

PREDICTION OF CRCP TERMINAL MOVEMENTS

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ABSTRACT

The purpose of this study is to provide pavement designers with substantive information about CRCP terminal movement. A mechanistic model, PSCP2, was used to analyze free end movement and to predict the size of terminal movements. Field measurements were conducted at SH-225 in Houston, Texas, in order to supplement the CRCP movement field data from a previous research study. A comparison between the collected data and the predictions of the PSCP2 program was performed to verify the reliability of the PSCP2 mechanistic model. A procedure was presented that estimates the terminal movement of a CRCP.

INTRODUCTION

The designer of a CRCP must eventually make a decision as to the type of terminal treatment that will be used at structures and other pavement ends on a project. The type of treatment selected is dependent on the magnitude of movement expected, which, in turn, is dependent on the annual temperature range, subbase type, pavement thickness, and the season the pavement is to be placed. Thus, the application of a successful treatment at another location may prove to be inadequate on the project of interest. This paper which presents a reliable procedure for estimating CRCP terminal movement was based on a study conducted for the Texas Department of Transportation (1).

General Comments

The volume change of Portland Cement Concrete (PCC), like most materials, is significantly affected by a variation in temperature and moisture conditions. If the length of a pavement is substantial, changes in its thickness and width can be overlooked (2). Accordingly, in this report, the end movement stands for the change of pavement length that is related to variations in temperature and moisture content. This longitudinal movement, whether expanding or contracting, can create detrimental results.

Since CRCP is a long slab without joints (other than construction joints), the problem of longitudinal movement in the end portions of the slab must always be taken into consideration by the designer. Therefore, the significant factors affecting the end movements of CRCP should be identified, and the magnitude of the pavement's terminal movements should be characterized. With this information, the designer can choose the most suitable techniques to absorb or to reduce the end movement.

In previous studies (2 thru 5), the factors influencing the free end movement of CRCP have been evaluated by analyzing the terminal movements data; researchers gathered the data by measuring in-service pavements. These factors include environmental conditions, slab geometry, and the coefficient of friction between the pavement and the subbase.

The literature covering the design or construction methods that accommodate or restrict terminal movement for CRCP was reviewed. Several methods were noted (5, 6, 8, and 13). For instance, expansion joints, steel finger joints, and wide-flange beam joints are designed to accommodate longitudinal movement (a space is created so that the longitudinal movement is allowed). The end anchorage system, a series of concrete lugs extending beneath the slab, restrains the movement of the pavement. However, anchor lugs cannot be used where soil characteristics prove inadequate, that is, where the soil's displacement resistance is marginal (8).

Previous studies of terminal movement were based on observations of existing CRCP's and provided limited information. Using a mechanistic computer model that reliably predicts the end movement for a range of conditions provides a better understanding of the CRCP movements. After the analyst calibrates the movements predicted by the mechanistic computer program using observed pavement end movements in the field, the mechanistic model can accurately predict the end movement for a range of conditions. The designer may then use these predictions to choose the most suitable techniques to accommodate or offset the terminal movements.

Objectives of the Study

The general objective of this paper is to provide the designer with substantive information to assist in developing design details to accommodate CRCP terminal movement. With this framework, the specific objectives of this paper are:

- (1) to determine the terminal movement characteristics of CRCP using a mechanistic model and to verify those characteristics with field data,
- (2) to conduct a sensitivity study of the problem, and
- (3) to develop mechanistic equations for use by designers or with nomographs or computer programs to estimate movements for a range of conditions.

Scope

An examination of all possible considerations requires an extensive paper. Thus, the scope of this paper was narrowed to an analytical study of CRCP only, and limited to developing design information summarized as follows:

- (1) The focus will be on the free end movement of CRCP (i.e., terminal anchorages and effects are not considered).
- (2) The mechanistic model, PSCP2, will be used to analyze the terminal movement.
- (3) The data from a previous project and selected case studies will be used for verification.

DATA ANALYSIS USING MECHANISTIC MODELING

The terminal movement of concrete pavements has long been studied by analyzing the observed performance measurements of in-service pavements, but the data are limited. There are many computer models that can simulate the behavior of concrete pavements, and program PSCP2 is one that can predict the movement of concrete pavement. The purpose of this section is to briefly introduce the PSCP2 program, its input requirement, the analysis design factorial, and the analysis.

The Analysis Program

The data analysis for this paper was performed with the PSCP2 computer program (11), developed by the Center for Transportation Research of The University of Texas at Austin. The PSCP2 program provides a complete analytical procedure for prestressed concrete pavement, especially the prediction of movement in a long pavement, a capability not present in other programs. For example, the JRCF mechanistic computer program can give a researcher information about the joint width that can be used to predict slab movement (14); however, the input of the slab length is limited. When the length of the slab is excessive the program does not produce reliable results (15), since it does not account for the condition of full sliding present in the terminal conditions. PSCP2 has an input requirement that allows the researcher to select the time of year at which the slab movement should be predicted. Therefore, different seasons can be chosen consistent with the study parameters desired.

Intrinsic to the application of the PSCP2 program model (11 and 12) is the assumption that concrete is a homogeneous, linearly elastic material. For a more detailed review of the key assumptions, the reader is referred to 11 and 12.

It is important to note the friction coefficient versus displacement relationship which characterizes the frictional resistance under the slab as represented by Figure 1. Note the displacement is linear elastic until sliding is experienced (i.e. small movements representative of a normal daily temperature cycle), but when major temperature changes occur, a sliding of the slab occurs. Thus, the large movements of $\frac{1}{2}$ inch to six inches associated with a CRCP terminal are experienced.

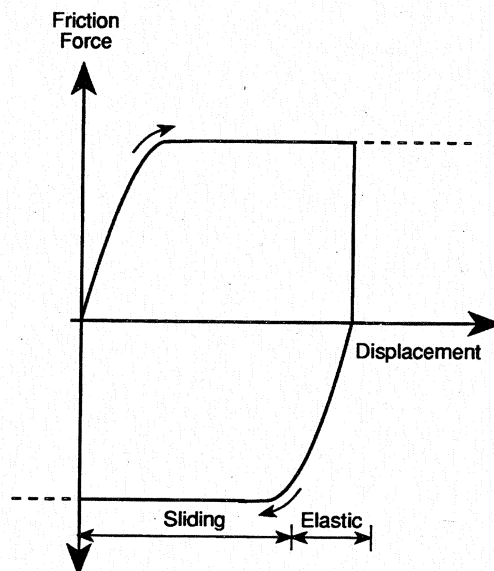


FIGURE 1 Friction force versus displacement curve assumption for the PSCP2 mechanistic computer program (11).

Input Data and Variables

The variables considered in this study for input into the PSCP2 program are aggregate type, friction force, slab thickness, and season of placement.

Concrete Property Inputs

Field and laboratory studies in Texas showed that there were significant differences in the material properties of concrete using Siliceous River Gravel (SRG) and Limestone (LS) aggregates (7). Since these two aggregate types are widely used in Texas, they are the principal aggregates considered in this paper. The wide range in properties between the aggregates provides a national application of results. The concrete property inputs, such as thermal coefficient, compressive strength, and shrinkage, were given two values: one value for SRG and one value for LS, as shown in Table 1. The other concrete property inputs, such as the unit weight, Poisson ratio, and the creep coefficient, are treated as constant values for each item; the values are shown in Table 2.

TABLE 1 Inputs of thermal coefficient (7)

Coarse Aggregate Type	Thermal Coefficient	28 Day Compressive Strength (psi)
SRG	8×10^{-6} in./in./°F	4000
LS	6×10^{-6} in./in./°F	500

Note that the input value of the ultimate shrinkage strain for the PSCP2 program is zero. Shrinkage can be considered to be zero because the primary purpose of this study is to predict the daily and annual changes of end movement after the first year. The basic approach was to compute the annual movements after the slab movement stabilizes, i.e., after total concrete shrinkage had occurred.

TABLE 2 Concrete property inputs (11)

Concrete Property	Value
Ultimate Shrinkage Strain	0
Unit Weight	144 pcf
Poisson Ratio	0.2
Creep Coefficient	2.1

where:

μ = coefficient of friction,

f = friction force, psi, and

D = depth of slab, inches.

The inputs for the relative friction values for an 8- and a 12-inch pavement are listed in Table 3. Basically, they represent the values just prior to sliding.

TABLE 3 Input of coefficient of friction

Friction Force	Coefficient of Friction	
	8-in.-thick slab	12-in.-thick slab
1.0 psi	1.5	1.0
4.6 psi	6.9	4.6
15.0 psi	22.5	15.0

Coefficient of Friction-Displacement Relationship

A study by Andrew W. Wimsatt presents the friction forces acting between CRCP and several types of subbases (16). Figure 2 illustrates the friction-movement relationship used for this paper. Figure 2 shows that after the curve reaches the maximum friction force, sliding occurs, the curve is in the elastic range of the material beneath the slab. The selected friction forces at sliding levels are 1.0, 4.6, and 15.0 psi. The 1.0 psi is indicative of a subbase with polyethylene sheeting, 4.6 psi is indicative of an asphaltic subbase and the 15.0 psi represents CTB (16).

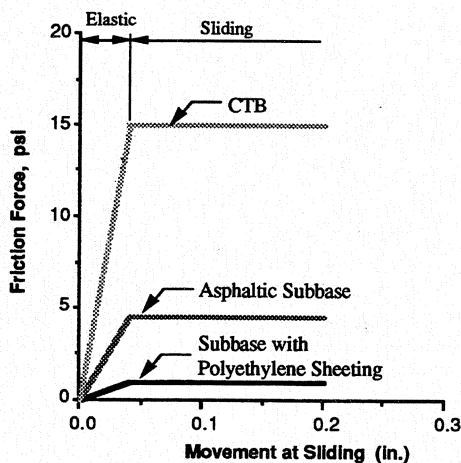


FIGURE 2 Friction-sliding movement input relationships for CTB, asphaltic subbase, and subbase with polyethylene sheeting.

Since the PSCP2 program requires a coefficient of friction, the friction forces must be converted to a coefficient of friction. The relationship between friction force and coefficient of friction, assuming that the unit weight of the concrete is 144 pcf, is:

$$\mu = \frac{12f}{D}$$

Steel Properties

Since the PSCP2 program was designed for prestressed concrete pavement, there are inputs for prestressed steel strands. However, because there is no prestress in CRCP, all of the values of the steel properties for the PSCP2 program were zero. Therefore, the CRCP was analyzed as a prestressed concrete pavement with no prestress. Such an analysis implies no cracks in the computer output. However, in reality, cracks always occur in CRCP (13 and 17), but they do not significantly affect the end movement.

Environmental Inputs

The pavement temperature data for critical periods throughout the pavement's service life may be input. The pavement temperature data fall into two categories: one is the sequence of temperature for the initial period (i.e., the temperature of the pavement as it hardens), and the other is the temperature data for subsequent periods (i.e., the typical daily temperature for the season in which the analysis is taking place). The former category requires that a number of temperature sequences be considered during the initial period, namely, the mid-depth temperature when the concrete sets up (curing temperature), and the mid-depth and top/bottom temperature differentials at each of the temperature sequence periods. The temperature sequence period is set at two-hour intervals. The latter category requires twelve pairs of mid-depth and top/bottom temperature differentials (for a 24-hour cycle) for the desired data output period.

For this study, a range of curing temperatures was obtained by selecting the summer and winter placement periods. The curing temperature forms the basis for comparing by placement season. Table 4 shows the typical curing temperatures used for winter and summer placement (19). Terminal movement predictions were then calculated for the winter, summer, and fall with the ranges of the selected seasonal temperatures shown in Table 5 (18).

TABLE 4 Seasonal concrete curing temperatures (19)

Placement Season	Curing Temperature
Winter	70°F
Summer	87°F

TABLE 5 Ranges of seasonal concrete temperature

Observation Season	Mid-depth Temperature of the Concrete
Winter	36 to 53°F
Summer	83 to 108°F
Fall	55 to 79°F

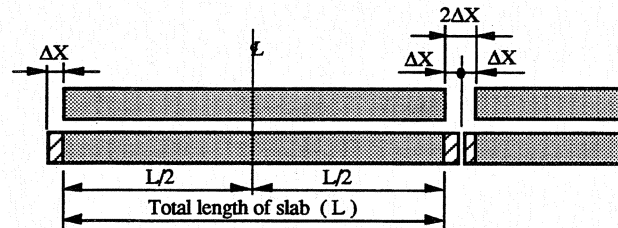
Analysis Factorial

The analysis factorial is shown in Figure 3. Thus, there are four variables considered forming twenty-four sets of combinations. Different slab lengths ranging from 50 to 3,000 feet were tested with each combination of variables shown in the figure. Thus, a total of 300 computations were made with the mechanistic computer program.

Aggregate Type		SRG		LS	
Slab Thickness		8"	12"	8"	12"
Summer Placement	Friction				
	1.0	x	x	x	x
	4.6	x	x	x	x
Winter Placement	Friction				
	1.0	x	x	x	x
	4.6	x	x	x	x
Summer Placement	Friction				
	15.0	x	x	x	x
	4.6	x	x	x	x
Winter Placement	Friction				
	15.0	x	x	x	x
	4.6	x	x	x	x

FIGURE 3 Analysis factorial**Analysis Results**

The slab length used in the analysis is the total length of the slab. However, only half of the slab length is contributing to the end movement. Figure 4 illustrates the relationship between total slab length, L , and total end movement, $2\Delta X$. Note that the end movement on both ends is one-half of the total end movement, ΔX , which is the result shown by the PSCP2 program.

**FIGURE 4** The relationship of total slab length and total end movement.

In the output for each slab length, there are twelve end movements for each seasonal observation. Every end movement corresponds to a slab temperature that is part of the typical daily movement-temperature cycle (twelve observations) for each season. The relationship between end movement and slab temperature is illustrated in Figure 5. When the slab temperature is equal to the curing temperature, the end movement is zero, because there is no temperature change. When the slab temperature is higher than the curing temperature (e.g., during summer observations), positive movement (expansion) is produced. When the slab temperature is lower than the curing temperature (e.g., during winter observations), the end movement is negative (contraction). For instance, Figure 5(a) indicates that, for summer placement, the ratio of temperature change between summer and winter ($\frac{\Delta T_{sw}}{\Delta T_{ss}}$) is smaller than the ratio of end

movement ($\frac{\Delta X_{sw}}{\Delta X_{ss}}$), since the pavement slides in the winter and remains in the elastic range in the summer. For the winter placement case, Figure 5(b), shows the ratio of temperature change between summer and winter ($\frac{\Delta T_{ww}}{\Delta T_{ws}}$) is approximately

equal to the ratio of end movement ($\frac{\Delta X_{ww}}{\Delta X_{ws}}$), because the sliding that occurs both in the summer and in the winter is in the elastic range.

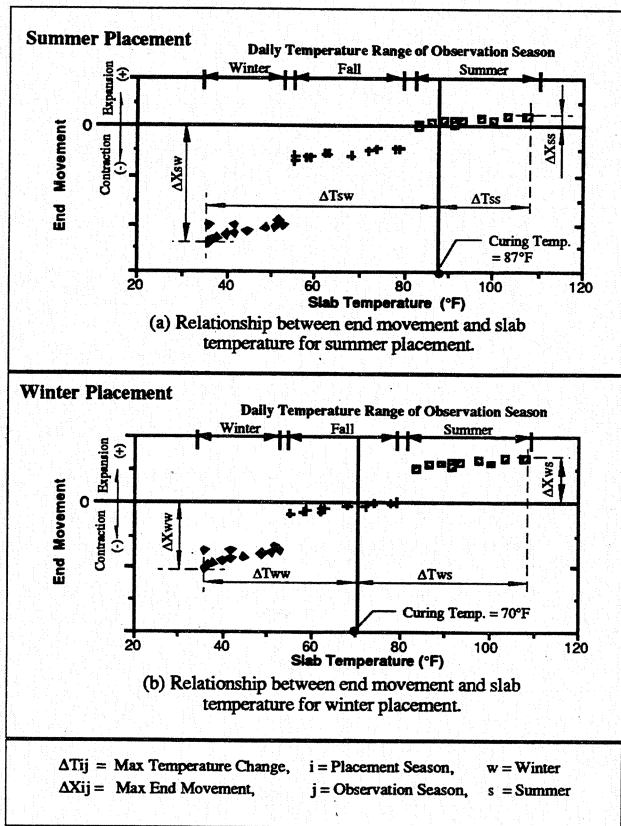
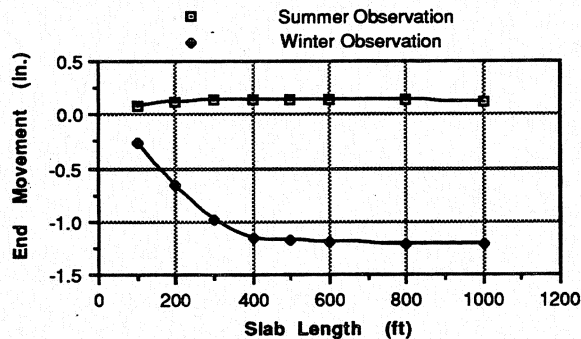


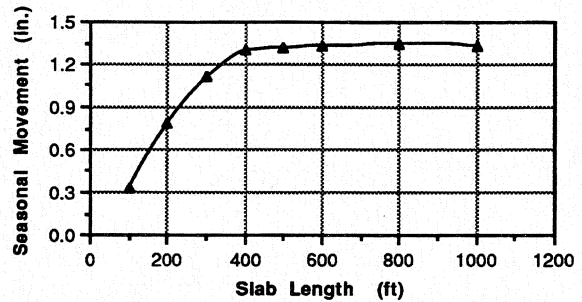
FIGURE 5 Relationship between end movement and slab temperature.

The relationship illustrated in Figure 6 between end movement and slab length was obtained by choosing the maximum expansion, ΔX_{ss} (see Figure 6), and the maximum contraction, ΔX_{sw} , from different slab lengths. In Figure 6 there are two curves in the plot, one for winter observations and one for summer observations.



End movement in relation to slab length.

FIGURE 6 Relationship between end movement and slab length



Seasonal movement in relation to slab length.

FIGURE 7 End and seasonal movements in relation to slab length for 8-inch-thick SRG aggregate slab placed in the summer over a subbase with a 4.6 psi friction force.

In Tables 6 and 7, the maximum lengths of the slab contributing to end movements and the maximum seasonal movements are summarized for each set of variables.

TABLE 6 Summary of a study of CRCP end movement
Aggregate type: SRG

SUBBASE TYPE	PLACEMENT SEASON	THICKNESS OF SLAB	MAX SLAB LENGTH OF CRCP MOVING (FT)	SEASONAL MOVEMENT (IN.)	MAX RATE OF MOVEMENT (IN./°F)
Friction = 1.0 psi	Summer	8"	1000	5.81	0.0854
		12"	1250	8.70	0.1264
	Winter	8"	750	3.83	0.0577
		12"	1000	5.78	0.0873
Friction = 4.6 psi	Summer	8"	200	1.32	0.0184
		12"	300	1.92	0.0282
	Winter	8"	200	0.93	0.0130
		12"	250	1.33	0.0197
Friction = 15 psi	Summer	8"	100	0.46	0.0062
		12"	150	0.66	0.0092
	Winter	8"	100	0.36	0.0052
		12"	100	0.49	0.0070

TABLE 7 Summary of a study of CRCP end movement
Aggregate type: Limestone

SUBBASE TYPE	PLACEMENT SEASON	THICKNESS OF SLAB	MAX SLAB LENGTH OF CRCP MOVING (FT)	SEASONAL MOVEMENT (IN.)	MAX RATE OF MOVEMENT (IN./°F)
Friction = 1.0 psi	Summer	8"	800	3.75	0.0541
		12"	1100	5.53	0.0813
	Winter	8"	600	2.45	0.0376
		12"	800	3.61	0.0549
Friction = 4.6 psi	Summer	8"	200	0.83	0.0122
		12"	250	1.25	0.0181
	Winter	8"	200	0.62	0.0092
		12"	250	0.87	0.0134
Friction = 15 psi	Summer	8"	100	0.32	0.0046
		12"	100	0.40	0.0061
	Winter	8"	100	0.27	0.0040
		12"	100	0.35	0.0052

Note that the maximum slab length is one-half of the slab length at which the maximum seasonal movement becomes constant. The maximum slab length is the actual slab length that produces the maximum seasonal movement at one end.

Aggregate Type

Figure 8 was created by graphing an LS aggregate type on Figure 7. Figure 8 demonstrates, by holding other variables constant, a typical comparison of effects for two aggregate types, LS and SRG. For the same conditions, the end movement of the SRG aggregate is always greater than that of the LS aggregate. This is explained by the fact that the thermal coefficient of SRG is 1.33 times greater than the thermal coefficient of the LS aggregates (see Table 1).

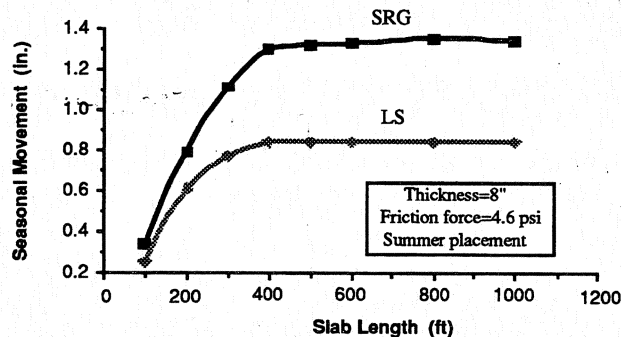


FIGURE 8 Typical seasonal movement in relation to slab length and a comparison between SRG and LS

Comparing Tables 6 and 7, note that for the maximum lengths of moving CRCP there is only a minor difference between SRG and LS aggregates. Therefore, the slab lengths contributing to end movement are almost the same, regardless of the aggregate type. Also, the maximum seasonal movement of the SRG aggregate is, on average, approximately 1.5 times the value of the LS aggregate, which is greater than the ratio of the thermal coefficients (i.e. 1.33). This results because more cases of full sliding and excessive movement occur with the SRG than occur with LS.

Subbase Friction Force

Figure 9 was created by merging the other two friction force cases, 1.0 and 15.0 psi, with Figure 7(b), and it illustrates that a smaller friction force corresponds to greater end movement. This is consistent with expectations because, as the friction force decreases, the pavement movement has less resistance so that the end movement increases. The effect of the friction force is significant in terms of the maximum seasonal movement and the maximum lengths of moving CRC pavement, but it is not significant in the end movement when the slab length is short. This is explained by the fact that, if the slab length is short, the friction force will be in the elastic range, within which no sliding occurs.

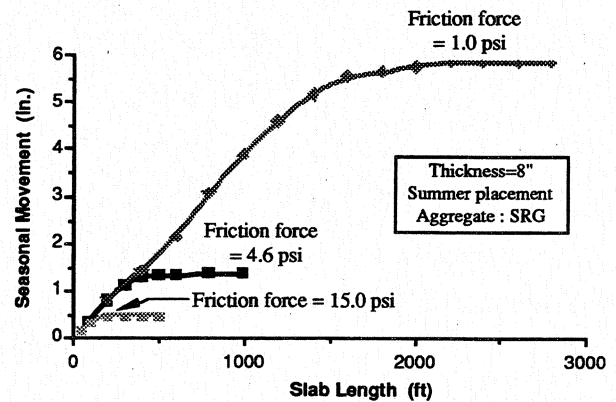


FIGURE 9 Typical seasonal movement in relation to slab length, and a comparison among three different friction forces

Figure 10 was derived from Figure 9 to directly display the effects of friction force on the maximum seasonal movement and maximum length of CRCP moving. A significant decrease in the end movement occurs when the subbase friction is increased from 1.0 psi to 4.6 psi. When the subbase friction is from 4.6 psi to 15.0 psi, a smaller slope is noted. It may be concluded that the end movement is in the elastic range when the friction force is higher than 4.6 psi and, possibly, the "break point" value is lower than 4.6 psi.

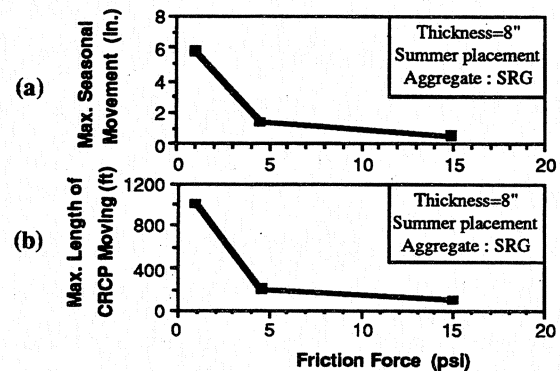


FIGURE 10 (a) Maximum seasonal movement and friction force, (b) Maximum Length of moving CRCP and friction force

Placement Season

Because of temperature change, there is more expansion in the winter placement case, and more contraction in the summer placement case. For total movement in a year, however, the winter placement can result in less end movement for the slab as shown in Figure 11, created by merging the winter placement case with Figure 7(b). This larger end movement for summer placement is caused by the inelastic range of the friction forces developing beneath long pavement slabs (11), because of the longer overall temperature differentials. Since there is a higher setting temperature for summer placements, the ratio of decreasing temperature to increasing temperature in the summer placement case is higher than that in the winter placement. Although the yearly temperature change is the same, the summer placement case will have 1.33 times the end movement of the winter placement case.

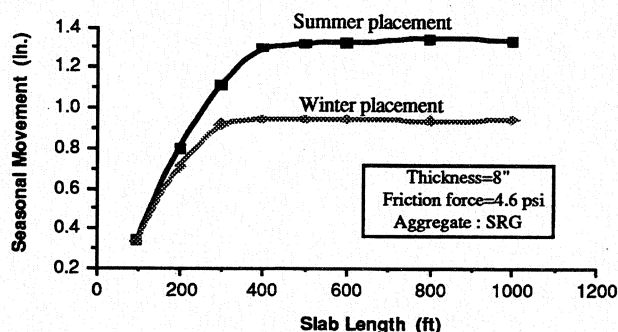


FIGURE 11 Typical seasonal movement in relation to slab length and a comparison between summer and winter placement

Slab Thickness

Figure 12 was created by merging a 12-inch-thick slab case with Figure 3. With increasing slab thickness more total movement can result from the thicker slab, as depicted in Figure 12. The thicker slab, as expected, produces a heavier weight and more volume, resulting in more horizontal force and more movement. Moreover, the 12-inch-thick CRCP has about 1.5 times the maximum seasonal movement of the 8-inch-thick CRCP. The ratio of the maximum seasonal movement of the 12- and 8-inch CRCP is equal to the ratio of the two slab thicknesses, 12 and 8 inches. Note that previous subbase friction studies have shown that frictional resistance is a fixed value and does not vary with slab thickness, thus explaining the observation.

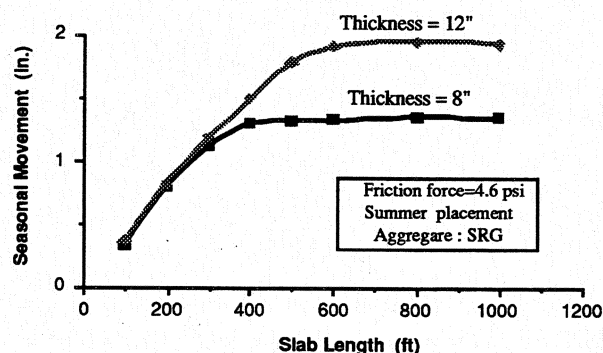


FIGURE 12 Typical seasonal movement in relation to slab length and a comparison between 8" and 12" slabs

Summary

Generally, the maximum end movement of a CRCP is directly related to temperature change and slab thickness and is inversely related to subbase friction, when one considers the total annual movement. Winter placement conditions and the Limestone aggregate will generate less end movements, with all other conditions being equal.

The conclusions derived from the set of conditions considered (i.e. temperature, etc.) are as follows:

- The end movements with frictions of 4.6 psi or greater are more elastic, whereas those end movements with frictions of less than 4.6 psi have a much greater sliding tendency.
- The end movement of the SRG aggregate is 1.5 times the value of the LS aggregate.
- A winter placement reduces the end movement to approximately 0.75 times that of a summer placement.
- An end movement change that is affected by the slab thickness is approximately equal to the ratio of slab thickness.

ANALYSIS USING FIELD DATA

Obviously, the mechanistic computer program can be an excellent tool for predicting the terminal movement of pavement. However, before the computer results are used in design decisions, the reliability of the results should be verified by comparing the model results with field data. In the interest of saving space, only the results of a recent field study at one terminal and an extensive field study are presented herein. For more detailed information as to the data collection, 1 may be referred to.

In order to match and to compare the conditions of the available field data, predicted data having the same conditions were chosen as displayed in Table 8. For the three fall placement cases, the average rates of movement for winter and summer placements were used. All of the rates of movement shown in the table are from the 8-inch slabs.

TABLE 8 Predicted Rates of Movement for Different Types of Continuously Reinforced Concrete Pavement

Subbase Friction Force	CRCP Type					
	4.6 psi	4.6 psi	4.6 psi	15.0 psi	1.0 psi	1.0 psi
Placement Season	Fall*	Fall*	Winter	Fall*	Fall*	Fall*
Slab Length	40 ft	1000 ft	400 ft	Over 500 ft	400 ft	400 ft
Rate of Movement (in./°F)	0.0021	0.0157	0.0130	0.0057	0.0120	0.0200

* The rate of movement for fall placement is the average rate of movement for winter and summer placement derived from the PSCP2 program.

The predicted rates of movement were plotted in relation to field replicates that have equal parameters, such as subbase type, thickness of slab, and placement season. Ideally, if there were no difference between the predicted rate of movement and the field data, the points would result in a 45 degree line. Figure 13 is a plot of this type.

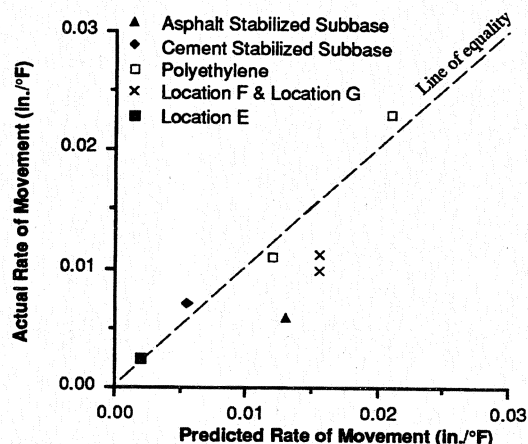


FIGURE 13 Predicted rates in relation to actual rates of movement

In Figure 13, the computer program predicts the cement stabilized subbase, polyethylene, and Location E cases very well, since the two points are on or near the 45 degree line. The other two cases, especially the case of the asphalt stabilized subbase, are below the line of equality. This means that the predicted value is higher than the field value in the two cases. In other words, the field friction forces in the two cases are higher than those input into the predicted model. Since the asphalt subbase data were taken approximately 30 years ago, a number of key inputs were not available. Thus, a calibration was performed and provided an improved fit.

IMPLEMENTATION

Because the PSCP2 mechanistic model can be used reliably to predict free end movement of CRCP's, the pavement designer may now compute the terminal movement of a slab in order to design joint dimensions and sealant types that fit specific site conditions. If the movements are too large, the designer may consider restricting the movement with terminal anchorages or other devices. For the convenience of pavement designers who have the responsibility of estimating terminal movement in CRCP, a design equation and design charts based on the analyzed results of the PSCP2 program were developed.

Development of Design Equation

Previously, it was shown that a linear relationship exists between end movement and slab temperature such that the rate of movement, $\Delta X/\Delta T$ (in./°F), is a constant—that is, the temperature change is directly proportional to the total end movement. Relationships were also established for slab thickness and concrete thermal coefficient. The effect of placement season and subbase type were also developed.

Therefore, based on the analysis herein, we can develop a design equation as follows:

$$\Delta X = a \frac{D}{8} \Delta T \left(\frac{\alpha_c}{6 \times 10^{-6}} \right)^{1.5} k \quad (\text{Eq. 1})$$

a = parameter of placement season,

k = parameter of subbase type.

Placement season parameters for summer and winter are listed in Table 9. Since the CRCP placed in the summer produces 1.33 times the total end movement of the CRCP placed in the winter, the value of the placement season parameter, a , for winter placement is 1.0, and the value for summer is 1.33. In addition, the total end movement also varies with subbase type. The values of subbase type parameters are listed in Table 10.

TABLE 9 Parameters of placement season

Season of Placement	Summer	Winter
a	1.33	1.0

TABLE 10 Parameters of subbase type

Type of Subbase	Polyethylene	ACB	CTB
k	0.0370	0.0086	0.0031

In order to verify the end movement computed by the design equation (1), a comparison of the CRCP end movements derived from Equation 1 and the end movements obtained from the PSCP2 program was made as presented in Figure 14. This figure indicates that the design equation (1) can estimate the end movement of CRCP as well as the PSCP2 computer program. Thus, the design equation can be used reliably to estimate the end movement of CRCP.

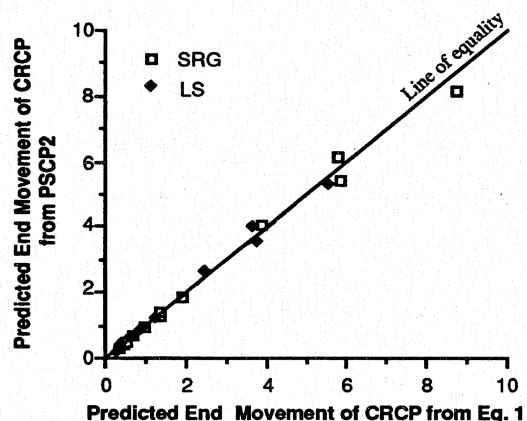


FIGURE 14 Predicted end movements of CRCP from PSCP2 in relation to predicted end movements of CRCP from Eq. 1

Note that since this study is focused on CRCP constructed in Texas, the values input into each item in the design equation must be in the ranges previously discussed.

Design Charts

Using the design equation, design charts (Figures 15 and 16) were drawn to estimate the total end movement. Figure 15 is for SRG aggregate type and Figure 16 for Limestone aggregate type. There are two scales of total end movement for each type of aggregate: the one on the left side is for 8-inch-thick CRCP and the one on the right is for 12-inch-thick CRCP. In each chart, there are three types of subbases: polyethylene, ACB, and CTB. For each subbase type, there are two placement seasons: the solid line is for summer placement and the dash line is for winter placement.

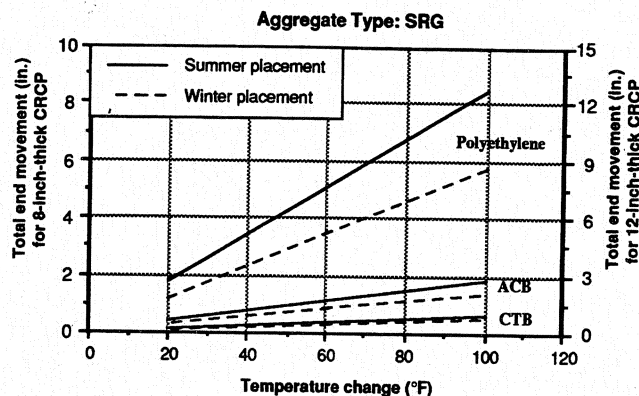


FIGURE 15 Total end movement design chart for SRG aggregate

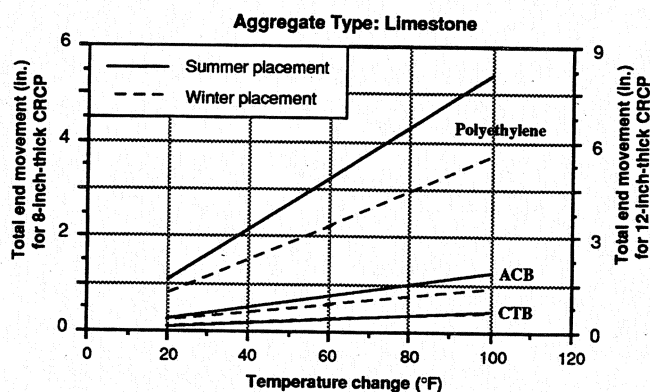


FIGURE 16 Total end movement design chart for Limestone aggregate

Project Evaluation Procedure

The design objective is to specifically quantify the problem so that the designer may provide a design detail for the plans. The steps are as follows:

- (1) A specific subbase type is selected.
- (2) Estimate the mean friction force (K).
- (3) Estimate the annual temperature variation and concrete thermal coefficient for the pavement thickness to be used. Also select the placement season.
- (4) Estimate the joint movement (ΔX) using the design.
- (5) Select a joint system using the estimated annual joint movement as follows:
 - (a) If the annual movement is 2 inches or less, a conventional terminal expansion joint should be developed.
 - (b) If the annual movement is greater than 2 inches, consideration should be given to restrain the system by using a terminal anchorage or by using other techniques.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following specific conclusions were drawn from the analyses and the results of this study:

1. The relationship between factors affecting terminal movement is complex, and the size of the terminal movement depends on whether sliding occurs. Interpreting the field data to determine whether or not sliding occurs is difficult.
2. This study shows that the maximum length of CRCP moving is 1,250 ft.
3. Terminal movement is directly related to slab length until the maximum slab length is exceeded. When the maximum slab length is exceeded, the movement is invariant. The value of the maximum slab length varies with environmental conditions.
4. CRC Limestone aggregate type pavement has approximately two-thirds the end movement of CRC Siliceous River Gravel aggregate type pavement.
5. Thicker CRCP produces more end movement in a linear fashion.
6. For typical Texas temperature conditions, winter placement generates approximately 25 percent less end movement in CRCP than summer placement.
7. Friction force is a significant factor affecting the end movement of CRCP.

Recommendations for Predicting End Movement

The following steps are recommended to predict the free end movement of CRCP.

For estimations, Figure 14 for CRCP should be referred to.

1. Figure 14 is illustrative of CRCP. The total seasonal temperature change is needed for any computations derived from Figure 14.
2. The estimations listed in the charts are the movements which occur at one end of the slab.

For unusual conditions and for more exact estimation, the PSCP2 program should be applied:

1. A proper number of elements should be used, especially when the slab is long. The recommended element length is not more than 15 feet, that is, 100 elements for a 1500-foot slab.
2. When a subbase with a higher coefficient of friction is analyzed, a larger number of elements should be selected.
3. If the PSCP2 computer program is used to predict the free end movement, then the input item of the ultimate shrinkage strain of the concrete should be zero.
4. If the PSCP2 computer program is used to predict the joint opening, the proper value of the ultimate shrinkage strain of the concrete should be input.

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