural strength that depends on the coarse aggregate type of the concrete:

Concrete Type	Ratio of Split-tensile Strength to Flexural Strength *
Gravel	5/8
Limestone	2/3
Light-weight Aggregate	3/4

To have a clearer understanding of how to find the compressive strength, bond stress and modulus of elasticity of the concrete, a step-by-step summary will be discussed (Ref 7).

(1) Find the flexural strength using the above relationship.

(2) Find the compressive strength (f'_c) by using

---

*Average value

TABLE 3.1. CONCRETE THERMAL COEFFICIENT AS DEPENDENT OF AGGREGATE TYPES (Ref 6)

Type of Coarse Aggregate	Concrete Thermal Coefficient (10^{-6} in/in/°F)
Quartz	6.6
Sandstone	6.5
Gravel	6.0
Granite	5.3
Basalt	4.8
Limestone	3.8

$$f'_c = \frac{4000\ f_r}{1000-f_r} \tag{3.6}$$

where

f_r = flexural strength (psi) and
f'_c = compressive strength (psi).

(3) Compute modulus of elasticity of the concrete by

$$E_c = \gamma^{1.5}\ 33\sqrt{f'_c} \tag{3.7}$$

where

γ = unit weight of the concrete (pcf) and
E_c = modulus of elasticity of concrete (psi).

(4) Compute the bond stress by using

$$\mu = \frac{9.5\sqrt{f'_c}}{\phi} \tag{3.8}$$

where

μ = bond stress (psi) and
ϕ = bar diameter (inches).

If age-tensile strength data cannot be provided, the solution may still be possible if the 28-day compressive strength is provided, and used with the United States Bureau of Reclamation formula (Ref 3) which gives the percent of the 28-day compressive strength for various intermediate ages as seen in Fig 3.4.

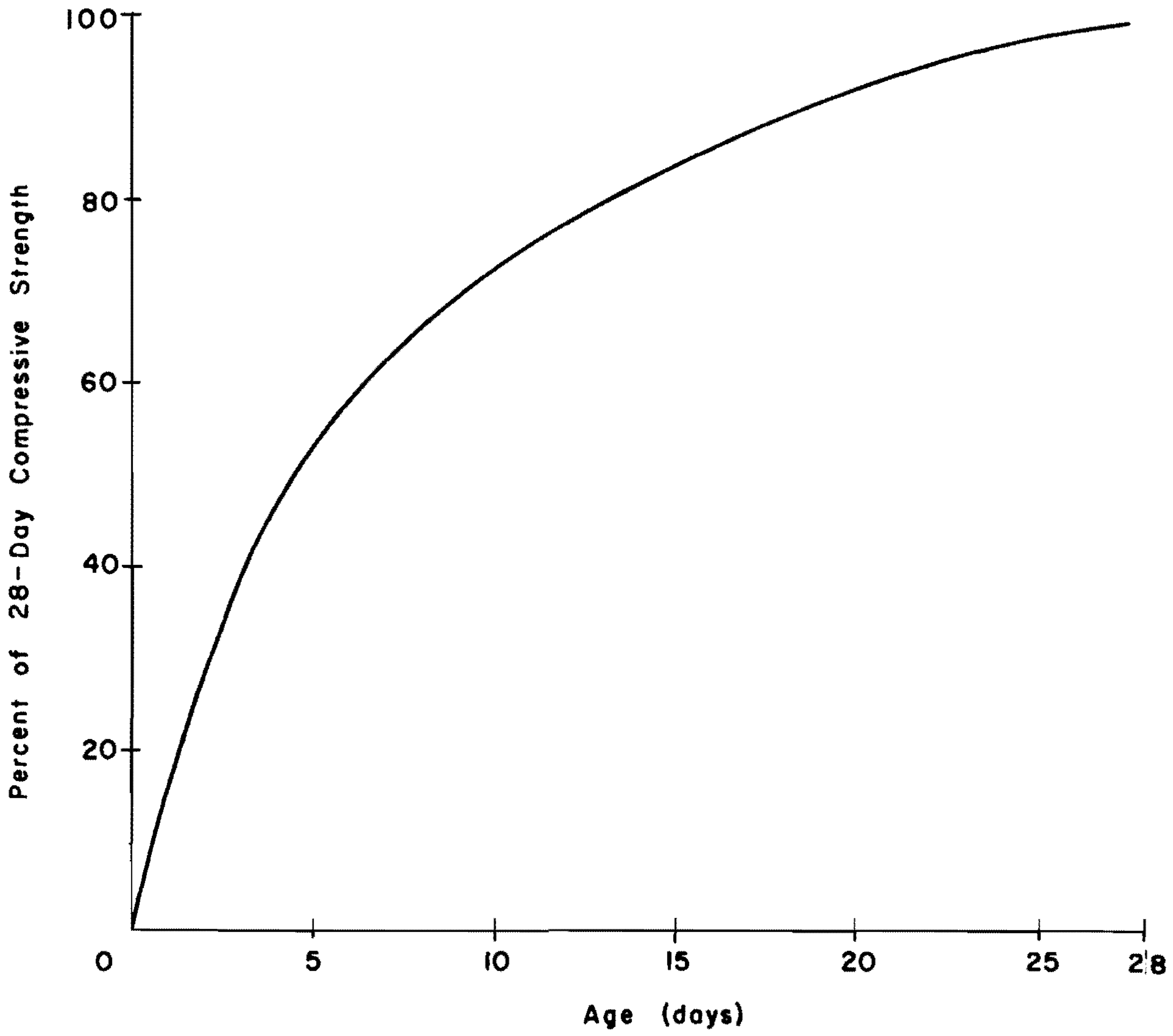


Fig 3.4. Average variation of compressive strength of concrete with age (Ref 3).

From this, it is clear that the concrete compressive strength can be known for each day and the modulus of elasticity for each also can be obtained applying the equation previously mentioned:

$$E_c = \gamma^{1.5} 33 \sqrt{f'_c} \tag{3.7}$$

CHAPTER 4. GEOMETRIC MODELS

In Jointed Reinforced Concrete Pavement (JRCP), crack occurrence is due primarily to internal stresses induced by changes in temperature and drying shrinkage. A set of basic equations that describe the stress variations with time is developed in the following sections. The externally induced stresses due to wheel load and other factors are not within the scope of this study, but the stress solutions due to other factors can be easily superimposed.

Two models are necessary for the derivation of the basic equations to represent the behavior of the slab. A JRCP slab is a symmetrical element with each portion having a free end and a fixed end at the centerline of the slab where no movement will occur as graphically represented in Fig 4.1. This model is termed Model-1, and is used to determine the first crack occurrence. If a crack occurs using this model, the behavior of the slab will be different, because there will be two concrete free ends, but the steel is fixed in one end, creating the need of a different model, this model to be termed as Model-2, and is graphically represented in Fig 4.2.

ASSUMPTIONS

In order to solve the problem, the following assumptions are made:

(1) The steel and concrete are linearly elastic.

(2) A crack occurs when the concrete stress is equal to or exceeds the concrete strength.

(3) After cracking, the concrete stress at the crack is zero.

(4) The relative movement between concrete and reinforcing steel is zero in the fully bonded sections.

(5) The frictional resistance to movement of dowels and tie bars is neglected.

(6) Temperature variations and drying shrinkage are distributed uniformly throughout the slab.

(7) Material properties are independent of space.

(8) The friction force-displacement curve is elastic.

(9) The steel is placed at the neutral axis of the slab.

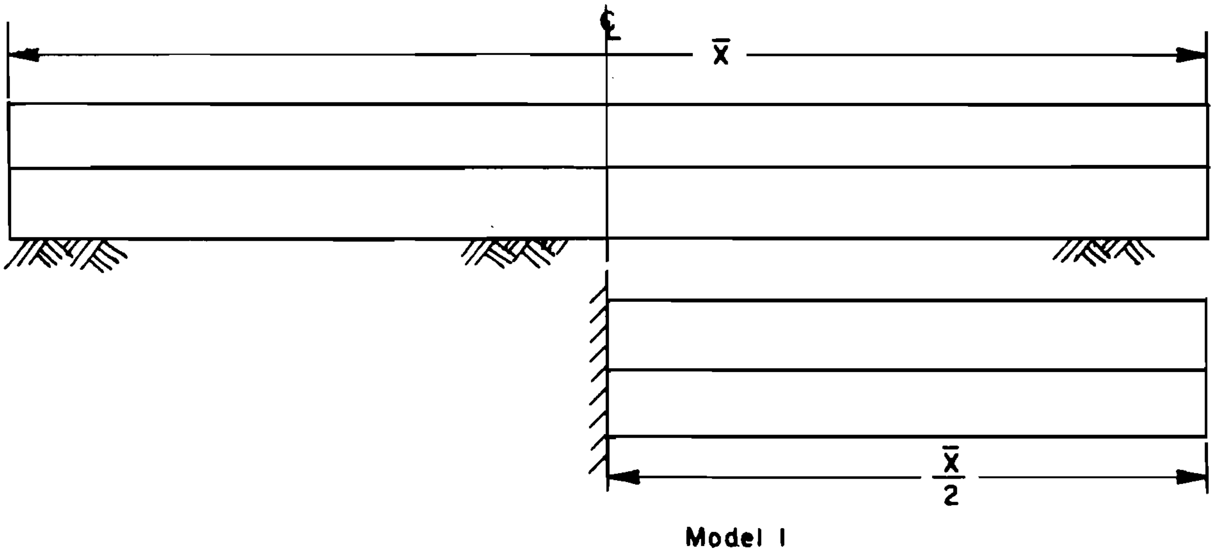


Fig. 4.1. JRCP Geometric model, namely Model-1.

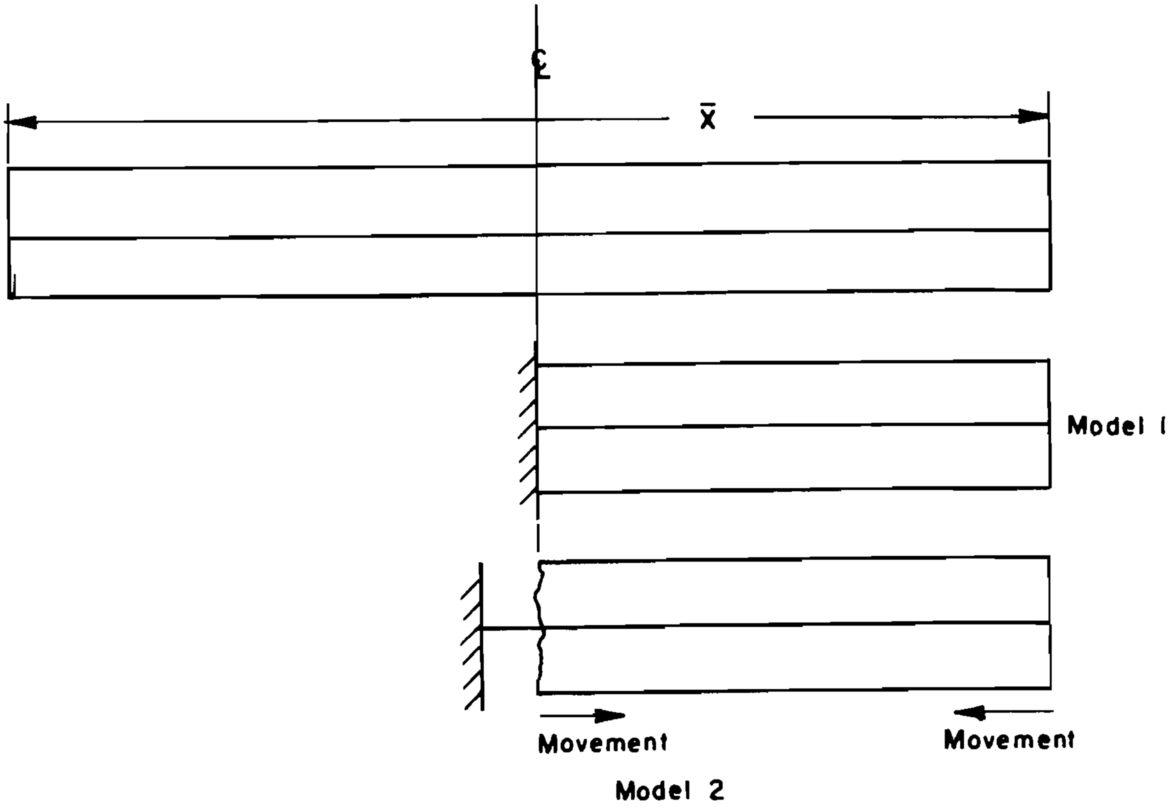


Fig. 4.2. JRCP Geometric model used to search for the second crack, namely Model-2.

SIGN CONVENTION

(1) Tension is positive.

(2) Friction forces in the x-direction are positive.

(3) Temperature drop is defined as the difference between the temperature at which the concrete set and the minimum temperature at the time of consideration.

(4) Movements in the x-direction are positive.

Basic Equations for Model-1

For modeling the interaction between concrete, steel and the underlying soil when subjected to drying shrinkage and drop in temperature contractions, the several equations were developed. The concepts developed in Ref 7 for a continuously reinforced concrete pavement were taken as a starting point to solve the geometric Model-1. These equations can be categorized into the following groups:

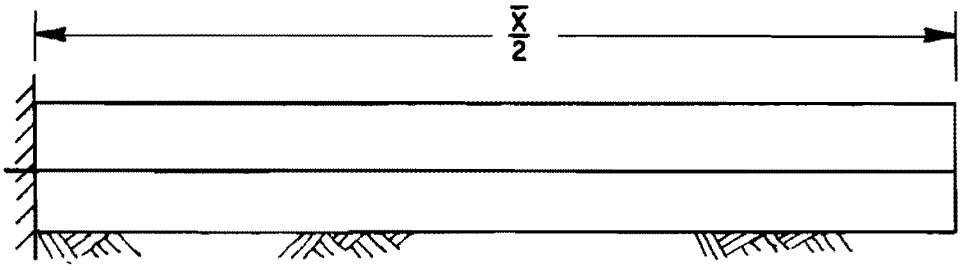
(1) general equilibrium, and

(2) compatibility,
  (a) shrinkage,
  (b) temperature drop, and
  (c) friction.

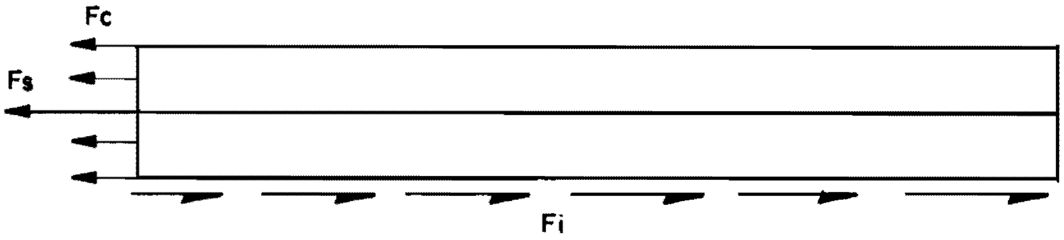
General Equilibrium. A free body diagram for Model-1, and stress distribution in the steel and concrete for a given drying shrinkage strain (Z) and temperature drop (ΔT) are shown in Fig 4.3. The steel stress in the fixed end of the model might be tension or compression, depending on the magnitude of the shrinkage and drop in temperature. The concrete stress is always in tension, going from a maximum at the fixed end to zero at the free end; $\Sigma F_x = 0$ must be satisfied for equilibrium of the system, gives:

$$\Sigma F_x = 0$$

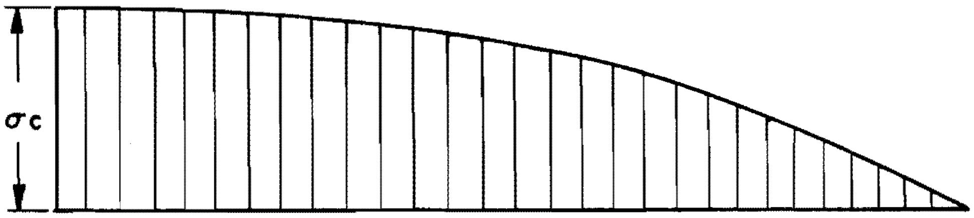
$$F_c + F_s = \int_0^x F_i dx$$



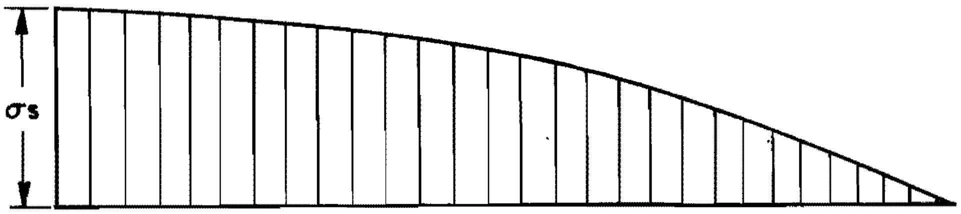
(a) Model-1



(b) Free-body diagram of Model-1



(c) Stress distribution in concrete



(d) Stress distribution in steel

Fig. 4.3. Free body diagram and corresponding stress distribution of Model-1.

or

$$F_c + F_s - \int_o^x F_i' dx = 0 \qquad (4.1)$$

where

F_c = force in the concrete (lb),
F_s = force in the steel (lb), and
F_i' = friction force per unit length along the slab,
F_i = friction force per unit length per unit width.

As we are interested in determining the stresses, then equation 4.1 may be transformed to a stress equation by

$$A_c \sigma_c + A_s \sigma_s - \int_o^x F_i' dx = 0 \qquad (4.2)$$

where

σ_c = stress in the concrete, psi,
σ_s = stress in the steel, psi,
A_s = cross-sectional area of longitudinal steel, in^2, and
A_c = cross-sectional area of concrete, in^2.

For a unit width slab (L), equation 4.2 can be rewritten as

$$D \sigma_c + \frac{A_s}{L} \sigma_s - \int_o^x F_i dx = 0$$

where D = slab thickness (inches).
Therefore, dividing by D , the equation becomes

$$\sigma_c + \frac{A_s}{L A_c} \sigma_s - \frac{\int_o^x F_i dx}{D} = 0$$

where

L = slab width.

Substituting

$$p = \frac{A_s}{A_c} = \frac{A_s}{D \times L}$$

implies

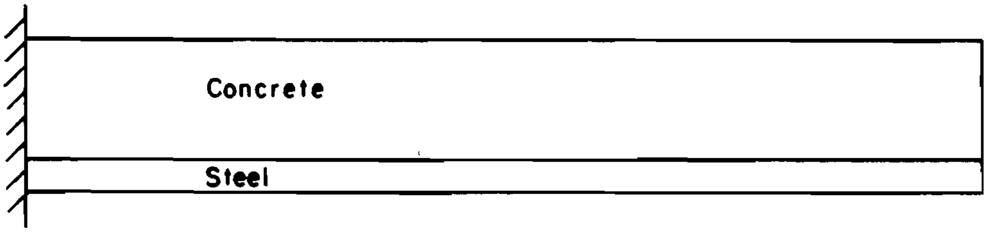
$$\sigma_c + p\sigma_s - \frac{\int_o^x F_i dx}{D} = 0 . \tag{4.3}$$

<u>Compatibility Equations for Model-1</u>. The compatibility equations reflect the influence of the interaction between the slab contraction due to shrinkage and drop in temperature and friction in the concrete and steel stresses. For a more clear understanding, separate equations are derived for shrinkage and temperature drop, and then the principle of superimposition is applied to account for the total effect. In the development of the equations for shrinkage and drop in temperature, it was assumed there was no relative movement between concrete and steel.

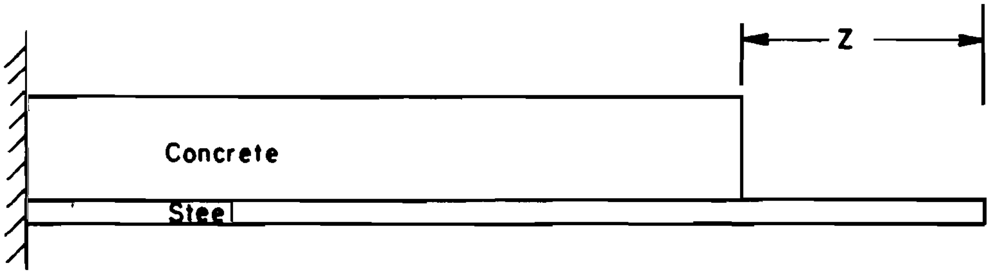
(1) <u>Shrinkage</u>. The development of an equation is achieved by first assuming no bond between steel and concrete; that means that if the concrete contracts in the horizontal direction, no strain will develop because there is no restraint to that movement. But, if the restraint provided by the reinforcing steel (Fig 4.4) is taken into account, the concrete and the steel will experience strains, and the following relationship exists:

$$\epsilon_{cz} + \epsilon_{sz} = Z$$

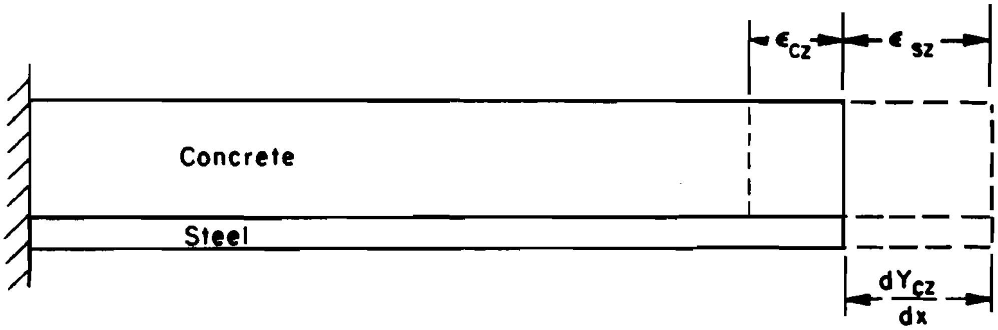
where



(a) State of no shrinkage



(b) Shrinkage without bond between two materials



(c) Shrinkage for a fully bonded condition

Fig. 4.4. Reinforced member behavior when subjected to a uniform shrinkage Z.

where

Z = free drying shrinkage strain of concrete,

ϵ_{cz} = concrete strain due to shrinkage (strain of concrete due to restraint of steel),

ϵ_{sz} = steel strain due to shrinkage (strain of steel due to shrinkage of concrete).

The concrete will be in tension, and the steel in compression, then according to the sign convention

$$Z = \epsilon_{cz} + \epsilon_{sz}$$

Converting to stress with sign convention (tension is positive),

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

rearranging terms,

$$\frac{\sigma_{cz}}{E_c} = Z + \frac{\sigma_{sz}}{E_s}$$

let

$$n = \frac{E_s}{E_c}$$

solving for σ_{cz} ,

$$\sigma_{cz} = E_c Z + \frac{\sigma_{sz}}{n} \tag{4.5}$$

where

σ_{cz} = stress in the concrete due to shrinkage, Z,
σ_{sz} = stress in steel due to shrinkage, Z,
E_c = elastic modulus of concrete,
n = modulus ratio, and
E_s = elastic modulus of steel.

(2) Drop in Temperature. The variations in temperature tend to cause volume changes in both the steel and the concrete. As the air temperature goes below the casting temperature, the material contracts and induces tensile stresses in the concrete. In this work, both steel and concrete thermal properties are characterized by the linear coefficient of contraction or expansion. As previously pointed out, the aggregate type governs the concrete thermal coefficient.

To solve the problem, the concrete and steel are aśsumed to be fully bonded, meaning that both materials will have the same movement. From Fig 4.5 for a unit length slab, the following may be derived:

$$\epsilon_{c\Delta T} - \epsilon_{s\Delta T} = \Delta T(\alpha_c - \alpha_s)$$

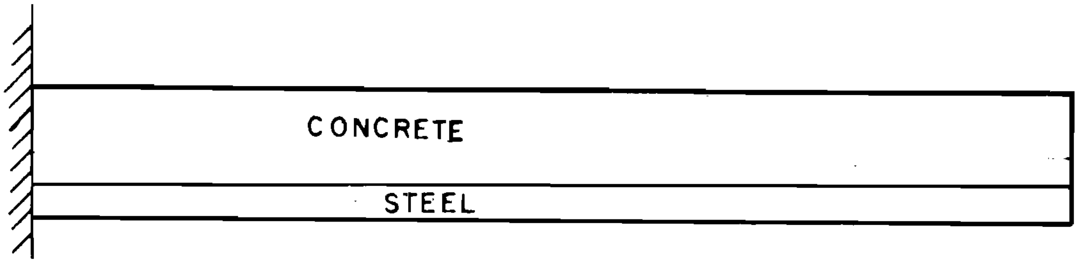
$$\epsilon_{c\Delta T} = \Delta T(\alpha_c - \alpha_s) + \epsilon_{s\Delta T} \qquad (4.6)$$

where

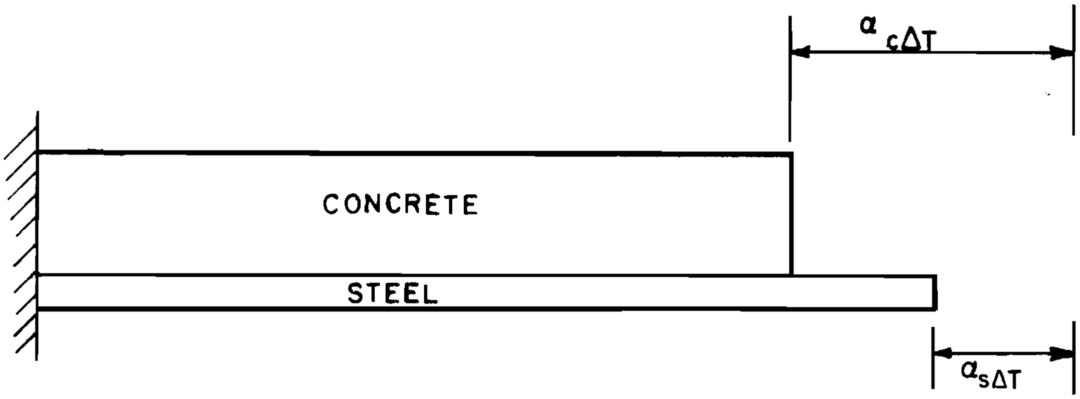
$\epsilon_{c\Delta T}$ = strain in the concrete due to a temperature drop ΔT ,
$\epsilon_{s\Delta T}$ = strain in the steel due to a temperature drop ΔT ,
ΔT = drop in concrete temperature ($^\circ$F),
α_c = concrete linear thermal coefficient (/$^\circ$ F), and,
α_s = steel linear thermal coefficient (/$^\circ$ F).

For a stress equation, equation 4.6 can be written

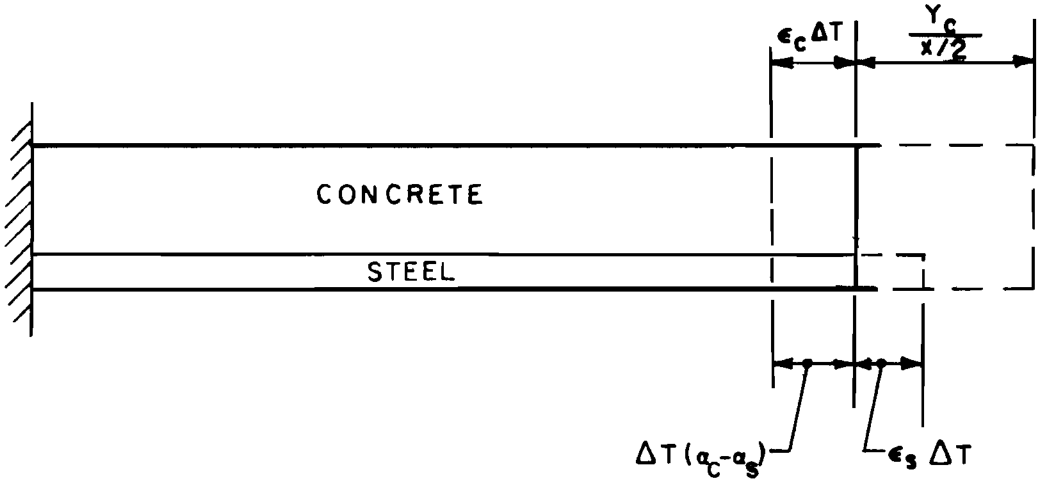
$$\sigma_{c\Delta T} = \Delta T(\alpha_c - \alpha_s)\ Ec + \frac{\sigma_{s\Delta T}}{n} \qquad (4.7)$$



(a) Undisturbed state



(b) Contraction due to ΔT with complete slippage between concrete and steel. No restriction condition



(c) Contraction due to ΔT with no slippage between concrete and steel.

Fig 4.5. Reinforced element subjected to uniform temperature drop ΔT.

where

$\sigma_{c\Delta T}$ = stress in the concrete due to ΔT (psi),

$\sigma_{s\Delta T}$ = stress in the steel due to ΔT (psi).

If the principle of superimposition is applied to the concrete and steel stresses due to Z and ΔT, the total stress can be predicted as follows:

$$\sigma_c = \sigma_{cz} + \sigma_{c\Delta T}$$

$$\sigma_s = \sigma_{sz} + \sigma_{s\Delta T}$$

Substituting the values of σ_{cz} and $\sigma_{c\Delta T}$ from Eqs 4.5 and 4.7,

$$\sigma_c = \frac{\sigma_s}{n} + E_c[Z + \Delta T(\alpha_c - \alpha_s)] \qquad (4.8)$$

Equation 4.8 represents the effects of shrinkage and drop in temperature in the concrete slab.

(3) Friction. When a concrete slab contracts due to loss in moisture and drop in temperature, the local movement of the slab increases from zero at the geometric center of the slab to a maximum at the edges as shown in Fig 4.6. This movement, if restrained, will produce stresses in the slab as happens when the base friction acts. The stresses produced in the slab by the base restraint will decrease from a maximum at the geometric center of the slab to zero at the free edges. Therefore, tensile stresses will be generated by this restraint to the slab, increasing the tensile stresses created by the reinforcing steel which also restrains the contraction of the concrete.

The frictional resistance increases with movement; therefore, its effect should be represented by the complete curve defining the friction-movement relationship. Considering the free body diagram of a slab element of length dx, which experiences a movement Y_c and a corresponding friction force F_i (Fig 4.7), then $\Sigma Fx = 0$ gives

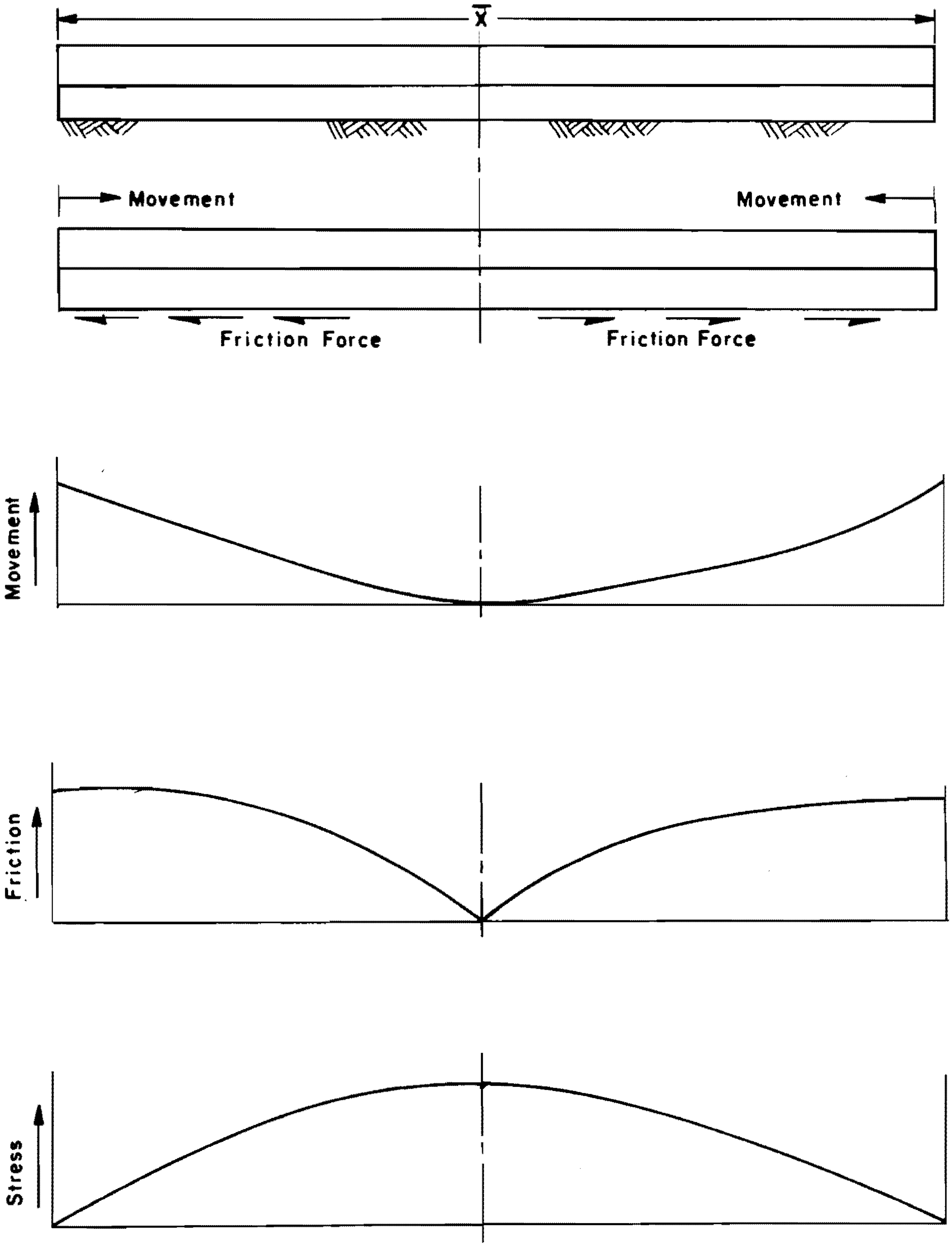
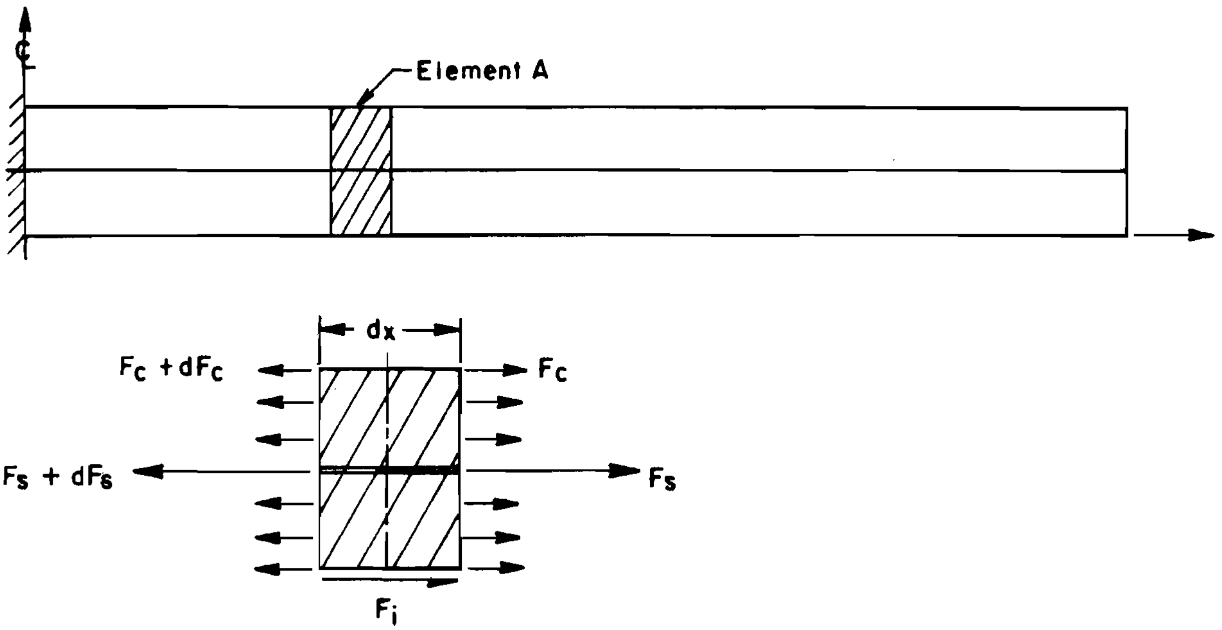
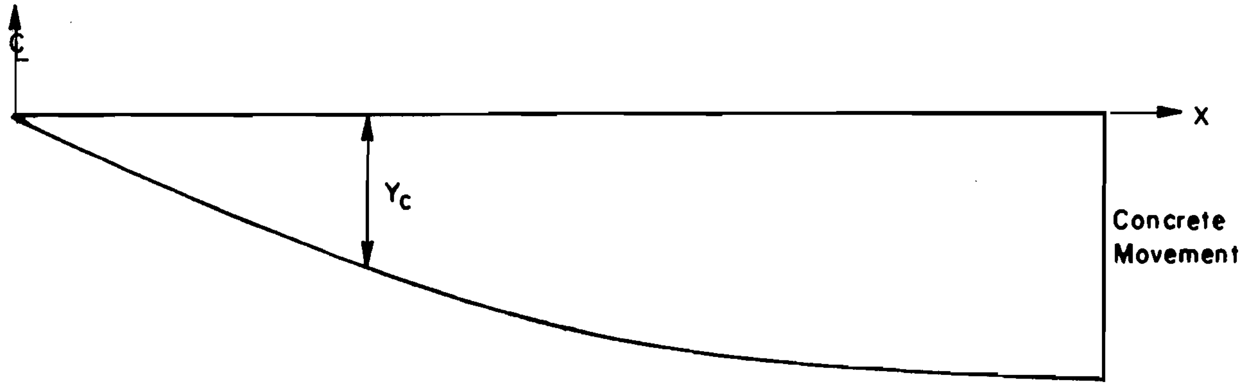


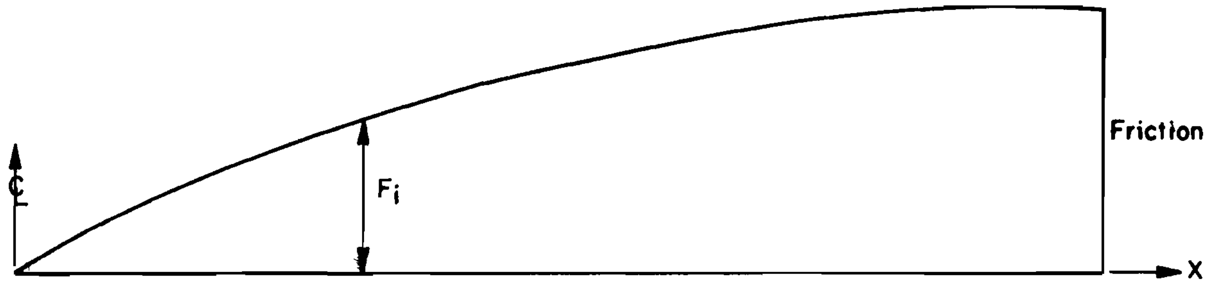
Fig 4.6 Effect of the restraint provided by the subbase on a concrete slab.



(a) Free body diagram of element A.



(b) Concrete movement



(c) Frictional resistance

Fig. 4.7. Free body diagram of an element in Model-1.

$$dFc + dFs = -Fi'dx$$

or expressed into a stress equation:

$$A_c d\sigma_c + A_s d\sigma_s = -F'_i dx$$

$$d\sigma_c + pd\sigma_s = -\frac{F_i}{D} dx \qquad (4.9)$$

but from Eq. 4.8 and since material properties are assumed to be independent of space (assumption 7) we conclude:

$$\sigma_c = \frac{\sigma_s}{n} + E_c[Z + \Delta T(\alpha_c - \alpha_s)] \qquad (4.8)$$

Differentiating, with respect to x,

$$\frac{d\sigma_c}{dx} = \frac{d\sigma_s}{dx} \times \frac{1}{n} + 0$$

and solving for $d\sigma_s$

$$d\sigma_s = nd\sigma_c \qquad (4.10)$$

Substituting into equation 4.9

$$d\sigma_c + pnd\sigma_c = \frac{F_i dx}{D}$$

$$\frac{d\sigma_c}{dx} = \frac{F_i}{D} \frac{1}{(1 + pn)} \qquad (4.11)$$

With equation 4.11, the inclusion of the friction forces into the generalized system of equations is possible.

Equation 4.11 shows the concrete stress changes at a rate along the slab, which is a function of the frictional resistance between the base and the slab.

(4) Movement of Concrete. The local movements of the slab are required in order to compute the frictional resistance. As pointed out before, different points along the slab will experience different movements which go from a maximum value at the free edges to zero at the geometric center of the slab.

The slab movement can be obtained when superimposing the movements due to shrinkage and drop in temperature as follows:

for shrinkage:

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

Integrating:

$$Y_{cz} = \int_o^x \epsilon_{cz}\, dx - Zx + k_1 \tag{4.12}$$

for temperature:

$$\frac{d\, Y_{c\Delta T}}{dx} = \epsilon_{c\Delta T} - \alpha_c \Delta T$$

Intergrating:

$$Y_{c\Delta T} = \int_o^x \epsilon_{c\Delta T} - \alpha_c \Delta Tx + k_2 \tag{4.13}$$

Thus,

$$Y_c = Y_{c\Delta T} + Y_{cz} \tag{4.14}$$

where

Y_{cz} = concrete movement due to shrinkage (inches)

$Y_{c\triangle T}$ concrete movement due to drop in temperature (inches)

Y_c = total concrete movement at the joint due to Z and $\triangle T$ (inches), and

k_1, k_2 = constants of integration.

Then, from 4.12, 4.13, and 4.14

$$Yc = \int_o^x \epsilon_{c\triangle T}\, dx - \alpha_c \triangle T x + \int_o^x \epsilon_{cz} dx - Zx + k_2 + k_1$$

If

$$\epsilon_c = \epsilon_{c\triangle T} + \epsilon_{cz}$$

$$k_3 = k_2 + k_1$$

then

$$Y_c = \int_o^x \epsilon_c dx - (Z + \alpha_c \triangle T)x + K_3$$

But at $x = 0$, $Y_c = 0$.

Therefore,

$$Y_c = \int_o^x \epsilon_c dx - (Z + \alpha_c \triangle T)\, x \qquad (4.15)$$

or if expressed into a stress equation,

$$Y_c = \int_o^x \frac{\sigma_c}{E_c}\, dx - (Z + \alpha_c \triangle T)\, x \qquad (4.16)$$

(5) Joint Width. From equation 4.15, it is possible to evaluate the joint width, by integrating at $x = \frac{\bar{x}}{2}$ as follows:

$$Y_j = \int_o^{\frac{\bar{x}}{2}} \frac{\sigma_c}{E_c} dx - (Z + \alpha_c \Delta T)x$$

But Y_c will be the concrete movement of one half of the slab, thus if ΔX is the joint width, it can be written that

$$\Delta X_j = 2 Y_c = 2\left(\frac{\sigma_c}{E_c} \frac{\bar{x}}{2} - (Z + \alpha_c \Delta T) \frac{\bar{x}}{2}\right)$$

$$\Delta X_j = \bar{x} \left[\frac{\sigma_c}{E_c} - (Z + \alpha_c \Delta T)\right] \tag{4.17}$$

where

ΔX = joint width (inches), and

$\bar{x}$ = total length of the slab (inches).

It is very important to know the width of a joint, because limiting it to a maximum value that will provide load transfer and avoid percolation, the design of the required steel percentage to produce that condition can be determined using a trail and error procedure.

With the equations previously developed, Model-1 can be solved for stresses, strains, movements and joint width, but these equations are not sufficient enough to solve Model-2 which is required after the first crack occurs.

Basic Equations for Model-2

After the first crack occurs, Model-1 will change into Model-1 plus Model-2, because the portion of the slab going from the crack to the free end will have one end with longitudinal steel in the crack resisting and the other end free. A problem of bond development length is present at the crack, because the steel requires some finite length to transmit the stress to the concrete. Both ends will contract, but the one with the steel, in a fixed condition, will have more restraint. Consequently, the point of zero movement will be more towards the crack side as represented in Fig 4.8.

From Fig 4.9 the need for Model-2, that consists of a portion of the slab with a fixed end can be seen. The boundary conditions for Model-2 are similar to the model developed in Ref 7 to solve a continuously reinforced concrete pavement.

The basic equations for Model-1 are also useful for this model taking into account the signs, but they are not sufficient to solve the problem. As previously discussed, the steel stress at the crack will be transmitted to the concrete through a development length or a bond slip length. The steel at the crack is under considerable tension since the concrete provides no resistance. However, beyond the crack, the concrete does resist moderate amounts of tension stresses, reducing the tensile forces in the steel, creating a variable force in the bar. From this, it can be seen that an equation for this bond slip zone is needed.

Bond Slip Zone Equation. Since the steel bar must be in equilibrium, the change in bar force is resisted at the contact surface between concrete and steel. From the free body diagram in Fig 4.10 for the steel bar, $\Sigma F_x = 0$ yields:

$$F_s - (F_s + dF_s) + Udx = 0$$

where

U = average bond force per unit length of the slab.

Therefore:

$$\frac{dF_s}{dx} = U \qquad (4.18)$$

Since

$$U = \mu \, \Sigma_o \qquad (4.19)$$

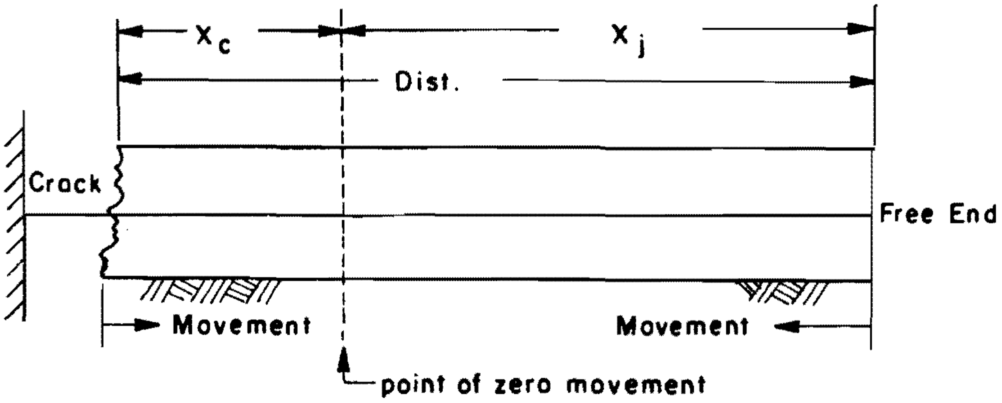


Fig 4.8. Behavior of the slab after the first crack.

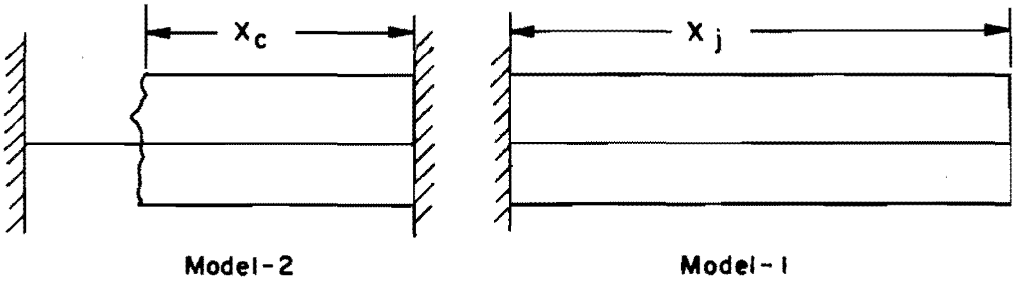


Fig 4.9. Geometric models needed to search for the second crack.

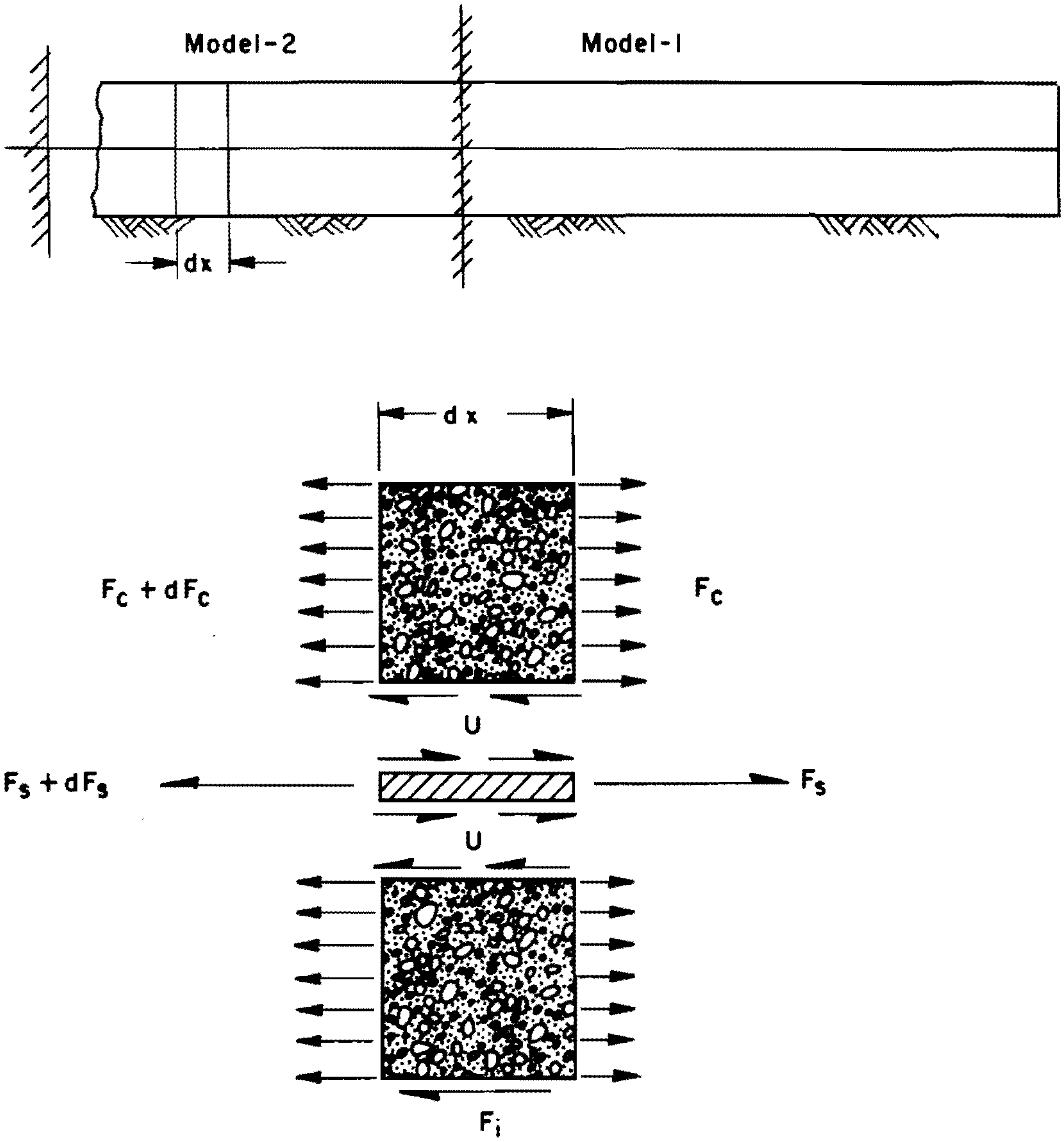


Fig. 4.10. Free body diagram of an element in the bond slip zone of Model-2.

where

μ = bond stress; $\mu = \dfrac{9.5\sqrt{f'_c}}{\phi}$,

f'_c = compressive strength of concrete,

Σ_o = perimeter of the bar(s).

ϕ = bar diameter.

Substituting the value of U from Eq 4.19 into Eq 4.18

$$\frac{dFs}{dx} = \mu \Sigma o \qquad (4.20)$$

and transforming equation 4.20 to a stress equation using

$$Fs = \sigma_s A_s$$

yields

$$A_s \frac{d\sigma s}{dx} = \mu \Sigma o$$

and

$$\frac{d\sigma_s}{dx} = \frac{\mu \Sigma o}{As}$$

Since

$$A_s = \frac{\pi\phi^2}{4}$$

and

$$\Sigma_o = \pi\phi$$

then

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

Therefore:

$$\frac{d\sigma_s}{dx} = \frac{4\mu}{\phi} \tag{4.21}$$

For a constant bond stress μ, the variation of the distribution of steel stress in the bond slip zone is linear. The slope in the concrete stress curve in the bond slip zone also depends on the bond properties; then, if $\Sigma F_x = 0$ is applied to the concrete element in Fig 4.10, the following is obtained:

$$F_c - (F_c + dF_c) - F_i'dx - Udx = 0$$

$$dF_c + F_i'dx + Udx = 0$$

$$dF_c = -F_i'dx - Udx$$

$$\frac{dF_c}{dx} = -F_i' - U$$

Since

$$p = \frac{A_s}{A_c} \text{ and } \sigma_c = \frac{F_c}{A_c}$$

then

$$\frac{d\sigma_c}{dx} . A_c = -F_i' - \mu\Sigma_o$$

$$\frac{d\sigma_c}{dx} = \frac{F_i'}{A_c} - \frac{\mu p\Sigma_o}{A_s}$$

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

$$\frac{d\sigma_c}{dx} = \frac{-F_i'}{A_c} - \frac{4\mu p}{\phi}$$

For a unit width slab $Ac = D \times 1$, then

$$\frac{d\sigma_c}{dx} = -\frac{F_i}{D} - \frac{4\mu p}{\phi} \qquad (4.22)$$

The shape of the concrete stress curve can be linear if the maximum frictional resistance force is developed, because the slope of that curve is a function of bond as well as bond properties as can be seen in Eq 4.22.

Also, the general equilibrium for Model-2 is different than the one for Model-1, because of the steel being fixed at one end of the slab. Figure 4.11 shows the free-body diagram for Model-2, and solving for equilibrium of the system, $\Sigma Fx = 0$ yields

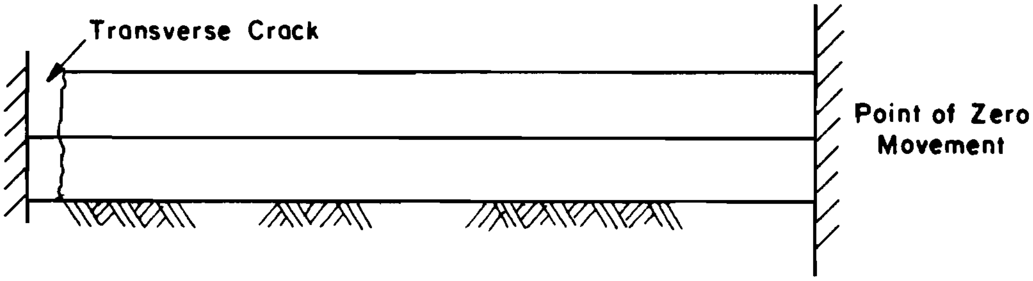
$$F_{so} + F_{co} - F_{sc} - \int_o^{x_c} F_i' dx = 0 \qquad (4.23)$$

where

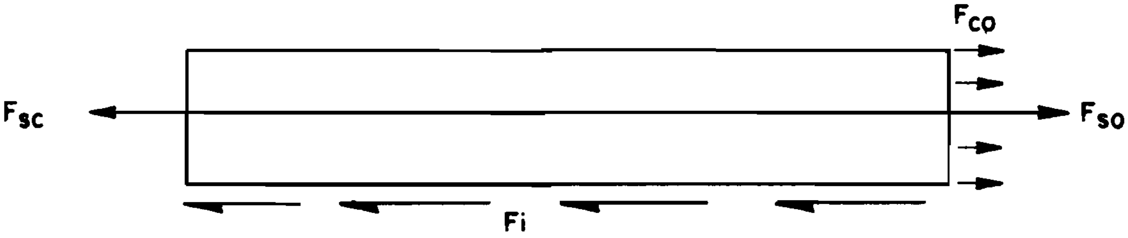
F_{so} = force in the steel at point of zero movement (lb),
F_{co} = force in the concrete at point of zero movement (lb),
F_{sc} = force in the steel at the crack (lb), and
F_i = friction force per unit length along the slab (lb/in).

Transforming Eq 4.23 to a stress equation,

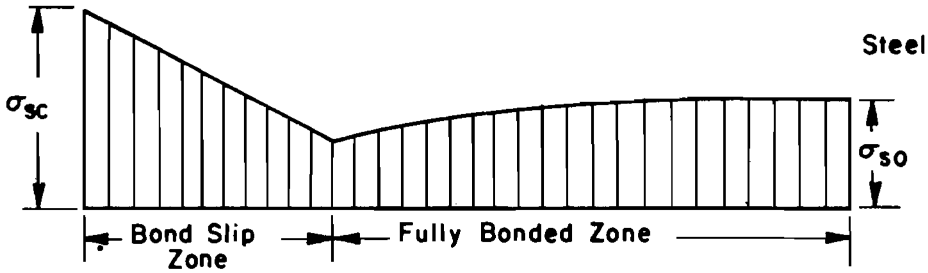
$$A_s\sigma_{so} + A_c\sigma_{co} - A_s\sigma_{sc} - \int_o^{x} F_i' dx = 0 \qquad (4.24)$$



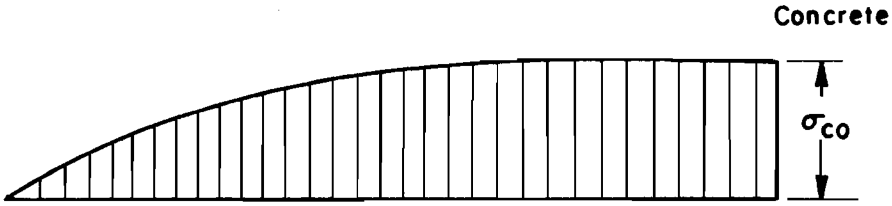
(a) Model-2



(b) Free body diagram of Model-2



(c) Stress distribution in steel



(d) Stress distribution in concrete

Fig 4.11. Free-body diagram and corresponding stress distribution of Model-2.

and for a unit width slab

$$p\sigma_{so} + \sigma_{co} - p\sigma_{sc} - \frac{\int_o^x Fidx}{D} = 0$$

or

$$\sigma_{co} + p\sigma_{so} = p\sigma_{sc} + \frac{\int_o^x Fidx}{D} \tag{4.25}$$

At transverse cracks, local lateral movement will not be experienced by the steel. This means that the length of the steel bars will remain constant with temperature changes, then,

$$\epsilon_s = \alpha_s \Delta T$$

for x ,

$$\int_o^a \epsilon_s dx = \alpha_s a \Delta T$$

$$\int_a^b \epsilon_s dx = \alpha_s b \Delta T$$

where

X_c = the distance between the first crack and the point of zero movement.

Since

$$X_c = a + b$$

substituting for a + b,

$$\int_o^a \epsilon_s dx + \int_a^b \epsilon_s dx = \alpha_s \Delta T X_c$$

and

$$\sigma_s = \epsilon_s . E_s$$

therefore

$$\int_o^a \sigma_s dx + \int_a^b \sigma_s dx = E_s \alpha_s X_c T \tag{4.26}$$

where

a = fully bonded length of X_c ,
b = bond slip zone.

Summary of Equations

A summary of equations for each model follows to clarify for the reader which equations apply to each model:

Model-1:

(1) Equilibrium

$$\sigma_c + p\sigma_s - \frac{\int_o^x F_i dx}{D} = 0 \tag{4.3}$$

(2) Concrete stress due to shrinkage and drop in temperature

$$\sigma_c = \frac{\sigma_s}{n} + E_c \left[Z + \Delta T(\alpha c - \alpha s) \right] \tag{4.8}$$

(3) Friction

$$\frac{d\sigma_c}{dx} = \frac{-F_i}{D} \times \frac{1}{(1+pn)} \tag{4.11}$$

(4) Concrete movement at joint

$$Y_c = \int_o^x \frac{\sigma_c}{E_c} dx - (Z + \alpha c\Delta T)x \qquad (4.16)$$

(5) Joint width

$$\Delta X_j = x\left[\frac{\sigma_c}{E_c} - (Z + \alpha c\Delta T)\right] \qquad (4.17)$$

Model-2:

(1) Equilibrium

$$\sigma_{co} + p\sigma_{so} - p\sigma_{sc} + \frac{\int_o^x F_i dx}{D} \qquad (4.25)$$

(2) Concrete stress due to shrinkage and drop in temperature,

$$\sigma_c = \frac{\sigma_s}{n} + E_c[Z + \Delta T\ (\alpha_c - \alpha s)] \qquad (4.8)$$

(3) Friction,

$$\frac{d\sigma_c}{dx} = -\frac{F_i}{D} \times \frac{1}{(1+pn)} \qquad (4.11)$$

(4) Crack width

$$\Delta X_c = 2\left[\int_o^{x_c} \frac{\sigma_c}{E_c} dx - (Z + \alpha_c \Delta T)\ X_c\right]$$

(5) Steel boundary conditions

$$\int_o^a \sigma_s dx + \int_a^b \sigma_s dx = E_s \alpha_s X_c \Delta T \qquad (4.26)$$

The Approach

The work done in Research Project NCHRP 1-15 (Ref 7) reduced the degree of difficulty in solving this problem. The mathematical model developed in the above research project corresponds to the Model-2 and makes the solution of this work less problematic.

The first step in solving this problem is to search for the time and slab position at which the crack will occur. The approach used will be to divide the slab length into N number of increments and solve the basic equation for Model-1 (N/2) times for a fixed time and change the length of the model by adding one ΔX to the previous one for each new cycle, as illustrated in Fig 4.12. This means that for a given time, the concrete stress-distance relationship will be known and will change with time as shown in Fig 4.13.

To know if cracking of the slab is going to occur, the concrete stress-distance relationship for each time is equated to the concrete strength at the corresponding time. The remaining equation is solved for distance, and this distance is compared with $\bar{x}/2$ and if it is equal or less, a crack is going to occur. If the distance is greater than $\bar{x}/2$, there will be no crack.

If a crack does occur, say at time t_1 , then the problem changes into a different one, because now the slab will have only the steel at the crack. This steel bar takes all the tensile stresses generated at that point, and then throughout the bond-slip zone, the concrete receives part of the total tensile stresses. Due to shrinkage and temperature drop, this portion of the slab will tend to contract. The restraint to the movement of contraction at the free end will be provided by the friction resistance between slab and base, and by the reinforcing steel. At the other end, that is where the first crack occurred, the same restrictions as for the other end apply plus the restriction given by the steel that is fixed to the other face of the crack as shown in Fig 4.14.

It is obvious that the solution for the second crack is not possible to achieve by using one model. The approach to find the solution is to solve Model-1 and Model-2 separately for the time which follows the occurrence of the first crack. Then find the corresponding curves for each model of the concrete stress-distance relationship (Fig 4.15a) and then find the

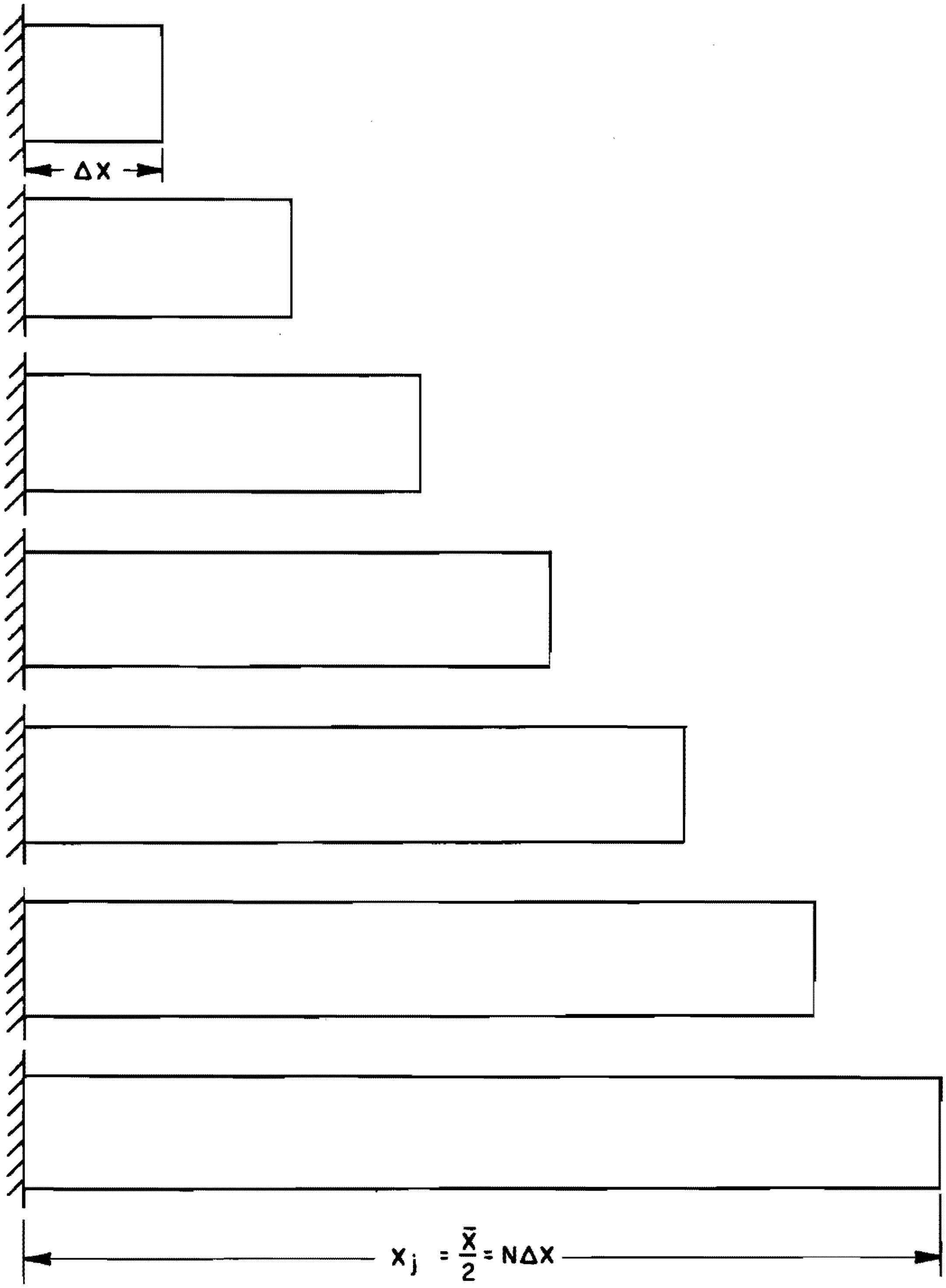


Fig. 4.12. Change in length of the model, increasing ΔX by ΔX each time.

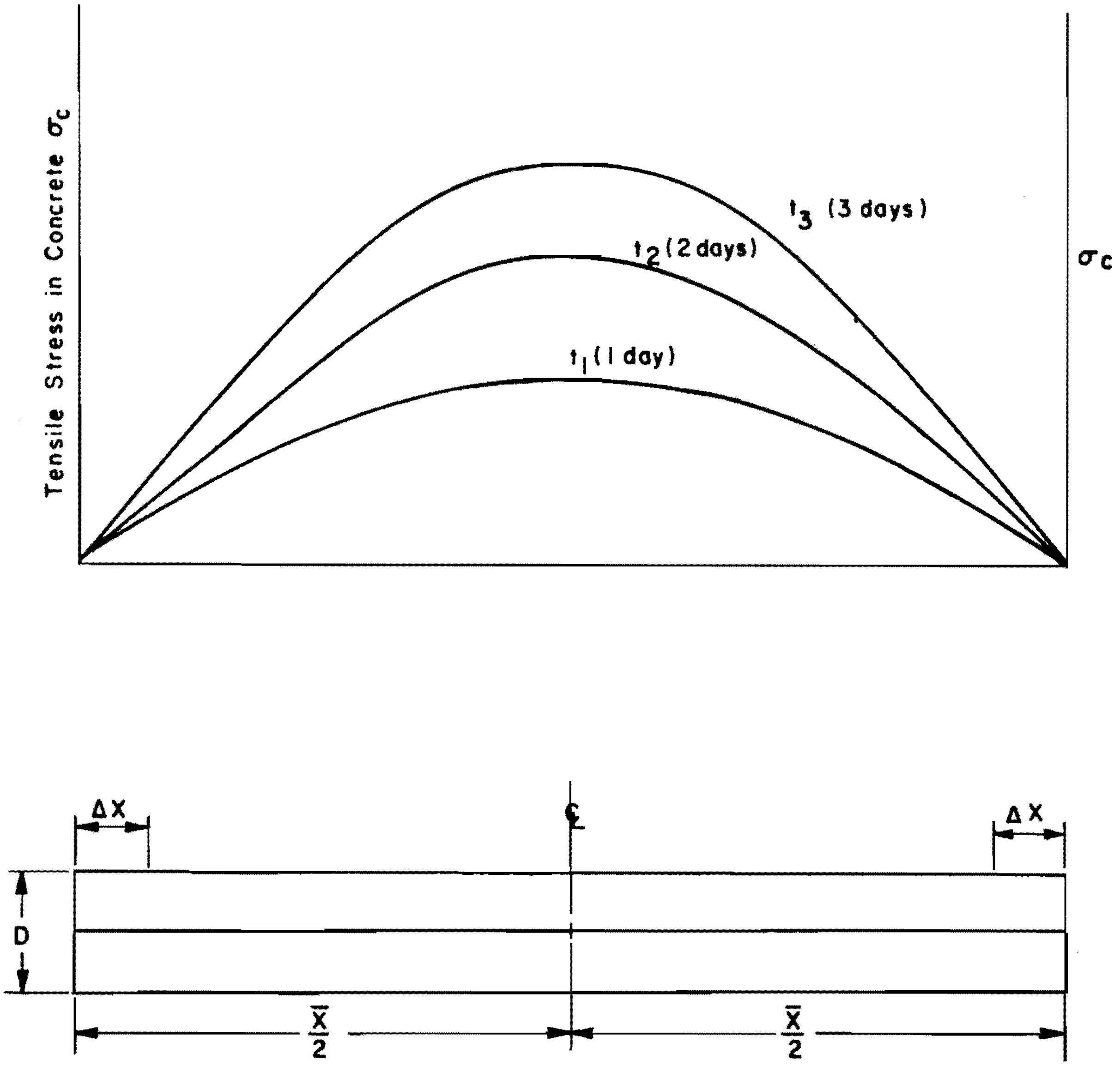
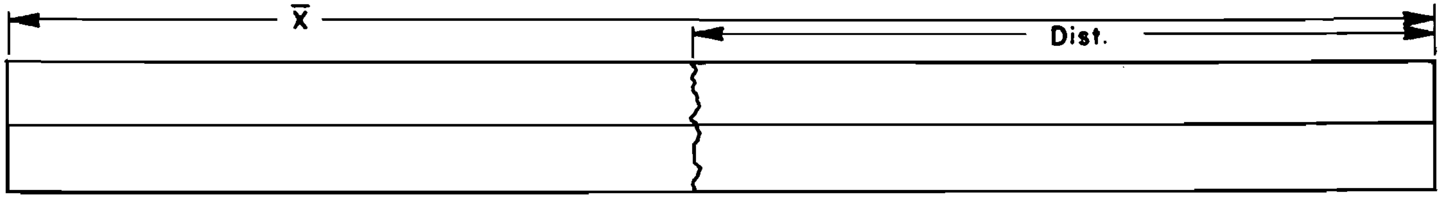
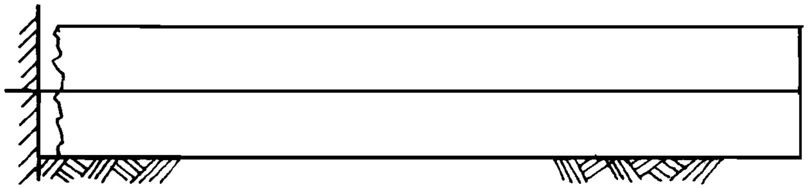


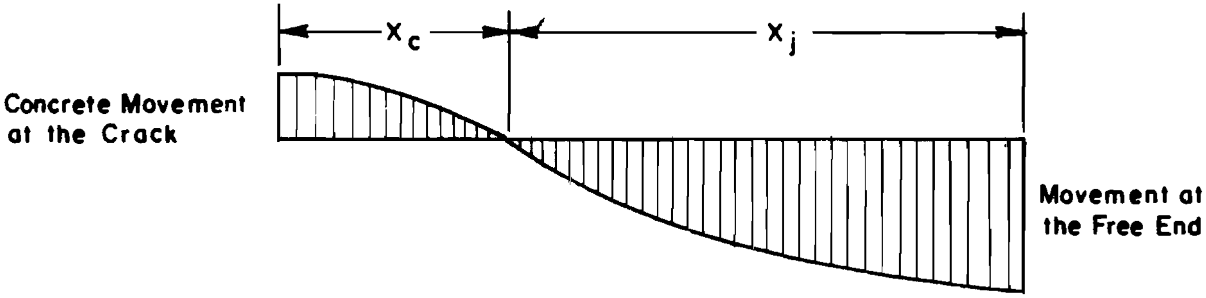
Fig 4.13. Concrete stresses with time.



(a) View of slab after first crack.

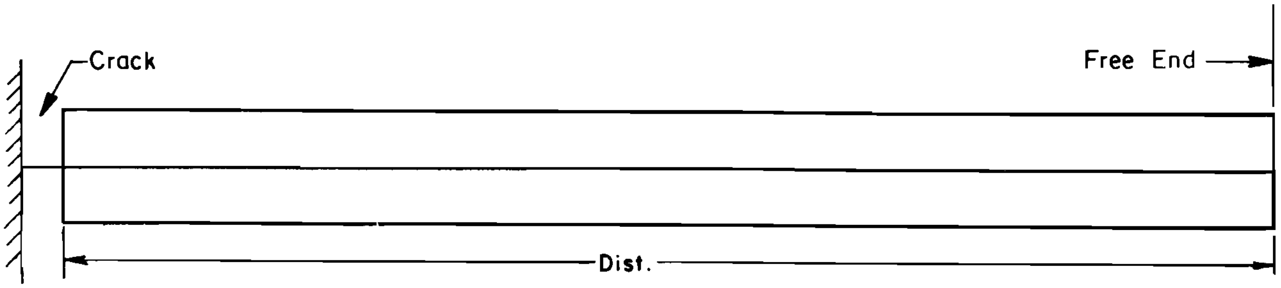


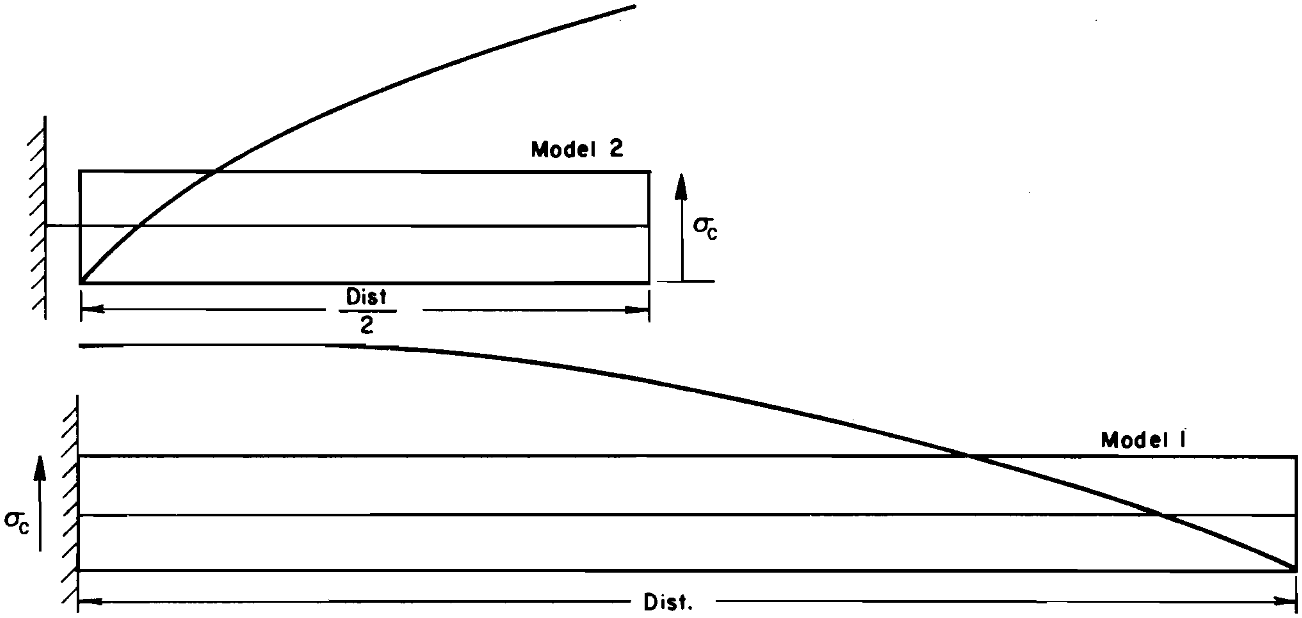
(b) Right portion of slab after first crack



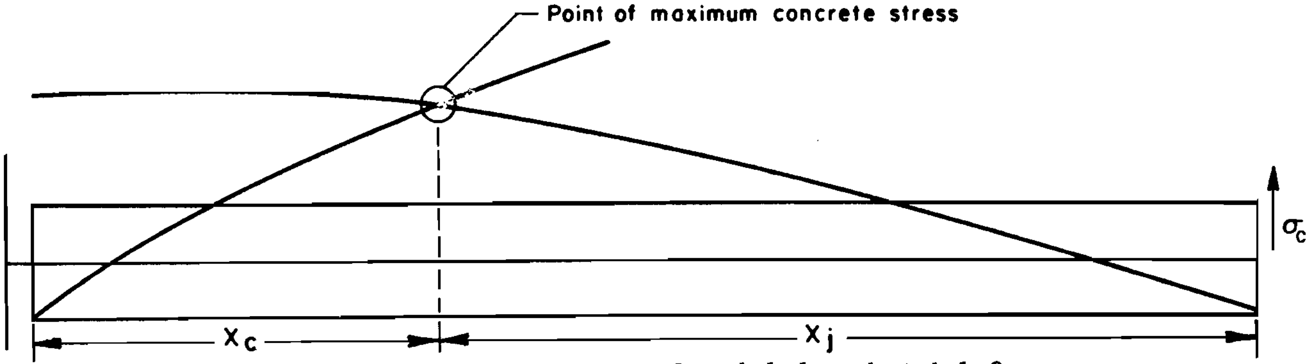
(c) Contraction movement of slab portion

Fig. 4.14. Slab portion after first crack.





Concrete stress-distance curves for Model-1 and Model-2.



Intersection of curves of Model-1 and Model-2.

Fig. 4.15. Method used to search for the second crack.

intersection point of the two curves. Now, the maximum concrete stress can be found that will correspond to the point of zero movement (Fig 4.15b). A crack can be detected by comparing the maximum stress with the concrete tensile strength at the same time.

SOLUTION OF THE BASIC EQUATIONS

As the primary purpose of this work is to search for cracks in jointed reinforced concrete pavement slabs, knowing that a crack is going to occur if the concrete tensile stress is greater than the concrete tensile strength, the equations will be solved first for the stress in the concrete as follows:

Model-1

Solving Eq 4.8 for σ_s yields

$$\sigma_s = n\sigma_c - nE_c[Z + \Delta T(\alpha_c - \alpha_s)]$$

and substituting σ_s into Eq 4.3 yields

$$\sigma_c + pn\sigma_c - pnE_c[Z + \Delta T(\alpha_c - \alpha_s)] - \frac{\int_o^x F_i dx}{D} = 0$$

Solving for σ_c

$$\sigma_c(1 + pn) = pnE\,[Z + \Delta T(\alpha_c - \alpha_s)] + \frac{\int_o^x F_i dx}{D}$$

$$\sigma_c = \frac{pnE_c[Z + \Delta T(\alpha_c - \alpha_s)] + \frac{\int_o^x F_i dx}{D}}{[1 + pn]} \qquad (4.27)$$

Using the friction-movement relationship provided by the user, and using Eq 4.16, the friction force can be obtained, thus Eq 4.27 can be solved. An iterative procedure must be used, because the concrete movement is a direct function of the concrete stress, and the concrete stress is dependent on the friction force. Using the findings from Research Project NCHRP 1-15, this problem was solved by using a binary search technique by which the concrete stress is computed by assuming $F_1 = 0$ and then the concrete movement Y_1 is computed using that concrete stress. Movement Y_1 is then used to determine F_s from the experimental curve, with F_2 being the upper boundary. The basic equation is again solved for concrete stress using F_2 and computing the concrete movement Y_2, which will correspond to F_3, the lower boundary, from the experimental curve. Now, F_4 will be the arithmetical average of F_3 and F_2. To determine the relative location of F_4 with respect to the closure point, Y_4 is computed and compared with the experimental Y_{4e} that corresponds to F_4. If Y_4 is greater than Y_{4e}, then F_4 to find F_5, and if Y_{4e} is greater than Y_4, then F_4 is above the closure point, and then F_5 will be the average of F_3 and F_4, and continue to relative closure (Fig 4.16).

Then the values of σ_c and F_i corresponding to the friction-movement closure point are used to compute the stress in the steel by using the following equation:

$$\sigma_s = \frac{\int_o^x F_i dx}{pD} - \frac{\sigma_c}{p} \tag{4.28}$$

With the above information, Model-1 is solved for any point along the slab.

The method of attack to search for a crack consists of the following steps:

(1) Divide the total slab length into N number of increments to have an increment length equal to $\Delta X = \bar{x}/N$,

(2) for a given time, solve Model-1 for a distance equal to ΔX, the increment length

(3) increment the Model-1 length into another ΔX and solve for σ_c and σ_s,

(4) continue incrementing ΔX by one ΔX and compute σ_c and σ_s until ΔX is equal to half the total slab length,

(5) having the stress in the concrete for each ΔX, an equation relating σ_c = f(distance) is computed,

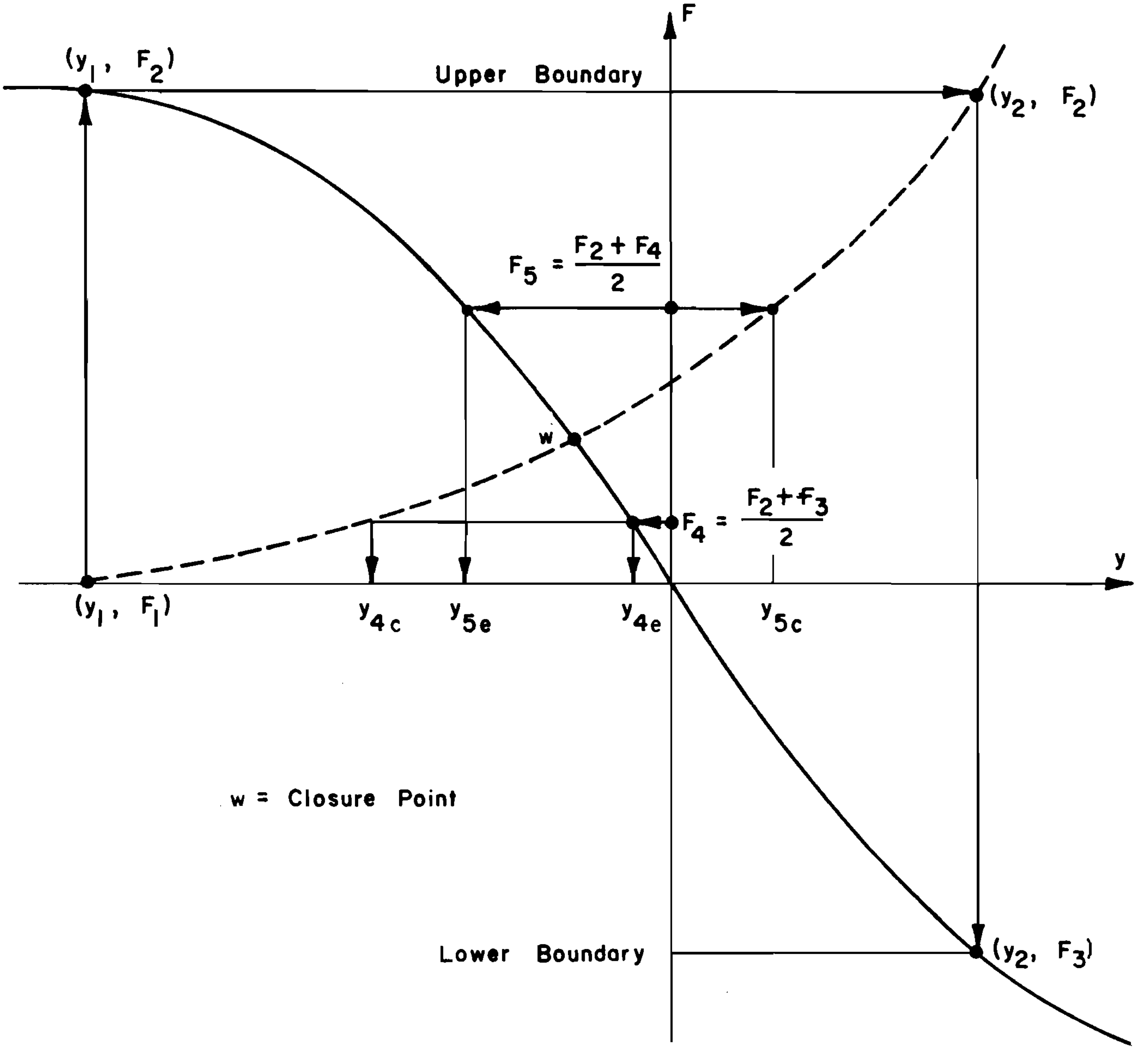


Fig. 4.16. Binary search technique as applied to frictional resistance-movement curve.

(6) substitute the value of σ_c in the above equation by the concrete strength f'_t at that time and find the corresponding distance, Dist = $f(f'_t)$, and

(7) if that distance is greater than half the slab length, no crack will occur at that time, but if the distance is less than or equal to half the slab length, then a crack occurs at that same distance.

This process is shown in the flow diagram in Fig 4.17.

Model-2

For information on how Model-2 is solved, the reader is referred to Ref 7 where a complete discussion and explanation of the solution of the Model-2 is given.

If the first crack occurs, say at time t7 , then, Model-1 is used as described above for time t8 , and Model-2 is also solved for that time t8 .

The solution of Model-2 is achieved by using the solution given by Research Project NCHRP 1-15 (Ref 7) to the CRCP model and is the same as for Model-2. The only variation is that the concrete stress is computed for each ΔX until ΔX is equal to half the length between the crack and the free end. At the end of each time, there will be a stress-distance relationship, and when intersected with the one for Model-1 at the same time (age), it will indicate the magnitude and location of the maximum concrete stress for that age, so that when compared with the concrete strength at the same age it will indicate if a second crack wll occur.

Combining Models 1 and 2

(1) Model-1 is solved for concrete stress at any point along the slab for one-half the slab length using the first five steps of the procedure described previously.

(2) Model-2 is solved for concrete stress at any point along the slab for one-fourth the slab length using procedure described in NCHRP 1-15 Report.

(3) The stress distance relationships from Models-1 and 2 are equated to find the point of zero movement. The distance point of intersection from the Model-1 relationship is designated as distance from joint to point of zero movement (x_j). The equivalent movement from Model-2 is designated as distance from crack to point of zero movement (x_c).

(4) The concrete stress at the point of equal movement is checked against the concrete strength at that time. If the concrete strength is exceeded, a crack is assumed at that point. Its width is computed and the procedure halts.

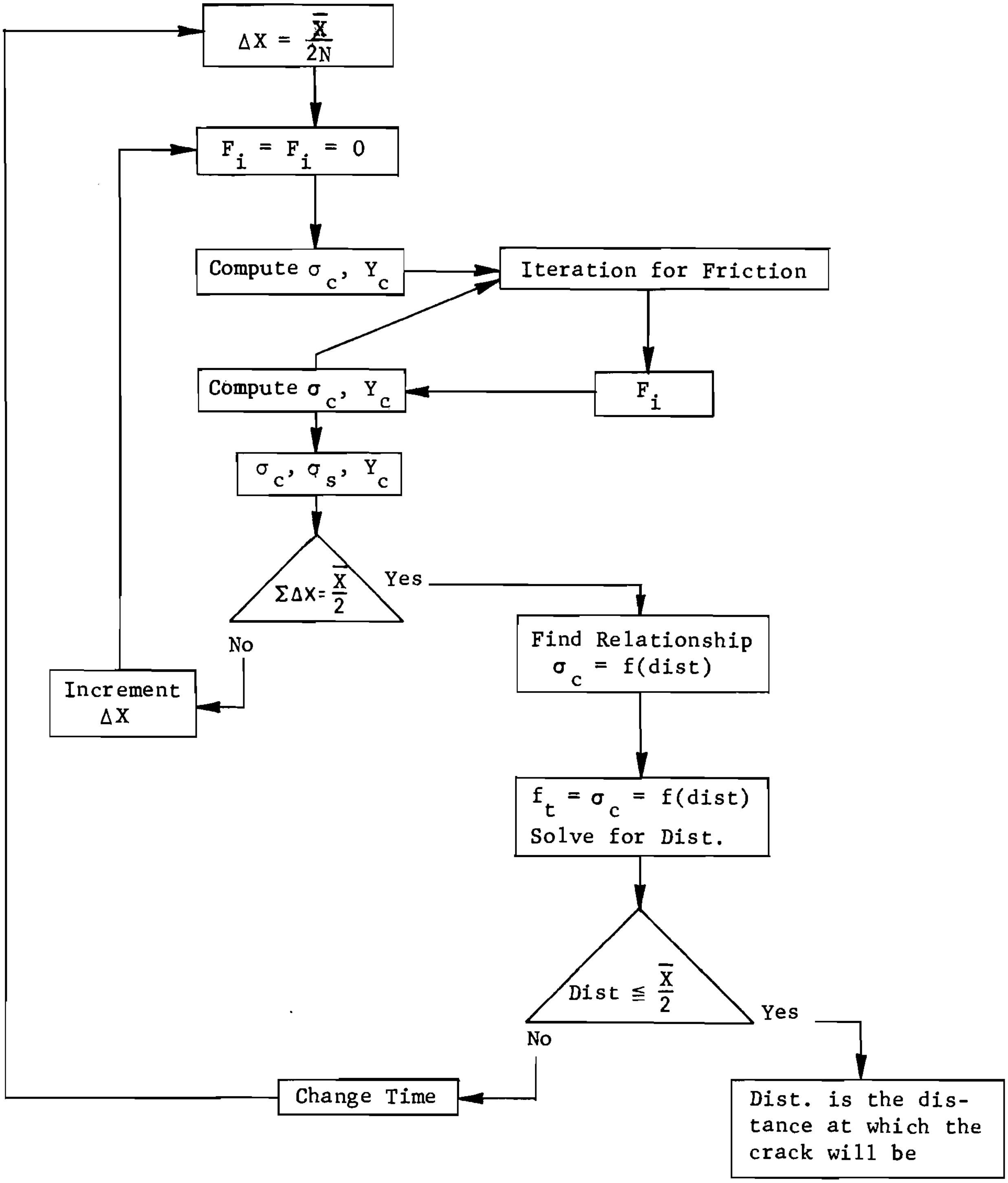


Fig. 4.17. Flow diagram for the search for the first crack.

(5) If the concrete strength is not exceeded at the point of zero movement, the time is incremented. This procedure continues until the concrete strength is exceeded, the concrete reaches full strength, or the steel stress at the first crack rises above a specified maximum.

If the concrete reaches full strength, the procedure is performed one more time using the minimum temperature expected for the area to test the stresses in the steel and concrete.

If the specified maximum (.75 X yield stress) is exceeded by the steel stress at the crack, a message is printed and the problem terminates.

STEEL DESIGN

The methods currently used to determine the percent reinforcement for the JRCP originated from several questionable assumptions and limitations, and the present pavements are having different performance problems. To explain and avoid the performance differences, a better qualitative evaluation is required.

The subgrade drag theory is the most recent approach in the solution of the reinforcing steel design, and because of that, the present work will use this method as a first approximation to find the steel percentage that will hold the cracks tightly together.

The process will be as follows:

(1) Compute steel percentage by subgrade drag theory (Ref 19).

$$p = \frac{LF}{2f_s} \times 100 \qquad (4.29)$$

where

p = percentage steel required (cross-sectional area) (percent),

L = distance between free edges (feet),

f_s = allowable working stress in steel (0.75 of yield strength),

F = friction factor of subbase.

(2) With the computed steel percentage, analyze the slab and search for a crack, and if a crack does not occur, remove the steel.

(3) If a crack occurs, check crack width, and if it is less than the maximum crack width, the steel design is checked for stress versus strength.

(4) If a crack occurs, check crack width, and if it is greater than the maximum crack width, the steel percentage is increased in half of its previous value and is checked again.

(5) If a crack occurs, and the crack width is within the range, the stress in the steel at the crack is checked for its allowable working strength, and if the stress is greater than its allowable working strength, the steel percentage is increased by half of its value and checked again.

Table 4.1 suggest values of the friction factor F for use in equation 4.28. When the steel percentage using the maximum crack width criteria is obtained, the steel spacing is computed by means of the following relationship (Ref 19):

$$Y = \frac{A_B}{D \times p} \times 100 \qquad (4.30)$$

where

p = percentage steel required,

D = slab thickness (inches),

A_B = cross-sectional area of steel bar or wire (square inches), and

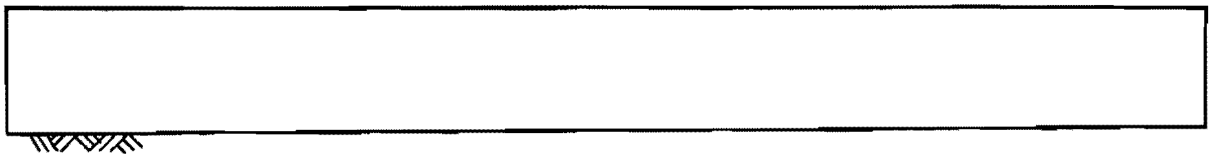
Y = center to center spacing (inches).

The procedure used can be explained as follows. Each time the slab length is divided into NT increments; for each increment the concrete and steel stresses are solved. At the completion of the study of half the slab length, a stress equation as a function of slab length is obtained by using the stress values of each increment. So, for each day there will be a stress-distance relationship. The concept used to search for a crack was to equate the stress equation with the value of the strength of the concrete at the same time; then, by solving the equation for distance, the distance at which the concrete stress is equal to the concrete strength is obtained, and if that distance is less than or equal to half of the slab length, a crack will occur at that distance; but, if the distance obtained is greater than half of the slab length, there will be no crack (Fig 4.18).

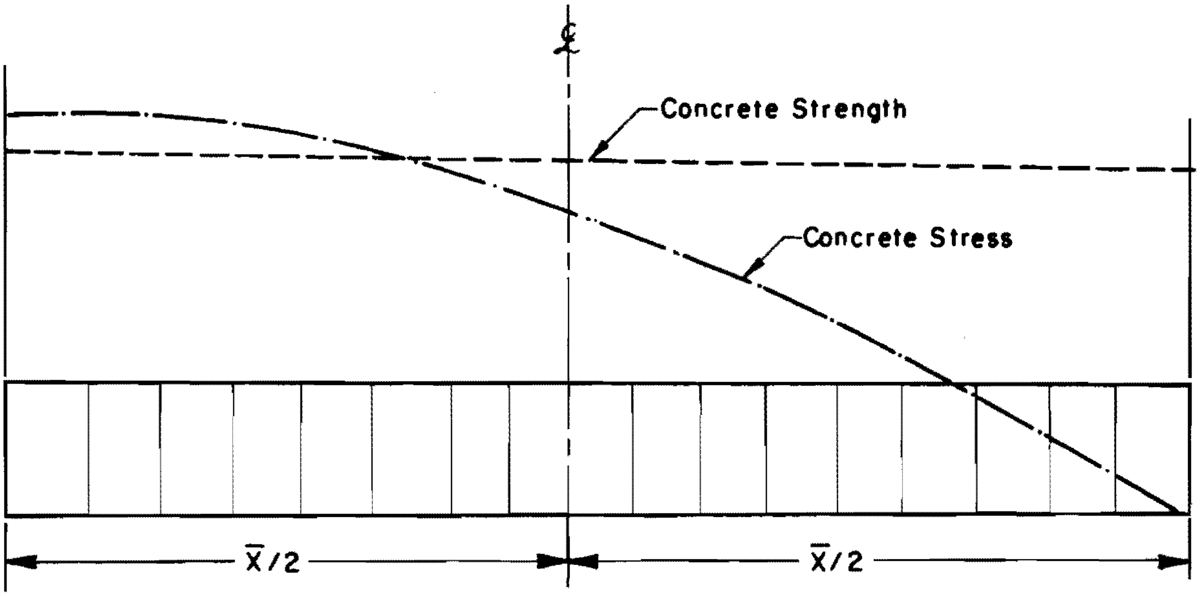
TABLE 4.1. RECOMMENDED FRICTION FACTORS (Ref 19).

Subbase Type	Subbase Friction Factor
Surface Treatment	2.2
Lime Stabilization	1.8
Asphalt Stabilization	1.8
Cement Stabilization	1.8
River Gravel	1.5
Crushed Stone	1.5
Sandstone	1.2
Natural Subgrade	0.9

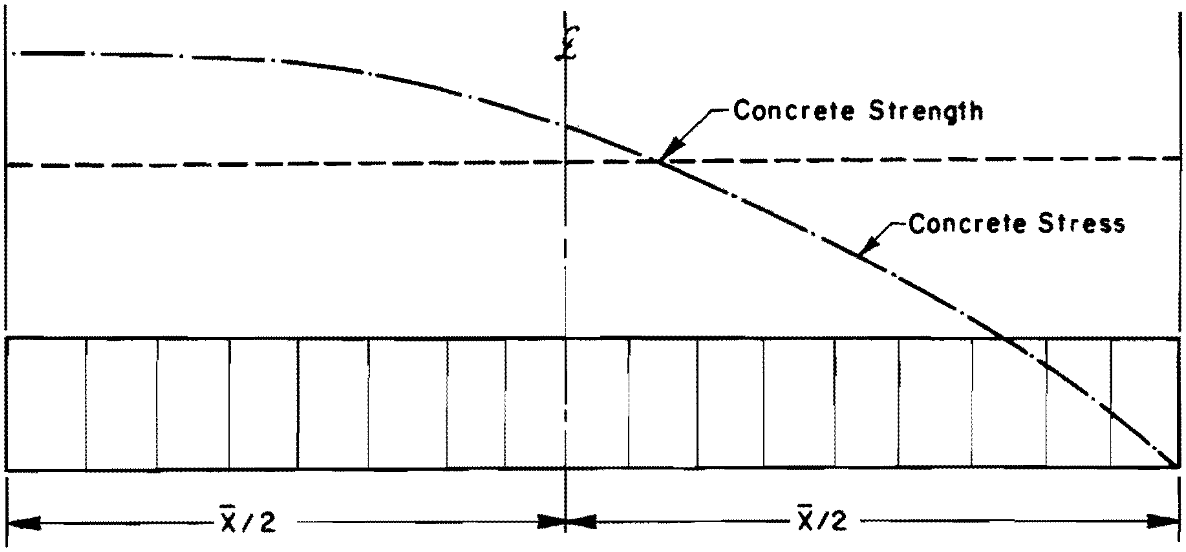
Note: These are approximate values derived from experimental observations. The friction factors in this table cannot be equated with the slab-base friction relationship required to properly characterize the restraint forces.



Initial State



Nonoccurence of Crack, Dist > $\bar{X}/2$



Crack Occurrence, Dist. ≤ $\bar{X}/2$

Fig. 4.18. Search for first crack.

If a crack occurs, the corresponding crack width is calculated and compared with a maximum allowable value of crack width*; when the crack width is within this range, the program will change to the Model-2 at the time when the first crack occurred; the stress in the steel is obtained and is checked against the steel strength, and if the stress is greater or equal to the allowable working strength, the steel percentage is increased and the analysis starts again. If the stress in the steel is less than its allowable working stress, the program continues searching for the second crack occurence for the following day. The solution for the second crack occurrence is achieved by solving Model-1 and Model-2, as previously discussed. At the intersection of these two curves, the value of the maximum concrete stress is obtained; then, by comparing this value with the concrete strength for that same time, it is possible to see if a second crack is going to appear, following the computation of the width of that second crack. If a second crack occurs, the crack width of this secon crack is checked by using the above procedure, and then the program is terminated. If either the first or second crack width is not within the range, the steel percentage will be changed, incrementing its value in P/2 if the crack width is greater than it maximum value, or reducing its value in P/2 if the crack width is less than 0.012 inch. Then the new design is analyzed again starting from day one. The program is finished when both the first and second crack widths are within the specified range and the stress in the steel at the crack is less than its allowable working strength.

NON-REINFORCEMENT DESIGN

For possibly obtaining a less expensive pavement slab, a design procedure for non-reinforced slabs was included in the program. This design procedure will give a slab length which will provide a non-cracked slab, which is the desired state of a non-reinforced pavement slab. In order to get a realistic design, the slab is analyzed at each time until the twenty-eighth day, and if for each of the days the concrete stress curve intersects the

---

*Maximum value for crack width is provided by the user.

concrete strength curve between 0.50 and 0.75 of the slab length, this slab length will be taken as optimum and is the one that will be given as the result (Fig 4.19).

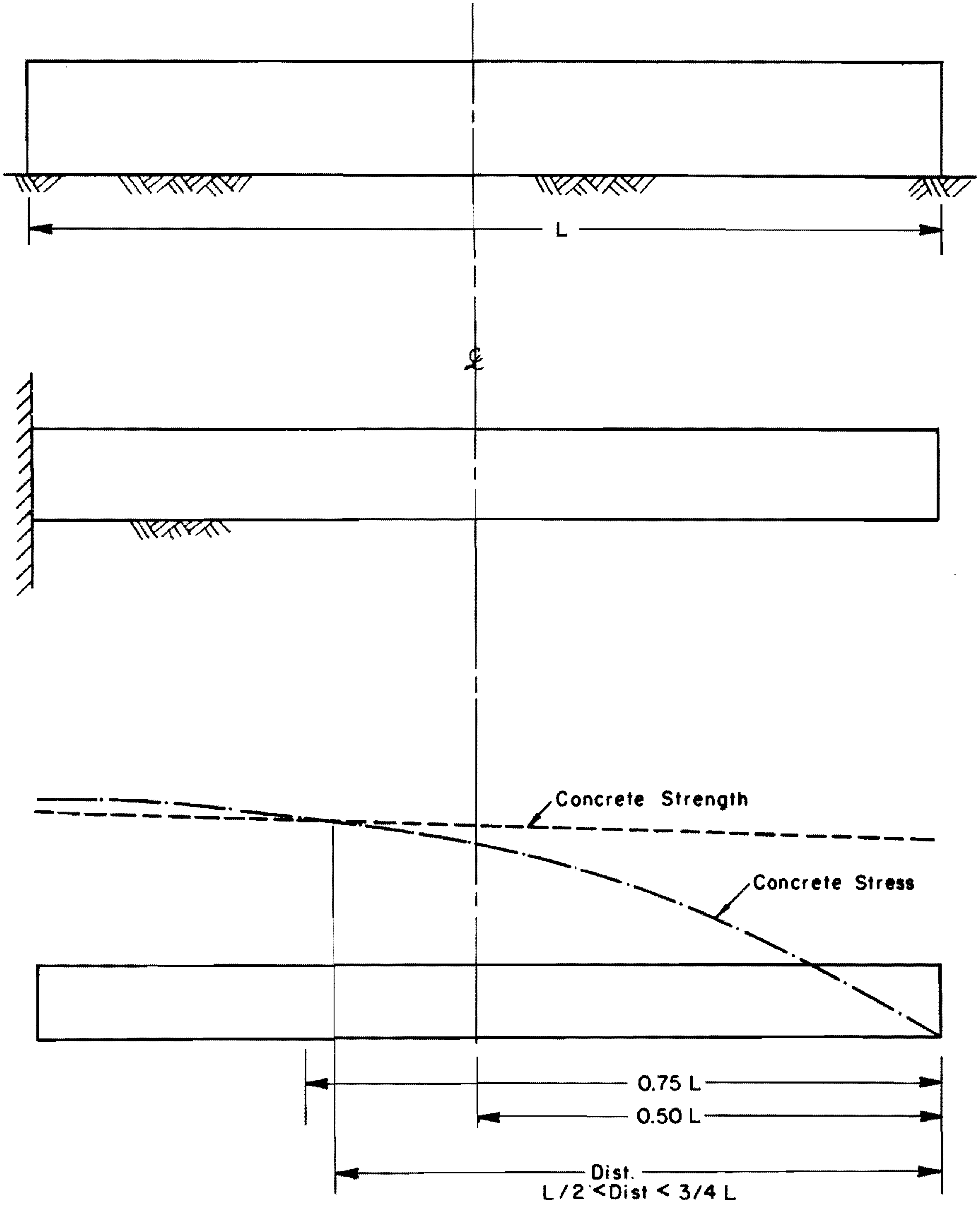


Fig 4.19. Criteria used for the non-reinforced slab design.

CHAPTER 5. REINFORCEMENT ANALYSIS PACKAGE

The computer program developed is designated by JRCP-1. The number 1 signifies that this is the first version of the chronological sequence intended for future development.

The program is written in FORTRAN IV computer language for the Control Data Corporation 6600 digital computer, which has a 60-bit word length. The compile time for the basic program is less than 12 seconds. If desired, normal operating decks may be compiled on binary cards, thus reducing compiler time in the computer significantly. The exact storage requirement for the program presently is 60,000 locations. The program can be adapted for use with the IBM 360/370 computer by very slight modifications.

The time required to run problems varies, of course, with the complexity of the system, e.g., the nature of the friction-movement relationship, the variation of the concrete strength with time, increment length, and the number of iterations required to obtain the desired accuracy and the option being used. To give a general idea of the operating time, for a relative closure tolerance of one percent and an average problem similar to the sample problems in the report, the computer time is in the range of 70 to 80 seconds for the steel design option. By considering the number of nonlinearities involved in the encountered problem it can be concluded that the algorithms developed in the various nonlinearities provide extremely fast convergence. The cost of seconds of computer time is negligible compared to the benefits derived from the fact that this computer program provides a new and better way of solving highly complex JRCP problems.

THE INPUT DATA

The format used for inputting data into the program is arranged as conveniently as possible. The problem input deck starts with two cover cards which identify the program and the particular run being made. The information on these cards is alphanumeric and is used to denote projects, coding dates, a description of the problems being run, etc. After these two alphanumeric cards the following cards come in this order:

(1) Problem number card with alphanumeric description of the problem.

(2) Slab Dimensions - one card. This card includes the length of the slab, the width of the slab, the friction factor used to compute the initial percent of steel, the maximum allowable crack width, the steel design option and the non-reinforcement option. The format and units used are fully described in the user's guide (Appendix 1). It is important to point out that even if the non-reinforcement option is used a slab length must be provided.

(3) Steel Properties - one card. Information on this card includes the type of longitudinal reinforcement, bar diameter, yield stress, modulus of elasticity, thermal coefficient, and spacing of transverse wires in the case of deformed wire fabric. The format used to input the required information is shown in the Guide for Data Input in Appendix 1.

(4) Concrete Properties - two or more cards. The first card contains the slab thickness, thermal coefficient, final or total drying shrinkage, unit weight, and 28-day compressive strength. On the second card is Age-Tensile Strength relationship; if unavailable, the data will be generated internally using the recommendations suggested by the United States Bureau of Reclamation.

(5) Slab-Base Friction Relationship. The number of cards is variable depending on the number of points defining the F-y relationship. It is worth noting that according to the sign convention adopted in this study, the input movements should be negative and the friction forces should be positive. The program assumes a symmetric curve with respect to the origin.

(6) Temperature Data. This part of the input data deals with the analysis period directly after concrete placement where the average curing temperature and the minimum daily temperature for the desired number of days are input. The number of cards required is variable and depends on the number of data points.

(7) Maximum Iterations and Closure Tolerance - one card. The primary objective for the maximum number of iterations is to prevent excessive computation. Most pavement problems should close to a reasonable tolerance within ten iterations; an allowed maximum of 20 is usually adequate. Relative closure tolerance is used for all the nonlinearities involved in the problem. It should be expressed in percent. If the tolerance is unreasonably small, closure may be difficult to achieve. A value of one percent is recommended.

PROGRAM OPTIONS

In order to obtain the major benefit of the program capability, the user is provided with three options. The options are as follows:

(1) Analysis of a given design. The user by using this option can analyze a given design (slab dimensions, steel percentage) for crack occurrence and crack width. Also, when there is a crack, the program will tell the user if the crack width is bigger than the maximum allowable value of crack width for aggregate interlock provided by the user.

(2) Steel reinforcement design. For a given slab geometry, the program designs the steel for two differen kinds of reinforcement, deformed bars and deformed wire mesh. The steel design is based on the concept of having a crack width between 0.023 inch and 0.012 inch.

(3) Design of the required length for a non-reinforced slab. Given a tentative slab length, the program will analyze the slab for a non-crack occurrence state, and will give the optimum length for that case, based on the concept of optimization for non-reinforced slab length previously discussed.

ADDITIONAL RESEARCH NEEDED

A basic theoretical procedure which analyzes the effects of drying, shrinkage, and drop in temperature in a concrete pavement slab (either reinforced or non-reinforced) has been developed; it is a useful tool to the man trying to simulate nature with theory. The design procedures developed tend to be more realistic, but in order to make a real, or better said, more real, representation of the "real world conditions," the following points need to be studied:

(1) frictional resistance of the sub-base layer,

(2) the inclusion of the restriction to movement of the slab provided by the dowels,

(3) variability of concrete properties,

(4) prediction of the concrete temperature from air temperature,

(5) effects of the slab movement in the transverse direction,

(6) addition of load and warping stresses, and

(7) field studies to test the reliability of the program.

CHAPTER 6. STUDY OF VARIABLES

The purpose of this chapter is to describe how temperature drop and subgrade friction influence the concrete tensile stress pattern. These two factors are considered to be the most important for the scope of this study. Also, a graph of steel stress at the crack versus time is presented to emphasize the importance of having the steel stresses checked versus its allowable working stress each day.

STUDY OF SUB-BASE FRICTION

It is important to note as shown in Figs 6.1 through 6.4, the concrete-tensile stress versus the number of increments in which the slab length was divided is plotted for high and low sub-base frictions. The increment numbers start at the joint and increase toward the center. The large difference in the stress levels demonstrates the great effect the sub-base friction has on the crack occurrence in the concrete slab. For this graph, all elements except daily drop in temperature remain constant for each sub-base friction.

STUDY OF DROP IN TEMPERATURE

For this study, all the factors, but temperature drop, were held constant for each day. The concrete-tensile stresses versus the number of increments were plotted for drops in temperature of ten and thirty degrees Farenheit as shown in Figs 6.5 and 6.7. From these figures it can be seen that for large drops in temperature, the concrete-tensile stresses may exceed the concrete-tensile strength, leading to a crack formation.

STUDY OF THE STRESSES OF THE STEEL AT THE CRACK

After a crack occurred in the concrete slab, the reinforcing steel was subjected to the tensile stresses that the concrete had before the crack, and, at the crack, the only element capable of resisting the tensile stresses was the reinforcing steel. As the slab attempted to contract with time, the tensile

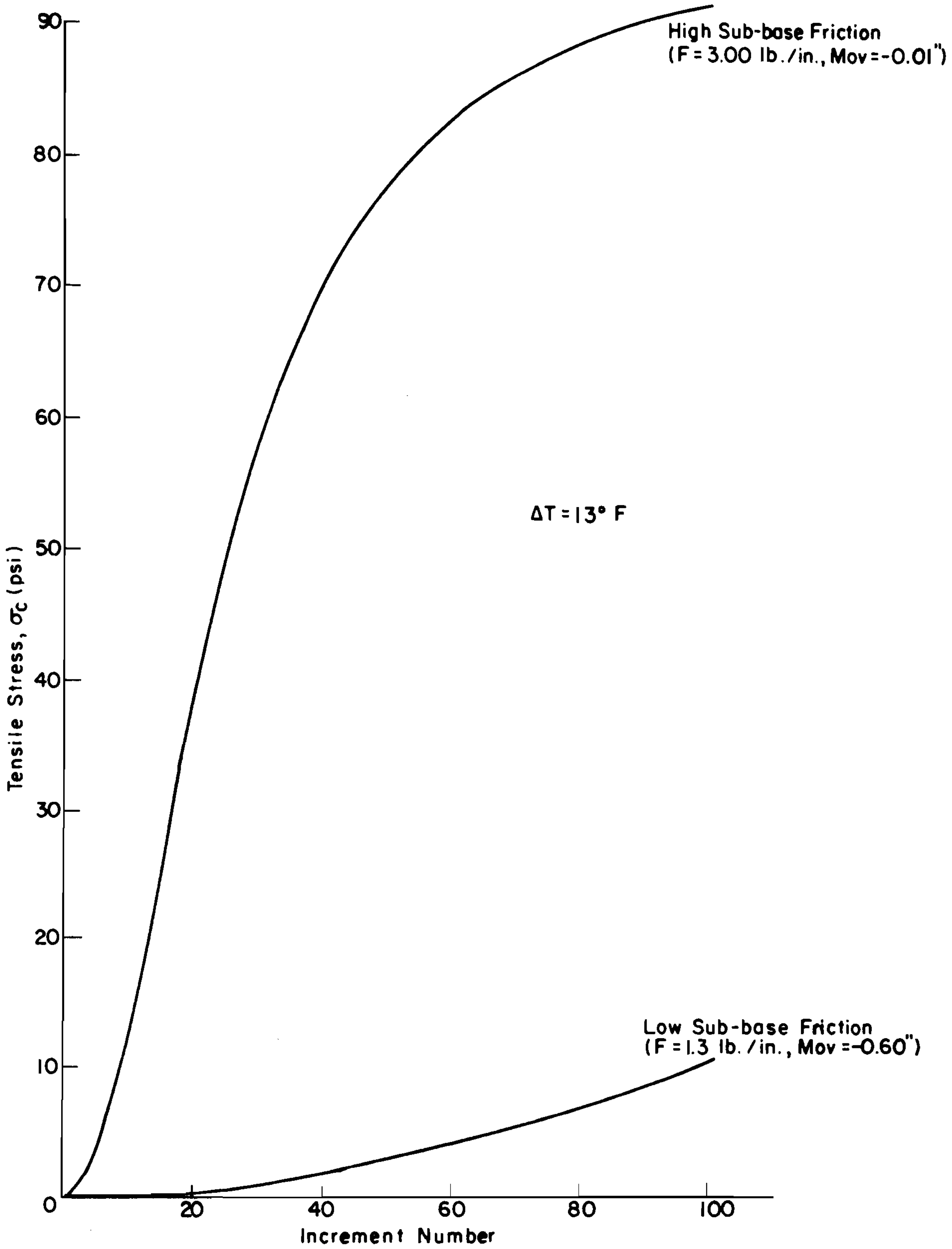


Fig 6.1. Concrete tensile stress for two sub-base frictions at the first day after concrete placement.

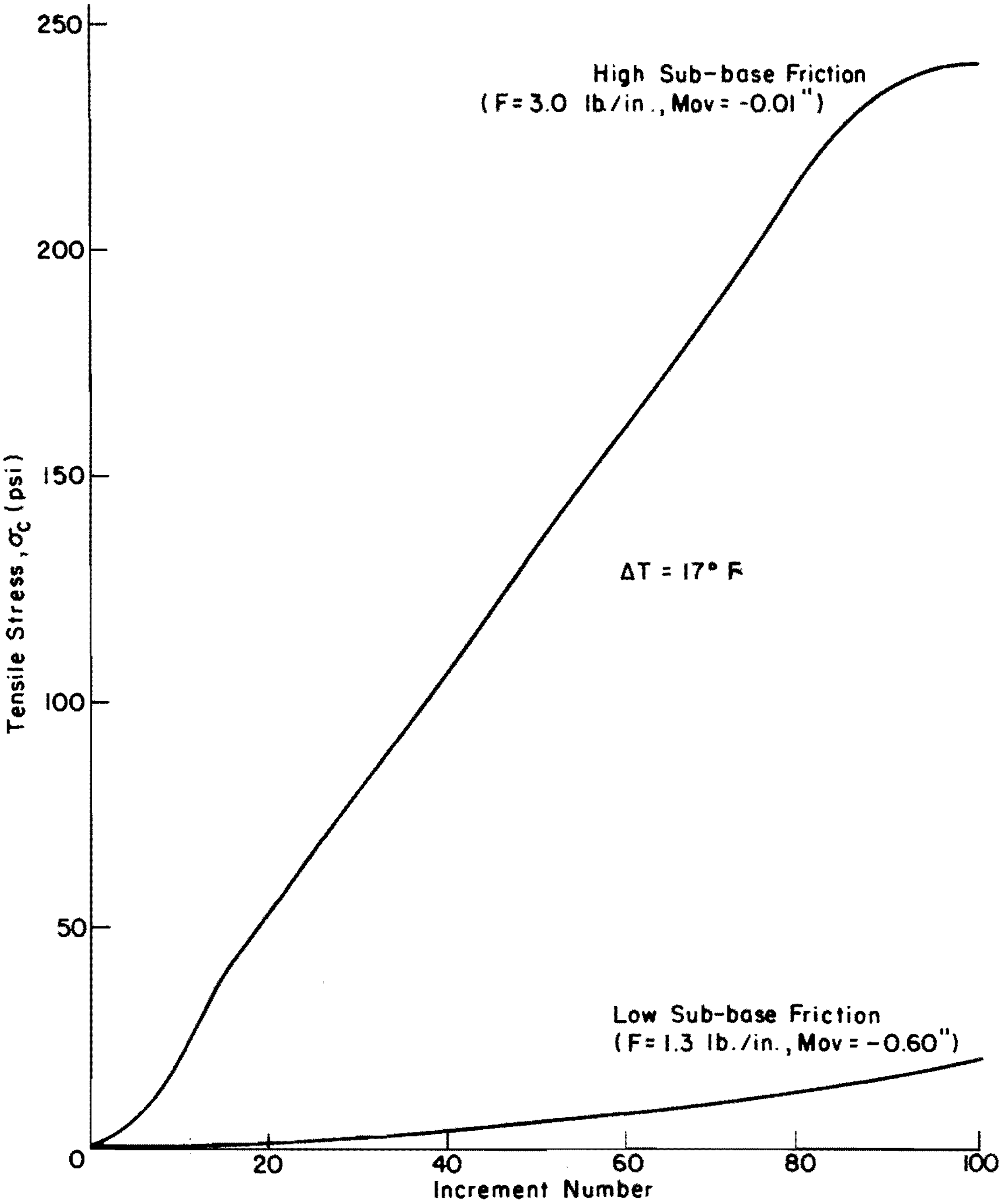


Fig. 6.2. Concrete tensile stresses for two sub-base frictions at seven days after placement.

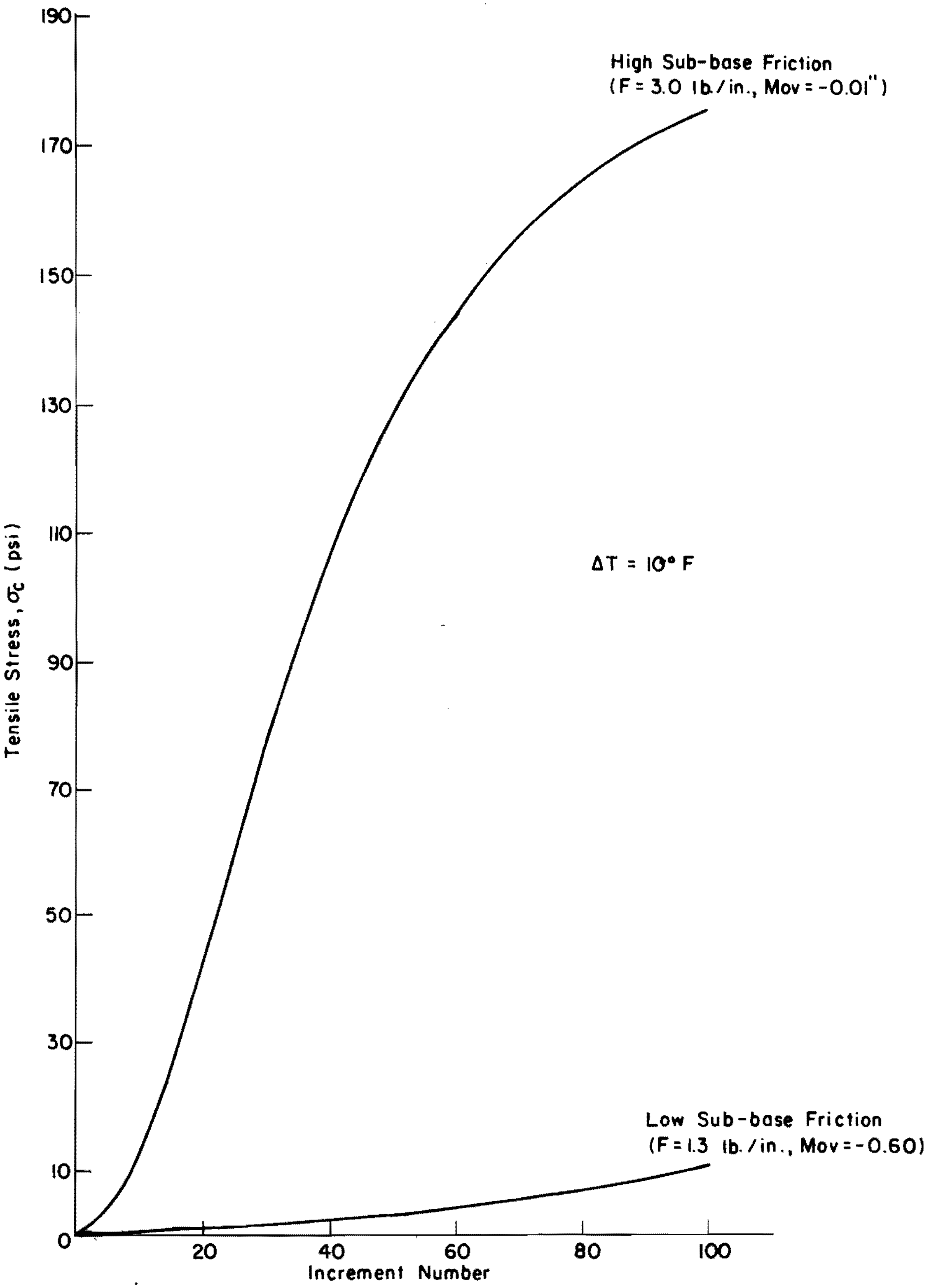


Fig. 6.3. Concrete tensile stresses for two sub-base frictions at 14 days concrete placement.

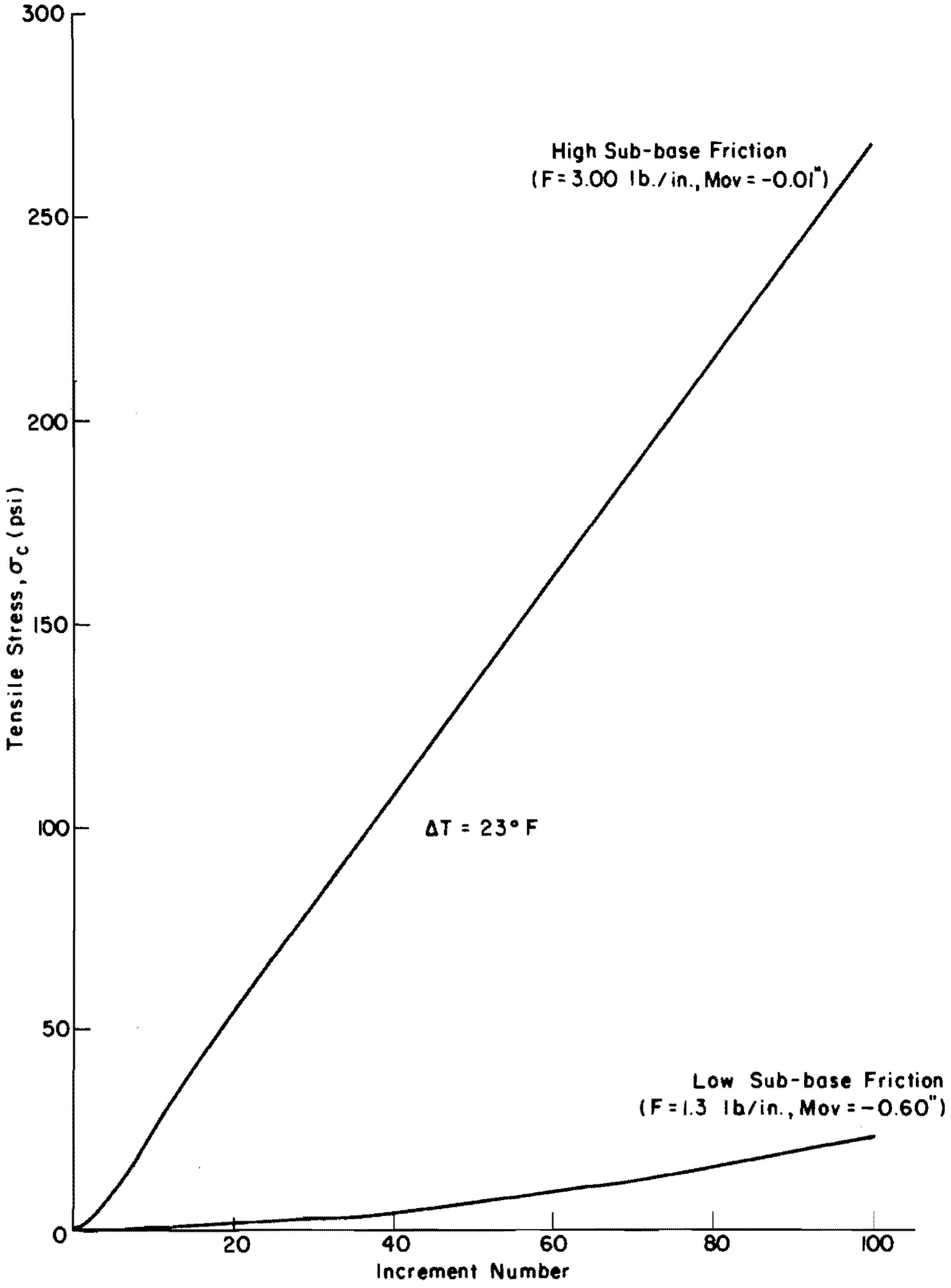


Fig. 6.4. Concrete tensile stress for two sub-base frictions after 28 days of concrete placement.

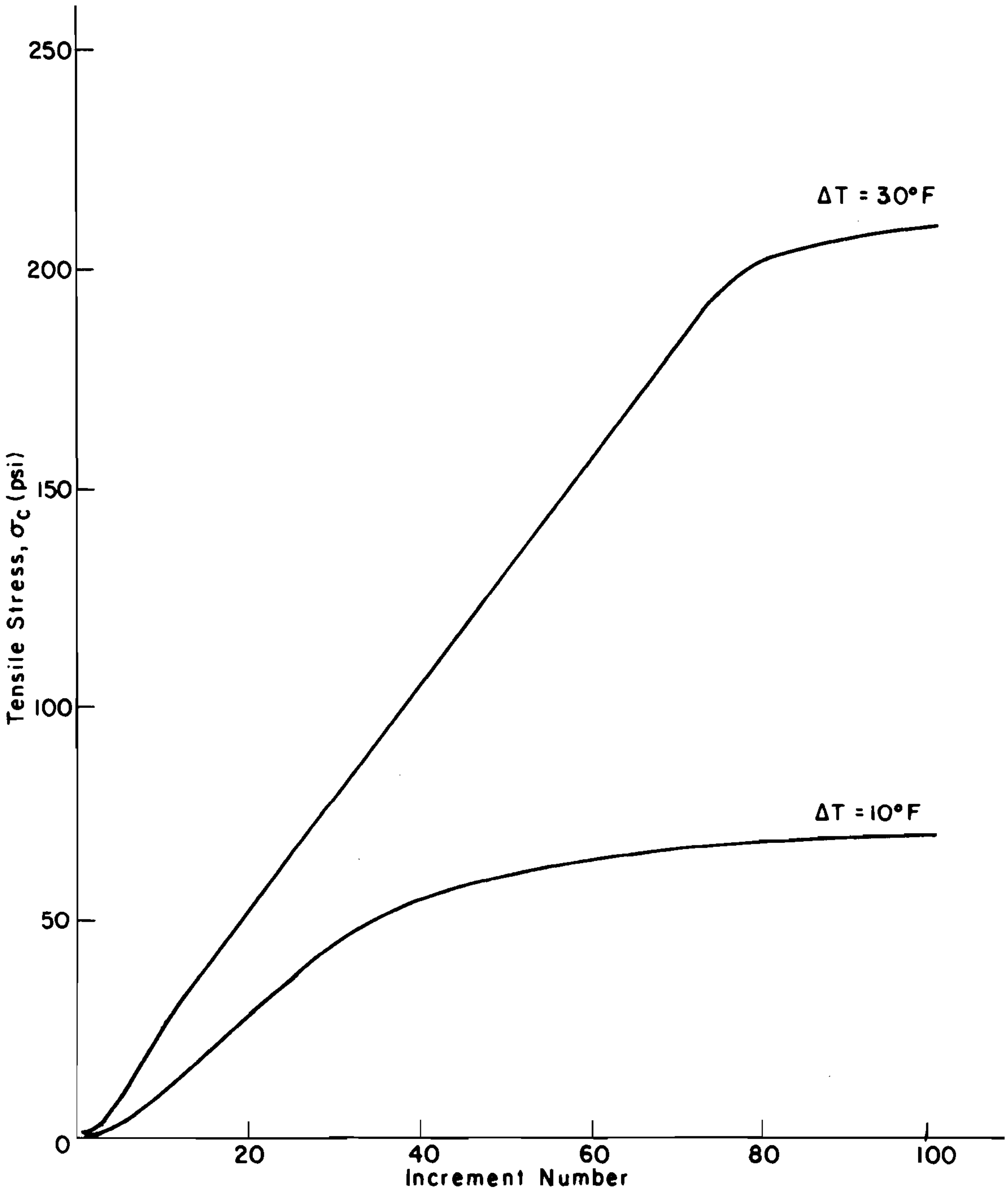


Fig. 6.5. Concrete tensile stresses for two drops in temperature at the first day after concrete placement.

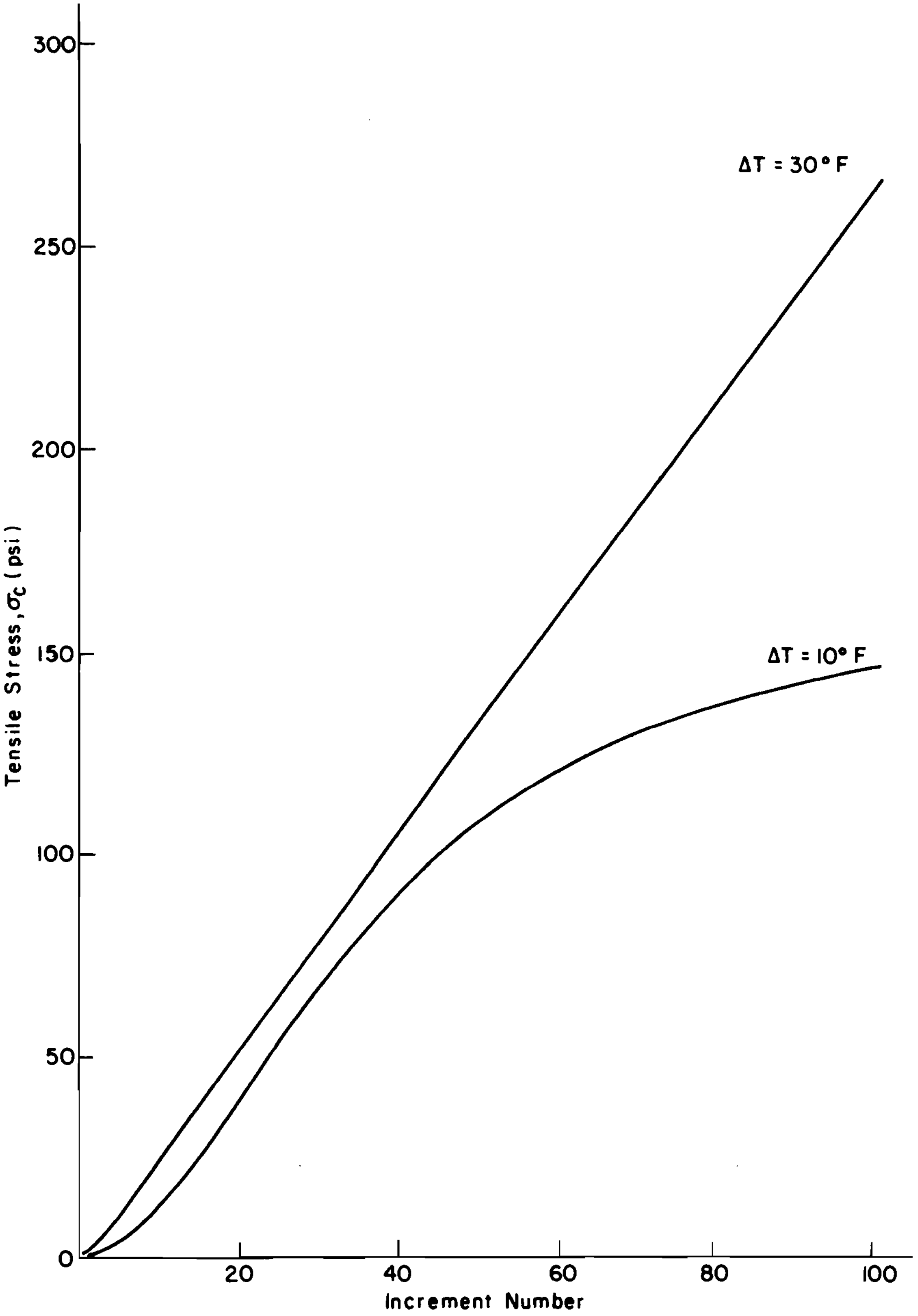


Fig. 6.6. Concrete tensile stresses for two drops in temperature after seven days of concrete placement.

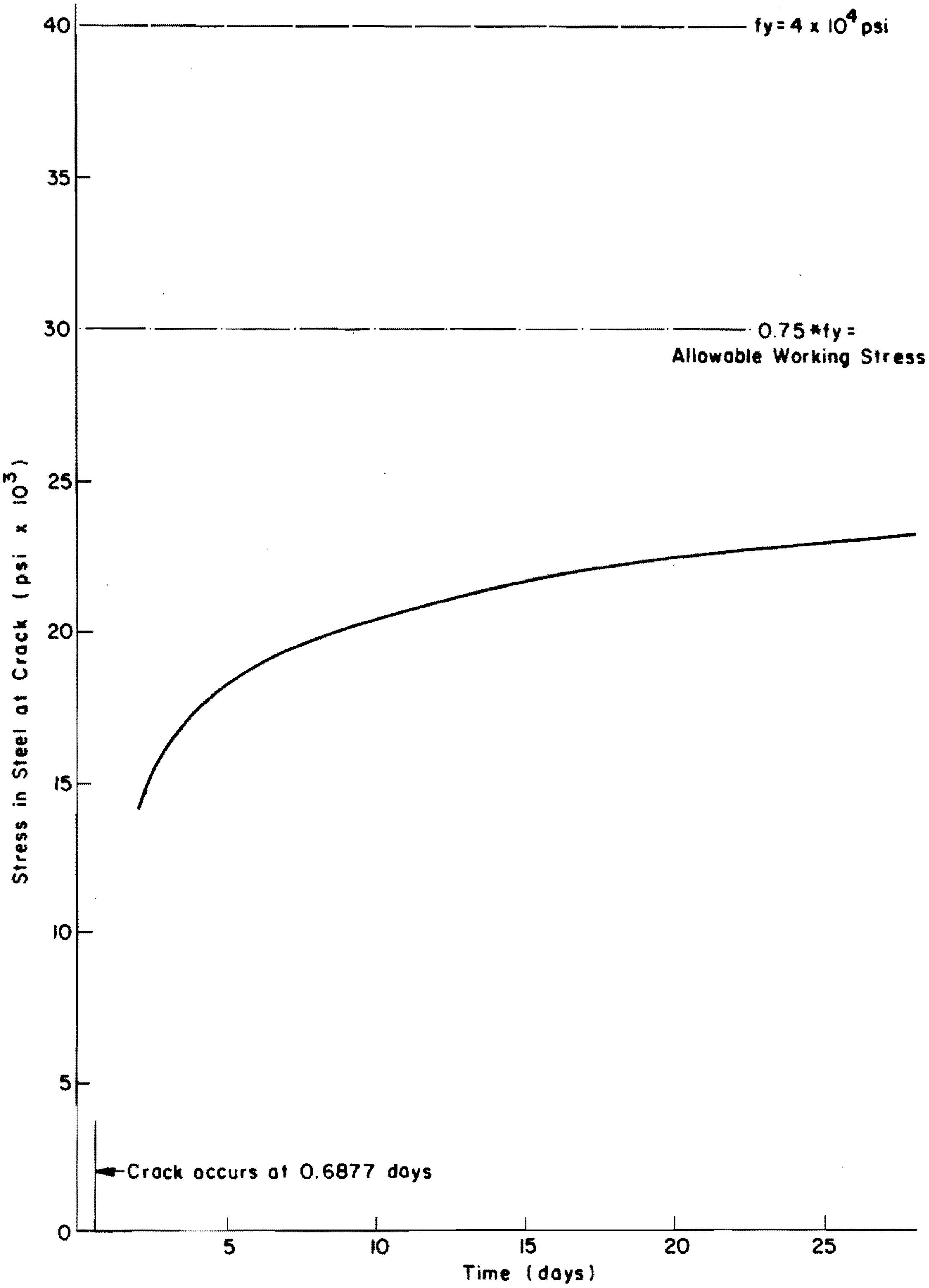


Fig. 6.7. Tensile stress of the steel at the crack.

pattern of the tensile stress of the steel at the crack emphasized the importance of checking the tensile stress of the steel at the crack against its allowable working stress on a daily basis.

CHAPTER 7. CONCLUSIONS, RECOMMENDATIONS AND IMPLEMENTATION GUIDELINES

Cracking in a jointed reinforced concrete pavement is a prime factor leading to the reduction in pavement performance depending on the crack width. Water percolation, spalling, loss of laod carrying capacity, and pumping are some of the distress manifestations which vary with cracking in the slab. This study focused on developing a design analysis package that would consider the effects of drying shrinkage and drop in temperature to minimize the effect of transverse cracks in jointed concrete pavement.

CONCLUSIONS

Based on this study the following conclusions are warranted:

(1) The subgrade drag theory currently used for the design of longitudinal reinforcement in a jointed reinforced concrete pavement is inadequate for the range of subbase conditions currently in use throughout the U. S. The present method makes unrealistic static assumptions in computing the required steel, whereas the joint width and crack width function vary immediately with changes in temperature and shrinkage. Although the primary mode of failure for these paveemtns is at transverse cracks and joints there is no control in the present methods for crack width or joint width.

(2) A computer program (JRCP-1) developed in this study more realistically models the complex interaction and movement characteristics between the concrete slab and the subbase layer at their interface. The crack width, longitudinal steel stress, and the concrete stress are predicted as a function of temperature and concrete drying shrinkage. The maximum crack width information developed in connection with NCHRP 1-15, "Design of Continuously Reinforced Concrete Pavements for Highways," may be used with this program to design jointed concrete pavements.

(3) The program internally examines the occurrence of three cracks in the slab. The first crack (model 1) is assumed to occur near the center of the slab; the second crack and third crack (model 2) are assumed to occur between the middle of the slab and the free joints.

(4) The program has the capability of providing the user with the following three options:

   - (a) analysis of a given design, crack occurrence and crack width,
   - (b) steel reinforcement designed for a given slab geometry in environmental conditions, and
   - (c) the design of the required maximum length for a non-reinforced slab to eliminate the possibility of intermediate transverse cracking.

(5) A limited sensitivity analysis in the program shows that subbase slab friction characteristics and the tmperature conditions during curing have a large influence on the occurrence of crack, resulting crack width and the resulting steel stress at the crack.

RECOMMENDATIONS

Based on the study the following recommendations are made:

(1) The wheel load stresses should be superimposed on thise predicted by temperature changes and drying shrinkage. There is evidence from studies of continuously reinforced concrete pavement that wheel load stresses may influence the formation of transverse cracks, especially during the early life of the pavement.

(2) A range in temperature conditions should be selected on the basis of geographic areas in Texas to study variations in performance with respect to temperature and shrinkage cracking. These geographic areas should be the same as recommended for implementation of computer program CRCP-1.

(3) The stochastic variations of cracking should be approximated in the program by using standard deviations of the more important inputs and a random generator to simulate this variation.

IMPLEMENTATION GUIDELINES

The following steps are recommended for implementation of the computer program after recommendation (1) has been completed:

(1) A user's manual should be developed for the SDHPT using the operating manual for program JRCP-1 in Appendix 1 as a guideline.

(2) The temperature data developed in connection with the recommendation (2) should be used to develop a range of solutions, crack width, crack spacing, and steel stress for different material properties.

(3) The information from the preceding number should be used to develop a design manual for CRCP that woudl reflect more variables than taken in to account at the present time; thus the performance level of CRCP would be improved.

REFERENCES

1. Foster, James A., "The Durability and Low Annual Cost of Concrete Pavements in U. S. A.," paper presented at the International Concrete Roads Congress, Rome, Italy, 1957.
2. Austin Research Engineers, Inc. Report FC-1/5, "Mid-Span Cracking Investigation for the Jointed Reinforced Concrete Pavement of the Dallas-Fort Worth Regional Airport," July 1972.
3. Orchard, D. F., "Concrete Technology," Volume 1, Properties of Materials, John Wiley and Sons, 1973.
4. Winter, George et al., "Design of Concrete Structures," McGraw-Hill, Inc. International Student Edition, 1964.
5. Concrete Manual, Seventh Edition, U. S. Department of the Interior, Bureau of Reclamation, Denver, Colorado, 1966.
6. "Mass Concrete for Dams and Other Massive Structures," Journal of the American Concrete Institute, Proceedings, Vol 67, April 1970.
7. Hudson, W. R., B. F. McCullough, Adnan Abou-Ayyash, and Jack Randall, "Design of Continuously Reinforced Concrete Pavements for Highways," Research Project NCHRP 1-15, Center for Highway Research, The University of Texas at Austin, August 1974.
8. Villalaz, Carlos Crespo, "Vias Terrestres y Aeropistas," Impresos Tecnicos y Tesis, Monterry, N. L. Mexico, 1972.
9. Large, George E., "Basic Reinforced Concrete Design: Elastic & Creep," The Ronald Press Company, 1975.
10. Yoder, E. J., "Pavement Design," John Wiley, 1965.
11. Powers, T. C., "Causes of Volume Change," Journal, Portland Association Research and Development Laboratories, January 1959.
12. Neville, A. M., "Properties of Concrete," John Wiley, 1963.
13. Troxell, G. E., and H. E. Davis, "Composition and Properties of Concrete," McGraw-Hill, 1970.
14. Lea, F. M., "The Chemistry of Cement and Concrete," Edward Arnold, Glasgow, 1970.
15. Price, G. E., "Curling of Rigid Pavement Slabs due to Temperature Differentials," Thesis, The University of Texas, 1967.
16. Harr, M. E., and G. A. Leonards, "Warping Stresses and Deflections in Concrete Pavements," Highway Research Board Proceedings No. 44, 1963.
17. Bradbury, R. D., "Reinforced Concrete Pavements," Wire Reinforcement Institute, Washington, D. C., 1968.

18. Lydon, F. D., "Concrete Mix Design," Applied Science Publishers, Ltd., London, 1972.

19. "ASSHTO Interim Guide for Design of Pavement Structures," 1972.

20. Elver, R. H., and M. Shafi, "Analysis of Shrinkage Effects on Reinforced Concrete Structural Members," A. C. I. Journal, January 1970.

21. Kelley, E. F., "Application of the Results of Research to the Structural Design of Concrete Pavements," Public Roads, Vol. 20, No. 5, July 1939.

22. McCullough, B. F., and T. F. Swell, "An Evaluation of Terminal Anchorage Installations on Rigid Pavements," Texas Highway Department, Research Project 1-8-63-39. Report No. 39-4(F), September 1966.

APPENDIX 1

OPERATING MANUAL FOR PROGRAM JRCP-1

APPENDIX 1. OPERATING MANUAL FOR PROGRAM JRCP-1

Program Operation

The general procedures followed in the program are described in the attached flow chart. A problem number card at the beginning of each problem controls the start of the solution. Unless an error occurs because of unacceptable data, the program will work any number of problems in sequence, finally stopping when a blank problem number card is encountered.

The data deck starts with two cover cards used to identify the program and the particular run being made. The problems to be solved together in one run are stacked behind the cover cards in sequence as illustrated in Fig. A1.1. Each problem consists of one problem number card with alphanumeric description of the problem. This is followed by slab properties, steel properties, concrete properties, slab-base friction relationship, temperature data, minimum allowable number of iterations, and tolerance for relative closure.

Guide for Data Input

The following pages provide a guide for Data Input. It should be expected that revisions of these forms and instructions will be developed in the future and may supersede the present versions.

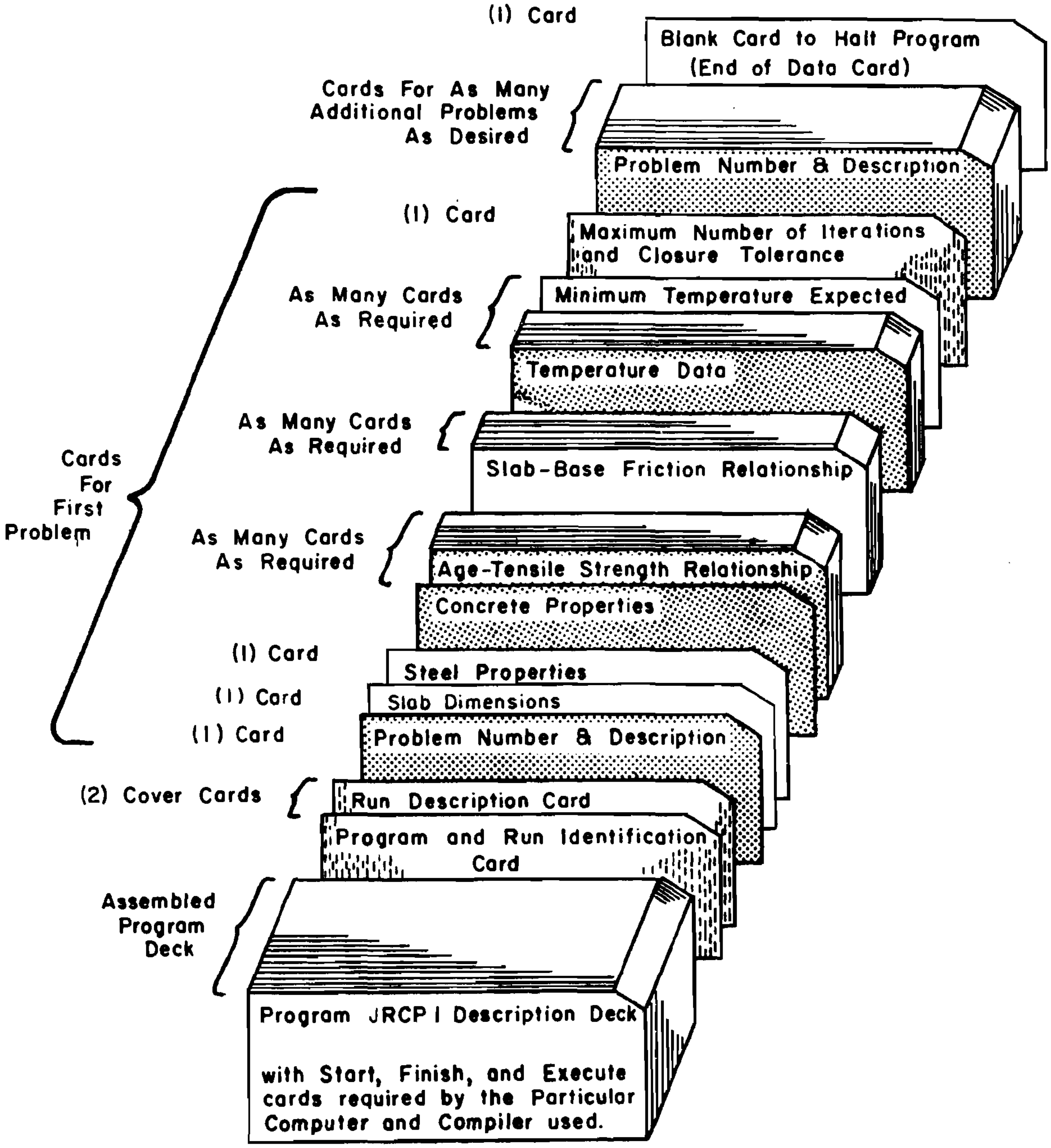


Fig A1.1. Assembly order for JRCP-1 program deck with data, ready to run.

JRCP-1 - GUIDE FOR DATA INPUT -- Card forms

IDENTIFICATION OF PROGRAM AND RUN (2 alphanumeric cards per run)

Description of Run	
1	80

1	80

IDENTIFICATION OF PROBLEM (one card each problem; program stops if PROB NUM is left blank)

PROB NUM		
A5	Description of Problem (alphanumeric)	
1 5	11	80

SLAB DIMENSIONS

FT SLAB LENGTH	FT SLAB WIDTH	NUMBER OF INCREMENTS	lb/in/in FRICTION FACTOR	IN CRWM	ISTDS	NRF
F8.4	F8.4	I5	F8.4	F8.4	I2	I2
8	16	21	29	37	41	43

slab length must be understood as transverse joint spacing

STEEL PROPERTIES (one card each problem)

ITYPER	PERCENT REINFORCEMENT	in^2 BAR DIAMETER	(PSI) YIELD STRESS	(PSI) ELASTIC MODULUS	/°F THERMAL COEFFICIENT	TRANSVERSE WIRE SPACING*
I5	E10.3	E10.3	E10.3	E10.3	E10.3	E10.3
1 5	11	21	31	41	51	61 70

ISTDS = 0 for analysis of a given design (user needs to input percentage of steel and slab dimension)

ISTDS = 1 if steel design option is used (the program will design percentage of steel required for a given slab geometry)

*Required only in the case of deformed wire fabric analysis.

JRCP-1 - GUIDE FOR DATA INPUT -- Card forms

NRF = 0 if ISTDS = 0 or 1
NRF = 1 if non-reinforcement option is used (design optimum slab length for non-reinforced slab)
ITYPER = 1 for deformed bar
ITYPER = 2 for deformed wire fabric
CRWM = Maximum allowable crack width, inches.

CONCRETE PROPERTIES

CONSTANTS (one card each problem)

(IN) SLAB THICKNESS	/°F THERMAL COEFFICIENT	(IN/IN) DRYING SHRINKAGE STRAIN	UNIT WEIGHT OF CONCRETE (pcf)	(PSI) 28-DAY COMPRESSIVE STRENGTH*	TENS. STRENGTH / FLEX. STRENGTH
E10.3	E10.3	E10.3	E10.3	E10.3	E10.3
11	21	31	41	51	61 70

AGE-TENSILE STRENGTH RELATIONSHIP

NTS	AGE(1)	TS(1)	AGE(2)	TS(2)									AGE(7)	TS(7)
	F5.1	F5.1	F5.1	F5.1									F5.1	F5.1
1 5	11	16	21	26	31	36	41	46	51	56	61	66	71	76 80

AGE(8)	TS(8)									AGE(NTS)	TS(NTS)		
F5.1	F5.1									F5.1	F5.1		
11	16	21	26	31	36	41	46	51	56	61	66	71	76 80

NTS = 0, if no tensile strength data is available (data are generated).
NTS = Total number of points on Age-Strength relationship (maximum is 20).
AGE(I) = Age of concrete in days.
TS(I) = Tensile strength in psi.

---

*Not required if Age-Tensile Strength data are provided.

JRCP-1 - GUIDE FOR DATA INPUT -- Card forms

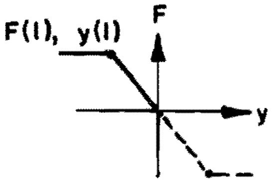
SLAB-BASE FRICTION RELATIONSHIP (F-y curve)

IFY
I5
1 — 5

F(1)	y(1)	F(2)	y(2)									F(7)	y(7)
F5.2	F5.2	F5.2	F5.2									F5.2	F5.2
11	16	21	26	31	36	41	46	51	56	61	66	71	76 — 80

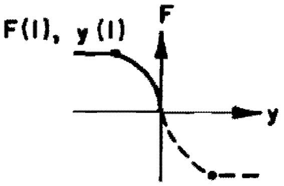
F(8)	y(8)							F(IFY)	y(IFY)				
F5.2	F5.2							F5.2	F5.2				
11	16	21	26	31	36	41	46	51	56	61	66	71	76 — 80

IFY = 1*



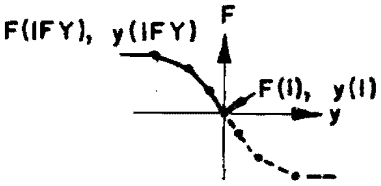
Straight Line

IFY = 2*



Parabola

IFY = Total Number of Points*



Multilinear

F(I) = Force per unit length (lb/in/in).

y(I) = Movement (inches).

*Only the solid portion of the curve need to be defined; the dotted portion is generated by symmetry with respect to the origin.

JRCP-1 - GUIDE FOR DATA INPUT -- Card forms

TEMPERATURE DATA

Average curing temperature and minimum daily temperature (^{o}F)

CURT	NTEMP	TD(1)	TD(2)	TD(3)										TD(13)	TD(14)
F5.1	I5	F5.1	F5.1	F5.1										F5..1	F5.1
1	6	11	16	21	26	31	36	41	46	51	56	61	66	71	76 80

TD(15)	TD(16)							TD(NTEMP)					
F5.1	F5.1							F5.1					
11	16	21	26	31	36	41	46	51	56	61	66	71	76 80

CURT = Average curing temperature of concrete, °F.
NTEMP = Number of days.
TD(I) = Minimum daily temperature, °F.

Minimum temperature expected after concrete gains full strength

DTMAX
F5.1
11 15

ITERATIONS AND TOLERANCE CONTROL

MAXITE	TOL
I5	F5.1
1	6 10

MAXITE = Maximum number of iterations.
TOL = Relative closure tolerance in percent.

STOP PROGRAM	One blank card to end program
1	80

GENERAL PROGRAM NOTES

The data cards must be stacked in the proper order for the program to run.

All integer format and E format numbers must be right justified.

The problem number may be alphanumeric.

Sign convention adopted is as follows:

(1) tension is positive,

(2) friction forces in the positive x-direction are positive,

(3) movements in the positive x-direction are positive, and

(4) temperature drop at a given time is defined as the difference between the temperature at which concrete has set and the temperature at that time.

SLAB DIMENSIONS

Only one card is required per problem. This card includes the commands to use the steel design option or the non-reinforcement option. The slab length must be always provided, even if the non-reinforcement option is used. The units are slab length, feet, slab width, feet, maximum allowable crack width, inches.

STEEL PROPERTIES

Only one card is required per problem. Program JRCP-1 has the capability of analyzing the most commonly used types of longitudinal reinforcement, deformed bars and deformed wire fabric. The desirable type of reinforcement can be specified by ITYPER option. ITYPER = 1 is for deformed bars while ITYPER = 2 is for deformed wire fabric. The units to be used are pounds and inches. The unit of temperature used in the analysis should be degrees Fahrenheit in the thermal coefficient and temperature data.

CONCRETE PROPERTIES

The input of concrete properties consists of two or more cards. The first card has slab thickness, thermal coefficient, final drying shrinkage, unit weight, and 28-day compressive strength. Units are pounds and inches except for unit weight of concrete, where pounds per cubic foot should be used. In case the thermal coefficient and/or final drying shrinkage of the concrete mix used are not available, Fig 3.3 contains recommended values obtained from the present state-of-the-art.

The second card contains the age-tensile strength relationship of the concrete. If these data are not provided, the recommendations given by the United States Bureau of Reclamation will be used to generate the age-tensile strength relationship. In this case, the 28-days compressive strength of concrete is required, and NTS should be zero.

SLAB-BASE FRICTION RELATIONSHIP (F-y curve)

Various relationships can be input to define the F-y curve used in the computations. Regardless of the type of curve, symmetry is assumed with respect to the origin of the axes. This implies that only one portion of the curve is needed, while the remainder is generated by the program.

The three types of frictional resistance relationships are: straight line, parabola, and multilinear curves. The desired relationship is specified by the control IFY, where a value of one, two, or greater than two indicates that the F-y curve is a straight line, parabola, or multilinear relationship, respectively. In the case of a straight line or a parabola, only one point is required to define the curve. This point is where sliding occurs. If the multilinear curve is used, then the first point should be the origin $F(1) = 0$, $y(1) = 0$, while the last point [F(IFY), y(IFY)] should be sliding. The force should be expressed in lbs/in^2 and the movement in inches.

TEMPERATURE DATA

In the temperature data, the average curing temperature and the minimum daily temperature over a period of NTEMP days should be specified. NTEMP should be equal to the time when the tensile strength reaches its maximum value, as specified in the Age-Tensile Strength relationship. If no tensile strength data are available, then as discussed previously, strength values will be generated by the program, in which case NTEMP should be 28 days, and 28 minimum daily temperatures will be required.

One more piece of information is required for the analysis: minimum temperature expected after concrete gains full strength.

MAXIMUM NUMBER OF ITERATIONS AND CLOSURE TOLERANCE

The maximum number of iterations should be set to prevent excessive computation. Most jointed concrete pavement problems should close to a reasonable tolerance within 10 iterations; an allowed maximum of 20 is usually adequate.

The closure tolerance is Relative closure and should be expressed in percent. If it is unreasonably small, closure may be difficult to achieve. For many structural road problems, a value of one percent is satisfactory.

APPENDIX 2

GLOSSARY OF NOTATION FOR COMPUTER PROGRAM JRCP-1

APPENDIX 2. GLOSSARY OF NOTATION FOR COMPUTER PROGRAM JRCP-1

NOTATION FOR JRCP-1 PROGRAM

AAA	Counter for the number of iterations for friction closure
AGE	Age of concrete generated by program
AGEU	Age of concrete input by user
ALPHAC	Thermal coefficient of concrete
ALPHAS	Thermal coefficient of steel
ANTEMP	Last day on time temperature curve
BAD	Counter to indicate friction closure
BHIGH	Spacing of transverse wire in deformed wire fabric
BLOW	Half spacing of transverse wires
BONDL	Bond or development length
COMSTR	Compressive strength of concrete
CONSTR( )	Concrete stress
CRACKW1	Width of the first crack
CRACKW2	Width of the second crack
CURTEMP	Curing temperature
DELTAT	Drop in temperature at any time
DELTATM	Maximum drop in temperature
DIA	Diameter of individual bar
DELTAX	Increment length
DIF( )	Difference between two successive iterations
DT( )	Daily temperature
DIST	Distance between free edge and first crack
EC	Modulus of elasticity of concrete
ES	Modulus of elasticity of the steel
F( )	Friction force
FEXP( )	Flexural strength
FLESTRN	Flexural strength of concrete
FOUT	Value of flexural strength calculated by linear interpolation
FPC	Compressive strength
FU	Maximum friction force
FY	Yield stress of the steel
FRF	Friction factor for the AASHO steel equations
IFY	Number of points defining the friction movement curve
INDEX	Closure control
ITEB	Counter for the number of iterations on bond length
ITYPER	Option for the type of reinforcement
ISTDS	Option for steel design
L	Length of JRCP-1 Model
MA1	AAA-1
MAXITE	Maximum allowable number of iterations
N	Index for reading data

NPROB	Problem number (stops if blank)
NT	Total number of increments in the JRCP-1 Model
NTEMP	Number of daily temperatures
NTP1	NT+1
NRF	Option for non-reinforcement design
P	Percent longitudinal reinforcement
P2	Percent transverse reinforcement
PERCENT	Percentage of 28-day flexural strength
REFF	Upper bound on FU
SS( )	Steel strain
STRAIN( )	Concrete strain
STRESSS( )	Steel stress
STRNMUL	Transformation factor between tensile and flexural strength
STRSCO	Concrete stress at point of zero movement
STRSC1	Concrete stress for Model-1
STRSC2	Concrete stress for Model-2
THICK	Slab thickness
TIME	Time in days
TOL	Tolerance for closure criteria
UNWT	Unit weight of concrete
VDS	Volume to surface ratio
W	Slab width
XBAR	Slab length
Y( )	Concrete movement
YEXP( )	Movement on the frictional-resistance curve
YP( )	Movement for testing criteria
YPITE( )	Movement from the previous iteration
YST	Center to center spacing for transverse steel
Z	Drying shrinkage at any time
ZTOT	Total drying shrinkage

C-------------Notation for subroutine DFBARF

A	Length of the fully bonded section in the JRCP Model
AA	Coefficient of the square term in quadratic equation
AAAAA	Summation of area under the steel stress diagram
ANA	Number of stations in the fully bonded section
A1,A2,A3	Magnitude of areas under the steel stress diagram
BB	Coefficient of the linear term in quadratic equation
BONDCON	Bond constant
BONDLC	Computed bond length
CC	Constant term in quadratic equation
C1,...,C9	Coefficients in the solution of equations
DELTA	Magnitude of delta for the solution of quadratic equation
DENO	Constant used for computing the slope of the steel curve
E	Distance in the fully bonded section of the JRCP Model
LOCMAX	Location of maximum concrete stress
NA	Number of increments
NAM1	NA - 1
NAP1	NA + 1
NAP2	NA + 2
RATIO	Ratio of modulus of elasticity of steel to that of concrete
ROOT1	Positive root of the quadratic equation
ROOT2	Negative root of the quadratic equation

SIGMASB	Stress in the steel between cracks
SIGMASC	Stress in the steel at the crack
SUM1	Summation for solution of equations
SUM2	Summation of the slopes to the steel stress distribution
U	Bond Stress

C--------------Notation for subroutine DFBAR

AA	Coefficient of the square term in quadratic equation
B	Bond length
BB	Coefficient of the linear term in quadratic equation
CHECK	Check for solution of equations
CONCRES	Concrete stress between cracks
DD	Constant term in the quadratic equation
DEL	Value of delta in quadratic equation
R2, R6	Roots of quadratic equation
STRAREA	Area under the steel stress distribution
STRC	Stress in the concrete between cracks
STRSB	Stress in the steel between cracks
STRSC	Stress in the steel at the crack

APPENDIX 3

COMPUTER PROGRAM

APPENDIX 3. COMPUTER PROGRAM

```
              PROGRAM JRCP1(INPUT,OUTPUT)
    3         DIMENSION AN1(40),AN2(18)
    3         DIMENSION F(501),SUM(501),AGE(8),PERCENT(8)
    3         COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
    3         COMMON /BLOCK2/ SS(501),AAA,WS(501),MAXITE,CRACKW
    3         COMMON /BLOCK3/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB
    3         COMMON /BLOCK4/ AL(501),STRAIN(501),CONSTR(501),STRESSS(501)
    3         COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
    3         COMMON /BLDCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
    3         COMMON /BLOC28/ Y(501),REFF(501),YP(501),H,ICLOSER,YPITE(501)
    3         COMMON /BLOCK9/ STX,STY,PSX,PSY,ITE
    3         COMMON /BLOCK10/ NSTRN,VDS,AGEU(20),TENSION(20),STRNMUL
    3         COMMON /BLOCK12/ DT(50),NTEMP,NTIFLAG,UPINC,DOWNINC
    3         COMMON/BLOCKA/Z,YP1,Y1(501),DELTAX,DELTAT,TEMP1,REFF1,YPITE1,W
    3         COMMON/BLOCKB/BHIGH,BLOW,YSL,P2,YST,
    3         COMMON/BLOCKC/STRSC1(501),STRSS1(501),INC,FRF,FY,L
    3         DATA AGE/0.,1.,3.,5.,7.,14.,21.,28./
    3         DATA PERCENT/0.,15.,38.,53.,63.,82.,94.,100./
    3         REAL NEGT
   .3         INTEGER AAA
    3         REAL L
    3                 ITEST=5H
       C
       C      PROGRAM AND PROBLEM IDENTIFICATION
       C
    5         READ 510, (AN1(N),N=1,40)
   12     10  CONTINUE
   12         READ 520, NPROB,(AN2(N),N=1,18)
   22            IF (NPROB-ITEST) 20,450,20
   24     20  CONTINUE
   24         PRINT 530
   30         PRINT 540, (AN1(N),N=1,40)
   36         PRINT 550, NPROB,(AN2(N),N=1,18)
       C
       C      READ SLAB DIMENSIONS AND DESIGN FLAGS
       C
   46         READ 555, XBAR,W,NT,FRF,CRWM,ISTOS,NRF
   72         PRINT 580
   76         PRINT 556
  102         PRINT 580
  106         PRINT 557,XBAR,W,NT,FRF,CRWM
  124         XBAR=XBAR*12.
  126     557 FORMAT(//,15X,22H SLAB LENGTH          = ,E10.3,/,
             1          15X,22H SLAB WIDTH           = ,E10.3,/,
             2          15X,22H NUMBER OF INCREMENTS= ,I5,/,
             3          15X,22H FRICTION FACTOR      = ,E10.3,/,
             4          15X,22H MAX. CRACKWIDTH      = ,E10.3,///)
  126          IF(ISTDS.EQ.1)PRINT 551
  133          IF(NRF.EQ.1)7RINT 553
  141          IF(NRF.NE.1.AND.ISTDS.NE.1)PRINT 554
  154     555 FORMAT(2F8.4,I5,2F8.4,3I2)
  154     556 FORMAT( 10X,1H*,46X,1H*,/,
             1      10X,48H*                  SLAB OIMENSIONS                  *,/,
             2      10X,1H*,46X,1H*)
  154     551 FORMAT(/,10X,* STEEL DESIGN OPTION *,/)
```

```
  154     553 FORMAT(/,10X,* NON-REINFORCEMENT OPTION *,/)
  154     554 FORMAT(/,10X,* SLAB ANALYSIS OPTION *,/)
       C
       C      INPUT STEEL PROPERTIES
       C
  154         READ 560, ITYPER,P,DIA,FY,ES,ALPHAS,BHIGH
  176         PRINT 580
  202         PRINT 570
  206         PRINT 580
  212            IF (ITYPER.EQ.1) PRINT 590
  220            IF (ITYPER.EQ.2) PRINT 600
  226            IF (ITYPER.LT.1.OR.ITYPER.GT.2) GO TO 450
  236         PRINT 610, P,DIA,FY,ES,ALPHAS
  253                  P=P/100.
       C
       C      INPUT CONCRETE PROPERTIES
       C
  255         READ 620, THICK,ALPHAC,ZTOT,UNWT,FPC,STRNMUL
  274         PRINT 580
  300         PRINT 630
  304         PRINT 580
  310         PRINT 640, THICK,ALPHAC,ZTOT,UNWT,FPC,STRNMUL
       C
       C      INPUT AGE-TENSILE STRENGTH RELATIONSHIP
       C
  330             IF (STRNMUL.EQ.0.0) STRNMUL=1.0
       C
       C      NSTRN  DESIGNATES WHETHER AGE-STRENGTH RELATIONSHIP IS AVAILABLE
       C
       C              NSTRN  = 1  AGE-STRENGTH DATA IS PROVIDED
       C
  332         READ 660, NSTRN,(AGEU(I),TENSION(I),I=1,7)
  350            IF (NSTRN.GT.7) READ 650, (AGEU(I),TENSION(I),I=8,NSTRN)
  367                 TENS=TENSION(NSTRN)
  371            IF (NSTRN.EQ.0) GO TO 30
  372         PRINT 670, ((AGEU(I),TENSION(I)),I=1,NSTRN)
  406            GO TO 60
  407     30  CONTINUE
  407         PRINT 680
  413         PRINT 690
  417         DO 50 I=1,8
  421                 DUMDUM=FPC*PERCENT(I)/100.
  424            IF (DUMDUM.EQ.0.) GO TO 40
  425                 DUMDUM=STRNMUL*3000./(3.+12000./DUMDUM)
  431     40  CONTINUE
  431         PRINT 700, AXE(I),DUMDUM
  441     50  CONTINUE
  443                 TENS=STRNMUL*3000./(3.+12000./FPC)
  450     60  CONTINUE
       C
       C      INPUT SLAB-BASE FRICTION RELATIONSHIP **(FORCE-DISPLACEMENT**)
       C
       C      FORCE-DISPLACEMENT RELATIONSHIP
       C
  450         PRINT 710
  454         READ 730, IFY,(FEXP(I),YEXP(I),I=1,7)
```

```
    472            IF (IFY.GT.7) READ 720, (FEXP(I),YEXP(I),I=8,IFY)
    511            IF (IFY.EQ.1) GO TO 70
    513            IF (IFY.EQ.2) GO TO 80
    515            IF (IFY.GT.2) GO TO 90
    517     70   CONTINUE
    517                  FRICMUL=FEXP(1)/YEXP(1)
    521                  FU=FEXP(1)
    522            GO TO 100
    523     80   CONTINUE
    523                  FRICMUL=SQRT(ABS(1/YEXP(1)))*FEXP(1)
    532                  FU=FEXP(1)
    533            GO TO 100
    533     90   CONTINUE
    533             IF (FEXP(1).NE.0.OR.YEXP(1).NE.0.) GO TO 450
    541    100   CONTINUE
    541             IF (IFY.EQ.2) PRINT 750, FEXP(1),YEXP(1)
    553             IF (IFY.EQ.1) PRINT 740, FEXP(1),YEXP(1)
    565             IF (IFY.GT.2) PRINT 760, ((FEXP(I),YEXP(I)),I=1,IFY)
          C
          C      INPUT MAXIMUM DAILY DROP IN TEMPERATURE
          C
    604          READ 770, CURTEMP,NTEMP,(DT(I),I=1,14)
    616             IF (NTEMP.GT.14) READ 780, (OT(I),I=15,NTEMP)
    633          PRINT 800
    637          PRINT 790, CURTEMP
    645          PRINT 810
    651          DO 110 I=1,NTEMP
    653                  TEM7T=OT(I)
    655                  DT(I)=CURTEMP-DT(I)
    657             IF (DT(I).LT.0) DT(I)=0.
    662          PRINT 820, I,TEMPT,DT(I)
    674    110   CONTINUE
          C
          C
          C
          C      INPUT MINIMUM TEMPERATURE AFTER
          C      CONCRETE GAINS FULL STRENGTH
          C
    677          READ 830, DE3TATM
    704          PRINT 840, DELTATM
    712                  DELTATM=CURTEMP-DELTATM
    714          READ 850, MAXITE,TOL
    724          PRINT 860
    730          PRINT 870, MAXITE,TOL
          C      ***********************************
          C          INITIALIZE PARAMETERS          *
          C      ***********************************
    740                  IFINISH=0
    741                  TOL=TOL/100.
    743    120   CONTINUE
    743             IF (IFINISH.EQ.0) GO TO 130
    744          PRINT 530
    750          PRINT 540, (AN1(N),N=1,40)
    756          PRINT 550, NPROB,(AN2(N),N=1,18)
    766             IF (IFINISH.EQ.1) PRINT 480
    774    130   CONTINUE
```

```
   774            IF (ITYPER.EQ.2) ICLOSEB=1
   777                  ANTEMP=NTEMP
  1001                  IBABY=0
  1002                  IBXBAR=0
  1003                  IENDONE=0
  1004                  ITEB=0
  1005          NTP1=NT+1
  1007                  IB=1
  1010          VDS=THICK
  1011                  EP=1.E-9
  1013                  AAA=1
  1014                  BLOW=BHIGH/2.
  1016     140  CONTINUE
  1016          CALL DRIVER(NRF,ISTDS,ZTOT,F,SUM,CRWM)
  1022          IF(ISTDS.NE.1.O.NRF.EQ.1)GOTO 450
        C
        C       PREPARE FOR PRINTING RESULTS IF STEEL DESIGN OPTION CHOSEN
        C
  1032          AB=3.1416*DIA*DIA/4.
  1035           P=P*100.
  1036           YSL=AB*100./(THICK*P)
  1042          PRINT 880,P,YSL
  1051     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 ,/)
  1051     490  FORMAT ( 2X,F5.2,2X,F5.1,2X,E10.3,2X,F5.1,3X,F6.1,
              1       1X,F10.3,2(2X,E10.3))
  1051     510  FORMAT ( 20A4)
  1051     520  FORMAT (A5,5X,17A4,A2)
  1051     530  FORMAT (5H1    ,76X,10H1-----TRIM)
  1051     540  FORMAT (1X,20A4)
  1051     550  FORMAT (//,5H PROB,/,A5,5X,17A4,A2,//)
  1051     560  FORMAT (I5,5X,6(E10.3))
  1051     570  FORMAT (10X,1H*,46X,1H*,/,
              1      10X,48H*                 STEEL PROPERTIES                 *,/,
              2      10X,1H*,46X,1H*)
  1051     580  FORMAT (10X,48(1H*))
  1051     590  FORMAT (//,15X,39H TYPE OF LONGITUDINAL REINFORCEMENT IS ,/,
              1               26X,14H DEFORMED BARS)
  1051     600  FORMAT (//,15X,39H TYPE OF LONGITUDINAL REINFORCEMENT IS ,/,
              1               23X,21H DEFORMED WIRE FABRIC)
  1051     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,///)
  1051     620  FORMAT (10X,6E10.3)
  1051     630  FORMAT (10X,1H*,46X,1H*,/,
              1      10X,48H*               CONCRETE PROPERTIES                *,/,
              2      10X,1H*,46X,1H*)
  1051     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,/,
```

```
             5              15X,22H (TENS/FLEX)RATIO    =,E10.3,//)
   1051     650  FORMAT ((10X,14F5.0))
   1051     660  FORMAT (I5,5X,14F5.0)
   1051     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))
   1051     680  FORMAT (14X,22H TENSILE STRENGTH DATA,/,15X,21(1H*))
   1051     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 ,/)
   1051     700  FORMAT (13X, 2(2X,F5.1))
   1051     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*),//)
   1051     720  FORMAT ((10X,14F5.2))
   1051     730  FORMAT (I5,5X,14F5.2)
   1051     740  FORMAT (15X,41HTYPE OF FRICTION CURVE IS A STRAIGHT LINE,//,
             1     15X,24H MAXIMUM FRICTION FORCE=,2X,F6.3,/,
             2     15X,24H MOVEMENT AT SLIDING   =,2X,F6.3)
   1051     750  FORMAT (15X,36HTYPE OF FRICTION CURVE IS A PARABOLA,//,
             1     15X,24H MAXIMUM FRICTION FORCE=,2X,F6.3,/,
             2     15X,24H MOVEMENT AT SLIDING   =,2X,F6.3)
   1051     760  FORMAT (15X,45HTYPE OF FRICTION CURVE IS A MULTILINEAR CURVE,//,
             1      15X,5H F(I),2X,5H Y(I),//,(15X,F6.3,2X,F6.3),//)
   1051     770  FORMAT (F5.1,I5,14F5.1)
   1051     780  FORMAT ((10X,I4F5.1))
   1051     790  FORMAT (    14X,20H CURING TEMPERATURE=,F5.1,//)
   1051     800  FORMAT (///,10X,30(1H*),/,
             1      10X,1H*,28X,1H*,/,
             2      10X,30H*       TEMPERATURE DATA      *,/,10X,1H*,28X,1H*,/,
             3      10X,30(1H*),//)
   1051     810  FORMAT (20X,7HMINIMUM,6X,7HDROP IN,/,
             1      10X,3HDAY,SX,11HTEMPERATURE,2X,I1HTEMPERATURE,/)
   1051     820  FORMAT (10X,(I3,8X,F5.1,8X,F5.1))
   1051     830  FORMAT (10X,F5.1)
   1051     840  FORMAT (/,14X,36H MINIMUM TEMPERATURE EXPECTED AFTER ,/
             1             14X,36H CONCRETE GAINS FULL STRENGTH      =,F5.0,
             2             20H DEGREES FARENHITE  ,//)
   1051     850  FORMAT (I5,F5.1)
   1051     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*),///)
   1051     870  FORMAT (10X,40H MAXIMUM ALLOWABLE NUMBER OF ITERATIONS=,I5  ,//
             1          10X,28H RELATIVE CLOSURE TOLERANCE=,F5.1, 8H PERCENT,//)
   1051      880 FORMAT(1X,* LONGITUDINAL STEEL = *,EI0.3,* PERCENT. *,/,
             1       *  SPACED = *,E10.3,* INCHES CENTER TO CENTER *,//)
   1051     900  FORMAT (10X,15,2X,F5.1,2X,4(E10.3,2X,))
   1051     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              10X,24H PROGRAM IS TERMINATED. ,)
```

```
   1051     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 *)
   1051     950  FORMAT  (//,10X,* ERROR IS DETECTED *,/,
             1    10X,*TYPE OF PERCENT REINFORCEMENT OPTION IS NOT RIGHT*,/,
             2    10X,*ITYPER=*,I5)
   1051     960  FORMAT (//,10X,* PROGRAM IS TERMINATED , ITE = *,I5)
   1051      450 CONTINUE
   1051          ENO
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

PROGRAM LENGTH INCLUDING I/O BUFFERS
  6410

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
10      -      12   20      -      24   30      -     407   40      -     431
60      -     450   70      -     517   80      -     523   90      -     533
100     -     541   120     -     743   130     -     774   140     -    1016
450     -    1051   480     -    1201   490     -    1231   510     -    1243
520     -    1245   530     -    1250   540     -    1254   550     -    1256
551     -    1151   553     -    1156   554     -    1163   555     -    1125
556     -    1131   557     -    1065   560     -    1263   570     -    1266
580     -    1306   590     -    1311   600     -    1324   610     -    1337
620     -    1400   630     -    1403   640     -    1423   650     -    1472
660     -    1475   670     -    1500   680     -    1530   690     -    1536
700     -    1603   710     -    1606   720     -    1635   730     -    1640
740     -    1643   750     -    1665   760     -    1707   770     -    1724
780     -    1727   790     -    1732   800     -    1740   810     -    1767
820     -    2004   830     -    2010   840     -    2013   850     -    2035
860     -    2037   870     -    2061   880     -    2077   900     -    2114
910     -    2121   940     -    2152   950     -    2202   960     -    2222

EXTERNALS AND TAGS
 INPUTC -  S00200   OUTPTC -  S00300   SQRT    -  S00400   DRIVER -  S00500
END     -  S00600   Q8NTRY -  S00100

BLOCK NAMES AND LENGTHS
BLOCK1 -       12C01 BLOCK2 -     1755C02 BLOCK3 -        6C03 BLOCK4 -    3724C04
BLOCK5 -       30C05 BLOCK6 -       10C06 BLOCK8 -     3726C07 BLOCK9 -       5C10
BLOCK10-       53C11 BLOCK12-       66C12 BLOCKA -      775C13 BLOCKB -       6C14
BLOCKC -    1756C15

VARIABLE ASSIGNMENTS
AAA     -     765C02 AB      -    4343     AGE     -    4300     AGEU    -       2C11
AL      -       0C04 ALPHAC  -       0C06 ALPHAS  -       1C06 ANTEMP  -    4337
AN1     -    2234    AN2     -    2304     BHIGH   -       0C14 BLOW    -       1C14
CONSTR  -    1752C04 CRWM    -    4324     CURTEMP-     4333     DELTATM-    4335
DIA     -      10C01 DT      -       0C12 DUMDUM  -    4332     EP      -       5C06
ES      -       5C01 F       -    2326     FEXP    -       0C05 FPC     -       3C06
FRF     -    1753C15 FRICMUL-      24C05 FU      -      26C05 FY      -    1754C15
I       -    4330    IB      -    4342     IBABY   -       4C03 IBXBAR  -    4340
ICLOSEB-     2740C07 IENDONE-     4341     IFINISH-     4336     IFY     -      27C05
ISTDS   -    4325    ITEB    -       5C03 ITEST   -    4321     ITYPER  -       7C06
L       -    1755C15 MAXITE  -    1753C02 MODFLAG-        5C14 N       -    4322
NEGT    -    4320    NPROB   -    4323     NRF     -    4326     NSTRN   -       0C11
NT      -      25C05 NTEMP   -      62C12 NTP1    -       6C01 P       -       2C01
PERCENT-     4310    REFF    -     765C07 SS      -       0C02 STRAIN  -     765C04
STRESSS-     2737C04 STRNMUL-      52C11 STRSC1  -       0C15 STRSS1  -     765C15
SUM     -    3313    TEMPT   -    4334     TENS    -    4331     TENSION-      26C11
THICK   -       1C01 TOL     -       6C06 UNWT    -      11C01 VDS     -       1C11
W       -     774C13 WS      -     766C02 XBAR    -       0C03 Y       -       0C07
YEXP    -      12C05 YP      -    1752C07 YPITE   -    2741C07 YSL     -       2C14
Y1      -       2C13 ZTOT    -    4327

START OF CONSTANTS
  1052


JRCP1
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

START OF TEMPORARIES
  2227

START OF INDIRECTS
  2234

START OF VARIABLES
  2234

SPACE REQUIRED TO COMPILE -- JRCP1
 40200


JRCP1
```

```
                SUBROUTINE DRIVER(NRF,ISTDS,ZTOT,F,SUM,CRWM)
    11          DIMENSION F(501),SUM(501)
    11          COMMON/BLOCK1/RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
    11          COMMON/BLOCK2/ SS(501),AAA,WS(501),MAXITE,CRACKW
    11          COMMON/BLOCK3/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB
    11          COMMON/BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
    11          COMMON/BLOCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
    11           COMMON /BLOCK8/ Y(501),REFF(501),YP(501),H,ICLOSEB,YPITE(501)
    11          COMMON/BLOCKD/STRSC2(501),DIST
    11          COMMON/BLOCKA/Z,YP1,Y1(501),DELTAX,DELTAT,TEMP1,REFF1,YPITE1,W
    11          COMMON/BLOCKB/BHIGH,BLOW,YSL,P2,YST,MODFLAG
    11          COMMON/BLOCKC/STRSC1(501),STRSS1(501),INC,FRF,FY,L
    11          COMMON /BLOCK12/ DT(50),NTEMP,NTIFLAG,UPINC,DOWNINC
    11          REAL L
    11          L=XBAR
    12          IP=0
    13          IFS=0
    14          IF(NRF.NE.1)XOTO 5
    16          P=0.
    17          GOTO 10
    17        5 IF(ISTDS.NE.1)GOTO 10
    21          CALL STDS(FRW,FY,W)
    23       10 CONTINUE
    23          ITIME=0
    24       20 CONTINUE
        C
        C       MAIN LOOP ON TIME
        C
    24          ITIME=ITIME+1
    26          TIME=FLOAT(ITIME)
    27          IF(TIME.GT.28.0)GOTO 30
    36          DELTAT=DT(ITIME)
    37          IGB=0
    40          CALL FORWARD(TENSTRN,ZTOT,Z)
    42          IS=0
    43          CALL MODEL1(TIME,IS,INT)
    46          CALL DIST1(DIST,TENSTRN,IGB)
    51          IF(NRF.EQ.1)XOTO 50
    57          IF(IGB.EQ.1)XOTO 27

    62          IF(DIST.NE.XBAR/2.)GO TO 20
    65          INC=DIST/H
        C
        C       CALCULATE FIRST CRACK WIDTH
        C
    67          DUM=DIST-(INC*H)
    71          IF(DUM.EQ.0.)GOTO 123
    72          YC=DUM*(Y1(INC+1)-Y1(INC))/H
    77          GOTO 12
    77      123 YC=Y1(INC)
   101       12 CRACKW1=2.*ASS(YC)
   104          IF(CRACKW1.GT.CRWM)GOTD 70
   107          IF(CRACKW1.GT.0.00100)GOTO 45
   112          IF(ISTDS.EQ.1)GOTO 38
   113       45 CONTINUE
```

```
   113          PRINT 540, CRACKW1,TIME
   123          IF(MODFLAG.EQ.1)RETURN
   131      250 ISC=1
   132          CALL MODEL2(F,BONDL,Z,DELTAT,SUM,INDEX,STRMAX,ISC)
   141          L=XBAR
   143          DIFF=STRSC-0.75*FY
   146          IF(DIFF.GT.0.1)GOTO 200
        C
        C       SUB-LOOP ON TIME FOR CRACK 2
        C
   155          ITIME=ITIME+1
   156          TIME=FLOAT(ITIME)
   160          IF(TIME.GT.28.0)GOTO 220
   163          DELTAT=DT(ITIME)
   164          CALL FORWARD(TENSTRN,ZTOT,Z)
   166          IS=1
   167          CALL MODEL1(TIME,IS,INT)
   172          ISC=0
   173          CALL MODEL2(F,BONDL,Z,DELTAT,SUM,INDEX,STRMAX,ISC)
   206          L=XBAR
   210          H=L/NT
   212          CALL STRSCO(STRSCON)
   214          IF(TENSTRN.GT.STRSCON)GOTO 250
   223          TENSTRN=STRSCON
   223          CALL DIST1(DIST,TENSTRN,IGB)
        C
        C       CALCULATE THE SECOND CRACK WIDTH
        C
   226          CRACKW2=ABS((STRSCON*DIST)/2.-2.*(Z+ALPHAC*DELTAT))
   235          IF(CRACKW2.GT.CRWM)GOTO 260
   244          ISC=1
   245          CALL MODEL2(F,BONDL,Z,DELTAT,SUM,INDEX,STRMAX,ISC)
   254          L=XBAR
   256          H=L/NT
   260          DIFF=STRSC-0.75*FY
   263          IF(DIFF.GT.0.1)GOTO 200
   272          PRINT 300,TIME,CRACKW2,DIST
   303      300 FORMAT(29H SECOND CRACK OCCURS AT TIME ,F8.4,16H WITH A WIDTH OF ,
              1         F8.4,/,36H AT A DISTANCE FROM THE FREE EDGE OF ,E10.3)
   303          RETURN
   304       30 IF(NRF.EQ.1)XOTO 35

   314          IF(ISTDS.EQ.1)GO TO 38
   316          PRINT 510
   321      510 FORMAT(/,5X,34HNO CRACK OCCURS AT END OF 28 DAYS.)
   321          RETURN
   322       35 CONTINUE
   322          PRINT 520,L
   330          RETURN
   331      200 IF(IFS.EQ.1)GOTO 70
   337          IF(ISTDS.EQ.1)GOTO 270
   340          PRINT 210,STRSC,TIME
   347      210 FORMAT(20H STRESS IN THE STEEL,E10.3,25H IS GREATER THAN ITS WORK
              1,20HING STRENGTH AT TIME,F8.4)
   347          RETURN
   350      220 CONTINUE
```

```
  350           PRINT 230
  354       230 FORMAT(46H AT THE END OF 28 DAYS NO SECOND CRACK OCCURS   )
  354           RETURN
  355       260 CONTINUE
  355           IF (ISTDS.EQ.1)GOTO 270
  363           PRINT 280,CRACKW2,TIME
  372       280 FORMAT(13H SECOND CRACK,F8.4,51H IS WIDER THAN MAXIMUM ALLOWABLE C
               1RACKWIDTH AT TIME    ,F8.4)
  372           RETURN
  373        50 CONTINUE
  373           IF(DIST.LE.XBAR/2.)GOTO 51
  402           IF(DIST.GT.0.75*XBAR)GOTO 52
  406           GOTO 20
  406       520 FORMAT(/,1X,*FOR THE GIVEN INPUT DATA, THE LENGTH OF THE NON-*
               1 ,/,    * REINFORCED SLAB IS *,E10.3,* INCHES.*)
  406        51 CONTINUE
        C
        C       ADJUST LENGTH FOR NON-REINFORCED.
  406           L=L-L/2.
  411           GOTO 10
  411        52 CONTINUE
  411           L=L+L/2.
  414           GOTO 10
  414        60 CONTINUE
  414           PRINT 530, CRACKW1,TIME,STRSC1(INC)
  426       530 FORMAT(/,1X,11H CRACKWIDTH,F8.4,
               154H IS GREATER THAN MAXIMUM ALLOWABLE CRACKWIDTH AT TIME
               2F8.4,/,26H WITH A CONCRETE STRESS OF ,F8.4)
  426           RETURN
  427        70 CONTINUE
  427           IF(ISTDS.NE.1)GOTO 60
  435           IP=IP+1
  436           IF(IP.GT.MAXITE)GOTO 14
        C
        C       ADJUST STEEL PERCENTAGE FOR STEEL DESIGN OPTION
        C
  441           P=P+P/2.
  443           GOTO 10
  444       540 FORMAT(24H WIDTH OF FIRST CRACK IS  ,F8.4,7H INCHES,8H AT TIME,
               1         F8.4,7H DAYS.   ,//)
  444        38 IF(IFS.EQ.1)XOTO 18
  446           P=P-P/2.
  451           IF(P.EQ.0.)G6TO 39
  451           IF(P.LE..00005)P=0.
  454           GOTO 10
  455       270 CONTINUE
  455           SA=THICK*P
  457           SFC=STRSC*SA
  461           SA=SFC/(0.75*FY)
  464           P=SA/THICK
  466           IFS=1
  467           GOTO 10
  467        18 PRINT 915
  473       915 FORMAT(3X,*FOR THE GIVEN SLAB LENGTH, THE PERCENT OF STEEL WAS *
               1    *DICTATED BY THE STEEL *,/,* STRESSES AND NOT BY CRACKWIDTH. *,
               2     /)
```

```
  473           RETURN
  474        27 CALL INTRSCT(TENSTRN,IS,INT,YC,DIST,ZTOT,ISTDS)
  507           IGB=0
  510           GOTO 12
  514        39 CONTINUE
  514           PRINT 550,CRACKW1
  522       550 FORMAT(/,3X,* NO STEEL IS NEEDED, WIDTH OF FIRST CRACK = *,E10.3,
               1        * INCHES. *,/)
  522           GOTO 1000
  526        14 IF(STRSC.LE.0.75*FY)GOTO 15
  532           PRINT 920,STRSC,TIME
  541           GOTO 1000
  545        15 IF(CRACKW1.LE.CRWM)GOTO 45
  550           P=P*100.
  551           PRINT 910,CRACKW1,P
  561           PRINT 920,STRSC,TIME
  571       920 FORMAT(* FOR THE MAX NUMBER OF ITERATION THE STRESS IN THE STEEL*
               1 ,/,* AT THE CRACK IS *,E10.3,* PSI, AT TIME *,F8.4,/)
  571       910 FORMAT(3X,*SLAB LENGTH NEEDS TO BE REDUCED,CRACKW1 = *,E10.3,
               1 ,/,     * INCHES WITH PERCENT STEEL = *,E10.3)
  571      1000 CONTINUE
  571           END
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENGTH
  1043

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
S       -       17   10      -      23   12      -     101   14      -       526
15      -      545   18      -     467   20      -      24   27      -       474
30      -      304   35      -     322   38      -     444   39      -       514
45      -      113   50      -     373   51      -     406   52      -       411
60      -      414   70      -     427   123     -      77   200     -       331
210     -      626   220     -     350   230     -     641   250     -       131
260     -      355   270     -     455   280     -     650   300     -       602
510     -      620   520     -     662   530     -     676   540     -       720
550     -      752   910     -    1002   915     -     733   920     -       765
1000    -      571

EXTERNALS AND TAGS
STOS    -  S00100    FORWARD-  S00200    MODEL1 -  S00300    DIST1   -  S00400
OUTPTC  -  S00500    MODEL2 -  S00600    STRSCO -  S00700    INTRSCT-  S01000
END     -  S01100

BLOCK NAMES AND LENGTHS
BLOCK1 -        12C01 BLOCK2 -     1755C02 BLOCK3 -        6C03 BLOCKS -       30C04
BLOCK6 -        10C05 BLOCK8 -     3726C06 BLOCKD -      766C07 BLOCKA -      775C10
BLOCKB -         6C11 BLOCKC -     1756C12 BLOCK12-      66C13

VARIABLE ASSIGNMENTS
ALPHAC -         0C05 BONDL   -    1033    CRACKW1-     1031    CRACKW2-     1040
DELTAT -       770C10 DIFF    -    1036    DIST    -   765C07 DT      -       0C13
DUM     -     1027    FEXP    -      0C04 FRF     -  1753C12 FY      -    1754C12
H       -     2737C06 IFS     -    1021    IGB     -    1023    INC     -    1752C12
INDEX   -     1034    INT     -    1026    IP      -    1020    IS      -    1025
ISC     -     1032    ITIME   -    1022    L       -  1755C12 MAXITE  -    1753C02
MODFLAG-         5C11 NT      -     25C04 P       -     2C01 REFF    -     765C06
SA      -     1041    SFC     -    1042    SS      -     0C02 STRMAX  -    1035
STRSC   -        1C03 STRSCON-     1037    STRSC1  -    0C12 STRSC2  -       0C07
STRSS1  -      765C12 TENSTRN-     1024    THICK   -     1C01 TIME    -       4C05
W       -      774C10 WS      -    766C02 XBAR    -     0C03 Y       -       0C06
YC      -     1030    YEXP    -     12C04 YP      -  1752C06 YPITE   -    2741C06
Y1      -        2C10 Z       -      0C10

START OF CONSTANTS
   572

START OF TEMPORARIES
  1015

START OF INDIRECTS
  1020

START OF VARIABLES
  1020

SPACE REQUIRED TO COMPILE -- DRIVER
 35600
```

DRIVER

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

                      SUBROUTINE MODEL1(TIME,IS,INT)
      6               COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
      6               COMMON/BLOCK5/FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
      6               COMMON/BLOCK2/ SS(501),AAA,WS(501),MAXITE,CRACKW
      6               COMMON/BLOCKA/Z,YP1,Y1(501),DELTAX,DELTAT,TEMP1,REFF1,YPITE1,W
      6               COMMON/BLOCKC/ STRSC1(501),STRSS1(501),INC,FRF,FY,L
      6               COMMON /BLOC2D/ STRSC2(501),DIST
      6               COMMON/BLOCK8/ Y(501),REFF(501),YP(501),H,ICLOSEB,YPITE(501)
      6               REAL L
      6               IF(INT.EQ.1)XOTO 40
            C         INITIALIZE L6OP PARAMETERS
     10               INC=0
     11               H=L/NT
     13               DELTAX=0.0
            C         MAIN LOOP ON INCREMENT.
     14            10 OELTAX=OELTAX+H
     16               INC=INC+1
     20               IF(DELTAX.GT.L)RETURN
     23               IF(IS.NE.1)G6TO 40
     25               IF(DELTAX.GT.DIST)RETURN
     30            40 F0=0.0
     31               CALL STRSCS(F0)
     33               CALL FRIC1(F1)
     35               REFF1=F1
     37               CALL STRSCS(F1)
     40               CALL FRIC1(F2)
     42               F3=(F1+F2)/2.
     45            20 CONTINUE
     45               CALL BACFRC1(F3)
     47               CALL STRSCS(F3)
     51               CALL CLOSE1(INDEX,F3)
     53               IF(INDEX.EQ.1)GOTO 30
     57               CALL BINRYF1(F3)
     61               GOTO 20
     64            30 CONTINUE
     64               IF(INT.EQ.1)RETURN
     66               IF(P.EQ.0.)G6TO 10
     67               STRSS1(INC)=F3*DELTAX/(P*THICK)-STRSC1(INC)/P
     75               GOTO 10
     75               END
```

MODEL1

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPPOGRAM LENGTH
   105

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
10      -      14    20      -      45    30      -      64    40      -      30

EXTEPNALS AND TAGS
STRSCS -  500100    FRIC1   -  500200    BACFRC1-  500300    CLOSE1 -  500400
BINRYF1-  500500    END     -  500600

RLOCK NAMES AND LENGTHS
BLOCK1 -      12C01 BLOCK5 -      30C02 BLOCK2 -     1755C03 BLOCKA -      775C04
BLOCKC -    1756C05 9LOCKD -     766C06 BLOCK8 -     3726C07

VARIABLE ASSIGNMENTS
DELTAX -     767C04 DIST   -     765C06 FEXP   -        0C02 F0     -      100
F1     -     101    F2     -     102    F3     -     103    H      -      2737C07
INC    -    1752C05 INDEX  -     104    L      -     1755C05 NT     -       25C02
P      -       2C01 REFF   -     765C07 REFF1  -      772C04 SS     -        0C03
STRSC1 -       0C05 STRSC2 -       0C06 STRSS1 -      765C05 THICK  -        1C01
WS     -     766C03 Y      -       0C07 YEXP   -       12C02 YP     -     1752C07
YPITE  -    2741C07 Y1     -       2C04

START OF CONSTANTS
    76

START OF TEMPORARIES
    77

START OF INDIRECTS
   100

START OF VARIABLES
   100

SPACE REQUIRED TO COMPILE -- MODEL1
 33000




MODEL1
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

                   SUBROUTINE OIST1(DIST,TENSTRN,IGB)
      6            COMMON /BLOCK3/XBAR,STRSC,STRSB,STRC,IBABY,ITEB
      6            COMMON /BLOC25/FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
      6            COMMON /9LOCK8/Y(501),REFF(501),YP(501),H,ICLOSEB,YPITE(501)
      6            COMMON /BLOC2C/STRSC1(501),STRSS1(501),INC,FRF,FY,L
      6            DO 10 J=1,NT
      7            IF(ABS(TENSTRN).LE.ABS(STRSC1(J)))GOTO 20
     13         10 CONTINUE
     16            OIST=0.75*XBAR
     17            RETURN
     20         20 IF(J.EQ.1)GOTO 30
     22            OUMDUM=(STRSC1(J)-STRSC1(J-1))/(ABS(H*J)-ABS(H*(J-1)))
     35            DIST=ABS(H*(J-1))+(ABS(TENSTRN)-STRSC1(J-1))/DUMDUM
     47            IF(DIST.GE.XBAR/2.)RETURN
     52         30 IGB=1
     53            RETURN
     54            END




OIST1
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENGTH
    67

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
20      -       20    30      -       52

EXTERNALS AND TAGS
END    -  S00100

BLOCK NAMES AND LENGTHS
BLOCK3 -        6C01 BLOCK5 -      30C02 BLOCK8 -    3726C03 BLOCKC -    1756C04

VARIABLE ASSIGNMENTS
DUMDUM -       66    FEXP   -       0C02 H      -    2737C03 J      -      65
NT     -     25C02 REFF   -     765C03 STRSC1 -       0C04 STRSS1 -     765C04
XBAR   -      0C01 Y      -       0C03 YEXP   -      12C02 YP     -    1752C03
YPITE  -    2741C03

START OF CONSTANTS
    55

START OF TEMPORARIES
    57

START OF INDIRECTS
    65

START OF VARIABLES
    65

SPACE REQUIRED TO COMPILE -- DIST1
 32700
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

                 SUBROUTINE STRSCO(STRSCON)
   3             COMMON /BLOCK8/Y(501),REFF(501),YP(501),H,ICLOSEB,YPITE(501)
   3             COMMON /BLOCKC/STRSC1(501),STRSS1(501),INC,FRF,FY,L
   3             COMMON /BLOC2D/STRSC2(501),DIST
   3             REAL LONG,M,M1
   3             DELTAX=0.0
   4          50 CONTINUE
   4             LONG=(0.50*DIST)-DELTAX
   7             MIS=0
  10             CALL STRSC12(MIS,STRSCO1,STRSCO2,LONG,J,I)
  14             MIS=1
  15             CALL STRSC12(MIS,STRSCO1,STRSCO2,LONG,J,I)
  21             DIFF=STRSCO1-STRSCO2
  23             IF(DIFF)20,30,40
  26          20 DELTAX=DELTAX+H
  30             GOTO 50
  31          30 STRSCON=STRSCO1
  32             RETURN
  33          40 M1=-((STRSC1(I)-STRSC1(I-1))/H)
  37             B1=STRSC1(I-1)
  41             IF(J.EQ.0)GOTO 45
  42             M=(STRSC2(J+1)-STRSC2(J))/H
  45             B=STRSC2(J)
  46          46 STRSCON=(B-B1*M/M1)/(1-M/M1)
  56             RETURN
  56          45 M=STRSC2(J+1)/H
  61             B=0.
  62             GOTO 46
  62             END
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENGTH
   102

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
20      -       26    30       -       31    40       -       33    45       -       56
46      -       46    50       -        4

EXTERNALS AND TAGS
STRSC12-  S00100    END     -  S00200

BLOCK NAMES AND LENGTHS
BLDCKB -     3726C01 BLOCKC -     1756C02 BLOCKD -      766C03

VARIABLE ASSIGNMENTS
B       -      101   BI       -      100   DELTAX -       71   DIFF     -       77
DIST    -     765C03 H        -     2737C01 I       -       76   J        -       75
LONG    -      66    M        -       67   MIS      -       72   MI       -       70
REFF    -     765C01 STRSC01-        73   STRSC02-        74   STRSCI -        0C02
STRSC2 -        0C03 STRSSI -       765C02 Y        -      0C01 YP       -     1752C01
YPITE   -     2741C01

START OF CONSTANTS
    63

START OF TEMPORARIES
    64

START OF INDIRECTS
    66

START OF VARIABLES
    66

SPACE REQUIRED TO COMPILE -- STRSCO
 32600
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

                    SUBROUTINE STRSC12(MIS,STRSC01,STRSC02,LONG,J,I)
     11             COMMON /BLOC25/FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
     11             COMMON /BLOCK8/Y(501),REFF(501),YP(501),H,ICLOESB,YPITE(501)
     11             COMMON /BLOCKC/STRSC1(501),STRSS1(501),INC,FRF,FY,L
     11             COMMON /BLOC20/STRSC2(501),DIST
     11             REAL LONG
     11             DO 100 J=1,NT
     12             IF(ABS(LONG-J*H).LT.0.10)GOTO 110
     17         100 CONTINUE
     21             ILONG=LONG
     22             IF(ILONG.EQ.0)GOTO 120
     23             PRINT 80
     26             PRINT 85,LONX,H
     41          85 FORMAT(* IN STRSC12 *,* LONG = *,E10.3,* H = *,E10.3)
     41          80 FORMAT(40H ERROR IS DETECTED DISTANCES ARE WRONG     )
     41             STOP 100
     43         110 CONTINUE
     43             IF(MIS.NE.1)XOTO 140
     51             DUMDUM=(STRSC2(J)-STRSC2(J-1))/(ABS(H*J)-ABS(H*(J-1)))
     65             STRSC02=STRSC2(J-1)+DUMDUM*(ABS(LONG)-ABS(H*(J-1)))
     76             RETURN
     76         140 CONTINUE
     76              I=(NT+1)/2-J
    101             DUMDUM=(STRSC1(I+1)-STRSCI(I))/(ABS(H*J)-ABS(H*(J-1)))
    113             STRSC01=STRSC1(I)+DUMDUM*(ABS(H*J)-ABS(LONG))
    121             RETURN
    122         120 STRSC02=0.
    123             J=0
    123             I=(NT+1)/2
    125             STRSC01=STRSC1(I)
    127             RETURN
    127             END
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENGTH
   160

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
80      -      141    85      -      133    110     -       43    120     -      122
140     -       76

EXTERNALS AND TAGS
OUTPTC -  S00100    STOP    -  S00200    END     -  S00300

BLOCK NAMES AND LENGTHS
BLOCK5 -       30C01 BLOCKB -     3726C02 BLOCKC -     1756C03 BLOCKD -      766C04

VARIABLE ASSIGNMENTS
DUMDUM -       157    FEXP    -       0C01 H       -     2737C02 ILONG   -      156
NT     -       25C01 REFF    -     765C02 STRSC1 -         0C03 STRSC2 -        0C04
STRSS1 -      765C03 Y       -       0C02 YEXP    -        12C01 YP      -     1752C02
YPITE  -     2741C02

START OF CONSTANTS
   130

START OF TEMPORARIES
   147

START OF INDIRECTS
   156

START OF VARIABLES
   156

SPACE REQUIRED TO COMPILE -- STRSC12
 33200
```

STRSC12

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

                    SUBROUTINE INTRSCT(TENSTRN,IS,INT,YC,DIST,ZTOT,ISTDS)
      12            COMMON/BLOCK2/SS(501),AAA,WS(501),MAXITE,CRACKW
      12            COMMON/BLOCK3/XBAR,STRSC,STRSB,STRC,IBABY,ITEB
      12            COMMON/BLOCK9/STX,STY,PSX,PSY,ITE
      12            COMMON/BLOCKC/STRSC1(501),STRSS1(501),INC,FRF,FY,L
      12            COMMON/BLOCK6/ALPHAC,ALPHAS,EC,FRP,TIME,EP,TOL,ITYPER
      12            COMMON/BLOCK5/FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
      12            COMMON/BLOCKA/Z,YP1,Y1(501),DELTAX,DELTAT,TEMP1,REFF1,YPITE1,W
      12            INC=NT/2
      13            Y1TEMP=STRSC1(INC)
      15            X1=TENSTRN
      16            TIME=TIME-0.5
      20            IDT=0
      21         50 CALL DELTEM1(TIME,DELTAT)
      23            CALL FORWARD(TENSTRN,Z,ZTOT)
      31            DELTAX=XBAR/2.
      33            INT=1
      40            ITE=1
      41            CALL MODEL1(TIME,IS,INT)
      42            IF(IDT.EQ.1)XOTO 30
      50            X2=TENSTRN
      51            Y2=STRSC1(INT)
      53            IF(TIME.LE.0.1)GOTO 80
      55            IF(Y2-X2)20,30,10
      60         10 TIME=TIME-0.1
      62            GOTO 50
      63         20 X2=TENSTRN
      64             Y2=STRSC1(INC)
      66            0IF=(Y2-X2)/X2
      71            IF(ABS(DIF).3E.TOL)GOTO 30
      74            ITE=ITE+1
      75            IF(ITE.GT.MAXITE)GOTO 35
     100            CALL GETME(X1,Y1TEMP,X2,Y2,FOUT)
     103            TENSTRN=FOUT
     110            CALL BACKTIM(TENSTRN,ZTOT,Z)
     112            CALL OELTEM1(TIME,DELTAT)
     114            CALL MODEL1(TIME,IS,INT)
     121            GOTO 20
     125         30 INT=0
     126            DIST=XBAR/2.
     127            YC=Y1(INC)
     131            RETURN
     132         80 TIME=0.33
     134            IDT=1
     135            IF(ISTDS.EQ.1)GOTO 50
     137            PRINT 400
     142        400 FORMAT(* SLAB GETS A CRACK RIGHT AFTER CONCRETE PLACEMENT *
                  1  ,/,*.  THE TIME IS ASSUMED TO BE 0.33 DAYS. *,/)
     142            GOTO 50
     146         35 6ONTINUE
     146            PRINT 355,ITE,MAXITE
     156        355 FORMAT(*  THE SOLUTION DID NOT CLOSE IN INTRSCT.*,I3,I3,//)
     156            END
```

INTRSCT

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENGTH
   221

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
10      -       60    20      -        63    30      -       125   35      -        146
50      -       21    80      -       132    355     -       202   400     -        165

EXTERNALS AND TAGS
DELTEM1-  S00100    FORWARD-  S00200    MODEL1 -  S00300    GETME  -  S00400
BACKTIM-  S00500    OUTPTC -  S00600    END    -  S00700

BLOCK NAMES AND LENGTHS
BLOCK2 -     1755C01 BLOCK3 -        6C02 BLOCK9 -       5C03 BLOCKC -     1756C04
BLOCK6 -       10C05 BLOCK5 -       30C06 BLOCKA -     775C07

VARIABLE ASSIGNMENTS
DELTAT -      770C07 DELTAX -      767C07 DIF    -     217    FEXP   -         0C06
FOUT   -      220    IDT    -      214    INC    -    1752C04 ISTOS  -         0
ITE    -        4C03 MAXITE -     1753C01 NT     -      25C06 SS     -         0C01
STRSC1 -        0C04 STRSS1 -      765C04 TIME   -       4C05 TOL    -         6C05
WS     -      766C01 XBAR   -        0C02 X1     -     213    X2     -       215
YEXP   -       12C06 Y1     -        2C07 Y1TEMP -     212    Y2     -       216
Z      -        0C07

START OF CONSTANTS
   157

START OF TEMPORARIES
   210

START OF INDIRECTS
   212

START OF VARIABLES
   212

SPACE REQUIRED TO COMPILE -- INTRSCT
 33400
```

INTRSCT

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

                      SUBROUTINE STOS(FRF,FY,W)
      6               COMMON/BLOCK1/RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNMT
      6               COMMON/BLOCK3/XBAR,STRSC,STRSB,STRC,IBABY,ITEB
      6               COMMON/BLOCK6/ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
      6               COMMON/BLOCK8/BHIGH,BLOW,YSL,P2,YST,MODFLAG
      6               REAL L
      6               L=XBAR/12.
     10               FS=0.75*FY
     11               P=L*FRF/(2.*FS)
     14               AB=3.1416/4*DIA**2
     20               P2=W*FRF*100.0/(2.*FS)
     23               IF(ITYPER.EQ.1)GOTO 10
     25               BHIGH=AB/(THICK*P2)
     30               PRINT 500,P2,BHIGH
     37               BLOW=BHIGH/2.
     41               RETURN
     42            10 YST=AB*100./(THICK*P2)
     46               PRINT 510,P2,YST
     55               RETURN
     56           500 FORMAT(* FOR ITYPER EQUAL TO 2, THE TRANSVERSE STEEL IS *,E10.3,
                    1    * PERCENT SPACED.*,/,*E10.3,* INCHES CENTER TO CENTER.*)
     56           510 FORMAT(* FOR ITYPER EQUAL TO 1, THE TRANSVERSE STEEL IS *,E10.3,
                    1    * PERCENT SPACED.*,E10.3,/,* INCHES CENTER TO CENTER.*)
     56               END
```

STOS

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENGTH
   123

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
10      -       42     500      -       66     510      -       103

EXTERNALS AND TAGS
OUTPTC -  S00100     END     -  S00200

BLOCK NAMES AND LENGTHS
BLOCK1 -       12C01 BLOCK3 -        6C02 BLOCK6 -       10C03 BLOCKB -        6C04

VARIABLE ASSIGNMENTS
AB      -       122    BHIGH  -        0C04 BLOW    -        1C04 DIA     -       10C01
FS      -       121    ITYPER -        7C03 L       -      120    P       -        2C01
P2      -          3C04 THICK  -        1C01 XBAR    -        0C02 YST     -        4C04

START OF CONSTANTS
    57

START OF TEMPORARIES
   117

START OF INDIRECTS
   120

START OF VARIABLES
   120

SPACE REQUIRED TO COMPILE -- STDS
 32700




STDS
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75


                SUBROUTINE STRSCS(FRIC1)
      3         COMMON/BLOCK1/RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
      3         COMMON/BLOCK6/ALPHAC,ALPHAS,EC,FRP,TIME,EP,TOL,ITYPER
      3         COMMON/BLOCKA/Z,YP1,Y1(501),DELTAX,DELTAT,TEMP1,REFF1,YPITE1,W
      3         COMMON/BLOCKC/STRSC1(501),STRSS1(501),INC,FRF,FY,L
      3         DUMDUM=FRIC1*DELTAX/(THICK*(1+P*ES/EC))
     12         STRSC1(INC)=DUMDUM+P*ES*(Z+DELTAT*(ALPHAC-ALPHAS))/(1+P*ES/EC)
     26         Y1(INC)=STRSC1(INC)*DELTAX/EC-DELTAX*(ALPHAC*DELTAT+Z)
     35         RETURN
     35         END




STRSCS
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENGTH
    41

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS

EXTERNALS AND TAGS
END     -  S00100

BLOCK NAMES AND LENGTHS
BLOCK1 -       12C01 BLOCK6 -       10C02 BLOCKA -      775C03 BLOCKC -     1756C04

VARIABLE ASSIGNMENTS
ALPHAC -        0C02 ALPHAS -        1C02 DELTAT -      770C03 DELTAX -      767C03
DUMDUM -       40    EC     -        2C02 ES     -        5C01 INC    -     1752C04
P      -        2C01 STRSC1 -        0C04 STRSS1 -      765C04 THICK  -        1C01
Y1     -        2C03 Z      -        0C03

START OF CONSTANTS
    36

START OF TEMPORARIES
    36

START OF INDIRECTS
    40

START OF VARIABLES
    40

SPACE REQUIRED TO COMPILE -- STRSCS
 32600
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

                 SUBROUTINE FRIC1(FA)
      3          COMMON/BLOCK5/FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
      3          COMMON/BLOCKA/Z,YP1,Y1(501),DELTAX,DELTAT,TEMP1,REFF1,YPITE1,W
      3          COMMON/BLOCKC/STRSC1(501),STRSS1(501),INC,FRF,FY,L
      3          IF(IFY.EQ.1)XOTO 10
      5          IF(IFY.EQ.2)XOTO 40
      7          GOTO 90
      7       10 CONTINUE
      7          SLOPE=FRICMUL
     11          FA=Y1(INC)*SLOPE
     13          IF(ABS(FA).LE.FU)RETURN
     16          IF(FA.GT.0.0)FA=FU
     21          IF(FA.LE.0.0)FA=-FU
     24          RETURN
     25       40 CONTINUE
     25          IF(Y1(INC).GT.0.0)GOTO 50
     30          FA=FRICMUL*SQRT(ABS(Y1(INC)))
     35          GOTO 60
     36       50 CONTINUE
     36          FA=-FRICMUL*SQRT(Y1(INC))
     44       60 CONTINUE
     44          IF(ABS(FA).LE.FU)RETURN
     50          IF(FA.GT.0.0)FA=FU
     53          IF(FA.LT.0.0)FA=-FU
     56          RETURN
     57       90 CONTINUE
     57          DO 100 J=1,IWY
     61          IF(ABS(Y1(INT)).LT.ABS(YEXP(J)))GOTO 110
     67      100 CONTINUE
     72          FA=FEXP(IFY)
     73          GOTO 120
     73      110 CONTINUE
     73          DUMDUM=(FEXP(J)-FEXP(J-1))/(ABS(YEXP(J))-ABS(YEXP(J-1)))
    102          FA=FEXP(J-1)+DUMDUM*(ABS(Y1(INC))-ABS(YEXP(J-1)))
    112      120 CONTINUE
    112          IF(Y1(INC).GT.0.0)FA=-FA
    115          RETURN
    116          END
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENGTH
   125

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
10      -        7    40      -        25    50      -        36    60      -        44
90      -       57    110     -        73    120     -       112

EXTERNALS AND TAGS
SQRT    -  S00100     END     -  S00200

BLOCK NAMES AND LENGTHS
BLOCKS -       30C01 BLOCKA -      775C02 BLOCKC -    1756C03

VARIABLE ASSIGNMENTS
DUMDUM -     124     FEXP    -       0C01 FRICMUL-      24C01 FU      -       26C01
IFY    -       27C01 INC     -    1752C03 J       -     123     SLOPE   -     122
STRSC1 -        0C03 STRSS1 -      765C03 YEXP    -      12C01 Y1      -        2C02

START OF CONSTANTS
   117

START OF TEMPORARIES
   117

START OF INDIRECTS
   122

START OF VARIABLES
   122

SPACE REQUIRED TO COMPILE -- FRIC1
 33100




FRIC1
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

                  SUBROUTINE BACFRC1(F3)
      3           COMMON /BLOC25/FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
      3           COMMON/BLOCKA/Z,YP1,Y1(501),DELTAX,DELTAT,TEMP1,REFF1,YP1TE1,W
      3           IF(FRICMUL.EQ.0.0)RETURN
      5           IF(IFY.EQ.1)XOTO 40
      7           IF(IFY.EQ.2)XOTO 60
     11           DO 10 J=1,IFY
     12           IF(ABS(F3).LT.ABS(FEXP(J)))GOTO 20
     16        10 CONTINUE
     20           YP1=YEXP(IFY)
     22           RETURN
     22        20 CONTINUE
     22           DUMDUM=(FEXP(J)-FEXP(J-1))/(ABS(YEXP(J))-ABS(YEXP(J-1)))
     31           YP1=ABS(YEXP(J-1))+(ABS(F3)-FEXP(J-1))/DUMDUM
     37           IF(F3.GT.0.0)YP1=-YP1
     41           RETURN
     42        40 CONTINUE
     42           YP1=F3/FRICMUL
     44           IF(ABS(F3).GE.FU)YP1=YEXP(1)
     50           RETURN
     51        60 CONTINUE
     51           YP1=(F3/FRICMUL)**2
     53           IF(ABS(F3).GE.FU)YP1=YEXP(1)
     60           IF(F3.GT.0.0)YP1=-YP1
     63           RETURN
     64           END




BACFRC1
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENGTH
    70

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
20      -       22    40      -       42    60      -       51

EXTERNALS AND TAGS
END     -  S00100

BLOCK NAMES AND LENGTHS
BLOCKS -      30C01 BLOCKA -     775C02

VARIABLE ASSIGNMENTS
DUMDUM -       67    FEXP    -       0C01 FRICMUL-      24C01 FU      -       26C01
IFY    -       27C01 J       -      66    YEXP    -     12C01 YP1     -        1C02
Y1     -        2C02

START OF CONSTANTS
    65

START OF TEMPORARIES
    65

START OF INDIRECTS
    66

START OF VARIABLES
    66

SPACE REQUIRED TO COMPILE -- BACFRC1
 32700
```

BACFRC1

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

                SUBROUTINE BINRYF1(F3)
      3         COMMON/BLOCKA/Z,YP1,Y1(501),DELTAX,DELTAT,TEMP1,REFF1,YPITE1,W
      3         COMMON/BLOCKC/STRSC1(501),STRSS1(501),INC,FRF,FY,L
      3         IF(YP1.GT.Y1(INC))GOTO 10
      7         TEMP1=REFF1
     10         REFF1=F3
     11         F3=(3.*F3-TEMP1)/2.
     14         RETURN
     14      10 CONTINUE
     14         F3=(REFF1+F3)/2.
     17         RETURN
     17         END
```

BINRYF1

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENGTH
    23

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
10      -       14

EXTERNALS AND TAGS
ENO     -  S00100

BLOCK NAMES AND LENGTHS
BLOCKA -      775C01 BLOCKC -    1756C02

VARIABLE ASSIGNMENTS
INC     -     1752C02 REFF1   -      772C01 STRSC1 -        0C02 STRSS1 -      765C02
TEMP1   -      771C01 YP1     -        1C01 Y1     -        2C01

START OF CONSTANTS
    20

START OF TEMPORARIES
    22

START OF INDIRECTS
    23

START OF VARIABLES
    23

SPACE REQUIRED TO COMPILE -- BINRYF1
 32400
```

BINRYF1

```
RUNW VERSION FEB 74 I6.51.06. 23 JUL 75

               SUBROUTINE C3OSE1(INDEX,F3)
      5        COMMON/BLOCK2/SS(501),AAA,WS(501),MAXITE,CRACKW
      5        COMMON /BLOCK6/ ALPHAC,ALPHAS,EC,FRC,TIME,EP,TOL,ITYPER
      5        COMMON/BLOCKA/Z,YP1,Y1(501),DELTAX,DELTAT,TEMPI,REFF1,YP1TE1,W
      5         COMMON/BLDCKC/STRSC1(501),STRSS1(501),1NC,FRF,FY,L
      5        INTEGER AAA
      5        INDEX=0
      5        BAD=1.
      7        IF(AAA.EQ.1)XOTO 50
     11        IF(Y1(INC).EQ.0.0)GOTO 10
     12        IF(ABS(Y1(INT)).LT.1.E-06)GOTO 10
     16        DIF1=(Y1(INC)-YPITE1)/Y1(INC)
     21        IF(ABS(DIF1).GT.TOL)BAD=BAD+1.
     26     10 CONTINUE
     26        IF(BAD.GT.1.)GOTO 50
     32        INDEX=1
     32        AAA=1
     33        RETURN
     34     50 CONTINUE
     34        AAA=AAA+1
     36        IF(AAA.GT.MAXITE)GOTO 70
     41        MA1=AAA-1
     41        YPITE1=Y1(INC)
     43    110 FORMAT(* MA1 IS*,I5,*BAD IS*,F5.1,* AAA IS *,I5)
     43        RETURN
     44     70 CONTINUE
     44        PRINT 120
     50        PRINT 110,MA1,BAD,AAA
     62    120 FORMAT(* IN SUBROUTINE CLOSE1 THE SOLUTION DID NOT CLOSE*)
     62        END
```

CLOSE1

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENGTH
   110

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
10      -       26    50      -       34    70      -       44    110     -       67
120     -       76

EXTERNALS AND TAGS
OUTPTC -  S00100     END     -  S00200

BLOCK NAMES AND LENGTHS
BLOCK2 -     1755C01 BLOCK6 -       10C02 BLOCKA -      775C03 BLOCKC -     1756C04

VARIABLE ASSIGNMENTS
AAA    -      765C01 BAD     -      105     DIF1    -     106     INC     -     1752C04
MAXITE -     1753C01 MAI     -      107     SS      -       0C01 STRSC1 -        0C04
STRSS1 -      765C04 TOL     -        6C02 WS      -     766C01 YPITE1 -      773C03
Y1     -        2C03

START OF CONSTANTS
    63

START OF TEMPORARIES
   104

START OF INDIRECTS
   105

START OF VARIABLES
   105

SPACE REQUIRED TO COMPILE -- CLOSE1
 32700


CLOSE1
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

                    SUBROUTINE FORWARD (TENSTRN,ZTOT,Z)
             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      ******************************************************************
         6          COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
         6          COMMON /BLOC22/ SS(501),AAA,WS(501),MAXITE,CRACKW
         6          COMMON /BLOCK3/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB
         6          COMMON /BLOCK4/ AL(501),STRAIN(501),CONSTR(501),STRESSS(501)
         6          COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
         6          COMMON /BLOC26/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
         6          COMMON /BLOCK8/ Y(501),REFF(501),YP(501),H,ICLOSEB,YPITE(50I)
         6          COMMON /BLOCK10/ NSTRN,VDS,AGEU(20),TENSION(20),STRNMUL
         6          DIMENSION PERCENT(8),AGE(8)
         6          DATA PERCENT/0.,15.,38.,53.,63.,82.,94.,100./
         6          DATA AGE/0.,3.,3.,5.,7.,14.,21.,28./
         6          INTEGER AAA
             C
         6             IF (NSTRN.GT.0.) GO TO 30
        10          DO 10 I=1,8
        11                   J=I
        11             IF (TIME.3E.AGE(I)) GO TO 20
        14     10   CONTINUE
        16          PRINT 80, TIME
        24             GO TO 70
        27     20   CONTINUE
        27                   PERCOM=(PERCENT(J)-PERCENT(J-1))/(AGE(J)-AGE(J-1))
        34                   PERTOM=PERCENT(J-1)+PERCOM*(TIME-AGE(J-1))
        40                   COMSTR=PERCOM*FPC/100
        42                   FLESTRN=3000./(3.+12000./COMSTR)
        46                   TENSTRN=FLESTRN*STRNMUL
        47             GO TO 60
        50     30   CONTINUE
        50          DO 40 1=1,NSTRN
        52                   J=I
        52             IF (TIME.3E.AGEU(I)) GO TO 50
        55     40   CONTINUE
        60          PRINT 80, TIME
        65             GO TO 70
        70     50   CONTINUE
             C
             C      COMPUTE SLOPE BY LINEAR INTERPOLATION
             C
        70                   SLOPE=(TENSION(J)-TENSION(J-1))/(AGEU(J)-AGEU(J-I))
        75                   TENSTRN=TENSION(J-1)+SLOPE*(TIME-AGEU(J-1))
       101                   FLESTRN=TENSTRN/STRNMUL
       102                   COMSTR=(12000.*FLESTRN)/(3000.-3.*FLESTRN)
             C
       106     60   CONTINUE
             C
       106                   EC=33.*(UNWT**1.5)*SQRT(COMSTR)
       116                   RATIO=ES/EC
       117                   U=9.5*SQRT(COMSTR)/DIA
       124              IF (U.GT.800.) U=800.


FORWARD
```

```
   131                SHRN=26.*EXP(0.36*VDS)
   137                Z=(TIME/(SHRN*TIME))*ZTOT
   143         RETURN
   144     70  CONTINUE
   144     80  FORMAT (//,10X,*ERROR IS DETECTEO 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*)
   144          END
```

```
SUBPROGRAM LENGTH
   242

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
20      -       27    30      -       50    50      -        70   60      -       106
70      -      144    80      -      161

EXTERNALS AND TAGS
OUTPTC -  S00100     SQPT    -  S002C0     RBAREX -  S00300     EXP     -  S00400
END    -  S00500

BLOCK NAMES AND LENGTHS
BLOCK1 -       12C01 BLOCK2 -     1755C02 BLOCK3 -        6C03 BLOCK4 -     3724C04
BLOCK5 -       30C05 BLOCK6 -        10C06 BLOCK8 -     3726C07 BLOCK10-       53C10

VARIABLE ASSIGNMENTS
AAA     -     765C02 AGE     -     223    AGEU    -        2C10 AL      -        0C04
COMSTR -     236     CONSTR -    1752C04 DIA     -       10C01 EC      -        2C06
ES      -       5C01 FEXP    -        0C05 FLESTRN-     237     FPC     -        3C06
I       -     233    J       -     234    NSTRN  -        0C10 PERCENT-     213
PERCOM -     235    RATIO  -        0C01 REFF    -     765C07 SHRN    -     241
SLOPE  -     240    SS      -        0C02 STRAIN -     765C04 STRESSS-     2737C04
STRNMUL-       52C10 TENSION-       26C10 TIME    -        4C06 U       -        7C01
UNWT    -       11C01 VDS     -        1C10 WS      -     766C02 Y       -        0C07
YEXP    -       12C05 YP      -     1752C07 YPITE  -     2741C07

START OF CONSTANTS
   I45

START OF TEMPORARIES
   210

START OF INDIRECTS
   213

START OF VARIABLES
   213

SPACE REQUIRED TO COMPILE -- FORWARD
 33500
```

```
                SUBROUTINE MODEL2 (F,BONDL,Z,DELTAT,SUM,INDEX,STRMAX,ISC)
      13        DIMENSION F(S01),SUM(S01)
      13        COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
      13        COMMON /BLOCK2/ SS(S01),AAA,WS(S01),MAXITE,CRACKW
      13        COMMON /BLOC23/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB
      13        COMMON /BLOCK4/ AL(S01),STRAIN(S01),CONSTR(S01),STRESSS(S01)
      13        COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
      13        COMMON /BLOCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
      13        COMMON /BLOC28/ Y(501),REFF(501),YP(S01),H,ICLOSEB,YPITE(S01)
      13        COMMON /BLOCK9/ STX,STY,PSX,PSY,ITE
      13        COMMON /BLOC214/ IFINISH
      13         COMMON /BLOCKC/ STRSC1(501),STRSS1(S01),INC,FRF,FY,L
      13        COMMON /BLOC2D/STRSC2(S01),DIST
      13        REAL NEGT
      13        INTEXER AAA
      13        REAL L
      13         IF(ISC.EQ.1)GOTO 15
      15        INC=2
      16        GH=XBAR/NT
      20        L=0.0
      21     18 L=GH+L
      23        H=L/NT
      25        INC=INC+1
      27        GOTO 16
      27     15 CONTINUE
      27        L=DIST/2.
      31        H=L/NT
      33        INC=NT/2
      34     16 CONTINUE
      34        DO 10 I=1,NTP1
      36                  Y(I)=REFF(I)=YP(I)=AL(I)=F(I)=0.
      54                  SS(I)=STRAIN(I)=CONSTR(I)=STRESSS(I)=0.
      66    10  CONTINUE
      70            IF (ITYPER.EQ.1) CALL DFBAR (BONDL,STRMAX,Z,DELTAT)
     100            IF (ITYPER.EQ.2) CALL DFWIRE (BONDL,STRMAX,Z,DELTAT)
     110           IF (BONDL.GE.L) GO TO 80
     113        IF(L.GT.0.75*DIST)GOTO 88
     117                  STRAINC=STRMAX/EC
     121        CALL STRGENE (BONDL)
     122        CALL SIMPSPE (STRAIN,NTP1,H,SUM)
     131        CALL CONMOV (SUM,Z,DELTAT)
     137        CALL FRIC (F)
     144        DO 20 J=1,NTP1
     151                  REFW(J)=F(J)
     153    20  CONTINUE
     156            IF (ITYPER.EQ.1) CALL DFBARF (F,BONDL,STRMAX,Z,DELTAT)
     167            IF (ITYPER.EQ.2) CALL DFWIREF (F,BONDL,STRMAX,Z,DELTAT)
     201        IF(BONDL.GE.3)GOTO 80
     204        CALL SIMPSPE (STRAIN,NTP1,H,SUM)
     207        CALL CONMOV (SUM,Z,DELTAT)
     215        CALL FRIC (F)
     222        DO 30 J=1,NTP1
     227                  F(J)=(REFF(J)+F(J))/2.
     233    30  CONTINUE
     235        CALL SIMPSPE (F,NTP1,H,SUM)
```

```
     240                  FF=SUM(NTP1)
     246    40  CONTINUE
     246            IF (AAA.LT.MAXITE) GO TO 50
     251        PRINT 90, AAA
     256        PRINT 100
     262        PRINT 110, (I,AL(I),REFF(I),YP(I),Y(I),F(I),I=1,NTP1)
     335        STOP
     337    50  CONTINUE
     337        CALL BAKFRIC (F)
     344             IF (ITYPER.EQ.1) CALL DFBARF (F,BONDL,STRMAX,Z,DELTAT)
     361             IF (ITYPER.EQ.2) CALL DFWIREF (F,BONDL,STRMAX,Z,DELTAT)
     373        IF(BONDL.GE.3)GOTO 80
     376        CALL SIMPSPE (STRAIN,NTP1,H,SUM)
     401    201 FORMAT(10X,*BONDL IN MODEL2 =*,E10.3,//)
     401        CALL CONMOV (SUM,Z,DELTAT)
     407        CALL CLOSE (NTP1,INDEX,F)
     415            IF (INDEX.EQ.1.AND.ICLOSEB.EQ.I) GO TO 70
     430        CALL BINARYF (F)
     431        CALL SIMPSPE (F,NTP1,H,SUM)
     437                  FF=SUM(NTP1)
     445           GO TO 40
     446    70  CONTINUE
     446        STRSC2(INC)=STRMAX
     451        IF(ISC.EQ.1)RETURN
     453        IF(L.LE.DIST/2.)GO TO 18
     457     88 DELTAX=L
        C       PRINT 161
     461    161 FORMAT(10X,*STRSC2*,9X,*  INC  *,/)
        C       PRINT 160,(STRSC2(I),I,I=1,INC)
     461        RETURN
     461    80  CONTINUE
     461        STRSC2(INC)=STRMAX
     464        IF(ISC.EQ.1)RETURN
     466        IF(L.LE.DIST/2.)GOTO 18
     472     81 CONTINUE
     472        PRINT 150
     476        RETURN
     477    150 FORMAT(//,10X,* BOND LENGTH IS GREATER THAN DIST.*)
     477    160 FORMAT(10X,E10.3,5X,I5)
     477   90   FORMAT (//,10X,*RESULTS FOR ITERATION *, I5,/)
     477   100  FORMAT (/,12X,*I*,7X,*AL(I)*,7X,*REFF*,9X,*YP*,11X,*Y*,11X,*F*,/)
     477   110  FORMAT (10X,I5,5(2X,E10.3))
     477   130  FORMAT (  10X,* STRMAX =*,E10.3)
     477   140  FORMAT (//,15X,* FOR TIME OF * ,E10.3,/,
               1   10X,*SHRINKAGE=*,E10.3,/,
               2   10X,*DELTAT   =*,E10.3)
     477        END
```

```
RUNW VERSION FEB 74 16.S1.06. 23 JUL 75

SUBPROGRAM LENGTH
   613

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
15      -        27    16      -        34    18      -        21    40      -       246
50      -       337    70      -       446    80      -       461    81      -       472
88      -       457    90      -       530    100     -       535    110     -       544
130     -       550    140     -       554    150     -       517    160     -       525
161     -       513    201     -       506

EXTERNALS AND TAGS
DFBAR  -  S00100      DFWIRE -  S00200      STRGENE-  S00300      SIMPSPE-  S00400
CONMOV -  S00500      FRIC   -  S00600      DFBARF -  S00700      DFWIREF-  S01000
OUTPTC -  S01100      STOP   -  S01200      BAKFRIC-  S01300      CLOSE  -  S01400
BINARYF-  S01500      END    -  S01600

BLOCK NAMES AND LENGTHS
BLOCK1 -       12C01 BLOCK2 -     1755C02 BLOCK3 -        6C03 BLOCK4 -     3724C04
BLOCK5 -       30C05 BLOCK6 -       10C06 BLOCK8 -     3726C07 BLOCK9 -        5C10
BLOCK14-        1C11 BLOCKC -     1756C12 BLOCKO -      766C13

VARIABLE ASSIGNMENTS
AAA     -     765C02 AL      -        0C04 CONSTR -     1752C04 DELTAX -      612
DIST    -     765C13 EC      -        2C06 FEXP   -        0C05 FF     -        3C01
GH      -     607    H       -     2737C07 I      -      610    ICLOSEB-     2740C07
INC     -    1752C12 ISC     -        1    ITYPER -        7C06 J      -      611
L       -    1755C12 MAXITE -     1753C02 NEGT   -      606    NT     -       25C05
NTP1    -       6C01 REFF    -      765C07 SS     -        0C02 STRAIN -      765C04
STRAINC-        4C01 STRESSS-     2737C04 STRMAX -        0    STRSC1 -        0C12
STRSC2 -        0C13 STRSS1 -      765C12 WS     -      766C02 XBAR   -        0C03
Y       -       0C07 YEXP    -       12C05 YP     -     1752C07 YPITE  -     2741C07

START OF CONSTANTS
   500

START OF TEMPORARIES
   574

START OF INDIRECTS
   577

START OF VARIABLES
   606

SPACE REQUIRED TO COMPILE -- MODEL2.
 35100




MODEL2
```

```
RUNW VERSION FEB 74 16.S1.06. 23 JUL 75

                      SUBROUTINE C6NMOV (SUM,Z,OELTAT)
               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      ****************************************************************
          6           DIMENSION SUM(501)
          6           COMMON /BLOCK1/ RAT1O,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
          6           COMMON /BLOCK2/ SS(501),AAA,WS(501),MAXITE,CRACKW
          6           COMMON /BLOC23/ XBAR,STRSC,STRSB,STRC,1BABY,1TEB
          6           COMMON /BLOCK4/ AL(501),STRAIN(501),CONSTR(501),STRESSS(501)
          6           COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU
          6           COMMON /BLOCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL
          6           COMMON /BLOC28/ Y(501),REFF(501),YP(501),H,1CLOSEB,YPITE(501)
          6           INTEGER AAA
          6           DO 10 I=1,NTP1
          7                   Y(I)=SUM(I)-AL(I)*(ALPHAC*DELTAT+Z)+Y(I)
         15              IF (ABS(Y(I)).GT.1.) GO TO 20
         22       10  CONTINUE
         24           RETURN
         24       20  CONTINUE
         24           PRINT 50, (Y(I),I=1,NTP1)
         37       50  FORMAT (/,10X,47H MOVEMENTS GREATER THAN 1 INCH ARE ENCOUNTERED ,
                     1,      10X,8(2X,E10.3))
         37           END




CONMOV
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENGTH
    57

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
20      -       24    50      -       43

EXTERNALS AND TAGS
OUTPTC -  S00100    END     -  S00200

BLOCK NAMES AND LENGTHS
BLOCK1 -      12C01 BLOCK2 -    1755C02 BLOCK3 -       6C03 BLOCK4 -    3724C04
BLOCK5 -      27C05 BLOCK6 -       7C06 BLOCK8 -    3726C07

VARIABLE ASSIGNMENTS
AAA     -    765C02 AL      -      0C04 ALPHAC -       0C06 CONSTR -    1752C04
FEXP    -      0C05 I       -     56    NTP1   -       6C01 REFF   -     765C07
SS      -      0C02 STRAIN -     765C04 STRESSS-    2737C04 WS     -     766C02
Y       -      0C07 YEXP    -     12C05 YP     -    1752C07 YPITE  -    2741C07

START OF CONSTANTS
    40

START OF TEMPORARIES
    54

START OF INDIRECTS
    56

START OF VARIABLES
    56

SPACE REQUIRED TO COMPILE -- CONMOV
 32700
```

CONMOV

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

                 SUBROUTINE C3OSE (N,INDEX,F)
           C     ****************************************************************
           C         THIS SUBROUTINE IS USED WITH THE BINARY TECHNIQUE
           C         OF MOVEMENT CLOSURE
           C     ****************************************************************
      6          COMMON /BLOCK2/ SS(501),AAA,WS(501),MAXITE,CRACKW
      6          COMMON /BLOCK4/ AL(501),STRAIN(501),CONSTR(501),STRESSS(501)
      6          COMMON /BLOCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
      6          COMMON /BLDC28/ Y(501),REFF(501),YP(501),H,ICLOSEB,YPITE(501)
      6          DIMENSION DIW(501),F(501)
      6          INTEGER AAA
      6                  INDEX=0
      6                  BAD=1.
     10             IF (AAA.EQ.1) GO TO 50
     12          DO 20 I=2,N
     13             IF (Y(I).EQ.0.) GO TO 10
     14             IF (ABS(Y(I)).LT.1.E-06) GO TO 10
     20                  DIF(I)=(Y(I)-YPITE(I))/Y(I)
     23               IF (ABS(DIF(I)).GT.TOL) BAD=BAD+1.
     31      10  CONTINUE
     31      20  CONTINUE
     34             IF (BAD.GT.1.) GO TO 50
     37                  INDEX=1
     37                  AAA=1
     40          RETURN
     41      50  CONTINUE
           C
     41                  AAA=AAA+1
     43             IF (AAA.GT.MAXITE) GO TO 70
     46                  MA1=AAA-1
     46          DO 60 I=1,N
     50                  YPITE(I)=Y(I)
     52      60  CONTINUE
     54          RETURN
     54      70  CONTINUE
     54          PRINT 120
     60          PRINT 110, MA1,BAD,AAA
     72          PRINT 80
     76          PRINT 130, ((I,Y(I),YPITE(I),OIF(I),SS(I),STRESSS(I),STRAIN(I),
                1     CONSTR(I),F(I)),I=1,N)
    154      80  FORMAT (//,28X,*      Y           YPITE        DIF      *,/)
    154     110  FORMAT (//,10X,* SOLUTION OIO 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,//)
    154     120  FORMAT (//,10X,* BAO LUCK, SOLUTION DID NOT CLOSE *,//)
    154     130  FORMAT ( 20X,I5,8(2X,E10.3))
    154          END
```

CLOSE

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENGTH
  1217

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
10      -       31   20      -       31   50      -       41   70      -       54
80      -      162   110     -      170   120     -      213   130     -      221

EXTERNALS AND TAGS
OUTPTC -  S00100    END     -  S00200

BLOCK NAMES AND LENGTHS
BLOCK2 -    1755C01 BLOCK4 -    3724C02 BLOCK6 -      10C03 BLOCK8 -    3726C04

VARIABLE ASSIGNMENTS
AAA     -     765C01 AL      -       0C02 BAD     -    1214    CONSTR -    1752C02
DIF     -     227    I       -    1215    MAXITE -    1753C01 MAI     -    1216
REFF    -     765C04 SS      -       0C01 STRAIN -     765C02 STRESSS-    2737C02
TDL     -       6C03 WS      -     766C01 Y       -       0C04 YP      -    1752C04
YPITE   -    2741C04

START OF CONSTANTS
   155

START OF TEMPORARIES
   224

START OF INDIRECTS
   227

START OF VARIABLES
   227

SPACE REQUIRED TO COMPILE -- CLOSE
 33300
```

CLOSE

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

                  SUBROUTINE BAKFRIC (F)
      3           DIMENSION F(501)
      3           COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
      3           COMMON /BLOC22/ SS(501),AAA,WS(501),MAXITE,CRACKW
      3           COMMON /BLOCK3/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB
      3           COMMON /BLOCK4/ AL(501),STRAIN(501),CONSTR(501),STRESSS(501)
      3           COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
      3           COMMON /BLOC26/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
      3           COMMON /BLOC28/ Y(501),REFF(501),YP(501),M,ICLOSEB,YPITE(501)
      3           INTEGER AAA
      3               IF (FRICMUL.EQ.0.0) RETURN
      5              IF (IFY.EQ.1) GO TO 40
      7              IF (IFY.EQ.2) GO TO 60
     11           DO 30 I=1,NTP1
     12           DO 10 J=1,IFY
     13              IF (ABS(F(I)).LT.ABS(FEXP(J))) GO TO 20
     21     10    CONTINUE
     23                   YP(I)=YEXP(IFY)
     25              GO TO 30
     25     20    CONTINUE
     25                   DUMDUM=(FEXP(J)-FEXP(J-1))/(ABS(YEXP(J))-ABS(YEXP(J-1)))
     34                   YP(I)=ABS(YEXP(J-1))+(ABS(F(I))-FEXP(J-1))/DUMDUM
     45               IF (F(I).GT.0) YP(I)=-YP(I)
     50     30    CONTINUE
     53           RETURN
     53     40    CONTINUE
     53           DO 50 I=1,NTP1
     55                   YP(I)=F(I)/FRICMUL
     60               IF (ABS(F(I)).GE.FU) YP(I)=YEXP(1)
     66     50    CONTINUE
     71           RETURN
     71     60    CONTINUE
     71           DO 70 I=1,NTP1
     73                   YP(I)=(F(I)/FRICMUL)**2
     76               IF (ABS(F(I)).GE.FU) YP(I)=YEXP(1)
    104               IF (F(I).GT.0) YP(I)=-YP(I)
    110     70    CONTINUE
    113           RETURN
    113           END
```

BAKFRIC

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENGTH
   121

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
20      -        25    30      -        50    40      -        53    50      -        66
60      -        71    70      -       110

EXTERNALS AND TAGS
END     -  S00100

BLOCK NAMES AND LENGTHS
BLOCK1 -       12C01 BLOCK2 -    1755C02 BLOCK3 -       6C03 BLOCK4 -    3724C04
BLOCK5 -       30C05 BLOCK6 -      10C06 BLOCK8 -    3726C07

VARIABLE ASSIGNMENTS
AAA     -     765C02 AL      -       0C04 CONSTR -    1752C04 DUMDUM -     120
FEXP    -       0C05 FRICMUL-      24C05 FU      -      26C05 I       -     116
1FY     -      27C05 J       -    117     NTP1   -       6C01 REFF    -     765C07
SS      -       0C02 STRAIN -     765C04 STRESSS-    2737C04 WS      -     766C02
Y       -       0C07 YEXP    -      12C05 YP      -    1752C07 YPITE   -    2741C07

START OF CONSTANTS
   114

START OF TEMPORARIES
   114

START OF INDIRECTS
   116

START OF VARIABLES
   116

SPACE REQUIRED TO COMPILE -- BAKFRIC
 33100
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

                    SUBROUTINE BINARYF (F)
       3            DIMENSION F(501)
       3            COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
       3            COMMON /BLOC22/ SS(501),AAA,WS(501),MAXITE,CRACKW
       3            COMMON /BLOCK3/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB
       3            COMMON /BLOCK4/ AL(501),STRAIN(501),CONSTR(501),STRESSS(501)
       3            COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,1FY
       3            COMMON /BLOC26/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
       3            COMMON /BLOCK8/ Y(501),REFF(501),YP(501),H,ICLOSE8,YPITE(501)
       3            COMMON /BLOC29/ STX,STY,PSX,PSY,ITE
       3            DO 30 I=1,NTP1
       5               IF (YP(I),GT,Y(I)) GO TO 10
      11                    TEM7=REFF(I)
      12                    REFW(I)=F(I)
      14                    F(I)=(3*F(I)-TEMP)/2.
      21               GO TO 20
      21      10    CONTINUE
      21                    F(I)=(REFF(I)+F(I))/2.
      25      20    CONTINUE
      25      30    CONTINUE
      30            RETURN
      30            END
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENGTH
    36

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
10      -       21    20      -       25    30      -       25

EXTERNALS AND TAGS
END     -  S00100

BLOCK NAMES AND LENGTHS
BLOCK1 -       12C01 BLOCK2 -    1755C02 BLOCK3 -       6C03 BLOCK4 -    3724C04
BLOCK5 -       30C05 BLOCK6 -      10C06 BLOCK8 -    3726C07 BLOCK9 -       5C10

VARIABLE ASSIGNMENTS
AL      -       0C04 CONSTR -    1752C04 FEXP   -       0C05 I      -      34
NTP1    -       6C01 REFF   -     765C07 SS     -       0C02 STRAIN -     765C04
STRESSS-     2737C04 TEMP   -      35    WS     -     766C02 Y      -       0C07
YEXP    -      12C05 YP     -    1752C07 YPITE  -    2741C07

START OF CONSTANTS
    31

START OF TEMPORARIES
    33

START OF INDIRECTS
    34

START OF VARIABLES
    34

SPACE REQUIRED TO COMPILE -- BINARYF
 32600


BINARYF
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

                    SUBROUTINE DWBARF (F,BONDL,STRMAX,Z,DELTAT)
              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 DEVE3OPMENT LENGTH CRITERIA OR BOUNDARY CONDITION IS IMPOS
              C        IN THE SOLUTION OF THE BASIC EQUATIONS.
              C     ****************************************************************
              C
     10             DIMENSION F(S01),SUM(501)
     10             COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
     10             COMMON /BLOC22/ SS(S01),AAA,WS(501),MAXITE,CRACKW
     10             COMMON /BLOCK3/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB
     10             COMMON /BLOCK4/ AL(501),STRAIN(501),CONSTR(501),STRESSS(501)
     10             COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
     10             COMMON /BLOC26/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
     10             COMMON /BLOC28/ Y(501),REFF(S01),YP(501),H,ICLOSEB,YPITE(S01)
     10             COMMON /BLOC27/ SIGMASC,SIGMASB,NA,NAP1,E,A,S,DENO,NAP2
     10             COMMON /BLOC214/ IFINISH
     10             INTEGER AAA
     10             REAL L
     10                      ICL6SEB=0
     11                      A=A3(NTP1)-BONDL
     13                IF (A.LE.0.) GO TO 30
     14                      NA=A/H+1+EP
     21                      E=A-AL(NA)
     23                IF (NA.GT.NT) GO TO 50
     26                      NAP1=NA+1
     27                      NAP2=NA+2
     30                      NAM1=NA-1
     31                      DEN6=THICK*(P+1./RATIO)
              C              SLOTE(I) = -  F(I) / DENO
     35                      SUM1=0.
     36                      SUM2=0.
     37             DO 10 I=1,NAM1
     40                      SUM1=SUM1+(2*NA-(2.*I+1))*(-F(I)/DENO)
     54                      SUM2=SUM2+(-F(I)/DENO)
     60        10   CONTINUE
              C
              C     DEFINE CONSTANTS
              C
     62                      S=-W(NAP1)/OENO
     64                      BONDCON=DIA/(4.*U)
     67                      ANA=NA
     70                      C1=1.+1./(RATIO*P)
     74                      C2=EC*(Z+DELTAT*(ALPHAC-ALPHAS))/P
    101                      C3=FF/(P*THICK)
    103                      C4=C2-C3
    105                      C5=H*SUM2+S*E
    110                      C6=H*H*SUM1/2.
    113                      C7=(ANA-1.)*H
    115                      C8=H*SUM2*E+S*E*E/2.
    121                      C9=-C4/C1+C5
              C
              C     DEFINE QUADRATIC EQUATION CONSTANTS
              C


OFBARF
```

```
   124                AA=BONDCON*(1.-1./(C1*C1))/2.
   130                BB=(C7+E)/C1-BONOCON*C9/C1
   135          CC=KALPHAS*AL(NTP1)*DELTAT*ES-C4*(C7+E)/C1+C6+C8-BONDCON*C9*C9/2.
         C
   152                OELTA=BB*BB-4.*AA*CC
   156            IF (DELTA.LT.0.) GO TO 60
         C
   157                ROOT1=(-BB+SQRT(DELTA))/(2.*AA)
   165                ROOT2=(-BB-SQRT(DELTA))/(2.*AA)
   173            IF (ROOT2.GT.0.) GO TO 40
   201                SIGMASC=ROOT1
   202                SIGMASB=(SIGMASC-C4)/C1
   205                BONDLC=(SIGMASC-(SIGMASB+C5))*BONDCON
   211      201 FORMAT(10X,*BONDLC = *,E10.3,/,10X,*SIGMASC = *,E10.3,/
               1        10X,*SIGMASB = *,E10.3,/,10X,*C5      = *,E10.3,/
               2        10X,*SONDCON = *,E10.3,//)
   211                DUM=(BONDLC-BONDL)/BONDLC
   213             IF (ABS(DUM).LE.TOL) ICLOSEB=1
   220             IF (ICLOSEB.EQ.1) ITEB=0
   223                ITES=ITEB+1
   225            IF (ITEB.XT.MAXITE) GO TO 20
   230                BONDL=BONDLC
   230      202 FORMAT(10X,*BONDL IN DFBARF =*,E10.3,//)
         C
         C     COMPUTE AREAS FOR SUMMATION CHECK
         C
   230                A1=H*((2.*ANA-2.)*SIGMASB+H*SUM1)/2.
   237                A2=SIGMASB*E+H*SUM2*E+S*E*E/2.
   245                A3=(SIGMASB+C5+SIGMASC)*BONDL/2.
   252                AAAA=A1+A2+A3
         C
   255                DUM2=ALPHAS*AL(NTP1)*DELTAT*ES
   260            IF (ABS(AAAA-DUM2).GT.1.E-5) GO TO 70
   265         CALL POIRES (F,BONDL,STRMAX,LOCMAX,Z,DELTAT)
   270         RETURN
   271     20  CONTINUE
   271         PRINT 90, ITEB
   277            GO TO 80
   303     30  CONTINUE
   303         PRINT 100, A
   311            GO TO 80
   315     40  CONTINUE
   315         PRINT 110, DELTA,ROOT1,ROOT2
   327            GO TO 80
   333     50  CONTINUE
   333         PRINT 120, NA,NT
   343            GO TO 80
   347     60  CONTINUE
   347         PRINT 130, DELTA
   355     70  CONTINUE
   355         PRINT 140, DUM2,AAAA
   365     80  CONTINUE
   365     90  FORMAT (//,10X,* SOLUTION DID NOT CLOSE BY ITERATING ON BOND *,
              1      *LENGTH IN SUBROUTINE DFBARF*,/,10X,*PROGRAM IS TERMINATED*,
              2      /,10X,* ITEB=*,I5)
   365    100  FORMAT (//,10X,*ERROR IS DETECTED IN DFBARF*,/,
```

```
               1       10X,*A IS NEGATIVE AND=*,E10.3)
   365    110  FORMAT (//,10X,*OELTA=*,E10.3,/,
               1             10X,*ROOT1=*,E10.3,/,
               2             10X,*ROOT2=*,E10.3,/,
               3       10X,* ERROR IS DETECTED IN SUBROUTINE DFBARF,ROOT2 IS POS.*)
   365    120  FORMAT (/,20X,* ERROR IS DETECTED *,/,
               1             10X,* NA = *,I5,10X,* NT = *,I5)
   365    130  FORMAT (/,10X,*ERROR IS DETECTED*,/,
               1        10X,* DELTA IS NEGATIVE AND=*,E10.3)
   365    140  FORMAT (/,10X,* ERROR IS DETECTED IN SUBROUTINE DFBARF*,/,
               1    10X,* DUM2 IS NOT EQUAL TO AAAA*,/,
               2    10X,* DUM2=*,E10.3,5X,* AAAA=*,E10.3)
   365         END
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENGTH
  1613

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
20      -     271    30      -     303    40      -     315    50      -     333
60      -     347    70      -     355    80      -     365    90      -     423
100     -     443    110     -     456    120     -     511    130     -     525
140     -     541    201     -     373    202     -     414

EXTERNALS AND TAGS
SQRT    -  S00100    POIRES -  S00200    OUTPTC -  S00300    ENO     -  S00400

BLOCK NAMES ANO LENGTHS
BLOCK1 -       12C01 BLOCK2 -    1755C02 BLOCK3 -       6C03 BLOCK4 -    3724C04
BLOCK5 -       30C05 BLOCK6 -      10C06 BLOCK8 -    3726C07 BLOCK7 -      11C10
BLOCK14-        1C11

VARIABLE ASSIGNMENTS
A       -        5C10 AA      -    1575    AAA     -     765C02 AAAA    -    1610
AL      -        0C04 ALPHAC  -      0C06 ALPHAS  -       1C06 ANA     -    1563
A1      -    1605     A2      -    1606    A3      -    1607    BB      -    1576
BONOCON-    1562     BONDLC  -    1603    CC      -    1577    CONSTR  -    1752C04
C1      -    1564     C2      -    1565    C3      -    1566    C4      -    1567
C5      -    1570     C6      -    1571    C7      -    1572    C8      -    1573
C9      -    1574     DELTA   -    1600    OENO    -       7C10 OIA     -      10C01
DUM     -    1604     DUM2    -    1611    E       -       4C10 EC      -       2C06
EP      -        5C06 ES      -      5C01 FEXP    -       0C05 FF      -       3C01
H       -    2737C07  I       -    1561    ICLOSEB-    2740C07 ITEB    -       5C03
L       -    1555     LOCMAX  -    1612    MAXITE  -    1753C02 NA      -       2C10
NAM1    -    1556     NAP1    -      3C10 NAP2    -      10C10 NT      -      25C05
NTP1    -        6C01 P       -      2C01 RATIO   -       0C01 REFF    -     765C07
ROOT1   -    1601     ROOT2   -    1602    S       -       6C10 SIGMASB-       1C10
SIGMASC-         0C10 SS      -      0C02 STRAIN  -     765C04 STRESSS-    2737C04
SUM     -     570     SUM1    -    1557    SUM2    -    1560    THICK   -       1C01
TOL     -        6C06 U       -      7C01 WS      -     766C02 Y       -       0C07
YEXP    -       12C05 YP      -   1752C07 YPITE   -    2741C07

START OF CONSTANTS
   366

START OF TEMPORARIES
   562

START OF INOIRECTS
   570

START OF VARIABLES
   570

SPACE REQUIREO TO COMPILE -- OFBARF
 34600




OFBARF
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

                    SUBROUTINE OWBAR (BONDL,STRMAX,Z,DELTAT)
            C
            C       THIS SUBROUTINE COMPUTES THE STRESSES AND STRAINS IN THE CONCRETE
            C       STEEL DUE TO A TEMPERATURE OROP AND/OR SHRINKAGE .
            C       THE EQUATIONS ARE WRITTEN FOR A FRICTIONLESS SYSTEM
            C
      7             COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
      7             COMMON /BLOCK2/ SS(501),AAA,WS(501),MAXITE,CRACKW
      7             COMMON /BLOC23/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB
      7             COMMON /BLOCK4/ AL(501),STRAIN(501),CONSTR(501),STRESSS(501)
      7             COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
      7             COMMON /BLOC26/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
      7              COMMON /BLOTKC/STRSC1(501),STRSS1(501),INC,FRF,FY,L
      7             COMMON /BLOC28/ Y(501),REFF(501),YP(501),H,ICLOSEB,YPITE(501)
      7             COMMON /BLOC20/ STRSC2(501),DIST
      7             INTEGER AAA
      7             REAL L,L2
      7             L2=L*2.
     11                IF (Z.LT.0.OR.OELTAT.LT.0.) GO TO 40
            C
            C           COMPUTE CONSTANTS
            C
     17                      C1=(RATIO*P)/(1.+RATIO*P)
     24                      C2=(ES*Z)/(1.+RATIO*P)
     27                      C3=(1.-C1)*OIA/(4.*U)
     33                      C4=C2*DIA/(4.*U)
     36                      AA=C3-C1*C3
     40                      BB=L2*C1-C1*C4+C2*C3+C4
     45                      DD=-ES*L2*DELTAT*ALPHAS-L2*C2+C2*C4
     53                      DELTA=BB*BB-4.*AA*DD
     57                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
     61                      STRSC=(-BB+(DELTA**0.5))/(2.*AA)
     67                      STRSB=C1*STRSC-C2
     71                      STRT=STRSB/RATIO+EC*Z
     75                      B=(STRSC-STRSB)*DIA/(4.0*U)
    101                IF (B.LE.0.) GO TO 30
    103                      CHE=(L2-2.*B)*STRSB+(STRSC+STRSB)*B
    111                      CHETK=CHE-ES*L2*DELTAT*ALPHAS
    115                IF (ABS(CHECK).GT.1.E-2) GO TO 70
            C
            C       *   CHECKING THE SOLUTION BY SOLVING FOR CONCRETE STRESS FIRST
    121                      C11=OIA/(4.*U*P*P)
    125                      C12=2.*L2*RATIO/2.
    130                      C13=2.*L2*ES*Z/2.
    132             *        C14=2.*ALPHAS*L2*ES*DELTAT/2.
    135                      DEL=C12*C12+4.*C11*(C13+C14)
    142                      CONCRES=(-C12+SQRT(DEL))/(2.*C11)
    150                      R2=(-BB-SQRT(DELTA))/(2.*AA)
    156                      R4=C1*R2-C2
    161                      R6=R4/RATIO+EC*Z




OFBAR
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

    167             IF (R6.GT.0) GO TO 50
    171             IF (R2.GT.0) GO TO 50
    173      10   CONTINUE
    173             IF (ABS(STRC-CONCRES).GT.1.E-7) GO TO 80
           C
           C      *   END OF ASOVE CHECK
           C
    201      20   CONTINUE
           C
           C           COMPUTE AREA UNDER STEEL STRAIN DIAGRAM FOR THE ASSUMED
           C           FRICTION3ESS SYSTEM
           C
    201                     DUM1=L-B
    203                     STRAREA=DUM1*STRSB/ES+(STRSB+STRSC)*B/(2.*ES)
    214             IF (ABS(STRAREA-ALPHAS*DELTAT*L).GT.1.E-7) GO TO 100
    223                     STRMAX=STRC
           C
    224                     STRAINC=STRC/EC
    225                     BONDL=B
    226           RETURN
    226      30   CONTINUE
    226           PRINT 140, B
    234             GO TO 110
    237      40   CONTINUE
    237           PRINT 150, Z,DELTAT
    247             GO TO 110
    252      50   CONTINUE
    252           PRINT 160, R2,R4,R6
    264             GO TO 110
    267      70   CONTINUE
    267           PRINT 120, P,DELTAT,Z,XBAR,STRSC,STRSB,STRC,EC,B
    315           PRINT 180, CHECK
    323             GO TO 110
    326      80   CONTINUE
    326           PRINT 120, P,DELTAT,Z,XBAR,STRSC,STRSB,STRC,EC,B
    354           PRINT 190
    360             GO TO 110
    363      90   CONTINUE
    363           PRINT 200
           C
    367     100   CONTINUE
    367           PRINT 210
    373           PRINT 220, STRAREA
    401     110   CONTINUE
    401     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,//)
    401      140 FORMAT(//,10X,*ERROR IS DETECTED IN SUBROUTINE DFBAR*,/,
                1        10X,*B6ND LENGTH IS NEGATIVE AND=*,E10.3,/,
                2        10X,*PROGRAM IS TERMINATED*)


DFBAR
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

    401     150  FORMAT (//,10X,* ERROR IS DETECTED IN SUBROUTINE TEMPSHR *,
               1              10X,*       Z = *,E10.3,/,
               2              10X,* DELTAT = *,E10.3)
    401     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)
    401     180  FORMAT (///, 10X,* ROOTS DO NOT SATISFY EQUATION 1 *,/, 10X,
               1 * CHECK= *, E10.3)
    401     190  FORMAT (//,10X,* SOLUTION ONE DOES NOT MATCH SOLUTION TWO *)
    401     200  FORMAT (///,30X,*DELTA IS NEGATIVE*)
    40I     210  FORMAT  (/,10X,*SOMETHING IS WRONG, THE AREA UNDER STEEL STRAIN DI
               1AGRAM IS NOT EQUAL TO ALPHAS X DELTAT X XBAR / 2*,/)
    40I     220  FORMAT (//,10X,* AREA UNDER STEEL STRAIN DIAGRAM FOR FRICTIONLESS
               1SLAB = *,E10.3,//)
    401          END


DFBAR
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENGTH
   713

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
10      -      173    20      -      201    30      -      226    40      -      237
50      -      252    70      -      267    80      -      326    90      -      363
100     -      367    110     -      401    120     -      413    140     -      506
150     -      530    160     -      551    180     -      603    190     -      614
200     -      623    210     -      627    220     -      644

EXTERNALS AND TAGS
RBAREX -  S00100    SQRT    -  S00200    OUTPTC -  S00300    ENO     -  S00400

BLOCK NAMES AND LENGTHS
BLOCK1 -       12C01 BLOCK2 -     1755C02 BLOCK3 -        6C03 BLOCK4 -     3724C04
BLOCK5 -       30C05 BLOCK6 -       10C06 BLOCKC -     1756C07 BLOCK8 -     3726C10
BLOCKD -      766C11

VARIABLE ASSIGNMENTS
AA      -      671    AAA     -    765C02 AL      -        0C04 ALPHAS -        1C06
B       -      675    BB      -    672    CHE     -     676     CHECK   -     677
CONCRES-       705    CONSTR  -   1752C04 C1      -     665     C11     -     700
C12     -      701    C13     -    702    C14     -     703     C2      -     666
C3      -      667    C4      -    670    OO      -     673     DEL     -     704
DELTA   -      674    DIA     -     10C01 DUM1    -     711     EC      -        2C06
ES      -        5C01 FEXP    -      0C05 L       -    1755C07 L2      -     664
P       -        2C01 RATIO   -      0C01 REFF    -     765C10 R2      -     706
R4      -      707    R6      -    710    SS      -        0C02 STRAIN -      765C04
STRAINC-         4C01 STRAREA-    712    STRC    -        3C03 STRESSS-     2737C04
STRSB   -        2C03 STRSC   -      1C03 STRSC1 -        0C07 STRSC2 -        0C11
STRSS1  -      765C07 U       -      7C01 WS      -     766C02 XBAR    -        0C03
Y       -        0C10 YEXP    -     12C05 YP      -    1752C10 YP1TE   -    2741C10

START OF CONSTANTS
   402

START OF TEMPORARIES
   654

START OF INDIRECTS
   664

START OF VARIABLES
   664

SPACE REQUIRED TO COMPILE -- OFBAR
 34700




OFBAR
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

                 SUBROUTINE GETME (X1,Y1,X2,Y2,FOUT)
           C     *************************************************************
           C         THIS SUBROUTINE SOLVES FOR THE POINT OF INTERSECTION OF TWO ST
           C         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
 10              COMMON /BLOCK2/ SS(501),AAA,WS(501),MAXITE,CRACKW
 10              COMMON /BLOCK9/ STX,STY,PSX,PSY,ITE
 10                 IF (ITE.EQ.2) GO TO 10
 12                 IF (X2-Y2) 40,40,20
 14        10    CONTINUE
 14                       DUMX2=PSX*X1
 16                       DUMY2=PSY*Y1
 17                 GO TO 30
 20        20    CONTINUE
 20                       DUMX2=PSX
 22                       DUMY2=PSY
 23        30    CONTINUE
 23                       DUMX1=STX*X2
 25                       DUMY1=STY*Y2
 26                 GO TO 50
 27        40    CONTINUE
 27                       DUMX1=STX
 31                       DUMY1=STY
 32                       DUMX2=PSX*X2
 34                       DUMY2=PSY*Y2
 35        50    CONTINUE
 35              FOUT=(DUMX2*DUMY1-DUMX1*DUMY2)/((DUMX2-DUMX1)-(DUMY2-DUMY1))
 44              RETURN
 45              END




GETME
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENGTH
    55

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
10      -       14    20      -       20    30      -       23    40      -       27
50      -       35

EXTERNALS AND TAGS
END     -  S00100

BLOCK NAMES AND LENGTHS
BLOCK2 -     1755C01 BLOCK9 -        5C02

VARIABLE ASSIGNMENTS
DUMX1   -       53    DUMX2   -       51    DUMY1   -       54    DUMY2   -       52
ITE     -        4C02 PSX     -        2C02 PSY     -        3C02 SS      -        0C01
STX     -        0C02 STY     -        1C02 WS      -      766C01

START OF CONSTANTS
    46

START OF TEMPORARIES
    46

START OF INDIRECTS
    51

START OF VARIABLES
    51

SPACE REQUIRED TO COMPILE -- GETME
 32600



GETME
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

                 SUBROUTINE FRIC (F)
     3           DIMENSION F(501)
     3           COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
     3           COMMON /BLOCK2/ SS(501),AAA,WS(501),MAXITE,CRACKW
     3           COMMON /BLOC23/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB
     3           COMMON /BLOCK4/ AL(501),STRAIN(501),CONSTR(501),STRESSS(501)
     3           COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
     3           COMMON /BLOCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
     3           COMMON /BLOC28/ Y(501),REFF(501),YP(501),H,ICLOSEB,YPITE(501)
     3           INTEGER AAA
           C
     3                       BEYOND=0.
     4               IF (IFY.EQ.1) GO TO 10
     6               IF (IFY.EQ.2) GO TO 40
     7               IF (IFY.GT.2) GO TO 90
    11       10  CONTINUE
    11                       SLO7E=FRICMUL
           C
           C     COMPUTE FRICTION FORCES FROM STRAIT LINE GRAPH
           C
    13           DO 30 I=1,NTP1
    14                       F(I)=Y(I)*SLOPE
    17               IF (ABS(F(I)).LE.FU) GO TO 20
    23                IF (F(I),GT.0.0) F(I)=FU
    27                IF (F(I),LT.0.0) F(I)=-FU
    33       20  CONTINUE
    33       30  CONTINUE
    36               GO TO 140
    36       40  CONTINUE
           C
           C     COMPUTE FRICTION FORCES FROM PARABOLA
           C
    36           DO 80 I=1,NTP1
           C
    40               IF (Y(I).XT.0.) GO TO 50
    43                       F(I)=FRICMUL*SQRT(ABS(Y(I)))
    52               GO TO 60
    52       50  CONTINUE
    52                       F(I)=-FRICMUL*SQRT(Y(I))
    61       60  CONTINUE
    61               IF (ABS(F(I)).LE.FU) GO TO 70
    66                IF (F(I).GT.0.0) F(I)=FU
    71                IF (F(I),LT.0.0) F(I)=-FU
    75       70  CONTINUE
    75       80  CONTINUE
   100               GO TO 140
   100       90  CONTINUE
           C     COMPUTE FRICTION FORCES FROM INPUT POINT CURVE
   100           DO 130 I=1,NTP1
   102           DO 100 J=1,IWY
   103               IF (ABS(Y(I)).LT.ABS(YEXP(J))) GO TO 110
   110      100  CONTINUE
   113                       BEYOND=BEYONO+1.
   115                       F(I)=FEXP(IFY)
   116               GO TO 120



FRIC
```

```
  117     110  CONTINUE
  117                  DUMDUM=(FEXP(J)-FEXP(J-1))/(ABS(YEXP(J))-ABS(YEXP(J-1)))
  126                  F(I)=FEXP(J-1)+DUMDUM*(ABS(Y(I))-ABS(YEXP(J-1)))
  137     120  CONTINUE
  137              IF (Y(I).GT.0.0) F(I)=-F(I)
  143     130  CONTINUE
        C
        C          COMPUTE THE TOTAL FRICTION FORCE
        C
  146     140  CONTINUE
  146             IF (BEYOND.GT.0.) PRINT 190, BEYOND
  156                  FF=0
  157          DO 150 I=1,NT,2
  161                  FF=FF+(F(I)+4.*F(I+1)+F(I+2))*H/3.
  170     150  CONTINUE
  173              IF (LONG7R.NE.100) RETURN
  175          PRINT 200, FW
  203          RETURN
  204     190  FORMAT (//,10X,*IN COMPUTING THE FRICTION FORCES FROM MOVEMENTS*,/
              1,   10X,F5.0,* POINTS EXCEEDED THE MAX MOV ON F-Y CURVE*)
  204     200  FORMAT (/,10X,* TOTAL FRICTION FORCE FROM FRIC =*,E10.3)
  204          END
```

```
SUBPROGRAM LENGTH
   245

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
10      -       11   20      -      33   30      -      33   40      -      36
50      -       52   60      -      61   70      -      75   80      -      75
90      -      100   110     -     117   120     -     137   130     -     143
140     -      146   190     -     212   200     -     227

EXTERNALS AND TAGS
SORT    -  S00100    OUTPTC -  S00200    END     -  S00300

BLOCK NAMES AND LENGTHS
BLOCK1 -       12C01 BLOCK2 -    1755C02 BLOCK3 -       6C03 BLOCK4 -    3724C04
BLOCK5 -       30C05 BLOCK6 -      10C06 BLOCK8 -    3726C07

VARIABLE ASSIGNMENTS
AAA     -     765C02 AL     -       0C04 BEYOND -    237     CONSTR -    1752C04
DUMDUM  -     243    FEXP   -       0C05 FF     -       3C01 FRICMUL-      24C05
FU      -      26C05 H      -    2737C07 I      -    241     IFY    -      27C05
J       -     242    LONGPR -    244     NT     -      25C05 NTP1   -       6C01
REFF    -     765C07 SLOPE  -    240     SS     -       0C02 STRAIN -     765C04
STRESSS-     2737C04 WS     -     766C02 Y      -       0C07 YEXP   -      12C05
YP      -    1752C07 YPITE  -    2741C07

START OF CONSTANTS
   205

START OF TEMPORARIES
   234

START OF INDIRECTS
   237

START OF VARIABLES
   237

SPACE REQUIRED TO COMPILE -- FRIC
 33500
```

```
                SUBROUTINE DWWIREF (F•BONDL•STRMAX•Z•DELTAT)
     10         DIMENSION F(501)•SUM(501)
     10         COMMON /BLOC21/ RATIO•THICK•P•FF•STRAINC•ES•NTP1•U•DIA•UNWT
     10         COMMON /BLOCK2/ SS(501)•AAA•WS(501)•MAXITE•CRACKW
     10         COMMON /BLOC23/ XBAR•STRSC•STRSB•STRC•IBABY•ITEB
     10         COMMON /BLOCK4/ AL(501)•STRAIN(501)•CONSTR(501)•STRESSS(501)
     10         COMMON /BLOCK5/ FEXP(10)•YEXP(10),FRICMUL•NT•FU,IFY
     10         COMMON /BLOCK6/ ALPHAC•ALPHAS•EC•FPC•TIME•EP•TOL•ITYPER
     10         COMMON /BLOC27/ SIGMASC•SIGMASB•NA•NAP1•E•A•S•DENO•NAP2
     10         COMMON /BLOC28/ Y(501)•REFF(501)•YP(501)•H•ICLOSEB•YPITE(501)
     10         REAL L
     10         INTEGER AAA
          C
          C
          C          COMPUTE THE STRAINS DUE TO FRICTION FORCES DEVELOPED
          C          DUE TO SLAB MOVEMENT
          C
     10                   EP=1.E-9
     11                   A=A3(NTP1)-BONDL
     14             IF (A.LE.0.) GO TO 50
     15                   NA=A/H•1•EP
     22                   E=A-AL(NA)
     24             IF (NA.GT.NT) GO TO 60
     27      10 CONTINUE
     27                   NAP1=NA•1
     31                   NAP2=NA•2
     33                   NAM1=NA-1
     34                   NAM2=NA-2
          C          COMPUTE THE SLOPE TO THE STEEL STRAIN DISTRIBUTION CURVE BY
     35                   DEN6=THICK*(P•1./RATIO)
          C
          C          DIVIDING THE FRICTION FORCE BY DENO AND CONSIDERING THE
          C          SIGN CONVENTION ADOPTED IN THIS STUDY
          C
          C               CCC          SLOPE(I) = -  F(1) / DENO
     41                   SUM1=0.
     42                   SUM2=0.
     43         DO 20 I=1•NAM1
     44                   SUM1=SUM1•(2*NA-(2.*I•1))*(-F(1)/DENO)
     60                   SUM2=SUM2•(-F(I)/DENO)
     64      20 CONTINUE
          C
          C          DEFINE  CONSTANTS FOR SOLUTION OF EQUATIONS
          C
     66                   C1=1.•1./(P*RATIO)
     71                   C2=((Z•DELTAT*(ALPHAC-ALPHAS))*EC)/P
     77                   C3=FF/(P*THICK)
    101                   S=-F(NAP1)/DENO
          C
          C          SOLVE FOR STRESS IN STEEL BETWEEN CRACKS AND AT CRACK
          C
    104         DUM1=ALPHAS*AL(NTP1)*DELTAT*ES-H*H*SUM1/2.-E*H*SUM2-S*E*E/2.-(H*
               1      SUM2•S*E•C2-C3)*BONDL/2.
    126                   ANA=NA
    130                   DUM2=H*(2.*ANA-2.)/2.•E•((1.•C1)*BONDL)/2.
```

```
          C
    140                   SIGMASB=DUM1/DUM2
    142                   SIGMASC=C1*SIGMASB•C2-C3
          C
          C          CHECK FOR THE SUMMATION OF STEEL STRESSES UNDER THE
          C          STEEL DIAGRAM
          C
    145                   A1=(((2.*ANA-2.)*SIGMASB•H*SUM1)*H)/2.
    154                   A2=(2.*SIGMASB•2.*H*SUM2•S*E)*E/2.
    161                   A3=(SIGMASB•H*SUM2•S*E•SIGMASC)*BONDL/2.
    171                   DUM1=A1•A2•A3
    174                   DUM2=ALPHAS*AL(NTP1)*DELTAT*ES
    177                   DUM3=DUM1-DUM2
    201             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
    205         CALL POIRES (F•BONDL•STRMAX•LOCMAX•Z•DELTAT)
    210      40 CONTINUE
    210         RETURN
    211      50 CONTINUE
    211         PRINT 130, A
    217            GO TO 80
    223      60 CONTINUE
    223         PRINT 140, NA,NT
    233            GO TO 80
    237      70 CONTINUE
    237         PRINT 150, SIGMASC•SIGMASB•DUM1•DUM2•DUM3
    255      80 CONTINUE
    255     130 FORMAT (//,10X,*ERROR IS DETECTED IN DFWIREF*,/,
               1      10X,*A IS NEGATIVE AND =*,E10.3)
    255     140 FORMAT (/,20X,* ERROR IS DETECTED *,/,
               1            10X,* NA = *,I5,10X,* NT = *,I5)
    255     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)
    255          END
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENGTH
  1374

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
10       -        27    40       -      210     50       -      211     60       -      223
70       -       237    80       -      255     130      -      264     140      -      277
150      -       313

EXTERNALS AND TAGS
POIRES -  S00100    OUTPTC -  S00200    END      -  S00300

BLOCK NAMES AND LENGTHS
BLOCK1 -        12C01 BLOCK2 -    1755C02 BLOCK3 -        6C03 BLOCK4 -    3724C04
BLOCK5 -        30C05 BLOCK6 -      10C06 BLOCK7 -       11C07 BLOCK8 -    3726C10

VARIABLE ASSIGNMENTS
A       -        5C07 AAA     -     765C02 AL      -        0C04 ALPHAC -        0C06
ALPHAS -         1C06 ANA     -    1365    A1      -    1367     A2      -    1370
A3      -    1371     CONSTR -    1752C04 C1      -    1361     C2      -    1362
C3      -    1363     DENO    -       7C07 DUM1    -    1364     OUM2    -    I366
DUM3    -    1372     E       -       4C07 EC      -       2C06 EP      -        5C06
ES      -        5C01 FEXP    -       0C05 FF      -       3C01 H       -    2737C10
I       -    1360     L       -    1353    LOCMAX -    1373     NA      -        2C07
NAM1    -    1354     NAM2    -    1355    NAP1    -       3C07 NAP2    -       10C07
NT      -       25C05 NTP1    -       6C01 P       -       2C01 RATIO   -        0C01
REFF    -     765C10 S       -       6C07 SIGMASB-       1C07 SIGMASC-        0C07
SS      -        0C02 STRAIN -     765C04 STRESSS-    2737C04 SUM     -     366
SUM1    -    1356     SUM2    -    1357    THICK   -       1C01 WS      -      766C02
Y       -        0C10 YEXP    -      12C05 YP      -    1752C10 YPITE   -    2741C10

START OF CONSTANTS
   256

START OF TEMPORARIES
   361

START OF INDIRECTS
   366

START OF VARIABLES
   366

SPACE REQUIRED TO COMPILE -- DFWIREF
 34100
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

                      SUBROUTINE OWWIRE (BONOL,STRMAX,Z,DELTAT)
 •          C         ****************************************************************
            C            THIS SUBROUTINE SOLVES FOR THE STRESS IN THE STEEL AND
            C            CONCRETE FOR OEFORMEO WIRE FABRIC -NO FRICTION FORCES
            C            ARE CONSIOEREO IN THE SOLUTION
 •          C         ****************************************************************
       7              COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
       7              COMMON /BLOC22/ SS(501),AAA,WS(501),MAXITE,CRACKW
       7              COMMON /BLOCK3/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB
       7              COMMON /BLOCK4/ AL(501),STRAIN(501),CONSTR(501),STRESSS(501)
       7              COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
       7              COMMON /BLOC26/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
       7              COMMON /BLOC2D/ STRSC2(501),DIST
       7              COMMON /BLOC27/ SIGMASC,SIGMASB,NA,NAP1,E,A,S,DENO,NAP2
       7              COMMON /BLOC28/ Y(501),REFF(501),YP(501),H,ICLOSEB,YPITE(501)
       7              REAL L
            C
            C         OEFINE CONSTANTS
            C
       7                       C1=EC*Z+EC*DELTAT*(ALPHAC-ALPHAS)
      13                       C2=ALPHAS*L*DELTAT*ES
      16                       C3=BONDL/(2.*RATIO)+P*L
            C
            C                  SOLVE FOR STRESSES
      22                       STRC=(C1*P*L+C2*P/RATIO)/C3
      26                       STRSB=(-C1*BONDL/2.+P*C2)/C3
      33                       STRSC=(C2/RATIO+C1*(L-BONDL/2.)+P*C2)/C3
      42                       STRMAX=STRC
            C
            C         CHECK EQUILISRIUM - EQUATION 1
            C
      43                       DUM1=STRC+P*STRSB
      45                       DUM2=P*STRSC
      46                  IF (ABS(DUM1-DUM2).GT.1.E-5) GO TO 10
      53                       SRAINC=STRC/EC
      54              RETURN
      55       10     CONTINUE
      55              PRINT 20, STRC,STRSB,STRSC,DUM1,DUM2
      73       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)
      73              END
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENXTH
   144

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
I0      -       55    20      -      10I

EXTERNALS AND TAGS
OUTPTC -  S00100    END     -  S00200

BLOCK NAMES AND LENGTHS
BLOCKI -       12C01 BLOCK2 -    1755C02 BLOCK3 -       6C03 BLOCK4 -    3724C04
BLOCK5 -       30C05 BLOCK6 -      I0C06 BLOCKD -     766C07 BLOCK7 -      I1CI0
BLOCK8 -    3726C11

VARIABLE ASSIGNMENTS
AL      -        0C04 ALPHAC -       0C06 ALPHAS -       1C06 CONSTR -    1752C04
C1      -      136    C2     -    137     C3     -    140    DUM1   -     141
DUM2    -      142    EC     -       2C06 ES     -       5C01 FEXP   -       0C05
L       -      135    P      -       2C01 RATIO  -       0C01 REFF   -     765C11
SRAINC  -      143    SS     -       0C02 STRAIN -     765C04 STRC   -       3C03
STRESSS-    2737C04 STRSB  -       2C03 STRSC  -       1C03 STRSC2 -       0C07
WS      -     766C02 Y      -       0C11 YEXP   -      12C05 YP     -    1752C1I
YPITE   -    274IC11

START OF CONSTANTS
    74

START OF TEMPORARIES
   133

START OF INDIRECTS
   135

START OF VARIABLES
   135

SPACE REQUIRED TO COMPILE -- DFWIRE
 33100
```

DFWIRE

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

                  SUBROUTINE POIRES (F,BONDL,STRMAX,LOCMAX,Z,DELTAT)
    11            DIMENSION F(501),SUM(501)
    11            COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
    11            COMMON /BLOC22/ SS(501),AAA,WS(501),MAXITE,CRACKW
    11            COMMON /BLOCK3/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB
    11            COMMON /BLOCK4/ AL(501),STRAIN(501),CONSTR(50I),STRESSS(501)
    11            COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
    11            COMMON /BLOC26/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
    11            COMMON /BLOCK7/ SIGMASC,SIGMASB,NA,NAP1,E,A,S,DENO,NAP2
    11            COMMON /BLOC28/ Y(501),REFF(501),YP(501),H,ICLOSEB,YPITE(501)
    11            INTEGER AAA
    11            REAL L
             C
    11                        II=NAP2
    12                        SUM3=0.
    13                        SUM4=0.
    14                        STRESSS(1)=SIGMASB
    15                        SS(1)=STRESSS(1)/ES
    17                        STRAIN(1)=SS(1)+Z+DELTAT*(ALPHAC-ALPHAS)
    23                        CONSTR(1)=STRAIN(1)*EC
    25                        LOCMAX=1
    26                        STRMAX=CONSTR(1)
             C
    27            DO 20 I=2,NA
    30                        STRESSS(I)=STRESSS(I-1)+H*(-F(I)/DENO)
    36                        SS(I)=STRESSS(I)/ES
    41                        STRAIN(I)=SS(I)+Z+DELTAT*(ALPHAC-ALPHAS)
    46                        CONSTR(I)=STRAIN(1)*EC
    50                IF (CONSTR(I).LT.STRMAX) GO TO 10
    53                        STRMAX=CONSTR(I)
    54                        LOCMAX=I
    54       10   CONTINUE
    54                        SUM3=SUM3+(SS(I)+SS(I-1))*H/2.
    62                        SUM4=SUM4+(STRESSS(I)+STRESSS(I-1))*H/2.
    70       20   CONTINUE
    73                        ADDI=STRESSS(NA)+S*E
    76                        ADDIAR=(STRESSS(NA)+ADDI)*E/2.
   101                        SUM3=SUM3+(ADDIAR)/ES
   103                        SUM4=SUM4+ADDIAR
   105                        SLO7E2=(SIGMASC-ADDI)/BONDL
   107                        ADDIC=ADDI/ES+Z+DELTAT*(ALPHAC-ALPHAS)
   114                        SLO7ECC=-ADDI/BONDL
   115                        STRESSS(NAP1)=ADDI+(AL(NAP1)-A)*SLOPE2
   124                        SS(NAP1)=STRESSS(NAP1)/ES
   126            STRAIN(NAP1)=ADDIC-F(NAP1)*H/(THICK*EC)-(STRESSS(NAP1)-ADDI)*P/EC
   142                        CONSTR(NAP1)=STRAIN(NAP1)*EC
   144                IF (CONSTR(NAP1).LT.STRMAX) GO TO 30
   147                        STRMAX=CONSTR(NAP1)
   150                        LOCMAX=NAP1
   150       30   CONTINUE
   150                        SUM4=SUM4+(STRESSS(NAP1)+ADDI)*(AL(NAP1)-A)/2.
   160                        SUM3=SUM3+(STRESSS(NAP1)+ADDI)*(AL(NAP1)-A)/(2.*ES)
   171                  IF (NA.EQ.NT) II=NAP1
   175            DO 50 I=II,NTP1
   177                        STRESSS(I)=ADDI+(AL(I)-A)*SLOPE2
```

POIRES

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

   205                     SS(I)=STRESSS(I)/ES
   210           STRAIN(I)=STRAIN(I-1)-F(I)*H/(THICK*EC)-(STRESSS(I)-STRESSS(I-1))*
                1        P/EC
   224                     CONSTR(I)=STRAIN(I)*EC
   227              IF (CONSTR(I).LT.STRMAX) GO TO 40
   231                     STRMAX=CONSTR(I)
   232                     LOCMAX=I
   233      40   CONTINUE
   233                     SUM3=SUM3+(SS(I)+SS(I-1))*H/2.
   241                     SUM4=SUM4+(STRESSS(I)+STRESSS(I-1))*H/2.
   247      50   CONTINUE
   251           RETURN
   252           END








 POIRES
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENGTH
  1267

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
10      -       54    30      -      150    40      -      233

EXTERNALS AND TAGS
END     -  S00100

BLOCK NAMES AND LENGTHS
BLOCK1 -       12C01 BLOCK2 -    1755C02 BLOCK3 -       6C03 BLOCK4 -    3724C04
BLOCK5 -       30C05 BLOCK6 -      10C06 BLOCK7 -      11C07 BLOCK8 -    3726C10

VARIABLE ASSIGNMENTS
A       -       5C07 AAA     -     765C02 ADDI    -    1262     ADDIAR -    1263
ADDIC  -    1265     AL      -       0C04 ALPHAC -       0C06 ALPHAS -       1C06
CONSTR -    1752C04 DENO    -       7C07 E       -       4C07 EC      -       2C06
ES      -       5C01 FEXP    -       0C05 H       -    2737C10 I       -    1261
II      -    1256     L       -    1255     NA      -       2C07 NAP1    -       3C07
NAP2    -      10C07 NT      -      25C05 NTP1    -       6C01 P       -       2C01
REFF    -     765C10 S       -       6C07 SIGMASB-       1C07 SIGMASC-       0C07
SLOPECC-    1266     SLOPE2 -    1264     SS      -       0C02 STRAIN -     765C04
STRESSS-    2737C04 SUM     -     270     SUM3    -    1257     SUM4    -    1260
THICK  -       1C01 WS      -     766C02 Y       -       0C10 YEXP    -      12C05
YP      -    1752C10 YPITE   -    2741C10

START OF CONSTANTS
   253

START OF TEMPORARIES
   255

START OF INDIRECTS
   264

START OF VARIABLES
   270

SPACE REQUIRED TO COMPILE -- POIRES
 34000








POIRES
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

            SUBROUTINE SIMPSPE (Y,N,H,SUM)
   7        DIMENSION Y(N),SUM(N)
        C
        C       THIS SUBROUTINE COMPUTES THE AREA UNDER A DISTRIBUTION USING
        C       SIMPSONS RULE WITH A SPECIAL MODIFICATION
        C
   7        DO 10 I=1,N
  10                 SUM(I)=0.
  12     10 CONTINUE
  14                 SUM(1)=0.
  15                 A1=(Y(1)+Y(2))*H/2.
  20                 AOLD=A1
  20                 SUM(2)=AOLD
  21                 NM1=N-1
        C
  23        DO 20 I=2,NM1
  24                 AS=(Y(I-1)+4.*Y(I)+Y(I+1))*H/3
  33                 A=AS-AOLD
  35                 SUM(I+1)=SUM(I)+A
  40                 AOLD=A
  41     20 CONTINUE
  44        RETURN
  44        END




SIMPSPE
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75
SUBPROGRAM LENGTH
    57

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS

EXTERNALS AND TAGS
END     -  S00100

BLOCK NAMES AND LENGTHS

VARIABLE ASSIGNMENTS
A       -       56    AOLD    -       53    AS      -       55    A1      -       52
I       -       51    NM1     -       54

START OF CONSTANTS
    45

START OF TEMPORARIES
    47

START OF INDIRECTS
    51

START OF VARIABLES
    51

SPACE REQUIRED TO COMPILE -- SIMPSPE
 32500




SIMPSPE
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

          SUBROUTINE STRGENE (BONDL)
      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   ****************************************************************
   3      COMMON /BLOCK1/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
   3      COMMON /BLOC22/ SS(501),AAA,WS(501),MAXITE,CRACKW
   3      COMMON /BLOCK3/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB
   3      COMMON /BLOCK4/ AL(501),STRAIN(501),CONSTR(501),STRESSS(501)
   3      COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
   3      COMMON /BLOC26/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
   3      COMMON /BLOC28/ Y(501),REFF(501),YP(501),H,ICLOSEB,YPITE(501)
   3      COMMON /BLOC2C/ STRSC1(501),STRSS1(501),INC,FRF,FY,L
   3      INTEGER AAA
   3      REAL L
      C
   3              A=L-BONOL
   5              HH=-H
   7      DO 20 I=1,NTP1
      C
  10              STRAIN(I)=STRAINC
  12              AL(I)=HH+H
  15              HH=AL(I)
  16         IF (AL(I).LE.A) GO TO 10
  20              STRAIN(I)=STRAINC-STRAINC*(AL(I)-A)/BONDL
  24    10 CONTINUE
  24              CONSTR(I)=STRAIN(I)*EC
  27    20 CONTINUE
  31      RETURN
  32      END




 STRGENE
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75
SUBPROGRAM LENGTH
    37

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
10      -       24

EXTERNALS AND TAGS
END     -  S00100

BLOCK NAMES AND LENGTHS
BLOCK1 -       12C01 BLOCK2 -    1755C02 BLOCK3 -       6C03 BLOCK4 -    3724C04
BLOCK5 -       30C05 BLOCK6 -      10C06 BLOCK8 -    3726C07 BLOCKC -    1756C10

VARIABLE ASSIGNMENTS
A      -       34    AAA    -     765C02 AL     -       0C04 CONSTR -    1752C04
EC     -        2C06 FEXP   -       0C05 H      -    2737C07 HH     -         35
I      -       36    L      -    1755C10 NTP1   -       6C01 REFF   -     765C07
SS     -        0C02 STRAIN -     765C04 STRAINC-       4C01 STRESSS-    2737C04
STRSC1 -        0C10 STRSS1 -     765C10 WS     -     766C02 Y      -       0C07
YEXP   -       12C05 YP     -    1752C07 YPITE  -    2741C07

START OF CONSTANTS
    33

START OF TEMPORARIES
    33

START OF INDIRECTS
    34

START OF VARIABLES
    34

SPACE REQUIRED TO COMPILE -- STRGENE
 32700




STRGENE
```

```
                SUBROUTINE BACKTIM (TENSTRN,ZTOT,Z)
        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       ****************************************************************
   6            DIMENSION PERCENT(8),AGE(8)
   6            COMMON /BLOC21/ RATIO,THICK,P,FF,STRAINC,ES,NTP1,U,DIA,UNWT
   6            COMMON /BLOCK2/ SS(501),AAA,WS(501),MAXITE,CRACKW
   6            COMMON /BLOC23/ XBAR,STRSC,STRSB,STRC,IBABY,ITEB
   6            COMMON /BLOCK4/ AL(501),STRAIN(501),CONSTR(501),STRESSS(501)
   6            COMMON /BLOCK5/ FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
   6            COMMON /BLOCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,ITYPER
   6            COMMON /BLOC28/ Y(501),REFF(501),YP(501),H,ICLOSEB,YPITE(501)
   6            COMMON /BLOCK10/ NSTRN,VDS,AGEU(20),TENSION(20),STRNMUL
   6            DATA AGE/0.,3.,3.,5.,7.,14.,21.,28./
   6            DATA PERCENT/0.,15.,38.,53.,63.,82.,94.,100./
   6            INTEGER AAA
        C
        C
   6            IF (NSTRN.GT.0.) GO TO 30
  10                     FLESTRN=TENSTRN/STRNMUL
  11                     COMSTR=(12000.*FLESTRN)/(3000.-3.*FLESTRN)
  15                     PERTOM=(COMSTR/FPC)*100.
  20                     EC=33.*(UNWT**1.5)*SQRT(COMSTR)
  27                     RATIO=ES/EC
  30                     U=9.5*SQRT(COMSTR)/DIA
  35                IF (U.GT.800.) U=800.
  42            DO 10 I=1,8
  44                     J=I
  44               IF (PERCOM.LE.PERCENT(I)) GO TO 20
  47      10    CONTINUE
  51            PRINT 80, PERCOM
  57               GO TO 70
  62      20    CONTINUE
  62                     TIME=(PERCENT(J)-PERCENT(J-1))/(AGE(J)-AGE(J-1))
  67                     TIME=AGE(J-1)+(PERCOM-PERCENT(J-1))/TIME
  73               GO TO 60
  73      30    CONTINUE
        C
        C       COMPUTE THE TIME CORRESPONDING
        C       TO TENSILE STRENGTH
        C
  73            DO 40 I=1,NSTRN
  75                     J=I
  75               IF (TENSTRN.LE.TENSION(I)) GO TO 50
 100      40    CONTINUE
 103            PRINT 90, TENSTRN
 110               GO TO 70
 113      50    CONTINUE
        C
        C       COMPUTE SLOPE BY LINEAR INTERPOLATION
        C
 113                     TIME=(TENSION(J)-TENSION(J-1))/(AGEU(J)-AGEU(J-1))
 120                     TIME=AGEU(J-1)+(TENSTRN-TENSION(J-1))/TIME
```

```
        C
 124      60    CONTINUE
        C
 124                     SHRN=26.*EXP(0.36*VDS)
 132                     Z=(TIME/(SHRN+TIME))*ZTOT
 136            RETURN
 137      70    CONTINUE
 137      80    FORMAT (//,10X,*ERROR IS DETECTED IN SUBROUTINE BACKTIM.*,/,
               1         10X,*THE COMPUTED PERCENT COMPRESSION IS GREATER THAN T
               2E MAXIMUM PERCENT AVAILABLE*,/,
               3         10X,*PERCOM =*E10.3,/,
               4         10X,*PROGRAM IS TERMINATED*)
 137      90    FORMAT (//,10X,*ERROR IS DETECTED IN SUBROUTINE BACKTIM.*,/,
               1         10X,*THE COMPUTED TENSILE STRENGTH IS GREATER THAN THE
               2AXIMUM STRENGTH PROVIDED BY THE USER*,/,
               3         10X,*TENSTRN=*,E10.3,/,
               4         10X,*PROGRAM IS TERMINATED*)
 137            END
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENGTH
   302

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
20      -      62    30      -      73    50      -     113    60      -     124
70      -     137    80      -     154    90      -     213

EXTERNALS AND TAGS
SQRT    -  S00100    RBAREX -  S00200    OUTPTC -  S00300    EXP     -  S00400
END     -  S00500

BLOCK NAMES AND LENGTHS
BLOCK1 -       12C01 BLOCK2 -     1755C02 BLOCK3 -        6C03 BLOCK4 -     3724C04
BLOCK5 -       30C05 BLOCK6 -       10C06 BLOCK8 -     3726C07 BLOCK10-       53C10

VARIABLE ASSIGNMENTS
AAA    -     765C02 AGE     -    264      AGEU    -       2C10 AL      -       0C04
COMSTR -     275    CONSTR -    1752C04 DIA     -      10C01 EC      -       2C06
ES     -       5C01 FEXP    -       0C05 FLESTRN-    274     FPC     -       3C06
I      -     277    J       -    300      NSTRN   -       0C10 PERCENT-    254
PERCOM -     276    RATIO   -       0C01 REFF    -     765C07 SHRN    -    301
SS     -       0C02 STRAIN -     765C04 STRESSS-    2737C04 STRNMUL-      52C10
TENSION-      26C10 TIME    -       4C06 U       -       7C01 UNWT    -      11C01
VDS    -       1C10 WS      -     766C02 Y       -       0C07 YEXP    -      12C05
YP     -    1752C07 YPITE   -    2741C07

START OF CONSTANTS
   140

START OF TEMPORARIES
   251

START OF INDIRECTS
   254

START OF VARIABLES
   254

SPACE REQUIRED TO COMPILE -- BACKTIM
 33500
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

                    SUBROUTINE DELTEM1 (TIME,DELTAT)
              C
              C          THIS SUBROUTINE RETURNS THE TEMPERATURE DROP AT NON-
              C          INTEGER TIMES.
              C
       5            COMMON /BLOCK12/ DT(50),NTEMP,NTIFLAG,UPINC,DOWNINC
       5            DO 10 ITIME=1,NTEMP
       6                 REA3TI=FLOAT(ITIME)
      10               IF (REALTI.GT.TIME) GO TO 20
      13       10   CONTINUE
      15            PRINT 130, TIME,REALTI
      24            STOP 66
      26       20   CONTINUE
      26            DTIME=TIME-(REALTI-1)
      33            IF(DTIME.EQ.0.)GOTO 40
      34            DELTAT=DT(ITIME)*DTIME
      35            RETURN
      36         40 DELTAT=DT(ITIME)
      40            RETURN
      40        130 FORMAT(* ERROR IN DELTEM1 TIME = *,E10.3,*REALTI = *,E10.3)
      40            END
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENXTH
    56

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
20     -       26    40      -       36    130     -       44

EXTERNALS AND TAGS
OUTPTC -  S00100    STOP    -  S00200    END     -  S00300

BLOCK NAMES AND LENGTHS
BLOCK12-      66C01

VARIABLE ASSIGNMENTS
DT      -       0C01 DTIME   -       55    ITIME   -       53    NTEMP   -       62C01
REALTI -      54

START OF CONSTANTS
    41

START OF TEMPORARIES
    52

START OF INDIRECTS
    53

START OF VARIABLES
    53

SPACE REQUIRED TO COMPILE -- DELTEM1
 32500




DELTEM1
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

                  SUBROUTINE DELTEMP (TIME,DELTAT)
            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     *****************************************************************
      5           COMMON /BLOCK12/ DT(50),NTEMP,NTIFLAG,UPINC,DOWNINC
      5                     PI=3.14159265359
      6           DO 10 ITIME=1,NTEMP
     10                     REA3TI=FLOAT(ITIME)
     12              IF (REALTI.GT.TIME) GO TO 20
     15     10    CONTINUE
     17           PRINT 130, DELTAT,TIME
     26           STOP 66
     30     20    CONTINUF
     30              IF (TIME.GT.REALTI-.75.A.TIME.LT.REALTI-.25) GO TO 30
     45                     DELTAT=0.
     46              GO TO 40
     46     30    CONTINUE
     46                     DELTAT=DT(ITIME)*SIN((TIME-REALTI+.75)*2.*PI)
     57     40    CONTINUE
     57              IF (NTIFLAG) 100,80,50
     61     50    CONTINUE
     61                     DELTAT=DELTAT+UPINC
     63              IF (TIME.XT.REALTI-.5) GO TO 90
     70              IF (DELTAT.GE.DT(ITIME)+UPINC-1.E-7) GO TO 90
     74              IF (DELTAT.LE.DT(ITIME)) GO TO 120
     76     60    CONTINUE
     76                     DELTAT=DT(ITIME)
    100     70    CONTINUE
    100                     TIME=REALTI-.5
    102     80    CONTINUE
    102           RETURN
    103     90    CONTINUE
    103                     REA3TI=REALTI+1.
    105                     ITIME=ITIME+1
    107                     DELTAT=DELTAT-UPINC
    111              IF (ITIME.GT.NTEMP) GO TO 70
    114              IF (DELTAT.GE.DT(ITIME)) GO TO 60
    116              GO TO 120
    116     100   CONTINUE
    116                     DELTAT=DELTAT-DOWNINC
    120              IF (DELTAT) 110,110,120
    121     110   CONTINUE
    121                     DELTAT=0.
    122                IF (TIME.LE.REALTI-.5) TIME=REALTI-.75
    130                IF (TIME.GT.REALTI-.5) TIME=RFALTI+.25
    135           RETURN
    136     120   CONTINUE
    136                     TPLUS=ABS(ASIN(OELTAT/DT(ITIME))/(2.*PI)-.25)
    151                IF (TIME.LE.REALTI-.5) TPLUS=-TPLUS



DELTEMP
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

   156                  TIME=REALTI+TPLUS-.5
   161          RETURN
   161     130  FORMAT (* END OF TEMPERATURE ARRAY ENCOUNTERED*,/,* DELTAT =*,F6.3
               1,* TIME =*,F6.3)
   161          END
```

```
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

SUBPROGRAM LENGTH
   213

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
20      -        30     30      -        46     40      -        57     50      -        61
60      -        76     70      -       100     80      -       102     90      -       103
100     -       116     110     -       121     120     -       136     130     -       174

EXTERNALS AND TAGS
OUTPTC -  S00100     STOP    -  S00200     SIN     -  S00300     ASIN    -  S00400
END    -  S00500

BLOCK NAMES AND LENGTHS
BLOCK12-      66C01

VARIABLE ASSIGNMENTS
DOWNINC-      65C01 DT      -        0C01 1TIME  -        210     NTEMP  -      62C01
NTIFLAG-      63C01 PI      -       207    REALTI -        211     TPLUS  -       212
UPINC  -      64C01

START OF CONSTANTS
   162

START OF TEMPORARIES
   204

START OF INDIRECTS
   207

START OF VARIABLES
   207

SPACE REQUIRED TO COMPILE -- DELTEMP
 33200
```

APPENDIX 4

SAMPLE PROBLEMS

APPENDIX 4. SAMPLE PROBLEMS

```
        T OF PROGRAM-MODEL1


***********************************************
*                                             *
*               SLAB DIMENSIONS               *
*                                             *
***********************************************


      SLAB LENGTH          = 6.000E+01
      SLAB WIDTH           = 2.400E+01
      NUMBER OF INCREMENTS=  100
      FRICTION FACTOR      = 2.000E+00
      MAX. CRACKWIDTH      = 3.000E-02



 NON-REINFORCEMENT OPTION

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


      TYPE OF LONGITUDINAL REINFORCEMENT IS
                 DEFORMED BARS


      PERCENT REINFORCEMENT = 0.
      BAR DIAMETER          = 6.250E-01
      YIELD STRESS          = 6.000E+04
      ELASTIC MODULUS       = 2.900E+07
      THERMAL COEFFICIENT   = 5.000E-06



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


      SLAB THICKNESS       = 1.000E+01
      THERMAL COEFFICIENT = 6.000E-06
      TOTAL SHRINKAGE      = 4.000E-04
      UNIT WEIGHT CONCRETE= 1.440E+02
      COMPRESSIVE STRENGTH= 4.000E+03
      (TENS/FLEX)RATIO     = 6.666E-01


     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   86.9
            3.0  183.6
            5.0  230.9
            7.0  257.6
           14.0  300.3
           21.0  323.0
           28.0  333.3
    *********************************************
    *                                           *
    *      SLAB-BASE FRICTION CHARACTERISTICS   *
    *              F-Y RELATIONSHIP             *
    *                                           *
    *********************************************

          TYPE OF FRICTION CURVE IS A STRAIGHT LINE

           MAXIMUM FRICTION FORCE=   3.000
           MOVEMENT AT SLIDING   =   -.010


    ****************************
    *                          *
    *      TEMPERATURE DATA    *
    *                          *
    ****************************

          CURING TEMPERATURE= 75.0


               MINIMUM       DROP IN
    DAY      TEMPERATURE   TEMPERATURE

      1          55.0          20.0
      2          55.0          20.0
      3          55.0          20.0
      4          55.0          20.0
      5          55.0          20.0
      6          55.0          20.0
      7          55.0          20.0
      8          55.0          20.0
      9          55.0          20.0
     10          55.0          20.0
     11          55.0          20.0
     12          55.0          20.0
     13          55.0          20.0
     14          55.0          20.0
     15          55.0          20.0
```

```
16          55.0          20.0
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       =    0 DEGREES FARENHITE


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


MAXIMUM ALLOWABLE NUMBER OF ITERATIONS=   20

RELATIVE CLOSURE TOLERANCE=  1.0 PERCENT


  FOR THE GIVEN INPUT DATA, THE LENGTH OF THE NON-
  REINFORCED SLAB IS  1.800E+02 INCHES.
```

```
          T OF PROGRAM-MODEL1

*************************************************
*                                               *
*                SLAB DIMENSIONS                *
*                                               *
*************************************************


      SLAB LENGTH         = 6.000E+01
      SLAB WIDTH          = 2.400E+01
      NUMBER OF INCREMENTS=  100
      FRICTION FACTOR     = 2.000E+00
      MAX. CRACKWIDTH     = 3.000E-02



 STEEL DESIGN OPTION

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


      TYPE OF LONGITUDINAL REINFORCEMENT IS
                 DEFORMED BARS


      PERCENT REINFORCEMENT = 0.
      BAR DIAMETER          = 6.250E-01
      YIELD STRESS          = 6.000E+04
      ELASTIC MODULUS       = 2.900E+07
      THERMAL COEFFICIENT   = 5.000E-06


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


      SLAB THICKNESS      = 1.000E+01
      THERMAL COEFFICIENT = 6.000E-06
      TOTAL SHRINKAGE     = 4.000E-04
      UNIT WEIGHT CONCRETE= 1.440E+02
      COMPRESSIVE STRENGTH= 4.000E+03
      (TENS/FLEX)RATIO    = 6.666E-01


     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    86.9
       3.0   183.6
       5.0   230.9
       7.0   257.6
      14.0   300.3
      21.0   323.0
      28.0   333.3
************************************************
*                                              *
*      SLAB-BASE FRICTION CHARACTERISTICS      *
*               F-Y RELATIONSHIP               *
*                                              *
************************************************

     TYPE OF FRICTION CURVE IS A STRAIGHT LINE

      MAXIMUM FRICTION FORCE=   3.000
      MOVEMENT AT SLIDING   =   -.010


******************************
*                            *
*      TEMPERATURE DATA      *
*                            *
******************************

     CURING TEMPERATURE= 75.0

          MINIMUM      DROP IN
DAY     TEMPERATURE  TEMPERATURE

  1         55.0         20.0
  2         55.0         20.0
  3         55.0         20.0
  4         55.0         20.0
  5         55.0         20.0
  6         55.0         20.0
  7         55.0         20.0
  8         55.0         20.0
  9         55.0         20.0
 10         55.0         20.0
 11         55.0         20.0
 12         55.0         20.0
 13         55.0         20.0
 14         55.0         20.0
 15         55.0         20.0
```

```
  16          55.0          20.0
  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      =    0 DEGREES FARENHITE


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


  MAXIMUM ALLOWABLE NUMBER OF ITERATIONS=   20

  RELATIVE CLOSURE TOLERANCE=  1.0 PERCENT

FOR ITYPER EQUAL TO 1, THE TRANSVERSE STEEL IS  5.333E-02 PERCENT SPACED. 5.752E+0
INCHES CENTER TO CENTER.
WIDTH OF FIRST CRACK IS   .0084 INCHES AT TIME   .4791 DAYS.


WIDTH OF FIRST CRACK IS   .0087 INCHES AT TIME   .4860 DAYS.


WIDTH OF FIRST CRACK IS   .0089 INCHES AT TIME   .4927 DAYS.


WIDTH OF FIRST CRACK IS   .0093 INCHES AT TIME   .5048 DAYS.


WIDTH OF FIRST CRACK IS   .0095 INCHES AT TIME   .5000 DAYS.


WIDTH OF FIRST CRACK IS   .0103 INCHES AT TIME   .5176 DAYS.

AT THE END OF 28 DAYS NO SECOND CRACK OCCURS
 LONGITUDINAL STEEL =  7.173E-01 PERCENT.
 SPACED =  4.277E+00 INCHES CENTER TO CENTER
```

```
     T OF PROGRAM-MODEL1

************************************************
*                                              *
*                SLAB DIMENSIONS               *
*                                              *
************************************************


      SLAB LENGTH          = 6.000E+01
      SLAB WIDTH           = 2.400E+01
      NUMBER OF INCREMENTS=  100
      FRICTION FACTOR      = 2.000E+00
      MAX. CRACKWIDTH      = 3.000E-02



 SLAB ANALYSIS OPTION

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


      TYPE OF LONGITUDINAL REINFORCEMENT IS
                 DEFORMED BARS


      PERCENT REINFORCEMENT = 2.000E-01
      BAR DIAMETER          = 6.250E-01
      YIELD STRESS          = 6.000E+04
      ELASTIC MODULUS       = 2.900E+07
      THERMAL COEFFICIENT   = 5.000E-06


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


      SLAB THICKNESS       = 1.000E+01
      THERMAL COEFFICIENT = 6.000E-06
      TOTAL SHRINKAGE      = 4.000E-04
      UNIT WEIGHT CONCRETE= 1.440E+02
      COMPRESSIVE STRENGTH= 4.000E+03
      (TENS/FLEX)RATIO     = 6.666E-01


     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   86.9
            3.0  183.6
            5.0  230.9
            7.0  257.6
           14.0  300.3
           21.0  323.0
           28.0  333.3

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


          TYPE OF FRICTION CURVE IS A STRAIGHT LINE

           MAXIMUM FRICTION FORCE=   3.000
           MOVEMENT AT SLIDING   =   -.010


    *****************************
    *                           *
    *      TEMPERATURE DATA     *
    *                           *
    *****************************


          CURING TEMPERATURE= 75.0


               MINIMUM       DROP IN
    DAY      TEMPERATURE   TEMPERATURE

      1         55.0          20.0
      2         55.0          20.0
      3         55.0          20.0
      4         55.0          20.0
      5         55.0          20.0
      6         55.0          20.0
      7         55.0          20.0
      8         55.0          20.0
      9         55.0          20.0
     10         55.0          20.0
     11         55.0          20.0
     12         55.0          20.0
     13         55.0          20.0
     14         55.0          20.0
     15         55.0          20.0
```

```
16            55.0           20.0
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       =    0 DEGREES FARENHITE



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


          MAXIMUM ALLOWABLE NUMBER OF ITERATIONS=   20

          RELATIVE CLOSURE TOLERANCE=  1.0 PERCENT

WIDTH OF FIRST CRACK IS   .0087 INCHES AT TIME   .4845 DAYS.

STRESS IN THE STEEL 4.883E+04 IS GREATER THAN ITS WORKING STRENGTH AT TIME
 3.000
```

THE AUTHORS

Felipe Vallejo-Rivero was born in Huauchinango, Puebla, Mexico, on January 20, 1950, the son of Rosa Lilia Rivero de Vallejo and Felipe Vallejo Perez. After completing high school at "Colegio Humboldt de Puebla," Puebla, Puebla, Mexico, in 1967, he entered Instituto Tecnologico y de Estudios Superiores de Monterrey, Monterrey, Nuevo Leon, Mexico. He received the degree of Civil Engineer from the Instituto Tecnologico y de Estudios Superiores de Monterrey, Monterrey, Nuevo Leon, Mexico. Felipe Vallejo-Rivero worked as resident Engineer and work-coordinator for a private contractor firm in highway construction in the State of Puebla, Mexico.

He was awarded with a scholarship from the Asociacion Mexicana de Caminos through a special agreement between that agency and the Transportation Department of The University of Texas at Austin.

He attended the Intensive English Program for Foreign Students at The University of Texas at Austin.

Felipe Vallejo-Rivero is presently concerned with graduate studies in The Graduate School of Civil Engineering in The University of Texas at Austin, and also assists in the research of rigid pavement performance at the Center for Highway Research at The University of Texas at Austin.

B. Frank McCullough is an Associate Professor of Civil Engineering at The Unviersity of Texas at Austin. He has strong interests in pavements and pavement design and has developed design methods for continuously reinforced concrete pavement currently used by the State Department of Highways and Public Transportation, U. S. Steel Corporation, and others. He has also developed overlay design methods now being used by the FAA, U. S. Air Force, and FHWA. During nine years with the State Department of Highways and Public Transportation he was active in a variety of research and design activities. He worked for two years with Materials Research and

Development, Inc., Oakland, California, and for the past eight years for The University of Texas at Austin. He participates in many national committees and is the author of over 100 publications that have appeared nationally.