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 underlying 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.
DRYING SHRINKAGE AND TEMPERATURE DROP STRESSES 
IN JOINTED REINFORCED CONCRETE PAVEMENT 

by 

Felipe Rivero-Vallejo 
B. Frank McCullough 

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Federal Highway Administration 

by the 

CENTER FOR HIGHWAY RESEARCH 
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May 1976
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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
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LIST OF REPORTS

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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.
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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.
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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.
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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 that 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.
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<tr>
<td>37.5'</td>
<td>Shorter Slab</td>
<td>0%</td>
<td><img src="image" alt="Stress-Strength Distribution Diagram" /></td>
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</table>

\[
\sigma_c/S = \left( \frac{\text{Max. Tensile Stress}}{\text{Tensile Strength}} \right)
\]

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 phenomena 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 approximately 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).
Concrete Tensile Strength

\[ 25' = L_L > L_H \]

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

(a) Prior to cracking

(b) At cracking
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 friction 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 \( \frac{L}{2} - x \) 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).
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 the movement depends on slab length, drying shrinkage and temperature drop. The task now is to relate all these factors and predict the concrete stress.
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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 arbitrarily 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 water equal 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 17 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 ($\Delta T$) 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 porosity, 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:

\[
\frac{Z_t}{Z_f} = \frac{t}{M + t} \quad \text{(3.1)}
\]
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).
\[
\frac{Z_t}{Z_f} = \frac{t}{M + t}
\]  

(3.1)

\[
M = 26e^{0.36\left(\frac{v}{s}\right)}
\]  

(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:

\[
Z_t = \left(\frac{t}{26e^{0.36D} + t}\right)Z_f
\]  

(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 particularly 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 $5.5 \times 10^{-6}$ 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 ($\theta$) at any given depth ($x$) below the surface at any time ($t$) is obtained by means of the following relationships:

$$\theta = \theta_0 e^{-\frac{x}{h}} \sqrt{\frac{\pi}{T}} \sin \left( \frac{2\pi}{T} t - \frac{x}{h} \sqrt{\frac{\pi}{T}} \right)$$

(3.4)

and

$$\theta_0^* = \frac{1.5 \theta_{max} - \theta_{min}}{2}$$

(3.5)

where

- $\theta_0$ = 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,
- $T$ = periodic time of the temperature cycle (24 hours for the daily cycle),
- $\theta_{max}$ = maximum air temperature on a particular day, and
- $\theta_{min}$ = 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:

<table>
<thead>
<tr>
<th>Concrete Type</th>
<th>Ratio of Split-tensile Strength to Flexural Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel</td>
<td>5/8</td>
</tr>
<tr>
<td>Limestone</td>
<td>2/3</td>
</tr>
<tr>
<td>Light-weight Aggregate</td>
<td>3/4</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>Type of Coarse Aggregate</th>
<th>Concrete Thermal Coefficient ($10^{-6}$ in/in/°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>6.6</td>
</tr>
<tr>
<td>Sandstone</td>
<td>6.5</td>
</tr>
<tr>
<td>Gravel</td>
<td>6.0</td>
</tr>
<tr>
<td>Granite</td>
<td>5.3</td>
</tr>
<tr>
<td>Basalt</td>
<td>4.8</td>
</tr>
<tr>
<td>Limestone</td>
<td>3.8</td>
</tr>
</tbody>
</table>
\[ f'_c = \frac{4000 f_r}{1000-f_r} \]  

(3.6)

where

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

(3) Compute modulus of elasticity of the concrete by

\[ E_c = \gamma^{1.5} \cdot 33 \sqrt{f'_c} \]  

(3.7)

where

\[ \gamma \] = unit weight of the concrete (pcf) and  
\[ E_c \] = modulus of elasticity of concrete (psi).

(4) Compute the bond stress by using

\[ \mu = \frac{9.5 \sqrt{f'_c}}{\phi} \]  

(3.8)

where

\[ \mu \] = bond stress (psi) and  
\[ \phi \] = 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:

\[ E_c = \gamma^{1.5} 33 \sqrt{f'_c} \quad (3.7) \]
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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; \( \sum F_x = 0 \) must be satisfied for equilibrium of the system, gives:

\[
\sum F_x = 0
\]

\[
F_c + F_s = \int_0^x F_1 \, dx
\]
Fig. 4.3. Free body diagram and corresponding stress distribution of Model-1.
or

\[ F_c + F_s - \int_0^x F'_i \, dx = 0 \]  \hspace{1cm} (4.1)

where

\[ F_c = \text{force in the concrete (lb)}, \]
\[ F_s = \text{force in the steel (lb)}, \]
\[ F'_i = \text{friction force per unit length along the slab}, \]
\[ F_i = \text{friction force per unit length per unit width}. \]

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

\[ A_c \sigma_c + A_s \sigma_s - \int_0^x F'_i \, dx = 0 \]  \hspace{1cm} (4.2)

where

\[ \sigma_c = \text{stress in the concrete, psi}, \]
\[ \sigma_s = \text{stress in the steel, psi}, \]
\[ A_s = \text{cross-sectional area of longitudinal steel, in}^2, \]
\[ A_c = \text{cross-sectional area of concrete, in}^2. \]

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

\[ D \sigma_c + \frac{A_s}{L} \sigma_s - \int_0^x F'_i \, dx = 0 \]

where \( D = \text{slab thickness (inches)}. \)

Therefore, dividing by \( D \), the equation becomes

\[ \sigma_c + \frac{A_s}{L A_c} \sigma_s - \frac{\int_0^x F_i \, dx}{D} = 0 \]
where

\[ L = \text{slab width}. \]

Substituting

\[ p = \frac{A_s}{A_c} = \frac{A_s}{D \times L} \]

implies

\[ \sigma_c + \rho \sigma_s - \frac{\int_0^X F_i \, dx}{D} = 0. \] (4.3)

**Compatibility Equations for Model-1.** 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) **Shrinkage.** 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:

\[ \varepsilon_{cz} + \varepsilon_{sz} = Z \]

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

\[ Z = \text{free drying shrinkage strain of concrete}, \]
\[ \varepsilon_{cz} = \text{concrete strain due to shrinkage (strain of concrete due to restraint of steel)}, \]
\[ \varepsilon_{sz} = \text{steel strain due to shrinkage (strain of steel due to shrinkage of concrete)}. \]

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

\[ Z = \varepsilon_{cz} + \varepsilon_{sz} \]

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 \( \sigma_{cz} \),

\[ \sigma_{cz} = E_c Z + \frac{\sigma_{sz}}{n} \quad (4.5) \]
where

\[ \sigma_{cz} = \text{stress in the concrete due to shrinkage}, \ Z, \]
\[ \sigma_{sz} = \text{stress in steel due to shrinkage}, \ Z, \]
\[ E_c = \text{elastic modulus of concrete}, \]
\[ n = \text{modulus ratio}, \]
\[ E_s = \text{elastic modulus of steel}. \]

(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 assumed 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:

\[ \epsilon_{c\Delta T} - \epsilon_{s\Delta T} = \Delta T (\alpha_c - \alpha_s) \]
\[ \epsilon_{c\Delta T} = \Delta T (\alpha_c - \alpha_s) + \epsilon_{s\Delta T} \]  \hspace{1cm} (4.6)

where

\[ \epsilon_{c\Delta T} = \text{strain in the concrete due to a temperature drop } \Delta T, \]
\[ \epsilon_{s\Delta T} = \text{strain in the steel due to a temperature drop } \Delta T, \]
\[ \Delta T = \text{drop in concrete temperature } (^\circ F), \]
\[ \alpha_c = \text{concrete linear thermal coefficient } (^\circ F), \]
\[ \alpha_s = \text{steel linear thermal coefficient } (^\circ F). \]

For a stress equation, equation 4.6 can be written

\[ \sigma_{c\Delta T} = \Delta T (\alpha_c - \alpha_s) E_c + \frac{\sigma_{s\Delta T}}{n} \]  \hspace{1cm} (4.7)
(a) Undisturbed state

(b) Contraction due to $\Delta T$ with complete slippage between concrete and steel. No restriction condition

(c) Contraction due to $\Delta T$ with no slippage between concrete and steel.

Fig 4.5. Reinforced element subjected to uniform temperature drop $\Delta T$. 
where

\[ \sigma_{c\Delta T} = \text{stress in the concrete due to } \Delta T (\text{psi}), \]
\[ \sigma_{s\Delta T} = \text{stress in the steel due to } \Delta T (\text{psi}). \]

If the principle of superimposition is applied to the concrete and steel stresses due to \( Z \) and \( \Delta T \), 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 \( \sigma_{cz} \) and \( \sigma_{c\Delta T} \) from Eqs 4.5 and 4.7,

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

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 \( \Sigma F_x = 0 \) gives
Fig 4.6 Effect of the restraint, provided by the subbase on a concrete slab.
Fig. 4.7. Free body diagram of an element in Model-1.
\[ dF_c + dF_s = -F_1' \, dx \]

or expressed into a stress equation:

\[ A_c \, d\sigma_c + A_s \, d\sigma_s = -F_1' \, dx \]

\[ d\sigma_c + p d\sigma_s = -\frac{F_1}{D} \, dx \]  \hspace{1cm} (4.9)

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

\[ \sigma_c = \frac{\sigma_s}{n} + E_c [Z + \Delta T (\alpha_c - \alpha_s)] \]  \hspace{1cm} (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 \( d\sigma_s \)

\[ d\sigma_s = nd\sigma_c \]  \hspace{1cm} (4.10)

Substituting into equation 4.9

\[ d\sigma_c + pd\sigma_c = \frac{F_1}{D} \, dx \]

\[ \frac{d\sigma_c}{dx} = \frac{F_1}{D} \left( \frac{1}{1 + pn} \right) \]  \hspace{1cm} (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:

\[ Y_{cz} = \int_{0}^{x} \epsilon_{cz} dx - Zx + k_1 \] (4.12)

for temperature:

\[ \frac{d}{dx} Y_{c\Delta T} = \epsilon_{c\Delta T} - \alpha_{c\Delta T} \]

Integrating:

\[ Y_{c\Delta T} = \int_{0}^{x} \epsilon_{c\Delta T} dx - \alpha_{c\Delta T}x + k_2 \] (4.13)

Thus,

\[ Y_c = Y_{c\Delta T} + Y_{cz} \] (4.14)
where

\[ Y_{cz} = \text{concrete movement due to shrinkage (inches)} \]
\[ Y_{c\Delta T} = \text{concrete movement due to drop in temperature (inches)} \]
\[ Y_c = \text{total concrete movement at the joint due to } Z \text{ and } \Delta T \text{ (inches)}, \text{ and} \]
\[ k_1, k_2 = \text{constants of integration}. \]

Then, from 4.12, 4.13, and 4.14

\[ Y_c = \int_0^x \varepsilon_{c\Delta T} \, dx - \alpha_c \Delta T x + \int_0^x \varepsilon_{cz} \, dx - Z x + k_2 + k_1 \]

If

\[ \varepsilon_c = \varepsilon_{c\Delta T} + \varepsilon_{cz} \]
\[ k_3 = k_2 + k_1 \]

then

\[ Y_c = \int_0^x \varepsilon_c \, dx - (Z + \alpha_c \Delta T) x + K_3 \]

But at \( x = 0, \ Y_c = 0. \)

Therefore,

\[ Y_c = \int_0^x \varepsilon_c \, dx - (Z + \alpha_c \Delta T) x \quad (4.15) \]

or if expressed into a stress equation,

\[ Y_c = \int_0^x \frac{\sigma_c}{E_c} \, dx - (Z + \alpha_c \Delta T) x \quad (4.16) \]
(5) **Joint Width.** From equation 4.15, it is possible to evaluate the joint width, by integrating at \( x = \frac{X}{2} \) as follows:

\[
Y_j = \int_0^{\frac{X}{2}} \frac{c}{E_c} \, dx - (Z + \alpha_c \Delta T)X
\]

But \( Y_c \) will be the concrete movement of one half of the slab, thus if \( \Delta X \) is the joint width, it can be written that

\[
\Delta X_j = 2 \, Y_c = 2 \left( \frac{c}{E_c} \frac{X}{2} - (Z + \alpha_c \Delta T) \frac{X}{2} \right)
\]

\[
\Delta X_j = \frac{X}{x} \left[ \frac{c}{E_c} - (Z + \alpha_c \Delta T) \right]
\]

where

- \( \Delta X \) = joint width (inches), and
- \( \overline{X} \) = 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:

$$F_s - (F_s + dF_s) + Ud\alpha = 0$$

where

$$U = \text{average bond force per unit length of the slab.}$$

Therefore:

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

Since

$$U = \mu \Sigma_o \quad (4.19)$$
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

\[ \mu = \text{bond stress}; \quad \mu = \frac{9.5 \sqrt{f' \_c}}{\phi}, \]

\[ f' \_c = \text{compressive strength of concrete}, \]

\[ \Sigma = \text{perimeter of the bar(s)}, \]

\[ \phi = \text{bar diameter}. \]

Substituting the value of \( U \) from Eq 4.19 into Eq 4.18

\[ \frac{dF_s}{dx} = \mu \Sigma o \]

and transforming equation 4.20 to a stress equation using

\[ F_s = \sigma A_s \]

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
\[
\frac{d\sigma_s}{dx} = \frac{\mu\psi}{1 + \phi^2} = \frac{4\mu}{\phi}
\]

Therefore:
\[
\frac{d\sigma_s}{dx} = \frac{4\mu}{\phi}
\]  \hspace{1cm} (4.21)

For a constant bond stress \( \mu \), 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 \( \Sigma_i = 0 \) 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
\[
\frac{d\sigma_c}{dx} \cdot A_c = -F_i' - \mu \Sigma_o
\]
\[
\frac{d\sigma_c}{dx} = \frac{F_i'}{A_c} - \frac{\mu \Sigma_o}{A_s}
\]
\[
\frac{d\sigma_c}{dx} = -\frac{F'_1}{A_c} - \frac{\mu p \phi}{2} + \frac{\mu p \phi}{4}
\]

\[
\frac{d\sigma_c}{dx} = -\frac{F'_1}{A_c} - \frac{4\mu p}{\phi}
\]

For a unit width slab \( A_c = D \times 1 \), then

\[
\frac{d\sigma_c}{dx} = -\frac{F'_1}{D} - \frac{4\mu p}{\phi}
\]

(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, \( \Sigma F_x = 0 \) yields

\[
F_{so} + F_{co} - F_{sc} - \int_0^X F'_1 dx = 0
\]

(4.23)

where

\[
F_{so} = \text{force in the steel at point of zero movement (lb),}
\]
\[
F_{co} = \text{force in the concrete at point of zero movement (lb),}
\]
\[
F_{sc} = \text{force in the steel at the crack (lb), and}
\]
\[
F'_1 = \text{friction force per unit length along the slab (lb/in).}
\]

Transforming Eq 4.23 to a stress equation,

\[
A_s \sigma_{so} + A_c \sigma_{co} = A_c \sigma_{sc} - \int_0^X F'_1 dx = 0
\]

(4.24)
Figure 4.11. Free-body diagram and corresponding stress distribution of Model-2.
and for a unit width slab

\[ p\sigma_{so} + \sigma_{co} - p\sigma_{sc} - \frac{\int_{0}^{x} F \, dx}{D} = 0 \]

or

\[ \sigma_{co} + p\sigma_{so} = p\sigma_{sc} + \frac{\int_{0}^{x} F \, dx}{D} \] (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,

\[ \varepsilon_{s} = \alpha_{s} \Delta T \]

for \( x \),

\[ \int_{a}^{b} \varepsilon_{s} \, dx = \alpha_{s} a \Delta T \]

\[ \int_{a}^{b} \varepsilon_{s} \, dx = \alpha_{s} a \Delta T \]

where

\[ X_{c} = \text{the distance between the first crack and the point of zero movement.} \]

Since

\[ X_{c} = a + b \]

substituting for \( a + b \),

\[ \int_{0}^{a} \varepsilon_{s} \, dx + \int_{a}^{b} \varepsilon_{s} \, dx = \alpha_{s} \Delta T X_{c} \]
and

\[ \sigma_s = \varepsilon_s E_s \]

therefore

\[ \int_0^a \sigma_s \, dx + \int_a^b \sigma_s \, dx = E_s \varepsilon_s X T \quad (4.26) \]

where

\[ a = \text{fully bonded length of } X_c, \]
\[ b = \text{bond slip zone}. \]

**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

\[ \sigma_c + \rho \sigma_s - \frac{\int_0^x F_i \, dx}{D} = 0 \quad (4.3) \]

2. Concrete stress due to shrinkage and drop in temperature

\[ \sigma_c = \frac{\sigma_s}{n} + E_c \left[ \varepsilon + \Delta T(\alpha_c - \alpha_s) \right] \quad (4.8) \]

3. Friction

\[ \frac{d\sigma_c}{dx} = -\frac{F_i}{D} \times \frac{1}{(1+pn)} \quad (4.11) \]
(4) Concrete movement at joint

\[ Y_c = \int_0^x \frac{\sigma_c}{E_c} \, dx - (Z + \alpha_c \Delta T)x \]  

(4.16)

(5) Joint width

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

(4.17)

Model-2:

(1) Equilibrium

\[ \sigma_{co} + \rho \sigma_{so} - \rho \sigma_{sc} + \frac{\int_0^x F_i \, dx}{D} \]  

(4.25)

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

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

(4.8)

(3) Friction,

\[ \frac{d\sigma_c}{dx} = - \frac{F_i}{D} \times \frac{1}{(1+pn)} \]  

(4.11)

(4) Crack width

\[ \Delta X_c = 2 \left[ \int_0^x \frac{\sigma_c}{E_c} \, dx - (Z + \alpha_c \Delta T) X_c \right] \]  

(5) Steel boundary conditions

\[ \int_0^a \sigma_s \, dx + \int_a^b \sigma_s \, dx = E_s \Delta T X_c \]  

(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 \( \Delta x \) 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 $\Delta X$ by $\Delta X$ each time.
Fig 4.13. Concrete stresses with time.
Concrete Movement at the Crack

(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.

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 $\sigma_s$ yields

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

and substituting $\sigma_s$ 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 $\sigma_c$

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

$$\sigma_c = \frac{pnE_c[Z + \Delta T(\alpha_c - \alpha_s)] + \int_o^x F_i \, dx}{[1 + pn]}$$  \hspace{1cm} (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 $\sigma_c$ and $F_1$ corresponding to the friction-movement closure point are used to compute the stress in the steel by using the following equation:

$$\sigma_s = \frac{\int_0^x F_i \, dx}{pD} - \frac{\sigma_c}{p}$$  \hspace{1cm} (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 $\Delta X = \frac{x}{N}$,
2. for a given time, solve Model-1 for a distance equal to $\Delta X$, the increment length
3. increment the Model-1 length into another $\Delta X$ and solve for $\sigma_c$ and $\sigma_s$,
4. continue incrementing $\Delta X$ by one $\Delta X$ and compute $\sigma_c$ and $\sigma_s$ until $\Delta X$ is equal to half the total slab length,
5. having the stress in the concrete for each $\Delta X$, an equation relating $\sigma_c = f($distance$)$ is computed,
Fig. 4.16. Binary search technique as applied to frictional resistance-movement curve.
(6) substitute the value of $\sigma_c$ in the above equation by the concrete strength $f'_t$ at that time and find the corresponding distance,
$$ \text{Dist} = f(f'_t), \quad \text{and} $$
(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 $t_7$, then, Model-1 is used as described above for time $t_8$, and Model-2 is also solved for that time $t_8$.

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 $\Delta X$ until $\Delta X$ 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 will 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).

\[
p = \frac{LF}{2f_s} \times 100
\]  

(4.29)

where

\[
p = \text{percentage steel required (cross-sectional area) (percent)},
L = \text{distance between free edges (feet)},
f_s = \text{allowable working stress in steel (0.75 of yield strength)},
F = \text{friction factor of subbase}.
\]

(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):

$$Y = \frac{A_B}{D \times p} \times 100$$

(4.30)

where

- $p = \text{percentage steel required}$,
- $D = \text{slab thickness (inches)}$,
- $A_B = \text{cross-sectional area of steel bar or wire (square inches)}$,
- $Y = \text{center to center spacing (inches)}$.

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).

<table>
<thead>
<tr>
<th>Subbase Type</th>
<th>Friction Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Treatment</td>
<td>2.2</td>
</tr>
<tr>
<td>Lime Stabilization</td>
<td>1.8</td>
</tr>
<tr>
<td>Asphalt Stabilization</td>
<td>1.8</td>
</tr>
<tr>
<td>Cement Stabilization</td>
<td>1.8</td>
</tr>
<tr>
<td>River Gravel</td>
<td>1.5</td>
</tr>
<tr>
<td>Crushed Stone</td>
<td>1.5</td>
</tr>
<tr>
<td>Sandstone</td>
<td>1.2</td>
</tr>
<tr>
<td>Natural Subgrade</td>
<td>0.9</td>
</tr>
</tbody>
</table>

**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.
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 occurrence 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 second 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 its 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 different 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.
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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 Fahrenheit 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

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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.
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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 load 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 pavements 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 temperature 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 those 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 would reflect more variables than taken in to account at the present time; thus the performance level of CRCP would be improved.
REFERENCES


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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)

<table>
<thead>
<tr>
<th>Description of Run</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
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<th>PROB NUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>A5</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Description of Problem (alphanumeric)</th>
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</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

SLAB DIMENSIONS

<table>
<thead>
<tr>
<th>FT</th>
<th>FT</th>
<th>lb/in/in</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLAB LENGTH</td>
<td>SLAB WIDTH</td>
<td>NUMBER OF INCREMENTS</td>
</tr>
<tr>
<td>F8.4</td>
<td>F8.4</td>
<td>I5</td>
</tr>
</tbody>
</table>

slab length must be understood as transverse joint spacing

STEEL PROPERTIES (one card each problem)

<table>
<thead>
<tr>
<th>ITYPER</th>
<th>in²</th>
<th>(PSI)</th>
<th>(PSI)</th>
<th>/°F</th>
<th>TRANSVERSE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PERCENT</td>
<td>BAR</td>
<td>YIELD</td>
<td>ELASTIC</td>
<td>THERMAL</td>
</tr>
<tr>
<td>ITYPER</td>
<td>REINFORCEMENT</td>
<td>DIAMETER</td>
<td>STRESS</td>
<td>MODULUS</td>
<td>COEFFICIENT</td>
</tr>
<tr>
<td>I5</td>
<td>E10.3</td>
<td>E10.3</td>
<td>E10.3</td>
<td>E10.3</td>
<td>E10.3</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>(IN) SLAB THICKNESS</th>
<th>/°F THERMAL COEFFICIENT</th>
<th>(IN/IN) DRYING SHRINKAGE STRAIN</th>
<th>UNIT WEIGHT OF CONCRETE (pcf)</th>
<th>(PSI) 28-DAY COMPRRESSIVE STRENGTH*</th>
<th>TENS. STRENGTH</th>
<th>FLEX. STRENGTH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>E10.3</td>
<td>E10.3</td>
<td>E10.3</td>
<td>E10.3</td>
<td>E10.3</td>
</tr>
</tbody>
</table>

AGE-TENSILE STRENGTH RELATIONSHIP

<table>
<thead>
<tr>
<th>NTS</th>
<th>AGE(1)</th>
<th>TS(1)</th>
<th>AGE(2)</th>
<th>TS(2)</th>
<th>AGE(7)</th>
<th>TS(7)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td></td>
<td>F5.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>AGE(8)</th>
<th>TS(8)</th>
<th>AGE(NTS)</th>
<th>TS(NTS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
</tr>
</tbody>
</table>

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.
SLAB-BASE FRICTION RELATIONSHIP (F-y curve)

<table>
<thead>
<tr>
<th>IFY</th>
<th>F(1)</th>
<th>y(1)</th>
<th>F(2)</th>
<th>y(2)</th>
<th>F(7)</th>
<th>y(7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F5.2</td>
<td>F5.2</td>
<td>F5.2</td>
<td>F5.2</td>
<td>F5.2</td>
<td>F5.2</td>
</tr>
<tr>
<td>2</td>
<td>F5.2</td>
<td>F5.2</td>
<td>F5.2</td>
<td>F5.2</td>
<td>F5.2</td>
<td>F5.2</td>
</tr>
</tbody>
</table>

*IFY = 1*

*IFY = 2*

*IFY = Total Number of Points*

<table>
<thead>
<tr>
<th>F(1), y(1)</th>
<th>F</th>
<th>F(1), y(1)</th>
<th>F</th>
<th>F(IFY), y(IFY)</th>
<th>F</th>
</tr>
</thead>
</table>

Straight Line  
Parabola  
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.*
TEMPERATURE DATA

Average curing temperature and minimum daily temperature (°F)

<table>
<thead>
<tr>
<th>CURT</th>
<th>NTEMP</th>
<th>TD(1)</th>
<th>TD(2)</th>
<th>TD(3)</th>
<th>TD(13)</th>
<th>TD(14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1</td>
<td>15</td>
<td>5.1</td>
<td>5.1</td>
<td>5.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TD(15)</th>
<th>TD(16)</th>
<th>TD(NTEMP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1</td>
<td>5.1</td>
<td>5.1</td>
</tr>
</tbody>
</table>

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

DITMAX

| F5.1 |

ITERATIONS AND TOLERANCE CONTROL

<table>
<thead>
<tr>
<th>MAXITE</th>
<th>TOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>5.1</td>
</tr>
</tbody>
</table>

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

STOP PROGRAM One blank card to end program
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/in² 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
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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
BHICH Spacing of transverse wire in deformed wire fabric
BLOW Half spacing of transverse wires
BOND 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
MAL AAA-1
MAXITE Maximum allowable number of iterations
N Index for reading data

105
NPROB  Problem number (stops if blank)
NT    Total number of increments in the JRCP-1 Model
NTMP  Number of daily temperatures
NTPI  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
AAAA  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
CI,...,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
CONCRESC  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
STRESSB   Stress in the steel between cracks
STRESBC   Stress in the steel at the crack
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APPENDIX 3

COMPUTER PROGRAM
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APPENDIX 3. COMPUTER PROGRAM

RUN DATE FEB 74 16.51.06. 23 JUL 75

PROGRAM JRCPI(INPUT,OUTPUT)

3 DIMENSION AN(140),AN2(118)
3 DIMENSION F(50),SUM(50),AGE(8),PERCENT(8)
3 COMMON /BLOCK/ RATIO,THICK,P,FF,STRAIN,CST,HTP,DIAM,UNW
3 COMMON /BLOCK2/ 55(50),AAA+55(50),MAXITE,CRACK
3 COMMON /BLOCK3/ XBAR,STRS5+STRS5+IBLACK+TBD
3 COMMON /BLOCK4/ AL(50)+STRAIN(50)+CONSTR+STRESS(50)
3 COMMON /BLOCKS/ PEXP(1),XEXP(1),XPICM,INT,PU,IFY
3 COMMON /BLOCK6/ ALPHAC,ALPHAS,EFC,FPC,TIME,EP,TOL,ITYPER
3 COMMON /BLOCK8/ 75(50)+REFP(50),P(50),H(CLOSED)+FPE(50)
3 COMMON /LOCK/ STA,STP,PSA,PSST,ITE
3 COMMON /LOCK1/ NSTRN+VDS+AGEU(20)+TENSION(20)+STMNUL
3 COMMON /LOCK2/ DT(50),NTEMP,HTFLAG,UPINC,NOINC
3 COMMON /LOCK3/ 21(2),XBAR+21(2),DELTAM+DELTAP+TEMP+REFF+TPE1+4
3 COMMON /LOCK4/ BHIGN+BLON+TOL+PE+TST
3 COMMON /LOCK5/ STRES(50)+STRESS(50)+INC+FRF+FY+L
3 DATA AGE/0.1,0.7,1.4,2.1,8.8/
3 DATA PERCENT/6.15,3.15,5.31,6.82,94.100./
3 REAL NCT0
3 INTEGER AAA
3 INTEGER AN,AN2
3 REAL L
3 ITEST=5H

C PROGRAM AND PROBLEM IDENTIFICATION

5 READ 510, (AN1(N),N=1,40)
10 CONTINUE
12 READ 520, NPR0B, (AN2(N),N=1,18)
22 IF (NPROB .EQ. ITEST) GO TO 20+50,20
24 CONTINUE
29 PRINT 530
30 PRINT 550, (AN1(N),N=1,40)
36 PRINT 550, NPR0B, (AN2(N),N=1,18)
3 C READ SLAB DIMENSIONS AND DESIGN FLAGS
4 C READ 555, XBAR+HTP,FPC+CRWN+ISTOS+NF
62 PRINT 580
72 PRINT 590
76 PRINT 565
102 PRINT 580
106 PRINT 590, XBAR+HTP+FPC+CRWN+ISTOS+NF
124 PRINT 590
128 557 FORMAT(/,15X,2HM SLAB LENGTH +<10.3/>,
1 15X 2HM SLAB WIDTH +<10.3/>,
2 15X 2HM NUMBER OF INCREMENTS +<15/>,
3 15X 2HM FRICTION FACTOR +<10.3/>,
4 15X 2HM MAX CRACKWIDTH +<10.3/>)
128 IF (ISTOS.EQ.1) PRINT 551
133 IF (NFR.EQ.1) PRINT 553
141 IF (NFR.EQ.1) PRINT 554
156 555 FORMAT(2FM,15X,2FM,15X,2FM,15X,2FM)
154 556 FORMAT(100X,4H1,100X,4H1,100X,4H1,100X,4H1)
154 556 FORMAT(100X,4H1,100X,4H1,100X,4H1,100X,4H1)
154 554 FORMAT(/,15X,2HM STEEL DESIGN OPTION */)

JRCPI

RUN DATE FEB 74 16.51.06. 23 JUL 75

154 C 553 FORMAT(/,10X,4H NON-REINFORCEMENT OPTION */)
154 C 554 FORMAT(/,10X,4H SLAB ANALYSIS OPTION */)
154 C 555 C
154 C INPUT STEEL PROPERTIES
154 C READ 560, ITYPEP+DIA+FPE+ALPHAS+BHIGH
154 C PRINT 580
154 C PRINT 570
154 C PRINT 580
154 C IF (ITYPER,EQ.1) PRINT 500 R
154 C IF (ITYPER,EQ.2) PRINT 600 R
154 C IF (ITYPER,EQ.1) GO TO 400 R
154 C PRINT 610, P+DIA+FPE+ALPHAS+BHIGH
154 C C INPUT CONCRETE PROPERTIES
154 C READ 620, THICK+ALPHAC+TST+UNW+FPC+STMNUL
154 C PRINT 580
154 C PRINT 570
154 C PRINT 580
154 C PRINT 590
154 C PRINT 580
154 C PRINT 580
154 C PRINT 640, THICK+ALPHAC+TST+UNW+FPC+STMNUL
154 C C INPUT AGE-TENSILE STRENGTH RELATIONSHIP
154 IF (STMNUL.EQ.0) STMNUL=1.0
154 C NSTRN DESIGNATES WHETHER AGE-STRENGTH RELATIONSHIP IS AVAILABLE
154 C NSTRN = 1 AGE-STRENGTH DATA IS PROVIDED
154 C REAO 640, NSTRN+AGEU(1)+TENSION(1)+1+1,1
154 IF (NSTRN.GT.7) READ 650, (AGEU(1)+TENSION(1)+1+1)+NSTRN
154 R TENS=TENSION(1)+NSTRN
154 IF (NSTRN.EQ.0) GO TO 20 R
154 PRINT 670, ((AGEU(1)+TENSION(1)+1+1)+NSTRN
154 C CONTINUE
154 C CONTINUE
154 C PRINT 700, AXE1+DUM
154 C CONTINUE
154 C CONTINUE
154 C CONTINUE
154 C CONTINUE
154 C CONTINUE
154 C CONTINUE
154 C CONTINUE
154 C CONTINUE
154 C input SLAB-BASE FRICTION RELATIONSHIP **FORCE-DISPLACEMENT**
154 C FORCE-DISPLACEMENT RELATIONSHIP
154 C PRINT 710
154 C READ 736, IFX,(IFXP(1),YXP(1)=1.7)

JRCPI
RUNW VERSION FEB 74 16.51.06. 23 JUL 75

774 IF (ITYPER.EQ.1) ICLOSE=1
775 ANTEMP=ANTEMP
1001 :RAPY=0
1002 :IBAHR=0
1003 :EFENDE=0
1004 :ITE=0
1005 :WTP1=NT+1
1006 :IB=1
1007 :VOS=THICK
1011 :EP=1.0E-9
1013 :AAA=1
1014 :ALDIB=MIGH/2.
1016 140 CONTINUE
1022 IF(ISTR.1,0,0.NQR=1)GOTO 450
1032 C C PREPARE FOR PRINTING RES...RES
1035 PPI=100.
1036 YSL=YAB=100./THICK*P
1042 PRINT 800.FYSTL
1047 190 FORMAT (12X.5H },TIME TEMP DRYING.
1050 190 FORM_T ( 2X.5.2.2X.F5.1.2X,E10.3.2X,F1.3X.R
1050 FORM_T (IOX.R--TRI
1050 FORM_T (IOX.R
1050 FORM_T(10X.R
1050 FORM_T (10X,48~
1050 FORM_T (10X,48H CONCRETE PROPERTIES
1050 FORM_T (10X,46X.1H
1074 C C INPUT MINIMUM TEMPERATURE AFTER
1075 C C CONCRETE GAINS FULL STRENGTH
1077 C C READ 830, OT3ATM
1079 840 FORMAT (840. DELTATM
1080 840 FORMAT (RA0. MAXIT3EOL
1084 840 FORMAT (RA0. INITALIZE PARAMETERS *
1085 840 FORMAT (ITL=OTL/100.
1087 840 120 CONTINUE
1089 840 IF (IFINISH,0.01) GO TO 130
1092 840 PRINT 530
1094 840 PRINT 540. ANNI(N)=N=140
1096 840 PRINT 550. NPROB.(AN2(N)=N=18)
1098 840 IF (IFINISH.0.01) PRINT 400
1099 840 130 CONTINUE

JRPC1
TENSILE STRENGTH DATA IS INPUT BY USER.

2. fT的关系是基于U.S. Bureau of Reclamation的建议。

3. 给定的年龄-拉伸强度关系。

4. 用于计算摩擦力的曲线类型是线性的。

5. 最大摩擦力。

6. 摩擦力-位移曲线的类型是抛物线的。

7. 摩擦力-位移曲线的类型是多线性的。

8. 砼的最低温度。

9. 温度数据。

10. 温度。

11. 温度。
RUNW VERSION FEB 74 16.51.06. 23 JUL 75
PROGRAM LENGTH INCLUDING I/O BUFFERS 6419

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS

10 - 12 20 - 24 30 - 407 40 - 4311
60 - 450 70 - 517 80 - 523 90 - 533
100 - 541 120 - 763 130 - 774 140 - 1016
450 - 1051 480 - 1201 490 - 1231 510 - 1243
520 - 1245 530 - 1250 540 - 1254 550 - 1256
551 - 1131 553 - 1156 554 - 1162 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 - 1534
700 - 1600 610 - 1600 720 - 1635 730 - 1640
740 - 1640 750 - 1665 760 - 1707 770 - 1772
780 - 1727 790 - 1732 800 - 1746 810 - 1767
820 - 2004 830 - 2010 840 - 2013 850 - 2035
860 - 2037 870 - 2061 880 - 2077 890 - 2114
900 - 2121 910 - 2152 850 - 2202 860 - 2222

EXTERNALS AND TAGs

INPUT = 500200 OUTPUT = 500300 SORT = 500400 DRIVER = 500500
END = 500600 QUERY = 500100

BLOCK NAMES AND LENGTHS

BLOCK1 - 12C01 BLOCK2 - 1755C02 BLOCK3 - 6CO3 BLOCK4 - 3724C04
BLOCK5 - 3CC5 BLOCK6 - 10C06 BLOCK7 - 3726C07 BLOCK8 - 5C10
BLOCK9 - 5C11 BLOCK10 - 66C12 BLOCK11 - 775C13 BLOCK12 - 6C14

VARIABLE ASSIGNMENTS

AAAA - 765C02 AR - 4343 AGE - 4300 AGEU - 2C11
AL - 0C04 ALPHAC - 0C06 ALPHAS - 0C06 ANTEMP - 4337
AMI - 2E34 ANZ - 2304 BHIGH - 0C14 BLOW - 1C14
CONTRA - 1752C04 CRM - 4324 CURTEMP - 4333 DELTATH - 4335
DIA - 10C01 DT - 0C12 DUMOUR - 4332 EP - 5C06
ES - 1E34 FEXP - 2326 3C1 P - 2326 FEXP - 0C05 FPC - 2C06
FRF - 1753C15 FRIOMUL - 24C05 FU - 26C05 FY - 1754C15
I - 4320 IBAB - 4342 IBAAR - 4340
ICLOSEC - 274C07 IENDONE - 4341 IFINISH - 4336 IFY - 27C05
ISTOS - 4325 ITEST - 5C03 ITEST - 4321 ITPER - 7C06
I - 1755C15 MAXI - 1753C02 MIDI - 3C14 N - 4322
MGT - 4320 NPROB - 4323 NRP - 4326 NSTRN - 4C11
NT - 25C05 NTETR - 62C12 NTPI - 0C01 P - 2C01
PERCENT - 4316 REFF - 76C07 SS - 0C02 STRAIN - 76C04
STRESSS - 2175C04 STRMUL - 5C21 STREI - 0C15 STRES - 76C05
SUM - 3C13 TETR - 4334 TENS - 4331 TENSION - 28C11
THICK - 1C01 TOL - 6C06 UMAT - 1101 VDOS - 1C11
W - 1754C13 W5 - 76C02 XBAR - 0C03 Y - 5C07
YEXP - 12C05 YP - 1752C07 YPIST - 27Y1017 YSL - 2C14

START OF CONSTANTS

1052

JRCPl
DRIVER

SUBROUTINE DRIVER(INF, ISTDS, ZTOT, F, SUM, CRWM)

DIMENSION F(1501), SUM(501)

COMMON/BLOCK/RATIO, THICK, PDR, STRAIN, EPS, NTPI, U, OIA, UNWT

COMMON/BLOCK2/ SSI5011, AAA.WSI5011, MAXITE.CACKW

COMMON/BLOCK3/ XBAR, STRSC, STRSB, STRC, IBAB.V, ITEB

COMMON/BLOCK4/ VFXPI1, OEXPI1, OEXPI1, TRICMUL, NT, U, fV

COMMON/BLOCK5/ ALPHAC, ALPHAS, EC, fPC, TIME, EP, TOL, ITYPE

COMMON/BLOCK6/ XBAR, STRSC, STRSB, STRC, IBAB.V, ITEB

COMMON/BLOCK7/ VFXPI1, OEXPI1, OEXPI1, TRICMUL, NT, U, fV

COMMON/BLOCK8/ XVAR, STRSC2, STRS1, NT, U, fV

REAL XBAR

IF(IS=0) GOTO 10

IF(INRf.NE.IIXOTO S) P:O.

GOTO 10

IF(IISTDS.NIGOTO 10

CALL STSFRw,FY,WI

CONTINUE

ITIME=O

CONTINUE

MAIN LOOP ON

TIME=ITIME'1

TIME=FLOAT(ITIME)

IF(ITIME.GT.28.0) GOTO 30

OELT=OTIITIMEI

CALL FORWARD(TENSTRN, ZTOT, 1)

5=0

CALL MODELIITIME, IS, INTI

CALL DISTICOIST.TENSTRN, IGBI

IF(INRf.EO.I)XOTO 50

IF(IGB.1O.I)XOTO

CALCULATE fiRST CRACK WIDTH

OUMaDIST=INC-HI

IfIDUM.EQ.O.IGOTO 133

VC=OUM·IVII[NC·I)-VII[NCII/H

GOTO 12

YC=Y1 INC'

CRACKWI=Z.-ASSIYC)

IfICRACKWI.GT.CRWMIGOTO 70

IfICRACKWI.GT.0.001GOTO 45

IfIISTOS.EQ.lGOTO 38

CONTINUE

PRINT S40. CRACKWI.TINE

IrIMOOflAG.(G.

IRETURN

250 ISC=I

CALL "OOEL21f.BONOl.Z, OELTAT, SUM, INDEX, STRMAX, ISC

L=XBAR

M=1/NT

CALL STRSCOISTRSCONI

IfITENSTRN.GT.STRSCONIGOTO 250

TENSTRN=STRSCON

CALL DISTICOIST.TENSTRN, IGBI

CALCULATE T~ SECOND CRACK WIDTH

CRACKW2=AABS(STRSCON)DIST/2.-.Z.*lZ·ALPHAC·DeltAtI ISCI

CALC MODELIIF.BONOl.Z, DeltAt, SUM, INDEX, STRMAX, ISC

L=XBAR

M=1/NT

Difff=STRSC-0.75·fY

IfCDifff.GT.O.IGOTO 200

PRINT 100. TIME, CRACKW2, DIST

300 FORMAT(29H SECOND CRACK OCCURS AT TIME JF8.4,16H WITH A WIDTH OF JJ

1 f8.4,16H AT A DISTANCE FROM THE FREE EDGE Of .E10.3) 

303 RETURN

304 30 IF(WRF.EQ.1,1)XOTO 35

314 IF(IISTOS.EQ.11)XOTO 38

315 PRINT 510

321 IFFORMAT/1,5A3.3A80 CRACK OCCURS AT END OF 28 DAYS.

321 RETURN

322 35 CONTINUE

322 PRINT 520.L

323 RETURN

330 260 IF(WRF.EQ.11)XOTO 70

337 4FISTOS.EQ.11)XOTO 270

340 PRINT 210, STRSC, TIME

347 210 FORMAT(29H STRESS IN THE STEEL.E10.3.25H IS GREATER THAN ITS WORK

1.ZEENING STRENGTH AT TIM£.JF8.4,16H AT A DISTANCE FROM THE FREE EDGE Of .E10.3)

353 RETURN

354 30 IF(WRF.EQ.1,1)XOTO 35

360 CONTINUE
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350 PRINT 230
354 230 FORMAT(46H AT THE END OF 28 DAYS NO SECOND CRACK OCCURS )
355 RETURN
359 260 CONTINUE
363 IF ISTDS.EQ.1 I GOTO 270
365 PRINT 280, CRACK1, TIME
372 280 FORMAT(18H SECOND CRACK T E M IS WIDER THAN MAXIMUM ALLOWABLE C
374 RACKWIDTH AT TIME *F8.4) 
375 RETURN
377 50 CONTINUE
379 IF ISTDS.LT. 2 I GOTO 51
381 IF ISTDS .LT. 0.75 * KBAR I GOTO 52
386 GOTO 20
388 520 FORMAT(13H FOR THE GIVEN INPUT DATA; THE LENGTH OF THE NON-*
390 REINFORCED SLAB IS **E10.3** INCHES,*)
392 51 CONTINUE
394 C C ADJUST LENGTH FOR NON-REINFORCED.
396 L=L-L/2.
398 GOTO 10
401 530 FORMAT(18H CRACK1, TIME, CRACK1 = )
405 530 CRACK1 = 0
412 514 39 CONTINUE
414 PRINT 550, CRACK1, TIME
422 550 FORMAT(18H Width Of First Crack Is **E10.3** INCHES. At TIME .F8.4,1)
425 RETURN
427 70 CONTINUE
429 IF ISTDS .NE. 1 I GOTO 60
431 IF IP .EQ. 1 I GOTO 14
433 C C ADJUST STEEL PERCENTAGE FOR STEEL DESIGN OPTION
441 P=P/P2.
443 GOTO 10
446 540 FORMAT(18H WIDTH OF FIRST CRACK IS **E8.4** INCHES AT TIME, 
448 **E8.4** DAYS, **)
452 38 IF FS .EQ.13 I GOTO 18
456 18 P=P/2.
458 IF IP .EQ. 0.1 GOTO 30
460 IF IP .EQ. 1.0005) P=0.
464 GOTO 10
468 270 CONTINUE
472 55 CONTINUE
475 SANTHCXH
477 SFC=STRCSG
481 SAB=0.7S*FY
484 P=0/THICK
488 IF S=1
490 GOTO 10
494 18 PRINT 015
497 015 FORMAT(13H FOR THE GIVEN SLAB LENGTH; THE PERCENT OF STEEL WAS *
499 dictated by the STEEL **/%% STRESSES and not BY CRACKWIDTH. **,
500 **)

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473 RETURN
474 27 CALL INTRSC ITENSTRAIN, IS, INT..C DIST , INTTSTOS)
507 IF IP .EQ. 1 I GOTO 12
510 IF IP .EQ. 1 I GOTO 12
514 CONTINUE
516 PRINT 550, CRACK1
522 550 FORMAT(18H NO STEEL IS NEEDED. Width Of First Crack = **E10.3,
524 ** INCHES, **)
526 GOTO 1000
528 14 IF ISTDS .LE. 0.75* FY I GOTO 15
532 PRINT 920, STRCS, TIME
536 GOTO 1000
540 15 IF ICRA KWI L.E. CRWMI GOTO 45
544 P=P100.,
546 PRINT 910, CRACK1, P
550 PRINT 920, STRCS, TIME
556 920 FORMAT(18H FOR THE MAX NUMBER OF ITERATION THE STRESS IN THE STEEL*
558 18*/ AT THE CRACK IS **E10.3** PSI, AT TIME **E8.4,1)
570 910 FORMAT(18H SLAB LENGTH NEEDS TO BE REDUCED CRACK WI
574 18** E10.3, 
578 18** INCHES WITH PERCENT STEEL = **E10.3)
572 1000 CONTINUE
576 END
SUBPROGRAM LENGTH
1043

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS

S                     17  10  -  23  12  -  101  14  -  526
15                    545  18  -  467  20  -  24  27  -  474
30                    204  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  330  -  602
510                   620  520  -  662  530  -  676  540  -  729
550                   752  910  -  1002  915  -  733  920  -  765
1000                  571

EXTERNALS AND TAGS
STOS       500100  FORWARD-  500200  MODELL-  500300  DIST1-  500400
OUTPTC     500500  MODEL2-  500600  STRSC0-  500700  INTRCT-  500800
END         501100

BLOCK NAMES AND LENGTHS
BLOCK1        12C01  BLOCK2       1755C02  BLOCK3-        6C03  BLOCKS-        30C04
BLOCK4        1OC05  BLOCK8       3736C06  BLOCKD       766C07  BLOCKA       775C10
BLOCK5        6C111  BLOCKC       1756C12  BLOCK12-       66C13

VARIABLE ASSIGNMENTS
ALPHA&     -   0C05  BONOL  -   1033  CRACKW1-    1031  CRACKW2-    1040
DELTAT     -   776C10  DIFF  -   1036  DIST-   765C07  DT  -   0C13
DUM         -   1027  CRACKW  -   1024  FRF  -   1752C12  FY  -   1754C12
M           -   2737C06  FJS  -   1821  IDT-   12023  INC-   1752C12
INDEX       -   1073  INT-   1826  IP-   1029  IS-   1025  K
ISC         -   1032  INT  -   1022  L  -   1752C12  MAXT-   1753C02
MODFLAG     -   5C111  INT-   25C04  P-   2001  REFF-   765C06
SA           -   1041  SFC-   1042  SS-   0C02  STRMAX-  1035
STRSC-     -   1C03  STRSCON-  1037  STRSC1  -   0C12  STRSCF  -   0C07
STRESS-    -   756C12  TENSTRN-   1024  TNGC-   1021  TIME-   4C05
W           -   774C10  V5-   766C02  XBAR-   0C03  Y-   0C06
YC          -   1033  YEXP  -   12C04  YP-   1752C06  YPITE-   274C06
Y1          -   2C10  Z-   0C10

START OF CONSTANTS
572

START OF TEMPORARIES
1015

START OF INORECTS
1020

START OF VARIABLES
1020

SPACE REQUIRED TO COMPILE -- DRIVER
35600

SUBROUTINE MODEL1:TIME=15,INT)
6  COMMON /BLOCK1/ RATIO,THICK,P,FP,STRN,INC(+5)=NT,INTA,UNNT
6  COMMON/BLOCK2/ FRF,P,FF,+FRF,INTA,FU,INTV
6  COMMON/BLOCK3/ SS(501)+AAA,WS(501),WAXT,CRACKW
6  COMMON/BLOCK4/ STRSC1(S01)+STRSC2(S01),INC(P,FP,FF)+L
6  COMMON/BLOCK5/ STRSC1(S01)+DIST
6  COMMON/BLOCK6/ Y(501)+REFF(S01)+Y(+5)+MICLOSE+YPITE(S01)
6  REAL L
6  IF (INT.EQ.)40 RETURN
6  INIC=0
10  END=
11  DELTAX=0.0
12  C MAIN LOOP ON INCREMENT.
14  10 DELTAX=DELTA-M
16  INC+INC-1
16  IF (DELTA,GT,1.)RETURN
20  IF (IS,NE,11660)+40
23  IF (DELTA,GT,DT,INT)+RETURN
25  40 F0=0.0
33  CALL STRSC1(F0)
33  CALL FRIC1(F1)
35  CALL STRSC1(F1)
37  CALL FRIC1(F1)
40  CALL STRSC1(F1)
42  F3=F1+F2/2.
42  20 CONTINUE
45  CALL BACFR1(F3)
45  CALL BACFR1(F3)
45  CALL BACFR1(F3)
47  CALL STRSC1(F3)
47  CALL STRSC1(F3)
51  CALL CLOSRE(INDEX,F3)
53  CALL INDEX(INDEX,F3)+30
53  CALL BIMWYI(F3)
61  30 CONTINUE
64  IF (INT.EQ.)1 RETURN
64  IF (INT.EQ.)1 RETURN
66  IF (INT.EQ.)1 RETURN
66  IF (INT.EQ.)1 RETURN
67  IF (INT.EQ.)1 RETURN
75  GOTO 10
75  END

SUBROUTINE MODELL:

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SUBPROGRAM LENGTH
105

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
10 - 14 29 - 45 30 - 64 40 - 30

EXTERNALS AND TAGS
STRSCP - 500300 FRIC1 - 502000 BACFRCI - 500300 CLOSE1 - 500400
BINARYFL - 500500 END - 500600

BLOCK NAMES AND LENGTHS
BLOCK1 - 126C05 BLOCK2 - 36C02 BLOCK3 - 175SC03 BLOCKA - 775C04
BLOCKC - 1756C05 BLOCKD - 765C06 BLOCKE - 1726C07

VARIABLE ASSIGNMENTS
DELTA - 767C04 DIST - 765C06 FEXP - 0C02 FO - 100
FL - 101 F2 - 102 F3 - 103 H - 273C07
INC - 1752C05 INOE - 104 L - 175C05 NT - 25C02
P - 2C01 REFF - 765C07 REFFI - 773C04 SS - 0C03
STRSCI - 0C05 STRSC2 - 0C06 STBS51 - 745C05 THICK - 1C01
WS - 765C03 Y - 0C07 YEXP - 12C02 YP - 1752C07
YPIFE - 2761C07 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

DISTI
SUBROUTINE STRSCO(STRSCON)
COMMON /BLOCK8/YISOII,REffISOII,YPISOII,H,ICLOSEB,YPITEISOII
COMMON /BLOCKC/STRSCIISOII,STRSSI15011,lNC,dF,f,V,L
COMMON /BLOCKD/STRSCZISOII,DIST
REAL LONG,M,'"'l
DELTA=O.O
SO CONTINUE
LONG=IO.SO-DISTI-DELTAX
~IS=O
CALL STRSCIZIMIS,STRSCOI,STRSCOZ,LONG,J,II
~IS=I
CALL STRSCIZIMIS,STRSCOI,STRSCOZ,LONG,J,II
DifT=STRSCOI-STRSCOZ
If IDifTl
ZO ,30,40
ZO DELTAX·DELTAX.H
GOTO SO
30 STRSCON_STRSCOI
RETURN
$1=STRSCIII-I I·II/HII-I I·II/HII
46 STRSCON'IB-BII-M/MII/II-M/MII
RETURN
4S M=STRSCZIJ.II/H
81:0.
GOTO 46
SUBROUTINE STRSCI2(MIS, STRSCO1, STRC02, LONG, J, Y)
COMON /BLDCKB/ (1501), REFF (501), YP (501), M (CLOSE5), YPITE (501)
COMON /BLOCD/ STRSCI (150), STRC02 (501), INC, X, YF, FT
COMON /BLDCKO/ STRSC2 (1501), DIST
REAL, LONG
DO 100 J = 1, NT
IF (ABS (LONG - J * M) .LT. 0.1) GOTO 110
100 CONTINUE
110 IF (LONG .GT. 0.0) GOTO 120
PRINT 80
PRINT 85, LONG, M
120 IF (ABS (M * J) .LE. 0.1) GOTO 130
PRINT 85, J, M
130 FORMAT (14D18)
STOP 100
100 CONTINUE
110 CONTINUE
140 CONTINUE
140 IF (M .GT. 0.1) GOTO 150
DUMMUM = (STRSCI (J) - STRSC2 (J)) / (ABS (M) - ABS (M * J - 1))
DUMMUM = (STRSCI (J) - STRSC2 (J)) / (ABS (M) - ABS (M * J - 1))
RETURN
150 RETURN
120 RETURN
121 RETURN
122 RETURN
123 RETURN
124 RETURN
125 RETURN
126 RETURN
127 RETURN
END

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SUBROUTINE STRSCI2 (MIS, STRSCI1, STRSCI2, LONG, J, Y1)
COMON /BLDCB/ (1501), REFF (501), YF (501), M (CLOSE5), YPITE (501)
COMON /BLDCK/ STRSCI (150), STRC01 (501), INC, X, YF, FT
COMON /BLDCKO/ STRSC1 (1501), DIST
REAL, LONG
DO 100 J = 1, NT
IF (ABS (LONG - J * M) .LT. 0.1) GOTO 110
100 CONTINUE
110 IF (LONG .GT. 0.0) GOTO 120
PRINT 80
PRINT 85, LONG, M
120 IF (ABS (M * J) .LE. 0.1) GOTO 130
PRINT 85, J, M
130 FORMAT (14D18)
STOP 100
100 CONTINUE
110 CONTINUE
140 CONTINUE
140 IF (M .GT. 0.1) GOTO 150
DUMMUM = (STRSCI (J) - STRSC2 (J)) / (ABS (M) - ABS (M * J - 1))
DUMMUM = (STRSCI (J) - STRSC2 (J)) / (ABS (M) - ABS (M * J - 1))
RETURN
150 RETURN
120 RETURN
121 RETURN
122 RETURN
123 RETURN
124 RETURN
125 RETURN
126 RETURN
127 RETURN
END
SUBROUTINE INTRSC

COMMON/BLOCK2/SIS(50), MAXITE, CRACKX
COMMON/BLOCK3/XBAR, STRSC, STRSB, STRC, EBAR, ITEB
COMMON/HLCV/STX(5), PSTX, PSY, ITE
COMMON/HLCV/STRSC(50), STRS(50) INC, FRP, FYL
COMMON/BLOCK6/ALPHAC, ALPHAS, EC, FRP, TIME, EP, TOL, ITPER
COMMON/BLOCK5/EXP(10), YEXP(10), FRICMUL, INT, CPU
COMMON/BLOCK4/X(101), Y(101) DELTA, DELTAT, TEMPI, REFF, IYPT1, W

INC = INT/2
10 YTEMP = STRSCI(INC)
11 X = TENSTAN
12 TIME = TIME - 0.5
20 Y = STRSCI(INC)
21 IF(Y.LE.0.33) GOTO 80
30 INT = 0
31 DIST = XBAR/2.
32 TIME = TIME + 0.1
40 TIME = TIME - 0.1
45 IYPT1 = IYPT1 + 1
50 RETURN
60 END

PRINT 40
410 FORMAT(*) SLAB GETS A CRACK RIGHT AFTER CONCRETE PLACEMENT
420 IF(Y2.X2120.30.10 X = TENSTN
430 Y2 = STRSCI(INC)
440 IF(Y2.X211.5) GOTO 50
450 CALL GETHE(X1, Y1, X2, Y2, IOUT)
460 TENSTN, FOUT
470 CALL BACK(IN, INT, IYPT1, W)
480 CONTINUE
490 FORMAT(*) THE SOLUTION DID NOT CLOSE IN INTRSC."
500 END

START OF VARIABLES
150

START OF INDIRECTS
156

START OF TEMPORARIES
167

SPACE REQUIRED TO COMPIL -- STRSCI2
33200
SUBROUTINE STOS(FRF,FY,W)

6 COMMON/BLOCK1/RATIO,E,R:THICK,PH,F,STRAIN,CE,SNTP1,U:DIAPUMT
6 COMMON/BLOCK3/XBAR,STRI,STR2,STRX,IBABY,ITER
6 COMMON/BLOCK6/ALPHA,ALPHVS,CE,FPC,TIMEP,TOL,ITYPER
6 COMMON/BLOCK7/STR1,STR2,STR3,EZ,ST2,ST3,ST4,ST5
6 REAL L
6 F5=0.75*F
10 P=FRF/12.*F5)
14 AB=3.14/16.*C1**2
20 P2=FRF*C04/2.*F5
24 IF(ITYPER.EQ.1)GOTO 10
25 B1=B1+B2/B1*P2)
30 PRINT S50,P2,B1
37 BLOW=HIH/2.*
41 RETURN
42 10 VST=AS0/I1*P2)
46 PRINT S50,P2,VST
51 RETURN
56 10 FORMAT(* FOR ITYPER EQUAL TO 2, THE TRANSVERSE STEEL IS *=E10.3,*
51 * PERCENT SPACED.=/.*E10.3,. INCHES CENTER TO CENTER.,*)
56 10 FORMAT(* FOR ITYPER EQUAL TO 1, THE TRANSVERSE STEEL IS *=E10.3,*
56 * PERCENT SPACED.=/.*E10.3,. INCHES CENTER TO CENTER.,*)
56 END
SUBROUTINE STRSCS(FR(1)
3 COMMON/BLOCK1/RATIO,T=TX,P,FK,STRAIN,ES+NP1,UT,NI,DATA
3 COMMON/BLOCK2/ALPHAC,ALPHAS,ES+NP1,FR+TIME,EP+10L,TP+10L
3 COMMON/BLOCK3/STRIE,STRIE+TIME,ES+NP1
3 COMMON/BLOCK4/STRIE,STRIE+TIME,ES+NP1
3 DUMMY=FR(1)*DELTA*PES=ES/EC
12 STRIE=STRIE+DUMM+PES*ES+Z+DELTA*ALPHAC=ALPHAS+PES/ES/EC)
26 Y=11*STRIE=STRIE+DELTA*ES=ES+ALPHAC*DELTA*Z)
35 RETURN
35 END

STROSCS

STDS

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SUBPROGRAM LENGTH
123

STATEMENT ASSIGNMENTS
10 42 500 - 66 510 - 103

EXTERNALS AND TAGS
OUTPTC - 500100 END - 500200

FUNCTION ASSIGNMENTS

EXTERNALS AND TAGS

START OF VARIABLES

SPACE REQUIRED TO COMPILE -- STDS
32760
SUBROUTINE FRCI (FA)

COMMON/BLOC5/EXP(10),YEXP(10),FRICMUL,NT,FU,FY

COMMON/BLOC2/1.Y1,Y101,Y10,DELTA,DELTA,TMP1,REFF1,YPITE1,WW

COMMON/BLOC5/STRSCI(501),STRSSI(501),INC,FRF,FY,FU

IF (FY,FQ,1)XOTO 10
5 IF (FY,FQ,2)XOTO 40
7 GOTO 90
10 CONTINUE
7 SLOPE*FRICMUL
11 IF (ABS(FA)>LE,FU)RETURN
13 IF (FA,GT,0,0)IFAFU
16 IF (FA,LE,0,0)IFAFU
21 RETURN
24 CONTINUE
40 CONTINUE
25 IF (Y1,INC,GT,0,0)GOTO 50
29 FA=FRICMUL*SQRT(ABS(Y1,INC)))
30 GOTO 60
35 GOTO 60
36 50 CONTINUE
36 60 CONTINUE
44 IF (ABS(FA)>LE,FU)RETURN
50 IF (FA,GT,0,0)IFAFU
53 IF (FA,LT,0,0)IFAFU
56 RETURN
57 90 CONTINUE
57 DO 100 J=1,Y1
61 IF (ABS(Y1,INT1),LT,ABS(YEXP(J,1)))GOTO 110
67 100 CONTINUE
70 FA=YEXP(J,1)
73 GOTO 120
77 110 CONTINUE
73 DUMDUM= (FEXP(J,1)-EXP(J,1))/ABS(YEXP(J,1))=ABS(YEXP(J,1))
102 FA=YEXP(J,1)+DUMDUM*ABS(Y1,INT1)+ABS(YEXP(J,1)))
112 120 CONTINUE
117 IF (Y1,INC,GT,0,0)FA=FA
115 RETURN
116 END

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SUBPROGRAM LENGTH
41
FUNCTION ASSIGNMENTS
STATEMENT ASSIGNMENTS
EXTERNALS AND TAGS
END = 501100
BLOCK NAMES AND LENGTHS
BLOCK1 - 12C01 BLOCK6 - 10C02 BLOCKA - 77C03 BLOCKC - 175C04
VARIABLE ASSIGNMENTS
ALPHAC - 0C02 ALPHAS - 1C02 DELTAT - 77C03 DELTAT - 76C04
DUMDUM - 40 EC - 2C02 ES - 5C01 INC - 175C04
P - 2C01 STRSCI - 0C04 STRSSI - 76C04 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
32680

RUNW VERSION FEB 74 16.51.06. 23 JUL 75

STSCS
SUBROUTINE BACFRC1(F3)

COMMON /BLOCKS/FEXP(10),YEXP(10),FRICMUL,NT,FU,IFY
COMMON /BLOCK2/YP1,YI(101),DELTAX,DELTAT,TEMP,YEFF,YP1E1,YW

IF(FRICMUL.EQ.0.D0) RETURN
IF(FU.EQ.1.D0) GO TO 40
IF(FU.EQ.2.D0) GO TO 60
DO 10 J=1,IFY
10 CONTINUE

YP3=YEXP(J)
RETURN

20 CONTINUE
DUMDUM=(FEXP(J)-FEXP(J-I),/(ABS(YEXP(J))-ABS(YEXP(J-I))
YPI=(ABS(YEXP(J)))/(ABS(FJ)-FEXP(J-I))/DUMDUM
IF(F3.GT.0.D0) YPI=-YP1
RETURN

40 CONTINUE
YPI=F3/FRICMUL
IF(ABS(FJ).GE.FU) YPI=YEXP(J)
RETURN

60 CONTINUE
YPI=(F3/FRICMUL)-Z
IF(ABS(FJ).GE.FU) YPI=YEXP(J)
IF(F3.GT.0.D0) YPI=-YP1
RETURN

END
SUBROUTINE BINARY1(F3)

COMMON/BLOCKA/Z,Y,STRS1(501),STRSST1(501),INC,FRF,FY,L
COMMON/BLOCKC/STRS1(501),STRSST1(501),INC,FRF,FY,L

IF(YP1.GT.YI)GOTO 10
    RETURN
  10 CONTINUE
    RETURN
END
SUBROUTINE CLOSE INDEX, F3
COMMON/RLOCK2/SSC5011, AAA, WSC5011, MAXITE, CRACKW
COMMON/IBLOCK6/ALPHAC, ALPHAS, EC, FRC, TIME, EP, TOL, ITYPER
COMMON/BLOCKA/Z, YP1(1), Y1(1), DELTA, DELTA, TEMP, REFF1, YPITE1
COMMON/BLOCKC/STRSCI(1), STRSSI(1), INC, PDF, YPI

INDEX = 0
BAD = 1.

IF (AAA, EQ, 0.) GOTO 50
IF (YPI(1), EQ, 0.) GOTO 10

INDEX = INDEX + 1
AAA = "A"
RETURN

CONTINUE
AAA = AAA + 1
YPITE1 = YPI(1)
FORMATC"IN SUBROUTINE CLOSE1 THE SOLUTION DID NOT CLOSE"
FORWARD

SUBROUTINE FORWARD (TENSTRN, ZT0T, ZI)

C **************************************************************
C THIS SUBROUTINE CALCULATES THE TIME DEPENDENT VARIABLES
C WHICH THE SLAB RESPONSES ARE COMPUTED. LINEAR INTERPOLATION
C IS USED TO GET FLEXURAL STRENGTH FROM AGE OF CONCRETE.
C **************************************************************
C
6 COMMON /BLCKI/ RATIO, MICH, FF, STRAIN(2E5+NT), U+DIA+UNW
6 COMMON /BLCK2/ S5(561),AAA,VS(561),MALT, TXCRACK
6 COMMON /BLCK3/ XBAR, STRS, STRS5, STRC, 10BAB, FDET
6 COMMON /BLCK4/ AL(561), STRAIN(561), CONST(561), STRES5(561)
6 COMMON /BLCK5/ FEXP, IYEP, (1O1), FRCMUL, NT, FU, FY
6 COMMON /BLCK6/ ALPHAC, ALPHAS, ECC, FPC, TIME, FPC, TOL, ITYPER
6 COMMON /BLCK7/ Y(561), REFF, PP(561), MFL, XBAR, PYPE(561)
6 COMMON /BLCK8/ VSTN, VOS, AGEU, TENSION, I201, TENSION
6 DIMENSION PERCENT(8), AGE(8)
6 DATA PERCENT/0, . . . , 9 . . . , 100.1
6 DATA AGE/0, . . . , 3 . . . , 100.
6 START OF TEMPORARIES 18
18 INTEGER AAA
18 IF (NSTRN.GT.O) GO TO 30
27 DO 10 1=1,8
27 J=I
23 IF (TIME.GE.AGEUI) GO TO 30
20 CONTINUE
16 PRINT 80. TIME
26 GO TO 70
27 CONTINUE
34 PERCOM=PERCENT(J)/PERCENT(J-1), PERCENT(TIME-AGEU(J))
36 PERCOM=PERCENT(J-1), PERCENT(TIME-AGEU(J))
38 PERCOM=PERCENT(J-1), PERCENT(TIME-AGEU(J))
40 COMSTRI=PERCOM*(FPC/100)
42 TENSFL=3000./FPC, 1, 12000./COMSTRI)
44 TENSFL=3000./FPC, 1, 12000./COMSTRI)
46 FLESTRN=3000./FPC, 1, 12000./COMSTRI)
48 TENSFL=3000./FPC, 1, 12000./COMSTRI)
50 GO TO 60
52 IF (TIME.GE.AGEU(1)) GO TO 50
54 CONTINUE
56 PRINT 80. TIME
58 GO TO 70
60 CONTINUE
C COMPUTE SLOPE BY LINEAR INTERPOLATION
C
70 SLOPE=(TENSION(J)-TENSION(J-1))/AGEU(J-AGEU(J-1))
72 TENSFL=TENSFL*TIME-AGEU(J-1))
74 FLESTRN=3000./FPC, 1, 12000./COMSTRI)
76 TENSFL=TENSFL*TIME-AGEU(J-1))
78 COMSTRI=12000./FPC, 1, 12000./COMSTRI)
80 IF (U.GE.05) U=0.5
82 CONTINUE
C EC=33.*UNW**1.5)*SQRT(COMSTRI)
106 RATIO=EC
116 IF (TIME.GE.0.1) U=0.5
124 CONTINUE
C
BEGIN

RUNW VERSION FEB 74 16.51.06. 23 JUL 75

RETURN

70 CONTINUE

88 FORMAT (//,1XI,E10.6)**ERROR IS DETECTED IN SUBROUTINE FORWARD//,1XI,
+TIME ENCOUNTERED IS GREATER THAN MAXIMUM AGE PROVIDED BY THE USE
2N**, //,1XI,E10.6)**TIME**E10.3**,//
3N**, 1XI,PROGRAM IS TERMINATED*)

END

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS

EXTERNALS AND TAGS

OUTPTC - S00100 SQPT - S00200 RBAREX - S00300 EXP - S00400

END - S00500

BLOCK NAMES AND LENGTHS

BLOCK1 - 12C01 BLOCK2 - 165C02 BLOCK3 - 6C03 BLOCK4 - 372404

BLOCKS - 36C05 BLOCK6 - 1OC06 BLOCK8 - 3726C07 BLOCK10 - 53C10

VARIABLE ASSIGNMENTS

AAA - 765C02 AGE - 223 AGEU - 2C10 AL - 0C04

CONSTR - 236 CONSTR - 1752C04 DIA - 1OC01 EC - 2C06

ES - 5C01 EPS - 0C05 FLESTRN- 237 FPC - 3C06

I - 233 J - 234 RETURN - 0C10 PERCENT - 213

PERCOM - 235 RATIO - 0C01 REFF - 765C07 SHRN - 241

SLOPE - 240 SS - 0C02 STRAIN - 765C04 STRESSES - 273704

STRAIN - 52C10 TENSION- 26C10 TIME - 4C06 U - 7C01

UNI1 - 11C01 VOS - 1C10 W5 - 765C02 Y - 0C07

YP - 12C05 YP - 1752C07 YPITE - 2741C07

START OF CONSTANTS

START OF TEMPORARIES

START OF INDIRECTS

START OF VARIABLES

SPACE REQUIRED TO COMPILE -- FORWARD

33500

FORWARD

END
RUN MODEL2

SUBROUTINE MODEL2 (F, BONDL, STRMAX, NTPI, INDEX, STRMAX, ISC)

DIMENSION F(501), SUM(501)

COMMON /BLOCK1/ RATIO(INC), FF, STRAIN(INC), DELTAT, SUM, INDEX
COMMON /BLOCK2/ S5(501), AAA, S5(501), MAXIT, CREACK
COMMON /BLOCK3/ BAR, STRSC(STRMAX), STRC, BAR
COMMON /BLOCK4/ AL(501), STRAIN(501), STRC, S5, STRSS5(501)
COMMON /BLOCK5/ FEP(10), EEXP(10), FRICMUL(NTPI), FF, F5
COMMON /BLOCK6/ ALPHAC, ALPHAS, EC, FPC, TIME, EP, TOL, ITYPE
COMMON /BLOCK7/ YI5011, REF(STRMAX), TPI, ISO, ICLOSEB, YPITE
COMMON /BLOCK8/ STX, STY, PSTX, PSTY, ITE
COMMON IFINISH
COMMON STRSCI501, STRSISO1, INC, FR, Fy, L
COMMON AL(501), STRAIN, CONSTR(STRMAX), STRESSSISO1

REAL NEGT
REAL IFI, ISC

100 CONTINUE
J = 1
10 CONTINUE
F(I) = F(I) + FF(I)
S5(I) = S5(I) + STRAIN(I) + CONSTR(I) + STRSS5(I)

10 CONTINUE
J = J + 1
100 CONTINUE

CALL BARIC(F)
IF (ITYPER.EQ.1) CALL DFBAR(F, BONDL, STRMAX, Z, DELTAT)
IF (ITYPER.EQ.2) CALL DFWIRE(F, BONDL, STRMAX, Z, DELTAT)
IF (BONDL.GE.3) GOTO 80
IF (L.GT.0.75) GOTO 18

STRSC(I) = STRMAX
IF (ISC.EQ.1) RETURN
IF (L.LE.0.75) GOTO 18

CONTINUE

150 FORMAT (1X, 'RESULTS FOR ITERATION', 15X, 'I)
160 FORMAT (12X, AL(I), 7X, REF(I), 9X, YP(I), 11X, Y(I), 11X, F(I))
170 FORMAT (15X, S5(I))
180 FORMAT (15X, 'STRMAX = ', 10X, STRMAX, 4X, 'FOR TIME STEP = ', DELTAT)
190 FORMAT (15X, 'SHRINKAGE = ', 10X, SHRINKAGE)
200 FORMAT (15X, 'DELTAT = ', 10X, DELTAT)

END
SUBROUTINE CONMOV (SUM,+Z,DELTA)
C *********************************************************
C THIS SUBROUTINE COMPUTES THE MOVEMENT OF THE CONCRETE AT
C EVERY STATION. THE MOVEMENT IS COMPUTED FROM THE DEVELOPED
C DIFFERENTIAL EQUATION.
C *********************************************************
DIMENSION SUM(501), CRACK(501), STRAIN(501), MAXITE(501),
       STRASS(501), NT, FU, EXP(10), YP(501), YPITE(501),
       ALPHA(10), EPS(10), RP(10), NTPI(10), AAA(10)
COMMON /BLOCK1/ RATIO, THICK, STRAIN(501), MAXITE, CRACK
COMMON /BLOCK2/ S5(501), AAA, WS(501), MAXITE, CRACK
COMMON /BLOCK3/ XBAR, STRAIN(501), MAXITE, BAF
COMMON /BLOCK4/ AL, S5(501), STRASS(501), MAXITE, CRACK
COMMON /BLOCK5/ AL, S5(501), STRASS(501), MAXITE, CRACK
COMMON /BLOCK6/ YPS(501), YP(501), YPITE(501)
COMMON /BLOCK7/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK8/ EXPC(10), YP(501), YPITE(501)
COMMON /BLOCK9/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK10/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK11/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK12/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK13/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK14/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK15/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK16/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK17/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK18/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK19/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK20/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK21/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK22/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK23/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK24/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK25/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK26/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK27/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK28/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK29/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK30/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK31/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK32/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK33/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK34/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK35/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK36/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK37/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK38/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK39/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK40/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK41/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK42/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK43/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK44/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK45/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK46/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK47/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK48/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK49/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK50/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK51/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK52/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK53/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK54/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK55/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK56/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK57/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK58/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK59/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK60/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK61/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK62/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK63/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK64/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK65/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK66/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK67/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK68/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK69/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK70/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK71/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK72/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK73/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK74/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK75/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK76/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK77/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK78/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK79/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK80/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK81/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK82/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK83/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK84/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK85/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK86/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK87/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK88/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK89/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK90/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK91/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK92/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK93/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK94/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK95/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK96/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK97/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK98/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK99/ ALPHA, EPS(10), RP(10), NT, FU
COMMON /BLOCK100/ ALPHA, EPS(10), RP(10), NT, FU

START OF CONSTANTS
500
START OF TEMPORARIES
574
START OF INDIRECTS
577
START OF VARIABLES
606
SPACE REQUIRED TO COMPILE -- MODEL2.
35100

MODEL2

CONMOV
SUBROUTINE CLOSE (N,INDEX,F)
C***********************************************************************
C THIS SUBROUTINE IS USED WITH THE BINARY TECHNIQUE OF MOVEMENT CLOSURE
C***********************************************************************
COMMON /BLOCKZI/ S5(SO1),AAA=5(SO1),MAXITE=CRACKW
COMMON /BLOCK4/ ALI(SO1),STRAIN(SO1),CONSTRI(SO1),STRESS(SO1)
COMMON /ALPHA/ ALPHAC,ALPHAS,EC,fPC,TIME,EP,TOL,ITYPER
COMMON /YPI/ YI(SO1),REffI(YI),YPIE(YI),H,ICLOSEB,YPITEI(YI)
DIMENSION DII(501),F(501)
INTEGER AAA

INDEX=0
IF (AAA.EQ.1) GO TO 50
IF (IAAA.GT.MAXITE) GO TO 70

AAA=AAA+1
IF (AAA.GT.MAXITE) GO TO 70

DO 60 I=2,N
YPITE(I)=YI(I)
60 CONTINUE

RETURN

AAA=AAA+1
IF (AAA.GT.MAXITE) GO TO 70

DO 60 I=1,N
YPITE(I)=YI(I)
60 CONTINUE

RETURN

PRINT 120
PRINT 110,MAI,BAD,AAA
PRINT 80,111,YII),YPITEII),Olf(I),SS(I),STRESSS(I),STRAIN(I),I-I,N)

PRINT 120
PRINT 110
PRINT 80

10 CONTINUE
20 CONTINUE
30 CONTINUE
40 CONTINUE
50 CONTINUE
60 CONTINUE
70 CONTINUE
80 CONTINUE

SUBROUTINE BAKFRIC (F)
DIMENSION F(5011)
COMMON /BLOCK1/RATIO,THICK,STRAIN,ESNP,UT,DIAM,MULT
COMMON /BLOCK2/SS(5011),AAA,WS(5011),MAXKE,CRACK
COMMON /BLOCK3/SHAPE,STR,STR5,STR6,STR7,BABY,TEB
COMMON /BLOCK4/AL(5011),STRAIN(5011),CONSTRAIN(5011),STRESS(5011)
COMMON /BLOCK5/EXP(10),EXP(30),FRICMUL,NT,FU,IFY
COMMON /BLOCK6/ALPHA,ALPHAS,PC,TIME,EP,TOL,ITYPER
COMMON /BLOCK7/YI5011,REF5011,V5011,ICLOSEB,VPITE(5011)
COMMON /BLOCK8/YI5011,REF5011,V5011,ICLOSEB,VPITE(5011)
COMMON AAA

IF (FRICMUL.EQ.0.0) RETURN

IF (IFY.EQ.1) GO TO 40
IF (IFY.EQ.2) GO TO 60
DO 30 I=I,NTPI

!ABSIFIIII.LT.ABSIFIIII
GO TO 20
CONTINUE
YP III = YOP OF Y III
GO TO 30
CONTINUE
DUMOUM = FEXPIJI-FEXPIJIII/ABS(IYEXPIJIII)
YPIII = YEXPIIII/DUMOUM
IF "1!l.GT.0 YPIII = -YPIII
CONTINUE
RETURN

DO 70 I=I,NTPI
YP III = FIII/FRICMUL
IF IABSIII).GE.FU) YPIII = YEXPIIII
IF IFIII.GT.0) YPIII = -YPIII
CONTINUE
RETURN

DO 70 I=I,NTPI
YP III = FIII/FRICMUL
IF IABSIII).GE.FU) YPIII = YEXPIIII
IF IFIII.GT.0) YPIII = -YPIII
CONTINUE
RETURN

END
SUBROUTINE BINARY(F)

DIMENSION F(501)

COMMON /BLOCK1/ RATIO,THICK,P,STRAINC,ES,NTP1,U,DIA*UNWT

COMMON /BLOCK2/ SS(501),AAA,WS(501),MAXITE*CRACW

COMMON /BLOCK3/ GR,STRS5,STRE,STRS1,IBABY*ITEB

COMMON /BLOCK4/ AL(501),STRAIN(501),CONSTRI(501),STRESSS(501)

COMMON /BLOCK5/ fEXP(10),YEXP(10),*FR(M,N),F*T,F*Y

COMMON /BLOCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,TOL,YTYPE

COMMON /BLOCK7/ Y(501),REP(501),YP(501),MAXCLOS+YPITE(501)

COMMON /BLOCK8/ STX,STY,PSX,PSY,ITE

DO 30 I=1,NTP1

IF (YP(I)+OT,I) GO TO 10

TEMF=REFF(I)

IF (TREFF(I)+F(I)) GO TO 20

RETURN

END

SPACE REQUIRED TO COMPILE -- BAKFRIC

33100
SUBROUTINE DBARF (F, BOND, STRMAX, Z, DELTA)

**This subroutine solves for the stress in the steel at the crack and between cracks. It is used in the case of deformed bars.**

**The development length criteria or boundary condition is imposed in the solution of the basic equations.**

**DIMENSION F(SOII), SUM(SOII)**

**COMMON /BLOCK1/, RATIO, THICK, P, FF, STRAINC, E5, NTPI, U, DIA, UNNT**

**COMMON /BLOCK2/, SS(SOII), AAA, W(SOII), MAXTE, CRACK**

**COMMON /BLOCK3/, XBAR, STRMAX, FPC, TIME, EP, TOL, TYPER**

**COMMON /BLOCK4/, STR1, STR101, YEXP101, FRICMUL, N, NAP1**

**COMMON /BLOCK6/, YEXP, SIGMA, SIGMA5, SIGMA6, MAXTE**

**COMMON /BLOCK5/, ALPHAC, ALPHAS, E, FC, TIME, EP, TOL, TYPER**

**COMMON /BLOCK6/, YEXP, SIGMA, SIGMA5, SIGMA6, MAXTE, NAP2**

**COMMON /BLOCK6/, IFINISH, AAA, E**

**REAL L**

**INTEGER NAPI, NAP2**

**If (NAPI .EQ. 0) Go TO 30**

**If (NAPI .GT. NAP2) Go TO 40**

**Continue with...**

**DO 10 I = NAP1, NAP2**

**SUM2 = SUM2 + F(I) / DENO**

**SUM = SUM + (2*NAPI - 2*I - 1)*F(I) / DENO**

**CONTINUE**

**DEFINE CONSTANTS**

**S = SNAP1 / DENO**

**BOND = 0.1 + 0.1**

**AN = N1**

**C1 = C1**

**C2 = C2**

**C3 = C3**

**C4 = C4**

**C5 = C5**

**C6 = C6**

**C7 = C7**

**C8 = C8**

**C9 = C9**

**DEFINE QUADRATIC EQUATION CONSTANTS**

**CONTINUE**

**SUBROUTINE DBARF (F, BOND, STRMAX, Z, DELTA)**

**COMMON /BLOCK1/, RATIO, THICK, P, FF, STRAINC, E5, NTPI, U, DIA, UNNT**

**COMMON /BLOCK2/, SS(SOII), AAA, W(SOII), MAXTE, CRACK**

**COMMON /BLOCK3/, XBAR, STRMAX, FPC, TIME, EP, TOL, TYPER**

**COMMON /BLOCK4/, STR1, STR101, YEXP101, FRICMUL, N, NAP1**

**COMMON /BLOCK6/, YEXP, SIGMA, SIGMA5, SIGMA6, MAXTE**

**COMMON /BLOCK5/, ALPHAC, ALPHAS, E, FC, TIME, EP, TOL, TYPER**

**COMMON /BLOCK6/, IFINISH, AAA, E**

**REAL L**

**INTEGER NAPI, NAP2**

**If (NAPI .EQ. 0) Go TO 30**

**If (NAPI .GT. NAP2) Go TO 40**

**Continue with...**

**DO 10 I = NAP1, NAP2**

**SUM2 = SUM2 + F(I) / DENO**

**SUM = SUM + (2*NAPI - 2*I - 1)*F(I) / DENO**

**CONTINUE**

**DEFINE CONSTANTS**

**S = SNAP1 / DENO**

**BOND = 0.1 + 0.1**

**AN = N1**

**C1 = C1**

**C2 = C2**

**C3 = C3**

**C4 = C4**

**C5 = C5**

**C6 = C6**

**C7 = C7**

**C8 = C8**

**C9 = C9**

**DEFINE QUADRATIC EQUATION CONSTANTS**

**CONTINUE**
C
DELTA+BB**4-+AAA**C
152 IF (DELTA.LT.0.) GO TO 60
156 C
ROOT1=(-BB+SQRT(DELTA))/2.,AAA)
157 ROOT2=(-BB-SQRT(DELTA))/2.,AAA)
158 C
SIGMAASC=ROOT1
201 SIGMA=SIGMAASC-C41/CI
205 BONDLC=(SIGMAASC=SIGMAASC=SIGMAASC=SIGMAASC=SIGMAASC=SUMI
211 201 FORMAT(I0X,*BONOLC IN OFBARF =*E10.3/)
212 A1=H**1/2.*ANA-2.*SIGMAASC=SUMI/SUMI/2.
213 A2=SIGMAASC=SUMI/SUMI=5./2.
214 A3=SIGMAASC=SUMI/SUMI+BONDLC/2.
215 AAAA=A1+A2+A3
255 C
256 IF (ABS(DUM2-AAAA-DUM2)GT.E-5) GO TO 10
257 CALL POIRES (f.BONOLC,STRMAX,LOCMAX,Z.OELTAT,
258 RETURN
270 20 CONTINUE
271 90 CONTINUE
273 30 CONTINUE
275 100 CONTINUE
300 A1=H**1/2.*ANA-2.*SIGMAASC=SUMI/SUMI/2.
303 BONDLC=(SIGMAASC=SIGMAASC=SIGMAASC=SIGMAASC=SIGMAASC=SUMI
311 20 CONTINUE
315 90 CONTINUE
327 50 CONTINUE
330 CONTINUE
333 PRINT 128, NA, NT
343 GO TO 60
347 100 CONTINUE
355 100 CONTINUE
358 100 CONTINUE
365 90 FORMAT (I0X,*SOLUTION DID NOT CONVERGE BY ITERATING ON BOND **,
366 * LENGTH IN SUBROUTINE DFBARF =*E10.3/)
367 100 FORMAT (I0X,*ERROR IS DETECTED IN DFBARF**/)
368 DFBARF
369
SUBROUTINE OWBAR (BOND, STRMAX, Z, DELTAT)

C THIS SUBROUTINE COMPUTES THE STRESSES AND STRAINS IN THE CONCRETE.
C STEEL DUE TO A TEMPERATURE DROP AND/OR SHRINKAGE.
C THE EQUATIONS ARE WRITTEN FOR A FRICTIONLESS SYSTEM.

C COMMON
C BLOCK1/ RATIO, THICK, P, FF, STRAIN, ES, NTPI, U, DIA, UNWT
C COMMON / BLOCK2/ S(SI), A, A4, S(SI), MAXITE, CRACK
C COMMON / BLOCK3/ BARR, STRSC, STRSB, STRSC, BABY, ITEB
C COMMON / BLOCK4/ AL(SI), STRAIN(SI), CONSTR(SI), STRESS(SI)
C COMMON / BLOCK5/ FEXP, ID, YEPIX, ID, FRMUL, NT, IF, IT
C COMMON / BLOCK6/ ALPHAS, EC, FPC, TIME, EP, TOL, TP, TPER
C COMMON / BLOCK7/ STRSC(SI), STRSB(SI), INC, FRF, FC, F
C COMMON / BLOCK8/ T(SI), REFF(SI), YP(SI), T(SI), HCLOSEB, M, YPITE(SI)
C COMMON / BLOCK8/ STRSC(SI), DIST
C INTEGER AIA
C REAL U, L, R
C IF (L.T.0 OR DELTAT.LT.0.) GO TO 40

C COMPILE CONSTANTS
C
C IF (DELTAT.LE.0.) GO TO 90

C STRESS IN THE STEEL AT THE CRACK
C STRESS IN THE STEEL BETWEEN CRACKS
C STRESS IN CONCRETE

C IF (ABS(FC).GT.1.0E-2) GO TO 70

C * CHECKING THE SOLUTION BY SOLVING FOR CONCRETE STRESS FIRST
C
C C1 = (RATIO/MP)**(1.0, RATIO/MP)
C C2 = (ES**2/1.0)**(1.0, RATIO/MP)
C C3 = (1.0-C1)*DIA/4.0, FPC
C CM = CM/DIA/4.0, FPC
C AA = C1*C1*C2
C BB = C1*C1*C2*C1*C1*C1*C1
C DD = ES**2*DELAT/ALPHAS*LZ/C2*C2*C4
C
C IF (DELTAT.LE.0.) GO TO 40

C START OF CONSTANTS
C
C 366

C START OF TEMPORARIES
C 562

C START OF INDIRECTS
C 570

C START OF VARIABLES
C 576

C SPACE REQUIRED TO COMPILE -- OFBARF
C 34608

C OFBARF
C
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167 IF IR1.GT.0) GO TO 50
171 IF IR2.GT.0) GO TO 50
173 CONTINUE
175 END OF ABOVE CHECK

C COMPUTE AREA UNDER STEEL STRAIN DIAGRAM FOR THE ASSUMED
C FRICTIONLESS SYSTEM
C
201 DUMMY=B
202 STRAREA=DUM+STPSB+ES*(STRSC+STRSCI)*B/2.*ES
203 IF IABS(STRAREA-ALPHAS*OELTAT*XBAR).GT.E-7) GO TO 100
223 STRMAX=STRC
C
224 STRAIN=STRC/EC
C
225 BOND=B
226 CONTINUE
226 PRINT 140, B
234 GO TO 110
237 CONTINUE
237 PRINT 150, XBAR+STRSC, STRSB, STRC, EC
252 CONTINUE
252 PRINT 160, R2.R4.R6
264 GO TO 110
267 CONTINUE
267 PRINT 170, P*OELTAT+XBAR+STRSC, STRSB, STRC, EC
281 CONTINUE
281 PRINT 180, L
315 CONTINUE
315 PRINT 190, L
323 CONTINUE
323 PRINT 200, L
363 CONTINUE
363 PRINT 200, STRAREA
401 CONTINUE
401 PRINT 210, STRAREA
401 CONTINUE
401 FORMAT (/& 10X* PERCENT REINFORCEMENT **E10.3/)
401 FORMAT (/& 10X* TEMPERATURE DROP **E10.3/)
401 FORMAT (/& 10X* SHRINKAGE **E10.3/)
401 FORMAT (/& 10X* CRACK SPACING **E10.3/)
401 FORMAT (/& 10X* STEEL STRESS AT CRACK **E10.3/)
401 FORMAT (/& 10X* STEEL STRESS BETWEEN CRACKS **E10.3/)
401 FORMAT (/& 10X* CONCRETE STRESS **E10.3/)
401 FORMAT (/& 10X* CONCRETE MODULUS **E10.3/)
401 FORMAT (/& 10X* DEVELOPMENT LENGTH **E10.3/)
401 FORMAT (/& 10X* ERROR IS DETECTED IN SUBROUTINE DFBA**E10.3/)
401 FORMAT (/& 10X* BOND LENGTH IS NEGATIVE AND**E10.3/)
401 FORMAT (/& 10X* PROGRAM IS TERMINATED)

DFBA
THIS SUBROUTINE SOLVES FOR THE POINT OF INTERSECTION OF TWO STRAIGHT LINES, WHERE ONE OF THE LINES IS V = X. THIS VERSION OF THE PROGRAM JOINS THE NEW POINT TO THE POINT ON THE OTHER SIDE OF THE EQ. LINE.

PSX AND PSY ARE STORED VALUES BELOW THE EQUALITY LINE AND SXY AND STY ARE STORED VALUES ABOVE THE EQUALITY LINE.

COMMON /BLOCK2/ SS(5011) + AAA(5011) + MAXTE + CRACKW
COMMON /BLOCK9/ STX, STY, PSX, PSY + ITE

IF (ITE + 0.2) GO TO 10
IF (X2 + Y2) GO TO 20

CONTINUE

GO TO 30

GO TO 50

FOUT + (DUM2 + DUM1 + DUM12 + DUM11) - (DUM2 + DUM11)

RETURN

END

START OF CONSTANT

402

START OF TEMPORARIES

654

START OF ININDIRECTS

664

START OF VARIABLES

684

SPACE REQUIRED TO COMPILE -- OFBAR

34700
SUBROUTINE FRIC (F)

DIMENSION F1501.

COMMON /BLOCK1/ RATIO,THICK,P,STRAINC,ES,NTPI,U+DIA+UNWT

COMMON /BLOCK2/ SS(S501),AAA(S501),MAXT,SRCRACK

COMMON /BLOCK3/ XBAR,STRSC,STRSB,STRC,IBAB1,ITEB

COMMON /BLOCK4/ ALI501,STRAIN501,CONSTRI501,STRESS501

COMMON /BLOCK5/ 1EXPI0.,1EXPI0),FRICMUL,NT,FU,IF1

COMMON /BLOCK6/ ALPHAC,ALPHAS,EC,FPC,TIME,EP,TOL,IT1PER

COMMON /BLOCK7/ ICLOSE8,1PITEI501,REFFI501,1PI501,H

INTEGER AAA

COND=O,

IF IF1.EQ.1) GO TO 10

IF IF1,EQ.2) GO TO 70

CONTINUE

SLOPE=FRICMUL

COMPUTE FRICTION FORCES FROM STRAIGHT LINE GRAPH

DO 30 I=1,NTPI

FE I)=IF (1111).X1.0. GO TO 30

CONTINUE

GO TO 1

CONTINUE

CONTINUE

CONTINUE

CONTINUE

COMPUTE FRICTION FORCES FROM PARABOLA

DO 80 I=1,NTPI

IF IABSIF11.).LT.ABSI1EXP(IJ))) GO TO 110

CONTINUE

CONTINUE

CONTINUE

CONTINUE

COMPUTE FRICTION FORCES FROM INPUT POINT CURVE

DO 130 I=1,NTPI

IF I1111.X1.0.) GO TO 130

CONTINUE

CONTINUE

CONTINUE

CONTINUE

CONTINUE

CONTINUE

CONTINUE

CONTINUE

CONTINUE

CONTINUE

CONTINUE

CONTINUE

CONTINUE

CONTINUE

CONTINUE

CONTINUE

CONTINUE

CONTERM=BEYOND=BEYOND=BEYOND=

GO TO 1

CONTINUE

CONTINUE

CONTINUE

CONTINUE

CONTINUE

CONTINUE

CONTINUE

CONTINUE

CONTINUE

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CONTINUE
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117 110 CONTINUE
117 DUMDUM=(EXP(J)*EXP(J-1))/(ABS(YEXP(J))-ABS(YEXP(J-1)))
126 F(I)=EXP(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 COMPUTE THE TOTAL FRICTION FORCE
C
146 140 CONTINUE
146 IF (BEYOND.GT.0.) PRINT 1999 REASON
156 FFR=0
157 DO 150 I=1,NT,2
158 FFF=(F(I)+F(I+1))/2.
161 CONTINUE
170 150 CONTINUE
173 IF (LONG7R.NE.1001) RETURN
175 PRINT 200, FW
203 RETURN

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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 - 500100 OUTPTC - 500200 END - 500300

BLOCK NAMES AND LENGTHS
BLOCK1 - 12C01 BLOCK2 - 155C02 BLOCK3 - 6C03 BLOCK4 - 324C04
BLOCK5 - 30C05 BLOCK6 - 10C06 BLOCK8 - 372C07

VARIABLE ASSIGNMENTS
AAA - 786C02 AL - 0C04 BEYOND - 237 CONSTR - 175C04
DUMDUM - 243 FEXP - 0C05 FF - 2C04 FRICMUL - 24C05
FU - 26C05 H - 273C07 J - 241 IFY - 27C05
J - 242 LMPR - 244 NT - 25C05 NTF - 6C01
I - 175C07 YP - 274C07

START OF CONSTANTS
205

START OF TEMPORARIES
234

START OF INDIRECTS
237

START OF VARIABLES
237

SPACE REQUIRED TO COMPIL ++ FRIC
35560

FRIC
SUBROUTINE DFNWIRE (F,BONDL,STRMAX,Z,DELTAT)

DIMENSION FISOII,SUM(SOII)

COMMON /IBLOC27/ SIGMASC,SIGMASB,NAP1,E,S,DENO,NAP2

COMMON /IBLOCK41/ ALPHA4,ALPHAC,ALPHAS,E,P,TIME,EP,TOL,YPER

COMMON /IBLOCKSI/ STRAIN(ISOII),CONSTRISOII,STRESSS(SOII)

COMMON /IBLOCKOI/ FEXPIIIOI,FRICMUL,NT,FU,IFY

COMMON /IBLOCKSI/ ALPHA4,ALPHAS,E,P,TIME,EP,TOL,YPER

COMMON /IBLOCZ/ SIGMASC,SIGMASB,NAP1,E,S,DENO,NAP2

REAL L

INTEGER A

COMPUTE THE STRAINS DUE TO FRICTION FORCES DEVELOPED DUE TO SLAB MOVEMENT

EP=1.E-9

IF (A.LE.0.1) GO TO 50

NA=A/H'EP

IF (NA.GT.NT) GO TO 60

CONTINUE

NAPI=NA/H

NAPZ=.A·Z

NAMI=NII-I

NAM2=NA-2

COMPUTE THE SLOPE TO THE STEEL STRAIN DISTRIBUTION CURVE BY DIVIDING THE FRICTION FORCE BY DENO AND CONSIDERING THE SIGN CONVENTION ADOPTED IN THIS STUDY

S=-F/DENO

SUMI=0.

SUM2=0.

DO 20 I=1,NAPI

SUMI=SUMI+(2.0NA-2.1)*F/DENO

SUM2=SUM2+F/DENO

20 CONTINUE

DEFINE CONSTANTS FOR SOLUTION OF EQUATIONS

C1=1.1/(P/RATIO)

C2=(2.0DELTAT*ALPHAC-ALPHAS)*EC1/P

C3=FF/(P/TIME)

S=FF/NAPI/DENO

SOLVE FOR STRESS IN STEEL BETWEEN CRACKS AND AT CRACK

DUM1=ALPHAC4ALPHAS)*DELTAT*ES+SUM/2.-EN+SUM2-S*E/2.-1)*1

SUM2=S*E+C2-CI+BONDL/2.

DUM2=S*E+C2-CI+BONDL/2.

DFNWIRE
SUBROUTINE OWWIRE (BOND, STORMAX, DELTAT)

!!! SUBROUTINE SOLVES FOR THE STRESS IN THE STEEL AND CONCRETE FOR DEFORMED WIRE FABRIC - NO FRICTION FORCES ARE CONSIDERED IN THE SOLUTION !!!

COMMON /BLOCK1/ RATIO, THICK, PFF, STRAIN, ENSP, S1=DIAX, DIAY, DIAY
COMMON /BLOCK2/ S5(SO1), AAA, WS(SO1), MAXITE, CARCH
COMMON /BLOCK3/ XBAR, STRSC, STRESS(SO1), NAPI
COMMON /BLOCK4/ L, MAXIL, CONST(501), STRESS(501)
COMMON /BLOCK5/ FEAR(10), FPFF(10), FRICMULT, FLUTIF
COMMON /BLOCK6/ ALPHAS, ALPHAC, ECF, FPFF, TME, EP, TOL, TPER
COMMON /BLOCK7/ SIGMAC, SIGMAS, NA, NAPI, E, AS, DEN, NAP2
COMMON /BLOCK8/ Y(501), REFF(501), MAXL, ICLOSER, TPE(501)

DEFINE CONSTANTS

C4 = ECF * ECF * DELTAT * (ALPHAC - ALPHAS)
C2 = ECF * DELTAT * E
C3 = BONDL(2) * RATIO(0) * P

SOLVE FOR STRESSES

STRC = (C1 + P * C2) / C3
STRCS = (C2 + P * C3) / C3
STRSC = STRC

CHECK EQUILIBRIUM = EQUATION 1

DUM = STRC + STRS
DUM = STRS
IF (ABS(DUM) .GT. 1.0E-05) GO TO 10
RETURN

CONTINUE

PRINT 20, STRC, STRS, STRSC, DUM
FORMAT (2/10X* ERROR IS DETECTED */,
1 10X * EQUILIBRIUM IS NOT SATISFIED */,
2 10X * STRC = *E10.3,5X* STRS = *E10.3,5X* STRSC =
3 E10.3,5X 10X* DUM1 = *E10.3,5X* DUM2 = *E10.3)
END
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SUBROUTINE POIES (IF.BOND,N,NAPX,LOCMA,XZ,DELTA)
11
DIMENSION F(50),SUM(50)
11 COMMON /BLCKI/RATIO,THICK,FF,STRAIN,E,NAP1,U+DIADU,WNT
11 COMMON /BLCK2/SS(50),AAA,SS(50),ALPHA,CRAFK
11 COMMON /BLCK3/ABAR,STRES,STRES,STRES,TITE,IBAR
11 COMMON /BLCK4/AL(50),STRAIN(50),CONSTR(50),STRES(50)
11 COMMON /BLCK5/FEP(10),YEP(10),FICMUL,NT,FUP,IFY
11 COMMON /BLCK6/ALPHA,ALPHAS,EC,PCTIME,EPS,TLI,TV,lYPR
11 COMMON /BLCK7/SIGNSSIGMA,N,NAP1,E,SAS,ND,END,NAP2
11 COMMON /BLCK8/Y(50),REFF(50),N1Y(50),N1Y,NCLOSE,Y,PITE(50)
11 INTEGER AAA
11 REAL L
11
C
12 II=NA2
12 SUM=0.
12 SUM=AAA.
14 STRESSS(1)*SIGMA(SB)
15 SIGMA(1)=STRESSS(1)*Z-DELTA*(ALPHA-ALPHAS)
17 STRAIN(1)*SIGMA(1)+Z-DELTA*(ALPHA-ALPHAS)
23 CONSTR(1)=STRAIN(1)*EC
25 LOCMA=X
26 STRMA=CONSTR(1)
27 DO 20 I=2.NA
28 STRESSS(1)=STRESSS(I-1)+H*(F(I)*DEN)
30 SIGMA(I)=STRESSS(I)*ES
32 STRAIN(I)=SIGMA(I)+Z-DELTA*(ALPHA-ALPHAS)
41 CONSTR(I)=STRAIN(I)*EC
50 IF (CONSTR(I)*LT.+STRESSS) GO TO 10
53 STRMA=CONSTR(I)
54 LOCMA=X
10 CONTINUE
59 SUM=SUM+I*S(i-1)*H/2.
60 SUM=SUM+I*(STRESSS(I-1)-STRESSS(I))*H/2.
80 DO 20 CONTINUE
71 ADDI=STRESSS(NA)+PE
76 ADDI=ADDI+STRESSS*ADDI+PE/2.
101 SUM=SUM+ADDI/ES
105 SLOTE=SIGNA=ADDI/BOND
108 ADDI=ADDI+Z-DELTA*(ALPHA-ALPHAS)
124 SLOTE=ADDI+BOND
125 STRESSS(NA)=ADDI=(AL-NAP1)-A+SIGNA
126 SIGMA=STRESSS(NA)*EC
142 IF (CONSTR(NA)*LT.+STRESSS) GO TO 30
147 TSTMA=CONSTR(NA)
170 LOCMA=NA1
150 CONTINUE
20 SUM=SUM+I*(STRESSS(NA)+ADDI*AL-NAP1)*A/2.
150 SUM=SUM+I*(STRESSS(NA)+ADDI*(AL-NAP1)-A)*2.
170 IF (NAP=0,NT=11-NAP1)
177 DO 50 I=1,NAP1
178 STRESSS(1)=ADDI*(AL-A)+SLDPE2

DOFILE

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

SUBPROGRAM LENGTH

1267

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS

10 - 54 30 - 150 40 - 233

EXTERNALS AND TAGS

END - 500100

BLOCK NAMES AND LENGTHS

BLOCK1 - 1260 BLOCK2 - 1755C02 BLOCK3 - 6C03 BLOCK4 - 3724C04
BLOCK5 - 30C05 BLOCK6 - 10C06 BLOCK7 - 11C07 BLOCK8 - 3726C10

VARIABLE ASSIGNMENTS

A - 6C07 AAA - 765C02 ADP1 - 1262 ADD1AR - 1263
ADD - 1265 AL - 6C04 ALPHA - 6C06 ALPHAS - 1C06
CONSTR - 1752C04 DENG - 7C07 E - 4C07 EC - 2C06
ES - 5C01 EXP - 2C05 h - 273C10 I - 1261
H - 125A L - 1255 NA - 2C07 NAP1 - 3C07
HAP2 - 10C07 MT - 25C05 MTP1 - 2C01 P - 2C01
IPEP - 765C10 S - 6C07 SIGMAS - 1C07 SIGMAC - 4C07
SLOPECC - 1266 SLOPE2 - 1264 SS - 6C02 STRAIN - 765C04
STRESS - 273C04 SUM - 270 SUM3 - 1257 SUM4 - 1260
THICK - 1C03 WS - 766C02 Y - 2C10 YEXP - 12C05

START OF CONSTANTS

253

START OF TEMPORARIES

255

START OF INDIRECTS

264

START OF VARIABLES

270

SPACE REQUIRED TO COMPIL -- POIRES

34600

POIRES

POIRES
SUBROUTINE SIMPSPE (Y,N,H,SUM)
DIMENSION Y(N),SUM(N)
C
C THIS SUBROUTINE COMPUTES THE AREA UNDER A DISTRIBUTION USING
C SIMPSON'S RULE WITH A SPECIAL MODIFICATION
C
DO 10 J=1,N
10 SUM(J)=0.
10 CONTINUE
SUM(1)=0.
A0=A1=0.
SUM(2)=AL0D
NM1=N-1
00 20 1=2,NM1
20 CONTINUE
RETURN
END

FUNCTION ASSIGNMENTS
STATEMENT ASSIGNMENTS
EXTERNALS AND TAGS
END = 500100
BLOCK NAMES AND LENGTHS
VARIABLE ASSIGNMENTS
A   56   A0LD   53   A5   55   A1   52
   N1   NM1   54
START OF CONSTANTS
 45
START OF TEMPORARIES
 47
START OF INDIRECTS
 51
START OF VARIABLES
 51
SPACE REQUIRED TO COMPILE -- SIMPSPE
32500
SUBROUTINE STRGENE (BOND)

*** THIS SUBROUTINE GENERATES THE STRAIN IN THE CONCRETE AT *
*** EVERY STATION IN THE FRICTIONLESS SLAB ;
*** RESULTS OF SUBROUTINE TEMPSHR. ARE USED -- NO FRICTION *

******************************************************************************
3 COMMON /BLOCKI/ RATIO,THICK,FT,FStrain,C,STRESSS(501),DTME,CRACK
3 COMMON /BLOCK2/ SS5001,AAA,STRESSS(501),STRAIN(501),STRESSS(501)
3 COMMON /BLOCK3/ RATIO,THICK,FT,FStrain,C,STRESSS(501),STRAIN(501),STRESSS(501)
3 COMMON /BLOCK5/ FEAP(10),FFC(10),FRECU(10),FRECU(10),FFC(10)
3 COMMON /BLOCK6/ ALPHA,ALPHA,EC,EC,FPC,TIME,DP,TOL,NDP,TPER
3 COMMON /BLOCK7/ STRESSS(501),STRAIN(501),STRAIN(501),INC,FMP,FTP,L
3 INTEGER A,A
3 REAL L

A=L-BOND

DO 20 I=1,NTPI

STRAIN(I)=STRAIN(I)+STRAINC(I)

IF (AL(I)=L,A) GO TO 10

STRAIN(I)=STRAINC(I)+STRAINC(I)+STRAIN(I)-A/BOND

10 CONTINUE

RETURN

END
SUBROUTINE BACKTIM (TENSTRN, ZTOT, ZI)

This subroutine calculates the time dependent variables from the computed strength on the line of equality of stress-strength curve.

DIMENSION PERCENT(8), AGE(8)

COMMON /BLOCK21/ RATIO, THICK, PFF, STRAIN, ES(NT), U0IA, UNWT

COMMON /BLOCK22/ S5(501), A4A, K5(501), MAXT, CHACK

COMMON /BLOCK23/ KBAR, STRS, STRSB, STRSC, BARBY, ITC

COMMON /BLOCK6/ AL(501), STRAIN501, CONST501, STRESS501

COMMON /BLOCK5/ FEP(10), EXP(10), FRI(10), LIMIT, TYPER

COMMON /BLOCK6/ ALPHA, ALPHAS, EC, FPC, TIME, EP, TOL, ITPER

COMMON /BLOCK7/ NSTRN, VOS, AGEUI, TENSIONI, STRNMUL

DATA AG(0, 10:3, 15, 38, 53, 63, 82, 94, 100, 1)

INTEGER AAA

C

IF (NSTRN .GT. 0.) GO TO 30
10 FLESTRN = TENSTRN / STRNMUL
15 CONSTR = (12000. + FLESTRN) / (3000. - 3. + FLESTRN)
16 PERTOM = CONSTR / FPC = 100.
20 EC = 0.5 * UNWT * 1.5 * SQRT(CONSTR)
27 RATIO = ES / EC
30 U = 0.5 * SQRT(CONSTR) / DIA
35 IF (U .GT. 0.) U = 0.8
40 DO 10 I = 1, 8
44 IF (PERCOM .LE. PERCENT(1)) GO TO 20
47 CONTINUE
51 PRINT 88, PERCOM
57 GO TO 70
62 CONTINUE
67 TIME = PERCENT(1 - PERCENT(1)) / AGE(1) - AGE(J - 1)
67 TIME = AGE(J - 1) - PERCOM .LE. PERCENT(J - 1) / TIME
73 GO TO 69
73 CONTINUE
C

COMPUTE THE TIME CORRESPONDING TO TENSILE STRENGTH

COMMON /BLOCK7/ NSTRN, VOS, AGEUI, TENSIONI, STRNMUL

DATA AG(0, 10:3, 15, 38, 53, 63, 82, 94, 100, 1)

INTEGER AAA

C

IF (NSTRN .GT. 0.) GO TO 30
10 FLESTRN = TENSTRN / STRNMUL
15 CONSTR = (12000. + FLESTRN) / (3000. - 3. + FLESTRN)
16 PERTOM = CONSTR / FPC = 100.
20 EC = 0.5 * UNWT * 1.5 * SQRT(CONSTR)
27 RATIO = ES / EC
30 U = 0.5 * SQRT(CONSTR) / DIA
35 IF (U .GT. 0.) U = 0.8
40 DO 10 I = 1, 8
44 IF (PERCOM .LE. PERCENT(1)) GO TO 20
47 CONTINUE
51 PRINT 88, PERCOM
57 GO TO 70
62 CONTINUE
67 TIME = PERCENT(1 - PERCENT(1)) / AGE(1) - AGE(J - 1)
67 TIME = AGE(J - 1) - PERCOM .LE. PERCENT(J - 1) / TIME
73 GO TO 69
73 CONTINUE
C

COMPUTE SLOPE BY LINEAR INTERPOLATION

TIME = TENSION(J - 1) - TENSION(J - 1) / AGEUI(J - 1) - AGEUI(J - 1)

CONTINUE

END
THIS SUBROUTINE RETURNS THE TEMPERATURE DROP AT NON-
INTEGER TIMES.

COMMON /BLOCK1, 2/ DT, ITEMP, NF, NTIFLAG, UPINC, DOWNINC
DO 10 ITIME = 1, ITEMP
  REALIT = FLOAT(ITEM)
  IF (REALIT.GT.0) GO TO 20
  CONTINUE
  PRINT 130, ITIME, REALIT
  STOP 66
  CONTINUE
  OTIME = ITIME - (REALIT - 1)
  IF (DT(ITEM).EQ.0) GO TO 40
  OELTAT = DT(ITEM) * OTIME
  RETURN
  DELTAT = OTIME
  RETURN
  FORMAT(130 ERROR IN DELTEM) TIME = **E10.3, REALIT = **E10.3)
END
**DELTEM**

```fortran
SUBROUTINE DELTEM (TIME, DELTAT)

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 DELTEM INCREMENTS UP BY UPINC IF NTIFLAG = 1
C INCREMENTS DOWN BY DOWINC IF NTIFLAG = -1
C IT GIVES THE TEMPERATURE DROP AT TIME IF NTIFLAG = 0
C
C**************************************************************
C COMMON /BLOCK12/ DT,501,NTMP,NTIFLAG,UPINC,DOWINC
C P1=3.14159265358
C 10 REALT=FLOAT(TIME)
C IF (REALT,GT,TIME) GO TO 20
C 15 CONTINUE
C PRINT 130, DELTAT,TIME
C STOP
C 20 CONTINUE
C IF (TIME,GT,REALT-.75,A,TIME,LT,REALT-.25) GO TO 30
C 45 DELTAT=0.
C 46 GO TO 60
C 48 CONTINUE
C DELTAT=DT(DTIME)*SIN((TIME-REALT+.75)*2.*PI)
C 50 CONTINUE IF (NTIFLAG) 100,80,50
C 55 DELTAT=DELTAT+UPINC
C 56 IF (TIME,GT,REALT-.5) GO TO 90
C 60 IF (DELTAT,LT,DT(DTIME)+DOWINC-1.E-7) GO TO 90
C 67 IF (DELTAT,GT,DT(DTIME)) GO TO 120
C 70 CONTINUE
C 75 DELTAT=DELTAT-DOWINC
C 76 IF (DELTAT) 110,110,0
C 77 GO TO 120
C 80 TIME=REALT-.5
C 85 CONTINUE
C 90 CONTINUE
C 95 RETURN
C 100 REALT=REALT+.1.
C 105 ITIME=ITIME+1.
C 107 DELTAT=DELTAT-UPINC
C 111 IF (TIME,GT,NTMP) GO TO 70
C 114 RETURN
C 116 DELTAT=DELTAT+DOWINC
C 120 IF (DELTAT) 110,110,0
C 121 CONTINUE
C 122 IF (TIME,LE,REALT-.5) TIME=REALT-.75
C 135 RETURN
C 140 TIME=REALT-.25
C 150 TPLUS=ABS(SIN(DELTAT/DTIME)/(2.*PI)**.25)
C 155 IF (TIME,LE,REALT-.5) TPLUS=TPLUS
```

**DELTEM**
RETURN  
130 FORMAT (* END OF TEMPERATURE ARRAY ENCOUNTERED/, *, DELTAT *=F6.3) 
END 

FUNCTION ASSIGNMENTS 

STATEMENT ASSIGNMENTS 
20 - 30 30 - 46 40 - 57 50 - 61 
60 - 70 70 - 100 80 - 102 90 - 103 
180 - 110 110 - 120 120 - 130 130 - 174 

EXTERNALS AND TAGS 
OUTPTC = 500100 STOP = 500200 SIN = 500300 ASIN = 500400 
END = 500500 

BLOCK NAMES AND LENGTHS 
BLOCK12 = 64C01 

VARIABLE ASSIGNMENTS 
DOWNINC = 65C01 DT - 0C01 TIME - 210 NTIME - 62C01 
NTILAG = 63C01 PI - 207 REALI - 211 TPLUS - 212 
UPINC = 64C01 

START OF CONSTANTS 162 
START OF TEMPORARIES 204 
START OF INDIRECTS 207 
START OF VARIABLES 207 
SPACE REQUIRED TO COMPIL -- DELEMP 33200 

DELEMP
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APPENDIX 4. SAMPLE PROBLEMS

T OF PROGRAM-MODEL1

SLAB DIMENSIONS

SLAB LENGTH = 6.00E+01
SLAB WIDTH = 2.40E+01
NUMBER OF INCREMENTS = 100
FRICITION FACTOR = 2.00E+00
MAX. CRACK WIDTH = 3.00E-02

STEEL PROPERTIES

TYPE OF LONGITUDINAL REINFORCEMENT IS
UNFORMED RARS

PFRCFT REINFORCEMENT = 0
BAR DIAMETER = 6.25E-01
YIELD STRESS = 6.00E+04
ELASTIC MODULUS = 2.90E+07
THERMAL COEFFICIENT = 5.00E-06

CONCRETE PROPERTIES

SLAB THICKNESS = 1.00E+01
THERMAL COEFFICIENT = 6.00E-06
TOTAL SHRINKAGE = 4.00E-04
UNIT WEIGHT CONCRETE = 1.440E+02
COMPRRESSIVE STRENGTH = 4.000E+03
STRESS/FLEX RATIO = 6.666E-01

TENSILE STRENGTH DATA
NC 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 = 0.010

TEMPERATURE DATA.

CURING TEMPERATURE = 75.0

<table>
<thead>
<tr>
<th>DAY</th>
<th>MINIMUM TEMPERATURE</th>
<th>DROP IN TEMPERATURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>55.0</td>
<td>20.0</td>
</tr>
<tr>
<td>2</td>
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<td>20.0</td>
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<tr>
<td>14</td>
<td>55.0</td>
<td>20.0</td>
</tr>
<tr>
<td>15</td>
<td>55.0</td>
<td>20.0</td>
</tr>
</tbody>
</table>
MINIMUM TEMPERATURE EXPECTED AFTER CONCRETE GAINS FULL STRENGTH = 0 DEGREES FARENHEIT

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 1.000E+02 INCHES.
T OF PROGRAM-MODEL1

SLAB DIMENSIONS

SLAB LENGTH = 6.00E+01
SLAB WIDTH = 2.40E+01
NUMBER OF INCREMENTS = 100
FRICTION FACTOR = 2.00E+00
MAX. CRACKWIDTH = 3.00E-02

STEEL DESIGN OPTION

STEEL PROPERTIES

TYPE OF LONGITUDINAL REINFORCEMENT IS DEFORMED BARS

PERCENT REINFORCEMENT = 0
BAR DIAMETER = 6.25E-01
YIELD STRESS = 6.00E+04
ELASTIC MODULUS = 2.90E+07
THERMAL COEFFICIENT = 5.00E-06

CONCRETE PROPERTIES

SLAB THICKNESS = 1.00E+01
THERMAL COEFFICIENT = 6.00E-06
TOTAL SHRINKAGE = 4.00E-04
UNIT WEIGHT CONCRETE = 1.440E+02
COMPRRESSIVE STRENGTH = 4.00E+03
(TENS/FLEX) RATIO = 6.666E-01

TEASILE STRENGTH DATA
**NC 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 STRENGTH (DAYS)**

<table>
<thead>
<tr>
<th>Days</th>
<th>Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>1</td>
<td>6.9</td>
</tr>
<tr>
<td>3</td>
<td>183.6</td>
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<tr>
<td>5</td>
<td>230.9</td>
</tr>
<tr>
<td>7</td>
<td>257.6</td>
</tr>
<tr>
<td>14</td>
<td>300.3</td>
</tr>
<tr>
<td>21</td>
<td>323.0</td>
</tr>
<tr>
<td>28</td>
<td>333.3</td>
</tr>
</tbody>
</table>

**Slab-Base Friction Characteristics**

- F-Y Relationship

**Type of Friction Curve is a Straight Line**

Maximum Friction Force = 3.00
Movement at Sliding = 0.010

**Temperature Data**

Curing Temperature = 75.0

<table>
<thead>
<tr>
<th>Day</th>
<th>Minimum Temperature</th>
<th>Drop in Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>55.0</td>
<td>20.0</td>
</tr>
<tr>
<td>2</td>
<td>55.0</td>
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<tr>
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<td>55.0</td>
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<td>55.0</td>
<td>20.0</td>
</tr>
<tr>
<td>15</td>
<td>55.0</td>
<td>20.0</td>
</tr>
<tr>
<td>Iteration</td>
<td>Minimum Temperature</td>
<td>After Concrete Gains Full Strength</td>
</tr>
<tr>
<td>-----------</td>
<td>---------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0 Degrees Fahrenheit</td>
</tr>
</tbody>
</table>

**Iteration and Tolerance Control**

- Maximum Allowable Number of Iterations: 20
- Relative Closure Tolerance: 1.0 Percent

For iteration equal to 1, the transverse steel is 5.333E-02 percent spaced 5.752E+0 inches center to center.

- Width of first crack is 0.0084 inches at time 0.4791 days.
- Width of first crack is 0.0087 inches at time 0.4660 days.
- Width of first crack is 0.0093 inches at time 0.4027 days.
- Width of first crack is 0.0095 inches at time 0.5648 days.
- Width of first crack is 0.0103 inches at time 0.5776 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.
SLAB DIMENSIONS

SLAB LENGTH = 6.000E+01
SLAB WIDTH = 2.400E+01
NUMBER OF INCREMENTS = 100
FRICITION 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

TEENSILE STRENGTH DATA
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

<table>
<thead>
<tr>
<th>Age (Days)</th>
<th>Tensile Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
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</tr>
<tr>
<td>1.0</td>
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<td>7.0</td>
<td>257.6</td>
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<tr>
<td>14.0</td>
<td>300.3</td>
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<td>21.0</td>
<td>323.0</td>
</tr>
<tr>
<td>28.0</td>
<td>333.3</td>
</tr>
</tbody>
</table>

SLAB-BASED FRICTION CHARACTERISTICS
F-Y RELATIONSHIP

TYPE OF FRICTION CURVE IS A STRAIGHT LINE

MAXIMUM FRICTION FORCE = 3.800
MOVEMENT AT SLIDING = -.810

TEMPERATURE DATA

CURING TEMPERATURE = 75.0

<table>
<thead>
<tr>
<th>Day</th>
<th>Minimum Temperature</th>
<th>Drop in Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>55.0</td>
<td>20.0</td>
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</tr>
<tr>
<td>28</td>
<td>55.0</td>
<td>20.0</td>
</tr>
</tbody>
</table>

Minimum temperature expected after concrete gains full strength = 0 degrees Fahrenheit

* * *

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 .4445 days.

Stress in the steel 4.883E+04 is greater than its working strength at time 3.000
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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 University 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.