EVALUATION OF TERMINAL ANCHORAGE INSTALLATIONS ON RIGID PAVEMENTS

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This paper explores the problem of cyclic movement with continuously reinforced concrete pavement. The growth and pushing outward effect, resulting from environmental changes, causes ruptures of abutment walls and is responsible for other undesirable pressure. It was hypothesized that the same type of anchorage system used on jointed pavements could be used on continuous pavements, thus solving the expansion problem. Anchorages were installed on continuous pavements in much the same manner as they had previously been installed on jointed pavements. The anchor lugs were placed in the ground transversely across the pavement and were attached to an anchor slab. Long-term observations and measurements were performed on 186 existing terminal anchorage systems on continuous concrete pavements. After several years of observation, it was found that no adverse movement or pavement growth took place. The terminal movement was found to be directly related to pavement length of up to 1,000 ft and temperature change and indirectly related to pavement grade, subbase coefficient, and number of lugs. An empirical equation expressing movement in terms of these variables is derived in this study. This equation, considering the boundary conditions, could be used as a design equation.

•AN ALARMING AMOUNT of pavement growth was experienced in the late 1950's in numerous jointed concrete pavements (JCP) on the Texas highway system especially along the coastal area. As a result of concrete pavement growth, internal forces are built up in the slab and produce an outward push toward the free ends that closes the expansion joint at the bridge ends, ruptures the abutment walls, and applies an undesirable amount of pressure on the bridge or structure. In an effort to check this pavement growth problem, the Houston District constructed the first terminal anchorage system in Texas in March 1959. The satisfactory performance obtained with these initial installations consequently resulted in terminal anchorages being installed at a number of structures throughout the state.

At about the same time that these anchorage installations were being installed on jointed concrete pavement, the Texas Highway Department initiated the use of continuously reinforced concrete pavement (CRCP) on a widespread scale throughout the state. Logically transposing the experience with the growth problem of jointed concrete pavements to continuous pavements resulted in the decision that continuous pavements would also require an extensive anchorage system. Figure 1 shows the details of the anchorage system developed for CRCP.

DESIGN

In their treatise on terminal anchorages, Shelby and Ledbetter enumerated the basic concepts and assumptions used in designing the terminal anchorage system that was initially used by the Texas Highway Department (1). Basically, the anchorage system for

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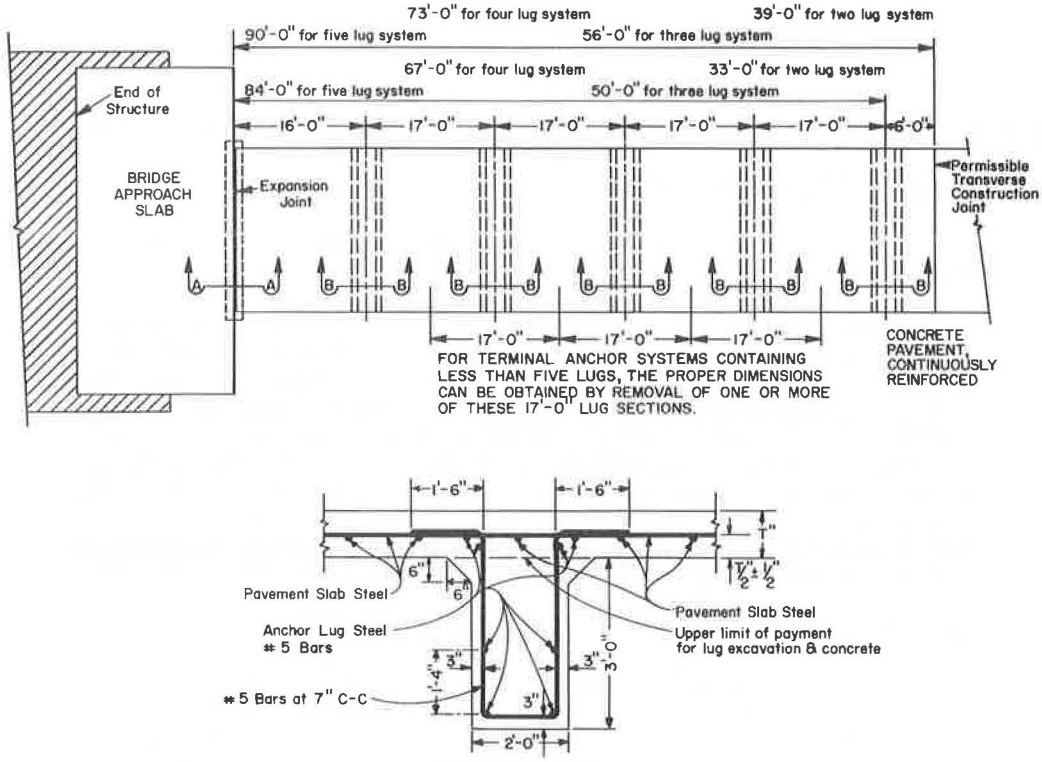
Sponsored by Committee on Rigid Pavement Design and presented at the 50th Annual Meeting.



ANCHOR LUG DETAIL

Figure 1. Typical lug design of continuously reinforced concrete pavement.

jointed concrete pavement consists of 2 anchor lugs, 3 ft deep and 2 ft wide, at each pavement terminal. The terminal anchorages are heavily reinforced to provide a stiff and rigid resistance member. The design concept of the anchorage system is to transfer the pavement growth forces to the soil mass through the passive bearing and shear resistance of the subsoil. It was felt that the critical elements were the bearing area of the lugs and the shear plane along the bottom of the lugs as well as along the face of a Coulomb wedge.

The design for the anchorage system on continuous pavements was basically the same as the design for jointed pavements with the exception that 5 anchor lugs were used, and this resulted in a longer anchor slab (90 ft).

The nomenclature of various components of the anchorage system may be enumerated at this point. The slab placed on top of the base or on top of the subsoil is defined as the anchor slab. The members extending vertically into the ground are defined as lugs; the one nearest the structure is considered the front lug.

PERFORMANCE

After 1959 the terminal anchorage systems of the types illustrated were installed on both jointed concrete pavements and continuously reinforced concrete pavements. During the early part of 1963, several cases of terminal anchorage failure were reported in the Houston area on jointed concrete pavements. A preliminary survey indicated that a number of the terminal anchorage systems had experienced cracking in the anchor slab, closing of the joints between the anchor slab and the bridge approach slab, and faulting of the abutment walls. During the same period, all of the terminal anchorage systems on CRCP were performing satisfactorily, and in no case was adverse movement occurring. The only disadvantage associated with CRCP anchorage systems was the excessive cost required to construct them at each pavement terminal. As a result of these 2 facts, a research project was initiated in March 1963 to evaluate terminal anchorage installations on rigid pavements.

OBJECTIVE OF STUDY

The objective of this study was to perform the field observations necessary to re-evaluate the lug anchorage designs. In addition, long-term observation and measurements were performed on 186 existing terminal anchorage systems on continuous concrete pavements.

EXPERIMENT DESIGN AND DISCUSSION OF DATA

The first phase of this study consisted of an appraisal of the factorial arrangement of test sections. On the basis and availability of other continuously reinforced concrete pavements throughout the state, sections were added as necessary to make as full a fractorial as possible. At the same time, sections were added in the northern part of Texas so that a comparison of environmental conditions could be made. The areas from which field data were obtained are shown in Figure 2. Locations could not be selected any farther south than shown because concrete pavements are not constructed in that area of the state. Data were taken as before on all sections for an additional year and were then analyzed.

Layout of Experiment

Figures 3 and 4 show the factorials of sections for 8 different subbase types including cement-stabilized, asphalt-stabilized, surface-treated, crushed sandstone, river gravel, rounded river gravel, crushed limestone, and lime-stabilized subbases. These experi-

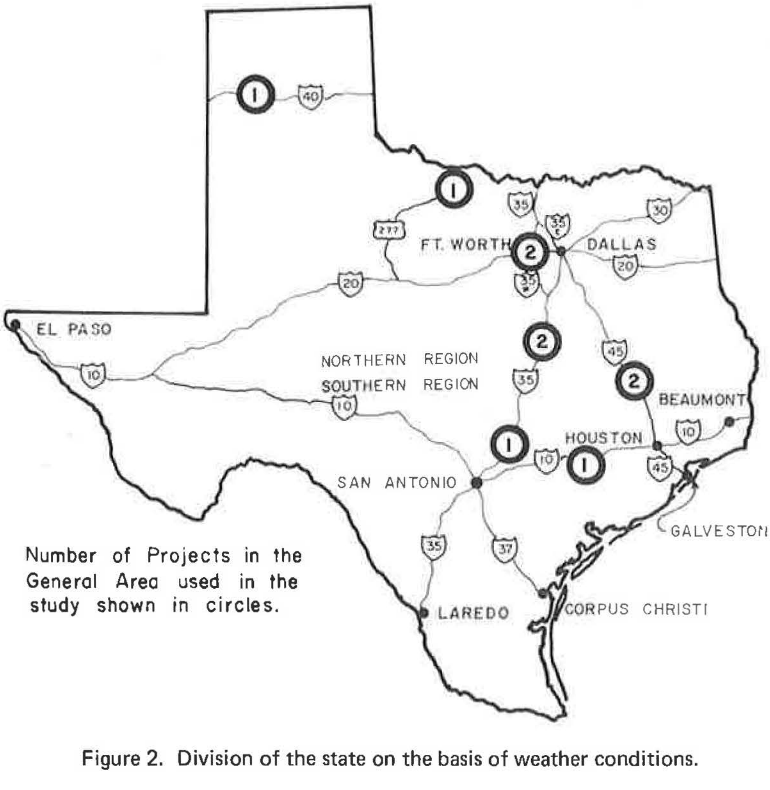
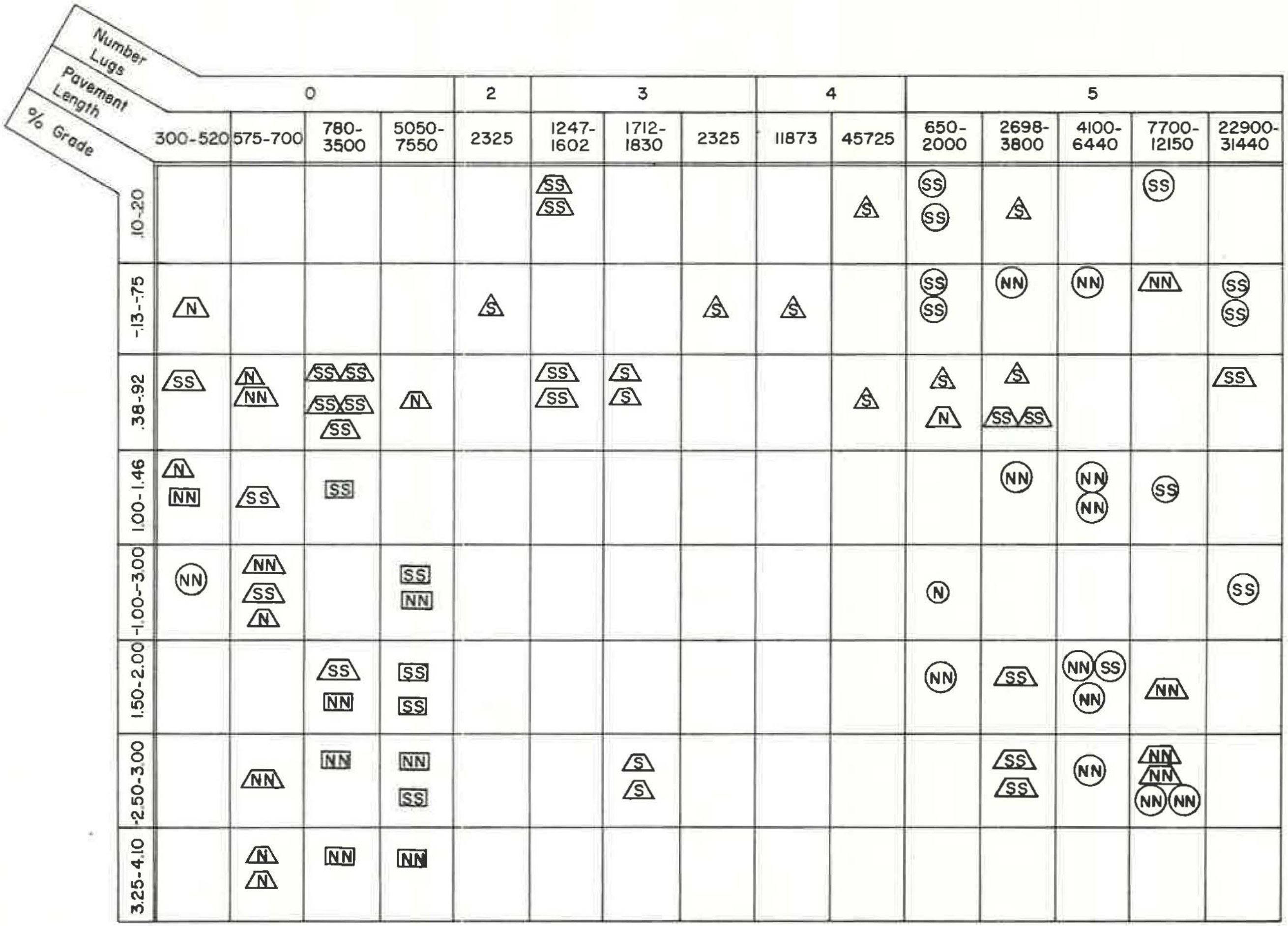


Figure 2. Division of the state on the basis of weather conditions.



N - Section in North Texas

S - Section in South Texas

Double letter - Section of divided highway

Single letter - Section of undivided highway

⏢ - Cement-stabilized subbase

▭ - Surface-treated subbase

○ - Asphalt-stabilized subbase

△ - Crushed sandstone subbase

Figure 3. Factorial of lugs, length, and grade for pavements having cement-stabilized, surface-treated, asphalt-stabilized, and crushed sandstone subbases.

(a)

NUMBER OF LUGS	0	5	
SLAB LENGTH / % GRADE	700	2600	3250
+1.96	NN	NN	
-1.96	NN		
+2.50		NN	
+4.00			NN

(b)

NUMBER OF LUGS	5		
SLAB LENGTH / % GRADE	2000	4900	5200
-.50		NN	
+.57		N	
+2.30			N
+3.00	NN		

(c)

NUMBER OF LUGS	0			
SLAB LENGTH / % GRADE	1225	2800	5900	12300
+.10				NN
-.28		NN		
+1.17			NN	
-2.48			NN	
+3.00	NN			
-3.00	NN			

(d)

NUMBER OF LUGS	0				
SLAB LENGTH / % GRADE	2700	3085	4030	4750	9594
+1.77		N			
+1.85		N			
+2.20					NN
+2.70				NN	N
+3.00		NN	NN	NN	N
+3.50	NN				

NOTE: N – Sections in North Texas S – Sections in South Texas

Figure 4. Factorial of lugs, length, and grade, and for pavements having (a) crushed river gravel subbase, (b) rounded river gravel subbase, (c) crushed limestone subbase, and (d) lime-stabilized subbase.

ment designs are for CRCP only and are presented to give an indication of the data used.

Sections in north Texas were also added to the factorials of 3 subbase types for the weather environment study (Fig. 3). These sections were chosen so that variables such as number of lugs, slab length, and percentage of grade for both northern and southern sections would be approximately the same.

The sections in south Texas with a 1-course surface treatment on the subbase and a crushed sandstone subbase were used to study the age factor (Fig. 3). These sections were chosen because data had been taken on them for a period of approximately 7 years.

Data Analysis

Data analysis for this paper was carried out first by obtaining cyclic end movement per degree of temperature for each section and second by using these as a basis for comparison. In this manner, temperature was eliminated as a variable, and the factorial arrangement of the test sections could be used to study the effect of pavement age, length, percentage of grade, number of lugs, environmental location, and subbase type.

Pavement Age—The main concern with pavement age is the possibility of pavement growth due to the infiltration of foreign material into the shrinkage cracks. It would seem plausible that any growth of the pavement end would show up as a permanent change in the distance between gage plugs (placed at 10-in. centers) at a given temperature. Furthermore, any major change in thermal coefficient would affect the cyclic end movement per degree of temperature change.

Figure 5 shows gage plug reading versus air temperature for a typical section used in the age study. All points are close to the line passed through the data, and, because these points represent data taken at random intervals during a period of 5 years, it can be said that pavement age has not affected the cyclic end movement or gage plug distance at zero degree temperature for this section. Similar plots for all other sections of the age study have shown the same relationship.

Effect of Slab Length on End Movement—Earlier research on this project revealed that a pavement length of more than 1,000 ft does not influence end movement more than a length of 1,000 ft (2). From this it may be concluded that a maximum length of 500 ft contributes to movement on each end of the pavement slab. In pavements longer than 1,000 ft, the center portion of the slab is restrained by the frictional force from the subbase.

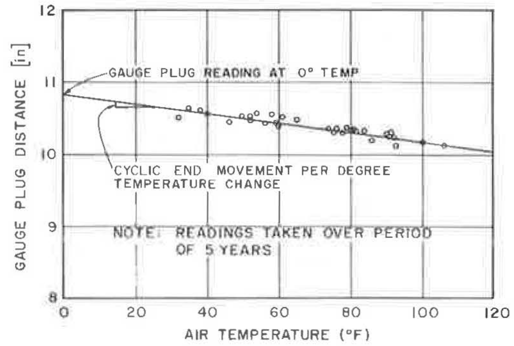


Figure 5. Effect of pavement age on end movement.

Environmental Location—A study of the effect of weather conditions on end movement has to exclude temperature so that northern and southern sections can be compared. Cyclic end movement for northern sections can be plotted versus replicated southern sections that have equal parameters such as subbase type, percentage of grade, length of slab, and number of lugs. Ideally, if there were no difference between northern and southern sections, the points would result in a 45-deg line. Figure 6 shows a plot of this type. It should be noted that all sections with slab lengths of more than 1,000 ft are considered equal, as far as slab length is concerned, on the basis of the preceding discussion. Also, all grades lower than 0.30 percent were considered equal because it was felt that grades lower than this would be inconsequential.

Although the points in Figure 6 do not fall exactly on the 45-deg line, there is approximately equal division. Therefore, on the basis of this study, it will be assumed that there is no appreciable difference in end movement characteristics resulting from environmental location within the state.

Length and Grade Percentage—The following relationship was found to exist between the cyclic end movement, slab length, and percentage of grade while other variables are held constant:

$$\text{Log } b = \log A_5 + A_4 \log \left(\frac{L}{|G| + 1}\right) \quad (1)$$

where

b = cyclic end movement, in./deg F;
L = length of slab contributing to end movement, ft;
|G| = absolute value of grade percentage;
A_4 = arbitrary constant; and
A_5 = constant dependent on subbase type and number of lugs.

Here again cyclic end movement is used so that temperature as a variable may be excluded from the study.

Because a purpose of this paper is to verify an equation format previously developed (2), Eq. 1 will be used as a starting point for analysis. Figure 7, in which each point represents 1 section, shows log b

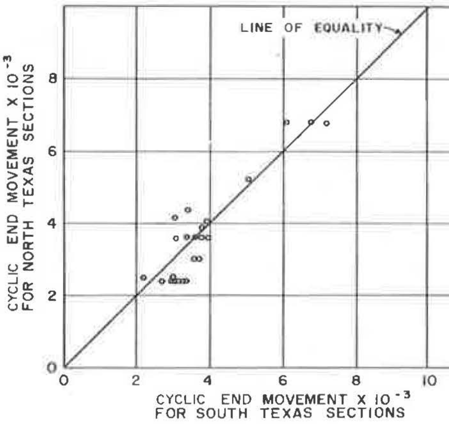


Figure 6. End movement in south Texas versus end movement in north Texas.

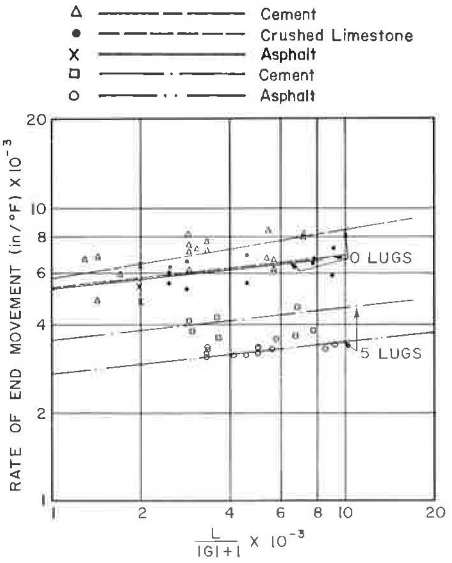


Figure 7. Cyclic end movement versus term for pavement length and percentage of grade for asphalt-stablized, cement-stabilized, and crushed limestone subbases.

TABLE 1

DIFFERENCE IN END MOVEMENT CHARACTERISTICS DUE TO NUMBER OF TERMINAL LUGS AND SUBBASE TYPE

Subbase	Number of Lugs	$A_5 \times 10^{-3}$
Surface treated	0	2.90
Cement stabilized	0	5.75
Cement stabilized	3	4.30
Cement stabilized	5	3.70
Asphalt stabilized	0	5.30
Asphalt stabilized	5	2.68
Crushed river gravel	0	5.50
Crushed river gravel	5	4.40
Crushed limestone	0	5.50
Rounded river gravel	5	3.40
Lime stabilized	0	4.50
Crushed sandstone	2	9.40
Crushed sandstone	3	7.70
Crushed sandstone	4	7.20
Crushed sandstone	5	7.00

plotted versus log $\left(\frac{L}{|G| + 1}\right)$ for different subbase types and number of lugs.

The A_5 intercept changes with subbase type and with number of lugs (Fig. 7, 0 lug), whereas A_4 is approximately equal for both. Therefore, it may be stated that A_4 is an arbitrary constant not dependent on any of the other variables, whereas A_5 is dependent on both subbase type and number of lugs. Thus, these data bear out the original equation format as given in Eq. 1.

Subbase Coefficient and Number of Lugs—Table 1 gives A_5 for each subbase type and number of lug combinations in this experiment. It was found that the following relationship existed between A_5, subbase coefficient of friction, and number of lugs:

$$\text{Log } A_5 = A_1 + A_2 \log C + A_3 \log (N + 1) \tag{2}$$

where

A_1, A_2, and A_3 = arbitrary constants,
C = subbase coefficient of friction, and
N = number of rigid lugs.

A literary search was conducted, and a value for each subbase coefficient or friction was obtained. These values were assumed values of subbase coefficient of friction, and A_5 was correlated in terms of these values. However, a more thorough study of this relationship indicates that the subbase part of A_5 may be a combination of effects and not just coefficient of friction. For example, the type of subbase may influence the cyclic end movement because of different types of soil masses acting against the lug surfaces. Therefore, it is felt that the part of A_5 determined by the subbase might be more appropriately called subbase coefficient C.

Based on this assumption, values of subbase coefficient of friction, as such, could not be used for final correlation; and, because A_5 is different for each subbase type with the same number of lugs, some arbitrary scale had to be set up and values obtained for the subbase coefficient so they could be correlated with A_5.

Values of subbase coefficients were obtained by making a linear relationship between C, for the different subbase types, and A_5. This was done by selecting random numbers to represent C for the subbase with the lowest cyclic end movement (surface-treated subbase) and the highest cyclic end movement (crushed sandstone subbase). A value of 2.65 was chosen for surface treatment and 1.35 for crushed sandstone. This then makes values of C, for the other subbase types, fall between 1.35 and 2.65.

To obtain these values, Eq. 2 was used. This equation contains 3 unknown constants. Therefore, by use of 3 simultaneous equations of this form, the coefficients A_1, A_2, and A_3 can be determined. These 3 equations are obtained by use of the A_5 constants given in Table 1 for sections with surface-treated and crushed sandstone subbases and their respective number of lugs. The equations used were as follows:

$$\text{Log } (2.9 \times 10^{-3} \text{ in./deg F}) = A_1 + A_2 \log (2.65) + A_3 \log (0 + 1) \qquad (3)$$

$$\text{Log } (9.4 \times 10^{-3} \text{ in./deg F}) = A_1 + A_2 \log (1.35) + A_3 \log (2 + 1) \qquad (4)$$

$$\text{Log } (7.0 \times 10^{-3} \text{ in./deg F}) = A_1 + A_2 \log (1.35) + A_3 \log (5 + 1) \qquad (5)$$

After solving the equations for A_1, A_2, and A_3, Eq. 2 was used to calculate C-values for each of the other subbases given in Table 1 by using A_5 and the respective number of lugs. Table 2 gives the calculated C-values for all sections in Table 1.

Verification of Equation Format

Substitution of Eq. 2 into Eq. 1 yields the following relationship:

$$\text{Log } b = A_1 + A_2 \log C + A_3 \log (N + 1) + A_4 \log \left(\frac{L}{|G| + 1}\right) \qquad (6)$$

On the basis of these data, the empirical relationship between end movement and the enumerated parameters is the same.

EMPIRICAL DESIGN EQUATION

On the basis of data taken on this project, it was found that Eq. 6 is valid and, furthermore, that no factor should be added to compensate for environmental location or pavement age. Therefore, a multiple regression correlation was run on this equation to determine the coefficient for each term. Then the equation could be used as a predictor of end movement in terms of the parameters contained in the equation.

Regression Analysis

The correlation of constants A_1, A_2, A_3, and A_4 of Eq. 6 was determined by a multiple regression technique using the values of the parameters of each end system and the values (1) of the subbase coefficient previously determined (Table 2). The following results of this regression analysis are $A_1 = -1.902$, $A_2 = -2.027$, $A_3 = -0.312$, $A_4 = 0.107$, and $R^2 = 0.71$, and standard error = 0.0008 in./deg F. The resulting empirical design equation is as follows:

$$\Delta X = \frac{0.01253 \left(\frac{L}{|G| + 1}\right)^{0.107} (\Delta T)}{C^{2.027} (N + 1)^{0.312}} \qquad (7)$$

where

ΔX = total movement for a given temperature change experienced at an expansion joint, in.; and
ΔT = change in air temperature for a given period, deg F.

TABLE 2

SUBBASE COEFFICIENTS FOR USE IN EMPIRICAL DESIGN EQUATION

Subbase	Subbase Coefficient of Friction
Surface treated	2.65
Lime stabilized	2.13
Asphalt stabilized	1.96
Rounded river gravel	1.95
Crushed river gravel	1.93
Crushed limestone	1.93
Cement stabilized	1.90
Crushed sandstone	1.35

Evaluation of Equation

The standard error given in the preceding paragraph means that Eq. 7 would predict an expected end movement for a given temperature change within ±0.0008 in./deg F. However, all of this error is not due to equation fit. A standard deviation analysis was run on all replicate sections, and the analysis indicated that an error of 0.00041 in./deg F of that measured could be expected from 2 sections under equal conditions. This replicate error is probably due to random variation in sampling and the existence of unknown variables.

Although the coefficients found by regression analysis are slightly different from the ones found in a previous study (probably due to more available data for each variable), the standard error in this study is much less. Therefore, it is felt that these coefficients fit the actual conditions much better and the resulting equations will be much more reliable as a design guide.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of this research project conducted by the Texas Highway Department during a period of 3½ years, the following conclusions are warranted:

1. The cyclic terminal movement of an 8-in. CRCP is directly related to pavement length and temperature change and indirectly related to pavement grade, subbase coefficient, and number of lugs. An empirical expression indicating movement in terms of these variables is presented here and may be used as a basis for design.
2. The cyclic terminal movement of an 8-in. CRCP with and without terminal anchorages was found to be independent of pavement age and environmental location.
3. The study assumed that a maximum of 500 ft of CRCP contributes to end movement experienced at an expansion joint.
4. Care should be taken in using the empirical equation derived here for design purposes. Parameters should not be used that are outside the limits of these data. Close observation of the values found to represent different types of bases indicates that these values may include more than just coefficient of friction because the values do not follow what might logically be expected. There is a possibility that some of the values derived here are partially due to the type of soil mass acting against the lug as well as the imposing force of surface friction. Because the equation is of an empirical form, no further distinction can be made at this time. However, it is felt that the values derived for each type of subbase apply to this empirical design equation.
5. With certain combinations of subbase coefficient and grade percentage, the number of terminal lugs for CRCP can be reduced to zero. A satisfactory performance during a period of 7 years and, in 1 case, 15 years verifies this.

ACKNOWLEDGMENT

This research was sponsored by the Texas Highway Department and the Federal Highway Administration. The opinions, findings, and conclusions expressed are those of the authors and not necessarily those of the sponsors.

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