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16. Abstract

The long-term work plan at the initial design phase of the McLennan County prestressed concrete pavement (PCP) overlay consisted of the determination of the variables that are relevant to design, the development of models and design procedures, and the study of the effect of environmental factors on PCP slabs. The present study focuses on the evaluation of the performance of PCP. The review of the existing models for Prestressed Concrete Pavements are discussed. Next, the use of collected data in an experimental field section for comparison against program PSCP1 is made. A new model for the prediction of curling in slabs caused by temperature variations is developed and tested. Program PSCP2 is introduced as the result of the upgrading in the models and calibration of models. Finally, conclusions and recommendations based on the instrumentation program, data analysis, and model are outlined.

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ANALYSIS OF CURLING MOVEMENTS AND CALIBRATION OF PCP PROGRAM

by

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Research Report Number 556-3

Research Project 3-10-88/9-556

Prestressed Concrete Pavement (PCP) Overlay on IH35 in McLennan County

conducted for

Texas State Department of Highways and Public Transportation

in cooperation with the

U.S. Department of Transportation Federal Highway Administration

by the

CENTER FOR TRANSPORTATION RESEARCH

Bureau of Engineering Research

THE UNIVERSITY OF TEXAS AT AUSTIN

November 1989

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PREFACE

The report presents an analysis of vertical slab movements to characterize the curling and expansion-contraction behavior of the slabs. Finally, an analytical model is developed and calibrated to the field data.

This work is part of Research Project 556, "Prestressed Concrete Pavement (PCP) Overlay," conducted as a part of the overall research program at the Center for Transportation Research (CTR), Bureau of Engineering Research, The University of Texas at Austin. The work was sponsored by the Texas State Department of Highways and Public Transportation (SDHPT) and the Federal Highway Administration under an agreement with The University of Texas at Austin and the Texas SDHPT.

Thanks go to Ken Hankins and Humberto Castedo for assistance with planning, Carl Bertrand for assistance with data acquisition, and all the personnel in the project and in the Center for Transportation Research who were so helpful during the project.

Jose Antonio Tena-Colunga
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Ned H. Burns

LIST OF REPORTS

Research Report 556-1, "Prestressed Concrete Pavement: Instrumentation and Data Collection for Its Analysis," by Jose A. Tena-Colunga, Elliott D. Mandel, Ned H. Burns, and B. Frank McCullough, describe the planning and organization for Research Project 556 and presents field data in tabular and graphical form. Results of deflection tests and condition surveys are also presented. June 1989.

Research Report 556-2, "Prestressed Concrete Pavement: Instrumentation, Behavior, and Analysis," by Elliott David Mandel, Ned H. Burns, and B. Frank McCullough, describes the instrumentation for Research Project 556 and presents an analysis of horizontal data in tabular and graphical form. July 1989.

Research Report 556-3, "Analysis of Curling Movements and Calibration of PCP Program," by Jose Tena-Colunga, Ned H. Burns, and B. Frank McCullough, presents the final results of vertical displacement data, reviews the analytical model PSCP-1, and describes the calibration of the model with the collected field data. November 1989.

ABSTRACT

The long-term work plan at the initial design phase of the McLennan County prestressed concrete pavement (PCP) overlay consisted of the determination of variables that are relevant to design, the development of models and design procedures, and the study of the effect of environmental factors on PCP slabs. The present study focuses on the evaluation of the performance of PCP. The review of the existing models for Prestressed Concrete Pavements are discussed. Next, the use of collected data in an experimental field section for comparison against progam PSCP1 is made. A new model for the prediction of curling in slabs caused by temperature variations is developed and tested. Program PSCP2 is introduced as the result of the ugrading in the models and calibration of models. Finally, conclusions and recommendations based on the instrumentation program, data analysis, and model are outlined.

KEY WORDS: Concrete pavements, highways, prestressed concrete pavements, overlays, stress, friction, curling, warping, elasticity, inelasticity, temperature changes, temperature gradient, temperature reversal, thermal coefficient, mathematical model, computer program.

SUMMARY

This report presents an analysis of the data collected from the McLennan County Prestressed Concrete Pavement (PCP) in detail. The objectives of the data collection and program calibration are outlined. The factors and variables in computer program PSCP1 are analyzed.

An analysis of the vertical displacement data is performed and related to the horizontal displacement data and temperature. Final results from the displacement data are presented in tabulated and graphical form. Results of an analysis of vertical displacements are outlined and discussed. The consistency and accuracy of the data are then addressed. Comparisons between the collected data and previous models used in PSCP1 are made. Then, the models for curling are reviewed.

An analytical model for the vertical displacements of PCP slabs is developed. The background and theory of the model is described. Then, the model is tested. The use of the model is presented along with user guidelines. The computational operation of the model is outlined in the appendix of the report.

Finally, conclusions are presented, followed by recommendations based on the instrumentation program and the field data analysis, and, the model studies are outlined.

IMPLEMENTATION STATEMENT

This report describes the analysis of curling and the procedures followed for the calibration of computer program PSCP1 and the subsequent development of program PSCP2 using data collected from the McLennan County Prestressed Concrete Pavement (PCP) . A field data analysis and the development and use of an analytical model for PCP are also presented. Data for a wide range of temperatures are reported.

The method of collection of field data is quite successful. The information presented in this report can be used as a guideline for future programs and analysis. Field measurements that can be used for the design of Prestresed Concrete Pavements constructed on a polyethylene surface or for the calibration of other mathematical models are provided. Testing of program PSCP2 shows that it can be used for the analysis and design of PCP.

CHAPTER 1. INTRODUCTION

This chapter presents the purpose of this report. A brief background on prestressed concrete pavements (PCP) is given, along with a review of some associated former work at the Center for Transportation Research (CTR) of The University of Texas at Austin. The relation of this project to previous studies of PCP and with other CTR work is discussed. The objectives and the scope of this work are included at the end of the chapter.

The study of various types of engineering structures and a translation of their behavior into models permits optimization of design. This is true for all the diverse areas included in the field of Civil Engineering. Behavior analysis is progressive in nature, yielding better models as it evolves. Modeling is a powerful tool in decision making as it allows the choice of more economic alternatives. The lack of models would make the decision-making process a cumbersome task at the levels of planning, design, and construction. This lack would also lead to inaccuracies and waste of resources. Models are of special importance in road construction. Presently roads are the preferred means of transport, and enormous resources are allocated for their development and maintenance. The PCP slab is one of the pavement types more recently available. The study and calibration of a model for PCP slabs will provide necessary information for the weighting of this option. An economic analysis using a model will help to improve use of the human, material, and economic resources.

RELATION OF THIS REPORT TO PRECEDING REPORTS

The development of a design procedure for PCP was conducted at CTR under Research Project 401. In that project, aspects of early post-tensioning, new concepts in prestress, subbase friction, prestress friction losses, fatigue life, monitoring instrumentation, and PCP design were studied.

The design procedures were developed from design recommendations proposed in the literature together with the experience gained from the McLennan County Project. Research Report 401-3 contains the development of the original program, PSCP1, which is calibrated herein.

This report includes the continuation of the physical measurements of the behavior of the PCP slabs in the McLennan County Project (1985). It also initiates the determination of the long-range characteristics of PCP slabs in service. Information for the validation or correction of the observations made during the preceding work, on Projects 556 and 401, is supplied here, together with a more accurate model for future PCP design. This model also offers a basis for better maintenance prediction and for decisions about design details on future projects.

The data collected during this project, and the planning and description of the instrumentation employed for the monitoring of the test sections, are presented in Research Reports 556-1 and 556-2. Research Report 556-2 deals mainly with the analysis of the horizontal data for the development of a finite element program. This report focuses mainly on the analysis necessary for the calibration and testing of program PSCP2. Research Report 556-4F presents a general summary and the main results of this study.

OBJECTIVES

The objectives of this study range from general objectives to those which are more specific. In this order, they are to:

(1) Study the characteristics and behavior of a prestressed concrete pavement overlay, monitoring the performance of the prestressed concrete pavement overlay to build statistical support for the calibration of the program.
(2) Perform a statistical analysis of the collected data.
(3) Calibrate the program PSCP1 for the computation of values more representative of the physical reality.
(4) Revise the models proposed in program PSCP1 as necessary.

The work was performed taking into account the existing available data and the new information that was produced in this study.

SCOPE

The present work is divided into seven chapters. The first three chapters present the necessary background on Prestressed Concrete Pavement (PCP) slabs, and the work carried out for this study is presented in Chapters 4 to 6. Chapter 7 contains the conclusions and recommendations.

Chapter 1 is a introduction to PCP, its background, and the background of this project. The concepts for analysis and calibration are discussed in Chapter 2. At the end of Chapter 2 a characterization of the input data is presented. This discussion provides the basis for the presentation and later analysis of formulas used in program PSCP1. In Chapter 3, the analysis of the data is presented.

The comparisons between predicted and measured behavior are presented in Chapter 4. Hypotheses for the modeling and calibration of PSCP1 are also developed in Chapter 4. The testing of the hypotheses is presented in Chapter 5 along with their introduction into program PSCP2, which is an upgraded version of program PSCP1. The final conclusions and recommendations from this study are presented in Chapter 6.

CHAPTER 2. PLAN FOR ANALYSIS AND CALIBRATION

CHARACTERIZATION OF INPUT FOR THE PCP MECHANISTIC MODEL

Before the plan for the calibration of the model is discussed, a listing of the input for program PSCP1 is provided. It describes the role of each variable in the program (see Table 2.1).

For a clear and simple representation of the program and its calibration, the concepts of "black box" and flow chart are used. In Fig 2.1, the black box of program PSCP1 is depicted. On the left side of the figure, the input with a constant value for a specific slab is shown under the classification of "Historical Data"; the letters "b, d, f, and g," etc., correspond to the letters of Table 2.1. In the second input group, the values that have to be updated for each program run are shown. The output of the program is on the right-hand side of the figure.

Figure 2.2 is the flow chart of the calibration process. Figure 2.3 illustrates the concepts of Fig 2.2. The process starts with the monitoring of PCP slabs. Next, the predicted values of program PSCP1 are compared to the collected data. If the difference between the values is higher than the accepted range for design, the calibration process continues; otherwise the calibration is not necessary. Step three is the analysis of the differences. In this part all the factors that might affect the values are weighted. Hence, statistical comparisons are performed between the data for dry and wet conditions, edge and interior, different slab lengths, etc. Once the analysis is finished, models and constants in PSCP1 are reviewed; here constants are corrected and updated if necessary. Next, a hypothesis for the correction of the problem is expressed. In step six, the necessary corrections and improvements to the models are introduced and checked for validity.

The degree of accuracy is a function of the data base available. Then, the accuracy obtained is checked against the existent data base. Here the process can follow either of two paths: (1) if more data base is required for this check, further monitoring of PCP is pursued and the process can go another cycle; or (2) if the accuracy achieved is reasonable for design or if it is not possible to obtain the required data, the process is terminated.

This process is systematic and can be repeated until the desired accuracy is reached. Each time the required data base will be more broad, extensive, and expensive. Therefore, it is usually pursued until practical values for design are achieved.

EFFECT OF MODELS IN PCP

In this section, the effect of models and input in PSCP1 is inspected. For this purpose, the models presented before are considered. The input is also taken into account. The purpose is to outline the best path for the calibration. The criterion followed is that for those models with higher effect, the results are calibrated first. Next, the calibration proceeds with models of secondary importance for the output. Then the calibration is gradual.

The models that have a higher effect on the input are those for the determination of the stresses and movements due to friction and curling. They are followed by the functions for the prediction of post-tensioning, steel ,and concrete. The inputs for the k-value for soil, creep and shrinkage then follow. Inputs of importance are the

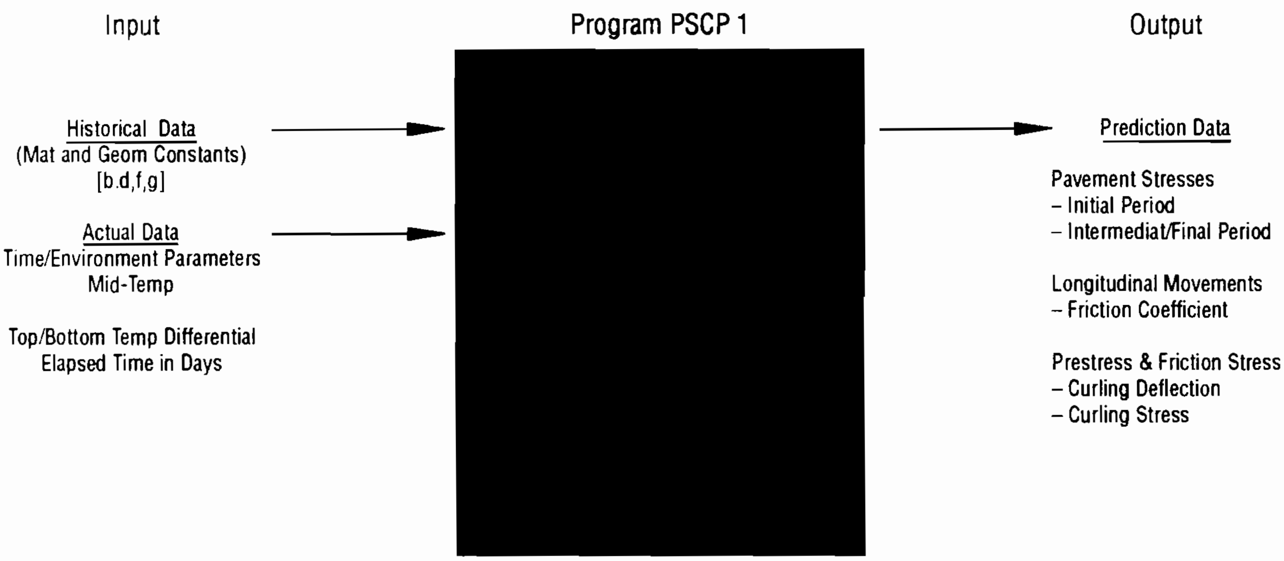


Fig 2.1. Input and output of Program PSCP1 (black box concept).

strength of concrete, modulus of elasticity, Poisson's ratio, and thermal coefficient of soil. The k-value is a function of the range of the other values. Thus, its effect on the output in some cases will be important while in other cases its importance will be marginal.

The friction model is iterative. This can induce roundup or truncation errors, as expressed in Table 2.1. The function of this model is a numeric integration of a polynomial function. The degree of the polynomial is given by the profile of the coefficients of friction. The magnitude of an error due to a mis-modeling of friction is illustrated with Fig 2.3(b) (6), which shows the difference between two polynomials of different order. For this determination, the employment of the correct coefficients and profiles of friction is necessary.

Curling is important in the output, too. Temperature gradients, thermal coefficients, modulus of elasticity, Poisson's modulus, and the k-value take part in its determination. Because of the architecture of PSCP1, curling is determined almost independently; it is affected also by the friction profile. Therefore, its effect is easy to detect once the friction model can simulate the physical phenomena. Figure 2.3(a) (3) is a schematic representation of the interaction of all the factors that intervene in curling and friction.

The effects of data input were mentioned in the preceding section. Some of the effects have already been mentioned here. Their main effect is to modify the rate of change in the values of the output. Some secondary effects are changes in the range of prediction values. Figure

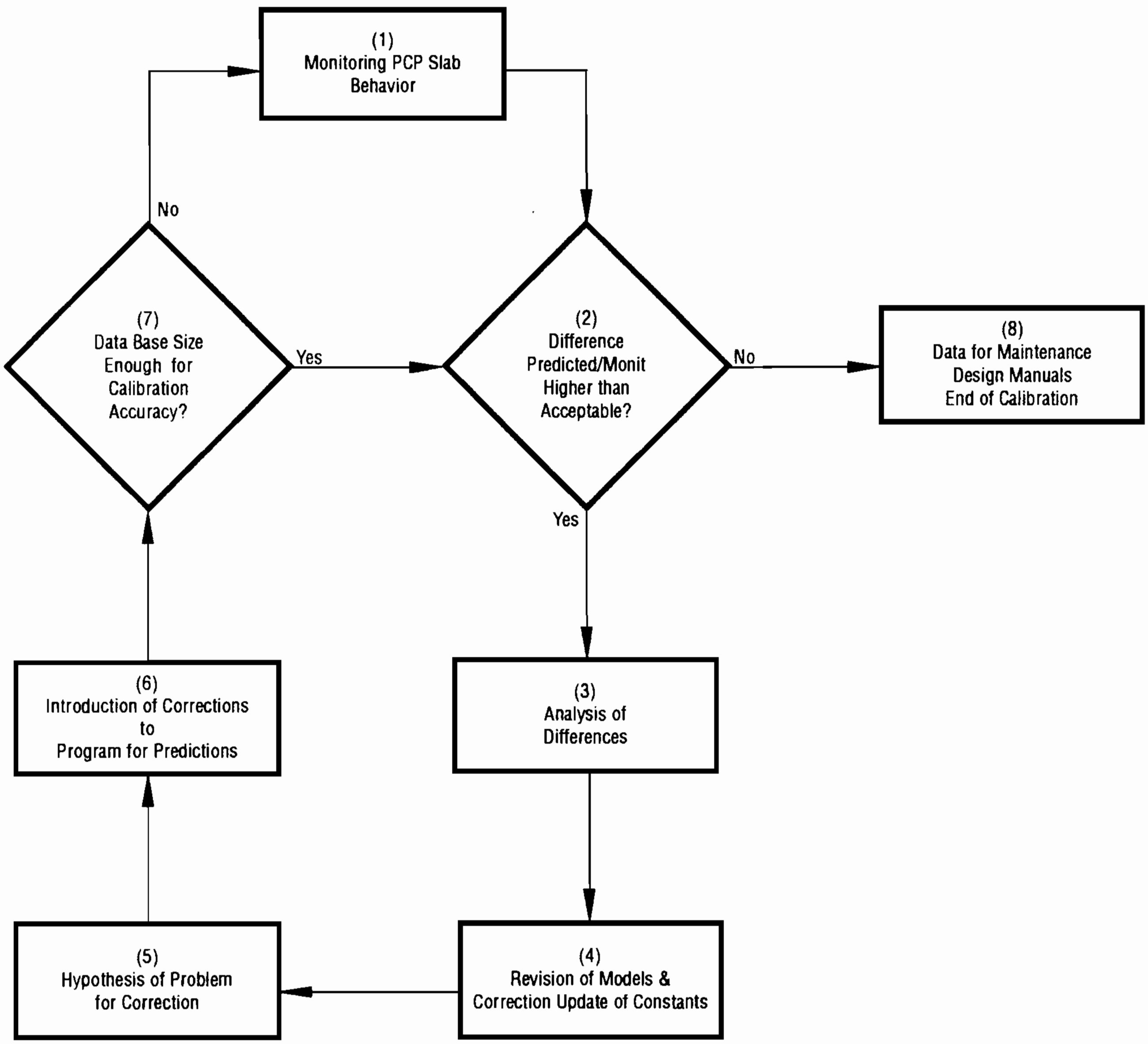


Fig 2.2. Flow chart of calibration process for Program PSCP1.

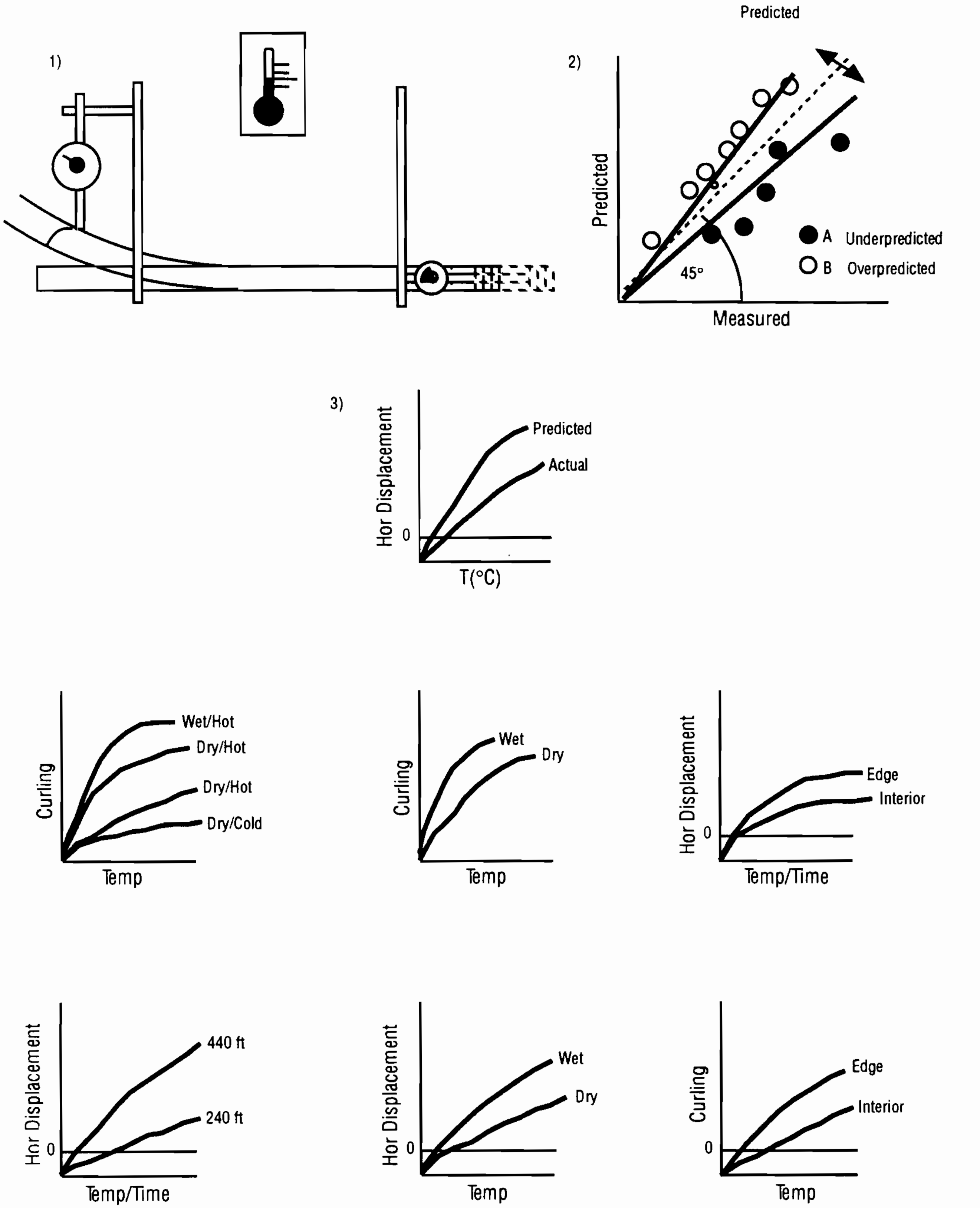


Fig 2.3(a). Graphical description of calibration process.

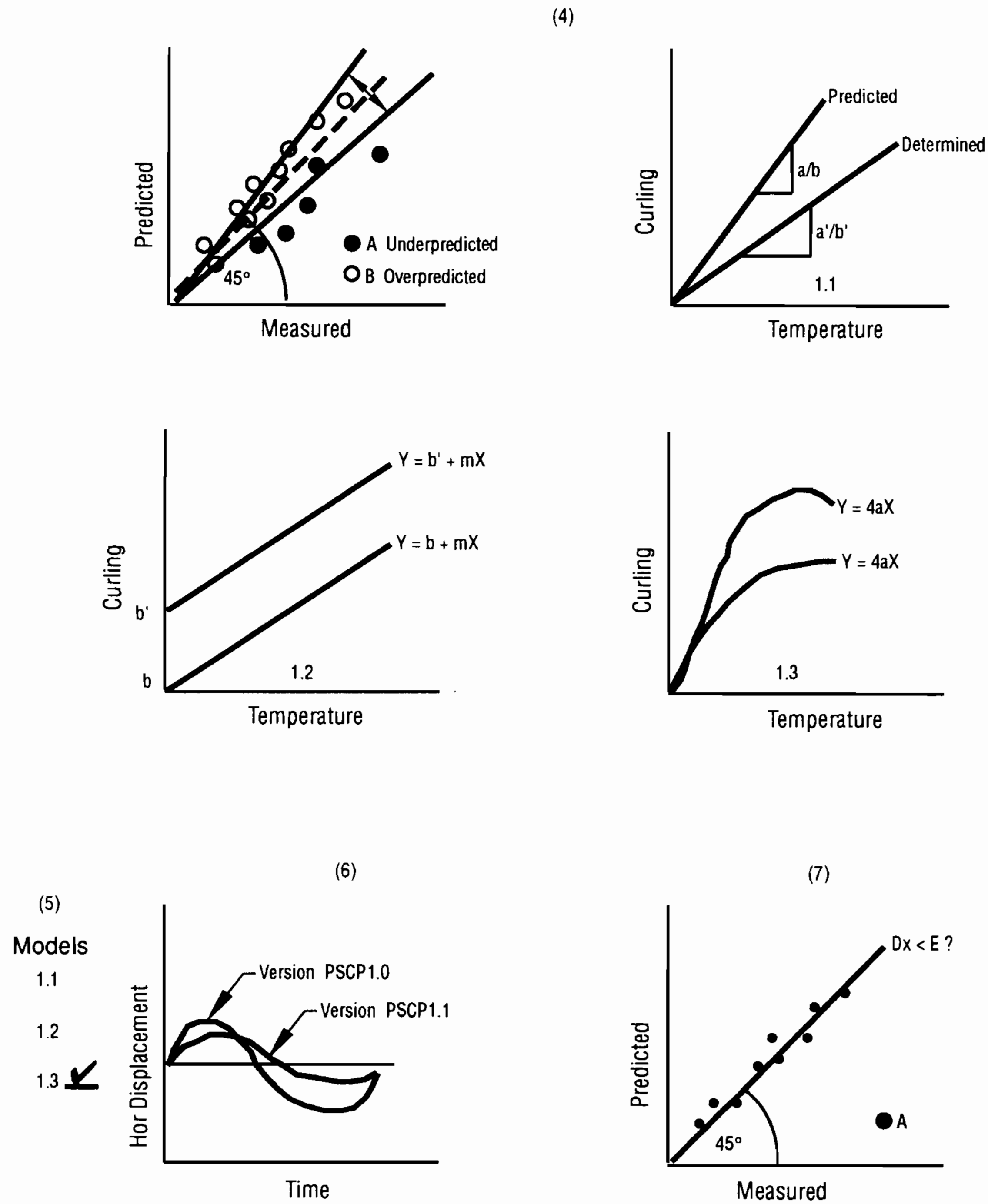


Fig 2.3(b). Graphical description of calibration process (continued).

2.3(b) (4) is a schematic representation of this effect. Among these input variables, we can point out creep and shrinkage and the thermal coefficient. The magnitude of error is small for the majority of the variables because of the range and magnitude of their own values.

Therefore, the recommended order for the calibration of the program is

(1) model and coefficients for friction,
(2) model and coefficients for curling,
(3) model and coefficients for concrete properties,
(4) model and coefficients for steel, and
(5) model and coefficients for post-tensioning.

The process of calibration is iterative. Figure 2.2 illustrates the flow process that is followed for the calibration of each model and for the general calibration. The process stops once the values are reasonable for design purposes or when a higher degree of accuracy is not possible with the available data base and resources.

TABLE 2.1. CHARACTER OF DATA

Data	Problems that May Derive From Wrong Values
(a) Tag problem indicator	Wrong solution path
(b) Geometric characteristic of slab	Proportionality/differences
(c) Iteration values of tolerance	Round up errors/truncated number errors
(d) Coefficients of concrete	Rate/range value error/ mis-modeling
-Creep	Range/rate/mis-modeling
-Shrinkage,	Initial range
Subsequent	Range
-Thermal coefficient	Rate/mis-modeling
-Specific weight	Range error
-Poisson's ratio	Cumulative deviation
(e) Concrete strength development	Rate prediction at early ages/range at higher ages
(f) Friction modes	Introduction of error/rate of increment
-Linear	
-Exponential	
-Multilinear	
(g) Steel properties	Same as concrete
(h) k-value for soil	Introduction of error/rate of increment
(i) Set of values for post-tensioning	Initial rate error/diminishing subsequent error
Change in the thermal coefficient of Concrete and soil for wet/dry conditions	Range of fluctuations
Aging in steel and concrete	Errors derived from prestress loss

Errors introduced by calibration procedure

*Difference between measured and representative temperature slab

*Thermal expansion/contraction of measuring devices

CHAPTER 3. ANALYSIS OF THE DATA

This chapter includes a summary of the results of the statistical analysis of the horizontal and vertical data, followed by an analysis of the relationships between vertical displacements and horizontal displacements with temperature.

REVISION HORIZONTAL DATA

The results of the statistical analysis of the horizontal displacement data are given in Table 3.1. The quality of the data and the uniformity in behavior between slabs can be seen in Table 3.1(a); the average scatter for the entire set of data was 0.005 for the 240-foot slabs and 0.006 for the 440-foot slabs.

RELATIONSHIP BETWEEN HORIZONTAL DISPLACEMENT AND TEMPERATURE

Table 3.1(b) shows the values for the relationship between the horizontal displacement and the temperature. Here, the displacement is around 0.005 inch per °F. The Coefficient of Thermal Expansion computed in Research Report 556-2 (Ref 5) was 4.80 x 10^{-5} (°F/inch/inch) for the 240-foot and 440-foot slabs. Additional work on the analysis of the horizontal displacements is made by Mandel et al in Research Report 556-2 (Ref 5).

VERTICAL DATA

For the analysis of the data, the quality and uniformity of the sample were tested. First, a regression analysis was performed. The purpose of this regression analysis was to check whether the data collected from each joint showed the same trend and whether the data from all the joints belonged to the same population. This analysis was performed for the two components of the curl-uncurl cycle of the PCP slabs; the first part takes place generally from sunset to sunrise while the second part (uncurl) corresponds to the period when the sunrays are heating the slab surface. Illustrative graphs of the analysis of curl and uncurl are in Figs E.1 through E.12 of Appendix E. In general, the results of this analysis showed a high uniformity within the sample population, with regression coefficients between 0.85 and 0.95 for the curling portion of the cycle and between 0.95 and 0.99

TABLE 3.1. SUMMARY OF ANALYSIS FOR THE HORIZONTAL MOVEMENTS

(a) Standard Deviation Between Slab Displacements (Average Value)

Slab	Trip Date						
Length	1988				1989		
(ft)	July 25	August 5	August 26	November 5	January 21	January 22	February 9
240	0.013	0.010	0.008	0.002	0.002	0.001	0.001
440	0.008	0.009	0.008	0.007	0.003	0.004	0.003

(b) Displacement in Temperature Ratio (inch/°F)

Slab	Trip Date						
Length	1988				1989		
(ft)	July 25	August 5	August 26	November 5	January 21	January 22	February 9
240	0.0031	0.0050	0.0050	0.0069	0.0058	0.0058	0.0055
440	0.0120	0.009	0.0130	0.0128	0.0136	0.0104	0.0097

(c) Calculated Coefficient of Expansion (°F/inch/inch) 10^{-5}

Slab	Trip Date						
Length	1988				1989		
(ft)	July 25	August 5	August 26	November 5	January 21	January 22	February 9
240	2.59	4.16	4.10	5.75	4.85	4.85	4.62
Average :	4.70	–	–	–	–	–	–
Std Dev:	0.667	–	–	–	–	–	–
440	5.40	5.90	5.80	6.18	4.75	4.75	4.40
Average:	5.40	–	–	–	–	–	–
Std Dev:	0.698	–	–	–	–	–	–

for the uncurling portion of the cycle. This uniformity in the data allowed the use of a representative set of data for the further study of the behavior.

Figures E.1 through E.6 show the characteristic trend of the sample for the part of the cycle when the slab is undergoing curling. For this part of the cycle, the best fit was obtained with second-degree equations for all the joints. Figures E.1 and E.4 show a high degree of correlation and show that all the joints behave in the same manner, with a normal scatter among them. The reasons for this scatter lie in the intrinsic variability of materials, construction, local particularities, etc.

For the part of the cycle where the slab uncurls, the trend showed a linear behavior. The curves and equations for this part of the cycle are shown in Figs E.7 through E.12. Again, there was some slight scatter between the joints, which is reflected in the slight differences in the slopes of the curves, but this scatter was due to the scatter considered as "normal" in statistics for population samples.

Another analysis performed was between the two sizes of slabs monitored. Figures E.1 and E.4 are illustrative of the regression equations for the 240-foot slabs, while Figs E.7 and E.9 depict the characteristic equations for the 440-foot PCP slabs. The general trend showed a slight difference between them for the curling and uncurling portions of the cycle, and the differences were different between seasons; a more detailed analysis is summarized and presented in Table 3.2.

A third comparison was made between the different regression curves for the curling experienced along the slab length. Figures E.1 through E.12 depict an example of these curves for the 240 and 440-foot slab lengths at the edge and of the sixth and third points along the length of the slab. Figures E.1 through E.6 show the curl period and Figs E.7 through E.12 show the uncurl period. This analysis showed that although there was a relationship between them, curling was not proportional between the third, sixth, and edge portions of the slab.

TABLE 3.2. SUMMARY OF ANALYSIS FOR THE VERTICAL MOVEMENTS

(a) Standard Deviation Between Slab Displacements (Average Value)

Slab Length (ft)	Trip Date 1988 July 25	August 5	August 26	November 5	1989 January 21	January 22	February 9
240	0.027	0.006	0.007	0.012	0.008	0.003	0.007
440	0.047	0.013	0.013	0.013	0.018	0.008	0.010

(b) Displacement to Temperature Ratio (inch/°F)

Slab Length (ft)	Trip Date 1988 July 25	August 5	August 26	November 5	1989 January 21	January 22	February 9
240	0.0017	0.0006	0.0061	0.0174	0.0011	0.0011	0.0013
440	0.0036	0.0018	0.0062	0.0078	0.0015	0.0012	0.0016

(c) Ratio Between Displacement and Top-Bottom Temperature Differential (inch/°F)

Slab Length (ft)	Trip Date 1988 July 25	August 5	August 26	November 5	1989 January 21	January 22	February 9
240	0.0064	0.0014	0.0018	0.0023	0.0015	0.0011	0.0021
440	0.0106	0.0033	0.0033	0.0032	0.0033	0.0031	0.0033

(d) Ratio Between Increment in Displacement and Increment in Temperature ($\Delta Y/\Delta T$) (inch/°F)

Slab Length (ft)	Trip Date 1988 July 25	August 5	August 26	November 5	1989 January 21	January 22	February 9
240	0.0055	0.0063	0.0067	0.0039	0.0023	0.0027	0.0027
440	0.0047	0.0060	0.0061	0.0034	0.0018	0.0018	0.0020

Table E.1 shows the regression equations for these sample data. A review of the eccentricities of the regression curves for curling and of the slopes for uncurling reveals the correlations and differences stated above which were typical of each data set. This analysis provided the necessary grounds for the simplification of the data sample for each data set. For this purpose the average value was obtained for each data set for the 240 and 440-foot slabs, as illustrated in Figs E.13 and E.14 for the first set of data. The use of representative data for each data set enabled an in-depth study of the behavior of the slabs and the determination of general trends; a good example is Fig E.15, which depicts the curling at the different lengths of the slab for each set of data. This curling is given with respect to the total curling at the edge of the slab; the right end of this graph shows the average proportional curling measured during the data collection period.

The results of the statistical analysis for the vertical data are shown in Table 3.2. The standard deviation of data between slabs is given in part (a); parts (b), (c), and (d) contain the computed values for the analysis of the different relationships between vertical displacements and temperatures.

The quality of the data and the uniformity in behavior between slabs can be noticed in Table 3.2(a). The exception among these values might be the set of data for the trip made on July 25. The deviation values are 0.027 and 0.047 for the 240-foot slabs and 0.012 for the 440-foot slabs. These values are reasonable if we consider that they are good for data collected in the field; nevertheless the scatter is two times higher than the scatter for the remaining sets of data. The reason for the wider range of values in this first trip was a problem experienced with the small surfaces that served as reaction surfaces for the tips of dial gauges and LVDTs. This problem was corrected on the next trip and never happened again. The average scatter for the remaining sets of data was 0.007 inch for the 240-foot slabs and 0.012 inch for the 440-foot slabs. These values are slightly higher than the values for the standard deviation of the horizontal movements, but it is understandable to obtain higher scatter since more factors affect the vertical displacement of the slabs.

We can state that the overall range of values is excellent for data obtained in the field. Therefore, all the sets of data collected are uniform and are representative of the behavior to be studied.

RELATIONSHIP BETWEEN VERTICAL DISPLACEMENT AND TEMPERATURE

For the final version, the ratio of the maximum increment in curling to that of the temperature in the middle depth of the slab was calculated. The cycle patterns for curling were also studied. The results are in Table 3.2 and in Figs 3.1 and 3.2. It is interesting to note that, although the tabulated values are not constant throughout the sample, they are fairly similar between seasons. Also, it is clear that curling has some relationship to temperature but is more strongly related to temperature differential.

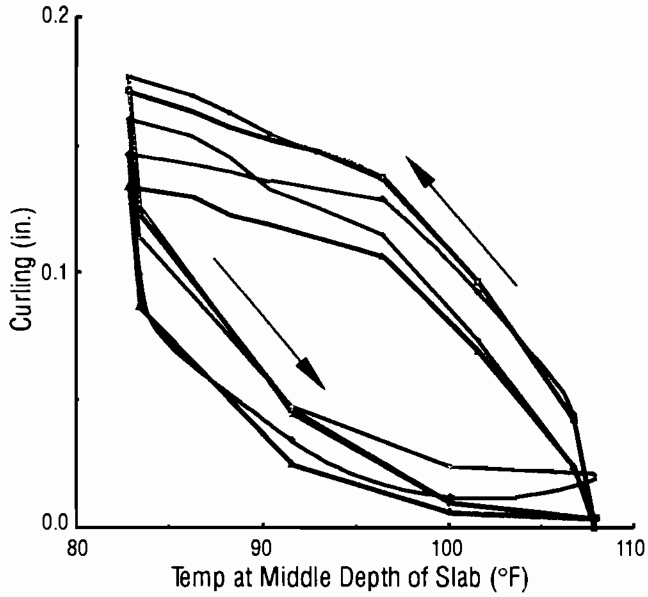


Fig 3.1. Curling versus temperature at middle depth of slab.

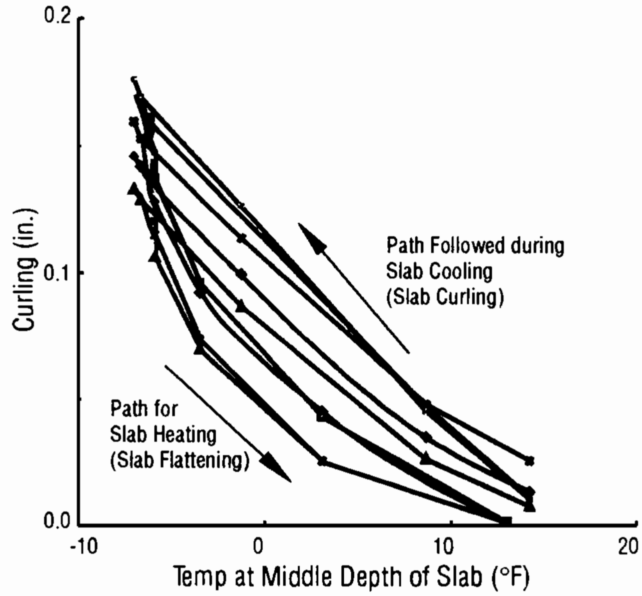


Fig 3.2. Curling versus temperature differential between top and bottom of the slab.

DISPLACEMENT AND TEMPERATURE RATIOS

The relationship between the displacement and the temperature of the slab at middle depth is shown in Table 3.2(b). The relationship between the vertical displacement and the temperature differential between the top and the bottom of the slab is shown in Table 3.2(c). A definite trend could not be detected with these values since the trends are different for the 240 and 440-foot slabs. Table 3.2(d) contains the values of the ratio between the increments of displacement and the increments of temperature. Here, a better correlation was obtained for 240 and 440-foot slabs. However, this correlation holds only for the same season.

CYCLE PATTERNS

The pattern of the temperature-displacement curves was studied for the temperature in the middle of the slab and for the temperature differential that develops between the top and the bottom of the slab. These patterns are depicted in Figs 3.1. and 3.2. The pattern that turned out to be more significant is the one traced by the vertical displacement versus the temperature differential. The general trend of the phenomena can be traced in Fig 3.2. From the figure, the general trend for curling can be ascertained. There is a path for the cooling period of the slab (I) and a path for the heating period (II) in which the flattening of the slab takes place after the curling period. The behavior between the slabs is more uniform for the cooling cycle since the slabs follow very close paths, and more scatter is observed during the heating cycle of the slab.

A conclusion from this analysis was that the curling behavior is more affected by changes in the temperature differential than by changes in the temperature in the middle of the slab. Also, the scatter between slabs is less for the 240-foot slabs than for the 440-foot slabs. Research Report 556-1 (Ref 3) has illustrations of the profiles for each set of vertical data.

RELATIONSHIP BETWEEN HORIZONTAL AND VERTICAL DISPLACEMENTS

The calculated values for the ratios between the horizontal and vertical displacements are shown in Table 3.3(a). A constant ratio could not be established for them. The relationship between the magnitudes of the vertical and the horizontal displacement diminishes with colder weather, and this relationship is higher for the 240-foot slabs. However, the relationship between the ratio of the 240 to the 440-foot slabs remains fairly constant for any weather condition.

TABLE 3.3. RATIO BETWEEN HORIZONTAL AND VERTICAL MOVEMENTS AND SIGNIFICANCE TEST BETWEEN LVDT AND DIAL GAUGE DATA

(a) Ratio between horizontal and vertical displacements

Slab Length (ft)	Trip Date 1988 July 25	1988 August 5	1988 August 26	1988 November 5	1989 January 21	1989 January 22	1989 February 9
240	1.293	1.247	1.183	0.589	0.402	0.493	0.460
440	0.508	0.467	0.478	0.281	0.171	0.201	0.186
240/440	2.58	2.69	2.51	2.10	2.35	2.45	2.47

(b) Results of significance test between LVDT and dial gauge data: t-values

Slab Length (ft)	Trip Date 1988 July 25	1988 August 5	1988 August 26	1988 November 5	1989 January 21	1989 January 22	1989 February 9
240	0.109	0.640	0.079	0.091	0.040	0.093	0.121
440	0.107	0.057	0.043	0.058	0.039	0.031	0.099

(c) Significance (%)

Slab Length (ft)	Trip Date 1988 July 25	1988 August 5	1988 August 26	1988 November 5	1989 January 21	1989 January 22	1989 February 9
240	37.10	< 30	37.20	35.00	35.05	35.00	34.80
440	37.05	37.30	37.35	37.32	35.05	35.30	34.95

VALIDITY OF THE DIAL GAUGE DATA AND LVDT DATA

The comparison between the dial gauge data and LVDT data in the final version was checked statistically. The purpose of this test was to determine whether the data collected with both instruments belonged to the same population. For this test, the LVDT values were compared against the average values of the dial gauge set.

The results of this significance test are shown in Table 3.3(b). The level of significance for the data is between 0.09 and 0.03. The only exception is the 0.6 obtained for August 5, and the source of error came from the LVDT on the 240-foot slab. This LVDT recorded erratic readings throughout the period. The other higher values (0.1 and 0.12) correspond to data for July 25, when some problems occurred with the leveling of the contact surfaces for the instruments, and to data for February 9, when the LVDTs could not be zeroed and registered readings in the boundaries of their linear range. Nevertheless, all the values determined from this check produced a value of significance higher than the 36 percent for a t distribution with 4 degrees of freedom (in the case of edge monitoring) and the 33 percent for 2 degrees of freedom (case of the interior monitoring).

From this test we can draw the following conclusions.

(1) All the data recorded belong to the same population.

(2) The uniformity of the data is excellent, being higher for the dial gauges than for the LVDT.

(3) A set of data composed of the average values for each set of readings can be considered as representative of that set.

The last conclusion is an important one, since it enables us to reduce the number of data values to use from six to one for each slab length. Thus, for the remaining portion of this report, a unique set of values for each set of data will be used. This set is formed by the average value of the dial gauge data and is truly representative of the average slab behavior. These sets of data are shown in Table 3.4.

TABLE 3.4. SUMMARY OF REPRESENTATIVE DATA SETS

(a) For horizontal displacements in 240-foot slabs (inch)

	Trip Date						
	1988				1989		
Hour	July 25	August 5	August 26	November 5	January 21	January 22	February 9
14:00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16:00	-0.0010	0.0086	-0.0036	-0.0027	0.0103	0.0143	0.0163
18:00	-0.0118	0.0076	-0.0176	-0.0397	-0.0153	-0.0087	-0.0007
20:00	-0.0408	-0.0086	-0.0492	-0.0757	-0.0467	-0.0347	-0.0267
22:00	-0.0724	-0.0452	-0.0768	-0.1010	-0.0693	-0.0440	-0.0467
0:00	-0.0986	-0.0686	-0.0948	-0.1203	-0.0860	-0.0560	-0.0633
2:00	-0.1140	-0.0890	-0.1116	-0.1367	-0.1003	-0.0680	-0.0737
4:00	-0.1298	-0.1040	-0.1270	-0.1523	-0.1117	-0.0763	-0.0817
6:00	-0.1212	-0.1178	-0.1424	-0.1617	-0.1200	-0.0833	-0.0887
8:00	-0.0816	-0.1234	-0.1434	-0.1670	-0.1287	-0.0833	-0.0937
10:00	-0.0260	-0.0794	-0.0914	-0.1240	-0.1023	-0.0690	-0.0627
12:00	–	-0.0216	-0.0382	-0.0590	-0.0463	-0.0413	-0.0050
14:00	–	0.0056	-0.0040	-0.0140	0.0010	0.0097	0.0433

(continued)

TABLE 3.4. SUMMARY OF REPRESENTATIVE DATA SETS (CONTINUED)

(b) For vertical displacements in 240-foot slabs (inch)

	Trip Date						
	1988				1989		
Hour	July 25	August 5	August 26	November 5	January 21	January 22	February 9
14:00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16:00	0.0273	0.0028	0.0355	0.0173	0.0052	0.0063	0.0036
18:00	0.1029	0.0207	0.0805	0.0554	0.0267	0.0233	0.0195
20:00	0.1344	0.0888	0.1231	0.0765	0.0370	0.0296	0.0290
22:00	0.1550	0.1237	0.1387	0.0857	0.0410	0.0349	0.0345
0:00	0.1678	0.1334	0.1449	0.0895	0.0449	0.0382	0.0385
2:00	0.1724	0.1358	0.1515	0.0931	0.0463	0.0388	0.0388
4:00	0.1830	0.1376	0.1584	0.0942	0.0476	0.0404	0.0396
6:00	0.1568	0.1470	0.1685	0.0954	0.0482	0.0411	0.0409
8:00	0.0729	0.1269	0.1291	0.0860	0.0475	0.0372	0.0380
10:00	0.0170	0.0545	0.0583	0.0352	0.0239	0.0242	0.0155
12:00	–	0.0201	0.0274	0.0151	0.0075	0.0154	0.0032
14:00	–	0.0095	0.0198	0.0167	0.0036	0.0058	-0.0001

(c) For horizontal displacements in 440-foot slabs (inch)

	Trip Date						
	1988				1989		
Hour	July 25	August 5	August 26	November 5	January 21	January 22	February 9
14:00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16:00	0.0000	0.0388	-0.0020	-0.0050	0.0130	0.0260	0.0273
18:00	-0.1010	0.0346	-0.0630	-0.0660	-0.0245	-0.0093	0.0027
20:00	-0.1773	-0.1228	-0.1406	-0.1383	-0.0870	-0.0553	-0.0477
22:00	-0.2433	-0.1648	-0.1912	-0.1900	-0.1300	-0.0710	-0.0883
0:00	-0.2875	-0.2078	-0.2278	-0.2230	-0.1635	-0.0970	-0.1157
2:00	-0.3100	-0.2484	-0.2594	-0.2493	-0.1890	-0.1140	-0.1357
4:00	-0.3443	-0.2772	-0.2884	-0.2780	-0.2110	-0.1263	-0.1513
6:00	-0.3560	-0.2988	-0.3208	-0.2947	-0.2235	-0.1403	-0.1650
8:00	-0.2628	-0.3026	-0.3178	-0.3027	-0.2365	-0.1417	-0.1717
10:00	-0.1315	-0.2164	-0.2254	-0.2320	-0.1945	-0.1180	-0.1170
12:00	–	-0.0912	-0.1036	-0.1113	-0.0830	-0.0700	-0.0050
14:00	–	0.0284	-0.0122	-0.0290	-0.0025	0.0203	0.0807

(d) For vertical displacements in 440-foot slabs (inch)

	Trip Date						
	1988				1989		
Hour	July 25	August 5	August 26	November 5	January 21	January 22	February 9
14:00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16:00	0.0688	0.0061	0.0347	0.0231	0.0068	0.0069	0.0054
18:00	0.1072	0.0237	0.0841	0.0617	0.0222	0.0220	0.0203
20:00	0.1400	0.1258	0.1231	0.0812	0.0313	0.0256	0.0264
22:00	0.1500	0.1330	0.1324	0.0857	0.0333	0.0261	0.0301
0:00	0.1631	0.1340	0.1368	0.0845	0.0362	0.0288	0.0297
2:00	0.1635	0.1360	0.1418	0.0851	0.0378	0.0293	0.0287
4:00	0.1749	0.1375	0.1476	0.0834	0.0383	0.0295	0.0312
6:00	0.1343	0.1396	0.1535	0.0829	0.0383	0.0283	0.0307
8:00	0.0727	0.1075	0.1058	0.0635	0.0346	0.0254	0.0270
10:00	0.0416	0.0381	0.0379	0.0171	0.0150	0.0159	0.0084
12:00	–	0.0136	0.0117	0.0018	0.0018	0.0083	0.0023
14:00	–	0.0095	0.0089	0.0037	0.0004	0.0041	0.0018

CHAPTER 4. COMPARISON OF PREDICTED AND MEASURED PERFORMANCE

Analysis of the collected data presented in the preceding chapter set up the background for the development of a hypothesis for the calibration and/or the introduction for improving the models in PSCP1. As a preliminary step for the computation of the predicted values by program PSCP1, the input values were calculated and compared to the weighted field values. In all cases the computed values were found acceptable and in agreement with field values for this project.

Part of the PSCP model is devoted to the friction between the PCP and the underlying pavement layer. For friction, Mendoza et al (Ref 1) reported expansion of the slab in the neighborhood of 0.10 inch. The value of friction reported by them for displacement of this magnitude was 0.20. The values recorded here under similar conditions were within the same range. Therefore, a coefficient of friction of 0.2 was used in the input. For the compressive strength of concrete, the mean value of the final strength determined by laboratory testing of the field samples was calculated. All the other input values were taken from field records. The input values are given in Appendix A.

The numbers turned out by program PSCP1 are shown in Table 4.1. Figures 4.1 through 4.6 show the shape of the displacement curves with time for each type of weather for the 240-foot slabs. These figures are also representative of the curve shapes for the 440-foot slabs.

The curves corresponding to the horizontal values are shown in Figs 4.1 through 4.3. They show good agreement between the predicted and the measured behavior. This is especially true for the fall, while slight scatter is present for the hot and the cold weather.

The curves corresponding to the vertical values are shown in Figs 4.4 through 4.6. They show clearly that the computed values do not follow the measured behavior. All the predicted values lie far below the values of the field data.

An initial comparison between the calculated values of program PSCP1 and the field records gave good agreement for the horizontal data. However, this did not hold true for the vertical data.

PROCEDURE FOR CALIBRATION

The calibration of the horizontal and the vertical displacements is made in sequence, because the output of the horizontal values affects the calculation of the values for curling. Hence, the models used in the prediction of the horizontal displacements are reviewed first.

CALIBRATION OF THE HORIZONTAL DISPLACEMENTS

The determination of the degree of correlation is used as an initial tool. It tells us how far is the model from computing representative values. The degree of correlation between predicted and field values for each set of data is shown in Figs 4.7 through 4.9, for representative conditions of hot, cold, and random weather. The field

TABLE 4.1. SUMMARY OF VALUES FROM PROGRAM PSCP1

(a) For horizontal displacements in 240-foot slabs (inch)

	Trip Date						
	1988				1989		
Hour	July 25	August 5	August 26	November 5	January 21	January 22	February 9
14:00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16:00	0.0349	0.0255	-0.0033	-0.0028	0.0111	0.0093	0.0112
18:00	0.0239	0.0093	-0.0377	-0.0321	-0.0184	-0.0207	-0.0249
20:00	-0.0266	-0.0895	-0.0755	-0.0716	-0.0566	-0.0477	2.3669
22:00	-0.0716	-0.1170	-0.1030	-0.1136	-0.0828	-0.0578	-0.0754
0:00	-0.1248	-0.1367	-0.1216	-0.1208	-0.1032	-0.0718	-0.0925
2:00	-0.1403	-0.1501	-0.1370	-0.1420	-0.1189	-0.0826	-0.1047
4:00	-0.1586	-0.1702	-0.1520	-0.1525	-0.1309	-0.0926	-0.1139
6:00	-0.1650	-0.1727	-0.1761	-0.1715	-0.1412	-0.1032	-0.1224
8:00	-0.1179	-0.1287	-0.1752	-0.1710	-0.1505	-0.1031	-0.1253
10:00	-0.0448	-0.0541	-0.1207	-0.1257	-0.1210	-0.0884	-0.0879
12:00	-0.0124	0.0207	-0.0569	-0.0513	-0.0504	-0.0513	-0.0155

(continued)

TABLE 4.1. SUMMARY OF VALUES FROM PROGRAM PSCP1 (CONTINUED)

(b) For vertical displacements in 240-foot slabs (inch)

	Trip Date						
	1988				1989		
Hour	July 25	August 5	August 26	November 5	January 21	January 22	February 9
14:00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16:00	0.0010	0.0010	0.0018	0.0015	0.0011	0.0012	0.0006
18:00	0.0023	0.0040	0.0029	0.0025	0.0028	0.0025	0.0021
20:00	0.0038	0.0043	0.0034	0.0026	0.0031	0.0025	0.0024
22:00	0.0041	0.0042	0.0034	0.0032	0.0031	0.0025	0.0025
0:00	0.0040	0.0041	0.0034	0.0027	0.0031	0.0027	0.0025
2:00	0.0041	0.0040	0.0034	0.0028	0.0031	0.0028	0.0025
4:00	0.0040	0.0040	0.0035	0.0028	0.0031	0.0027	0.0024
6:00	0.0032	0.0032	0.0036	0.0026	0.0031	0.0026	0.0025
8:00	0.0001	0.0015	0.0025	0.0022	0.0028	0.0024	0.0021
10:00	0.0002	0.0000	0.0008	0.0002	0.0010	0.0016	0.0004
12:00	-0.0002	-0.0002	-0.0002	-0.0006	-0.0001	0.0007	-0.0007

(c) For horizontal displacements in 440-foot slabs (inch)

	Trip Date						
	1988				1989		
Hour	July 25	August 5	August 26	November 5	January 21	January 22	February 9
14:00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16:00	0.0672	0.0355	-0.0032	-0.0028	0.0204	0.0170	0.0140
18:00	0.0554	0.0162	-0.0552	-0.0453	-0.0207	-0.0247	-0.0349
20:00	-0.0313	-0.1591	-0.1235	-0.1169	-0.0889	-0.0732	-0.0048
22:00	-0.1119	-0.2116	-0.1732	-0.1917	-0.1365	-0.0910	-0.1254
0:00	-0.2120	-0.2501	-0.2071	-0.2055	-0.1725	-0.1166	-0.1562
2:00	-0.2427	-0.2756	-0.2363	-0.2455	-0.2020	-0.1359	-0.1779
4:00	-0.2774	-0.3146	-0.2650	-0.2658	-0.2252	-0.1531	-0.1941
6:00	-0.2900	-0.3192	-0.3116	-0.3019	-0.2452	-0.1727	-0.2106
8:00	-0.2178	-0.2521	-0.3107	-0.3014	-0.2623	-0.1726	-0.2158
10:00	-0.0946	-0.1185	-0.2248	-0.2319	-0.2213	-0.1557	-0.1611
12:00	-0.0238	-0.0251	-0.1089	-0.0973	-0.0947	-0.0920	-0.0307

(d) For vertical displacements in 440-foot slabs (inch)

	Trip Date						
	1988				1989		
Hour	July 25	August 5	August 26	November 5	January 21	January 22	February 9
14:00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16:00	0.0010	0.0010	0.0018	0.0015	0.0011	0.0012	0.0006
18:00	0.0023	0.0040	0.0029	0.0025	0.0028	0.0025	0.0021
20:00	0.0038	0.0043	0.0034	0.0026	0.0031	0.0025	0.0024
22:00	0.0041	0.0042	0.0034	0.0032	0.0031	0.0025	0.0025
0:00	0.0040	0.0041	0.0034	0.0027	0.0031	0.0027	0.0025
2:00	0.0041	0.0040	0.0034	0.0028	0.0031	0.0028	0.0025
4:00	0.0040	0.0040	0.0035	0.0028	0.0031	0.0027	0.0024
6:00	0.0032	0.0032	0.0036	0.0026	0.0031	0.0026	0.0025
8:00	0.0001	0.0015	0.0025	0.0022	0.0028	0.0024	0.0021
10:00	0.0002	0.0000	0.0008	0.0002	0.0010	0.0016	0.0004
12:00	0.0002	0.0002	0.0002	0.0006	0.0001	0.0007	0.0007

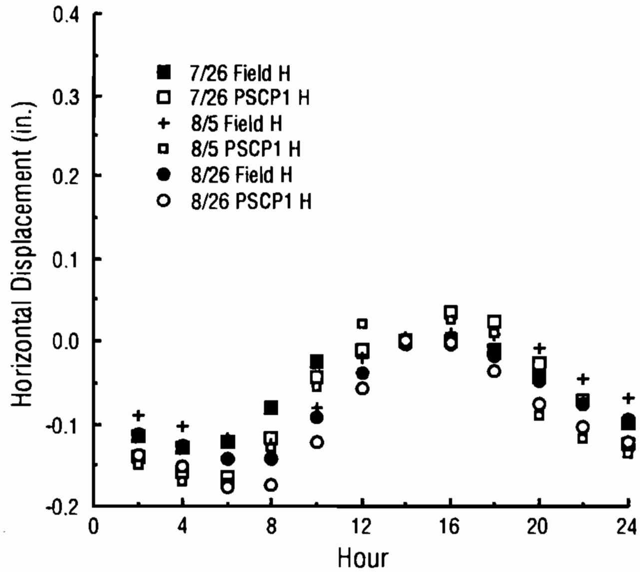


Fig 4.1. Horizontal displacements (measured and computed during the hot season for the 240-foot slabs.

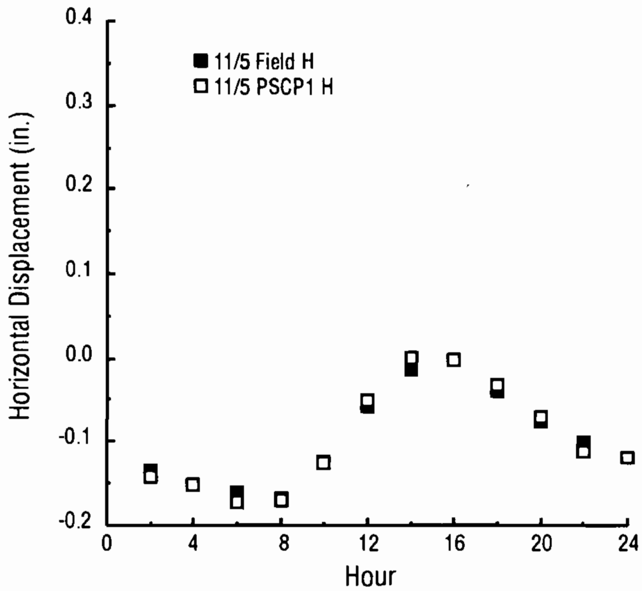


Fig 4.2. Horizonal displacements (measured and computed) during the fall season for the 240-foot slabs.

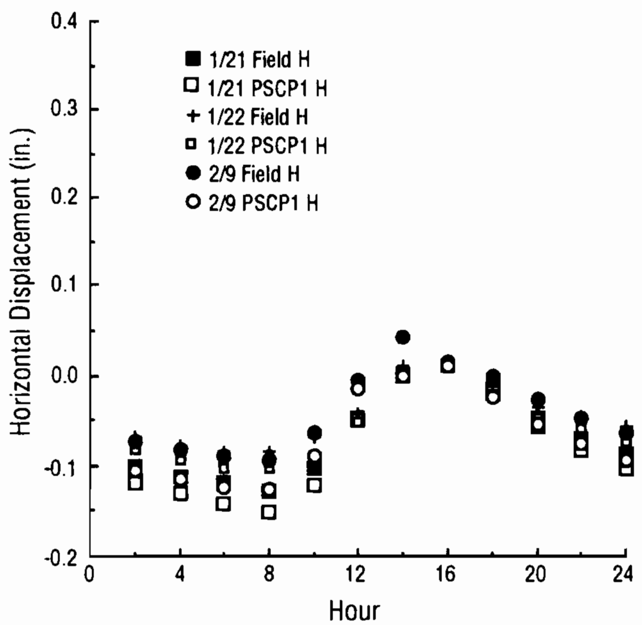


Fig 4.3. Horizontal displacements (measured and computed) during the cold season for 240-foot slabs.

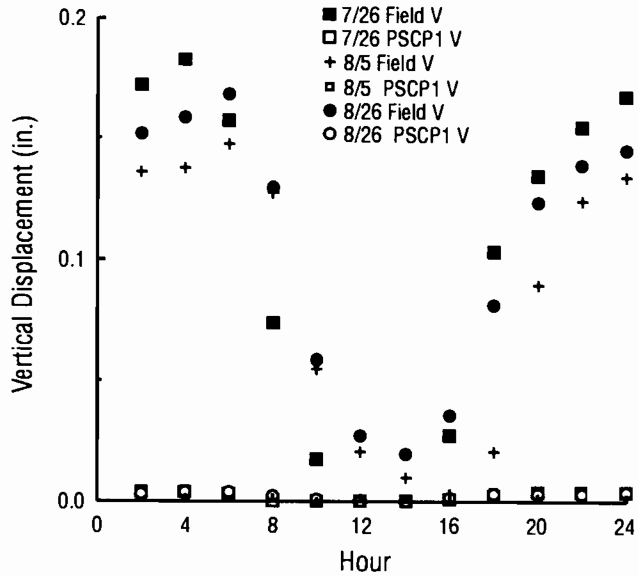


Fig 4.4. Vertical displacements (measured and computed) during the hot season for 240-foot slabs.

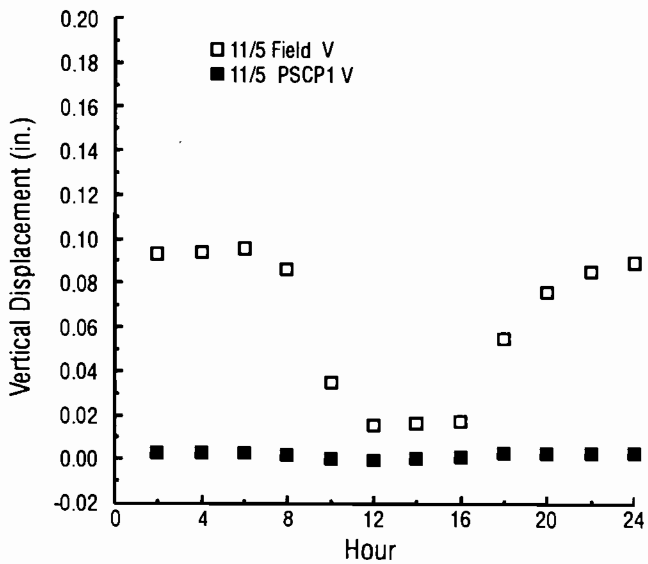


Fig 4.5. Vertical displacements (measured and computed) during the fall season for 240-foot slabs.

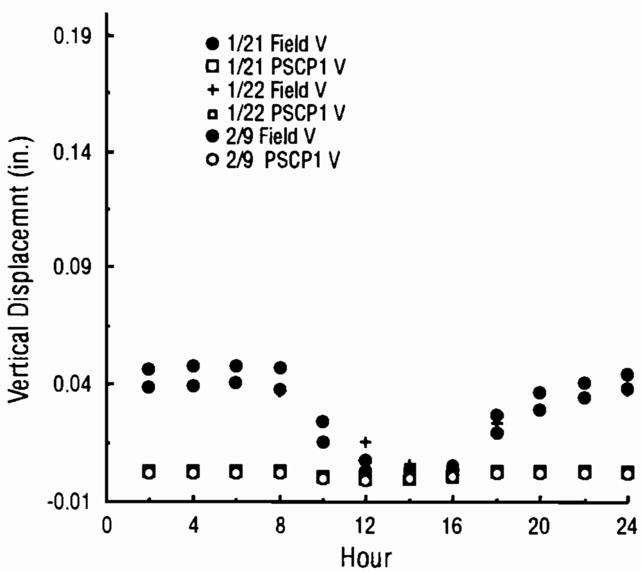
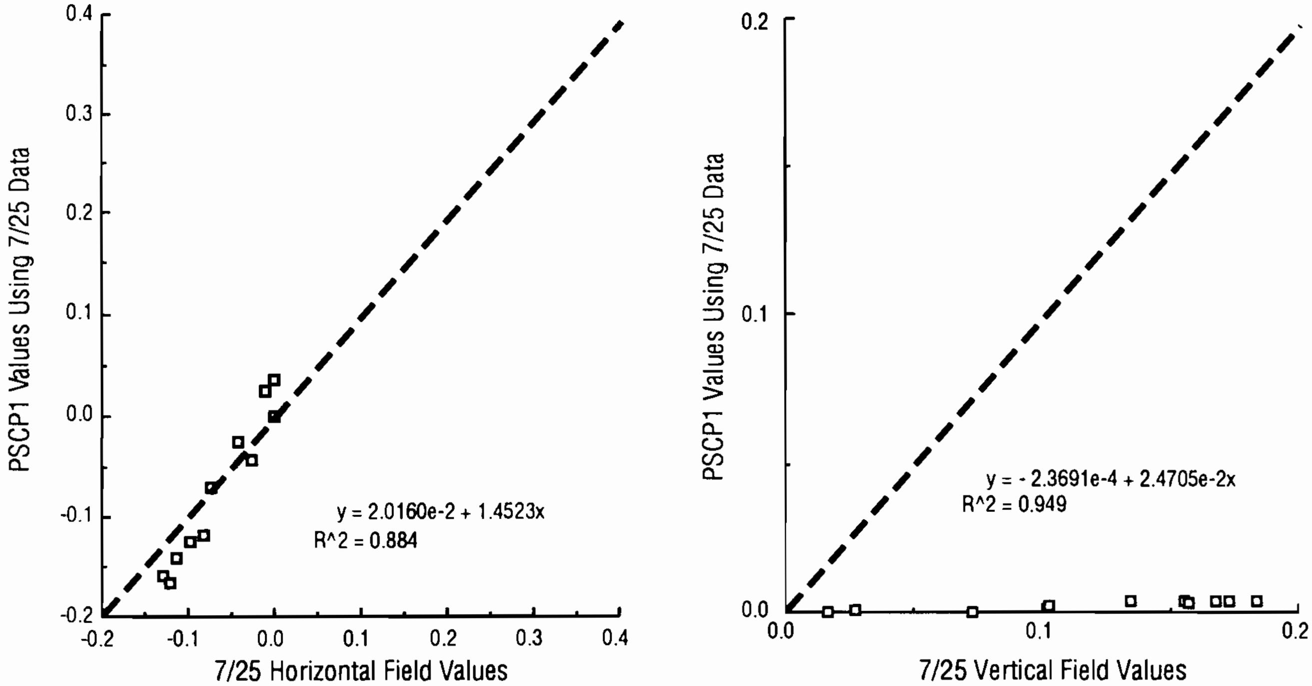
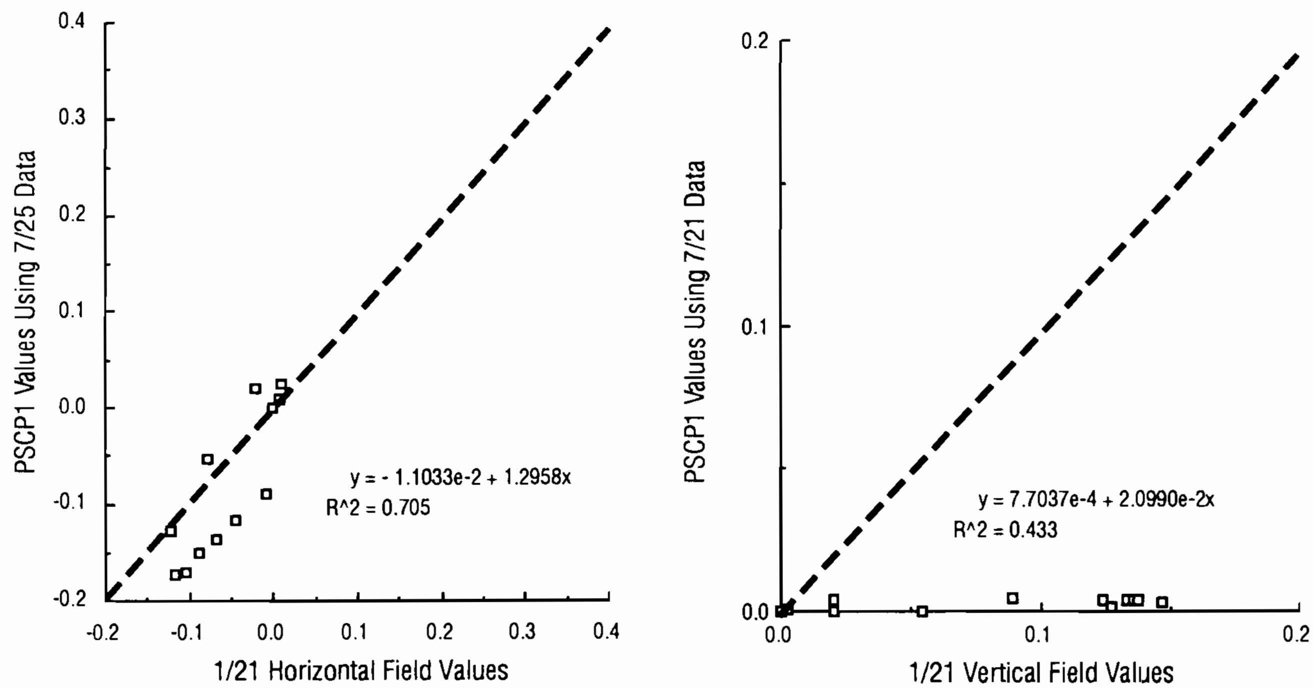


Fig 4.6. Vertical displacements (measured and computed) during the cold season for 240-foot slabs.



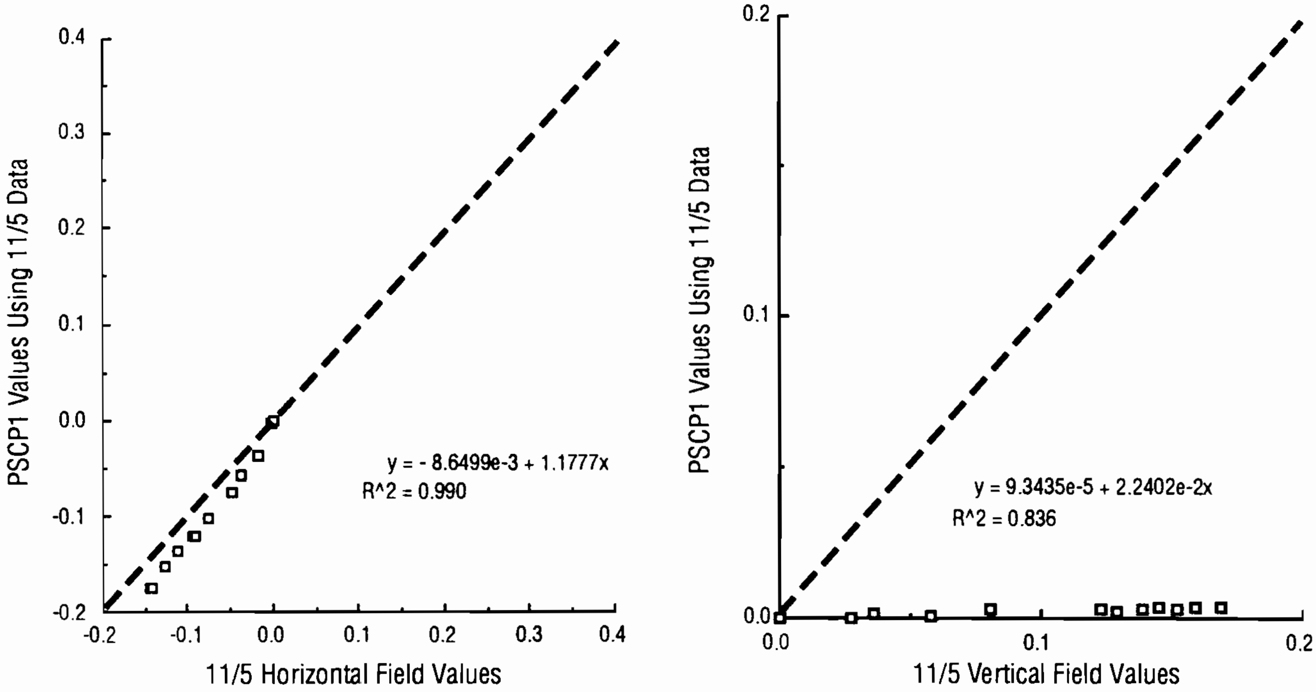
(a) Horizontal displacements. **(b) Vertical displacements.**

Fig 4.7. Degree of correlation between predicted and field data for July 25-26, 1988 (hot weather).



(a) Horizontal displacements. **(b) Vertical displacements.**

Fig 4.8. Degree of correlation between predicted and field data for January 21-22, 1989 (cold weather).



(a) Horizontal displacements. **(b) Vertical displacements.**

Fig 4.9. Degree of correlation between predicted and field data for November 5, 1988 (data set chosen at random).

values are shown on the horizontal axis, and the vertical axis corresponds to the predicted values. For a perfect correlation, the predicted and field values should be identical. In these cases, the plot lies on an imaginary straight line with a slope of 45 degrees. When the values are overpredicted the points fall above this imaginary line; they fall below this line if the values are underpredicted. The regression coefficient indicates the degree of dispersion and agreement of the model. Figures 4.7 through 4.9 show the correlation for the horizontal displacement, and part (b) of eachshows the values for the vertical displacement.

The predicted horizontal displacements are in close agreement with the measured values. The coefficients of partial determination in parts (a) of Figs 4.7 through 4.9 show that the correlation values for program PSCP1 range between 0.99 and 0.87 for the horizontal movement. This range of values is proof of a high level of reliability in the model, and the value of the coefficient of friction agrees with the one proposed in Research Project 401 (Ref 1). In this case, it is reasonable to assume that the model accurately predicts the displacements and no further calibration is necessary.

The only area in which better calibration would be possible is a higher precision in the determination of the value of the coefficient of friction. However, this should be considered with caution, since the output of the program is highly sensitive to the value of the coefficient of friction and the friction coefficient itself is affected by different factors, such as humidity, wear, etc.

HYPOTHESIS FOR THE CALIBRATION PROCEDURE FOR THE VERTICAL DISPLACEMENTS

For the vertical displacements, PSCP1 underpredicts the behavior. A comparison between the values of Table 3.3(b) and (d) and those of Table 4.1(a) and (d), shows that all the predicted values are far below the field values. These comparisons are confirmed by the general appearance of Figs 4.4 through 4.6 and parts (b) of Figs 4.7 through 4.9. A misleading factor is the high values reported for the coefficients of partial determination in parts (b) of Figs 4.7 through 4.9, and these values should not be considered.

The lack of accuracy of the models for curling in PSCP1 demand a more in-depth review of the model . The models should be compared and the values contrasted to the patterns determined in the analysis of the field data. The cause of disagreement between the values should be ascertained and the determination of a more adequate model carried out.

CRITICAL REVIEW OF MODELS

WESTERGAARD MODEL

The model suggested by Westergaard is used in PSCP1 for the prediction of displacements due to curling. Its main equations for displacements are

$$Y = Y_e\sqrt{2} \cdot \cos\left(\frac{\frac{L}{2} - X}{1 \cdot \sqrt{2}} + \frac{\pi}{4}\right) e^{-\left(\frac{\frac{L}{2} - X}{1\sqrt{2}}\right)} \quad (4.1)$$

$$Ye = \frac{(1+n)\sum \alpha \sum \Delta TD \sum l^2}{h} \quad (4.2)$$

$$I = \sqrt[4]{\frac{E_c h^3}{12(1 - \nu^2) k}} \quad (4.3)$$

where

- Ye = deflection at the edge,
- L = slab length,
- a = concrete thermal coefficient of contraction and expansion,
- TD = temperature differential between top and bottom,
- k = k-value of soil,
- n = Poisson's ratio of concrete,
- M_x = bending moment in x direction per unit width,
- h = thickness of slab, and
- E_c = modulus of elasticity of concrete.

An inspection of the model reveals that it is not sensitive to the following factors:

(1) The function is cyclical. That is, the values are repetitive and they always vary in the same fashion. Another consideration is that, within the effective range of the model, the displacements between slabs of different dimension in proportion with the dimensions of the slabs. A further consideration is that the predicted values are always larger for larger slabs.

(2) Equations 4.1 and 4.2 are not sensitive to the geometry of the slab. That is, the equations do not consider the relationship between length, width, and slab thickness. Therefore, the slab will have the same displacements notwithstanding how wide it is. An implication is that, according to this model, there is only a certain width of the slab that experiences curling and the remaining portion of the slab width is not affected and does not affects the values for curling.

(3) Relative ranges of temperature should be included. That is, the effect of term DT is the same whether or not the range of temperatures happens during hot and dry weather or in cold or wet weather. Another consideration is that it does not consider the effect with respect to the temperature at the casting of the slab.

(4) The coefficient produced on this model provide very low values only. Thus, the range of predicted values is always restricted to a narrow band.

These assertions can be checked numerically by inputting values in the functions and using the values obtained from program PSCP1 for curling. When we relate this model to the observed behavior, we note the mismatch of the model. A summary of the data records for the field visits is given in Table 4.2, a quick analysis of which reveals the following observed behavior trends:

(1) The displacements are not in relative proportion to the slab length. As a matter of fact, curling was higher for the 240 foot slabs than for the 440 foot slabs.

(2) The geometry of the slab has an effect on the displacement values. This is a natural consequence of the observation stated above.

(3) There is a non-linear effect on vertical displacement when the temperature is incremented. Displacement will not increase proportionally to the increment of temperature. Apparently there is a combined effect. That is, the effect of the increment is relative to the values of the maximum and minimum temperatures themselves. Table 4.2 shows that the differences between the increments of temperature for each trip varied within 10°F. However, the measured displacements were quite different, and these displacements were related to the relative values between temperatures, e.g., displacements were higher for temperatures around 106°F (July 25) than for 63°F (February 9) despite the fact that the temperature increment was higher for the latter (32°F versus 30°F).

We can conclude then that Westergaard's model is not appropriate for the prediction of curling in PCP slabs. Also, since the nature of the model is not conducive to revision, a different model is required.

OTHER MODELS

The available literature was reviewed and few models are available for the prediction of displacements due to temperature in concrete slabs. Westergaard's model is the most accepted. Other models for rigid plates from the structural field were tried to see if a combination of them with the Westergaard model could help describe the objective function. The majority of the models contained some empirical relationships and not one of them could describe the phenomena. Other equations tried, were those from elastic foundations. They proved to be similar in behavior to Westergaard's model. Therefore, the need for the development of a new model arose.

HYPOTHESIS FOR THE NEW MODEL

The problem with available models is the lack of fidelity with actual events which occur in the field. The model to be developed should consider and reflect actual data.

The hypothesis then is based on a model reflecting the concepts expressed in Chapter 2. That is, we will consider the slab as the interface of the exchange of temperature between two sources: the sun and the soil. From here we will develop the effect that temperature has on the material and the interaction of the other factors. A description of the general phenomena was described at the beginning of Chapter 2, and the modeling for this phenomena is carried out in the next chapter.

The planning and work developed for the collection of data resulted in very acceptable sets of data for the project. Analysis of these data sets revealed that values predicted for horizontal displacements in program PSCP1 are reasonable. The opposite is true with the predicted vertical values, which are out of range. Further analysis revealed the necessity to develop a new model for the prediction of displacements due to curling.

Due to the importance of this model, its development is presented in a separate chapter before the model is introduced it into the general body of computer program PSCP2, in Chapter 6. Thus, the next chapter is devoted to the development and testing of the new model for curling.

CHAPTER 5. DEVELOPMENT OF A MODEL FOR THE EFFECT OF TEMPERATURE GRADIENTS IN SLAB PAVEMENTS BEHAVIOR

The change of temperature in the environment develops a temperature gradient in the slab in conjunction with the thermal characteristics of the slab components. This gradient produces differences between the displacements that take place on the top and the bottom of the slab. The result is a relative contraction or expansion of one surface with respect to the other, that is, contraction displacements in one surface and expansion in the opposite surface of the slab. The interaction of the forces produces curling.

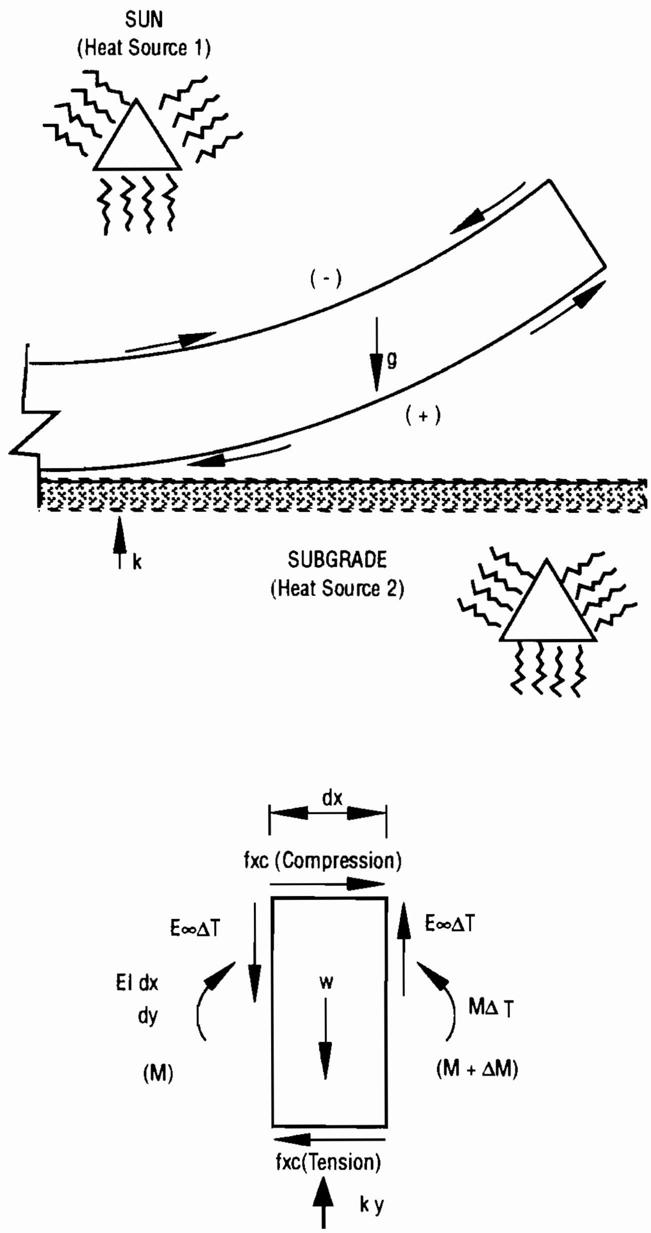
In this chapter, the necessary frame for the theoretical and mathematical work is developed to achieve the model and its objectives, and the model is tested against the collected data from the field.

GENERAL MODEL

Figures 5.1(a) and (b) contain the general representation of the model. Highway structures expose large surfaces to the environment. The structure is subjected to temperature variations and solar radiation by absorbing heat energy from the sun. Soils are, likewise, subjected to sun rays and temperature exchange. In this way, a system for heat exchange is formed. The active source of energy is the sun, and a second (passive) source is the soil. The soil acts as a "thermic battery" and the pavement constitutes the interface for the exchange of heat with the environment. A general statement could be that radiation absorption causes the expansion of materials. Similarly, the transfer of this heat to the environment has the opposite effect. Since temperature changes follow a cyclic pattern, pavement slabs are subjected to daily and seasonal variations. Generally, the principles of thermodynamics apply to the rate of heat exchange. The general state of the forces is shown in the free-body diagram in Fig 5.1(b). The symbols used are defined in the symbols list at the beginning of this report.

From Fig 5.1, we can see that three factors (temperature, friction, and stored energy) produce strains and stresses. These three factors affect PCP in the following manner:

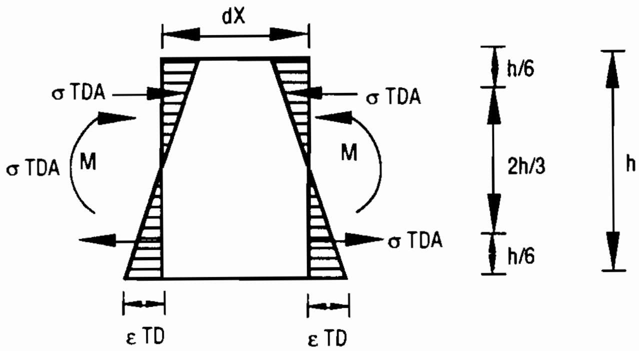
Temperature. Environment can be characterized in terms of moisture and temperature. Moisture and temperature in turn are affected by the daily and seasonal cycles of our planet. The daily temperature variations in the pavement are determined by heat gained and lost, plus other climatic conditions. The number of hours and the intensity of sunrays determine the seasons and the peaks in temperature for each season. All these factors



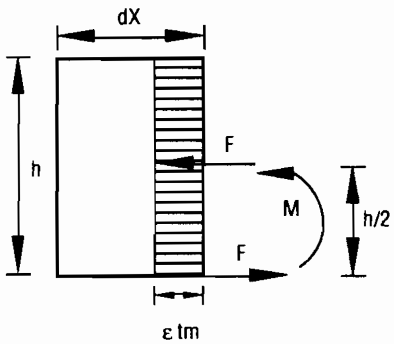
(a) Top: Free body diagrams for the slab representation.

(b) Bottom: Free body diagram of forces.

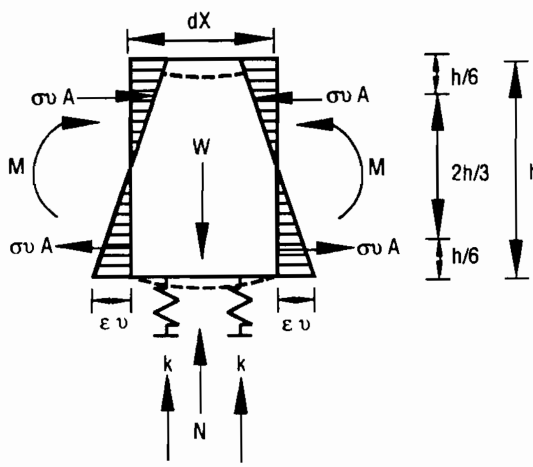
Fig 5.1. Schematic representation for warping and curling.



(c) Free body diagram for temperature gradient.



(d) Free body diagram for volumetric thermal change and friction.



(e) Free body diagram for stored deformation energy and dead weight.

Fig 5.1. Schematic representation for warping and curling (continued).

produce a new set of conditions for pavements in a repetitive fashion. This cyclical behavior produces periods of expansion and contraction under different service periods of the structure. In terms of conditions that affect the pavement structure we know that: (a) expansion happens during the hours of major traffic volume and (b) contraction takes place at night, with a lesser volume of vehicles. Then, temperature, as a parameter of environment, affects the behavior of pavement.

Friction. Variations in moisture and temperature cause minute volume changes in the pavement. However, this expansion and contraction are different from there that might occur in the subbase. Therefore, movement develops, with friction occurring between slab and subbase. The nature of the friction force is not completely known; however, it is assumed to be produced by two factors: (1) molecular attraction and the nature of the surfaces in contact and (2) irregularities between the surfaces in contact.

For PCP, the development of friction has a beneficial and detrimental effect. The type of effect depends on the direction of movement in relation to the prestressing as the friction develops. A detrimental effect results during the contraction of the slab. Friction introduces tensile stresses on the bottom of the slab. A beneficial effect is produced by the expansion of the slab, because of the compressive stresses that develop, also due to friction at the slab/subbase interface.

The movements normally vary from a maximum at the edge to the smallest at the center of the slab. Therefore, the maximum friction forces develop at the ends and decrease toward the center. Concrete stresses resulting from the accumulation of friction forces grow from zero at the end to a maximum at the center. Characteristically, in a daily cycle, two movement and friction resistance reversals happen. The reversals occur within a few degrees of the maximum or the minimum slab temperatures.

The magnitude of the friction restraint stresses depends primarily on three factors: (1) the concrete coefficients of contraction and expansion, (2) the concrete modulus of elasticity, and, (3) the friction force versus movement relationship. The tensile stresses are the most important since they result in unfavorable conditions for the PCP.

Stored Energy. An increasing amount of deformation energy is stored in the slab with time. This energy is considered to be stored because it is within the elastic range of deformation of the slab and the strains induced are susceptible to being released in certain conditions.

A more extensive summary of the effect of factors affecting the performance of PCP is presented in Research Report 556-4F (Ref 4).

GOVERNING FACTORS AND ASSUMPTIONS OF THE MODEL

In this section, the scheme and theory framework for the development of the model is introduced. An outline of the principal considerations, assumptions, and conventions for the development of the model is presented.

GOVERNING FACTORS AND MODEL OUTLINE

Different forces act while curling is produced. These actions affect curling. Then, the main forces that contribute to the development of curling must be considered. For the present research, curling is considered to be governed by the following factors:

(1) Stresses that are the product of the temperature gradient developed between opposite faces of the slab.
(2) Stresses that are the product of friction between the subbase and the slab produced by the thermic contraction of the slab.
(3) Stored deformation energy of the slab.
(4) Structural stiffness of the element.

Since we are mainly dealing with forces, the additive and associative properties of forces apply. Then, each component can be determined separately and their effect can be added at the end of the process.

ASSUMPTIONS OF THE MODEL

These assumptions for this model:

(1) The vertical reaction to any section is directly proportional to the deflection, Yk. The proportionality constant k being the modulus of subgrade reaction.
(2) Zero deflection is at the position of rest on the level subgrade from the initial deflection.
(3) Concrete is a homogeneous, linearly elastic material.
(4) Temperature or moisture differentials from top to bottom producing upward deflections are negative.
(5) Upward deflections are positive.
(6) Tensile stresses are positive.
(7) The origin of the coordinates of movement is taken at the midslab.
(8) In general, the principles of elasticity, friction, and energy apply to the model.

DEVELOPMENT OF THE MODEL

The different steps in the development of the model are discussed herein. They are

(1) solution of the model for the prediction of curling at the slab edges,
(2) generalization of the model for prediction of curling along the slab,
(3) solution for the transition during gradient reversal, and
(4) solution for the computation of stresses.

For clarity, expressions from the general theory are designated using a letter as extension, while the particular expressions developed for the model are numbered in the extension.

GENERAL STATE OF FORCES

The general state of forces in the body during curling was analyzed for each one of the governing factors. Figure 5.1(b) can be considered as a departing point for this development. Figure 5.1(c, d, and e) are diagrams representing the effects of temperature, friction, and stored energy in a slab element.

Development of Equations

From Fig 5.1, we can see that three factors (temperature, friction, and stored energy) produce strains and stresses.

Temperature. The strains and stresses produced by temperature, friction, and stored energy translate into bending moments acting on the slab. The basic equation for stress from the elastic theory can be employed for the analysis of these bending moments, that is;

$$s = E e \tag{5.1}$$

where

σ = stress in the material,
E = modulus of elasticity of the material, and
ε = strain of the material.

and for thermal changes, strains can be expressed as

$$\varepsilon = \alpha \Delta T \tag{5.2}$$

where

a = thermal coefficient of the material and
ΔT = increment in temperature.

For the determination of the expressions for the bending moments, a differential element of one section was studied and the necessary relations and algebra worked out. Finally, the effect along the slab width was considered. The developed equations for each factor are presented below.

Temperature Gradient. Assuming the temperature is DT_D degrees higher at the top of the pavement than at the bottom, the strain produced will be a product of the gradual work performed by the effective temperature increment. The state of strains, stresses, and forces produced is depicted in Fig 5.1(c). Then, the equation for stress for an effective increment of temperature gradient $DT_{D'}$ is

$$\sigma_{TD} = \frac{Ec\, \alpha\, \Delta T_{D'}}{2} \tag{5.3}$$

where

α = concrete thermal coefficient of contraction and expansion, and

E_c = concrete modulus of elasticity, psi.

$\Delta T_{D'}$ = effective increment of temperature, or

$$\int_0^n \Delta T_D \quad (5.4)$$

From the energy theory and from the concepts expressed before, we know that this function is continuous and that a continuous record of calorific energy would be necessary for the accurate determination of the work done. The input of such set of data would be impractical and uneconomical. Therefore a discrete equation is sought. From the work equations, we know that a good approximation for discrete increments is achieved using the average value of the discrete increments. Then, the adopted equation is

$$\Delta T_{D'} = \frac{1}{2n} \sum_0^n \Delta T_{Di} \quad (5.5)$$

The bending moment M_{TD} produced by this force is constant throughout the slab. If now we consider the slab width in the integrated expression along the slab profile we have

$$M_{TM} = \frac{Ec\, \alpha\ B\, D^2\, \Delta T_{D'}}{12} \quad (5.6)$$

where

B = width of slab, in., and

D = slab thickness, in.

Volumetric Thermal Change and Friction. The strains induced in a slab element are shown in Fig 5.1(d), assuming a thermal decrement ΔT_M. Here, the equation of stresses induced by the slab contraction has the form of Eq 5.3, but, for the term $\Delta T_{D'}$, which is replaced by $DT_{M'}$, that represents the increment in temperature with reference to the original casting temperature. Then, a virtual moment is produced by a contracting force and a friction force, where the friction force is of the same magnitude but opposite in direction to the contracting force. The equation for the constant bending moment M_{TM} produced by slab contraction and friction is

$$M_{TM} = \frac{Ec\, \alpha\ D^2\, \Delta T_{M'}}{4} \quad (5.7)$$

where

$$\Delta T_{M'} = \Delta T_{Mi}\,(T_{Mi}/T_{Mo}) \quad (5.8)$$

and

ΔT_{Mi} = increment of temperature at time i, °F,

T_{Mi} = temperature at middle depth of slab, °F, and

T_{Mo} = temperature of slab at initial curing, °F, and all other terms are as defined above.

Stored Deformation Energy and Dead Weight. Assuming that the slab deflects gradually when subjected to its dead weight, an increasing amount of deformation energy is stored in the slab with time. The effect of this deformation in the slab element is depicted in Fig 5.1(e). This energy is considered to be stored because it is within the elastic range of deformation of the slab and the strains induced are susceptible to be released if the conditions are given. This energy is proportional to the amount of strain e_U induced in the slab as it deforms. Then, the strain produced is related to the deflection of the slab, that is

$$\varepsilon_U = f(Yw)$$

where

$$Yw = \frac{\omega L^2}{k} \quad (5.9)$$

where

ε_U = strain due to stored deformation energy;

Yw = slab deflection after period T, inch;

ω = uniform distributed weight of concrete, lb/inch;

L = total length of the slab, inch; and

k = relative value of soil support (k-value), psi/inch.

Deflection Y can be related to the strain e_U produced by means of the Poisson's modulus. As stated, the stored strain affects the development of ongoing temporal strains in the slab since it is already stored in the slab. Therefore, it must be accounted for in the development of stresses. The final relation for a uniformly distributed load is

$$\varepsilon_U = \frac{\nu\, \omega\, L^3}{15\, Ec^2\, k} \quad (5.10)$$

where

ν = Poisson's ratio for concrete and all the other terms are as defined above.

SOLUTION OF THE MODEL

In the first part of this section, the particular solution for the model at the edge is determined separately, affecting it by a parameter representative of the function for intermediate points along the slab. In this way the handling of the integration operations is clearer. Once the initial particular expression is produced, the generalization of the model is achieved by the introduction of the parameter developed for the intermediate points along the slab. For clarity, the presentation of the development of the solutions follows the same order.

Since the development of the model is based on an established temperature gradient is acting on the slab, the model does not hold for a transition period when the temperature gradient experiences a reversal. In this portion of the cycle, the slab experiences a recovery of its former shape. For a better description of the entire cycle it is necessary to introduce a model describing this recovery period.

In the last part of the section, the solution for the computation of the stresses induced by curling is introduced.

Solution for the Slab Edge Vertical Displacements. A relation developed from the elastic theory is used for the determination of the displacements due to curling. From the theory of elasticity, we know that the second derivative of Y with respect to X is equal to the bending moment divided by the product of the modulus of elasticity times the moment of inertia of the element. Then, the following relation is established:

$$E\,I\,\frac{d^2y}{dx^2} = M \qquad (5.11)$$

the expression for slabs is

$$E\,I_D\,\frac{d^2y}{dx^2} = M \qquad (5.12)$$

where

$$I_D = \frac{E\,h^3}{12\,(1 - v^2)} \qquad (5.13)$$

and all others are as defined above.

In Eq 5.12, the moment of inertia I is replaced by the flexural rigidity of the slab D, which differs from the rigidity of the conventional beam by the factor $1/(1 - v^2)$.

The determination of Y implies the double integration of the function in Eq 5.12, that is,

$$Y = \frac{1}{E\,I_D} \int \int_0^n M\,dx^2 \qquad (5.14)$$

From the preceding section we got the expressions for the moments due to temperature and friction. Then, the total displacement for curling "Y" will be equal to the sum of both moments, that is:

$$Y = \frac{1}{E\,c\,I_D} \int \int_0^L (M_{TD} = M_{TM})\,dx^2 \qquad (5.9)$$

Now, we can consider that the displacements are symmetric for each half of the slab. Then, if we substitute M_{TD} and M_{TM} for their expressions in Eqs 5.4 and 5.5, and if we perform the integration from the center of the slab to the edge, the final result is

$$Y = \frac{1}{2}\left[\frac{\left(\Delta T_{D'}\,\alpha + \frac{v\,\omega\,L^3}{15\,Ec^2\,k}\right) x^2\,\phi\,(B/L)^2\,(1 - v^2)}{D} + \frac{\left(\Delta T_{M'}\,\alpha + \frac{v\,\omega\,L^3}{15\,Ec^2\,k}\right) x^2\,\phi\,(B/L)^2\,(1 - v^2)}{D^2}\right] \qquad (5.15)$$

where all the variables have already been defined, except f, which is a parameter representing a restricting factor affecting the level of displacements along the slab. For slab edges the value of this parameter is equal to unity.

Equation 5.16 is the function that describes the behavior of the corner of a the PCP slab as it curls due to temperature differentials.

As we can see, the model considers

(1) the relative effect of temperatures,
(2) friction,
(3) slab geometry and
(4) the value of the soil support.

Now the next step is the determination of the expression for intermediate points and their stresses. They are discussed below.

Solution for Vertical Displacement of Intermediate Points Along the Slab. The magnitudes of the curling displacements at different points of the slab length are a function of the increasing stiffness of the slab as it approaches the center. For the determination of the curling displacements along the slab, a regression analysis using the collected data was performed. From this analysis, the function determined for the model has the form

$$\phi = \frac{1}{3}\left[\frac{7x}{L} + \frac{7L}{x-1}\right] - 11 \quad (5.17)$$

Then, Eqs 5.16 and 5.17 constitute the generalization for the prediction of curling displacements in slabs.

Solution for the Transition of Temperature Gradient Reversal. A little after sunrise, when sunrays start heating the pavement again, the top of the pavement becomes hotter than the bottom. This heat produces a short transition and a reversal of the temperature gradient, and consequently the direction of the forces become opposite to the direction shown in Fig 5.1. It is during the transition moment when the slab flattens again. In fact, the slab is recovering its horizontal shape before undergoing the opposite part of the cycle, in which the slab stores strains and stresses.

From Figs 4.8 and 4.9, we learned that the path described by the slab is different from the cooling path. The heating path is steeper in relation to the cooling (or curling) path. The reasons for this influence is that the slab is helped by its own weight, its stiffness, and, in general, the release of energy stored during curling.

An in-depth analysis of this transition path is of no use since the values of interest for design are those of maximum curling and stresses caused by curling. In addition, the complexity of the data required for the study of this transition is beyond the scope of this research. However, for a better description of the slab behavior from cycle to cycle, this transition of temperature gradient reversal was studied. Regression analysis techniques were used to develop a parametric equation for this model. The final model for the transition of temperature gradient reversal is

$$Y = (\varphi - \Delta T_{Di})\left[\frac{Yc_{max}}{|\Delta T_{Dtmax}| + |\Delta T_{Dcmax}|}\right] \quad (5.18)$$

where

φ = parameter in function of the history of intensity of the heat radiation and the thermal effective coefficient of the pavement – for the present research, the values ranged between 18.5 for hot weather, and 13 and 10 for cold weather;

ΔT_{Di} = as defined before;

Yc_{max} = maximum curl experienced by the slab before the transition, inch;

ΔT_{Dtmax} = maximum positive temperature differential produced during the transition, °F; and

ΔT_{Dtmax} = maximum negative temperature differential produced during the curling cycle, °F.

Solution for the Computation of Stresses. As mentioned earlier, materials dissipate energy by means of deformations. Thus, when a slab is curling, it is dissipating energy and, in consequence, the stresses to which it is being subjected. The opposite happens when the material deformation is restricted. The restriction causes the material to start building up stresses. In this case, stresses due to a temperature differential build up in those portions of the slab that are restricted to deformation or curl. Therefore, the level of stresses is maximum where the stresses are fully restricted. For slabs, the full restriction occurs at the centerline of the slab.

Once the displacements have been modeled, we can see that curling is fully restricted at the centerline of the slab. From there, stresses decrease gradually and reach a value of zero at the slab edge. The location of this point is a function of the friction, stored energy, particularities of the slab, construction, etc. From the engineering point of view, the maximum stress is of interest for design of the slab. This is because no further economy is achieved in practical terms since slabs are designed with a constant thickness and the specifications of steel reinforcement from design is mainly uniform for the entire slab.

From the work developed above, a relationship can be stated for the determination of stresses based on the relationship of Eqs 5.11 and 5.12. This expressions covers only the effect of curling, since the effects of temperature with friction are covered in the model for determination of stresses due to slab friction. Then, the expression for the stresses produced by the temperature differential has the form

$$\sigma = Ec\left[\Delta T_{D'}\,\alpha + \frac{\nu\,\omega\,L^3}{15\,Ec^2\,k}\right] \quad (5.19)$$

A conservative and more practical value for the determination of the maximum stresses of the slab is given by the relationship

$$\sigma = Ec\,(\Delta T_{D'}\,\alpha) \quad (5.20)$$

This value is constant at the slab centerline and it is added to the stresses due to friction along the slab.

TESTING OF THE MODEL

The validation of the model is made comparing the predicted values of the model just developed with the actual collected data.

The values for the horizontal displacements were employed as input for the model for curling for the validation. In this way, the error of the predicted data was restricted to only the error of the model itself and the implicit error of the collected data. The predicted values are in Tables 5.1 to 5.3. Table 5.1 contains the values for the predicted vertical displacements at the edge, the results for curling at the one-sixth point from the slab corner are in Table 5.2, and the values for the predicted vertical displacements at the one-sixth point from the center of the slab (one-third point from the corner of the slab) are in Table 5.3. Then, the predicted values were compared with Table 4.15, which has the summary of the representative values from the data collected in the field, and with Tables 4.7 to 4.10 for comparison with intermediate data points.

Figures 5.2 to 5.9 depict the degree of correlation between the field and the predicted data for the data sets collected on July 25, November 5, and January 22. These data are representative of hot, random, and cold weather. The correlation obtained is good. The values ranged between 0.86 and 0.98. A look at the figures reveals that the degree of dispersion is higher for the initial readings of each set of data and the correlation points approach the forty-five degree line as the amount of data accumulates. This behavior is expected since the model uses a discrete approximation function for temperature. Therefore, the model yields reasonable predictions for use in design.

With the satisfactory testing of this model, the process for the development of a new model, required for the more accurate estimation of curling values in PCP slabs, has been achieved. The necessary assumptions were presented and the solutions for the model were worked out. In the following chapter, program PSCP2, the upgraded version of PSCP1, is introduced along with a summary of the principal factors and concepts involved in the calibration.

TABLE 5.1. SUMMARY OF PREDICTED VALUES FROM NEW MODEL FOR CURLING

(a) For vertical displacements at the corner of a 240-foot slab (inch)

	Trip Date						
	1988				1989		
Hour	July 25	August 5	August 26	November 5	January 21	January 22	February 9
14:00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16:00	0.0147	0.0284	0.0068	0.0034	0.0030	0.0031	0.0052
18:00	0.0791	0.0095	0.0530	0.0347	0.0158	0.0158	0.0089
20:00	0.1210	0.0490	0.0926	0.0567	0.0293	0.0257	0.0206
22:00	0.1466	0.0937	0.1162	0.0781	0.0368	0.0290	0.0287
0:00	0.1625	0.1171	0.1317	0.0818	0.0414	0.0342	0.0337
2:00	0.1726	0.1319	0.1432	0.0890	0.0445	0.0380	0.0366
4:00	0.1826	0.1412	0.1540	0.0925	0.0466	0.0408	0.0386
6:00	0.1595	0.1529	0.1684	0.0963	0.0481	0.0433	0.0404
8:00	0.0733	0.1271	0.1326	0.0968	0.0495	0.0398	0.0381
10:00	0.0177	0.0685	0.0502	0.0383	0.0228	0.0252	0.0154
12:00	0.0177	0.0211	0.0036	0.0127	0.0071	0.0106	0.0013
14:00	0.0177	0.0149	0.0185	0.0230	0.0072	0.0055	0.0020

(b) For vertical displacements at the corner of a 440-foot slab (inch)

	Trip Date						
	1988				1989		
Hour	July 25	August 5	August 26	November 5	January 21	January 22	February 9
14:00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16:00	0.0142	0.0276	0.0065	0.0030	0.0024	0.0025	0.0040
18:00	0.0732	0.0092	0.0489	0.0300	0.0133	0.0131	0.0073
20:00	0.1105	0.0452	0.0844	0.0483	0.0240	0.0208	0.0165
22:00	0.1326	0.0854	0.1051	0.0656	0.0298	0.0232	0.0228
0:00	0.1459	0.1058	0.1184	0.0685	0.0332	0.0273	0.0265
2:00	0.1542	0.1185	0.1281	0.0738	0.0354	0.0302	0.0286
4:00	0.1620	0.1262	0.1371	0.0763	0.0368	0.0322	0.0300
6:00	0.1401	0.1357	0.1486	0.0787	0.0378	0.0336	0.0312
8:00	0.0645	0.1221	0.1301	0.0824	0.0402	0.0328	0.0294
10:00	0.0156	0.0658	0.0507	0.0326	0.0185	0.0207	0.0119
12:00	0.0156	0.0203	0.0056	0.0108	0.0058	0.0087	0.0010
14:00	0.0156	0.0143	0.0201	0.0196	0.0059	0.0046	0.0016

TABLE 5.2. SUMMARY OF PREDICTED VALUES FROM NEW MODEL FOR CURLING

(a) For vertical displacements at the sixth point of a 240-foot slab (inch)

	Trip Date						
	1988				1989		
Hour	July 25	August 5	August 26	November 5	January 21	January 22	February 9
14:00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16:00	0.0091	0.0176	0.0042	0.0021	0.0018	0.0019	0.0032
18:00	0.0488	0.0059	0.0327	0.0214	0.0098	0.0098	0.0055
20:00	0.0747	0.0303	0.0571	0.0350	0.0181	0.0159	0.0127
22:00	0.0905	0.0579	0.0718	0.0482	0.0227	0.0179	0.0177
0:00	0.1003	0.0723	0.0813	0.0505	0.0255	0.0211	0.0208
2:00	0.1066	0.0814	0.0884	0.0550	0.0275	0.0235	0.0226
4:00	0.1127	0.0872	0.0951	0.0571	0.0287	0.0252	0.0239
6:00	0.0984	0.0944	0.1040	0.0594	0.0297	0.0267	0.0249
8:00	0.0453	0.0785	0.0818	0.0598	0.0306	0.0246	0.0235
10:00	0.0109	0.0423	0.0310	0.0236	0.0141	0.0155	0.0095
12:00	0.0109	0.0130	0.0022	0.0078	0.0044	0.0065	0.0008
14:00	0.0109	0.0092	0.0114	0.0142	0.0045	0.0034	0.0012

(b) For vertical displacements at the sixth point of a 440-foot slab (inch)

	Trip Date						
	1988				1989		
Hour	July 25	August 5	August 26	November 5	January 21	January 22	February 9
14:00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16:00	0.0088	0.0170	0.0040	0.0018	0.0015	0.0015	0.0025
18:00	0.0452	0.0057	0.0302	0.0185	0.0082	0.0081	0.0045
20:00	0.0682	0.0279	0.0521	0.0298	0.0148	0.0128	0.0102
22:00	0.0818	0.0527	0.0649	0.0405	0.0184	0.0143	0.0141
0:00	0.0901	0.0653	0.0731	0.0423	0.0205	0.0169	0.0163
2:00	0.0952	0.0731	0.0791	0.0456	0.0219	0.0187	0.0176
4:00	0.1000	0.0779	0.0846	0.0471	0.0227	0.0199	0.0185
6:00	0.0865	0.0838	0.0917	0.0486	0.0233	0.0207	0.0193
8:00	0.0398	0.0754	0.0803	0.0509	0.0248	0.0202	0.0182
10:00	0.0096	0.0406	0.0313	0.0201	0.0114	0.0128	0.0073
12:00	0.0096	0.0125	0.0035	0.0066	0.0036	0.0054	0.0006
14:00	0.0096	0.0088	0.0124	0.0121	0.0036	0.0028	0.0010

TABLE 5.3. SUMMARY OF PREDICTED VALUES FROM NEW MODEL FOR CURLING

(a) For vertical displacements at the third point of a 240-foot slab (inch)

	Trip Date						
	1988				1989		
Hour	July 25	August 5	August 26	November 5	January 21	January 22	February 9
14:00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16:00	0.0067	0.0130	0.0031	0.0016	0.0014	0.0014	0.0024
18:00	0.0361	0.0043	0.0242	0.0158	0.0072	0.0072	0.0041
20:00	0.0553	0.0224	0.0423	0.0259	0.0134	0.0118	0.0094
22:00	0.0669	0.0428	0.0531	0.0357	0.0168	0.0132	0.0131
0:00	0.0742	0.0535	0.0601	0.0374	0.0189	0.0156	0.0154
2:00	0.0789	0.0603	0.0654	0.0407	0.0203	0.0174	0.0167
4:00	0.0834	0.0645	0.0703	0.0422	0.0213	0.0186	0.0177
6:00	0.0728	0.0698	0.0769	0.0440	0.0220	0.0198	0.0185
8:00	0.0335	0.0581	0.0606	0.0442	0.0226	0.0182	0.0174
10:00	0.0081	0.0313	0.0229	0.0175	0.0104	0.0115	0.0070
12:00	0.0081	0.0096	0.0016	0.0058	0.0032	0.0048	0.0006
14:00	0.0081	0.0068	0.0085	0.0105	0.0033	0.0025	0.0009

(b) For vertical displacements at the third point of a 440-foot slab (inch)

	Trip Date						
	1988				1989		
Hour	July 25	August 5	August 26	November 5	January 21	January 22	February 9
14:00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16:00	0.0065	0.0126	0.0030	0.0014	0.0011	0.0011	0.0018
18:00	0.0334	0.0042	0.0223	0.0137	0.0061	0.0060	0.0033
20:00	0.0505	0.0206	0.0385	0.0221	0.0110	0.0095	0.0076
22:00	0.0606	0.0390	0.0480	0.0300	0.0136	0.0106	0.0104
0:00	0.0666	0.0483	0.0541	0.0313	0.0152	0.0125	0.0121
2:00	0.0704	0.0541	0.0585	0.0337	0.0162	0.0138	0.0130
4:00	0.0740	0.0576	0.0626	0.0349	0.0168	0.0147	0.0137
6:00	0.0640	0.0620	0.0679	0.0359	0.0173	0.0153	0.0142
8:00	0.0294	0.0558	0.0594	0.0376	0.0184	0.0150	0.0134
10:00	0.0071	0.0301	0.0231	0.0149	0.0085	0.0095	0.0054
12:00	0.0071	0.0093	0.0026	0.0049	0.0026	0.0040	0.0005
14:00	0.0071	0.0065	0.0092	0.0089	0.0027	0.0021	0.0007

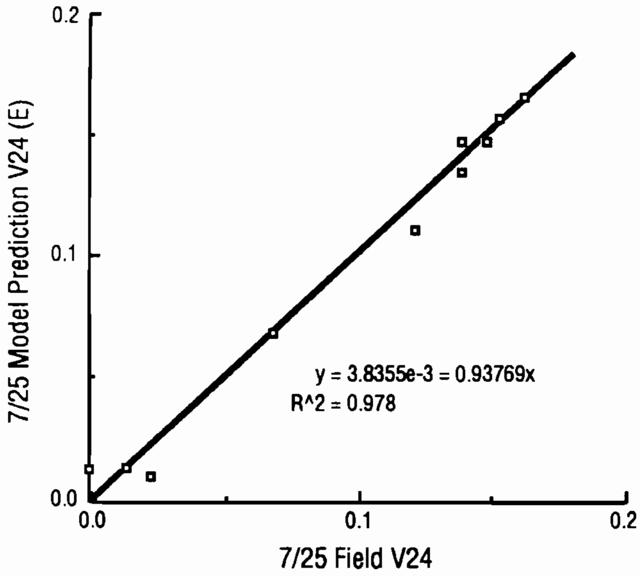


Fig 5.2. Degree of correlation between model and field vertical displacements at the corner predicted for a 240-foot slab for hot weather conditions.

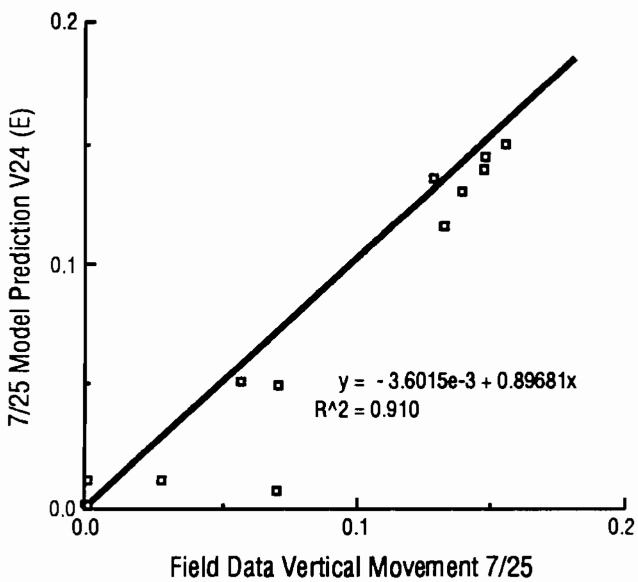


Fig 5.3. Degree of correlation between model and field vertical displacements at the corner predicted for a 440-foot slab for hot weather conditions.

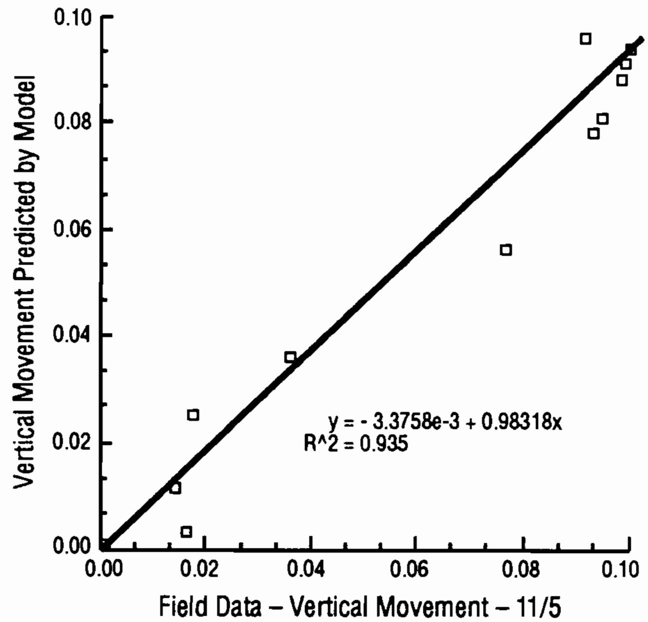


Fig 5.4. Degree of correlation between model and field vertical displacements at the corner of a 240-foot slab for a set of weather conditions chosen at random.

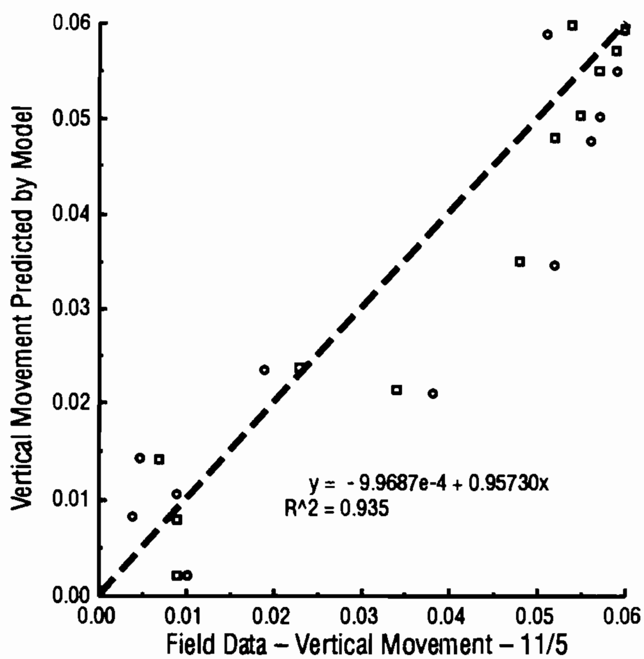


Fig 5.5. Degree of correlation between model and field vertical displacements at the sixth point of a 240-foot slab for a set of weather conditions chosen at random.

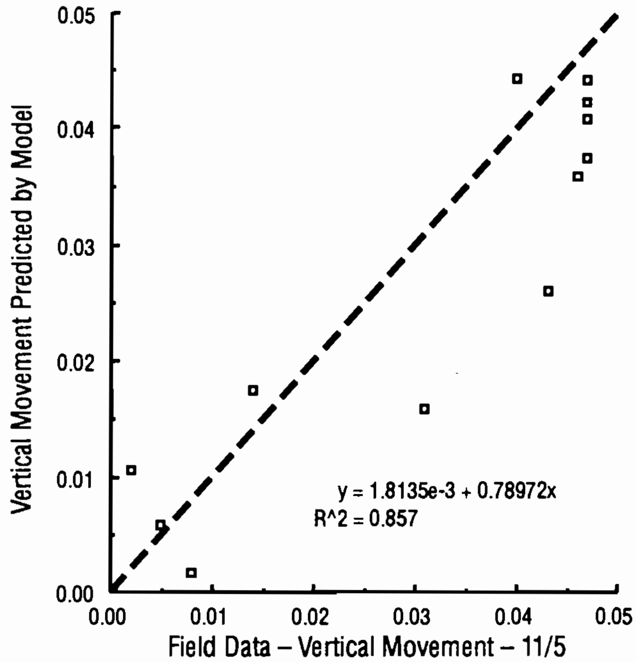


Fig 5.6. Degree of correlation between model and field vertical displacements at the third point of a 240-foot slab for a set of weather conditions chosen at random.

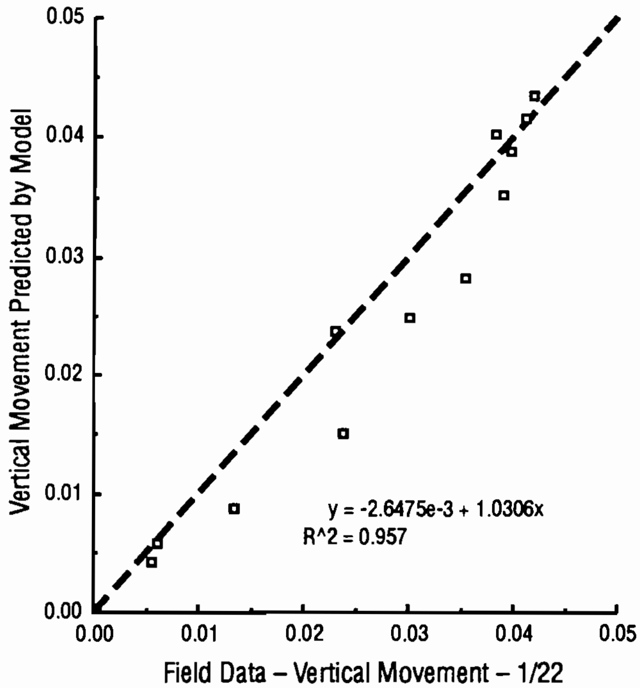


Fig 5.7. Degree of correlation between model and field vertical displacements at the corner of a 240-foot slab for cold weather conditions.

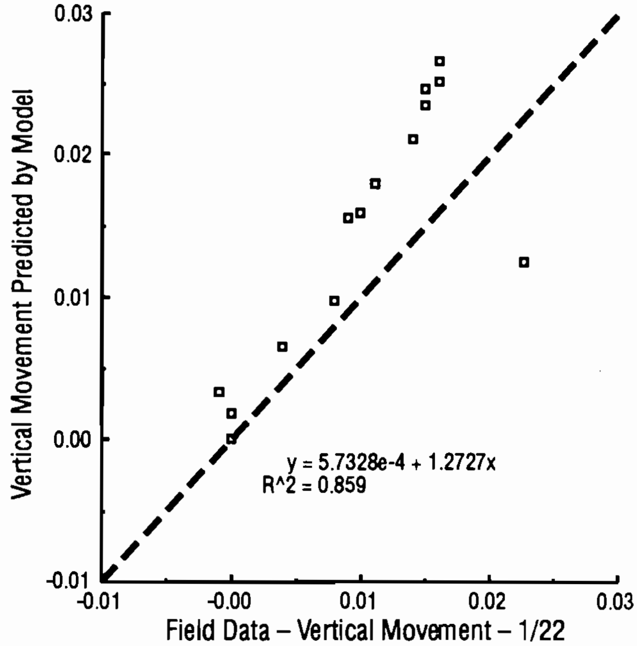


Fig 5.8. Degree of correlation between model and field vertical displacements at the sixth point of a 240-foot slab for cold weather conditions.

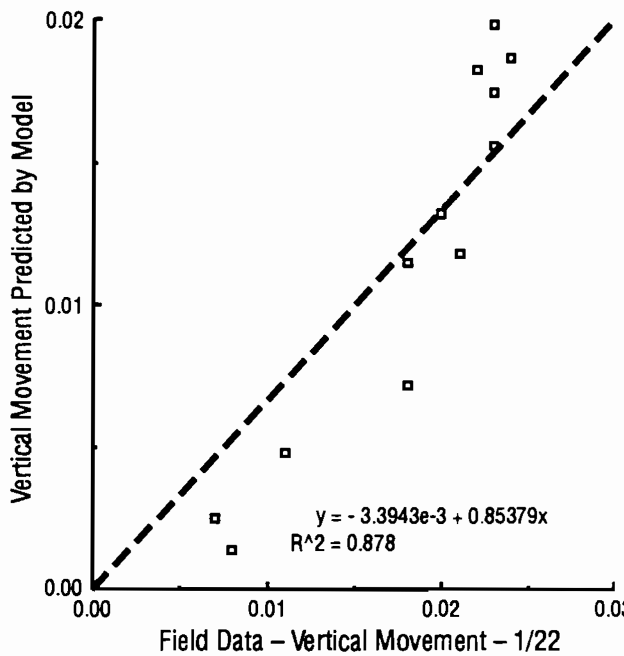


Fig 5.9. Degree of correlation between model and field vertical displacements at the third point of a 240-foot slab for cold weather conditions.

CHAPTER 6. CALIBRATION OF THE PROGRAM PSCP1

In this chapter, the main factors and the procedures executed for the calibration of the program are described and the principal concepts that resulted from this process are discussed. Program PSCP2 is introduced, and the correlation between the values predicted by the program and the field values are discussed, along with some considerations for better use of the program.

PRINCIPAL FACTORS IN CALIBRATION

In Chapter 2, an analysis of the principal variables was performed to detect the possible factors that could have a role of importance in the behavior of PCP slabs and consequently in the models used in the program. Table 2.1 and Fig 2.3(a) and (b) presented graphically the information product for this first analysis and served as a departure point for the data collection planning. The analysis became more objective in Chapter 3, where the analysis of the data for the models was discussed.

At the stage of research previous to the collection of data, it was stated that a prime part in the calibration would be the data collection. The input characterization made it clear that there were some factors which made it necessary to carefully plan for the collection of significant data under different conditions for their analysis. Also, a sequence for the calibration process was suggested. Afterwards, the required data were gathered and the analysis was concluded. Also it was possible to establish the relative weight of each factor in the calibration. From the work done up to this point, the factors that are considered to have a major role in the calibration of the program are:

(1) *Environment.* The driving force for curling is environment. The changing conditions of its principal parameters, moisture and temperature, provide a different set of conditions each time, making the pavement slab behave within different ranges of values for all the other factors (friction, thermal contraction, etc.). The collected values and the measured behavior confirmed the importance of stresses induced by environmental changes.

(2) *Friction.* The second factor for the calibration of the program was friction. The measurement of horizontal displacements permitted the analysis of the friction under the PCC slab. The models turn out to be especially sensitive to the friction values and profiles. From the analysis it was stated that the model in PSCP1 rendered reasonable results for the horizontal displacements, and the calibration proceeded to the adjustment of values determined in previous research projects. The results indicated that the values previously reported were somewhat high for the displacements experienced by the PCP slabs monitored in this study.

(3) *Temperature Gradients and Thermal Coefficient of the Slab.* A third factor for the calibration of the program was the analysis and determination of the effect of temperature gradients in the slab and their combination with other factors. The effect of the thermal coefficient of the material and its variations were studied along with friction and temperature gradients for the determination of the basic factors in curling. A model that considered this and other factors was developed and tested for accuracy. Then, the new model was implemented into program PSCP2 with the changes necessary to reflect the build-up of stresses due to curling in the slab. It is important to point out that during the analysis and testing of program PSCP2 it was possible to observe the range of variations that these three factors experienced during the collection period. These variations confirmed the range of variations suggested in manuals. It is also interesting to note the sensitivity reflected by the models to these variations. Variations in the values of the coefficients must be considered in the determination of values for design. An exemplification of this responsiveness is presented later on in this chapter.

(4) *K-value and Structural Stiffness of the Slab.* An aspect brought up by the analysis was that the variations in mechanical strength of the soil represented by the soil support value (k-value) do not affect to a large extent the behavior of the slab at this stage of the slab life. The k-value and the stiffness of the slab work in conjunction as a structural unit. The model developed in this respect is somewhat different from the Westergaard model and more closely related to the models used in soil mechanics. Once the structural stiffness effect was measured, it was translated and introduced in the model in terms of strain energy.

The calibration process ended when program PSCP2 was tested. From the test it was clear that it was not necessary to pursue a further calibration since the range of values predicted by program PSCP2 is accurate enough for use in design. Thus, the calibration did not have to further consider the remaining factors (such as models and coefficients for concrete and steel), which were mentioned for the tentative calibration procedure in Chapter 2.

CALIBRATED PROGRAM PSCP2

Program PSCP2 constitutes the upgraded version of program PSCP1. The flow charts of the model for the prediction of curling and its location within the general flow chart of program PSCP2 are presented in this section. For a more thorough discussion on the flow chart of program PSCP1, the reader should refer to Research

Report 401, by Mendoza-Diaz et al (Ref 1). Changes in the program input data and codification of data input can be found, along with an example of the data used, in Appendixes A and B. Appendixes C and D contain an example of the output data and the listing of the program. In this section, the results from the PSCP2 correlation with the data collected in the field are presented for the horizontal and the vertical data.

The program has been maintained and it is upgraded with the following changes:

(1) A new model for curling was developed. This model allows the prediction of vertical displacements due to curling and/or warping and introduces geometry factors that were not considered before in the calculation of this type of displacement. The model for curling is presented and discussed in Chapter 5.

(2) An equation developed at CTR for the computation of the modulus of elasticity for concretes made in Texas was added. This equation considers the type of aggregate in the computation of the modulus of elasticity.

The general flow chart diagram for program PSCP2 is shown in Fig 6.1. This flow chart is essentially identical to the one of program PSCP1 (Ref 2) except that subroutine PREDMD is added (to calculate the modulus of elasticity) and the newly developed model was installed in subroutine CURL. The flow chart for this new model for curling is presented in Fig 6.2.

The flow of the program in subroutine CURL with the model installed proceeds in the following manner. First, the values for the average temperature gradients are determined as well as the maximum and minimum temperature gradients for the cycle. Next, the program determines for each reading whether or not the slab is undergoing curling. If it is, the value for curling is determined for each time interval until the program detects a change in the gradient. Once the program establishes that the slab is experiencing a reversal in the temperature gradient, the program predicts the transition part of the cycle, which occurs when the slab is flattening. For each part of the process, the stresses that build up in the slab are computed after the displacements are calculated. Then, the command of the program returns to the main routine.

The program can also predict the build up of stresses from warping. The difference in this case is that the gradients to be input are the equivalent ones induced by the moisture differentials developed between the top and the bottom of the slab.

Additionally, a version of program PSCP2 was made for a personal computer (PC). This PC version of PSCP2 achieves the objectives of lower costs and higher availability of the program while keeping efficiency. The average time for one run is less than two minutes in a computer with a speed of 10 MHz. This running time is reduced to seconds for a 25 MHz machine. These running times allow the consideration of several design possibilities in a short period of time.

The general accuracy of the program was tested using data from the field. Previously, some correlation values were determined for the horizontal data in Chapter 4 and correlation values for the vertical displacements were presented with the testing of the model for curling. Here, the final correlation values for horizontal and vertical displacements from the interaction of models in PSCP2 were checked.

HORIZONTAL DISPLACEMENTS

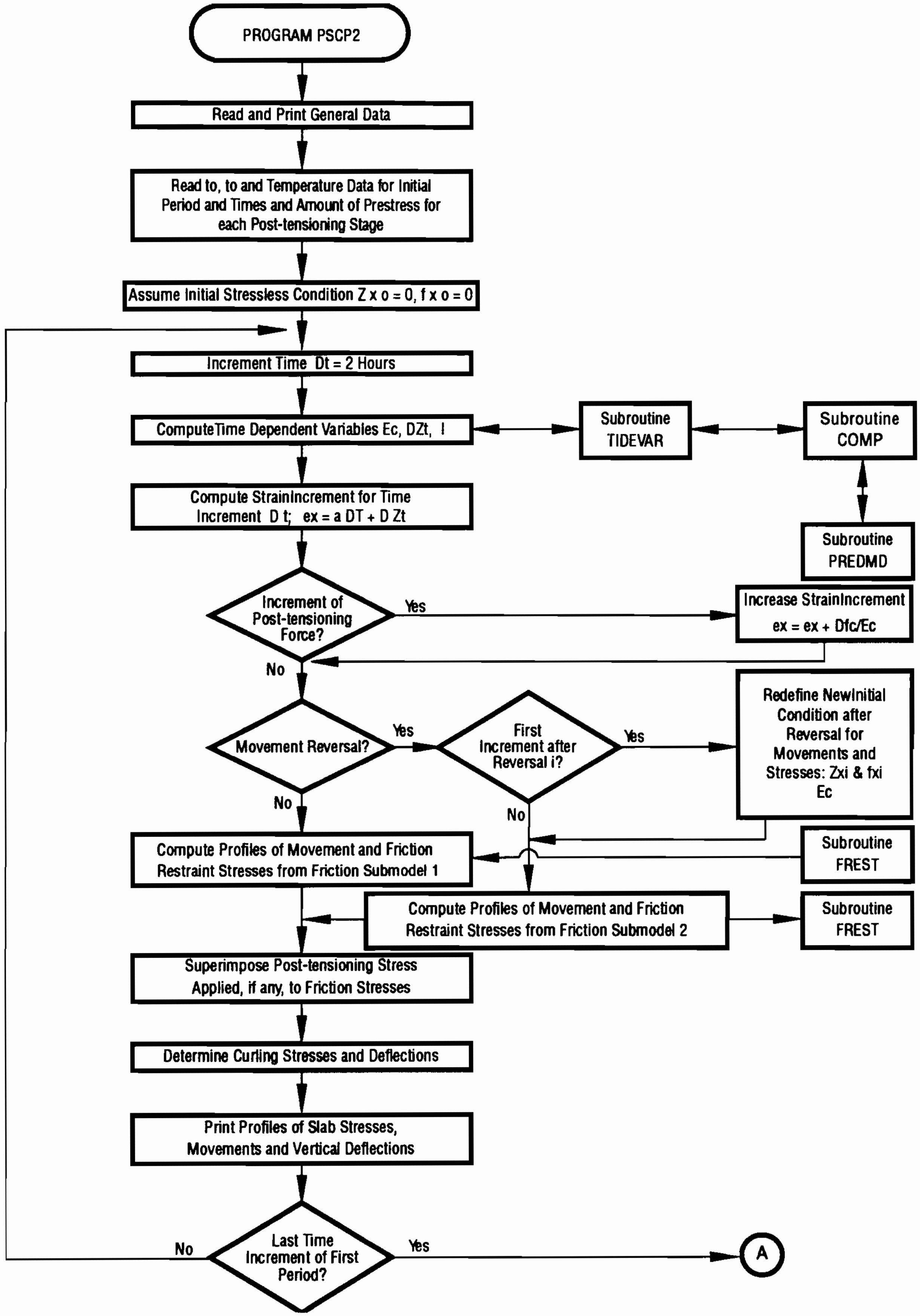
In all cases the computed values were found acceptable and in agreement with field values for this project. A coefficient of friction of 0.2 was used in the input. For the compressive strength of concrete, the mean value of the final strength determined by laboratory testing of the field samples was calculated. All the other input values were taken from field records. Input values are in Appendix B.

The numbers turned out by program PSCP2 are the same as those presented in Table 4.1. The curves corresponding to the horizontal displacement values are shown in Figs 4.1 to 4.3. They show good agreement between the predicted and the measured behavior. Parts (a) of Figs 4.7 to 4.9 show the correlation for the horizontal displacement. The predicted horizontal displacements are in close agreement with the measured values. The coefficients of partial determination in parts (a) of Figs 4.7 to 4.9 show that the correlation values for program PSCP1 ranged between 0.99 and 0.87 for the horizontal movement.

Figure 6.3(a) and (b) confirms the level of correlation between the field data and the data predicted by PSCP2 for the edge points of the data set collected on July 25. Figures 6.4 and 6.5(a) and (b) confirm the level of correlation between the field data and the data predicted by PSCP2 for the interior points of data sets collected on November 5 and January 22 for 240 and 440-foot slabs.

VERTICAL DISPLACEMENTS

For vertical displacements, the predicted values are summarized in Tables 6.1 and 6.2. Figures 6.6 to 6.8 show the correlation between the field and predicted vertical displacement data for the edge and interior locations of the data sets for July 25, November 5, and January 22. The correlation in these figures is slightly lower than the correlation obtained for the model alone in Figs 5.2 to 5.9. This is due to round-off and to truncation errors introduced by the interaction of the models and possibly to the variations in the value of the thermal coefficients of the materials with the seasons.



(continued)

Fig. 6.1. General flow diagram of computer program PSCP2.

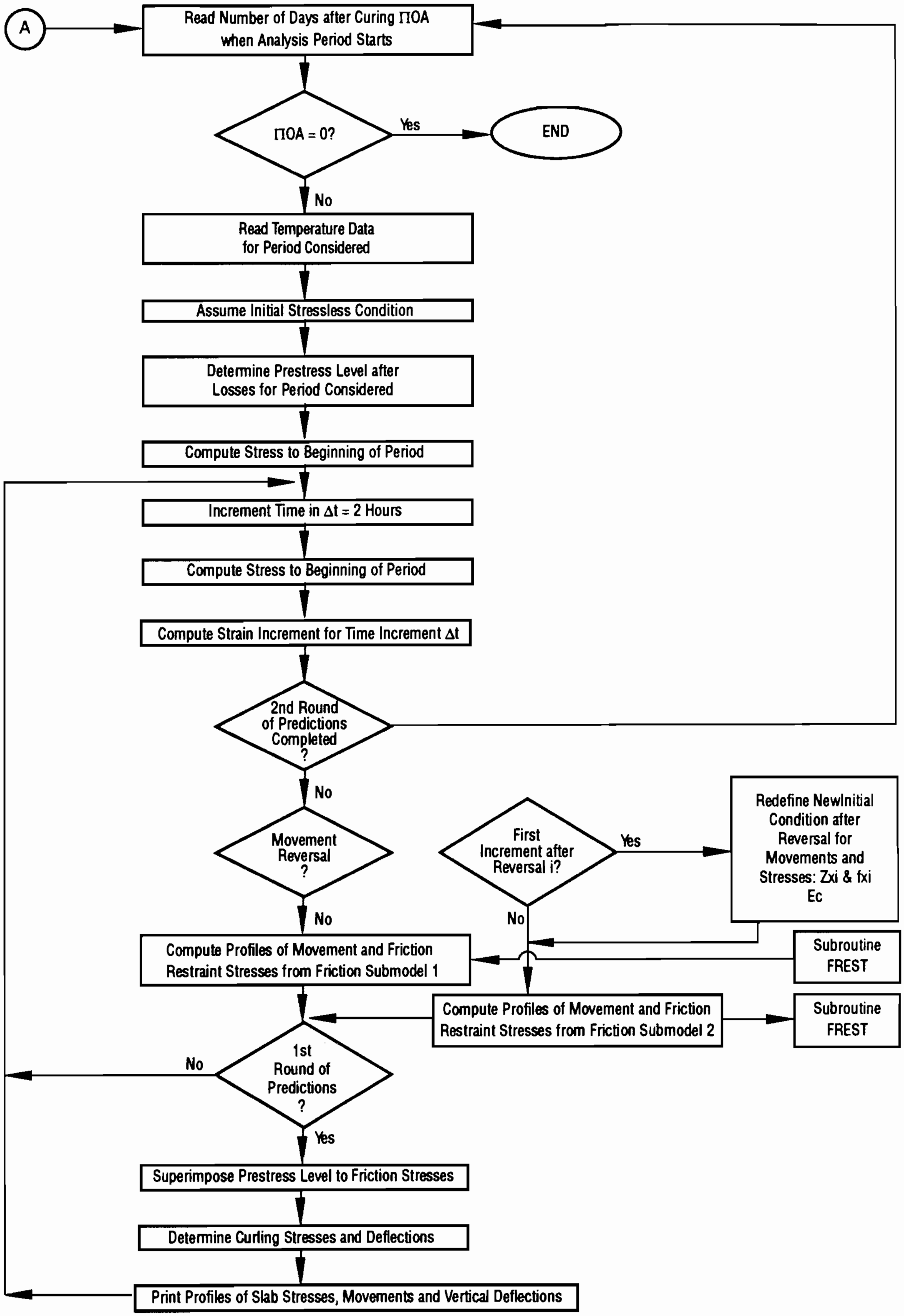


Fig. 6.1. General flow diagram of computer program PSCP2 (continued).

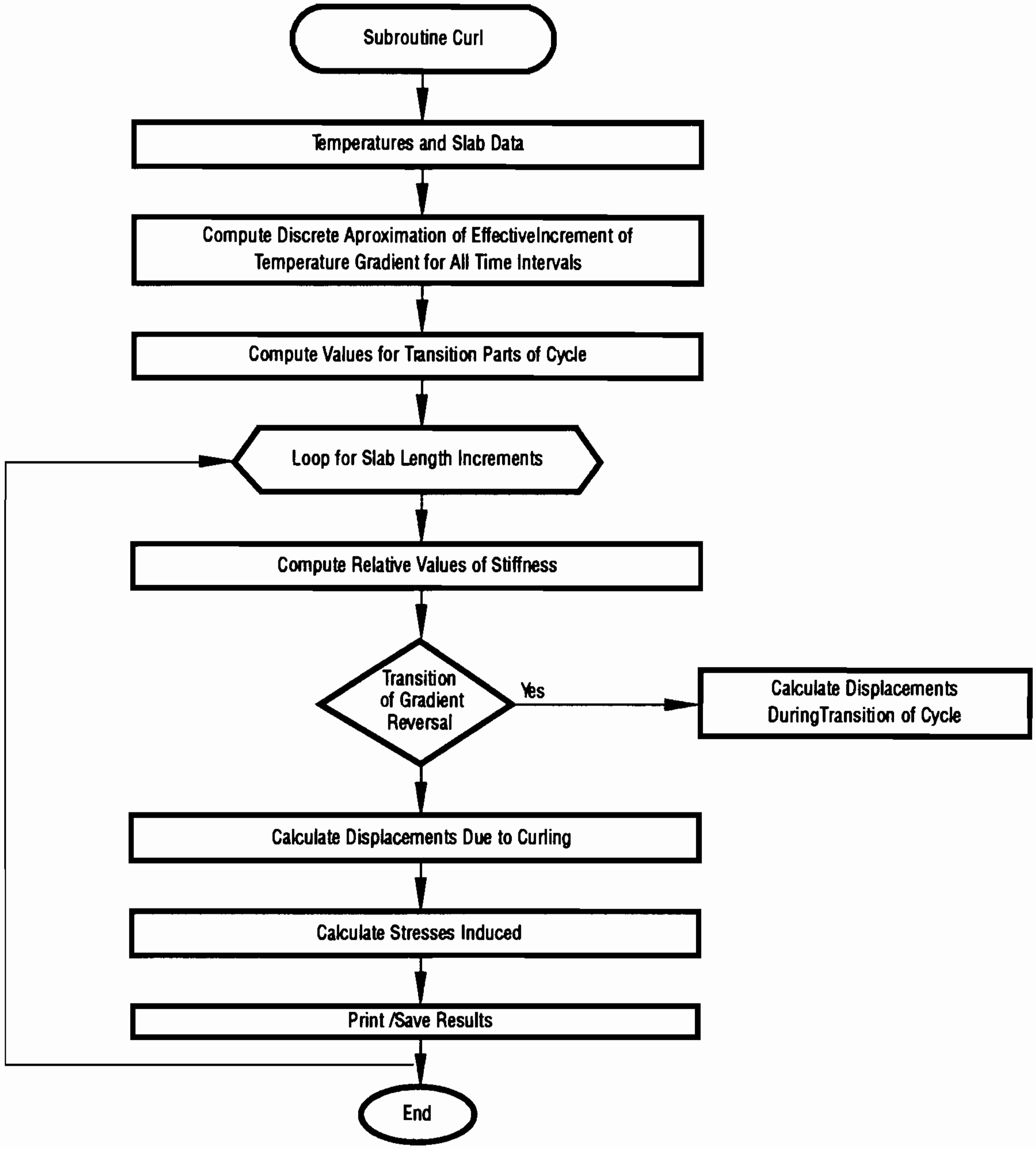
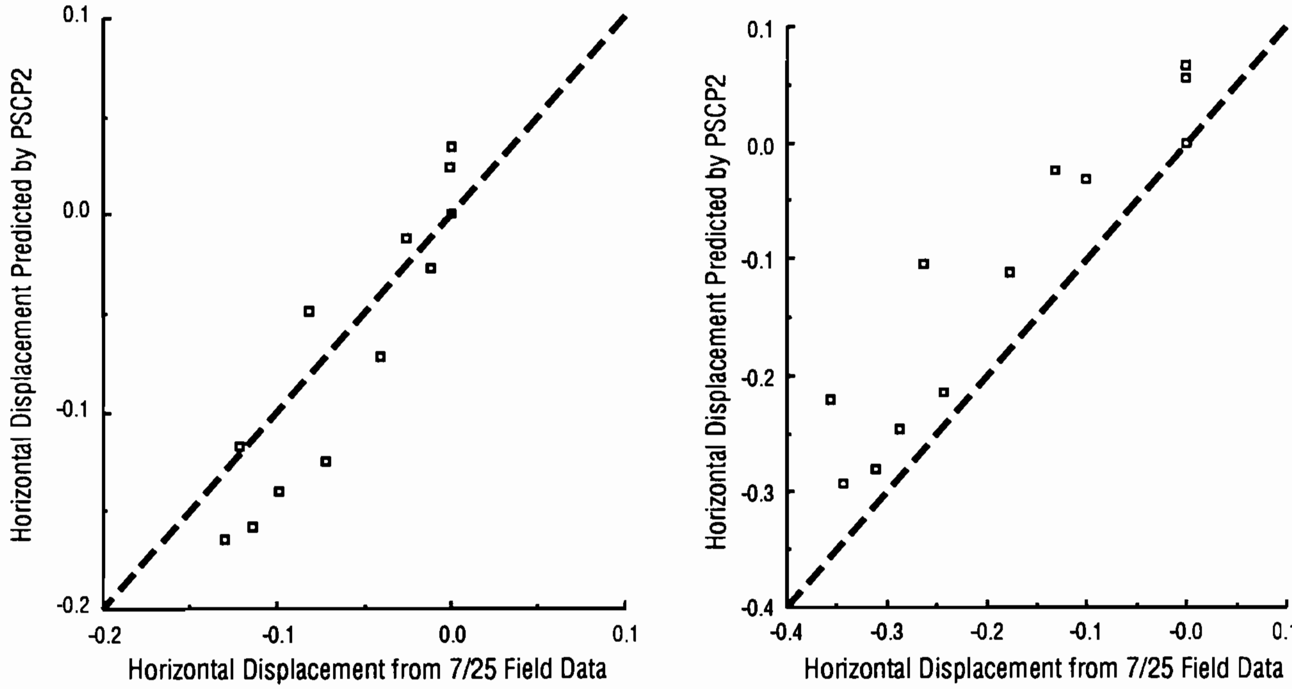
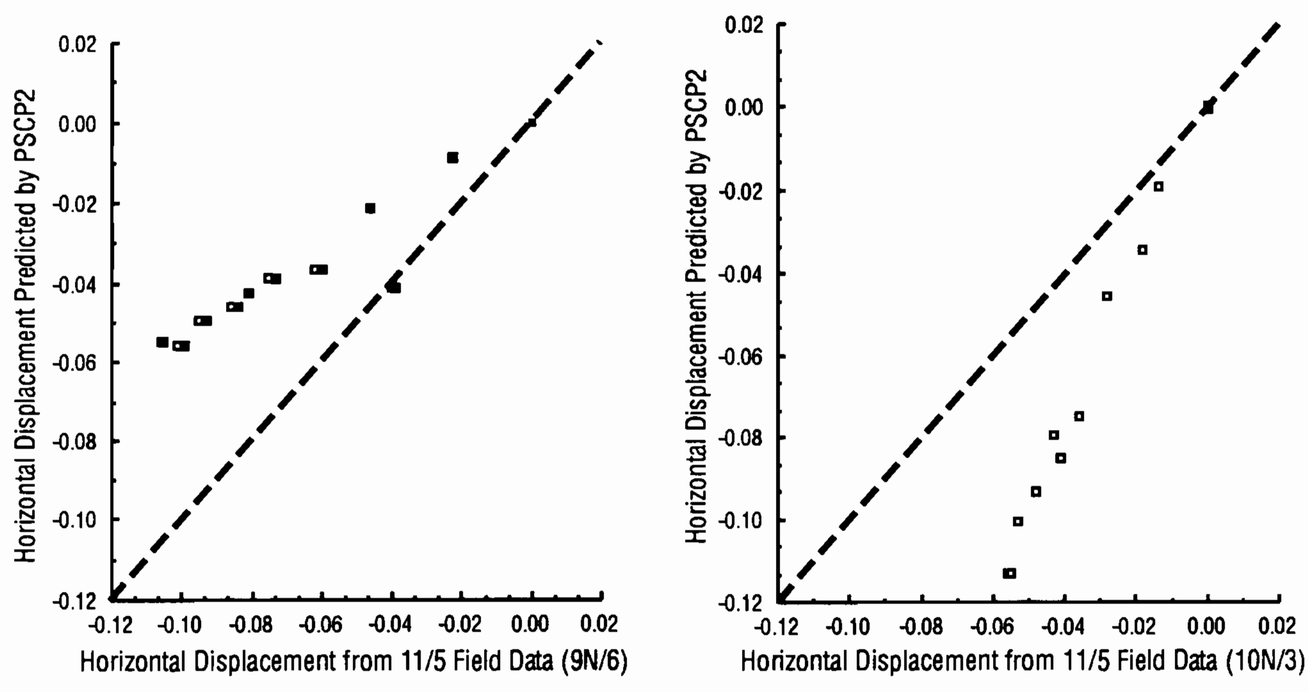


Fig 6.2. Flow diagram for subroutine CURL.



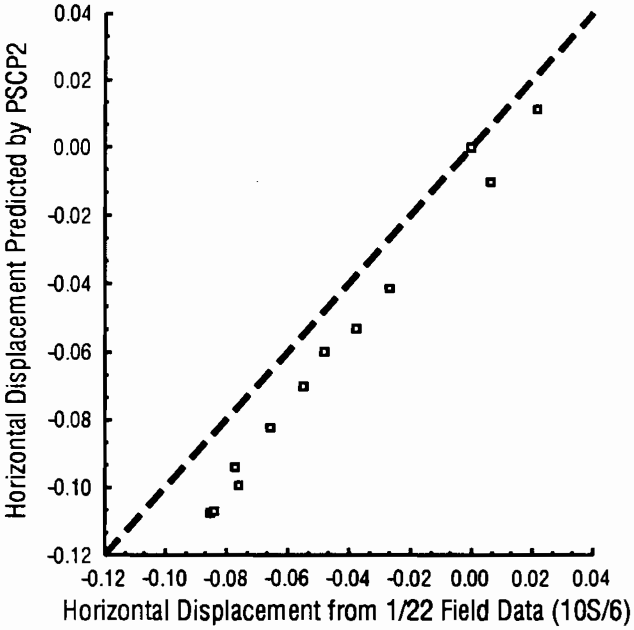
(a) At the corner of a 240-foot slab. **(b) At the corner of a 440-foot slab.**

Fig 6.3. Correlation of program PSCP with field data for horizontal displacements at the corner of a 240 and a 440-foot slab under hot weather conditions

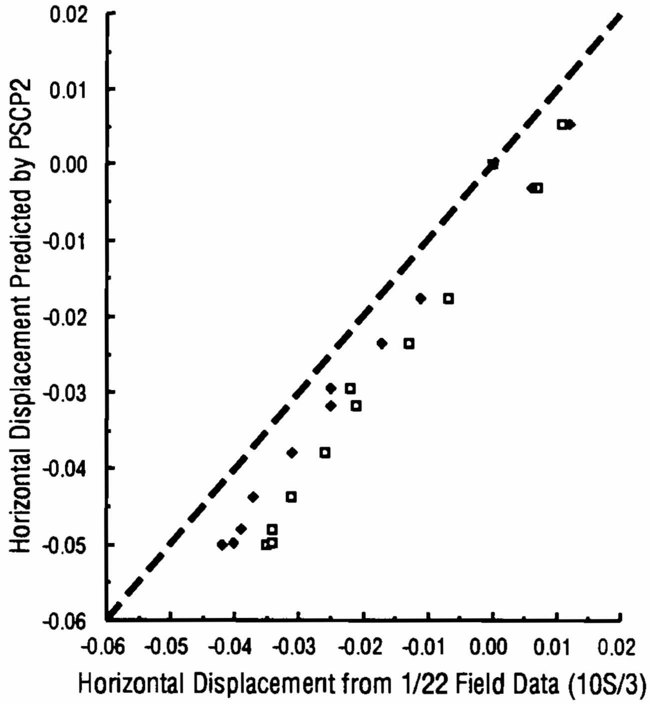


(a) At the sixth point of a 240-foot slab. **(b) At the third point of a 240-foot slab.**

Fig 6.4 Correlation of program PSCP2 with field data for horizontal interior points of a 240-foot slab for a set of weather chosen at random (a = 5 X 10^{-6}).

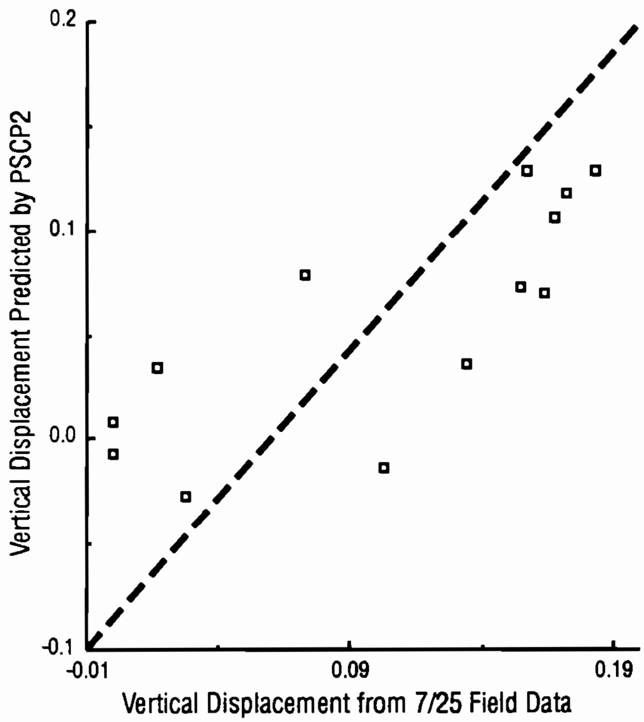


(a) At the sixth point of a 440-foot slab.

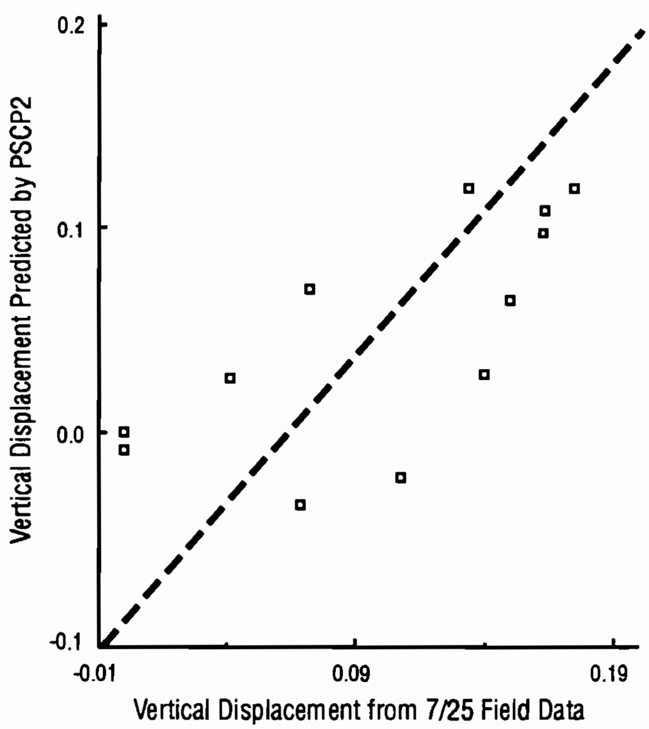


(b) At the third point of a 440-foot slab.

Fig 6.5. Correlation of program PSCP2 with field data for horizontal displacements at interior points of a 440-foot slab under cold weather conditions (a = 5 X 10^{-6}).



(a) At the corner of a 240-foot slab.



(b) At the corner of a 440-foot slab.

Fig 6.6. Correlation of program PSCP2 with field data for vertical displacement at the corner of a 240 and a 440-foot slab under hot weather conditions (a = 5 X 10^{-6}).

TABLE 6.1. SUMMARY OF PREDICTED VALUES FOR CURLING FROM PROGRAM PSCP2

(a) For vertical displacements at the corner of a 240-foot slab (inch)

	Trip Date						
	1988				1989		
Hour	July 25	August 5	August 26	November 5	January 21	January 22	February 9
14:00	-.00078	-.00078	-.00078	-.00078	-.00078	-.00078	-.00078
16:00	-.02750	-.02475	.00481	.00301	-.00540	-.00448	-.00692
18:00	-.01455	.01348	.04414	.03935	.02518	.01886	.01038
20:00	.03641	.08863	.07768	.06442	.04686	.03089	.02487
22:00	.07313	.10810	.09769	.08901	.05891	.03483	.03490
0:00	.10667	.11995	.11075	.09329	.06630	.04137	.04107
2:00	.11786	.12713	.12045	.10143	.07140	.04607	.04470
4:00	.12840	.13643	.12957	.10536	.07466	.04942	.04723
6:00	.12819	.13346	.14162	.10952	.07711	.05187	.04940
8:00	.07842	.08189	.13662	.10688	.07775	.05081	.04881
10:00	.03428	.03344	.08153	.06166	.04303	.03217	.02356
12:00	.00787	-.02197	.03953	.02668	.01889	.01787	-.00095

(b) For vertical displacements at the corner of a 440-foot slab (inch)

	Trip Date						
	1988				1989		
Hour	July 25	August 5	August 26	November 5	January 21	January 22	February 9
14:00	-.00478	-.00478	-.00478	-.00478	-.00478	-.00478	-.00478
16:00	-.03126	-.02854	.00076	-.00102	-.00936	-.00844	-.01087
18:00	-.01843	.00935	.03975	.03500	.02095	.01468	.00628
20:00	.03208	.08384	.07299	.05985	.04244	.02661	.02064
22:00	.06848	.10314	.09282	.08423	.05439	.03052	.03059
0:00	.10172	.11489	.10577	.08847	.06171	.03700	.03670
2:00	.11282	.12201	.11539	.09653	.06676	.04165	.04030
4:00	.12326	.13122	.12442	.10043	.07000	.04498	.04281
6:00	.12305	.12828	.13637	.10455	.07243	.04740	.04495
8:00	.07373	.07716	.13142	.10193	.07306	.04635	.04437
10:00	.02997	.02914	.07681	.05711	.03865	.02788	.01935
12:00	.00380	-.02579	.03518	.02244	.01472	.01371	-.00495

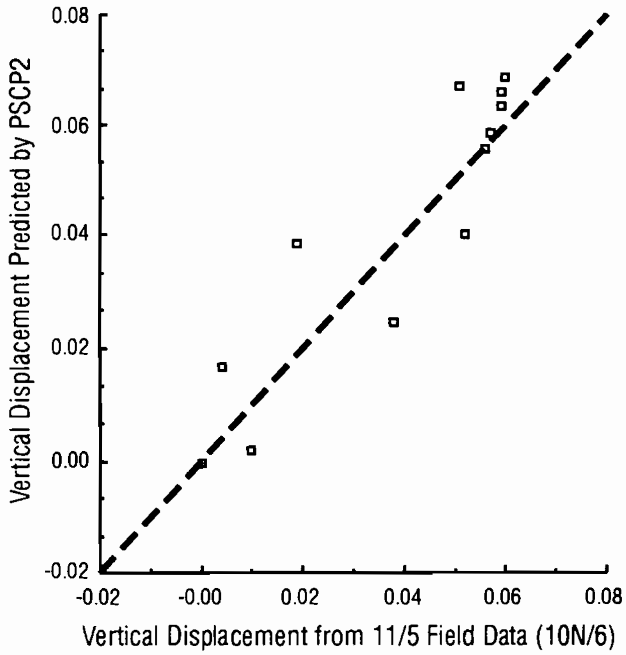
TABLE 6.2. SUMMARY OF PREDICTED VALUES FOR CURLING FROM PROGRAM PSCP2

(a) For vertical displacements at the sixth point of a 240-foot slab (inch)

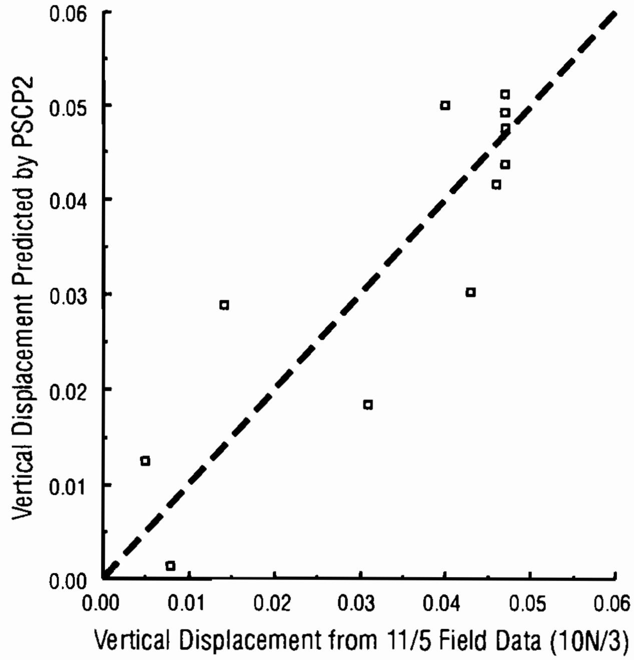
	Trip Date						
	1988				1989		
Hour	July 25	August 5	August 26	November 5	January 21	January 22	February 9
14:00	-.00049	-.00049	-.00049	-.00049	-.00049	-.00049	-.00049
16:00	-.01718	-.01546	.00301	.00188	-.00337	-.00280	-.00432
18:00	-.00909	.00842	.02758	.02458	.01573	.01178	.00649
20:00	.02275	.05537	.04853	.04025	.02928	.01930	.01554
22:00	.04569	.06753	.06103	.05561	.03680	.02176	.02181
0:00	.06664	.07494	.06919	.05828	.04142	.02585	.02566
2:00	.07363	.07942	.07525	.06336	.04460	.02878	.02792
4:00	.08021	.08523	.08095	.06582	.04664	.03088	.02951
6:00	.08008	.08337	.08848	.06842	.04817	.03240	.03086
8:00	.04899	.05116	.08535	.06677	.04857	.03174	.03049
10:00	.02141	.02089	.05094	.03852	.02688	.02010	.01472
12:00	.00492	-.01373	.02470	.01667	.01180	.01117	-.00059

(b) For vertical displacements at the sixth point of a 440-foot slab (inch)

	Trip Date						
	1988				1989		
Hour	July 25	August 5	August 26	November 5	January 21	January 22	February 9
14:00	-.00297	-.00297	-.00297	-.00297	-.00297	-.00297	-.00297
16:00	-.01942	-.01773	.00047	-.00063	-.00581	-.00525	-.00675
18:00	-.01145	.00581	.02470	.02174	.01302	.00912	.00390
20:00	.01993	.05209	.04535	.03719	.02637	.01654	.01283
22:00	.04255	.06408	.05767	.05233	.03379	.01896	.01901
0:00	.06320	.07138	.06572	.05497	.03834	.02299	.02280
2:00	.07010	.07581	.07170	.05998	.04148	.02588	.02504
4:00	.07659	.08153	.07731	.06240	.04349	.02795	.02660
6:00	.07646	.07971	.08473	.06496	.04500	.02945	.02793
8:00	.04581	.04795	.08165	.06333	.04540	.02880	.02757
10:00	.01862	.01811	.04773	.03549	.02401	.01732	.01202
12:00	.00236	-.01602	.02186	.01394	.00915	.00852	-.00308

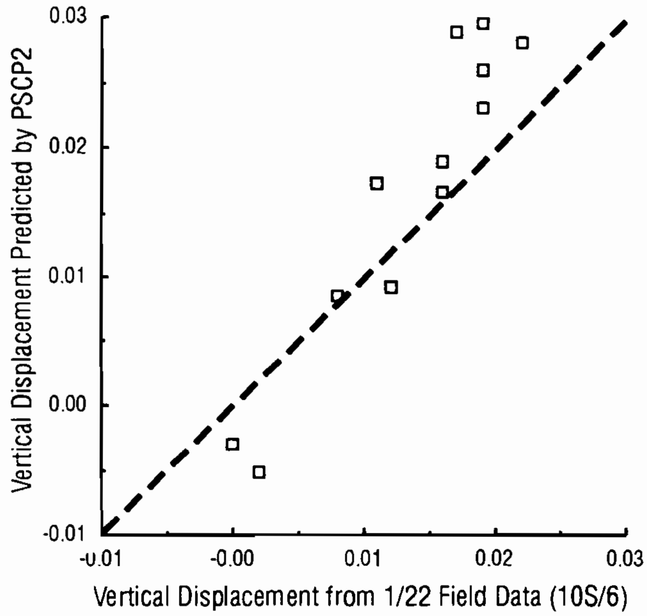


(a) At the sixth point of a 240-foot slab.

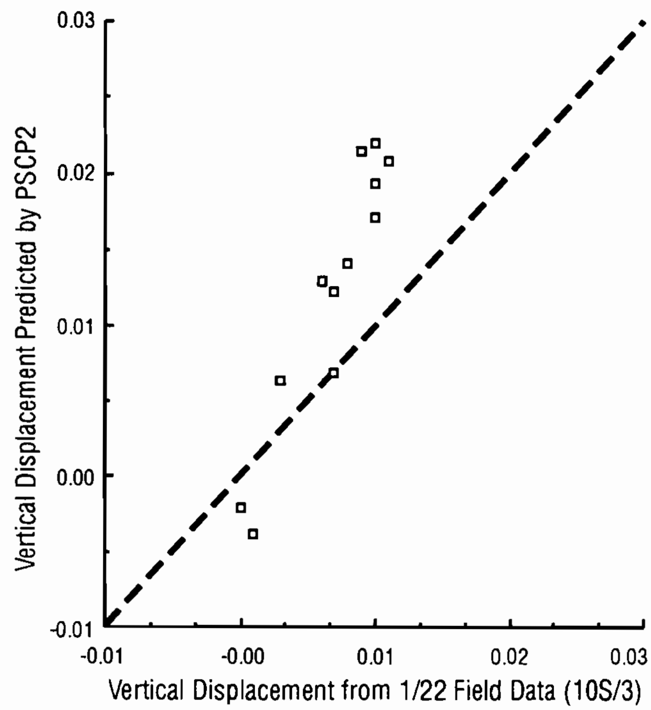


(b) At the third point of a 240-foot slab.

Fig 6.7. Correlation of program PSCP2 with field data for vertical displacements at interior points of a 240-foot slab for a set of weather conditions chosen at random ($\alpha = 5 \text{ X } 10^{-6}$).



(a) At the sixth point of a 440-foot slab.



(b) At the third point of a 440-foot slab.

Fig 6.8. Correlation of program PSCP2 with field data for vertical displacements at interior points of a 440-foot slab under cold weather conditions ($\alpha = 5 \text{ X } 10^{-6}$).

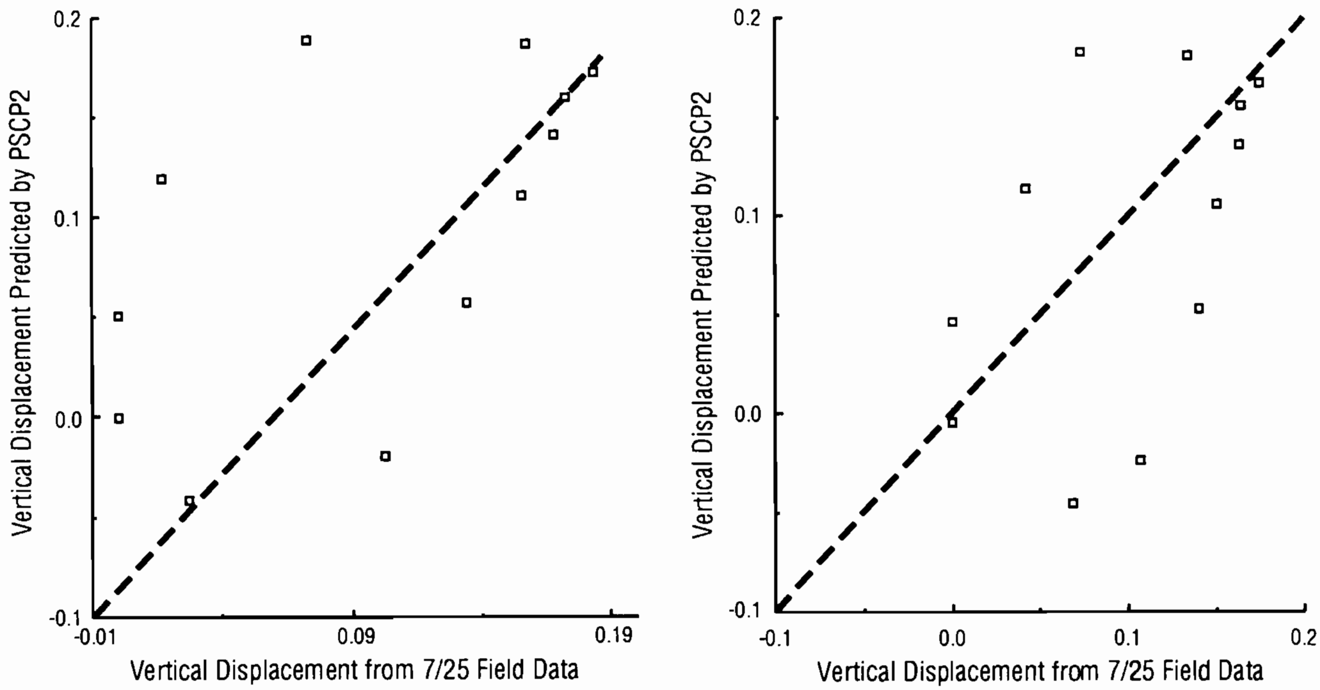
TABLE 6.3. SUMMARY OF PREDICTED VALUES FOR CURLING FROM PROGRAM PSCP2

(a) For vertical displacements at the third point of a 240-foot slab (inch)

	Trip Date						
	1988				1989		
Hour	July 25	August 5	August 26	November 5	January 21	January 22	February 9
14:00	.00037	.00037	.00037	.00037	.00037	.00037	.00037
16:00	.01286	.01157	.00225	.00141	.00252	.00209	.00324
18:00	.00680	.00630	.02064	.01840	.01177	.00882	.00485
20:00	.01702	.04144	.03632	.03012	.02191	.01444	.01163
22:00	.03419	.05054	.04568	.04162	.02754	.01629	.01632
0:00	.04987	.05608	.05178	.04362	.03100	.01934	.01920
2:00	.05511	.05944	.05632	.04742	.03338	.02154	.02090
4:00	.06003	.06379	.06058	.04926	.03491	.02311	.02208
6:00	.05994	.06240	.06622	.05121	.03605	.02425	.02310
8:00	.03667	.03829	.06388	.04997	.03635	.02375	.02282
10:00	.01603	.01564	.03812	.02883	.02012	.01504	.01102
12:00	.00368	.01027	.01848	.01247	.00883	.00836	.00044

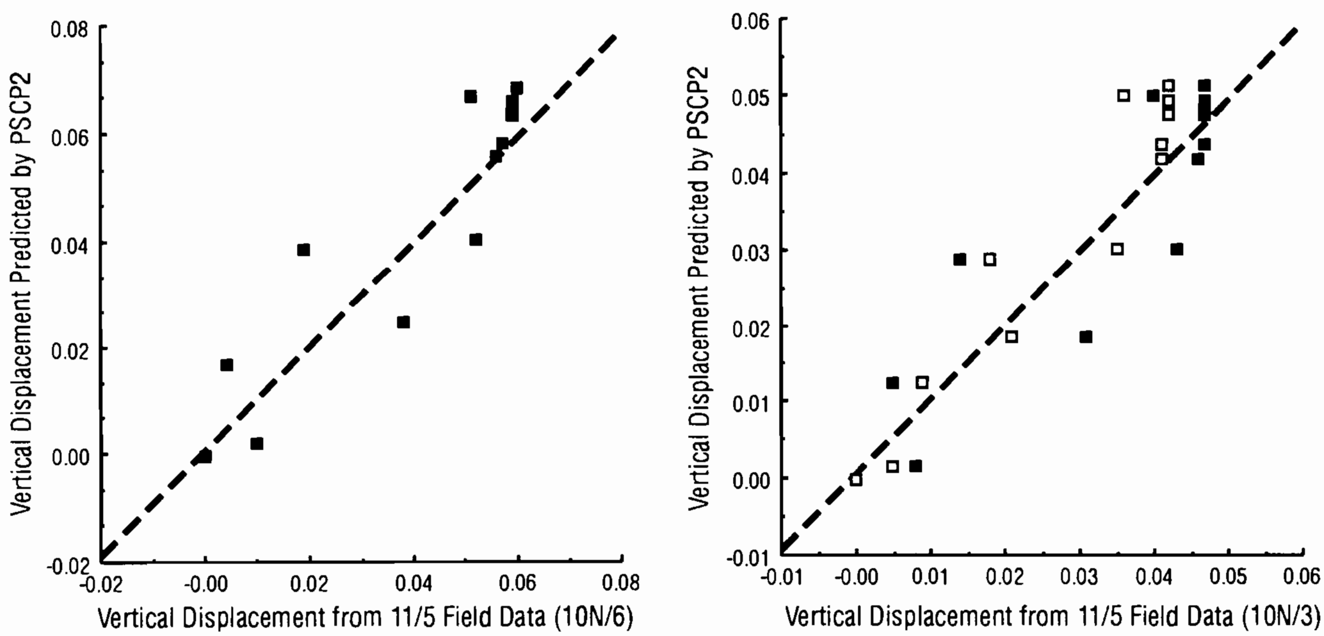
(b) For vertical displacements at the third point of a 440-foot slab (inch)

	Trip Date						
	1988				1989		
Hour	July 25	August 5	August 26	November 5	January 21	January 22	February 9
14:00	-.00221	-.00221	-.00221	-.00221	-.00221	-.00221	-.00221
16:00	-.01446	-.01320	.00035	-.00047	-.00433	-.00391	-.00503
18:00	-.00853	.00433	.01839	.01619	.00969	.00679	.00291
20:00	.01484	.03879	.03377	.02769	.01963	.01231	.00955
22:00	.03168	.04771	.04294	.03896	.02516	.01412	.01415
0:00	.04706	.05315	.04893	.04093	.02855	.01712	.01698
2:00	.05219	.05644	.05338	.04466	.03088	.01927	.01864
4:00	.05702	.06071	.05756	.04646	.03238	.02081	.01980
6:00	.05693	.05934	.06309	.04837	.03351	.02193	.02080
8:00	.03411	.03570	.06079	.04715	.03380	.02144	.02053
10:00	.01386	.01348	.03553	.02642	.01788	.01290	.00895
12:00	.00176	-.01193	.01627	.01038	.00681	.00634	-.00229



(a) At the corner of a 240-foot slab. **(b) At the corner of a 440-foot slab.**

Fig 6.9. Best correlation of program PSCP2 with field data for vertical displacements at the corner of a 240 and a 440-foot slab under hot weather conditions (α = ~7 X 10^{-6}).



(a) At the sixth point of a 240-foot slab. **(b) At the third point of a 240-foot slab.**

Fig 6.10. Best correlation of program PSCP2 with field data for vertical displacements at interior points of a 240-foot slab for a set of weather conditions chosen at random (α = ~5.5 X 10^{-6}).

CURLING

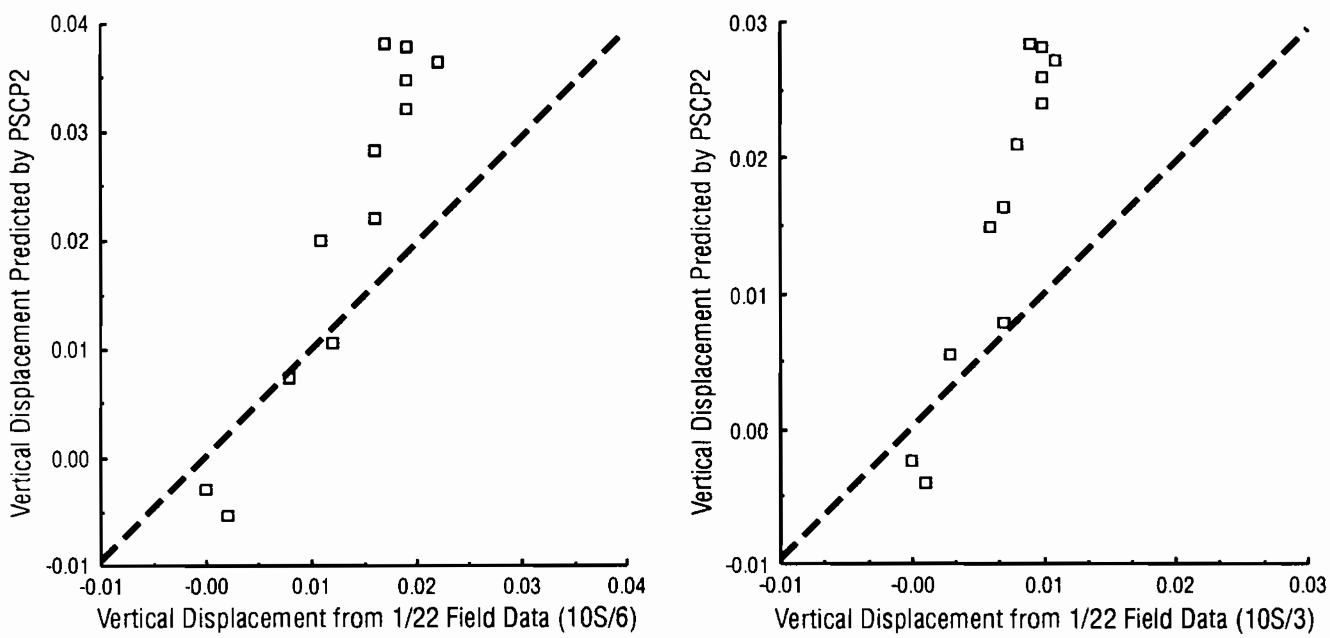
An outcome of the analysis was that curling in PCP slabs is specially sensitive to changes in the thermal changes of the slab along with some other factors, and as friction and rate of development of the temperature gradient. This range of values is consistent with values shown in the literature for similar aggregates.

An illustration of the effect of the variations of coefficients of friction and thermal conductivity is shown in Figs 6.9 to 6.11. The data were generated by running PSCP2 several times employing adequate values for the thermal coefficient. Figures 6.9 to 6.11 show the improved correlation achieved with these values. Therefore, the designer should consider this fact when selecting input values in order to achieve adequate values. This precaution will prevent the use of input data that might predict undesirably low results, leading to unconservative designs.

WARPING

Program PSCP2 can be used to predict warping in the slab. In this case, the gradient induced by the moisture differential has to be input as the equivalent temperature gradient. The nature of the data collected and the dry weather conditions prevailing during the period of the data collection prevented any such use of the program. Therefore, the use of PSCP2 for the prediction of warping is beyond the scope of this paper. Nevertheless, the program is designed and can be employed for this purpose in the future if needed.

Summarizing the statements earlier in this chapter, program PSCP2 provides satisfactory results with the calibration and upgrading introduced in the original program. The output values for the horizontal and vertical displacements were tested and proved to be satisfactory.



(a) At the sixth point of a 440-foot slab. **(b) At the third point of a 440-foot slab.**

Fig 6.10. Best correlation of program PSCP2 with field data for vertical displacements at interior points of a 440-foot slab under cold weather conditions (α = ~3.5 X 10^{-6}).

CHAPTER 7. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The findings of this study are presented in this chapter, along with the conclusions and, some recommendations for the design and construction of PCP slabs are made.

SUMMARY

This report has discussed the necessary background on PCP slabs and the analysis carried out for this study in the first three chapters. The collected data and the program calibration are discussed from Chapters 4 to 6. Chapter 5 is devoted to the development of a new model for curling. Some of the more important concepts presented are summarized here.

PCP is an attractive alternative to conventional pavements. The study of PCP and its materials and the study of the pavement as a unit are important for understanding PCP. For this study, the data collected in the field for the one-mile-long experimental section showed a high degree of uniformity. A correlation test showed that models for horizontal displacements of PCP slabs are reasonable but this did not hold for vertical displacements using the program PSCP1. A new model for the behavior of PCP slabs under temperature gradients is from existent models and has shown good agreement with the observed performance of PCP. Use of revised program PSCP2 can help in the study of PCC and in design applications.

CONCLUSIONS

The following conclusions were reached in these study.

FROM THE VISUAL SURVEY

(1) No signs of major distresses are present in the PCP slabs, and, no progress in the existent cracks was detected during the monitoring of the experimental section in Waco.

(2) The structural capacity in the experimental section is uniform and similar to that observed soon after the PCC construction.

(3) The selected joints have performed satisfactorily. No signs of spalling, cracking, or warping were noticed, which indicates the good protection and anchoring of the joints. However, the rate of debris accumulation leads to filled joints.

(4) If sufficient debris is present in the joint, the slabs can be prevented from expanding freely. This condition is more frequent during summer, when the slabs reach maximum expansion.

(5) If sufficient debris accumulates in a particular section of the joint, that section of the slab's joint will be prevented from expanding freely. This condition was noticed during this study and it induces development of uneven stresses in the slab. No distress in the slab was observed from this cause.

(6) The observed cracks running between the stressing pockets located at the center of the PCP slabs did not show appreciable signs of progress, remaining hairline tight. The same condition occurred with a pothole which probably resulted because of a clay ball in the aggregate. However a second pothole with the same characteristics as the first one was detected towards the end of the monitoring stage.

(7) In general terms, all the slabs are in good condition and from the visual survey it was clear that they are behaving normally.

FROM THE DATA ANALYSIS

(1) The analysis of the data collected in the field showed it to be highly consistent and uniform.

(2) The displacements of the slabs are uniform with no slabs showing abnormal displacements.

(3) The horizontal data were very consistent for all kinds of weather. The data are strongly related to the temperature and friction in the slab.

(4) The magnitude of the vertical displacements is higher than the amount all the previous models for curling could predict. The revised model predicts values that are similar to the vertical displacements measured.

(5) Vertical displacements in the slab are more related to the temperature gradient that develops between the top and the bottom of the slab than to the temperature at the middle of the slab. However, there is a correlation between this kind of displacement and the range of variations of the temperature at the middle of the slab.

(6) There are variations in the thermal and friction coefficients between seasons. These variations should be considered during the design stage for an optimum range of design parameters.

FROM THE PREDICTION MODELS

(1) The actual level of friction between the slab and the subbase is lower than that reported by previous studies but agrees with the back calculated coefficient in the parent research project, 401. A reason for this difference might be the time the experimental section has been in service, considering the continuous daily movements as temperature changes occur.

(2) The relationship between horizontal displacements and temperature at the middle depth of the slab is linear. The same relationship holds for horizontal displacements and friction.

(3) The model used for horizontal displacements in programs PSCP1 and PSCP2 showed a good level of accuracy in the prediction of edge and intermediate point movements.

(4) The relationship between vertical displacements and temperature is not linear. It is governed by the amount of work energy transferred in the temperature exchange from environment to the slab.

(5) The relationship between the vertical displacements at intermediate points along the slab is not linear. The calculated correlation showed it to be hyperbolic in nature.

(6) The main parameters for the characterization of the vertical and horizontal displacements are the coefficients of friction, which should be carefully determined in each case.

(7) Vertical displacements are related to the geometry of the slab and the soil resilient modulus. However, the impact of the resilient modulus on the vertical displacements in PCP is less than the one proposed by some existent models.

(8) The new model for vertical displacements in program PSCP2 represents an advance in modelling, providing the functional relationship between the vertical displacements and temperature, friction, slab geometry, and strength of road bed. From these factors, the temperature gradient plays a major role as the driving force for the curling of the slab. The results from this new model showed good accuracy for the prediction of edge and intermediate point movements.

(9) Program PSCP2 proved to be an excellent tool for the backcalculation of different coefficients as well as for the study of their seasonal variations. The use of PSCP2 should be helpful in optimization of design and the achievement of economical design values.

(10) The major stresses in the slab is along the axis of the center of the slab, where the stresses due to displacements and curling add to load stresses.

RECOMMENDATIONS

(1) Frequent maintenance is necessary to keep the slab joints working, free from debris accumulated by vehicular circulation. This maintenance must be performed with care to avoid breaking the seals used in the joints. Those joint seals found broken should be replaced, but no broken seals have been noted to date.

(2) The development of low cost and low maintenance joint details is encouraged as one of the key factors towards the achievement of low cost PCP highways.

(3) It is advisable to leave a safety margin between slab joints to assure that a total closing of the slabs will not take place. In this form the joints will not cause unnecessary stresses, with the consequent potential damage for the slab (no such damage was observed).

(4) The use of friction reduction media is encouraged in the construction of highways for the reduction of stresses in pavements.

(5) The use of early prestressing is encouraged to prevent overnight or early cracking in slabs.

(6) A check considering thermal stresses must be carried out to prevent the underdesign of slabs. This check should consider the design during the early ages of the slab.

(7) The occurrence of spots with stress concentration, such as corners of prestressing boxes, etc., must be avoided. If it can not be prevented, the use of reinforcement to take care of this concentration of stress is advised.

(8) Use of trained personnel is advised for the uninterrupted placing of PCP slabs. These measures will help in achieving good rideability .

(9) The careful selection of factors and coefficients for the design of PCP is suggested in order to avoid the use of unconservative design values and at the same time allow the achievement of economic designs.

(10) The continuation of periodical monitoring of PCP slabs is recommended as a way to gain knowledge of the evolution of the coefficients of friction and, in general, of the slab performance after a long period of service life.

REFERENCES

1. Mendoza-Diaz, Alberto, Ned H. Burns, and B. Frank McCullough, "Behavior of Long Prestressed Pavement Slabs and Design Methodology," Research Report 401-3, Center for Transportation Research, The University of Texas at Austin, September 1986.
2. Tena-Colunga, Jose A., "Analysis of Input/Output for PSCP1," CTR Technical Memorandum 556-7, June 17, 1988.
3. Mandel, Elliott, Jose Tena-Colunga, and Kenneth Hankins, "Performance Tests on a Prestressed Concrete Pavement—Presentation of Data," Research Report 556-1, Center for Transportation Research, The University of Texas at Austin, November 1989.
4. Mandel, Elliott, Jose Tena-Colunga, Kenneth Hankins, Ned H. Burns, and B. Frank McCullough, "The Performance of Prestressed Concrete Pavement," Research Report 556-4F, Center for Transportation Research, The University of Texas at Austin, November 1989.
5. Mandel, Elliott David, Ned H. Burns, and B. Frank McCullough, "Prestressed Concrete Pavement: Instrumentation, Behavior, and Analysis," Research Report 556-2, Center for Transportation Research, The University of Texas at Austin, August 1989.

APPENDIX A. USER MANUAL FOR COMPUTER PROGRAM PSCP2

GENERAL

This appendix provides the input data instructions that are necessary for operating the PSCP2 program. The user should refer to Chapter 6 of this report for criteria on the selection of appropriate values for the data. Additional information is offered in Mendoza-Diaz et al (Ref 1). As an additional help, an example of the program input and an example of the program output are provided in Appendices B and C. A listing of the program in FORTRAN is available in Appendix D.

The specification of a run consists of one alphanumeric card with a description of the problem, followed by cards defining the problem, slab dimensions, concrete properties, the concrete compressive strength-age curve, the type of aggregate, the slab-base friction relationship, the k-value of the slab support, steel properties, concrete temperature data for the initial period, the time and amount of prestress applied at each post-tensioning stage (at the initial period), and temperature data for subsequent periods. The following pages provide a guide for data input. Input for the FORTRAN variables in this program can be placed anywhere in the available field, but do not forget the decimal point. Integer numbers should be right justified in their fields without a decimal point. Not following these directions will lead to errors. Alphanumeric variables allow the use of any combination of numbers and/or letters in an available field. It is advised to check the echo print of the input data to detect any error or omission.

PSCP2- Guide for Data Input

PROBLEM IDENTIFICATION (One Card)

VECTOR1
(Alphanumeric) 13A4
1 – 56

PROBLEM DEFINITION (Two Cards)

Slab Length (in) DL	Slab Width (in) DW	Slab Thickness (in) D
F10.0	F10.0	F10.0
1	11	21 – 30

No. of Elements NILD	No. Max. Iterations NMAX	Tolerance (Percent) TOL
I5	I5	F10.O
1	6	11 – 20

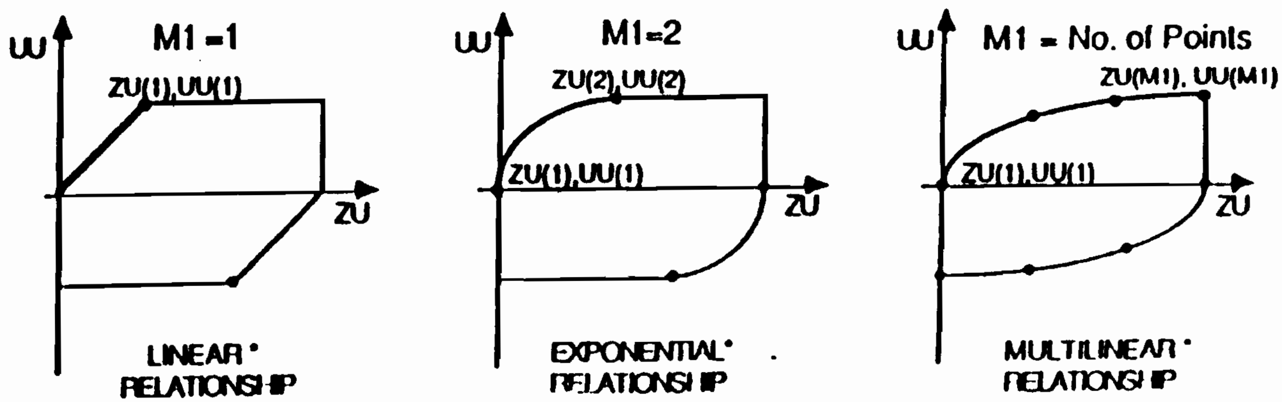
CONCRETE PROPERTIES (One Card)

Thermal Coeff. (in/in-Deg.F) ALTOT	ULtimate Shrink. Strain ZTOT	Unit Weigth (pcf) G	Poisson Ratio PR	Creep Coefficient CREEP	Aggregate Type AGGTYP
F10.0	F10.0	F10.0	F10.0	F10.0	F10.0
1	11	21	31	41	51 – 60

COEFF. OF FRICTION-DISPLACEMENT RELATIONSHIP
(Z-U Relationship)

No. of Points M1	Displ. (in) ZU(1)	Friction Coeff. UU(1)				ZU(7)	UU(7)
I5	F5.0	F5.0	F5.0	F5.0		F5.0	F5.0
1 5	11	16	21	26	31	71	76 80

ZU(8)	UU(8)				ZU(M1)	UU(M1)
F5.0	F5.0	F5.0	F5.0		F5.0	F5.0
11	16	21	26	31	61	66 70



* Only the thicker portion of the curve needs to be defined; the thinner portion is generated by the program.

PSCP2- Guide for Data Input
(Continued)

AGE-COMPRESSIVE STRENGTH RELATIONSHIP

No. of Points KK	Age (Days) AGEU(1)	Strength (psi) COMP(1)				AGEU(7)	COMP(7)
15	F5.0	F5.0	F5.0	F5.0		F5.0	F5.0
1 5	11	16	21	26	31	71	76 80

AGEU(8)	COMP(8)				AGEU(KK)	COMP(KK)
F5.0	F5.0	F5.0	F5.0		F5.0	F5.0
11	16	21	26	31	61	66 70

KK = 1, if no compressive strength data are available. The relationship will be generated by the program from the 28th day compressive strength. In this case, the 28th day should be input in COMP(1), and AGEU(1) should be equal 28.

PSCP2- Guide for Data Input
(Continued)

PCP1 - Guide for Data Input
(Continued)

STIFFNESS OF SLAB SUPPORT (One Card)

K-Value (psi/in) SK
F10.0
1 — 10

STEEL PROPERTIES (One Card)

Strand Sp. (in) SS	Nominal Area of Strand (sq.in) SA	Yield Strength (ksi) FPY	Elastic Modulus (psi) ES	Thermal Coeff. (in/in-Deg.F) ALS
F10.0	F10.0	F10.0	F10.0	F10.0
1	11	21	31	41 — 50

SS = 0, if post-tensioning forces are not to be specified.

PSCP2- Guide for Data Input
(Continued)

TEMPERATURE DATA FOR INITIAL PERIOD

No. of Temp. Data NTEMP	Setting Hour CURH	Setting Temp. (Deg. F) CURTEMP
I5	F10.0	F10.0
1 5	11	21 30

CURH = Setting hour between 0:00 and 24:00 hours

Mid-depth . Temperature (Deg. F) ADT(1)	Top-Bottom Temp. Diff. (Deg. F) TDIF(1)	Hour of Day (Optional) IHOUR(1)
F10.0	F10.0	I10
1	11	21 30

ADT(2)	TDIF(2)	IHOUR(2)
F10.0	F10.0	I10
1	11	21 30

ADT(NTEMP)	TDIF(NTEMP)	IHOUR(NTEMP)
F10.0	F10.0	I10
1	11	21 30

PSCP2- Guide for Data Input
(Continued)

SEQUENCE OF POST-TENSIONING APPLICATIONS DURING INITIAL PERIOD *
(* Specify only if SS = 0, and steel properties were provided)

No. of Post-Tensioning Stages
NS

I5
1 5

Time Since Setting (Hours)	Prestress Completed per Strand (Ksi)
IAGE	PS(1)
I5	F10.0
1 5	11 20
IAGE	PS(2)
I5	F10.0
1 5	11 20
—	—
IAGE	PS(NS)
I5	F10.0
1 5	11 20

PSCP2- Guide for Data Input
(Continued)

TEMPERATURE DATA FOR SUBSEQUENT PERIODS*
(*Repeat for as many subsequent periods as desired to analyse)

Time of Analysis
Since Setting (Days)

I5

1 5

Mid-depth . Temperature (Deg. F)	Top-Bottom Temp. Diff. (Deg. F)	Hour of Day (Optional)
ADT(1)	TDIF(1)	IHOUR(1)
F10.0	F10.0	I10
1	11	21 30
ADT(2)	TDIF(2)	IHOUR(2)
F10.0	F10.0	I10
1	11	21 30

ADT(12)	TDIF(12)	IHOUR(12)
F10.0	F10.0	I10
1	11	21 30

TERMINATION BLANK CARD

1 80

APPENDIX B. EXAMPLE OF INPUT DATA FOR COMPUTER PROGRAM PSCP2

```
ANALYSIS OF PRESTRESSED PVMT SLABS: REPORT 556-3
240.       12.00       6.00
   60  100  0.5
0.0000032 0.0003    150.      0.15      2.10      6.        4140000.
          28.0 4500.
    1     0.02  .2
1800.
34.0      0.216     270.      30000000. 0.000007
   18     14.       90.
95.       12.5
87.       -0.5
78.       -6.4
70.       -6.4
65.       -5.8
62.       -5.1
60.       -5.3
57.       -5.1
57.       -2.5
65.       1.8
80.       17.4
90.       20.4
95.       12.5
87.       -0.5
78.       -6.4
70.       -6.4
65.       -5.8
62.       -5.1
    2
   10     46.4
   24     215.
 1207
107.4     14.8           14
112.5     11.4           16
109.8      4.2           18
102.4     -5.0           20
96.4      -6.3           22
92.5      -5.8           24
89.6      -5.6            2
87.8      -5.2            4
85.       -5.1            6
84.1      -2.6            8
90.9       7.3           10
100.7     13.9           12
```

APPENDIX C. EXAMPLE OF OUTPUT FROM COMPUTER PROGRAM PSCP2

```
PPPPPP     SSSSSS     CCCCC  PPPPPP     222222 \
PPPPPPP   SSSSSSSS   CCCCCCC PPPPPPP   22222222 \
PP    PP  SS        CC       PP    PP  22\   22 \
PP    PP  SSSSSSS   CC       PP    PP    222222 \
PPPPPPP    SSSSSSS  CC       PPPPPPP    222222 \
PPPPPP          SS  CC       PPPPPP    22 \\\\
PP        SSSSSSSS   CCCCCCC PP        22222222 \
PP         SSSSSS     CCCCC  PP        22222222 \
                                        \\\\\\\\\
```

```
*******************************************************
*                                                     *
*     ANALYSIS OF PRESTRESSED CONCRETE PAVEMENTS      *
*             CONSIDERING THE INELASTIC               *
*       NATURE OF THE SLAB-BASE FRICTION FORCES       *
*              (VERSION 2, APRIL 1989)                *
*                                                     *
*          CENTER FOR TRANSPORTATION RESEARCH         *
*           THE UNIVERSITY OF TEXAS AT AUSTIN         *
*                                                     *
*******************************************************
```

```
*--**--**--**--**--**--**--**--**--**--**--**--**--**--*

*--*ANALYSIS OF PRESTRESSED PVMT SLABS: REPORT 556-3*--*

*--*            ECHO-PRINT OF GENERAL DATA           *--*

*--**--**--**--**--**--**--**--**--**--**--**--**--**--*
```

```
*********************************
*      PROBLEM DEFINITION       *
*********************************

SLAB LENGTH (FT)          =    240.0
SLAB EFFECTIVE WIDTH(FT)=       12.0
SLAB THICKNESS (IN)       =      6.0
NO.OF INCREMENTS          =       60
MAX. NO. OF ITERATIONS    =      100
REL. CLOSURE TOLERANCE    =       .5
```

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

THERMAL COEFFICIENT       =  .500E-05
TOTAL SHRINKAGE           =  .300E-03
UNIT WEIGHT (PCF)         =    150.0
POISSON RATIO             =      .15
CREEP COEFFICIENT         =     2.10
AGGREGATE TYPE            =      .00
YOUNG'S MODULUS PROVIDED=         .00

0=NOT SPECIFIED ;1=GRANITE ;2=DOLOMITE ;3=VEGA  ;4=BDG/TT;
 5=W-T ;6=FERRIS;7=LIMESTONE;8=SILICEOUS RIVER GRAVEL
```

```
**********************************
*         COMPRESSIVE            *
*        STRENGTH DATA           *
**********************************
```

THE FOLLOWING STRENGTH RELATIONSHIP WAS DEVELOPED BASED ON THE RECOMMENDATION GIVEN BY THE U.S. BUREAU OF RECLAMATION AND THE 28TH DAY COMPRES. STRENGTH PROVIDED BY USER

AGE (DAYS)	COMPRESSIVE STRENGTH
.0	.0
1.0	675.0
3.0	1710.0
5.0	2385.0
7.0	2835.0
14.0	3690.0
21.0	4230.0
28.0	4500.0

```
**********************************
* SLAB-BASE FRICTION PROPERTIES *
*       Z-U RELATIONSHIP         *
**********************************
```

TYPE OF FRICTION CURVE IS A STRAIGHT LINE

MOVEMENT AT SLIDING = .020
MAXIMUM COEFFICIENT OF FRICTION= .200

```
************************************
*   STIFFNESS OF SLAB SUPPORT     *
************************************


K-VALUE OF SUPPORT(PCI) =   1800.00



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


PERCENT REINFORCEMENT     =      .106
STRAND SPACING (IN)       =     34.00
NOMINAL AREA (SQ.IN)      =      .216
YIELD STRENGTH (KSI)      =    270.00
ELASTIC MODULUS (PSI)     =  .300E+08
THERMAL COEFFICIENT       =  .700E-05
```

*--**--**--**--**--**--**--**--**--**--**--**--**--*

*--*ANALYSIS OF PRESTRESSED PVMT SLABS: REPORT 556-3*--*

*--*PREDICTION PAVEMENT STRESSES FOR INITIAL PERIOD*--*

*--**--**--**--**--**--**--**--**--**--**--**--**--*

SETTING TEMP. (DEG.F) = 90.00

HOUR OF DAY	TEMP. AT MID-DEPTH (DEG.F)	TEMP. DIFF. (DEG.F)	PRESTRESS PER STRAND (KSI)
4 P.M.	95.0	12.5	.0
6 P.M.	87.0	-.5	.0
8 P.M.	78.0	-6.4	.0
10 P.M.	70.0	-6.4	.0
12 MIDNIGHT	65.0	-5.8	46.4
2 A.M.	62.0	-5.1	46.4
4 A.M.	60.0	-5.3	46.4
6 A.M.	57.0	-5.1	46.4
8 A.M.	57.0	-2.5	46.4
10 A.M.	65.0	1.8	46.4
12 NOON	80.0	17.4	46.4
2 P.M.	90.0	20.4	215.0
4 P.M.	95.0	12.5	215.0
6 P.M.	87.0	-.5	215.0
8 P.M.	78.0	-6.4	215.0
10 P.M.	70.0	-6.4	215.0
12 MIDNIGHT	65.0	-5.8	215.0
2 A.M.	62.0	-5.1	215.0

HOUR = 4 P.M.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-16.77	.00000	.00
4.00	.00100	-.00498	-16.75	-.00008	.00
8.00	.00199	-.01495	-16.69	-.00012	.00
12.00	.00299	-.02492	-16.59	-.00017	.00
16.00	.00399	-.03491	-16.44	-.00021	.00
20.00	.00499	-.04491	-16.25	-.00024	.00
24.00	.00600	-.05493	-16.03	-.00028	.00
28.00	.00700	-.06497	-15.75	-.00030	.00
32.00	.00801	-.07505	-15.44	-.00033	.00
36.00	.00902	-.08516	-15.09	-.00035	.00
40.00	.01004	-.09532	-14.69	-.00037	.00
44.00	.01107	-.10553	-14.25	-.00038	.00
48.00	.01210	-.11580	-13.77	-.00040	.00
52.00	.01313	-.12615	-13.24	-.00041	.00
56.00	.01418	-.13659	-12.67	-.00042	.00
60.00	.01523	-.14712	-12.06	-.00043	.00
64.00	.01630	-.15777	-11.40	-.00044	.00
68.00	.01737	-.16854	-10.70	-.00045	.00
72.00	.01846	-.17945	-9.95	-.00046	.00
76.00	.01957	-.19053	-9.16	-.00048	.00
80.00	.02069	-.19805	-8.33	-.00049	.00
84.00	.02183	-.20000	-7.50	-.00050	.00
88.00	.02298	-.20000	-6.67	-.00052	.00
92.00	.02415	-.20000	-5.83	-.00054	.00
96.00	.02535	-.20000	-5.00	-.00056	.00
100.00	.02656	-.20000	-4.17	-.00059	.00
104.00	.02778	-.20000	-3.33	-.00062	.00
108.00	.02903	-.20000	-2.50	-.00065	.00
112.00	.03030	-.20000	-1.67	-.00069	.00
116.00	.03158	-.20000	-.83	-.00073	.00
120.00	.03288	-.20000	.00	-.00078	.00

HOUR = 6 P.M.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	19.50	.00000	1.84
4.00	-.00050	.00749	19.47	.00318	1.84
8.00	-.00100	.02247	19.38	.00517	1.84
12.00	-.00151	.03746	19.22	.00702	1.84
16.00	-.00201	.05249	19.00	.00868	1.84
20.00	-.00252	.06756	18.72	.01015	1.84
24.00	-.00303	.08269	18.38	.01144	1.84
28.00	-.00355	.09789	17.97	.01258	1.84
32.00	-.00407	.11317	17.50	.01357	1.84
36.00	-.00460	.12857	16.96	.01444	1.84
40.00	-.00514	.14408	16.36	.01520	1.84
44.00	-.00569	.15975	15.70	.01586	1.84
48.00	-.00624	.17559	14.96	.01644	1.84
52.00	-.00681	.19162	14.17	.01697	1.84
56.00	-.00740	.19984	13.33	.01745	1.84
60.00	-.00799	.20000	12.50	.01790	1.84
64.00	-.00860	.20000	11.67	.01834	1.84
68.00	-.00923	.20000	10.83	.01878	1.84
72.00	-.00986	.20000	10.00	.01924	1.84
76.00	-.01052	.20000	9.17	.01975	1.84
80.00	-.01118	.20000	8.33	.02030	1.84
84.00	-.01186	.20000	7.50	.02093	1.84
88.00	-.01255	.20000	6.67	.02165	1.84
92.00	-.01325	.20000	5.83	.02247	1.84
96.00	-.01396	.20000	5.00	.02341	1.84
100.00	-.01469	.20000	4.17	.02448	1.84
104.00	-.01542	.20000	3.33	.02571	1.84
108.00	-.01616	.20000	2.50	.02711	1.84
112.00	-.01691	.20000	1.67	.02870	1.84
116.00	-.01767	.20000	.83	.03049	1.84
120.00	-.01843	.20000	.00	.03250	1.84

HOUR = 8 P.M.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	22.85	.00000	-70.15
4.00	-.00272	.01946	22.77	.00918	-70.15
8.00	-.00550	.05839	22.53	.01492	-70.15
12.00	-.00833	.09733	22.12	.02026	-70.15
16.00	-.01118	.13628	21.55	.02505	-70.15
20.00	-.01406	.17525	20.82	.02929	-70.15
24.00	-.01695	.19737	20.00	.03303	-70.15
28.00	-.01984	.20000	19.17	.03631	-70.15
32.00	-.02275	.20000	18.33	.03918	-70.15
36.00	-.02566	.20000	17.50	.04168	-70.15
40.00	-.02857	.20000	16.67	.04387	-70.15
44.00	-.03148	.20000	15.83	.04578	-70.15
48.00	-.03439	.20000	15.00	.04747	-70.15
52.00	-.03730	.20000	14.17	.04898	-70.15
56.00	-.04021	.20000	13.33	.05036	-70.15
60.00	-.04312	.20000	12.50	.05166	-70.15
64.00	-.04603	.20000	11.67	.05293	-70.15
68.00	-.04893	.20000	10.83	.05421	-70.15
72.00	-.05182	.20000	10.00	.05555	-70.15
76.00	-.05472	.20000	9.17	.05700	-70.15
80.00	-.05760	.20000	8.33	.05861	-70.15
84.00	-.06048	.20000	7.50	.06043	-70.15
88.00	-.06335	.20000	6.67	.06249	-70.15
92.00	-.06621	.20000	5.83	.06486	-70.15
96.00	-.06906	.20000	5.00	.06757	-70.15
100.00	-.07191	.20000	4.17	.07068	-70.15
104.00	-.07474	.20000	3.33	.07423	-70.15
108.00	-.07757	.20000	2.50	.07827	-70.15
112.00	-.08039	.20000	1.67	.08285	-70.15
116.00	-.08320	.20000	.83	.08802	-70.15
120.00	-.08601	.20000	.00	.09382	-70.15

HOUR = 10 P.M.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	23.54	.00000	-90.15
4.00	-.00464	.02909	23.42	.01203	-90.15
8.00	-.00935	.08727	23.05	.01957	-90.15
12.00	-.01410	.14546	22.45	.02657	-90.15
16.00	-.01888	.18728	21.67	.03285	-90.15
20.00	-.02368	.20000	20.83	.03841	-90.15
24.00	-.02850	.20000	20.00	.04332	-90.15
28.00	-.03332	.20000	19.17	.04762	-90.15
32.00	-.03815	.20000	18.33	.05138	-90.15
36.00	-.04298	.20000	17.50	.05467	-90.15
40.00	-.04782	.20000	16.67	.05753	-90.15
44.00	-.05266	.20000	15.83	.06004	-90.15
48.00	-.05749	.20000	15.00	.06225	-90.15
52.00	-.06233	.20000	14.17	.06423	-90.15
56.00	-.06717	.20000	13.33	.06605	-90.15
60.00	-.07200	.20000	12.50	.06775	-90.15
64.00	-.07683	.20000	11.67	.06941	-90.15
68.00	-.08166	.20000	10.83	.07109	-90.15
72.00	-.08648	.20000	10.00	.07285	-90.15
76.00	-.09130	.20000	9.17	.07476	-90.15
80.00	-.09611	.20000	8.33	.07687	-90.15
84.00	-.10091	.20000	7.50	.07924	-90.15
88.00	-.10570	.20000	6.67	.08195	-90.15
92.00	-.11049	.20000	5.83	.08505	-90.15
96.00	-.11527	.20000	5.00	.08861	-90.15
100.00	-.12004	.20000	4.17	.09269	-90.15
104.00	-.12480	.20000	3.33	.09735	-90.15
108.00	-.12955	.20000	2.50	.10265	-90.15
112.00	-.13430	.20000	1.67	.10866	-90.15
116.00	-.13904	.20000	.83	.11543	-90.15
120.00	-.14377	.20000	.00	.12304	-90.15

HOUR = 12 MIDNIGHT

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-25.26	.00000	-97.10
4.00	-.00642	.03802	-25.42	.01328	-97.10
8.00	-.01291	.11405	-25.90	.02159	-97.10
12.00	-.01945	.17604	-26.63	.02932	-97.10
16.00	-.02602	.20000	-27.46	.03625	-97.10
20.00	-.03260	.20000	-28.30	.04239	-97.10
24.00	-.03921	.20000	-29.13	.04780	-97.10
28.00	-.04581	.20000	-29.96	.05255	-97.10
32.00	-.05243	.20000	-30.80	.05670	-97.10
36.00	-.05905	.20000	-31.63	.06032	-97.10
40.00	-.06567	.20000	-32.46	.06348	-97.10
44.00	-.07229	.20000	-33.30	.06625	-97.10
48.00	-.07892	.20000	-34.13	.06869	-97.10
52.00	-.08554	.20000	-34.96	.07088	-97.10
56.00	-.09216	.20000	-35.80	.07288	-97.10
60.00	-.09878	.20000	-36.63	.07476	-97.10
64.00	-.10539	.20000	-37.46	.07659	-97.10
68.00	-.11201	.20000	-38.30	.07845	-97.10
72.00	-.11861	.20000	-39.13	.08039	-97.10
76.00	-.12521	.20000	-39.96	.08249	-97.10
80.00	-.13181	.20000	-40.80	.08482	-97.10
84.00	-.13840	.20000	-41.63	.08744	-97.10
88.00	-.14498	.20000	-42.46	.09043	-97.10
92.00	-.15155	.20000	-43.30	.09385	-97.10
96.00	-.15811	.20000	-44.13	.09778	-97.10
100.00	-.16467	.20000	-44.96	.10228	-97.10
104.00	-.17122	.20000	-45.80	.10742	-97.10
108.00	-.17775	.20000	-46.63	.11327	-97.10
112.00	-.18428	.20000	-47.46	.11990	-97.10
116.00	-.19081	.20000	-48.30	.12738	-97.10
120.00	-.19732	.20000	-49.13	.13577	-97.10

HOUR = 2 A.M.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-25.17	.00000	-98.42
4.00	-.00715	.04164	-25.35	.01379	-98.42
8.00	-.01436	.12493	-25.87	.02243	-98.42
12.00	-.02163	.18329	-26.63	.03046	-98.42
16.00	-.02892	.20000	-27.46	.03765	-98.42
20.00	-.03623	.20000	-28.30	.04403	-98.42
24.00	-.04356	.20000	-29.13	.04965	-98.42
28.00	-.05089	.20000	-29.96	.05458	-98.42
32.00	-.05823	.20000	-30.80	.05890	-98.42
36.00	-.06558	.20000	-31.63	.06266	-98.42
40.00	-.07292	.20000	-32.46	.06594	-98.42
44.00	-.08027	.20000	-33.30	.06881	-98.42
48.00	-.08762	.20000	-34.13	.07135	-98.42
52.00	-.09497	.20000	-34.96	.07362	-98.42
56.00	-.10231	.20000	-35.80	.07570	-98.42
60.00	-.10966	.20000	-36.63	.07766	-98.42
64.00	-.11700	.20000	-37.46	.07956	-98.42
68.00	-.12434	.20000	-38.30	.08149	-98.42
72.00	-.13167	.20000	-39.13	.08350	-98.42
76.00	-.13899	.20000	-39.96	.08569	-98.42
80.00	-.14632	.20000	-40.80	.08810	-98.42
84.00	-.15363	.20000	-41.63	.09083	-98.42
88.00	-.16093	.20000	-42.46	.09393	-98.42
92.00	-.16823	.20000	-43.30	.09749	-98.42
96.00	-.17552	.20000	-44.13	.10157	-98.42
100.00	-.18280	.20000	-44.96	.10624	-98.42
104.00	-.19007	.20000	-45.80	.11158	-98.42
108.00	-.19734	.20000	-46.63	.11766	-98.42
112.00	-.20459	.20000	-47.46	.12454	-98.42
116.00	-.21184	.20000	-48.30	.13231	-98.42
120.00	-.21908	.20000	-49.13	.14103	-98.42

HOUR = 4 A.M.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-25.11	.00000	-99.98
4.00	-.00763	.04407	-25.29	.01412	-99.98
8.00	-.01533	.13221	-25.85	.02296	-99.98
12.00	-.02308	.18814	-26.63	.03117	-99.98
16.00	-.03086	.20000	-27.46	.03853	-99.98
20.00	-.03866	.20000	-28.30	.04506	-99.98
24.00	-.04647	.20000	-29.13	.05081	-99.98
28.00	-.05429	.20000	-29.96	.05586	-99.98
32.00	-.06211	.20000	-30.80	.06027	-99.98
36.00	-.06994	.20000	-31.63	.06412	-99.98
40.00	-.07778	.20000	-32.46	.06748	-99.98
44.00	-.08561	.20000	-33.30	.07043	-99.98
48.00	-.09344	.20000	-34.13	.07302	-99.98
52.00	-.10128	.20000	-34.96	.07535	-99.98
56.00	-.10911	.20000	-35.80	.07747	-99.98
60.00	-.11694	.20000	-36.63	.07948	-99.98
64.00	-.12476	.20000	-37.46	.08142	-99.98
68.00	-.13259	.20000	-38.30	.08339	-99.98
72.00	-.14040	.20000	-39.13	.08546	-99.98
76.00	-.14822	.20000	-39.96	.08769	-99.98
80.00	-.15602	.20000	-40.80	.09017	-99.98
84.00	-.16382	.20000	-41.63	.09296	-99.98
88.00	-.17161	.20000	-42.46	.09613	-99.98
92.00	-.17939	.20000	-43.30	.09977	-99.98
96.00	-.18717	.20000	-44.13	.10395	-99.98
100.00	-.19493	.20000	-44.96	.10873	-99.98
104.00	-.20269	.20000	-45.80	.11419	-99.98
108.00	-.21044	.20000	-46.63	.12041	-99.98
112.00	-.21818	.20000	-47.46	.12746	-99.98
116.00	-.22591	.20000	-48.30	.13541	-99.98
120.00	-.23364	.20000	-49.13	.14433	-99.98

HOUR = 6 A.M.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-25.02	.00000	-100.51
4.00	-.00836	.04770	-25.22	.01445	-100.51
8.00	-.01678	.14309	-25.82	.02351	-100.51
12.00	-.02526	.19539	-26.63	.03192	-100.51
16.00	-.03376	.20000	-27.46	.03945	-100.51
20.00	-.04228	.20000	-28.30	.04614	-100.51
24.00	-.05082	.20000	-29.13	.05203	-100.51
28.00	-.05937	.20000	-29.96	.05720	-100.51
32.00	-.06792	.20000	-30.80	.06172	-100.51
36.00	-.07647	.20000	-31.63	.06566	-100.51
40.00	-.08503	.20000	-32.46	.06910	-100.51
44.00	-.09359	.20000	-33.30	.07211	-100.51
48.00	-.10215	.20000	-34.13	.07477	-100.51
52.00	-.11070	.20000	-34.96	.07715	-100.51
56.00	-.11926	.20000	-35.80	.07933	-100.51
60.00	-.12782	.20000	-36.63	.08138	-100.51
64.00	-.13637	.20000	-37.46	.08337	-100.51
68.00	-.14492	.20000	-38.30	.08539	-100.51
72.00	-.15346	.20000	-39.13	.08751	-100.51
76.00	-.16200	.20000	-39.96	.08979	-100.51
80.00	-.17053	.20000	-40.80	.09233	-100.51
84.00	-.17905	.20000	-41.63	.09518	-100.51
88.00	-.18757	.20000	-42.46	.09844	-100.51
92.00	-.19608	.20000	-43.30	.10216	-100.51
96.00	-.20458	.20000	-44.13	.10644	-100.51
100.00	-.21307	.20000	-44.96	.11133	-100.51
104.00	-.22155	.20000	-45.80	.11693	-100.51
108.00	-.23002	.20000	-46.63	.12329	-100.51
112.00	-.23849	.20000	-47.46	.13051	-100.51
116.00	-.24695	.20000	-48.30	.13865	-100.51
120.00	-.25540	.20000	-49.13	.14779	-100.51

HOUR = 8 A.M.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-25.02	.00000	-94.30
4.00	-.00836	.04772	-25.22	.01420	-94.30
8.00	-.01679	.14317	-25.82	.02309	-94.30
12.00	-.02527	.19545	-26.63	.03135	-94.30
16.00	-.03378	.20000	-27.46	.03875	-94.30
20.00	-.04231	.20000	-28.30	.04532	-94.30
24.00	-.05085	.20000	-29.13	.05110	-94.30
28.00	-.05940	.20000	-29.96	.05618	-94.30
32.00	-.06796	.20000	-30.80	.06062	-94.30
36.00	-.07652	.20000	-31.63	.06449	-94.30
40.00	-.08508	.20000	-32.46	.06787	-94.30
44.00	-.09365	.20000	-33.30	.07083	-94.30
48.00	-.10221	.20000	-34.13	.07344	-94.30
52.00	-.11077	.20000	-34.96	.07578	-94.30
56.00	-.11934	.20000	-35.80	.07792	-94.30
60.00	-.12790	.20000	-36.63	.07993	-94.30
64.00	-.13645	.20000	-37.46	.08189	-94.30
68.00	-.14501	.20000	-38.30	.08387	-94.30
72.00	-.15355	.20000	-39.13	.08595	-94.30
76.00	-.16210	.20000	-39.96	.08820	-94.30
80.00	-.17063	.20000	-40.80	.09068	-94.30
84.00	-.17916	.20000	-41.63	.09349	-94.30
88.00	-.18768	.20000	-42.46	.09668	-94.30
92.00	-.19620	.20000	-43.30	.10034	-94.30
96.00	-.20470	.20000	-44.13	.10454	-94.30
100.00	-.21320	.20000	-44.96	.10935	-94.30
104.00	-.22169	.20000	-45.80	.11485	-94.30
108.00	-.23017	.20000	-46.63	.12110	-94.30
112.00	-.23864	.20000	-47.46	.12819	-94.30
116.00	-.24710	.20000	-48.30	.13618	-94.30
120.00	-.25556	.20000	-49.13	.14516	-94.30

HOUR = 10 A.M.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-68.38	.00000	-23.57
4.00	-.00696	-.00702	-68.35	.01023	-23.57
8.00	-.01398	-.02109	-68.26	.01664	-23.57
12.00	-.02104	-.03523	-68.11	.02260	-23.57
16.00	-.02812	-.04948	-67.91	.02793	-23.57
20.00	-.03520	-.06386	-67.64	.03267	-23.57
24.00	-.04229	-.07836	-67.31	.03684	-23.57
28.00	-.04937	-.09300	-66.93	.04050	-23.57
32.00	-.05644	-.10780	-66.48	.04370	-23.57
36.00	-.06349	-.12276	-65.97	.04649	-23.57
40.00	-.07054	-.13789	-65.39	.04892	-23.57
44.00	-.07756	-.15323	-64.75	.05106	-23.57
48.00	-.08456	-.16877	-64.05	.05294	-23.57
52.00	-.09154	-.18455	-63.28	.05462	-23.57
56.00	-.09850	-.19625	-62.46	.05617	-23.57
60.00	-.10543	-.20000	-61.63	.05762	-23.57
64.00	-.11233	-.20000	-60.80	.05903	-23.57
68.00	-.11919	-.20000	-59.96	.06046	-23.57
72.00	-.12602	-.20000	-59.13	.06196	-23.57
76.00	-.13282	-.20000	-58.30	.06357	-23.57
80.00	-.13958	-.20000	-57.46	.06537	-23.57
84.00	-.14631	-.20000	-56.63	.06739	-23.57
88.00	-.15300	-.20000	-55.80	.06969	-23.57
92.00	-.15965	-.20000	-54.96	.07233	-23.57
96.00	-.16626	-.20000	-54.13	.07536	-23.57
100.00	-.17283	-.20000	-53.30	.07882	-23.57
104.00	-.17937	-.20000	-52.46	.08279	-23.57
108.00	-.18587	-.20000	-51.63	.08729	-23.57
112.00	-.19234	-.20000	-50.80	.09240	-23.57
116.00	-.19878	-.20000	-49.96	.09817	-23.57
120.00	-.20519	-.20000	-49.13	.10464	-23.57

HOUR = 12 NOON

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-72.52	.00000	-5.89
4.00	-.00332	-.02613	-72.41	.00591	-5.89
8.00	-.00663	-.07841	-72.08	.00961	-5.89
12.00	-.00994	-.13076	-71.54	.01305	-5.89
16.00	-.01324	-.17848	-70.80	.01614	-5.89
20.00	-.01653	-.20000	-69.96	.01887	-5.89
24.00	-.01981	-.20000	-69.13	.02128	-5.89
28.00	-.02309	-.20000	-68.30	.02339	-5.89
32.00	-.02635	-.20000	-67.46	.02524	-5.89
36.00	-.02960	-.20000	-66.63	.02685	-5.89
40.00	-.03284	-.20000	-65.80	.02826	-5.89
44.00	-.03607	-.20000	-64.96	.02949	-5.89
48.00	-.03929	-.20000	-64.13	.03058	-5.89
52.00	-.04250	-.20000	-63.30	.03155	-5.89
56.00	-.04570	-.20000	-62.46	.03244	-5.89
60.00	-.04888	-.20000	-61.63	.03328	-5.89
64.00	-.05205	-.20000	-60.80	.03410	-5.89
68.00	-.05521	-.20000	-59.96	.03492	-5.89
72.00	-.05836	-.20000	-59.13	.03579	-5.89
76.00	-.06148	-.20000	-58.30	.03672	-5.89
80.00	-.06460	-.20000	-57.46	.03776	-5.89
84.00	-.06769	-.20000	-56.63	.03893	-5.89
88.00	-.07077	-.20000	-55.80	.04026	-5.89
92.00	-.07383	-.20000	-54.96	.04178	-5.89
96.00	-.07687	-.20000	-54.13	.04353	-5.89
100.00	-.07989	-.20000	-53.30	.04553	-5.89
104.00	-.08290	-.20000	-52.46	.04782	-5.89
108.00	-.08588	-.20000	-51.63	.05042	-5.89
112.00	-.08885	-.20000	-50.80	.05338	-5.89
116.00	-.09180	-.20000	-49.96	.05670	-5.89
120.00	-.09474	-.20000	-49.13	.06044	-5.89

HOUR = 2 P.M.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-251.11	.00000	-1.47
4.00	-.00303	-.02757	-250.99	.00214	-1.47
8.00	-.00606	-.08273	-250.65	.00348	-1.47
12.00	-.00908	-.13796	-250.08	.00472	-1.47
16.00	-.01209	-.18280	-249.31	.00584	-1.47
20.00	-.01510	-.20000	-248.48	.00683	-1.47
24.00	-.01809	-.20000	-247.65	.00770	-1.47
28.00	-.02107	-.20000	-246.81	.00846	-1.47
32.00	-.02404	-.20000	-245.98	.00913	-1.47
36.00	-.02701	-.20000	-245.15	.00971	-1.47
40.00	-.02996	-.20000	-244.31	.01022	-1.47
44.00	-.03290	-.20000	-243.48	.01067	-1.47
48.00	-.03584	-.20000	-242.65	.01106	-1.47
52.00	-.03876	-.20000	-241.81	.01141	-1.47
56.00	-.04167	-.20000	-240.98	.01174	-1.47
60.00	-.04457	-.20000	-240.15	.01204	-1.47
64.00	-.04745	-.20000	-239.31	.01233	-1.47
68.00	-.05032	-.20000	-238.48	.01263	-1.47
72.00	-.05318	-.20000	-237.65	.01295	-1.47
76.00	-.05602	-.20000	-236.81	.01328	-1.47
80.00	-.05884	-.20000	-235.98	.01366	-1.47
84.00	-.06165	-.20000	-235.15	.01408	-1.47
88.00	-.06444	-.20000	-234.31	.01456	-1.47
92.00	-.06721	-.20000	-233.48	.01511	-1.47
96.00	-.06996	-.20000	-232.65	.01575	-1.47
100.00	-.07270	-.20000	-231.81	.01647	-1.47
104.00	-.07542	-.20000	-230.98	.01730	-1.47
108.00	-.07811	-.20000	-230.15	.01824	-1.47
112.00	-.08079	-.20000	-229.31	.01931	-1.47
116.00	-.08346	-.20000	-228.48	.02051	-1.47
120.00	-.08610	-.20000	-227.65	.02186	-1.47

HOUR = 4 P.M.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTIO' (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-251.40	.00000	.00
4.00	-.00184	-.03354	-251.26	-.00008	.00
8.00	-.00367	-.10065	-250.84	-.00012	.00
12.00	-.00550	-.16711	-250.15	-.00017	.00
16.00	-.00732	-.20000	-249.31	-.00021	.00
20.00	-.00912	-.20000	-248.48	-.00024	.00
24.00	-.01092	-.20000	-247.65	-.00028	.00
28.00	-.01271	-.20000	-246.81	-.00030	.00
32.00	-.01449	-.20000	-245.98	-.00033	.00
36.00	-.01626	-.20000	-245.15	-.00035	.00
40.00	-.01801	-.20000	-244.31	-.00037	.00
44.00	-.01976	-.20000	-243.48	-.00038	.00
48.00	-.02150	-.20000	-242.65	-.00040	.00
52.00	-.02323	-.20000	-241.81	-.00041	.00
56.00	-.02494	-.20000	-240.98	-.00042	.00
60.00	-.02664	-.20000	-240.15	-.00043	.00
64.00	-.02833	-.20000	-239.31	-.00044	.00
68.00	-.03001	-.20000	-238.48	-.00045	.00
72.00	-.03167	-.20000	-237.65	-.00046	.00
76.00	-.03332	-.20000	-236.81	-.00048	.00
80.00	-.03495	-.20000	-235.98	-.00049	.00
84.00	-.03656	-.20000	-235.15	-.00050	.00
88.00	-.03815	-.20000	-234.31	-.00052	.00
92.00	-.03973	-.20000	-233.48	-.00054	.00
96.00	-.04129	-.20000	-232.65	-.00056	.00
100.00	-.04283	-.20000	-231.81	-.00059	.00
104.00	-.04435	-.20000	-230.98	-.00062	.00
108.00	-.04586	-.20000	-230.15	-.00065	.00
112.00	-.04734	-.20000	-229.31	-.00069	.00
116.00	-.04881	-.20000	-228.48	-.00073	.00
120.00	-.05026	-.20000	-227.65	-.00078	.00

HOUR = 6 P.M.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-208.36	.00000	.00
4.00	-.00325	.00709	-208.39	.00325	.00
8.00	-.00651	.02129	-208.48	.00529	.00
12.00	-.00977	.03555	-208.62	.00719	.00
16.00	-.01303	.04991	-208.83	.00888	.00
20.00	-.01629	.06438	-209.10	.01039	.00
24.00	-.01955	.07898	-209.43	.01172	.00
28.00	-.02282	.09373	-209.82	.01288	.00
32.00	-.02610	.10863	-210.27	.01390	.00
36.00	-.02938	.12369	-210.79	.01479	.00
40.00	-.03267	.13893	-211.37	.01556	.00
44.00	-.03597	.15436	-212.01	.01624	.00
48.00	-.03928	.17002	-212.72	.01684	.00
52.00	-.04259	.18590	-213.49	.01737	.00
56.00	-.04593	.19695	-214.31	.01786	.00
60.00	-.04927	.20000	-215.15	.01833	.00
64.00	-.05263	.20000	-215.98	.01877	.00
68.00	-.05601	.20000	-216.81	.01923	.00
72.00	-.05939	.20000	-217.65	.01971	.00
76.00	-.06280	.20000	-218.48	.02022	.00
80.00	-.06621	.20000	-219.31	.02079	.00
84.00	-.06964	.20000	-220.15	.02143	.00
88.00	-.07308	.20000	-220.98	.02217	.00
92.00	-.07653	.20000	-221.81	.02301	.00
96.00	-.07999	.20000	-222.65	.02397	.00
100.00	-.08347	.20000	-223.48	.02507	.00
104.00	-.08695	.20000	-224.31	.02633	.00
108.00	-.09044	.20000	-225.15	.02776	.00
112.00	-.09394	.20000	-225.98	.02939	.00
116.00	-.09744	.20000	-226.81	.03122	.00
120.00	-.10095	.20000	-227.65	.03328	.00

HOUR = 8 P.M.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-204.84	.00000	.00
4.00	-.00547	.01905	-204.92	.00627	.00
8.00	-.01101	.05718	-205.16	.01020	.00
12.00	-.01659	.09536	-205.56	.01385	.00
16.00	-.02219	.13361	-206.12	.01712	.00
20.00	-.02782	.17196	-206.83	.02002	.00
24.00	-.03346	.19558	-207.65	.02257	.00
28.00	-.03910	.20000	-208.48	.02481	.00
32.00	-.04476	.20000	-209.31	.02677	.00
36.00	-.05042	.20000	-210.15	.02848	.00
40.00	-.05608	.20000	-210.98	.02998	.00
44.00	-.06174	.20000	-211.81	.03128	.00
48.00	-.06740	.20000	-212.65	.03244	.00
52.00	-.07306	.20000	-213.48	.03347	.00
56.00	-.07872	.20000	-214.31	.03441	.00
60.00	-.08438	.20000	-215.15	.03530	.00
64.00	-.09004	.20000	-215.98	.03617	.00
68.00	-.09569	.20000	-216.81	.03704	.00
72.00	-.10134	.20000	-217.65	.03796	.00
76.00	-.10698	.20000	-218.48	.03895	.00
80.00	-.11261	.20000	-219.31	.04005	.00
84.00	-.11824	.20000	-220.15	.04129	.00
88.00	-.12386	.20000	-220.98	.04270	.00
92.00	-.12947	.20000	-221.81	.04432	.00
96.00	-.13508	.20000	-222.65	.04617	.00
100.00	-.14067	.20000	-223.48	.04830	.00
104.00	-.14626	.20000	-224.31	.05072	.00
108.00	-.15184	.20000	-225.15	.05349	.00
112.00	-.15741	.20000	-225.98	.05662	00
116.00	-.16297	.20000	-226.81	.06015	.00
120.00	-.16852	.20000	-227.65	.06411	.00

HOUR = 10 P.M.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-204.13	.00000	.00
4.00	-.00739	.02868	-204.25	.00830	.00
8.00	-.01485	.08606	-204.61	.01350	.00
12.00	-.02235	.14349	-205.20	.01833	.00
16.00	-.02989	.18611	-205.98	.02266	.00
20.00	-.03744	.20000	-206.81	.02649	.00
24.00	-.04500	.20000	-207.65	.02988	.00
28.00	-.05258	.20000	-208.48	.03285	.00
32.00	-.06016	.20000	-209.31	.03544	.00
36.00	-.06774	.20000	-210.15	.03770	.00
40.00	-.07533	.20000	-210.98	.03968	.00
44.00	-.08292	.20000	-211.81	.04141	.00
48.00	-.09050	.20000	-212.65	.04294	.00
52.00	-.09809	.20000	-213.48	.04430	.00
56.00	-.10568	.20000	-214.31	.04555	.00
60.00	-.11326	.20000	-215.15	.04673	.00
64.00	-.12084	.20000	-215.98	.04788	.00
68.00	-.12842	.20000	-216.81	.04903	.00
72.00	-.13599	.20000	-217.65	.05025	.00
76.00	-.14356	.20000	-218.48	.05156	.00
80.00	-.15112	.20000	-219.31	.05302	.00
84.00	-.15867	.20000	-220.15	.05466	.00
88.00	-.16622	.20000	-220.98	.05652	.00
92.00	-.17375	.20000	-221.81	.05866	.00
96.00	-.18128	.20000	-222.65	.06112	.00
100.00	-.18880	.20000	-223.48	.06393	.00
104.00	-.19632	.20000	-224.31	.06714	.00
108.00	-.20382	.20000	-225.15	.07080	.00
112.00	-.21131	.20000	-225.98	.07494	.00
116.00	-.21880	.20000	-226.81	.07962	.00
120.00	-.22628	.20000	-227.65	.08486	.00

HOUR = 12 MIDNIGHT

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-203.86	.00000	.00
4.00	-.00860	.03471	-204.01	.00926	.00
8.00	-.01726	.10414	-204.44	.01505	.00
12.00	-.02597	.16943	-205.15	.02044	.00
16.00	-.03470	.20000	-205.98	.02527	.00
20.00	-.04346	.20000	-206.81	.02955	.00
24.00	-.05223	.20000	-207.65	.03332	.00
28.00	-.06101	.20000	-208.48	.03663	.00
32.00	-.06980	.20000	-209.31	.03953	.00
36.00	-.07859	.20000	-210.15	.04205	.00
40.00	-.08738	.20000	-210.98	.04426	.00
44.00	-.09617	.20000	-211.81	.04619	.00
48.00	-.10497	.20000	-212.65	.04789	.00
52.00	-.11376	.20000	-213.48	.04941	.00
56.00	-.12255	.20000	-214.31	.05081	.00
60.00	-.13134	.20000	-215.15	.05212	.00
64.00	-.14013	.20000	-215.98	.05340	.00
68.00	-.14891	.20000	-216.81	.05469	.00
72.00	-.15769	.20000	-217.65	.05604	.00
76.00	-.16646	.20000	-218.48	.05751	.00
80.00	-.17522	.20000	-219.31	.05913	.00
84.00	-.18398	.20000	-220.15	.06096	.00
88.00	-.19273	.20000	-220.98	.06304	.00
92.00	-.20148	.20000	-221.81	.06543	.00
96.00	-.21021	.20000	-222.65	.06817	.00
100.00	-.21894	.20000	-223.48	.07130	.00
104.00	-.22765	.20000	-224.31	.07489	.00
108.00	-.23636	.20000	-225.15	.07897	.00
112.00	-.24506	.20000	-225.98	.08359	.00
116.00	-.25375	.20000	-226.81	.08880	.00
120.00	-.26244	.20000	-227.65	.09465	.00

HOUR = 2 A.M.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-203.77	.00000	.00
4.00	-.00932	.03833	-203.93	.00972	.00
8.00	-.01871	.11502	-204.41	.01580	.00
12.00	-.02814	.17668	-205.15	.02146	.00
16.00	-.03760	.20000	-205.98	.02652	.00
20.00	-.04709	.20000	-206.81	.03102	.00
24.00	-.05659	.20000	-207.65	.03498	.00
28.00	-.06609	.20000	-208.48	.03845	.00
32.00	-.07560	.20000	-209.31	.04149	.00
36.00	-.08512	.20000	-210.15	.04414	.00
40.00	-.09463	.20000	-210.98	.04645	.00
44.00	-.10415	.20000	-211.81	.04848	.00
48.00	-.11367	.20000	-212.65	.05027	.00
52.00	-.12319	.20000	-213.48	.05187	.00
56.00	-.13270	.20000	-214.31	.05333	.00
60.00	-.14222	.20000	-215.15	.05471	.00
64.00	-.15173	.20000	-215.98	.05605	.00
68.00	-.16124	.20000	-216.81	.05740	.00
72.00	-.17074	.20000	-217.65	.05883	.00
76.00	-.18024	.20000	-218.48	.06036	.00
80.00	-.18973	.20000	-219.31	.06207	.00
84.00	-.19921	.20000	-220.15	.06399	.00
88.00	-.20869	.20000	-220.98	.06617	.00
92.00	-.21816	.20000	-221.81	.06868	.00
96.00	-.22762	.20000	-222.65	.07155	.00
100.00	-.23707	.20000	-223.48	.07484	.00
104.00	-.24651	.20000	-224.31	.07860	.00
108.00	-.25594	.20000	-225.15	.08288	.00
112.00	-.26537	.20000	-225.98	.08774	.00
116.00	-.27479	.20000	-226.81	.09321	.00
120.00	-.28420	.20000	-227.65	.09935	.00

*--**--**--**--**--**--**--**--**--**--**--**--**--**--**--**--*

*--*ANALYSIS OF PRESTRESSED PVMT SLABS: REPORT 556-3*--*

-- PREDICTION OF PAVEMENT STRESSES FOR *--*
-- INTERMEDIATE/FINAL PERIOD *--*

*--**--**--**--**--**--**--**--**--**--**--**--**--**--**--**--*

TIME OF ANALYSIS FROM END
OF SLAB SETTING (DAYS) = 1207

HOUR OF DAY	TEMP. AT MID-DEPTH (DEG.F)	TEMP. DIFF. (DEG.F)	PRESTRESS PER STRAND (KSI)
8 A.M.	107.4	14.8	179.8
10 A.M.	112.5	11.4	179.8
12 NOON	109.8	4.2	179.8
2 P.M.	102.4	-5.0	179.8
4 P.M.	96.4	-6.3	179.8
6 P.M.	92.5	-5.8	179.8
8 P.M.	89.6	-5.6	179.8
10 P.M.	87.8	-5.2	179.8
12 MIDNIGHT	85.0	-5.1	179.8
2 A.M.	84.1	-2.6	179.8
4 A.M.	90.9	7.3	179.8
6 A.M.	100.7	13.9	179.8

HOUR = 14:00 HRS.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-213.83	.00000	.00
4.00	-.01553	-.02656	-213.72	-.00008	.00
8.00	-.03111	-.07971	-213.39	-.00012	.00
12.00	-.04673	-.13290	-212.83	-.00017	.00
16.00	-.06237	-.17975	-212.08	-.00021	.00
20.00	-.07800	-.20000	-211.25	-.00024	.00
24.00	-.09363	-.20000	-210.42	-.00028	.00
28.00	-.10925	-.20000	-209.58	-.00030	.00
32.00	-.12485	-.20000	-208.75	-.00033	.00
36.00	-.14044	-.20000	-207.92	-.00035	.00
40.00	-.15601	-.20000	-207.08	-.00037	.00
44.00	-.17156	-.20000	-206.25	-.00038	.00
48.00	-.18709	-.20000	-205.42	-.00040	.00
52.00	-.20260	-.20000	-204.58	-.00041	.00
56.00	-.21809	-.20000	-203.75	-.00042	.00
60.00	-.23356	-.20000	-202.92	-.00043	.00
64.00	-.24901	-.20000	-202.08	-.00044	.00
68.00	-.26444	-.20000	-201.25	-.00045	.00
72.00	-.27984	-.20000	-200.42	-.00046	.00
76.00	-.29521	-.20000	-199.58	-.00048	.00
80.00	-.31056	-.20000	-198.75	-.00049	.00
84.00	-.32589	-.20000	-197.92	-.00050	.00
88.00	-.34119	-.20000	-197.08	-.00052	.00
92.00	-.35646	-.20000	-196.25	-.00054	.00
96.00	-.37170	-.20000	-195.42	-.00056	.00
100.00	-.38692	-.20000	-194.58	-.00059	.00
104.00	-.40210	-.20000	-193.75	-.00062	.00
108.00	-.41726	-.20000	-192.92	-.00065	.00
112.00	-.43240	-.20000	-192.08	-.00069	.00
116.00	-.44750	-.20000	-191.25	-.00073	.00
120.00	-.46258	-.20000	-190.42	-.00078	.00

HOUR = 16:00 HRS.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-214.14	.00000	.00
4.00	-.01431	-.03267	-214.00	-.00282	.00
8.00	-.02867	-.09802	-213.59	-.00459	.00
12.00	-.04307	-.16342	-212.91	-.00623	.00
16.00	-.05749	-.19807	-212.08	-.00771	.00
20.00	-.07190	-.20000	-211.25	-.00901	.00
24.00	-.08631	-.20000	-210.42	-.01016	.00
28.00	-.10070	-.20000	-209.58	-.01117	.00
32.00	-.11508	-.20000	-208.75	-.01205	.00
36.00	-.12945	-.20000	-207.92	-.01282	.00
40.00	-.14380	-.20000	-207.08	-.01350	.00
44.00	-.15813	-.20000	-206.25	-.01408	.00
48.00	-.17244	-.20000	-205.42	-.01460	.00
52.00	-.18673	-.20000	-204.58	-.01507	.00
56.00	-.20100	-.20000	-203.75	-.01549	.00
60.00	-.21525	-.20000	-202.92	-.01589	.00
64.00	-.22948	-.20000	-202.08	-.01628	.00
68.00	-.24368	-.20000	-201.25	-.01668	.00
72.00	-.25786	-.20000	-200.42	-.01709	.00
76.00	-.27202	-.20000	-199.58	-.01754	.00
80.00	-.28615	-.20000	-198.75	-.01803	.00
84.00	-.30025	-.20000	-197.92	-.01859	.00
88.00	-.31433	-.20000	-197.08	-.01922	.00
92.00	-.32838	-.20000	-196.25	-.01995	.00
96.00	-.34240	-.20000	-195.42	-.02079	.00
100.00	-.35639	-.20000	-194.58	-.02174	.00
104.00	-.37036	-.20000	-193.75	-.02284	.00
108.00	-.38430	-.20000	-192.92	-.02408	.00
112.00	-.39821	-.20000	-192.08	-.02549	.00
116.00	-.41210	-.20000	-191.25	-.02708	.00
120.00	-.42595	-.20000	-190.42	-.02886	.00

HOUR = 18:00 HRS.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-183.19	.00000	.00
4.00	-.01459	.00143	-183.20	-.00134	.00
8.00	-.02925	.00431	-183.22	-.00218	.00
12.00	-.04395	.00723	-183.25	-.00295	.00
16.00	-.05866	.01023	-183.29	-.00365	.00
20.00	-.07339	.01333	-183.35	-.00427	.00
24.00	-.08812	.01653	-183.42	-.00482	.00
28.00	-.10286	.01983	-183.50	-.00529	.00
32.00	-.11758	.02323	-183.59	-.00571	.00
36.00	-.13231	.02674	-183.71	-.00608	.00
40.00	-.14702	.03036	-183.83	-.00640	.00
44.00	-.16173	.03409	-183.97	-.00668	.00
48.00	-.17644	.03794	-184.13	-.00692	.00
52.00	-.19113	.04191	-184.31	-.00714	.00
56.00	-.20582	.04601	-184.50	-.00734	.00
60.00	-.22049	.05024	-184.71	-.00753	.00
64.00	-.23516	.05461	-184.94	-.00772	.00
68.00	-.24982	.05913	-185.18	-.00790	.00
72.00	-.26447	.06379	-185.45	-.00810	.00
76.00	-.27911	.06862	-185.73	-.00831	.00
80.00	-.29375	.07361	-186.04	-.00855	.00
84.00	-.30837	.07877	-186.37	-.00881	.00
88.00	-.32298	.08411	-186.72	-.00911	.00
92.00	-.33759	.08963	-187.09	-.00946	.00
96.00	-.35218	.09534	-187.49	-.00985	.00
100.00	-.36677	.10124	-187.91	-.01031	.00
104.00	-.38135	.10732	-188.36	-.01082	.00
108.00	-.39591	.11360	-188.83	-.01141	.00
112.00	-.41048	.12008	-189.33	-.01208	.00
116.00	-.42503	.12675	-189.86	-.01283	.00
120.00	-.43958	.13362	-190.42	-.01368	.00

HOUR = 20:00 HRS.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-169.72	.00000	-33.89
4.00	-.01621	.00954	-169.76	.00378	-33.89
8.00	-.03249	.02863	-169.88	.00614	-33.89
12.00	-.04881	.04778	-170.08	.00834	-33.89
16.00	-.06515	.06703	-170.36	.01031	-33.89
20.00	-.08151	.08642	-170.72	.01206	-33.89
24.00	-.09788	.10596	-171.16	.01360	-33.89
28.00	-.11425	.12567	-171.69	.01495	-33.89
32.00	-.13063	.14556	-172.29	.01613	-33.89
36.00	-.14701	.16567	-172.98	.01716	-33.89
40.00	-.16340	.18602	-173.76	.01806	-33.89
44.00	-.17980	.19813	-174.58	.01885	-33.89
48.00	-.19620	.20000	-175.42	.01954	-33.89
52.00	-.21261	.20000	-176.25	.02016	-33.89
56.00	-.22903	.20000	-177.08	.02073	-33.89
60.00	-.24546	.20000	-177.92	.02127	-33.89
64.00	-.26189	.20000	-178.75	.02179	-33.89
68.00	-.27834	.20000	-179.58	.02232	-33.89
72.00	-.29479	.20000	-180.42	.02287	-33.89
76.00	-.31125	.20000	-181.25	.02347	-33.89
80.00	-.32771	.20000	-182.08	.02413	-33.89
84.00	-.34418	.20000	-182.92	.02488	-33.89
88.00	-.36065	.20000	-183.75	.02573	-33.89
92.00	-.37713	.20000	-184.58	.02670	-33.89
96.00	-.39360	.20000	-185.42	.02782	-33.89
100.00	-.41007	.20000	-186.25	.02910	-33.89
104.00	-.42653	.20000	-187.08	.03056	-33.89
108.00	-.44299	.20000	-187.92	.03222	-33.89
112.00	-.45944	.20000	-188.75	.03411	-33.89
116.00	-.47589	.20000	-189.58	.03624	-33.89
120.00	-.49233	.20000	-190.42	.03863	-33.89

HOUR = 22:00 HRS.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-167.75	.00000	-57.44
4.00	-.01773	.01797	-167.83	.00738	-57.44
8.00	-.03558	.05393	-168.05	.01200	-57.44
12.00	-.05351	.08994	-168.42	.01629	-57.44
16.00	-.07150	.12602	-168.95	.02014	-57.44
20.00	-.08951	.16220	-169.63	.02355	-57.44
24.00	-.10754	.19016	-170.42	.02656	-57.44
28.00	-.12558	.20000	-171.25	.02920	-57.44
32.00	-.14362	.20000	-172.08	.03150	-57.44
36.00	-.16166	.20000	-172.92	.03352	-57.44
40.00	-.17969	.20000	-173.75	.03527	-57.44
44.00	-.19772	.20000	-174.58	.03681	-57.44
48.00	-.21574	.20000	-175.42	.03817	-57.44
52.00	-.23375	.20000	-176.25	.03938	-57.44
56.00	-.25175	.20000	-177.08	.04049	-57.44
60.00	-.26973	.20000	-177.92	.04154	-57.44
64.00	-.28771	.20000	-178.75	.04256	-57.44
68.00	-.30567	.20000	-179.58	.04359	-57.44
72.00	-.32362	.20000	-180.42	.04467	-57.44
76.00	-.34155	.20000	-181.25	.04584	-57.44
80.00	-.35947	.20000	-182.08	.04713	-57.44
84.00	-.37737	.20000	-182.92	.04859	-57.44
88.00	-.39526	.20000	-183.75	.05025	-57.44
92.00	-.41313	.20000	-184.58	.05215	-57.44
96.00	-.43098	.20000	-185.42	.05433	-57.44
100.00	-.44881	.20000	-186.25	.05683	-57.44
104.00	-.46662	.20000	-187.08	.05969	-57.44
108.00	-.48442	.20000	-187.92	.06294	-57.44
112.00	-.50220	.20000	-188.75	.06662	-57.44
116.00	-.51996	.20000	-189.58	.07078	-57.44
120.00	-.53770	.20000	-190.42	.07544	-57.44

HOUR = 24:00 HRS.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-167.28	.00000	-69.54
4.00	-.01866	.02267	-167.37	.00940	-69.54
8.00	-.03745	.06802	-167.65	.01529	-69.54
12.00	-.05632	.11342	-168.13	.02076	-69.54
16.00	-.07525	.15889	-168.79	.02566	-69.54
20.00	-.09420	.19082	-169.58	.03001	-69.54
24.00	-.11317	.20000	-170.42	.03384	-69.54
28.00	-.13215	.20000	-171.25	.03720	-69.54
32.00	-.15113	.20000	-172.08	.04014	-69.54
36.00	-.17011	.20000	-172.92	.04271	-69.54
40.00	-.18908	.20000	-173.75	.04494	-69.54
44.00	-.20805	.20000	-174.58	.04690	-69.54
48.00	-.22701	.20000	-175.42	.04863	-69.54
52.00	-.24595	.20000	-176.25	.05018	-69.54
56.00	-.26489	.20000	-177.08	.05160	-69.54
60.00	-.28382	.20000	-177.92	.05293	-69.54
64.00	-.30273	.20000	-178.75	.05423	-69.54
68.00	-.32164	.20000	-179.58	.05554	-69.54
72.00	-.34052	.20000	-180.42	.05691	-69.54
76.00	-.35940	.20000	-181.25	.05840	-69.54
80.00	-.37825	.20000	-182.08	.06005	-69.54
84.00	-.39710	.20000	-182.92	.06191	-69.54
88.00	-.41592	.20000	-183.75	.06402	-69.54
92.00	-.43473	.20000	-184.58	.06645	-69.54
96.00	-.45352	.20000	-185.42	.06923	-69.54
100.00	-.47229	.20000	-186.25	.07241	-69.54
104.00	-.49104	.20000	-187.08	.07605	-69.54
108.00	-.50978	.20000	-187.92	.08019	-69.54
112.00	-.52849	.20000	-188.75	.08488	-69.54
116.00	-.54719	.20000	-189.58	.09018	-69.54
120.00	-.56588	.20000	-190.42	.09612	-69.54

HOUR = 2:00 HRS.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-167.03	.00000	-76.93
4.00	-.01936	.02616	-167.13	.01074	-76.93
8.00	-.03885	.07850	-167.46	.01747	-76.93
12.00	-.05842	.13089	-168.01	.02373	-76.93
16.00	-.07804	.17855	-168.75	.02933	-76.93
20.00	-.09769	.20000	-169.58	.03429	-76.93
24.00	-.11736	.20000	-170.42	.03867	-76.93
28.00	-.13704	.20000	-171.25	.04252	-76.93
32.00	-.15672	.20000	-172.08	.04588	-76.93
36.00	-.17640	.20000	-172.92	.04881	-76.93
40.00	-.19607	.20000	-173.75	.05136	-76.93
44.00	-.21574	.20000	-174.58	.05360	-76.93
48.00	-.23539	.20000	-175.42	.05558	-76.93
52.00	-.25504	.20000	-176.25	.05735	-76.93
56.00	-.27468	.20000	-177.08	.05897	-76.93
60.00	-.29431	.20000	-177.92	.06049	-76.93
64.00	-.31392	.20000	-178.75	.06197	-76.93
68.00	-.33352	.20000	-179.58	.06347	-76.93
72.00	-.35311	.20000	-180.42	.06504	-76.93
76.00	-.37268	.20000	-181.25	.06674	-76.93
80.00	-.39224	.20000	-182.08	.06863	-76.93
84.00	-.41178	.20000	-182.92	.07075	-76.93
88.00	-.43130	.20000	-183.75	.07317	-76.93
92.00	-.45081	.20000	-184.58	.07594	-76.93
96.00	-.47029	.20000	-185.42	.07911	-76.93
100.00	-.48976	.20000	-186.25	.08275	-76.93
104.00	-.50922	.20000	-187.08	.08691	-76.93
108.00	-.52865	.20000	-187.92	.09165	-76.93
112.00	-.54807	.20000	-188.75	.09701	-76.93
116.00	-.56747	.20000	-189.58	.10306	-76.93
120.00	-.58685	.20000	-190.42	.10985	-76.93

HOUR = 4:00 HRS.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-166.92	.00000	-81.05
4.00	-.01980	.02834	-167.04	.01152	-81.05
8.00	-.03972	.08503	-167.39	.01873	-81.05
12.00	-.05972	.14177	-167.98	.02543	-81.05
16.00	-.07978	.18508	-168.75	.03144	-81.05
20.00	-.09987	.20000	-169.58	.03676	-81.05
24.00	-.11997	.20000	-170.42	.04146	-81.05
28.00	-.14009	.20000	-171.25	.04558	-81.05
32.00	-.16020	.20000	-172.08	.04918	-81.05
36.00	-.18032	.20000	-172.92	.05232	-81.05
40.00	-.20042	.20000	-173.75	.05506	-81.05
44.00	-.22052	.20000	-174.58	.05746	-81.05
48.00	-.24062	.20000	-175.42	.05958	-81.05
52.00	-.26070	.20000	-176.25	.06148	-81.05
56.00	-.28077	.20000	-177.08	.06321	-81.05
60.00	-.30083	.20000	-177.92	.06484	-81.05
64.00	-.32088	.20000	-178.75	.06643	-81.05
68.00	-.34092	.20000	-179.58	.06804	-81.05
72.00	-.36094	.20000	-180.42	.06973	-81.05
76.00	-.38095	.20000	-181.25	.07155	-81.05
80.00	-.40094	.20000	-182.08	.07357	-81.05
84.00	-.42091	.20000	-182.92	.07584	-81.05
88.00	-.44087	.20000	-183.75	.07844	-81.05
92.00	-.46081	.20000	-184.58	.08140	-81.05
96.00	-.48074	.20000	-185.42	.08481	-81.05
100.00	-.50064	.20000	-186.25	.08871	-81.05
104.00	-.52053	.20000	-187.08	.09317	-81.05
108.00	-.54040	.20000	-187.92	.09824	-81.05
112.00	-.56025	.20000	-188.75	.10399	-81.05
116.00	-.58009	.20000	-189.58	.11048	-81.05
120.00	-.59990	.20000	-190.42	.11776	-81.05

HOUR = 6:00 HRS.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-166.75	.00000	-83.88
4.00	-.02047	.03171	-166.88	.01251	-83.88
8.00	-.04107	.09516	-167.28	.02035	-83.88
12.00	-.06175	.15865	-167.94	.02763	-83.88
16.00	-.08248	.19520	-168.75	.03415	-83.88
20.00	-.10324	.20000	-169.58	.03994	-83.88
24.00	-.12402	.20000	-170.42	.04504	-83.88
28.00	-.14481	.20000	-171.25	.04951	-83.88
32.00	-.16560	.20000	-172.08	.05342	-83.88
36.00	-.18639	.20000	-172.92	.05683	-83.88
40.00	-.20717	.20000	-173.75	.05981	-83.88
44.00	-.22795	.20000	-174.58	.06242	-83.88
48.00	-.24872	.20000	-175.42	.06472	-83.88
52.00	-.26948	.20000	-176.25	.06678	-83.88
56.00	-.29022	.20000	-177.08	.06867	-83.88
60.00	-.31096	.20000	-177.92	.07044	-83.88
64.00	-.33168	.20000	-178.75	.07217	-83.88
68.00	-.35239	.20000	-179.58	.07391	-83.88
72.00	-.37309	.20000	-180.42	.07574	-83.88
76.00	-.39377	.20000	-181.25	.07772	-83.88
80.00	-.41444	.20000	-182.08	.07992	-83.88
84.00	-.43509	.20000	-182.92	.08239	-83.88
88.00	-.45572	.20000	-183.75	.08520	-83.88
92.00	-.47634	.20000	-184.58	.08843	-83.88
96.00	-.49694	.20000	-185.42	.09213	-83.88
100.00	-.51752	.20000	-186.25	.09637	-83.88
104.00	-.53808	.20000	-187.08	.10121	-83.88
108.00	-.55863	.20000	-187.92	.10672	-83.88
112.00	-.57915	.20000	-188.75	.11297	-83.88
116.00	-.59966	.20000	-189.58	.12001	-83.88
120.00	-.62016	.20000	-190.42	.12792	-83.88

HOUR = 8:00 HRS.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-166.69	.00000	-80.43
4.00	-.02069	.03281	-166.83	.01263	-80.43
8.00	-.04150	.09844	-167.24	.02055	-80.43
12.00	-.06240	.16412	-167.92	.02790	-80.43
16.00	-.08336	.19849	-168.75	.03449	-80.43
20.00	-.10434	.20000	-169.58	.04033	-80.43
24.00	-.12534	.20000	-170.42	.04548	-80.43
28.00	-.14635	.20000	-171.25	.05000	-80.43
32.00	-.16736	.20000	-172.08	.05395	-80.43
36.00	-.18836	.20000	-172.92	.05739	-80.43
40.00	-.20936	.20000	-173.75	.06040	-80.43
44.00	-.23036	.20000	-174.58	.06303	-80.43
48.00	-.25135	.20000	-175.42	.06536	-80.43
52.00	-.27232	.20000	-176.25	.06744	-80.43
56.00	-.29329	.20000	-177.08	.06934	-80.43
60.00	-.31425	.20000	-177.92	.07113	-80.43
64.00	-.33519	.20000	-178.75	.07288	-80.43
68.00	-.35612	.20000	-179.58	.07464	-80.43
72.00	-.37703	.20000	-180.42	.07649	-80.43
76.00	-.39794	.20000	-181.25	.07849	-80.43
80.00	-.41882	.20000	-182.08	.08070	-80.43
84.00	-.43969	.20000	-182.92	.08320	-80.43
88.00	-.46054	.20000	-183.75	.08604	-80.43
92.00	-.48138	.20000	-184.58	.08930	-80.43
96.00	-.50220	.20000	-185.42	.09304	-80.43
100.00	-.52300	.20000	-186.25	.09732	-80.43
104.00	-.54378	.20000	-187.08	.10221	-80.43
108.00	-.56454	.20000	-187.92	.10777	-80.43
112.00	-.58529	.20000	-188.75	.11408	-80.43
116.00	-.60602	.20000	-189.58	.12119	-80.43
120.00	-.62673	.20000	-190.42	.12918	-80.43

HOUR = 10:00 HRS.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-208.42	.00000	-20.11
4.00	-.01955	-.00569	-208.40	.00794	-20.11
8.00	-.03923	-.01708	-208.33	.01291	-20.11
12.00	-.05898	-.02852	-208.21	.01752	-20.11
16.00	-.07877	-.04006	-208.04	.02166	-20.11
20.00	-.09858	-.05171	-207.82	.02533	-20.11
24.00	-.11840	-.06348	-207.56	.02856	-20.11
28.00	-.13821	-.07538	-207.25	.03140	-20.11
32.00	-.15801	-.08742	-206.88	.03388	-20.11
36.00	-.17779	-.09960	-206.47	.03605	-20.11
40.00	-.19755	-.11194	-206.00	.03794	-20.11
44.00	-.21729	-.12445	-205.48	.03959	-20.11
48.00	-.23700	-.13714	-204.91	.04105	-20.11
52.00	-.25668	-.15003	-204.28	.04236	-20.11
56.00	-.27633	-.16313	-203.61	.04355	-20.11
60.00	-.29595	-.17647	-202.87	.04468	-20.11
64.00	-.31553	-.19004	-202.08	.04577	-20.11
68.00	-.33507	-.19845	-201.25	.04688	-20.11
72.00	-.35458	-.20000	-200.42	.04804	-20.11
76.00	-.37404	-.20000	-199.58	.04930	-20.11
80.00	-.39346	-.20000	-198.75	.05069	-20.11
84.00	-.41283	-.20000	-197.92	.05226	-20.11
88.00	-.43216	-.20000	-197.08	.05404	-20.11
92.00	-.45144	-.20000	-196.25	.05609	-20.11
96.00	-.47067	-.20000	-195.42	.05843	-20.11
100.00	-.48986	-.20000	-194.58	.06112	-20.11
104.00	-.50900	-.20000	-193.75	.06419	-20.11
108.00	-.52809	-.20000	-192.92	.06769	-20.11
112.00	-.54714	-.20000	-192.08	.07165	-20.11
116.00	-.56615	-.20000	-191.25	.07612	-20.11
120.00	-.58511	-.20000	-190.42	.08114	-20.11

HOUR = 12:00 HRS.

DISTANCE FROM MID SLAB(ft)	MOVEMENT (in)	COEFF OF FRICTION (psi)	PRST+FRICT STRESS (psi)	CURLING DEFLECTION (in)	BOT.CURL STRESS (psi)
.00	.00000	.00000	-213.15	.00000	-5.03
4.00	-.01716	-.01849	-213.07	.00336	-5.03
8.00	-.03439	-.05550	-212.84	.00547	-5.03
12.00	-.05165	-.09255	-212.46	.00742	-5.03
16.00	-.06893	-.12967	-211.92	.00917	-5.03
20.00	-.08621	-.16690	-211.22	.01073	-5.03
24.00	-.10348	-.19277	-210.42	.01210	-5.03
28.00	-.12074	-.20000	-209.58	.01330	-5.03
32.00	-.13799	-.20000	-208.75	.01435	-5.03
36.00	-.15522	-.20000	-207.92	.01527	-5.03
40.00	-.17243	-.20000	-207.08	.01607	-5.03
44.00	-.18962	-.20000	-206.25	.01677	-5.03
48.00	-.20680	-.20000	-205.42	.01739	-5.03
52.00	-.22395	-.20000	-204.58	.01794	-5.03
56.00	-.24108	-.20000	-203.75	.01845	-5.03
60.00	-.25820	-.20000	-202.92	.01892	-5.03
64.00	-.27529	-.20000	-202.08	.01939	-5.03
68.00	-.29235	-.20000	-201.25	.01986	-5.03
72.00	-.30940	-.20000	-200.42	.02035	-5.03
76.00	-.32642	-.20000	-199.58	.02088	-5.03
80.00	-.34341	-.20000	-198.75	.02147	-5.03
84.00	-.36037	-.20000	-197.92	.02213	-5.03
88.00	-.37731	-.20000	-197.08	.02289	-5.03
92.00	-.39423	-.20000	-196.25	.02376	-5.03
96.00	-.41111	-.20000	-195.42	.02475	-5.03
100.00	-.42797	-.20000	-194.58	.02589	-5.03
104.00	-.44480	-.20000	-193.75	.02719	-5.03
108.00	-.46160	-.20000	-192.92	.02867	-5.03
112.00	-.47838	-.20000	-192.08	.03035	-5.03
116.00	-.49512	-.20000	-191.25	.03224	-5.03
120.00	-.51185	-.20000	-190.42	.03437	-5.03

APPENDIX D. LISTING OF PROGRAM PSCP2

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      PROGRAM PSCP2
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                 C
C  PROGRAM PSCP2 - ANALYSIS OF PRESTRESSED CONCRETE PAVEMENTS    C
C  CONSIDERING THE INELASTIC NATURE OF THE SLAB-BASE FRICTION    C
C  FORCES, JULY 1989.                                     C
C                                                 C
C    PSCP2 IS THE UPGRADED AND CALIBRATED VERSION OF PROGRAM  C
C  PSCP1. PSCP2 VERSION WAS DEVELOPED BY JOSE A. TENA-COLUNGA    C
C  UNDER THE RESEARCH PROJECT 556 AT THE CENTER FOR TRANSPORTATION C
C  RESEARCH  THE UNIVERSITY OF TEXAS AT AUSTIN.  THIS VERSION     C
C  CONTAINS THE IMPROVED ALGORITM FOR CURLING.             C
C                                                 C
C        PSCP1 PROGRAM WAS DEVELOPED BY ALBERTO MENDOZA AT THE   C
C  CENTER FOR TRANSPORTATION RESEARCH, THE UNIVERSITY OF TEXAS AT  C
C  AUSTIN, IN RESEARCH PROJECT 401, 'DESIGN AND CONSTRUCTION OF   C
C  PRESTRESSED CONCRETE PAVEMENTS FOR OVERLAY APPLICATIONS',     C
C  CONDUCTED IN COOPERATION WITH THE TEXAS STATE DEPARTMENT OF    C
C  HIGHWAYS AND PUBLIC TRANSPORTATION, AND THE FEDERAL HIGHWAY    C
C  ADMINISTRATION.                                       C
C                                                 C
C        DOCUMENTATION RELATED TO THE DEVELOPMENT AND APPLICATION C
C  OF PSCP2 PROGRAM IS PRESENTED IN CTR REPORT NO. 556-3,        C
C  BY JOSE A. TENA-COLUNGA, B. FRANK MCCULLOUGH AND NED H. BURNS  C
C                                                 C
C        THIS PROGRAM DOES NOT CONSTITUTE A STANDARD OR POLICY OF C
C  THE TEXAS SDHPT. ANY USER SHOULD ACCEPT RESPONSIBILITY FOR THE  C
C  ACCURACY OF THE INPUTS AND VALIDITY OF THE RESULTS.          C
C                                                 C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
      IMPLICIT DOUBLE PRECISION (A-H,O,P,R-Z)
      DIMENSION VECTR1(12),VECTR2(12),ARRE(14)
      DIMENSION AGE(8),PCTC(8),PCTT(8)
      DIMENSION CURH(1),P(100)
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C                 LIST OF VARIABLES
C
C     INPUT VARIABLES:
C
C     VECTR1 = ALPHANUMERIC INFORMATION TO IDENTIFY THE PROBLEM
C         DL = SLAB LENGTH (FT)
C         DW = TOTAL WIDTH OF THE SLAB THAT CAN BE CONSIDERED FREE(FT)
C          D = SLAB THICKNESS (IN)
C       NILD = NO. OF INCREMENTS CONSIDERED BY THE PROGRAM FOR ANALYSIS
C              OF SLAB HALF
C       NMAX = MAXIMUM NO. OF ITERATIONS
C        TOL = RELATIVE CLOSURE TOLERANCE (PERCENT)
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C     ALTOT = CONCRETE THERMAL COEFFICIENT OF CONTRACTION OR EXPANSION
C            (IN/IN-DEG.F)
C      ZTOT = FINAL SHRINKAGE STRAIN (IN/IN)
C         G = CONCRETE UNIT WEIGHT (PCF)
C        PR = CONCRETE POISSON RATIO
C     CREEP = CONCRETE CREEP COEFFICIENT
C        KK = NO. OF POINTS IN COMPRESSIVE STRENGTH VS AGE
C            RELATIONSHIP PROVIDED BY USER
C    AGEU(I)= AGE IN DAYS FOR POINT I OF RELATIONSHIP
C    COMP(I)= COMPRESSIVE STRENGTH FOR POINT I OF RELATIONSHIP
C        M1 = NO OF POINTS IN THE FRICTION COEFFICIENT VS DISPLACEMENT
C            RELATIONSHIP
C     ZU(I) = DISPLACEMENT IN INCHES FOR POINT I OF RELATIONSHIP
C     UU(I) = FRICTION COEFFICIENT FOR POINT I OF RELATIONSHIP
C        SK = K-VALUE ON TOP OF SLAB SUPPORTING LAYER (PSI/IN)
C        SS = STRAND SPACING (IN)
C        SA = NOMINAL AREA OF THE STRANDS (SQ.IN)
C       FPY = STEEL YIELD STRESS (KSI)
C        ES = STEEL ELASTIC MODULUS (PSI)
C       ALS = STEEL THERMAL COEFFICIENT (PSI)
C      NPER = PAIRS OF SLAB MID-DEPTH TEMPERATURES AND TOP-TO-BOTTOM
C            TEMPERATURE DIFFERENTIALS PROVIDED AT 2-HOUR INTERVALS
C      CURH = SETTING HOUR (IN THE SCALE OF 0 TO 24 HOURS)
C   CURTEMP= SLAB MIDDEPTH TEMPERATURE AT THE SETTING HOUR (DEG.F)
C    ADT(I)= MID-DEPTH TEMPERATURE FOR DATA PAIR I (DEG.F)
C   TDIF(I)= TOP-TO-BOTTOM SLAB TEMPERATURE DIFFERENTIAL FOR DATA
C            PAIR I (DEG F)
C AVGDIF(I)= MOVING AVERAGE OF TOP-BOTTOM SLAB TEMPERATURE DIFFERENTI
C        AL FOR PAIR I (DEG.F)
C        NS = NUMBER OF POST-TENSIONING STAGES
C      IAGE = TIME SINCE CONCRETE SETTING TO COMPLETION OF POSTTENSIONING
C            STAGE I (HOURS)
C     PS(I) = AMOUNT OF PRESTRESS COMPLETED PER STRAND AT POST-
C            TENSIONING STAGE I (KSI)
C      ITOA = NUMBER OF DAYS SINCE CONCRETE SETTING TO BEGINNING OF PERIOD
C    AGGTYP = DENOTES TYPE OF AGGREGATE.  ONE OF 8 VALUES.
C             1 - GRANITE
C             2 - DOLOMITE
C             3 - VEGA
C             4 - BDG/TT
C             5 - W-T
C             6 - FERRIS
C             7 - LS
C             8 - SRG
C
C    TIME = THE TIME IN DAYS FOR WHICH THE QUANTITY IS DESIRED.
C
C           OF ANALYSIS CONSIDERED
C
C    OTHER VARIABLES:
C
C      FPA = MAXIMUM TENSILE STRESS ALLOWED BY ACI IN STEEL TENDONS
C           (KSI)
C      SFF = INCREMENT OF CONCRETE STRAIN (SINCE APPLICATION OF LAST
C           POST-TENSIONING FORCE) THAT RESULTS IN A CHANGE OF THE
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C           PRESTRESS LEVEL IN THE STRANDS (IN/IN)
C     ELONG = CHANGE IN THE STRESS IN THE STRANDS DUE TO THE
C           CONCRETE STRAIN INCREMENT SFF (KSI)
C     RELAX = LOSS IN THE STRESS IN THE STRANDS DUE TO STEEL RELAXATION
C           (KSI)
C    PRFINAL = TOTAL PRESTRESS IN THE STRANDS AFTER LOSSES (KSI)
C    SFINAL = PRESTRESS LEVEL IN THE CONCRETE AFTER LOSSES (PSI)
C
C    BLOCK VARIABLES USED:     COMMON/BLCK1/DT(10,25),TMID(10,25)
C        COMMON/BLCK2/KK,AGEU(20),COMP(20)
C        COMMON/BLCK3/M1,ZU(20),UU(20)
C        COMMON/BLCK4/IR,IW,IE
C        COMMON/BLCK5/KI,CURTEMP,AG(100),ADT(100),TDIF(100),PP(100),AVGDIF
C             1(100),IHOUR(100),ADTFIX(100),CRLMAX,ADTMAX,ADTMIN
C       COMMON/BLCK6/G,COMPF,ALTOT,ZTOT,CREEP,PR,SK,SL
C       COMMON/BLCK7/DL,NILD,NTEMP,TOL,NMAX,DW
C       COMMON/BLCK8/AL,EL,ZZ,SA,SS,PS(10),AGEP(10),IAGG,AGGTYP,EMOD28
C       COMMON/BLCK9/M,Z(200),U(200)
C       COMMON/BLCK10/Z1(200),X(200),FX(200),STF1(200)
C       COMMON/BLCK11/C,H,R
C       COMMON/BLCK12/TOA(10)
C       COMMON/BLCK13/CPF,CPM,ZZF,RELAX,FPY
C       COMMON/BLCK14/YVERT(30,100,10)
C
C     VARIBLES ORIGINATED:     COMMON/BLCK1/DT(10,25),TMID(10,25)
C       COMMON/BLCK2/KK,AGEU(20),COMP(20)
C       COMMON/BLCK4/IR,IW,IE
C       COMMON/BLCK5/KI,CURTEMP,AG(100),ADT(100),TDIF(100),AVGDIF(100)
C             IHOUR(100),ADTFIX(100),CRLMAX,ADTMAX,ADTMIN
C       COMMON/BLCK6/G,COMPF,ALTOT,ZTOT,CREEP,PR,SK,SL
C       COMMON/BLCK7/DL,NILD,NTEMP,TOL,NMAX,DW
C       COMMON/BLCK8/AL,EL,ZZ,SA,SS,AGEP(10),IAGG,AGGTYP
C       COMMON/BLCK11/C,H,R
C       COMMON/BLCK12/TOA(10)
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
      COMMON/BLCK1/DT(10,25),TMID(10,25)
      COMMON/BLCK2/KK,AGEU(20),COMP(20)
      COMMON/BLCK3/M1,ZU(20),UU(20)
      COMMON/BLCK4/IR,IW,IE
      COMMON/BLCK5/KI,CURTEMP,AG(100),ADT(100),TDIF(100),PP(100),AVGDIF
     1(100),IHOUR(100),ADTFIX(100),CRLMAX,ADTMAX,ADTMIN
      COMMON/BLCK6/G,COMPF,ALTOT,ZTOT,CREEP,PR,SK,SL
      COMMON/BLCK7/DL,NILD,NTEMP,TOL,NMAX,DW
      COMMON/BLCK8/AL,EL,ZZ,SA,SS,PS(10),AGEP(10),IAGG,AGGTYP,EMOD28
      COMMON/BLCK9/M,Z(200),U(200)
      COMMON/BLCK10/Z1(200),X(200),FX(200),STF1(200)
      COMMON/BLCK11/C,H,R
      COMMON/BLCK12/TOA(10)
      COMMON/BLCK13/CPF,CPM,ZZF,RELAX,FPY
      COMMON/BLCK14/YVERT(30,100,10)
C
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C     INITIALIZE VARIABLES FOR HEADINGS, COMPRESSIVE STRENGTH VS
C     AGE RELATIONSHIP AND INPUT/OUTPUT PARAMETERS
C
      DATA ARRE/14*4H*--*/
      DATA AGE/0.,1.,3.,5.,7.,14.,21.,28./
      DATA PCTC/0.,15.,38.,53.,63.,82.,94.,100./
C
      OPEN (5,FILE='INPUT PCP')
      OPEN (6,FILE='OUTPUT PCP')
      OPEN (7,FILE='PLOT PCP')
      OPEN (8,FILE='PCP2Y4 PAD')
C     ***************************************************
      IR=05
      IW=06
      IE=08
C     ***************************************************
C
C     PRINT TITLE
C
      CALL TITLE
C
C     INPUT AND ECHO-PRINT OF GENERAL DATA
C
C     ********************
C     *                  *
C     *  READ INPUT DATA *
C     *                  *
C     ********************
C
C     %
C     PROGRAM AND PROBLEM IDENTIFICATION
C
      READ(IR,1000)VECTR1
 1000 FORMAT(12A4)
      WRITE(IW,1020)ARRE
 1020 FORMAT('1',10(/),12X,14A4)
      WRITE(IW,1030)ARRE(1),VECTR1,ARRE(1)
 1030 FORMAT(/12X,A4,12A4,A4)
      WRITE(IW,1031)ARRE(1),ARRE(1)
 1031 FORMAT(/12X,A4,11X,'ECHO-PRINT OF GENERAL DATA',11X,A4)
      WRITE(IW,1032)ARRE
 1032 FORMAT(/12X,14A4,///)
C
C     READ PROBLEM DEFINITION
C
      READ(IR,1040)DL,DW,D
 1040 FORMAT(8F10.0)
      READ(IR,1050)NILD,NMAX,TOL
 1050 FORMAT(2I5,F10.0)
      WRITE(IW,1052)
 1052 FORMAT(/////,25X,33(1H*))
      WRITE(IW,1060)
 1060 FORMAT(25X,'*      PROBLEM DEFINITION      *')
      WRITE(IW,1070)
 1070 FORMAT(25X,33(1H*))
```

```
      WRITE(IW,1080)DL,DW,D
 1080  FORMAT(//25X,25HSLAB LENGTH (FT)          =,F10 1/
     1          25X,25HSLAB EFFECTIVE WIDTH(FT)=,F10 1/
     +          25X,25HSLAB THICKNESS (IN)      =,F1. 1)
      WRITE(IW,1086)NILD,NMAX,TOL
 1086  FORMAT(25X,25HNO OF INCREMENTS          =,I10/
     +       25X,25HMAX  NO. OF ITERATIONS  =,I10/
     +       25X,25HREL. CLOSURE TOLERANCE  =,F10 1///)
      TOL=TOL/100
C
C     READ CONCRETE PROPERTIES
C
      READ(IR,1040)ALTOT,ZTOT,G,PR,CREEP,AGGTYP,EMOD28
      IAGG= DINT(AGGTYP)
      IF(IAGG GT.8)WRITE(IW,1123)
      IF(IAGG GT.8)GO TO 1129
 1123 FORMAT(////17X,'ERROR,AGGREGATE SPECIFICATION HIGHER THAN 8')
      IF(CREEP.LE.0.0)CREEP=2.35
      IF(PR LE 0 0)PR=0.20
      WRITE(IW,1052)
      WRITE(IW,1090)
 1090  FORMAT(25X,'*      CONCRETE PROPERTIES       *')
      WRITE(IW,1070)
      WRITE(IW,1110)ALTOT,ZTOT,G,PR,CREEP,AGGTYP,EMOD28
 1110  FORMAT(//,25X,25HTHERMAL COEFFICIENT       =,E10.3/
     +          25X,25HTOTAL SHRINKAGE          =,E10 3/
     +          25X,25HUNIT WEIGHT (PCF)        =,F10 1/
     +          25X,25HPOISSON RATIO            =,F10 2/
     +          25X,25HCREEP COEFFICIENT        =,F10.2/
     +          25X,25HAGGREGATE TYPE           =,F10.2/
     +          25X,25HYOUNG'S MODULUS PROVIDED=,F10.2//
     + 12X,'0=NOT SPECIFIED ;1=GRANITE ;2=DOLOMITE ;3=VEGA  ;4=BDG/TT;'/
     + 13X,'5=W-T ;6=FERRIS;7=LIMESTONE;8=SILICEOUS RIVER GRAVEL'///)
C
C     INPUT AGE-COMPRESSIVE STRENGTH RELATIONSHIP
C
      READ(IR,1120)KK,(AGEU(I),COMP(I),I=1,7)
 1120  FORMAT(I5,5X,14F5.0)
      WRITE(IW,1121)
 1121  FORMAT('1',8(/))
      WRITE(IW,1052)
      WRITE(IW,1122)
 1122  FORMAT(24X,'*        COMPRESSIVE          *'/
     +       24X,'*       STRENGTH DATA         *')
      WRITE(IW,1070)
      IF(IAGG.LT.1)GO TO 1127
C
C     RELATIONSHIP IS NOT USER-SUPPLIED:STRENGTH DEVELOPMENT CURVE FROM CTR-422
C
      WRITE(IW,1124)
 1124  FORMAT(//18X,'THE FOLLOWING  STRENGTH RELATIONSHIP  WAS'/
     +          18X,'DEVELOPED BASED ON THE RECOMMENDATION GIVEN'/
     +          19X,'ON PROJECT CTR-422:UNIVERSITY OF TEXAS AT AUSTIN')
      COMP(8)=COMP(1)
      COMPF=COMP(1)
```

```
      DO 1125 I=1,8
      AGEU(I)=AGE(I)
      AGEUI=AGEU(I)
      CALL PREDMD (6 ,AGGTYP,AGEUI,COMPI)
      COMP(I)=COMPI*COMPF
 1125 CONTINUE
      GO TO 1280
 1127 CONTINUE
      IF(KK.GT.1)GO TO 1200
C
C     RELATIONSHIP IS NOT USER-SUPPLIED STRENGTH DEVELOPMENT FROM ACI MANUAL
C
      IF(AGEU(1).EQ.28.)GO TO 1135
      WRITE(IW,1130)
1128  CONTINUE
      WRITE(IW,1131)
1130  FORMAT(/////17X,'ERROR,STRENGTH VALUE PROVIDED IS NOT FOR 28TH
     + DAY')
1131  FORMAT(19X,'***          EXECUTION ABORTED          ***')
      GO TO 2000
1135  KL=8
C
C     AGE-COMPRESSIVE STRENGTH RELATIONSHIP DEVELOPED FROM
C     28TH DAY COMPRESSIVE STRENGTH SUPPLIED BY USER
C
      WRITE(IW,1144)
1144  FORMAT(//19X,'THE FOLLOWING  STRENGTH RELATIONSHIP  WAS'/
     +           19X,'DEVELOPED BASED ON THE RECOMMENDATION GIVEN'/
     +           19X,'BY THE  U.S.  BUREAU OF RECLAMATION AND THE'/
     +           19X,'28TH DAY COMPRES. STRENGTH PROVIDED BY USER')
      COMP(8)=COMP(1)
      COMPF=COMP(1)
      DO 1150 I=1,8
      AGEU(I)=AGE(I)
      COMP(I)=COMP(8)*PCTC(I)/100.
1150  CONTINUE
      GO TO 1280
1200  CONTINUE
      IF((AGEU(1).EQ.0.).AND.(COMP(1).EQ.0.))GO TO 1204
      WRITE(IW,1202)
      WRITE(IW,1131)
1202  FORMAT(//////,11X,'ERROR,THE AGE-STRENGTH RELATIONSHIP DOES NOT
     + BEGIN WITH (0.0,0.0)')
      GO TO 2000
1204  CONTINUE
      IF(KK.GT.7)READ(IR,1206)(AGEU(I),COMP(I),I=8,KK)
1206  FORMAT((10X,14F5.0))
      KL=KK
C
C     RELATIONSHIP IS USER-SUPPLIED
C     AGE-COMPRESSIVE STRENGTH RELATIONSHIP IS USER-SUPPLIED
C
      WRITE(IW,1230)
1230  FORMAT(//,19X,'THE COMPRESSIVE STRENGTH-AGE RELATIONSHIP'/
     +           19X,'AS SUPPLIED BY USER IS:')
```

```
      DO 1277 I = 2,KK
      IF(AGEU(I) LT 28 )GO TO 1277
      SLOPE = (COMP(I)-COMP(I-1))/(AGEU(I)-AGEU(I-1))
      COMPF = COMP(I-1) + SLOPE*(28 -AGEU(I-1))
      GO TO 1280
 1277 CONTINUE
      COMPF = COMP(KK)
 1280 CONTINUE
      WRITE(IW,1290)(AGEU(I),COMP(I),I = 1,KL)
 1290 FORMAT(//,30X,' AGE      COMPRESSIVE'/
     +         30X,'(DAYS)     STRENGTH'//
     +         (32X,F5.1,8X,F8.1))
C
C     INPUT COEFFICIENT OF FRICTION-DISPLACEMENT RELATIONSHIP
C
      READ(IR,1120)M1,(ZU(I),UU(I),I = 1,7)
      IF(M1 GT 7)READ(IR,1206)(ZU(I),UU(I),I = 8,M1)
      WRITE(IW,1052)
      WRITE(IW,1294)
 1294 FORMAT(25X,'* SLAB-BASE FRICTION PROPERTIES *'/
     +       25X,'*       Z-U RELATIONSHIP        *')
      WRITE(IW,1070)
      IF(M1.EQ.1)GO TO 1300
      IF(M1.GE.2)GO TO 1320
      WRITE(IW,1296)
      WRITE(IW,1131)
 1296 FORMAT(//17X,'ERROR,TYPE OF FRICTION CURVE INPUT NOT IDENTIFIED'
     + )
      GO TO 2000
 1300 CONTINUE
C
C     RELATIONSHIP IS LINEAR
C
      ZU(2) = ZU(1)
      UU(2) = UU(1)
      ZU(1) = 0.
      UU(1) = 0.
      GO TO 1330
 1320 CONTINUE
C
C     RELATIONSHIP IS EXPONENTIAL OR MULTILINEAR
C
      IF((ZU(1).EQ.0.).AND.(UU(1).EQ.0.))GO TO 1330
      WRITE(IW,1322)
      WRITE(IW,1131)
 1322 FORMAT(//////13X,'ERROR,THE Z-U RELATIONSHIP DOES NOT BEGIN WIT
     + H (0.0,0.0)')
      GO TO 2000
 1330 CONTINUE
      IF(M1.EQ.1)WRITE(IW,1340)ZU(2),UU(2)
 1340 FORMAT(//21X,'TYPE OF FRICTION CURVE IS A STRAIGHT LINE'//
     +         21X,'MOVEMENT AT SLIDING            = ',2X,F6.3/
     +         21X,'MAXIMUM COEFFICIENT OF FRICTION = ',2X,F6.3)
      IF(M1.EQ.2)WRITE(IW,1350)ZU(2),UU(2)
 1350 FORMAT(//18X,'TYPE OF FRICTION CURVE IS AN EXPONENTIAL CURVE'//
```

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     +           21X,'MOVEMENT AT SLIDING    =',2X,F6.3/
     +           21X,'MAXIMUM COEFFICIENT OF FRICTION =',2X,F6.3)
      IF(M1.GT.2)WRITE(IW,1360)(ZU(I),UU(I),I=1,M1)
 1360 FORMAT(//18X,'TYPE OF FRICTION CURVE IS A MULTILINEAR CURVE //
     + ,32X,'  Z(I)          U(I)'//(32X,F8.3,8X,F6.3))
C
C     INPUT PROPERTIES OF SLAB SUPPORT
C
      WRITE(IW,1121)
      WRITE(IW,1052)
      WRITE(IW,1542)
 1542 FORMAT(24X,' *   STIFFNESS OF SLAB SUPPORT   *')
      WRITE(IW,1070)
      READ(IR,1040)SK
      WRITE(IW,1544)SK
 1544 FORMAT(//24X,25HK-VALUE OF SUPPORT(PCI) =,F10.2)
C
C     READ STEEL PROPERTIES
C
      READ(IR,1040)SS,SA,FPY,ES,ALS
      IF(SS.EQ.0.)GO TO 1435
      IF(FPY.EQ.0.)FPY=230.
      IF(ES.EQ.0.)ES=28000000
      IF(ALS.EQ.0.)ALS=0.000005
      WRITE(IW,1052)
      WRITE(IW,1415)
 1415 FORMAT(24X,' *       STEEL PROPERTIES       *')
      WRITE(IW,1070)
      SPT=SA*100./(SS*D)
      WRITE(IW,1420)SPT,SS,SA,FPY,ES,ALS
 1420 FORMAT(//24X,25HPERCENT REINFORCEMENT    =,F10.3/
     +           24X,25HSTRAND SPACING (IN)      =,F10.2/
     +           24X,25HNOMINAL AREA (SQ.IN)     =,F10.3/
     +           24X,25HYIELD STRENGTH (KSI)     =,F10.2/
     +           24X,25HELASTIC MODULUS (PSI)    =,E10.3/
     +           24X,25HTHERMAL COEFFICIENT      =,E10.3/)
 1435 FPA=0.94*FPY
C
C     INPUT CONCRETE TEMPERATURES FOR FIRST PERIOD AND TIME AND AMOUNT
C     OF PRESTRESS FOR EACH POST-TENSIONING STAGE
C
      WRITE(IW,1020)ARRE
      WRITE(IW,1030)ARRE(1),VECTR1,ARRE(1)
      WRITE(IW,1700)ARRE(1),ARRE(1)
 1700 FORMAT(/12X,A4,'PREDICTION PAVEMENT STRESSES FOR INITIAL PERIOD'
     + ,A4)
      WRITE(IW,1032)ARRE
C
C     READ NO. OF TEMPERATURES FOR INITIAL PERIOD
C
      READ(IR,1367)NTEMP,CURH(1),CURTEMP
 1367 FORMAT(I5,5X,2F10.0)
      IF(NTEMP.EQ.0)GO TO 1710
      GO TO 1720
 1710 WRITE(IW,1386)CURTEMP
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      WRITE(IW,1715)
 1715 FORMAT(//,'WARNING NO TEMPERATURE DATA WERE PROVIDED FOR'/
     119X 'INITIAL ANALYSIS PERIOD GO TO ANALYZE NEXT PERIOD'/)
      NS=0
      GO TO 1446
 1720 CONTINUE
      IF(CURH(1).GT.6.)GO TO 1370
      K=CURH(1)+19
      GO TO 1372
 1370 K=CURH(1)-5
 1372 XK=K
      RES=XK/2.-K/2
      IF(RES.EQ.0.)GO TO 1374
      KI=K+2
      GO TO 1376
 1374 KI=K+1
 1376 CONTINUE
      ADTMIN=100
      ADTMAX=0.
      DO 1378 I=1,NTEMP
      READ(IR,1040)ADT(I),TDIF(I)
      ADTFIX(I)=ADT(I)
      IF(ADTMAX.LT.ADTFIX(I)) ADTMAX=ADTFIX(I)
      IF(ADTMIN.GT.ADTFIX(I)) ADTMIN=ADTFIX(I)
 1378 CONTINUE
      DO 1381 I=1,NTEMP
      TRADIF=(13.25-TDIF(I))/(DABS(ADTMAX)+DABS(ADTMIN))
 1381 CONTINUE
      MARCA=0
      GO TO 1471
 1379 MARCA=1
      IF(SS.EQ.0.)GO TO 1384
C
C     READ NO. OF POST-TENSIONING STAGES
C
      READ(IR,1050)NS
      DO 1382 I=1,NS
      READ(IR,1387)IAGE,PS(I)
      AGEP(I)=IAGE
 1382 CONTINUE
 1384 CONTINUE
C
C     PRINT SEQUENCE OF PAVEMENT TEMPERATURES AND APPLICATION OF POST-
C     TENSIONING FORCES
C
      WRITE(IW,1386)CURTEMP
 1386 FORMAT(//24X,25HSETTING TEMP. (DEG.F)    =,F10.2/)
      NG39=NTEMP/39+1
      NC24=1
      EL=0.
      PANT=0.
      DO 1440 I1=1,NG39
      IF(I1.EQ.1)GO TO 1390
      WRITE(IW,1388)
 1388 FORMAT('1',10(/),30X,'TEMP. AT      TEMP.     PRESTRESS'/
```

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     1         17X,' HOUR        MID-DEPTH       DIFF      PER STRAND'/
     2         17X,'OF DAY        (DEG F)       (DEG F)       (KSI) '/)
      GO TO 1394
 1390 CONTINUE
      WRITE(IW,1392)
 1392 FORMAT(17X,'             TEMP AT       TEMP      PRESTRESS'/
     1      17X,' HOUR       MID-DEPTH       DIFF      PER STRAND'/
     2      17X,'OF DAY       (DEG F)       (DEG F)      (KSI) '/)
 1394 NTEM=38
      IF(I1.EQ.NG38)NTEM=NTEMP-38*(NG38-1)
      DO 1418 I2=1,NTEM
      NCOUNT=38*(I1-1)+I2
      P(NCOUNT)=0.
      PP(NCOUNT)=0.
      ATIM=NCOUNT*2.
      AG(NCOUNT)=ATIM/24
      IF(SS.EQ.0.)GO TO 1400
      DO 1396 KP=1,NS
      NKP=NS-KP+1
      IF(ATIM.LT.AGEP(NKP))GO TO 1396
      P(NCOUNT)=PS(NKP)
      TIME=AGEP(NKP)/24.
      CALL TIDEVAR(TIME,D,0,0)
      GO TO 1400
 1396 CONTINUE
 1400 CONTINUE
      II=KI+2*NCOUNT-2-(NC24-1)*24
      IF(II.EQ.25)GO TO 1402
      GO TO 1404
 1402 NC24=NC24+1
 1404 CONTINUE
      ITIM=II+5
      IF(ITIM.GT.12)ITIM=ITIM-12
      IF(II.GT.7)GO TO 1406
      IF(II.LE.6)WRITE(IW,1408)ITIM,ADT(NCOUNT),TDIF(NCOUNT),P(NCOUNT)
 1408 FORMAT(12X,I5,' A.M.',3(3X,F10.1))
      IF(II.EQ.7)WRITE(IW,1410)ITIM,ADT(NCOUNT),TDIF(NCOUNT),P(NCOUNT)
 1410 FORMAT(12X,I5,' NOON',3(3X,F10.1))
      IF(P(NCOUNT).GT.FPA)GO TO 1445
      GO TO 1416
 1406 IF(II.LE.18)WRITE(IW,1412)ITIM,ADT(NCOUNT),TDIF(NCOUNT),P(NCOUNT)
 1412 FORMAT(12X,I5,' P.M.',3(3X,F10.1))
      IF(ITIM.GT.12)ITIM=ITIM-12
      IF(II.EQ.19)WRITE(IW,1414)ITIM,ADT(NCOUNT),TDIF(NCOUNT),P(NCOUNT)
 1414 FORMAT(12X,I5,' MIDNIGHT',1X,F8.1,2(3X,F10.1))
      IF(II.GT.19)WRITE(IW,1408)ITIM,ADT(NCOUNT),TDIF(NCOUNT),P(NCOUNT)
      IF(P(NCOUNT).GT.FPA)GO TO 1445
      GO TO 1416
 1445 WRITE(IW,1417)P(NCOUNT),FPA
 1417 FORMAT(//////23X,'ERROR,STRAND TENSILE STRESS =',F7.2,' KSI'/
     1           23X,'EXCEEDS MAXIMUM ALLOWED'/
     2           23X,'BY  ACI   (0.94*FPY)        =',F7.2,' KSI')
      WRITE(IW,1131)
      GO TO 2000
 1418 CONTINUE
```

```
      IF(SS.EQ.0.)GO TO 10
      P(NCOUNT)=1000.*P(NCOUNT)*SA/(SS*D)
      IF(EL.EQ.0.)GO TO 10
      PP(NCOUNT)=(P(NCOUNT)-PANT)/EL
      PANT=P(NCOUNT)
10    CONTINUE
      IF(NCOUNT.GT.1)GO TO 1418
      TEMPT1=ADT(1)
      ADT(1)=ADT(1)-CURTEMP
      GO TO 1419
1418  ADT(NCOUNT)=ADT(NCOUNT)-TEMPT1
      TEMPT1=ADT(NCOUNT)+TEMPT1
1419  CONTINUE
1440  CONTINUE
      LAPS=1
C
C     SOLVE FOR ALL TIME INCREMENTS
C
      CALL FREST(1,P,D,0.0D0,0.0D0,LAPS)
C
C     STARTS ANALYSIS FOR INTERMEDIATE/FINAL PERIOD IF REQUESTED
C     INITIALIZES PRESTRESS VARIABLES
C
1446  CONTINUE
      PRFINAL=0.
      SFINAL=0.
      NTEMP=24
      DO 1450 I=1,24
      P(I)=0.
      PP(I)=0.
1450  CONTINUE
      IF(SS.EQ.0.)GO TO 1462
C
C     CONVERT TIMES OF POST-TENSIONING TO DAYS FOR COMPUTATION OF
C     PRESTRESS LOSSES FOR INTERMEDIATE/FINAL PERIOD
C
      DO 1460 I=1,NS
      AGEP(I)=AGEP(I)/24.
1460  CONTINUE
      IP1=NS
      PRT=PS(NS)
      LAPS=0
      GO TO 1461
1462  PRT=0.
C
C     READ TEMPERATURES FOR 24-HOUR PERIOD
C
1461  CONTINUE
      READ(IR,1367)ITOA
      TOA(1)=ITOA
      IF(ITOA.EQ.0)GO TO 2000
      LAPS=LAPS+1
      CRLMAX=0.
      WRITE(IE,460)LAPS
 460  FORMAT(///15X,'STUDY SET NUMBER:',I5)
```

```
      DO 1470 I = 1,12
      READ(IR,1067)ADT(I),TDIF(I),IHOUR(I)
      ADTFIX(I) = ADT(I)
1067  FORMAT(2F10.0,I10)
      ITWO = I + 12
      IHOUR(ITWO) = IHOUR(I)
1470  CONTINUE
1471  CONTINUE
C
C     (A)COMPUTATION OF MOVING AVERAGES OF TEMPERATURE GRADIENT
C
      ADTMIN = 100.
      ADTMAX = 0.
      AKAVG = 3.
      KAVG = 3
C
C     (B)SORT TO FIND MAXIMUM AND MINIMUM TEMPERATURE OF CYCLE
C
      DO 1473 IS = 1,12
      JIS = IS
      IF(ADTMAX.LT.ADTFIX(IS)) ADTMAX = ADTFIX(IS)
      IF(ADTMIN.GT.ADTFIX(IS)) ADTMIN = ADTFIX(IS)
 1473 CONTINUE
C
C     (C)COMPUTATION OF AVERAGES
C
      DO 1478 IA = 1,12
      JIS = IA
      IAI = IA-1
      SUMDIF = 0.
      TDIFSM = TDIF(IA)
      TRADIF = (13.25-TDIFSM)/(DABS(ADTMAX) + DABS(ADTMIN))
      IF(TDIFSM.GT.0.) TDIFSM = 0.
      IF(IA.EQ.1.AND.TDIF(IA).GE.0.)AVGDIF(IA) = 0.
      IF(IA.EQ.1.AND.TDIF(IA).GE.0.)GO TO 1478
      IF(ADTMIN.LT.ADTFIX(IA).AND.TDIF(IA).GE.0.)AVGDIF(IA) = AVGDIF(IAI)/
     *4.
      IF(ADTMIN.LT.ADTFIX(IA).AND.TDIF(IA).GE.0.) GO TO 1478
      IF(JIS.LT.KAVG.AND.TDIF(IA).LT.0.) AVGDIF(IA) = TRADIF
      IF(JIS.LT.KAVG)GO TO 1478
      DO 1476 JAV = 1,JIS
      TDIFSM = TDIF(JAV)
      IF(TDIFSM.GT.0.) TDIFSM = 0.
      SUMDIF = SUMDIF + TDIFSM
 1476 CONTINUE
C
C     COMPUTATION OF NUMBER OF HOUR PERIODS FROM FIRST DECREMENT IN TOP TEMP
C
      AJIS = 0.
      LFLAG = 0
      DO 1477 JJS = JIS,2,-1
      JBFR = JJS-1
      JJA = JJS
      IF(ADTFIX(JJA).GT.ADTFIX(JBFR).AND.TDIF(JJA).GT.TDIF(JBFR))LFLAG = 1
      IF(TDIF(JJA).LE.0)LFLAG = 0
```

```
      IF(LFLAG EQ 1)GO TO 1477
      AJIS = AJIS + 1
 1477 CONTINUE
      IF(AJIS EQ 0 )AJIS = 1
      AVGDIF(JIS) = SUMDIF/AJIS
 1478 CONTINUE
      IF(MARCA EC 0)GO TO 1378
      WRITE(IE,400)ITOA
      WRITE(IE,410)(IHOUR(IS),IS = 1,12)
      WRITE(IE,430)(AVGDIF(IS),IS = 1,12)
  400 FORMAT(/15X,'DAYS PASSED   ',I5)
  410 FORMAT(30X,'HOURS '/10X,12I5)
  430 FORMAT(28X,'TEMPERATURES '/10X,12F5 1)
C
C     END OF MOVING AVERAGES ROUTINE
C
      KI = 3
      WRITE(IW,1020)ARRE
      WRITE(IW,1030)ARRE(1),VECTR1,ARRE(1)
      WRITE(IW,1480)ARRE(1),ARRE(1),ARRE(1),ARRE(1)
 1480 FORMAT(/12X,A4,8X,'PREDICTION OF PAVEMENT STRESSES FOR',5X,A4,/12X
     1,A4,11X,'INTERMEDIATE/FINAL PERIOD ,12X,A4)
      WRITE(IW,1032)ARRE
      IF(PRT EQ 0.)GO TO 1482
      TIME = TOA(1)
C
C     DETERMINE EFFECTIVE PRESTRESS LEVEL AT PERIOD CONSIDERED
C
      CALL TIDEVAR(TIME,D,NS,1)
      TEMPD = ADT(1)-CURTEMP
      SFF = (AL-ALS)*TEMPD-CPF-(ZZ-ZZF)
      ELONG = SFF*ES/(1000.*(1. + (SPT*ES)/(100.*EL)))
      PRFINAL = PRT + ELONG-RELAX
      SFINAL = 1000.*PRFINAL*SA/(SS*D*EL) + CPM
 1482 CONTINUE
C
C     PRINT SEQUENCE OF PAVEMENT TEMPERATURES AND EFFECTIVE
C     PRESTRESS LEVEL FOR PERIOD CONSIDERED
C
      WRITE(IW,1484)ITOA
 1484 FORMAT(//24X,25HTIME OF ANALYSIS FROM END/
     1        24X,25HOF SLAB SETTING (DAYS)   = ,I10/)
      IF(ITOA.GE.28)GO TO 1466
      WRITE(IW,1464)
 1464 FORMAT(//8X,'WARNING,THE TIME OF ANALYSIS FOR PERIODS OTHER'
     1/4X,'THAN THE INITIAL PERIOD SHOULD BE GREATER THAN 28 DAYS'/)
 1466 CONTINUE
      WRITE(IW,1392)
      DO 1516 I1 = 1,12
      NCOUNT = I1
      II = KI + 2*I1-2
      ITIM = II + 5
      IF(ITIM.GT.12)ITIM = ITIM-12
      IF(II.GT.7)GO TO 1506
      IF(II.LE.8)WRITE(IW,1408)ITIM,ADT(NCOUNT),TDIF(NCOUNT),PRFINAL
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      IF(II EQ 7)WRITE(IW,1410)ITIM ADT(NCOUNT),TDIF(NCOUNT),PRFINAL
      GO TO 1516
1506  IF(II LE 18)WRITE(IW,1412)ITIM ADT(NCOUNT),TDIF(NCOUNT),PRFINAL
      IF(ITIM GT 12)ITIM = ITIM-12
      IF(II EQ 18)WRITE(IW,1414)ITIM,ADT(NCOUNT),TDIF(NCOUNT),PRFINAL
      IF(II GT 18)WRITE(IW,1408)ITIM,ADT(NCOUNT),TDIF(NCOUNT),PRFINAL
1516  CONTINUE
1600  CONTINUE
      DO 1610 I = 13,24
      ADT(I) = ADT(I-12)
      AG(I) = (I-12)**2 + TOA(1)
1610  CONTINUE
      DO 1620 I = 1,12
      AG(I) = AG(I + 12)
1620  CONTINUE
      DO 1640 I = 1,NTEMP
      IF(I GT 1)GO TO 1630
      TEMPT1 = ADT(1)
      ADT(1) = ADT(1)-CURTEMP
      GO TO 1640
1630  ADT(I) = ADT(I)-TEMPT1
      TEMPT1 = ADT(I) + TEMPT1
1640  CONTINUE
C
C     SOLVE FOR ALL TIME INCREMENTS
C
      CALL FREST(2,P,D,SFINAL,PRFINAL,LAPS)
      GO TO 1461
2000  CONTINUE
      DO 591 KFT = 1,3
      FRAC6 = KFT
      SIZE6 = DL*FRAC6/6.
      WRITE(IE,501)SIZE6,LAPS
      WRITE(IE,511)((YVERT(III,JJJ,KFT),JJJ = 1,LAPS),III = 13,24)
 501 FORMAT(//20X,'DISTANCE FROM CENTER OF SLAB (FT):',F10.2/20X,
    1'NUMBER OF SETS IN STUDY',I5/)
 511 FORMAT(10X,8F8.5)
 591 CONTINUE
      WRITE(IW,2020)
2020  FORMAT('1',20(/),T30,'E N D     O F     J O B')
      WRITE(IW,2030)ARRE
2030  FORMAT(/T13,14A4)
      STOP
      END
      SUBROUTINE TITLE
      IMPLICIT DOUBLE PRECISION (A-H,O,P,R-Z)
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C     THIS SUBROUTINE PRINTS THE PROGRAM TITLE
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
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```
      COMMON/BLCK4/IR,IW,IE
      WRITE(IW,10)
10    FORMAT(19(/),16X,6('P')5X,6('S'),5X,5('C'),3X,6('P'),5X,6('2'),'\'
     1/   16X,7('P'),3X,8('S'),3X,7('C'),2X,7('P'),3X,8('2'),1X,'\'/
     2    16X,2('P'),4X,2('P'),2X,2('S'),8X,2('C'),8X,2('P'),4X,
     3    2('P'),2X,2('2'),'\',3X,2('2'),1X,'\'/
     4    16X,2('P'),4X,2('P'),2X,7('S'),3X,2('C'),8X,2('P'),4X,
     5    2('P'),4X,6('2'),1X,'\'/
     6    16X,7('P'),4X,7('S'),2X,2('C'),8X,7('P'),4X,6('2'),1X,'\'/
     7    16X,6('P'),10X,2('S'),2X,2('C'),8X,6('P'),4X,2('2'),1X,
     +     4('\')/
     8    16X,2('P'),8X,6('S'),3X,7('C'),2X,2('P'),8X,8('2'),1X,'\'/
     9     16X,2('P'),9X,6('S'),5X,5('C'),3X,2('P'),8X,8('2'),1X,'\'/
     1*   57X,8('\'))
      WRITE(IW,20)
20    FORMAT(4(/),13X,55('*')/13X,'*',53X,'*'/13X,'*',6X,'ANALYSIS',
     1     ' OF PRESTRESSED CONCRETE PAVEMENTS',5X,'*'/13X,'*',14X,
     2     'CONSIDERING THE INELASTIC',14X,'*'/13X,'*',7X,'NATURE',
     3     ' OF THE SLAB-BASE FRICTION FORCES',7X,'*'/13X,'*',15X,
     4     '(VERSION 2, APRIL 1989)',15X,'*'/13X,'*',53X,'*'/13X,
     5     '*',9X,'CENTER FOR TRANSPORTATION RESEARCH',10X,'*'/13X,
     6     '*',10X,'THE UNIVERSITY OF TEXAS AT AUSTIN',10X,'*'/13X,
     7     '*',53X,'*'/13X,55('*'))
      RETURN
      END
      SUBROUTINE FREST(KK,P,D,SFINAL,PRFINAL,LAPS)
      IMPLICIT DOUBLE PRECISION (A-H,O,P,R-Z)
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C    SUBROUTINE FREST DETERMINES THE PROFILES OF FRICTION RESTRAINT
C    STRESSES AND PRESTRESS, ACCUMULATED LONGITUDINAL MOVEMENTS AND
C    CURLING STRESSES AND DEFLECTIONS, FOR ALL TIME INCREMENTS OF
C    THE PERIOD OF ANALYSIS CONSIDERED.  THE FRICTION SUBMODELS FOR
C    THE INTERVALS OF CONTRACTION/EXPANSION AND THE MOVEMENT REVERSAL
C    INTERVALS, ARE INTEGRATED IN THIS SUBROUTINE.
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
C    VARIABLES:
C
C       X(I) = COORDINATE ALONG SLAB LENGTH OF POINT I (FT)
C      FX(I) = AVERAGE STRESS IN ELEMENT I (PSI)
C    STF1(I) = STRAIN THAT ELEMENT I TENDS TO DEVELOP AT TIME
C              INCREMENT CONSIDERED (IN/IN)
C    ZANT(I) = INITIAL CONDITION FOR MOVEMENTS OF POINT I, FROM WHICH
C              FURTHER MOVEMENTS OF THE POINT ARE COMPUTED (IN)
C       TIME = AGE SINCE SETTING HOUR FOR THE TIME INCREMENT CONSIDERED
C              (HOURS)
C       DELT = TEMPERATURE CHANGE FOR TIME INCREMENT CONSIDERED (DEG.F)
C         ZZ = STRAIN INCREMENT OF SLAB ELEMENTS DUE TO SHRINKAGE FOR TIME
C              INCREMENT CONSIDERED (IN/IN)
C      PP(I) = STRAIN INCREMENT DUE TO PRESTRESS APPLICATION DURING TIME
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C           INCREMENT CONSIDERED (IN/IN)
C       STF = TOTAL STRAIN INCREMENT OF SLAB ELEMENTS FOR TIME INCREMENT
C           CONSIDERED (IN/IN)
C       NEL = INITIAL ELEMENT FOR SEGMENT EXPERIENCING A REVERSAL OF
C           MOVEMENT (SEGMENT 2 IN FRICTION SUBMODEL 2)
C      Z(I) = TOTAL MOVEMENT EXPERIENCED BY POINT I AT TIME INCREMENT
C           CONSIDERED (IN)
C     RATIO = RATIO BETWEEN THE NORM OF THE CHANGE OF MOVEMENTS OF THE
C           SLAB POINTS BETWEEN SUCCESSIVE ITERATIONS, AND THE NORM OF
C           THE MOVEMENTS AT THE LAST ITERATION
C        Z0 = UNRESTRAINED MAXIMUM CURLING
C           FOR TIME INCREMENT CONSIDERED (IN)
C        S0 = FULLY RESTRAINED CURLING STRESS FOR THE TIME INCREMENT
C           CONSIDERED (PSI)
C      U(I) = AVERAGE FRICTION COEFFICIENT UNDER ELEMENT I
C        ZX = FINAL MOVEMENT OF GIVEN SLAB POINT AT TIME INCREMENT
C           CONSIDERED (IN)
C         F = AVERAGE PRESTRESS PLUS FRICTION RESTRAINT STRESS FOR GIVEN
C           SLAB ELEMENT AT TIME INCREMENT CONSIDERED (PSI)
C       ZFI = CURLING DEFLECTION OF GIVEN SLAB POINT AT TIME INCREMENT
C           CONSIDERED (IN)
C        SY = TOTAL CURLING STRESS AT BOTTOM OF GIVEN SLAB POINT AT
C           TIME INCREMENT CONSIDERED (PSI)
C      BLOCK VARIABLES USED:     COMMON /BLCK3/M1,ZU(20),UU(20)
C         COMMON/BLCK4/IR,IW,IE
C         COMMON/BLCK5/KI,CURTEMP,AG(100),ADT(100),TDIF(100),PP(100),AVGDIF
C              (100) IHOUR(100),ADTFIX(100),CRLMAX,ADTMAX,ADTMIN
C         COMMON /BLCK6/G,COMPF,ALTOT,ZTOT,CREEP,PR,SK,SL
C         COMMON/BLCK7/DL,NILD,NTEMP,TOL,NMAX,DW
C         COMMON/BLCK8/AL,EL,ZZ,SA,SS,PS(10),AGEP(10),IAGG,AGGTYP,EMOD28
C         COMMON /BLCK9/M,Z(200),U(200)
C         COMMON /BLCK10/Z1(200),X(200),FX(200),STF1(200)
C         COMMON /BLCK12/TOA(10)
C         COMMON /BLCK13/CPF,CPM,ZZF,RELAX,FPY
C         COMMON/BLCK14/YVERT(30,100,10)
C         DIMENSION Z2(200),ZANT(200),P(100)
C
C      VARIABLES ORIGINATED:  COMMON/BLCK5/PP(100)
C         COMMON/BLCK8/ZZ
C         COMMON /BLCK9/M,Z(200),U(200)
C         COMMON /BLCK10/Z1(200),X(200),FX(200
C         COMMON/BLCK14/YVERT(30,100,10)
C         DIMENSION Z2(200),ZANT(200),P(100)
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
C
      COMMON /BLCK3/M1,ZU(20),UU(20)
      COMMON/BLCK4/IR,IW,IE
      COMMON/BLCK5/KI,CURTEMP,AG(100),ADT(100),TDIF(100),PP(100),AVGDIF
     1(100),IHOUR(100),ADTFIX(100),CRLMAX,ADTMAX,ADTMIN
      COMMON /BLCK6/G,COMPF,ALTOT,ZTOT,CREEP,PR,SK,SL
      COMMON/BLCK7/DL,NILD,NTEMP,TOL,NMAX,DW
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      COMMON/BLCK8/AL.EL.ZZ.SA.SS.PS(10).AGEP(10).IAGG.AGGTYP.EMOD28
      COMMON /BLCK9/M,Z(200),U(200)
      COMMON /BLCK10/Z1(200),X(200),FX(200),STF1(200)
      COMMON /BLCK12/TOA(10)
      COMMON /BLCK13/CPF,CPM,ZZF,RELAX,FPY
      COMMON/BLCK14/YVERT(30,100,10)
      DIMENSION Z2(200),ZANT(200),P(100)
C
C     DEFINE LENGTH OF SLAB ELEMENTS AND INITIALIZE PARAMETERS
C
      DX = DL/NILD
      XN = NILD/2.
      IF((XN-IFIX(XN)) EQ 0 )GO TO 100
      X(2) = DX/2.
      AM = NILD/2. + 1.5
      M = AM
      K1 = 3
      GO TO 110
100   M = NILD/2 + 1
      K1 = 2
110   CONTINUE
      M2 = M-1
C
C     INITIALIZE TO ZERO THE VARIABLES FOR STRESS AND STRAIN
C     OF THE ELEMENTS (FX AND STF1)
C
      DO 120 I = 1,M2
      FX(I) = 0
      STF1(I) = 0.
120   CONTINUE
      FX(M) = 0.
      X(1) = 0.
      U(1) = 0.
C
C     DEFINE COORDINATES OF NODES BOUNDING THE ELEMENTS
C
      DO 130 I = K1,M
      X(I) = X(I-1) + DX
130   CONTINUE
C
C     INITIALIZE TO ZERO THE VARIABLES REPRESENTING NEW INITIAL CONDITION
C     FOR MOVEMENTS, DEFINED AT THE LAST REVERSAL OF MOVEMENTS (ZANT)
C
      DO 132 I2 = 1,M
132   ZANT(I2) = 0.
C
C     INITIALIZE TO ZERO VARIABLE REPRESINTING INCREMENT IN MOVEMENT OF
C     END POINT OF SEGMENT 1 (ZZ) BETWEEN SUCCESSIVE ITERATIONS AT
C     MOVEMENT REVERSAL INTERVAL
C
      ZZ = 0.
      TEMPT = CURTEMP
      INDIK = 0
      INDPP = 0
      NC24 = 1
```

```
C
C   SOLVE FOR DEFORMATIONS AND STRESSES FOR ALL TEMPERATURES OF
C   THE ANALYSIS PERIOD CONSIDERED. AT 2-HOUR INTERVALS
C
      DO 140 I=1,NTEMP
      NEL=0
      INDCON=0
      ZY=ZZ
      TIME=AG(I)
      DELT=ADT(I)
      TEMPT=TEMPT+DELT
C
C   DETERMINE ELASTIC MODULUS AND SHRINKAGE STRAIN OF CONCRETE
C   FOR THE TIME INTERVAL CONSIDERED
C
      CALL TIDEVAR(TIME,D,IP1,0)
      ZZ=ZZ-ZY
      IF(KK.EQ.1)GO TO 25
      IF(I.GT.1.AND.I.LE.12)ZZ=0
25    CONTINUE
C
C   DETERMINE STRAIN INCREMENT FOR SLAB ELEMENTS IN TIME INCREMENT
C   CONSIDERED
C
      STF=AL*DELT-ZZ-PP(I)
C
C   DETERMINE IF STRAIN INCREMENT LEADS TO A MOVEMENT REVERSAL
C   AND DEFINE STRAINS OF ELEMENTS FOR ANALYSIS
C
      DO 148 I1=1,M2
      FPROM=(FX(I1+1)+FX(I1))/2.
      IF(STF.GE.0..AND.FPROM.LE.0.)GO TO 146
      IF(STF.LE.0..AND.FPROM.GE.0.)GO TO 146
      FAUX=STF-FPROM/EL
      IF(FPROM.GT.0.)GO TO 142
      IF(FAUX.GT.0.)GO TO 148
      GO TO 144
142   CONTINUE
      IF(FAUX.LT.0.)GO TO 148
C
C   SLAB IN A MOVEMENT-REVERSAL INTERVAL
C
144   CONTINUE
      IF(NEL.NE.0)GO TO 145
C
C   DEFINE INITIAL ELEMENT OF SEGMENT 2 REVERSING MOVEMENT
C   IF IT HAS NOT BEEN DEFINED BEFORE
C
      NEL=I1
      INEL=NEL+1
      IF(NEL.EQ.1)INEL=1
C
C   DEFINE NEW INITIAL CONDITION FOR ELEMENTS REVERSING MOVEMENT
C
      DO 14 I2=INEL,M
```

```
14    ZANT(I2) = Z2(I2)
C
C     DEFINE STRAIN OF ELEMENTS REVERSING MOVEMENT
C
145   STF1(I1) = FAUX
      INDIK = 1
      GO TO 148
C
C     DEFINE STRAIN OF ELEMENTS IN CONTRACTION/EXPANSION INTERVAL
C     OR THAT DO NOT REVERSE MOVEMENT IN MOVEMENT-REVERSAL INTERVAL
C
146   STF1(I1) = STF1(I1) + STF
148   CONTINUE
      IF(INDIK.EQ.1.AND.NEL.LE.1)GO TO 3
      GO TO 2
11    INDPP = 0
3     CONTINUE
C
C     DEFINE NEW INITIAL CONDITION FOR ALL ELEMENTS
C     (MOVEMENT-REVERSAL INTERVAL COMPLETED)
C
      DO 4 I2 = 1,M
4     ZANT(I2) = Z2(I2)
      INDIK = 0
2     CONTINUE
      IF(NEL.LE.1)GO TO 190
C
C     SOLVE FOR SLAB IN MOVEMENT-REVERSAL INTERVAL
C
      NN = 0
      ZI = 0.
      ZULT = Z(NEL)
150   SII = SI
      SUM1 = 0.
      SUM2 = 0.
C
C     SOLVE FOR SEGMENT 2
C
      CALL ITER(ZI,NEL,M,INDCON)
      SII = FX(NEL)
C
C     SOLVE FOR SEGMENT 1
C
      CALL ITER(0.0D0,1,NEL,INDCON)
C
C     COMPUTE RATIO FOR SUCCESSIVE ITERATIONS
C
      DO 180 I1 = 2,M
      ZM = Z(I1)
      IF(I1.GT.NEL)GO TO 160
      Z(I1) = Z1(I1) + ZANT(I1)
      GO TO 170
160   Z(I1) = Z1(I1) + ZANT(I1) + ZI
170   SUM1 = SUM1 + (ZM-Z(I1))*(ZM-Z(I1))
180   SUM2 = SUM2 + Z(I1)*Z(I1)
```

```
      RATIO = SQRT(SUM1/SUM2)
      IF(RATIO LT TOL)GO TO 200
      Z1 = 0 10*(Z(NEL)-ZULT) + 0 90*Z1
      NN = NN + 1
      IF(NN LE NMAX)GO TO 150
      INDCON = 1
      GO TO 200
C
C     SLAB IN CONTRACTION/EXPANSION INTERVAL
C
190   CONTINUE
      CALL ITER(0 000,1,M,INDCON)
C
C     DEFINE MOVEMENT OF NODES
C
      DO 195 I1 = 1,M
195   Z(I1) = Z1(I1) + ZANT(I1)
200   CONTINUE
      IF(NEL LE 1)GO TO 202
      IF(PP(I) NE 0 )GO TO 201
      GO TO 212
201   INDPP = 1
202   CONTINUE
C
C     PREPARE VARIABLES FOR COMPUTATION OF NEXT TIME INCREMENT
C
      DO 210 I2 = 1,M
210   Z2(I2) = Z(I2)
212   CONTINUE
      ZZ = ZZ + ZY
      ITEMP = I
      IF(I.LE.12.AND.KK.NE.1)GO TO 140
C
C     PRINT HEADINGS AND RESULTS
C
      IF(KK.EQ.1)GO TO 214
      ITEMP = ITEMP-12
      II = KI + 2*I-26
      GO TO 216
214   II = KI + 2*I-2-(NC24-1)*24
      IF(II.EQ.25)GO TO 215
      GO TO 216
215   NC24 = NC24 + 1
216   CONTINUE
      ITIM = II + 5
      IF(IHOUR(I).GT.0)WRITE(IW,53)IHOUR(I)
      IF(IHOUR(I).GT.0)GO TO 50
   53 FORMAT('1',10(/),33X,7HHOUR  =  ,I2,':00 HRS '/)
      IF(ITIM.GT.12)ITIM = ITIM-12
      IF(II.GT.7)GO TO 10
      IF(II.LE.6)WRITE(IW,5)ITIM
5     FORMAT('1',11(/),33X,7HHOUR  =  ,I5,' A.M.'/)
      IF(II.EQ.7)WRITE(IW,6)ITIM
6     FORMAT('1',11(/),33X,7HHOUR  =  ,I5,' NOON'/)
      GO TO 50
```

```
10    IF(II.LE.18)WRITE(IW,7)ITIM
7     FORMAT(1H1,11(/),33X,7HHOUR  = ,I5,' P.M.'/)
      IF(ITIM.GT.12)ITIM=ITIM-12
      IF(II.EQ.19)WRITE(IW,8)ITIM
8     FORMAT('1',11(/),30X,7HHOUR  = ,I5,' MIDNIGHT'/)
      IF(II.GT.19)WRITE(IW,5)ITIM
50    CONTINUE
      NG55=M/56+1
      DO 310 I1=1,NG55
      IF(I1.EQ.1)GO TO 51
1000  WRITE(IW,302)
302   FORMAT('1',2(/),12X,'DISTANCE MOVEMENT  COEFF OF  PRST+FRICT  CURL
     1ING   BOT CURL'/12X,'FROM MID          FRICTION    STRESS    DEFL
     2ECTION  STRESS'/12X,'SLAB(ft)  (in)      (psi)     (psi)       (i
     3n)      (psi)'/)
      GO TO 304
51    CONTINUE
      WRITE(IW,314)
314   FORMAT(2(/),12X,'DISTANCE MOVEMENT  COEFF OF  PRST+FRICT  CURLING
     1  BOT CURL'/ 12X,'FROM MID          FRICTION    STRESS   DEFLECTI
     2ON  STRESS'/12X,'SLAB(ft)  (in)      (psi)     (psi)       (in)
     3   (psi)'/)
304   NELE=55
      IF(I1.EQ.NG55)NELE=M-55*(NG55-1)
      DO 310 I2=1,NELE
      NCOUNT=55*(I1-1)+I2
C
C     COMPUTE CURLING STRESSES
C
      XNC=X(NCOUNT)
      AVGDFT=AVGDIF(ITEMP)
      TDF=ADTFIX(ITEMP)-ADTFIX(1)
      TDIFI=ADTFIX(ITEMP)/CURTEMP
C     IF(ITEMP.EQ.12)WRITE(IE,307)LAPS,ADTFIX(ITEMP),CURTEMP,TDIFI
C 307 FORMAT(10X,'STUDY SET',I5,' ADT',F5.1,' CURTEMP',F5.1,
C    1' TDIFI',F5.1)
      CALL CURL(TDF,XNC,ZK,SK0,AVGDFT,TDIFI,D)
      IF(PRFINAL.EQ.0.)GO TO 309
      ZX=Z(NCOUNT)-SFINAL*X(NCOUNT)*12.
      F=FX(NCOUNT)-1000.*PRFINAL*SA/(SS*D)
      GO TO 311
309   ZX=Z(NCOUNT)
      F=FX(NCOUNT)-P(I)
311   IF(NCOUNT.EQ.1)FPLOT=F
      ZFI=ZK
      SY=SK0
      DL6TH=DL/6.
      DL3RD=DL/3.
      DLHALF=DL/2.-.1
      LP=LAPS
      IJK=I
      IF(LP.GT.99)LP=99
      IF(IJK.GT.29)IJK=29
      IF(X(NCOUNT).EQ.DL6TH)YVERT(IJK,LP,1)=ZK
      IF(X(NCOUNT).EQ.DL3RD)YVERT(IJK,LP,2)=ZK
```

```
      IF(X(NCOUNT).GE.DLHALF)YVERT(IJK,LP,3)=ZK
  490 CONTINUE
 310  WRITE(IW,320)X(NCOUNT),ZX,U(NCOUNT),F,ZFI,SY
 320  FORMAT(12X,F7.2,2F10.5,F10.2,F10.5,F10.2)
      IF(INDCON.EQ.1)GO TO 330
      GO TO 140
C
C     PRINT MESSAGE AT END OF ITERATIONS
C
330   WRITE(IW,350)
350   FORMAT(/////24X,'CONVERGENCE NOT ACHIEVED, ALGORITHM'/
     1           23X,'STOPPED FOR MAXIMUM NO. OF ITERATIONS')
140   WRITE(07,*)ZX,FPLOT
      RETURN
      END
      SUBROUTINE ITER(ZI,NEL,MT,INDCON)
      IMPLICIT DOUBLE PRECISION (A-H,O,P,R-Z)
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C     SUBROUTINE ITER HANDLES THE ITERATIVE PROCEDURES OF THE FRICTION
C     SUBMODELS FOR THE INTERVALS OF CONTRACTION/EXPANSION AND FOR THE
C     MOVEMENT REVERSAL INTERVALS. INFORMATION GENERATED IN THIS SUB-
C     ROUTINE IS USED IN SUBROUTINE FREST TO DETERMINE THE FRICTION
C     RESTRAINT PROFILES AND PROFILES OF LONGITUDINAL MOVEMENTS.
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
C     VARIABLES:
C
C     Z1(I) = RESTRAINED MOVEMENT OF POINT I AT TIME INCREMENT
C            CONSIDERED (IN)
C     FPROM = AVERAGE RESTRAINT STRESS IN ELEMENT I AT TIME INCREMENT
C            CONSIDERED (PSI)
C     DMOV = RESTRAINED STRAIN OF ELEMENT I AT TIME INCREMEN
C            CONSIDERED (IN/IN)
C     BLOCK VARIABLES USED:    COMMON /BLCK3/M1,ZU(20),UU(20)
C                   COMMON/BLCK7/NILD
C                   COMMON/BLCK8/EL
C                   COMMON /BLCK9/M,Z(200),U(200)
C                   COMMON /BLCK10/Z1(200),X(200),FX(200),STF1(200)
C
C     VARIABLES ORIGINATED:    COMMON /BLCK9/U(200)
C                   COMMON /BLCK10/Z1(200),X(200),FX(200),STF1(200)
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
      COMMON /BLCK3/M1,ZU(20),UU(20)
      COMMON /BLCK6/G,COMPF,ALTOT,ZTOT,CREEP,PR,SK,SL
      COMMON/BLCK7/DL,NILD,NTEMP,TOL,NMAX,DW
      COMMON/BLCK8/AL,EL,ZZ,SA,SS,PS(10),AGEP(10),IAGG,AGGTYP,EMOD28
      COMMON /BLCK9/M,Z(200),U(200)
```

```
      COMMON /BLCK10/Z1(200),X(200) FX(200) STF1(200)
      COMMON /BLCK13/CPF,CPM,ZZF,RELAX,FPY
C
C     DETERMINE UNRESTRAINED MOVEMENTS OF NODES
C
      NN = 0
      Z1(NEL) = ZI
      IN = NEL + 1
      DO 10 I = IN,MT
      Z1(I) = Z1(I-1) + STF1(I-1)*(X(I)-X(I-1))*12
10    CONTINUE
20    SUM1 = 0
      SUM2 = 0
C
C     DETERMINE FRICTION COEFFICIENTS FOR UNRESTRAINED MOVEMENTS
C     OF NODES
C
      CALL FRIC(NEL,MT,Z1)
      FX(MT) = 0
C
C     COMPUTE AVERAGE FRICTION COEFFICIENTS AND FRICTION
C     RESTRAINT STRESSES OF ELEMENTS
C
      DO 30 I = IN,MT
      K = MT-I + NEL
      U(K + 1) = (U(K + 1) + U(K))/2.
      FX(K) = FX(K + 1) + U(K + 1)*G*(X(K + 1)-X(K))/144
30    CONTINUE
C
C     DETERMINE RESTRAINED MOVEMENTS OF NODES AND COMPUTE
C     RATIO FOR SUCCESSIVE ITERATIONS
C
      DO 40 I = IN,MT
      ZM = Z1(I)
      FPROM = (FX(I) + FX(I-1))/2.
      DMOV = STF1(I-1) + FPROM/EL
      Z1(I) = 0.65*(Z1(I-1) + DMOV*(X(I)-X(I-1))*12.) + 0.35*Z1(I)
      SUM1 = SUM1 + (ZM-Z1(I))*(ZM-Z1(I))
      SUM2 = SUM2 + Z1(I)*Z1(I)
40    CONTINUE
      RATIO = SQRT(SUM1/SUM2)
      IF(RATIO.LT.TOL)GO TO 50
      NN = NN + 1
      IF(NN.LE.NMAX)GO TO 20
      MM = NILD/2 + 1
      IF(NEL.EQ.1.AND.MT.EQ.MM)GO TO 42
      GO TO 50
42    CONTINUE
C
C     MAKE SWITCH VARIABLE INDCON = 1 IF SLAB IS IN
C     CONTRACTION/EXPANSION INTERVAL
C
      INDCON = 1
50    CONTINUE
      RETURN
```

```
      END
      SUBROUTINE TIDEVAR(TIME,D,IP1,INDICA)
      IMPLICIT DOUBLE PRECISION (A-H,O,P,R-Z)
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C    SUBROUTINE TIDEVAR DETERMINES ESTIMATES OF CONCRETE ELASTIC
C    MODULUS, RADIUS OF RELATIVE STIFFNESS OF THE SLAB, SHRINKAGE,
C    CREEP AND RELAXATION OF THE STEEL STRANDS
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C    VARIABLES:
C
C        TIME = TIME OF EVALUATION SINCE CONCRETE SETTING (DAYS)
C      COMSTR = CONCRETE COMPRESSIVE STRENGTH AT TIME
C             OF EVALUATION (PSI)
C          EL = CONCRETE ELASTIC MODULUS AT TIME OF EVALUATION (PSI)
C          SL = RADIUS OF RELATIVE STIFFNESS (IN)
C          ZZ = SHRINKAGE STRAIN AT TIME OF EVALUATION (IN/IN)
C         CPF = CREEP STRAIN (FOR EVALUATION OF PRESTRESS LOSSES)
C             BY THE TIME OF EVALUATION, SINCE APPLICATION OF
C             LAST PRESTRESS FORCE (IN/IN)
C         CPM = TOTAL CREEP STRAIN BY THE TIME OF EVALUATION, SINCE
C             APPLICATION OF FIRST PRESTRESS FORCE (IN/IN)
C       RELAX = TOTAL STEEL RELAXATION BY THE TIME OF EVALUATION
C             (PERCENT)
C         ZZF = SHRINKAGE STRAIN (FOR EVALUATION OF PRESTRESS LOSSES)
C             BY THE TIME OF EVALUATION, SINCE APPLICATION OF
C             LAST PRESTRESS FORCE (IN/IN)
C
C      BLOCK VARIABLES USED:     COMMON/BLCK6/G,COMPF,ALTOT,ZTOT,CREEP,PR,SK,SL
C          COMMON/BLCK8/AL,EL,ZZ,SA,SS,PS(10),AGEP(10),IAGG,AGGTYP,EMOD28
C          COMMON/BLCK13/CPF,CPM,ZZF,RELAX,FPY
C      VARIABLES ORIGNATED:   DIMENSION CREEP(10,10)
C                       COMMON/BLCK6/SL
C                       COMMON/BLCK8/AL,EL,ZZ
C                       COMMON/BLCK13/CPF,CPM,ZZF,RELAX
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
      DIMENSION CREP(10,10)
      COMMON/BLCK6/G,COMPF,ALTOT,ZTOT,CREEP,PR,SK,SL
      COMMON/BLCK8/AL,EL,ZZ,SA,SS,PS(10),AGEP(10),IAGG,AGGTYP,EMOD28
      COMMON/BLCK13/CPF,CPM,ZZF,RELAX,FPY
C
C    DEFINE CONCRETE PROPERTIES INDEPENDENT OF PRESTRESS FORCE
C
      CALL COMPSTR(TIME,COMSTR)
      IF (IAGG.LT.1.OR.EMOD28.LE.0.0)GO TO 50
      CALL PREDMD (5.,AGGTYP,TIME,EL)
      EL = EL*EMOD28
```

```
      GO TO 60
   50 CONTINUE
      EL = 33.*(G**1.5)*SQRT(COMSTR)
   60 CONTINUE
      SL = ((EL*D**3.0)/(12.*(1-PR**2.0)*SK))**0.25
      IF(TIME.LT.1./3000.)GO TO 70
      AL = ALTOT
      GO TO 80
70     AL = (1.-8.*(1./3.-TIME)**2.)*ALTOT
80     SHRN = 26.*EXP(0.36*D)
      ZZ = (TIME/(SHRN + TIME))*ZTOT
      IF(INDICA.EQ.0)GO TO 200
C
C      DEFINE PARAMETERS DEPENDENT ON AMOUNT OF PRESTRESS FORCE
C
      CPM = 0
      PANT = 0
      DO 120 I1 = 1,IP1
      DP = PS(I1)-PANT
      TIMP = AGEP(I1)
      CALL COMPSTR(TIMP,COM)
      EP = 33.*(G**1.5)*SQRT(COM)
      STI = 1000.*DP*SA/(SS*D*EP)
      CRA = 0.
      DO 115 I2 = I1,IP1
      IF(I2.EQ.IP1)GO TO 112
      TIM = AGEP(I2 + 1)-AGEP(I1)
      GO TO 113
112    TIM = TIME-AGEP(I1)
113    CONTINUE
      CRAUX = TIM**0.6
      CR = (CRAUX*CREEP*STI)/(10. + CRAUX)
      CREP(I2,I1) = CR-CRA
      CPM = CPM + CREP(I2,I1)
      CRA = CR
115    CONTINUE
120    PANT = PS(I1)
      CPF = 0.
      DO 125 I1 = 1,IP1
      CPF = CPF + CREP(IP1,I1)
125    CONTINUE
C
C      DEFINE AMOUNTS OF SHRINKAGE AT THE TIME OF STRESSING
C      AND STRAND RELAXATION
C
      TIM = (TIME-AGEP(IP1))*24.
      RAUX = PS(IP1)/FPY-0.55
      IF(RAUX.LT.0.)RAUX = 0.
      RELAX = ((ALOG10(TIM)/10.)*RAUX)*PS(IP1)
      ZZF = (AGEP(IP1)/(SHRN + AGEP(IP1)))*ZTOT
200    CONTINUE
      RETURN
      END
      SUBROUTINE FRIC(NEL,MT,Z1)
      IMPLICIT DOUBLE PRECISION (A-H,O,P,R-Z)
```

```
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C    SUBROUTINE FRIC COMPUTES FRICTION COEFFICIENTS FROM THE
C    MOVEMENTS OF THE SLAB NODES  INFORMATION FROM THIS SUB-
C    ROUTINE IS USED IN SUBROUTINE ITER TO DETERMINE THE
C    PROFILES OF FRICTION RESTRAINT STRESSES
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C    VARIABLES
C
C      M1 = NO  OF POINTS IN THE SUPPLIED FRICTION COEFFICIENT
C          VS  DISPLACEMENT RELATIONSHIP  MOREOVER, M1 IS A CONTROL
C          VARIABLE INDICATING THE TYPE OF RELATIONSHIP:
C          IF M1 = 1, THE RELATIONSHIP IS A STRAIGTH LINE,
C          IF M1 = 2, THE RELATIONSHIP IS AN EXPONENTIAL RELATIONSHIP,
C          IF M1 > 2, THE RELATIONSHIP IS A MULTILINEAR CURVE
C    ZAUX = ABSOLUTE VALUE OF THE DISPLACEMENT Z1(I) OF POINT I (IN)
C    U(I) = FRICTION COEFFICIENT UNDER POINT I
C
C    BLOCK VARIABLES USED     COMMON /BLCK3/M1,ZU(20),UU(20)
C                             COMMON /BLCK9/M,Z(200),U(200)
C
C    VARIABLES ORIGINATED:    COMMON /BLCK9/Z(200),U(200)
C
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
      DIMENSION Z1(200)
      COMMON /BLCK3/M1,ZU(20),UU(20)
      COMMON /BLCK9/M,Z(200),U(200)
      IF(M1.EQ.1)GO TO 10
      IF(M1.EQ.2)GO TO 80
      IF(M1.GT.2)GO TO 20
10    CONTINUE
      M2=2
      GO TO 30
20    CONTINUE
      M2=M1
30    CONTINUE
C
C     COMPUTE FRICTION COEFFICIENTS FROM STRAIGTH LINE OR FROM MULTILINEAR
C     CURVE
C
      DO 40 I1=NEL,MT
      ZAUX=ABS(Z1(I1))
      DO 50 J=2,M2
      J1=J
      IF(ZAUX.LT.ZU(J))GO TO 60
50    CONTINUE
      U(I1)=UU(M2)
```

```
      GO TO 70
60    SLOPE = (UU(J1)-UU(J1-1))/(ZU(J1)-ZU(J1-1))
      U(I1) = UU(J1-1) + SLOPE*(ZAUX-ZU(J1-1))
70    CONTINUE
      IF(Z1(I1) GT 0 )U(I1) = -U(I1)
40    CONTINUE
      GO TO 110
80    CONTINUE
C
C     COMPUTE FRICTION COEFFICIENTS FROM EXPONENTIAL RELATIONSHIP
C
      DO 95 I1 = NEL,MT
      ZAUX = ABS(Z1(I1))
      IF(ZAUX LT ZU(2))GO TO 100
      U(I1) = UU(2)
      GO TO 90
100   PAUX = (ZAUX/ZU(2))**0 3333
      U(I1) = PAUX*UU(2)
90    IF(Z1(I1) GT 0 )U(I1) = -U(I1)
95    CONTINUE
110   RETURN
      END
      SUBROUTINE COMPSTR(TIME,COMSTR)
      IMPLICIT DOUBLE PRECISION (A-H,O,P,R-Z)
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C     SUBROUTINE COMP COMPUTES COMPRESSIVE STRENGTH OF CONCRETE
C     AT SPECIFIED TIMES
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C     VARIABLES:
C
C       TIME = TIME OF EVALUATION SINCE SLAB SETTING (DAYS)
C      COMPF = FINAL COMPRESSIVE STRENGTH (PSI)
C     PERCOM = PERCENT OF THE FINAL COMPRESSIVE STRENGTH
C     COMSTR = COMPRESSIVE STRENGTH EVALUATED (PSI)
C
C     BLOCK VARIABLES USED:     COMMON/BLCK2/KK,AGEU(20),COMP(20)
C            COMMON/BLCK6/G,COMPF
C            COMMON/BLCK8/AGEP(10)
C
C     VARIABLES ORIGINATED:  PERCOM, COMSTR, SLOPE
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
      DIMENSION PERCENT(8),AGE(8)
      COMMON/BLCK2/KK,AGEU(20),COMP(20)
      COMMON/BLCK6/G,COMPF,ALTOT,ZTOT,CREEP,PR,SK,SL
      COMMON/BLCK8/AL,EL,ZZ,SA,SS,PS(10),AGEP(10),IAGG,AGGTYP,EMOD28
      DATA AGE/0.,1.,3.,5.,7.,14.,21.,28./
```

```
      DATA PERCENT/0 ,15 ,38 ,53 ,63 ,82 ,94 ,100 /
      IF(IAGG LT 1)GO TO 30
C
C     COMPUTE COMPRESSIVE STRENGTH IF
C     THERE IS NO USER-SUPPLIED RELATIONSHIP
C
      CALL PREDMD (6 ,AGGTYP,TIME,COMSTR)
      COMSTR = COMSTR*COMPF
      GO TO 60
20    PERCOM = (PERCENT(J)-PERCENT(J-1))/(AGE(J)-AGE(J-1))
      PERCOM = PERCENT(J-1) + PERCOM*(TIME-AGE(J-1))
      COMSTR = PERCOM*COMPF/100
      GO TO 60
C
C     COMPUTE COMPRESSIVE STRENGTH IF
C     THERE IS A USER-SUPPLIED RELATIONSHIP
C
30    CONTINUE
      DO 40 I = 1,KK
      J = I
      IF(TIME LE AGEU(I))GO TO 50
40    CONTINUE
      COMSTR = COMPF
      GO TO 60
50    SLOPE = (COMP(J)-COMP(J-1))/(AGEU(J)-AGEU(J-1))
      COMSTR = COMP(J-1) + SLOPE*(TIME-AGEU(J-1))
60    CONTINUE
      RETURN
      END
      SUBROUTINE CURL(TDF,X,ZK,SK0,AVGDFT,TDIFI,D)
      IMPLICIT DOUBLE PRECISION (A-H,O,P,R-Z)
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C     SUBROUTINE CURL COMPUTES CURLING STRESSES AND
C     DEFLECTIONS
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C     VARIABLES:
C
C        Y = COORDINATE MEASURED FROM THE SLAB END, OF NODE LOCATED
C            AT COORDINATE X FROM THE MID-SLAB (IN)
C       ZK = TOTAL CURL DEFLECTION FOR NODE LOCATED A DISTANCE X FROM
C            MID-SLAB.
C    YGRAD = DEFLECTION CAUSED BY TOP-BOTTOM TEMPERATURE GRADIENT
C    YFRIC = DEFLECTION CAUSED BY FRICTION DURING CONTRACTION
C      SK0 = CURLING STRESS FOR NODE LOCATED A DISTANCE X FROM MID-SLAB.
C            ALONG THE LONGITUDINAL AXIS OF THE SLAB WITH FULLY RESTRIC
C       TED MOVEMENT
C  CRLMAX = MAXIMUM CURLING IN THE CYCLE
C  TRANSM = VALUES FOR TRANSITION FLATTENING SLOPE.
C
C     BLOCK VARIABLES USED      COMMON/BLCKS/ADT(100),TDIF(100),PP(100),IHOUR(100),ADTFIX(100),CRLMAX,ADTMAX,ADTMIN
```

```
C           COMMON /BLCK6/ALTOT ZTOT PR SK,SL
C           COMMON/BLCK7/DL NILD NTEMP,TOL NMAX DW
C           COMMON/BLCK8/AL EL  AGEP(10) IAGG AGGTYP EMOD28
C
C     VARIABLES ORIGINATED   SK0, ZK, CRLMAX
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
      COMMON/BLCK5/KI,CURTEMP,AG(100) ADT(100) TDIF(100) PP(100) AVGDIF
     1(100),IHOUR(100),ADTFIX(100),CRLMAX,ADTMAX ADTMIN
      COMMON /BLCK6/G,FPC,ALTOT,ZTOT,STRNMUL,PR,SK,SL
      COMMON/BLCK7/DL,NILD,NTEMP,TOL,NMAX,DW
      COMMON/BLCK8/AL,EL,ZZ,SA,SS,PS(10),AGEP(10),IAGG,AGGTYP,EMOD28
C
C     COMPUTATION OF CURLING DEFLECTION AND STRESS
C
      WSLAB = G*12 /D
      SDISIP = PR*WSLAB*( 5*DL*12.)**3 /(15.*EL**2 *SK)
      XSOR = (DW*Y 12 /(0 5*DL))**2.*(14 *X/DL + 3 5*DL/(X-1.)-11.)/3
      YGRAD = (AVGDFT*ALTOT + SDISIP)*XSOR*(1 -PR**2 )/D
      TDIF2 = TDIFI
      YFRIC = 3.*(TDF*TDIF2*ALTOT + SDISIP)*XSOR/D**2
      ZK = (YGRAD + YFRIC)/(-2 )
      SK0 = EL*ALTOT*AVGDFT
      IF(ZK.LT.CRLMAX)CRLMAX = ZK
      TRANSM = (13 25-TDF)/(DABS(ADTMAX) + DABS(ADTMIN))
      IF(TDF GT 0  AND AVGDFT EQ TRANSM)ZK = CRLMAX*TRANSM
C THIS LOOP AVAILABLE FOR DEBUGGING PURPOSES
      ILP = ILP + 1
      IF(ILP.EQ.12)ILP = 0
      RETURN
      END
      SUBROUTINE PREDMD (CALTYP,AGGTYP,TIME,Y)
      IMPLICIT DOUBLE PRECISION (A-H,O,P,R-Z)
C
C
C     ENTRY PREDMD USES THE MODEL AND TABLE VALUES SPECIFIED BY CALTYP
C     TO GET THE QUANTITY SPECIFIED.
C
C     CALTYP --> ONE OF FOUR VALUES. DENOTES WHICH DATA TABLE TO USE IN
C                THE CALCULATION.
C                4 - SPLITTING TENSILE STREGTH/NORMALIZED (TENSM2)
C                5 - MODULUS OF ELASTICITY/NORMALIZED (ELASM2)
C                6 - COMPRESSIVE STRENGTH/NORMALIZED (CMSTM2)
C                8 - DRY SHRINKAGE/NORMALIZED (DSHRM2)
C
C     AGGTYP --> DENOTES TYPE OF AGGREGATE.  ONE OF 8 VALUES.
C                1 - GRANITE
C                2 - DOLOMITE
C                3 - VEGA
C                4 - BDG/TT
C                5 - W-T
C                6 - FERRIS
C                7 - LS
```

```
C             8 - SRG
C
C     TIME --> THE TIME IN DAYS FOR WHICH THE QUANTITY IS DESIRED
C
C     Y <-- OUTPUT VALUE CALCULATED AS A COMBINATION OF THE ABOVE
C
      DIMENSION TENSM2(3,8),ELASM2(3,8),CMSTM2(3,8),DSHRM2(3,8)
      DATA TENSM2/ 504, 150,1 05, 5, 261,1 094, 5, 302, 3014, 5, 332,            +      723, 501, 196,2 505, 505, 137,2 479, 602, 177,1
     +      723, 601,.198,2 505, 505, 137,2 479, 602, 177,1 068,
     +      5, 267, 468/
      DATA ELASM2/ 5, 78,1 65, 5, 485,3 537, 5,.301,1 574, 5, 688,2.,   JRC03140
     +     5, 405,97 00, 5,.738,2 67E12, 5, 535,110 48, 5, 574,61755./  JRC03150
      DATA CMSTM2/ 518,.096, 623, 501, 231,.562, 5, 367,.367, 501, 582, JRC03160
     +     220,.501,.214, 647, 501, 206, 801,.510, 115, 49,.502,.182,   JRC03170
     +     473/                                                 JRC03180
      DATA DSHRM2/0 ,0.,0.,0 ,0 .0 ,0..0.,0..0 ,0.,0.,0 ,0.,0.,       JRC03190
     +     0  0 ,0 , 61, 042, 004, 576, 06, 005/                    JRC03200
       IAGG = DINT(AGGTYP)
       ICAL = DINT(CALTYP)
C
      Y = 0 0
C
      IF (ICAL .EQ  4) GOTO 33
      IF (ICAL .EQ. 5) GOTO 34
      IF (ICAL .EQ  6) GOTO 35
      IF (ICAL .EQ. 8) GOTO 37
C
C
 33   Y = TENSM2(1,IAGG)*(2-EXP(-TENSM2(2,IAGG)*TIME)-EXP(-TENSM2(3,
     +  IAGG)*TIME))
      GOTO 40
 34   Y = ELASM2(1,IAGG)*(2-EXP(-ELASM2(2,IAGG)*TIME)-EXP(-ELASM2(3,
     +  IAGG)*TIME))
      GOTO 40
 35   Y = CMSTM2(1,IAGG)*(2-EXP(-CMSTM2(2,IAGG)*TIME)-EXP(-CMSTM2(3,
     +  IAGG)*TIME))
      GOTO 40
 37   Y = DSHRM2(1,IAGG)*(2-EXP(-DSHRM2(2,IAGG)*TIME)-EXP(-DSHRM2(3,
     +  IAGG)*TIME))
C
 40   CONTINUE
      RETURN
      END

%
```

APPENDIX E. REGRESSION EQUATIONS FOR DATA SET OF NOVEMBER 5-6, 1988

TABLE E.1. SUMMARY OF REGRESSION EQUATIONS FOR THE DATA SET FOR NOVEMBER 5-6, 1988

	Slab Length (240 ft)		Slab Length (440 ft)	
Slab Portion	Equation	Regression Coefficient (R^2)	Equation	Regression Coefficient (R^2)
Corner	y = 0.0377 – 0.0075 x + 0.00028 x^2	0.849	y = 0.0379 – 0.0074 x + 0.00027 x^2	0.892
	y = 0.0344 – 0.0069 x + 0.00026 x	0.848	y = 0.0262 – 0.0052 x + 0.00019 x	0.908
	y = 0.0331 – 0.0062 x + 0.00021 x	0.899	y = 0.0332 – 0.0069 x + 0.00028 x	0.881
	y = 0.0298 – 0.0056 x + 0.00019 x	0.861	y = 0.0452 – 0.0060 x + 0.00002 x	0.967
	Average eccentricity = 0.00023		Average eccentricity = 0.00019	
L/6	y = 0.0217 – 0.0043 x + 0.00016 x	0.879	y = 0.0165 – 0.0029 x + 0.00009 x	0.901
	y = 0.0266 – 0.0041 x + 0.00016 x	0.838	Average eccentricity = 0.00009	
	Average eccentricity = 0.00016		y = 0.0122 – 0.0031 x + 0.00017 x	0.843
L/3	y = 0.0172 – 0.0035 x + 0.00014 x	0.892	y = 0.0145 – 0.0031 x + 0.00013 x	0.874
	Average eccentricity = 0.00014		Average eccentricity = 0.00015	
Corner	y = 0.0733 – 0.0065 x	0.987	y = 0.0662 – 0.0063 x	0.983
	y = 0.0782 – 0.0036 x	0.988	y = 0.0400 – 0.0044 x	0.978
	y = 0.0498 – 0.0060 x	0.986	y = 0.0585 – 0.0059 x	0.977
	y = 0.0561 – 0.0054 x	0.987	y = 0.0516 – 0.0043 x	0.966
	Average slope = -0.0054		Average slope = -0.0052	
L/6	y = 0.0410 – 0.0035 x	0.992	y = 0.0269 – 0.0028 x	0.989
	y = 0.0432 – 0.0033 x	0.985	Average slope = -0.0028	
	Average slope = -0.0034		y = 0.0301 – 0.0022 x	0.954
L/3	y = 0.0320 – 0.0028 x	0.983	y = 0.0270 – 0.0027 x	0.990
	Average slope = -0.0028		Average slope = -0.0025	

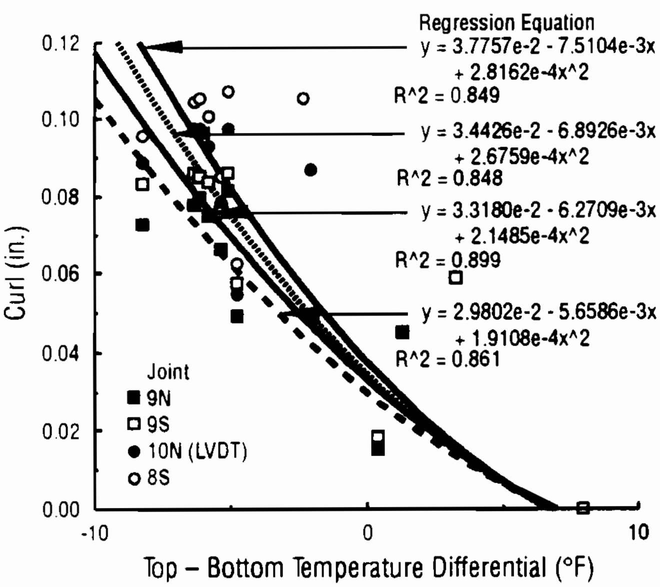

Fig E.1. Regression curves for the corner of a 240-foot slab collected on November 5-6, 1988, for the curling portion of the curl-uncurl cycle.

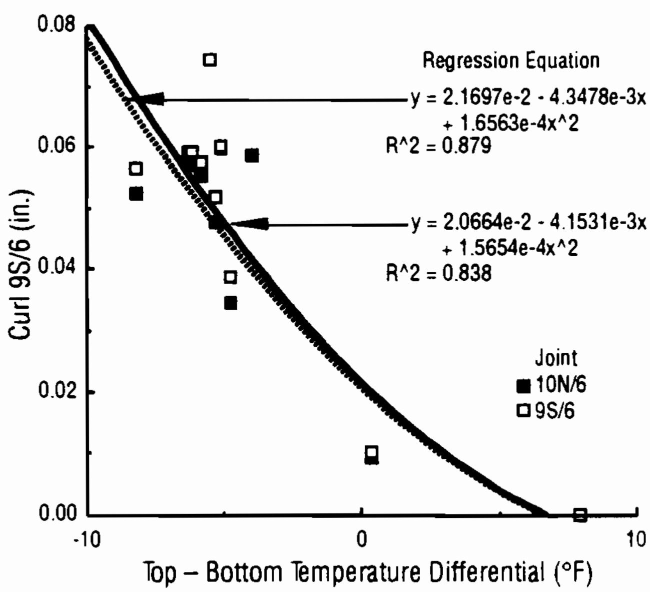

Fig E.2. Regression curves for the sixth point of a 240-foot slab collected on November 5-6, 1988, for the curling portion of the curl-uncurl cycle.

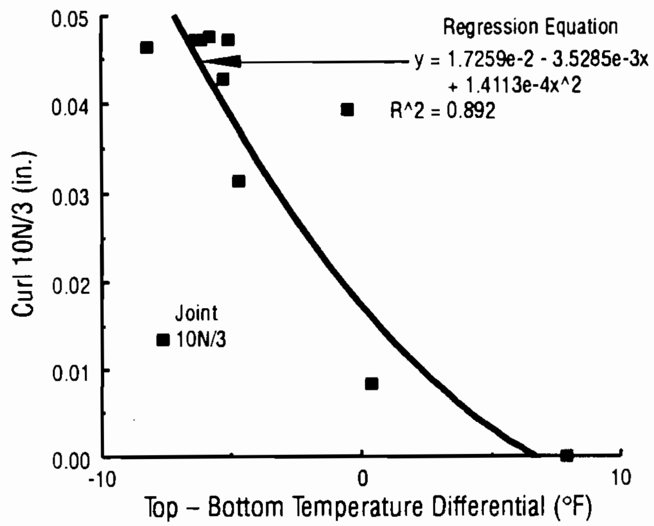

Fig E.3. Regression curves for the third point of a 240-foot slab collected on November 5-6, 1988, for the curling portion of the curl-uncurl cycle.

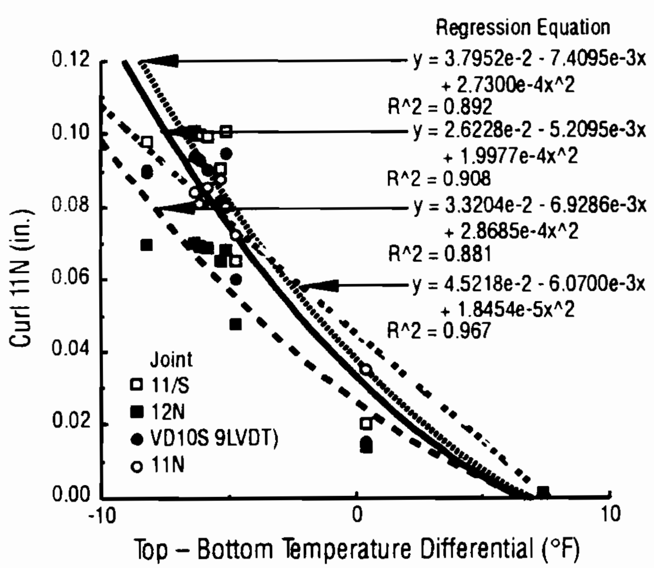

Fig E.4. Regression curves for the corner of a 440-foot slab collected on November 5-6, 1988, for the curling portion of the curl-uncurl cycle.

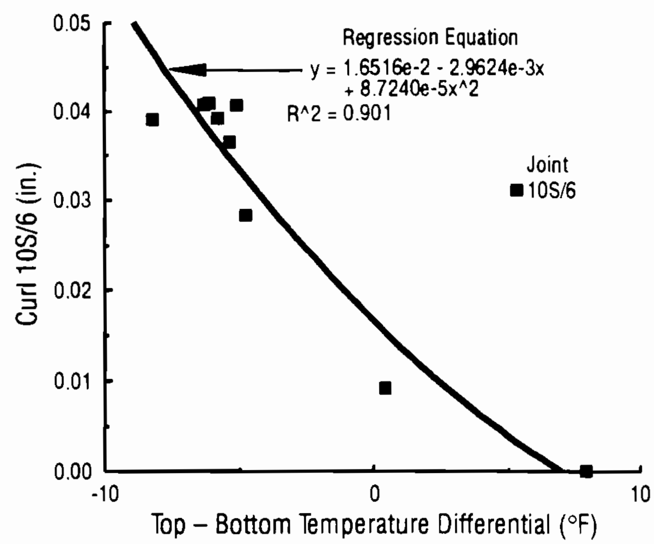

Fig E.5. Regression curves for the sixth point of a 440-foot slab collected on November 5-6, 1988, for the curling portion of the curl-uncurl cycle.

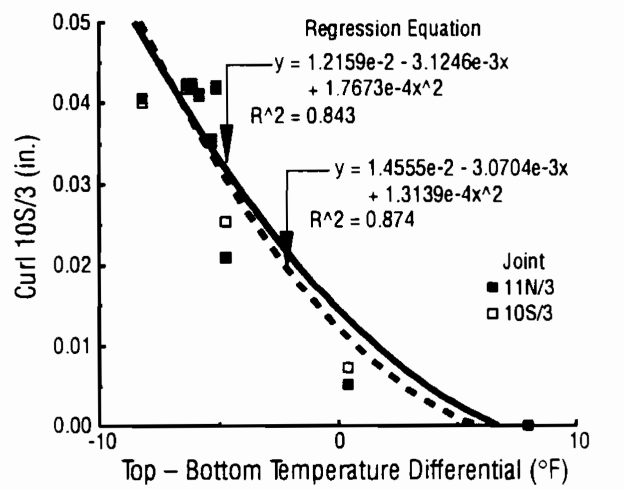

Fig E.6. Regression curves for the third point of a 440-foot slab collected on November 5-6, 1988, for the curling portion of the curl-uncurl cycle.

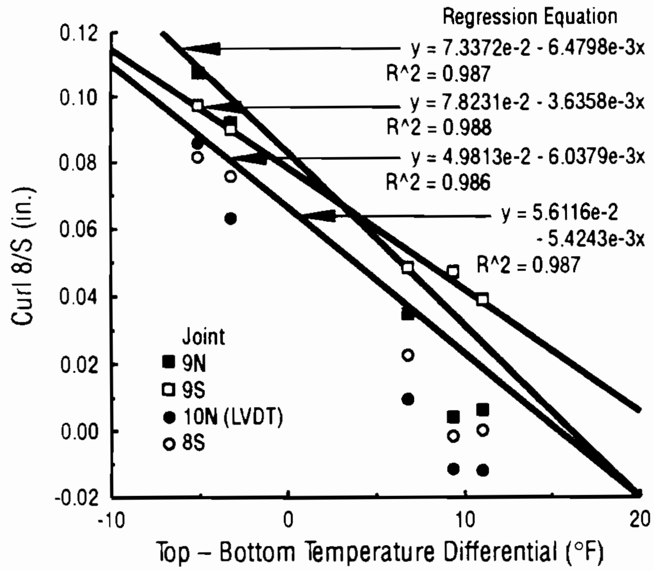

Fig E.7. Regression curves for the corner of a 240-foot slab collected on November 5-6, 1988, for the uncurling portion of the curl-uncurl cycle.

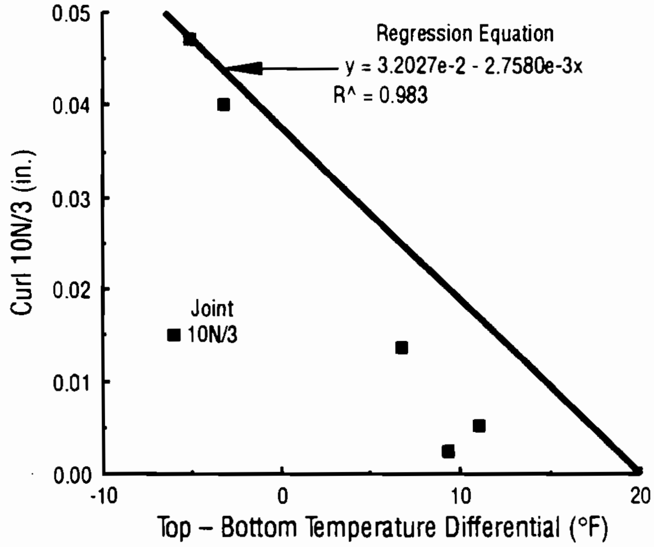

Fig E.9. Regression curves for the third point of a 240-foot slab collected on November 5-6, 1988, for the uncurling portion of the curl-uncurl cycle.

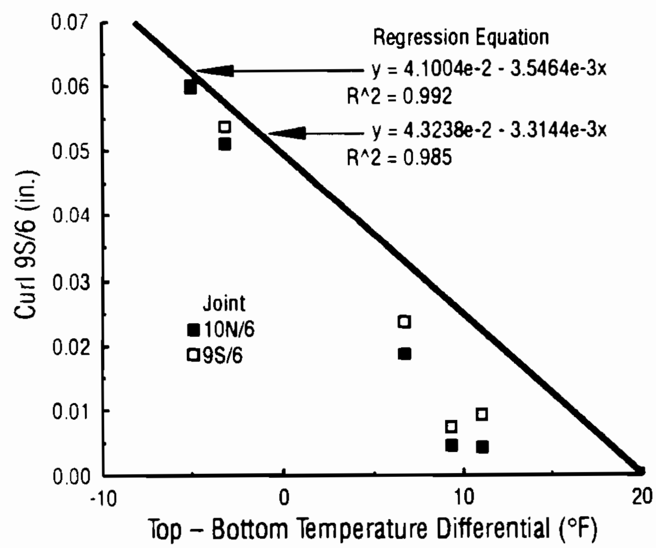

Fig E.8. Regression curves for the sixth point of a 240-foot slab collected on November 5-6, 1988, for the uncurling portion of the curl-uncurl cycle.

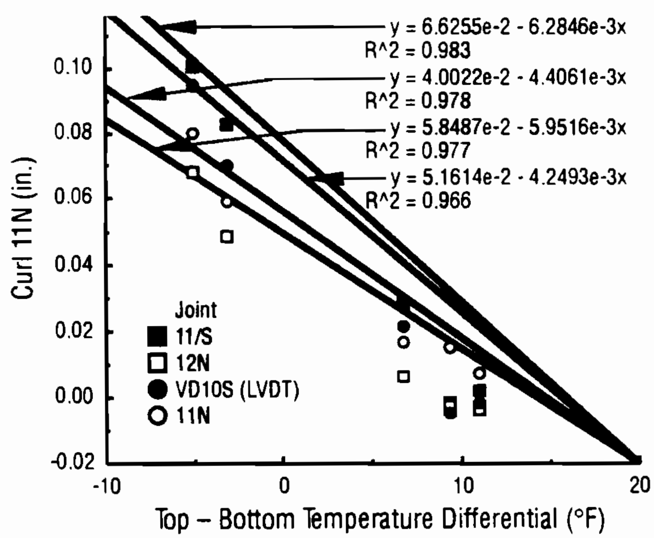

Fig E.10. Regression curves for the corner of a 440-foot slab collected on November 5-6, 1988, for the uncurling portion of the curl-uncurl cycle.

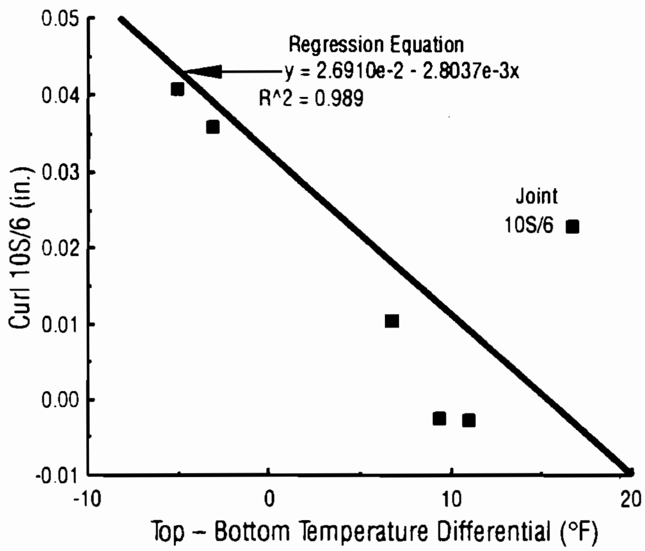

Fig E.11. Regression curves for the sixth point of a 440-foot slab collected on November 5-6, 1988, for the uncurling portion of the curl-uncurl cycle.

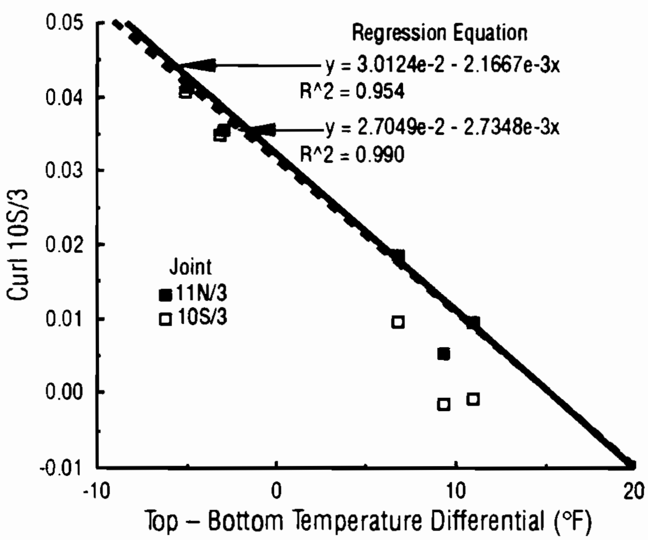

Fig E.12. Regression curves for the third point of a 440-foot slab collected on November 5-6, 1988, for the uncurling portion of the curl-uncurl cycle.

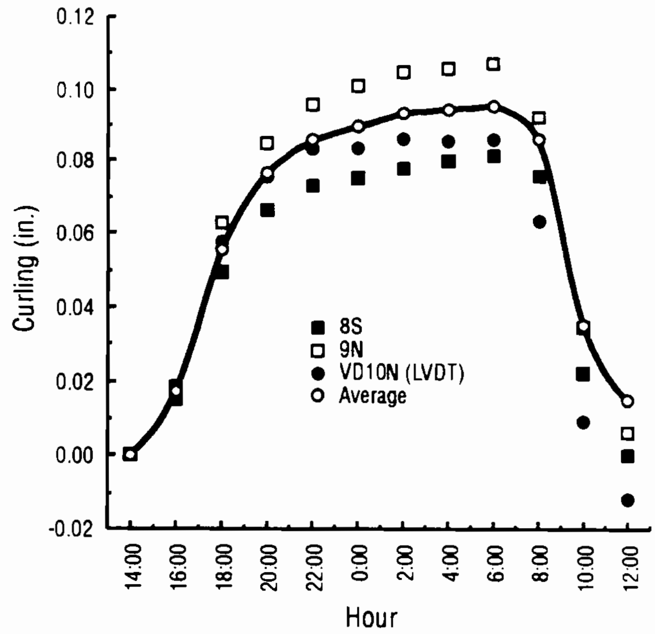

Fig E.13. Curve for the average values collected on July 25-26, 1988, for the corner positions of a 240-foot slab.

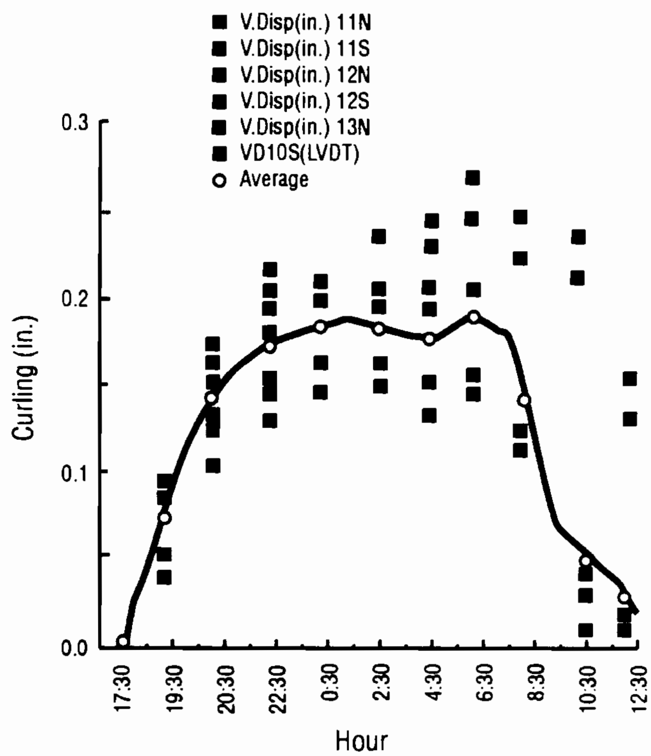

Fig E.14. Curve for the average values collected on July 25-26, 1988, for the corner positions of a 440-foot slab.

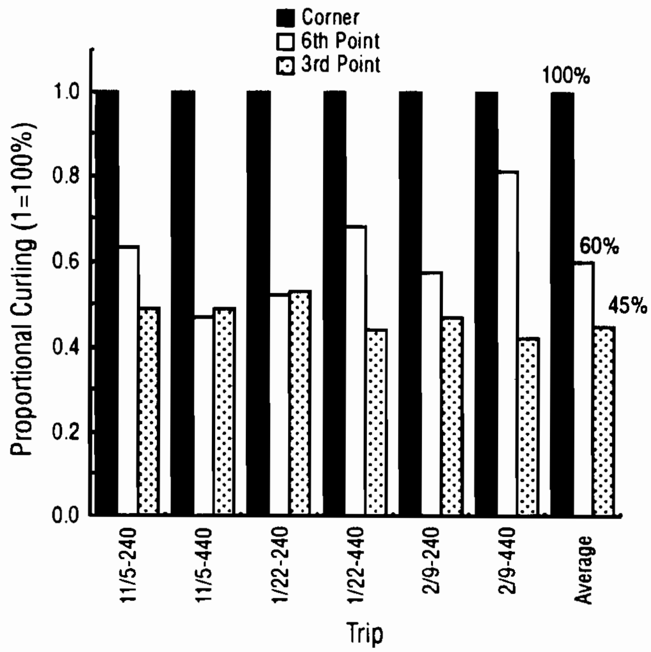

Fig E.15. Summary of average curling at different points along the edge of the slab.