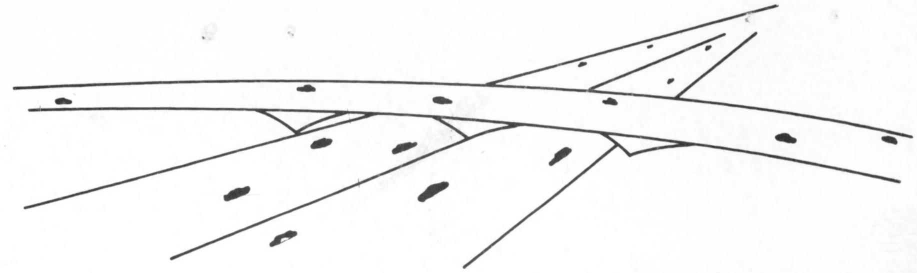

DEPARTMENTAL RESEARCH

Report Number 39 - 2

PARAMETERS INFLUENCING TERMINAL MOVEMENT ON CONTINUOUSLY REINFORCED CONCRETE PAVEMENT

By
B. F. McCullough
and
T. F. Sewell

Technical Report No. 2
Research Project 1-8-63-39

TEXAS HIGHWAY DEPARTMENT

PARAMETERS INFLUENCING TERMINAL MOVEMENT ON CONTINUOUSLY REINFORCED CONCRETE PAVEMENT

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Highway Design Division
Texas Highway Department

In Cooperation with
Department of Commerce
Bureau of Public Roads

Technical Report No. 2
Research Project 1-8-63-39
Evaluation of Terminal Anchorage
Installations on Rigid Pavements

August 1964

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A B S T R A C T

The excessive movement of concrete pavement terminals has long been a source of trouble to the highway engineer. The introduction of continuously reinforced concrete pavement in Texas reduced excessive movement to some degree, but movement still remained due to thermal expansion of end portions of the pavement. A system was devised by the Texas Highway Department to partially restrain this movement on continuously reinforced concrete pavement. This system consisted of five rigid lugs cast monolithically with the pavement end to act as a series of restraining members. To evaluate this design, numerous pavement ends were built using different numbers of lugs, subbase types, per cent grades, and pavement lengths. Data was obtained on all these systems for 2½ years and then analyzed to evaluate each of these parameter's influence on terminal movement. This study has shown that pavement length, per cent grade, temperature change, and subbase type have a definite effect upon the number of lugs needed to restrain terminal movement on continuously reinforced concrete pavement. Using the data obtained, an empirical equation was statistically developed

encompassing all these variables. In addition a nomograph was derived that enables the designer to determine the number of lugs required for given conditions.

Report on

PARAMETERS INFLUENCING TERMINAL MOVEMENT ON CONTINUOUSLY REINFORCED CONCRETE PAVEMENT

I. INTRODUCTION

Highway engineers have been concerned with the effects of terminal movement of concrete pavement for many years. Terminal movement can be defined as the change of pavement length due to a variation in temperature and moisture conditions. This movement, if excessive, can be detrimental to bridge abutment walls.

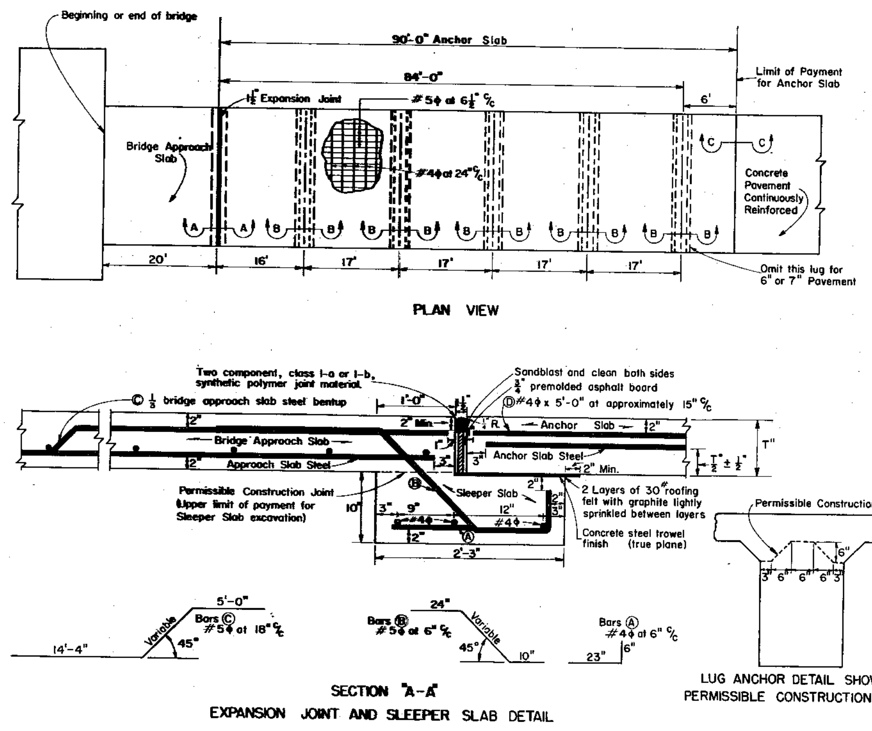
Background

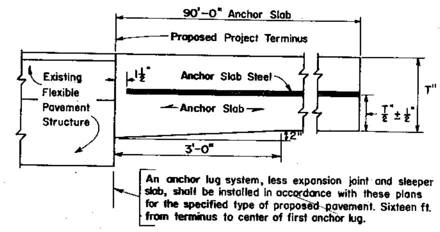
Concrete volume changes significantly with variations in temperature and moisture content, but due to a pavement's long length in relation to its depth and width, the volume change of interest occurs as an increase or decrease of length. Experience shows that the central portion of a concrete pavement slab is effectively restrained and the concrete is not allowed to expand and contract freely.[1] However, in the end portions, where the concrete pavement is relatively unrestrained, longitudinal movement of the pavement end is experienced.

Continuously Reinforced Concrete Pavement. In the last few years a new type pavement, (Continuously Reinforced Concrete Pavement, hereafter referred to as CRCP), has gained widespread acceptance in Texas.[2] With this type of pavement, enough steel is added to the concrete to eliminate all contraction joints. Elimination of contraction joints and the use of reinforcing steel results in the development of hair-line volume change cracks. These cracks are held tightly closed by the reinforcing steel.[3]

The hair-line cracks on CRCP are small enough to prevent the intrusion of foreign material, consequently the problem of pavement growth due to progressive crack opening in the end portions appears to have been eliminated on CRCP. In Texas a project with this type of pavement has been in service for 14 years and no problems of pavement growth have occurred.[4] Even though pavement growth has been eliminated, the end movement problem still remains due to temperature and moisture changes in the end portions of the slab.

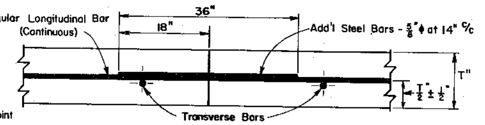
Devices for Allowing End Movement. Early experience in Texas indicated that 1½ inches of movement at the pavement ends could be expected on CRCP.[5] Various methods were introduced to provide for this movement, while still providing a smooth riding surface and sealing the roadbed





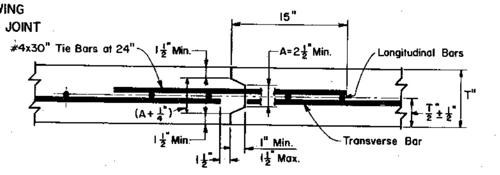
PAVEMENT TERMINUS DETAIL FOR JUNCTURE WITH EXISTING FLEXIBLE TYPE PAVEMENT STRUCTURE

NOTE: Details of junctures with existing concrete pavements (if applicable) shall be as shown elsewhere in the plans.



SECTION "C-C"
PERMISSIBLE TRANSVERSE CONSTRUCTION JOINT

LUG ANCHOR DETAIL SHOWING PERMISSIBLE CONSTRUCTION JOINT



LONGITUDINAL CONSTRUCTION JOINT
(Tongue and Groove with Tie Bars)

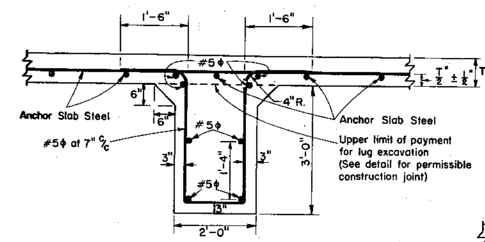
GENERAL NOTES

1. THE REQUIREMENTS OF THE BRIDGE APPROACH SLAB DESIGN AND THICKNESS SHALL BE AS SHOWN ELSEWHERE IN THE PLANS.
2. FOR FURTHER INFORMATION REGARDING THE PLACEMENT OF CONCRETE AND REINFORCING STEEL REFER TO THE ITEM "TERMINAL ANCHORAGE (CONCRETE PAVEMENT)".
3. DETAILS AS TO ANCHOR SLAB WIDTH, THICKNESS, CROWN CROSS-SLOPE, AND LOCATION AND TYPE OF LONGITUDINAL JOINTS SHALL BE AS SHOWN ELSEWHERE ON THE PLANS.
4. ALL CONCRETE, REINFORCING STEEL, AND REQUIRED EXCAVATION FOR THE SLEEPER SLAB, LUG ANCHORS, AND ANCHOR SLAB SHALL BE MEASURED AND PAID FOR UNDER THE ITEM "TERMINAL ANCHORAGE (CONCRETE PAVEMENT)" EXCEPT THAT PAYMENT WILL NOT BE MADE FOR CONCRETE USED IN BACK FILLING OVER-EXCAVATED AREAS OF LUG ANCHORS OR SLEEPER SLABS.
5. THE USE OF THIS DESIGN INVOLVES THE MODIFICATION OF THE BRIDGE APPROACH SLAB DETAIL AS SHOWN HEREON.
6. THE CONTRACTOR SHALL HOLD AND SAVE THE STATE, ITS OFFICERS, ITS AGENTS, AND ITS EMPLOYEES HARMLESS TO LIABILITY OF ANY NATURE OR KIND, INCLUDING COSTS AND EXPENSES, FOR OR ON ACCOUNT OF ANY PATENTED OR UNPATENTED INVENTION, ARTICLE OR APPLIANCE MANUFACTURED OR USED IN ACCORDANCE WITH THE DETAILS OF THESE PLANS.
7. THE LOCATIONS OF THE TERMINAL ANCHORAGE SYSTEMS SHALL BE AS SHOWN ELSEWHERE IN THE PLANS.
8. REINFORCING STEEL BARS SHALL BE OF THE SIZE AND SPACING AS DETAILED HEREON AND MAY BE ANY OF THE APPROVED GRADES OF REINFORCING STEEL AS SPECIFIED IN THE ITEM "TERMINAL ANCHORAGE (CONCRETE PAVEMENT)", WITH THE PROVISION THAT BARS THAT REQUIRE FIELD BENDING SHALL BE OF STRUCTURAL OR INTERMEDIATE GRADE.
9. WITHIN ANY AREA BOUNDED BY TWO FEET OF PAVEMENT LENGTH, MEASURED PARALLEL TO BE CENTER LINE; AND TWELVE FEET OF PAVEMENT WIDTH, MEASURED PERPENDICULAR TO THE CENTER LINE, NOT OVER 33% OF THE REGULAR LONGITUDINAL STEEL SHALL BE SPLICED.
10. MINIMUM SPLICE REQUIREMENT: 20 TIMES THE NOMINAL DIAMETER OF THE BAR.
11. TRANSVERSE CONSTRUCTION JOINTS IN THE ANCHOR SLAB WILL NOT BE ALLOWED EXCEPT IN AN EMERGENCY STOPPAGE OF THE CONCRETE PLACEMENT AND WITH THE APPROVAL OF THE ENGINEER. AT TRANSVERSE CONSTRUCTION JOINTS THE REGULAR LONGITUDINAL BARS SHALL EXTEND BEYOND THE JOINT SUCH THAT THE BAR SPLICES FOR THE REGULAR LONGITUDINAL BARS SHALL BE A MINIMUM OF FOUR FEET FROM THE CONSTRUCTION JOINT. (IF THE CONTRACTOR ELECTS TO OMIT THE CONSTRUCTION JOINT IN SECTION "C-C", THE ADDITIONAL STEEL BAR SHOWN HEREON MAY BE DELETED.)
12. AT LONGITUDINAL CONSTRUCTION JOINTS, IF THE CONTRACTOR ELECTS TO CONTINUE THE REGULAR TRANSVERSE STEEL THROUGH THE JOINT THE #4 Ø TIE BARS SHOWN HEREON MAY BE DELETED.
13. ANY APPROVED METAL CHAIR TYPE OR DESIGN, WHICH WILL SATISFY THE REQUIREMENTS NOTED HEREON, WILL BE PERMITTED. CHAIR SPACINGS SHALL NOT BE GREATER THAN 48" C-C MEASURED PARALLEL TO THE PAVEMENT CENTER LINE AND 30" C-C MEASURED PERPENDICULAR TO THE PAVEMENT CENTER LINE. ADDITIONAL CHAIRS SHALL BE USED IF NECESSARY TO MEET THE STEEL PLACEMENT REQUIREMENTS.
14. FOR SKEWED BRIDGES, THE APPROACH SLAB AND EXPANSION JOINT WILL BE SKEWED AS PER BRIDGE. LONGITUDINAL DIMENSION OF APPROACH SLAB, ANCHOR SLAB, AND ANCHOR LUG SPACINGS SHALL BE MEASURED ALONG THE CENTER LINE OF PAVEMENT.

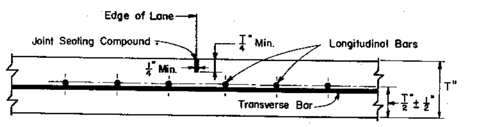
ESTIMATED QUANTITIES FOR ONE
24 FOOT WIDE TERMINAL ANCHORAGE

ITEM	PAVEMENT THICKNESS T(IN.)	CONCRETE (CU. YD.)	STEEL (LBS.)	EXCAVATION (CU. YD.)
SLEEPER SLAB	8	1.67	349	1.67
	7	1.67	343	1.67
	6	1.67	338	1.67
LUG ANCHORS	8 a	27.8	3318	27.8
	7 b	22.2	2624	22.2
	6 b	22.2	2624	22.2
ANCHOR SLAB	8	53.3 c	5001	—
	7	46.7 c	5001	—
	6	40.0 c	5001	—

a. Five lug anchors required
b. Four lug anchors required
c. For pavement terminus with existing flexible pavement structure, the concrete quantity should be increased by 0.2 C.Y. to include the thickened end detail.



SECTION "B-B"
LUG ANCHOR DETAIL



GROOVED LONGITUDINAL JOINT
(Sawed or Formed)

Figure 1.1

TEXAS HIGHWAY DEPARTMENT
TERMINAL ANCHORAGE
FOR
CONCRETE PAVEMENT
CONTINUOUSLY REINFORCED
TA(CPCR) - 62

DN: WBL	DRAWING	DATE	STATE	FEDERAL PROJECT NO.	SHEET NO.
CK. DN: MDS	Original	July 1961	TEXAS		

from weather conditions. Expansion joints were introduced at the pavement ends consisting of a load transfer device and a sealing material. Steel finger joints was another method used for allowing for end movement. Due to the expense encountered in maintenance of the normal expansion joints, and the high initial expense of the steel finger joints, the study of a new approach to the problem of terminal movement was undertaken.

End Restraint. After a careful study of several methods of coping with end movement on CRCP, a system was designed by the Texas Highway Department to restrain rather than allow free movement. The design consisted of a series of five shallow, rigid concrete lugs, cast monolithically with the pavement slab. These rigid lugs act as a series of restraining members by developing passive resistance of the soil.[4] This design is referred to in this report as TA(CRCP)-62 and is shown in Figure 1.1.

Purpose and Organization

The purpose of this report is to evaluate the parameters not considered as well as those considered in the original TA(CRCP)-62 design analysis. After evaluating the various parameters, an empirical relationship is developed encompassing the parameters found most influencial on the terminal movement of in-service pavements.

The study is presented in the following sections. Chapter II is concerned with the scope of the experiment. Chapter III gives an explanation of how the field data was analyzed. Chapter IV consists of a discussion of the analyzed data. Chapter V consists of the development of an empirical relationship, design equation, and nomograph. Chapter VI is a list of conclusions based on the findings from this study.

FACTORIAL OF LENGTH AND PERCENT GRADE FOR PAVEMENTS HAVING FIVE LUGS AND ASPHALT STABILIZED SUBBASE

% Grade \ Slab Length	650	1150	6440	7700	22,900	31,440
-1.46					X	
- .13	XX	XX				XX
.13	XX	XX				
1.46				X		
2.00			XX			

(A)

FACTORIAL OF LENGTH AND PERCENT GRADE FOR PAVEMENTS HAVING NO LUGS AND SURFACE TREATED SUBBASE

% Grade \ Slab Length	410	3500	5200	5400
- 1.95			XX	
.47	XX			
1.26		XX		
2.00			XX	
2.80				XX

(B)

FACTORIAL OF LENGTH, PERCENT GRADE, AND NUMBER OF LUGS OF PAVEMENTS HAVING CRUSHED SANDSTONE SUBBASE

No. of Lugs	2	3	4		5	
% Grade \ Slab Length	2,325	2,325	11,873	45,725	11,873	45,725
- .75				X		X
- .15	X	X				
+ .15				X		X
+ .75			X		X	

(C)

FACTORIAL OF LENGTH, PERCENT GRADE OF PAVEMENTS HAVING NO LUGS AND CEMENT STABILIZED SUBBASE

% Grade \ Slab Length	665	761	786	1254
+ .20	XX			XX
- .30	XX			
+ .40		XX XX	XX XX	
- .60				XX

(D)

TABLE 2.1
CRCP TERMINAL ANCHORAGE EXPERIMENT

II. SCOPE OF EXPERIMENT

The initial design for terminal anchors, to be used on CRCP, was developed largely on engineering judgement. There was relatively little information available on this type design during the design stages. Numerous parameters were known to exist that might influence end movement, but the only way to evaluate these parameters was in actual use of the design.

Shortly after this design was developed, a number of pavement ends were constructed in Texas that encompassed various parameters. After pavement ends were constructed, periodic measurements were made to obtain a broad range of temperature differences.

Parameters

The parameters to be investigated in this report are the number of rigid lugs used at the pavement end, length of the pavement slab contributing to end movement, per cent grade of the pavement end, temperature variation and coefficient of friction between the pavement and subbase. Table 2.1 is a factorial arrangement of the parameters studied in this report. Each "x" in the table represents an anchor system or pavement end.

It should be noted that the factorials are broken down into four basic subbase classes. Then each subbase type is further broken down in terms of other variables. This type of arrangement allows a systematic analysis of the data. When one variable is studied, the systems chosen from the factorial are constant insofar as the other variables are concerned. Consequently, any tentative conclusions drawn from any phase of the study is in terms of one variable.[6] From an analysis standpoint it would be desirable to have data for each factorial block, but this is impractical under field conditions.

Pavement Length. The TA (CRCP)-62 design was developed by making the fundamental assumption that only 300 feet of the pavement end moves and the interior portion of the slab is restrained due to the weight of the end portions.[4] It was desirable to check this value of 300 feet with in-service pavements.

A number of pavements were selected from ones under construction to acquire a large range of pavement lengths. Section A of Table 2.1 shows the pavements selected and the variables that each possess.

Per Cent Grade. For this report, a change was made in the normal sign convention used with grades in design work. Plus per cent grade is defined as a condition where the pavement end moves uphill toward the structure when it is expanding. Minus per cent grade is a condition where the pavement end moves downhill when expanding.

In the TA(CRCP)-62 design analysis, per cent grade was not considered as a parameter. However, it is felt that per cent grade could theoretically affect end movement, because the greater the grade, the more pavement weight acting down the plane in a direction parallel to the concrete movement force.

Per cent grade is studied for the systems appearing in Sections A, B of Table 2.1 since both factorials have a range of per cent grade.

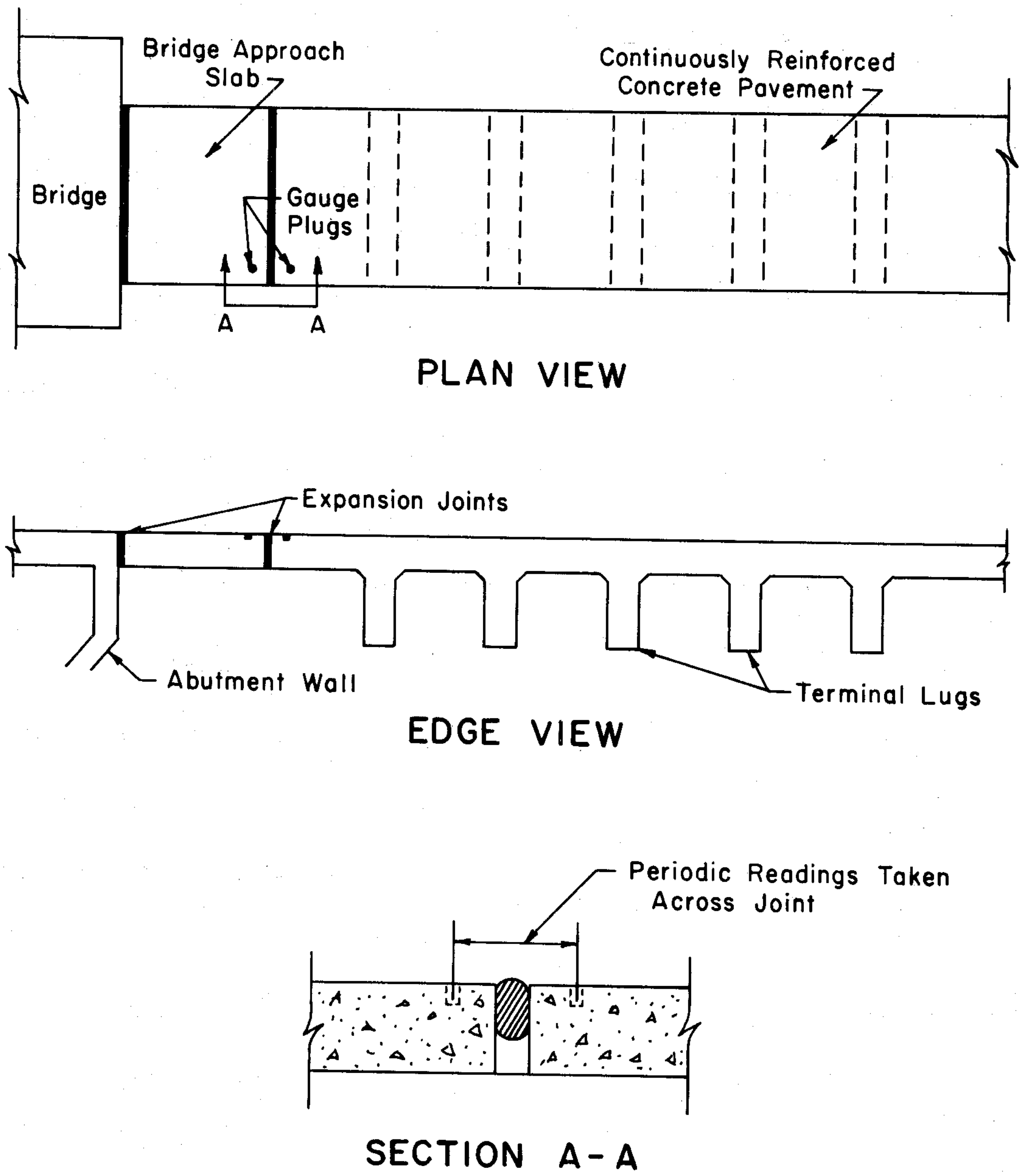
Coefficient of Subbase Friction. The coefficient of friction between the subbase and pavement was not considered in development of the TA(CRCP)-62 design. It is known however that crushed sandstone, asphalt treated subbase, cement treated, and surface treated subbase all differ considerably from the standpoint of coefficient of friction.

By the laws of mechanics, an object moving on a surface with friction is resisted by a restraining force due to the coefficient of friction. Consequently, it is theoretically possible that the fricional resistance of the subbase could partially restrain end movement.

Number of Lugs. The number of lugs used in the TA(CRCP)-62 design for an eight inch pavement is five. To study the effect the number of lugs has on end movement, pavement ends were built utilizing two, three, four, five and no lugs, holding all other variables as constant as possible. Section C of Table 2.1 is a listing of these different end systems.

Method of Taking Data

After selecting a number of terminal ends to be encompassed in the investigation, a method was devised to measure the end movement of each system. If the pavement end is referenced to a fixed point, any movement due to temperature change, will change the distance between the reference point and the pavement end. If the difference in temperature is known for a corresponding difference in distance, the amount of movement per degree Fahrenheit can be determined.



MEASUREMENT OF TERMINAL MOVEMENT

Fig. 2.1

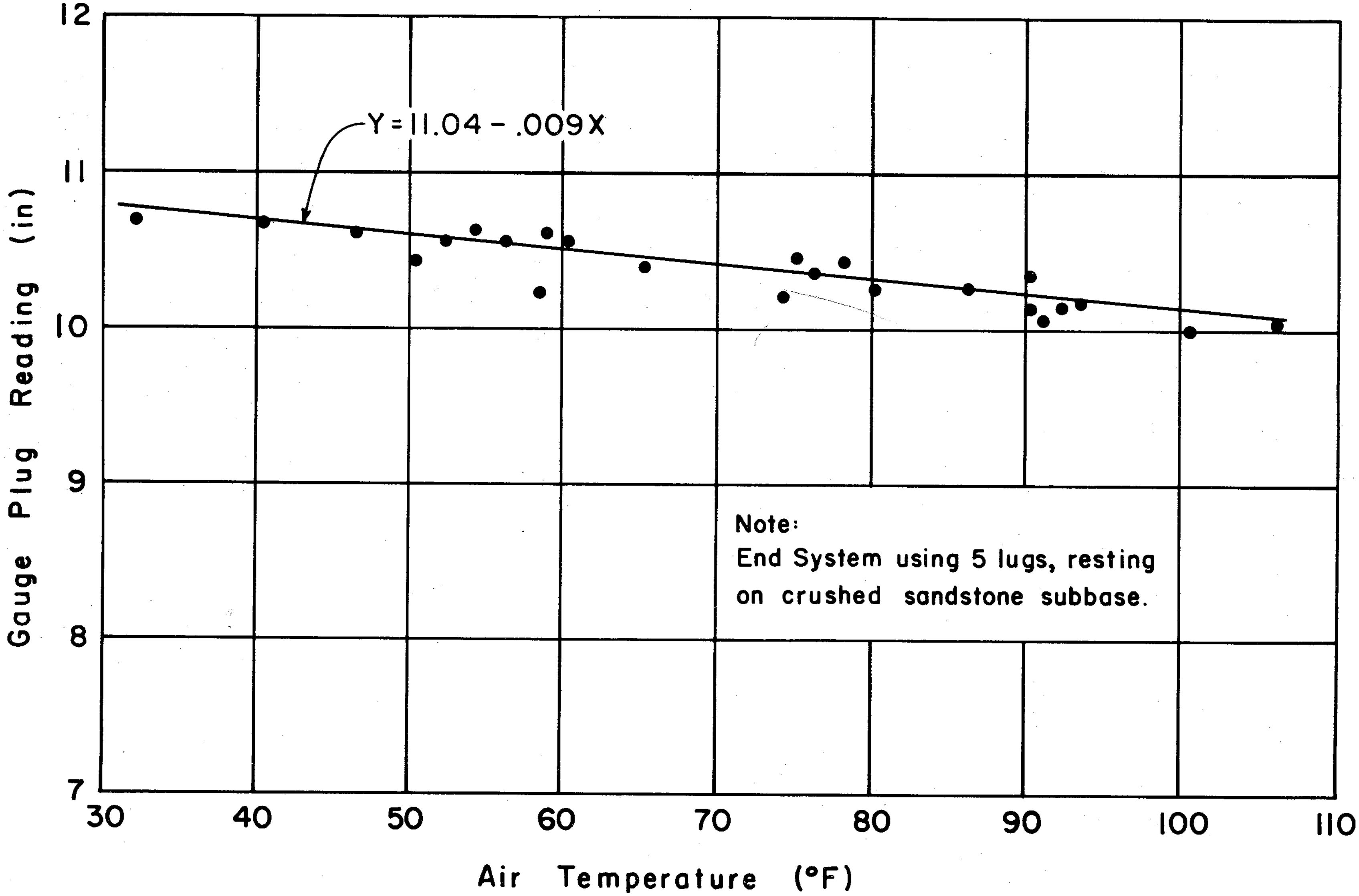
Bridge Approach Slabs. Between the pavement and bridge abutment wall there is a short slab called the bridge approach slab. This slab is fixed to the subbase and encounters no movement from either the bridge or the pavement end. The movement of the approach slab due to volume changes relative to the pavement end movement is insignificant. Therefore, using the approach slab as a fixed reference, movement of the pavement end in respect to a fixed point on the approach slab could be measured.

Figure 2.1 shows an edge view of the pavement end, approach slab, bridge abutment wall, and reference points.

Reference Points. Gauge plugs made of one-half inch brass dowels, cut 1 1/2 inches long were used as reference points. The plugs have a one-sixteenth of an inch hole drilled in one end. The plugs were placed approximately ten inches apart across the joint between the pavement end and approach slab. Plugs were placed on every pavement to be studied, one foot in from the pavement edge and perpendicular to the joint.

Readings. An instrument was used, similar to a pair of dividers, to determine the distance between the plugs. Inserting the points of the instrument into the holes in the center of the plugs gives readings accurate to 0.01 inch.

Readings have been taken periodically on all lug systems from one to three years, as some of the systems are older than others. Readings were taken at different air temperatures each time, and the temperature and readings recorded.



GAUGE PLUG READING VERSUS AIR TEMPERATURE

Fig. 3.1

III. METHOD FOR ANALYSIS OF FIELD DATA

An analysis of the field data obtained on each end system in the factorial on Page 2 was made to determine the end movement per unit change in temperature. This information was then used as a comparison basis for evaluating the different parameters influencing end movement.

Graphic Representation

The periodic readings taken on each end system in the study were plotted versus the corresponding temperatures when the readings were taken. These plots revealed that the relation between gauge plug reading and temperature on each system was linear. Therefore, the slope of the trend line for the points on the graph represents the change in length of the pavement per degree change in temperature. Figure 3.1 is a typical one of these graphs.

Statistical Analysis

Due to the amount of data and the accuracy needed, a high speed computer program was developed to statistically determine the slope of the line on each graph. The computer program utilized a linear regression analysis. The linear regression analysis results in a line describing the average relationship between the two variables under consideration.[7] This line is given by the equation:

$$Y = a + b X$$

where:

Y = the dependent variable,--in this case gauge plug width, inches.

X = the independent variable,--in this case air temperature, ^{o}F.

a = point where regression line crosses the Y axis

b = the slope of the line or change of the dependent variable per change in the independent variable.

<u>Basis for Comparison</u>

To compare one end system against another, the "b" term in the above equation was used as an indicator. The slope of the regression line "b" represents the change in pavement length per degree change in temperature for each end system. Therefore, variations in values of "b" for the end systems is characterized by the influence of the various parameters upon end movement of each system. In further analysis of the data, the "b" term is referred to as the rate of end movement, as the temperature range is assumed constant at one degree Fahrenheit.

FACTORIAL SHOWING RATE OF END MOVEMENT FOR PAVEMENTS ON ASPHALT STABILIZED SUBBASE (5 LUGS)

% Grade \ Slab Length	650	1150	6440	7700	22,900	31,440
-1.46					1.85	
- .13	2.75 1.78	3.47 3.08				3.18 3.26
.13	2.71 3.10	3.67 3.65				
1.46				4.17		
2.00			2.14 2.53			

(A)

FACTORIAL SHOWING RATE OF END MOVEMENT FOR PAVEMENTS ON SURFACE TREATED SUBBASE (NO LUGS)

% Grade \ Slab Length	410	3500	5200	5400
- 1.95			2.77 2.47	
.47	1.89 2.37			
1.26		4.44 5.28		
2.00			2.27 3.52	
2.80				2.91 1.99

(B)

FACTORIAL SHOWING RATE OF END MOVEMENT FOR PAVEMENTS ON CRUSHED SANDSTONE SUBBASE

No. of Lugs	2	3	4		5	
% Grade \ Slab Length	2,325	2,325	11,873	45,725	11,873	45,725
- .75				9.37		11.02
- .15	13.57	11.37				
+ .15				12.07		12.26
+ .75			7.99		6.83	

(C)

FACTORIAL SHOWING RATE OF END MOVEMENT FOR PAVEMENTS ON CEMENT STABILIZED SUBBASE (NO LUGS)

% Grade \ Slab Length	665	761	786	1254
+ .20	7.98 6.50			8.80 8.00
- .30	8.95 8.85			
+ .40		5.23 2.82 7.73 4.03	3.39 7.60 7.89 6.61	
- .60				7.74 6.76

(D)

TABLE 4.1 $\times 10^{-3}$

RATES OF END MOVEMENT FOR TERMINAL ANCHORAGE EXPERIMENT

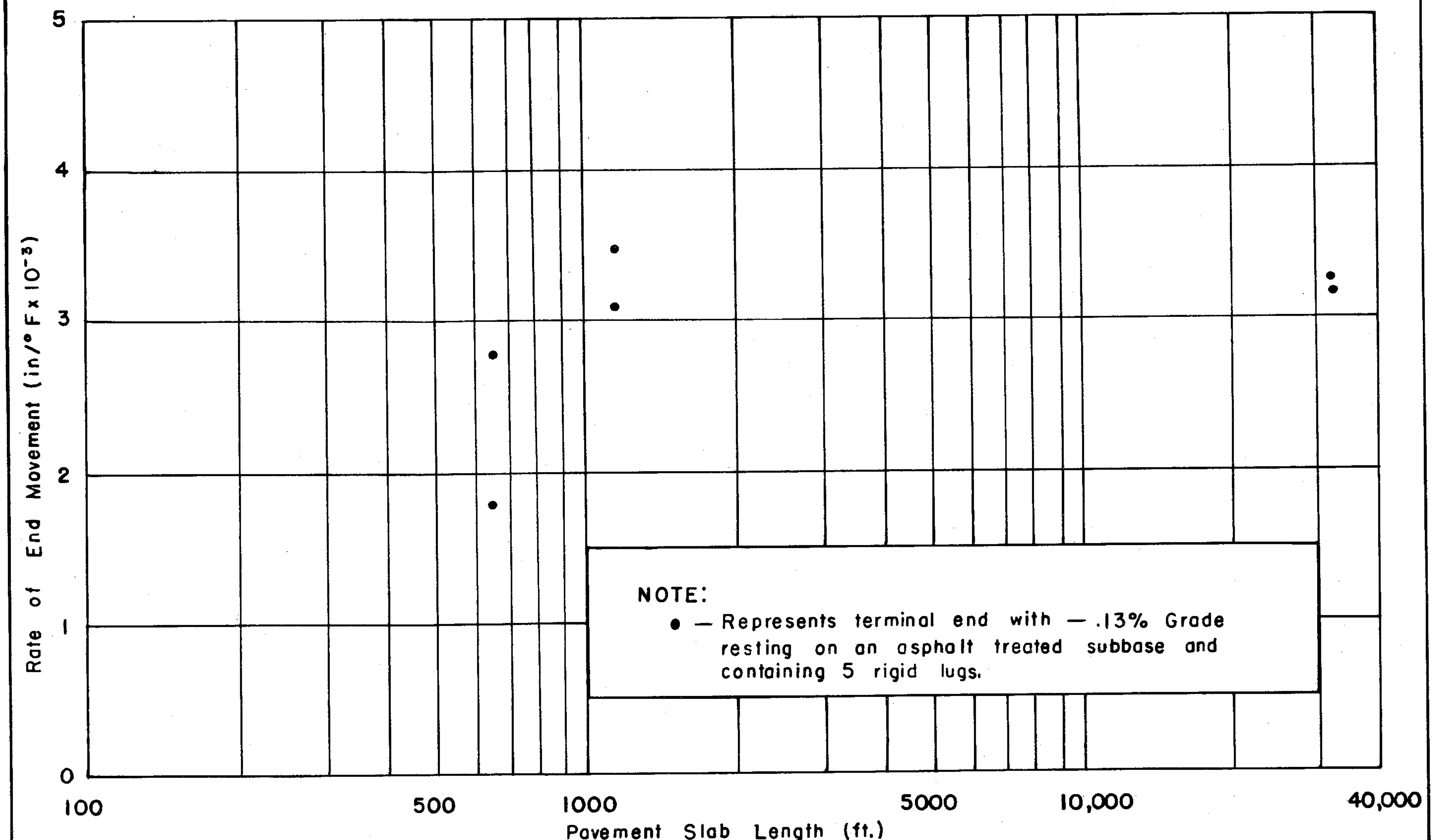
IV. PRESENTATION AND DISCUSSION OF DATA

Table 4.1 contains the rate of end movement per degree Fahrenheit for each system studied in this report. As was mentioned earlier, these numbers are used as the comparison basis for comparing one end system against another, assuming a change in temperature constant of one degree Fahrenheit.

Length of Slab

To analyze the effect the length of a slab has on terminal movement, the systems to be studied were selected from Section A of Table 4.1. The end systems chosen all have asphalt treated subbase, -0.13 per cent grade and five rigid lugs.

Figure 4.1 shows the relation between length of slab and the rate of end movement. This graph indicates that as the length of a slab increases to approximately 1000 feet, the rate of terminal movement increases. The graph also indicates that a slab length in excess of 1000 feet would not influence the rate of end movement any more than one of 1000 feet. If the rate of end movement is increasing with increasing slab lengths up to 1000 feet, then half of the total slab length is contributing to end movement on both ends. For slab lengths in excess of 1000 feet only



EFFECT OF SLAB LENGTH ON TERMINAL MOVEMENT

Fig. 4.1

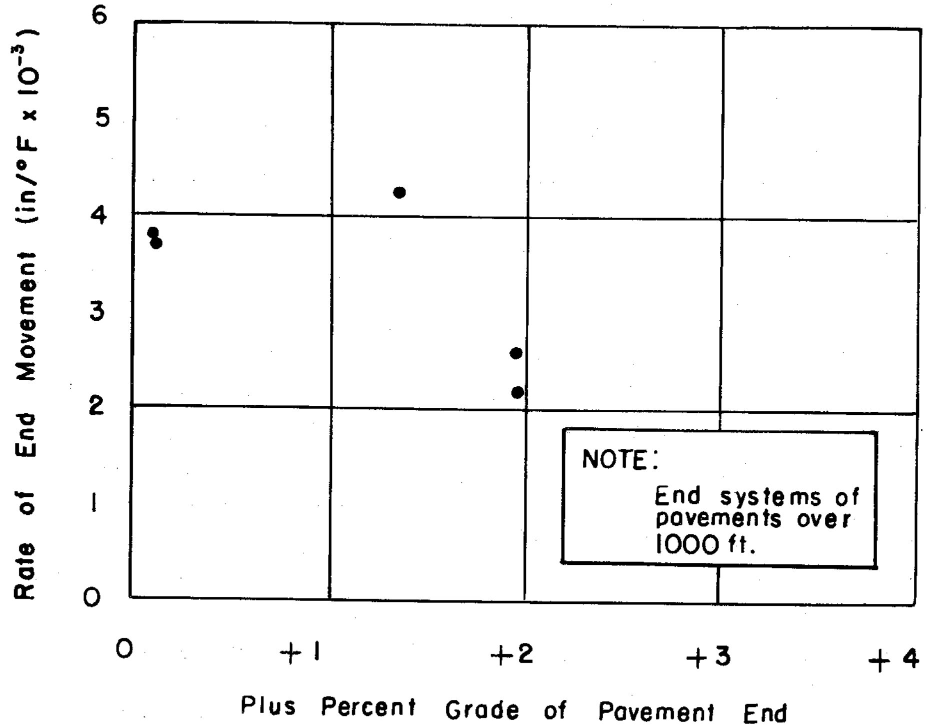
500 feet on each end of the slab is moving and the interior portion of the slab is restrained.

It was stated earlier that the interior portion of a continuously reinforced concrete pavement was restrained and did not move. On this basis of the preceeding discussion this statement is true for slab lengths greater than some optimum length.

It should be noted that this optimum length just found is for a pavement on asphalt stabilized subbase. It is felt that this length will change with different subbases due to a variation in subbase coefficient of friction. However, due to the lack of data, 1000 feet will be used for all type subbases in this report.

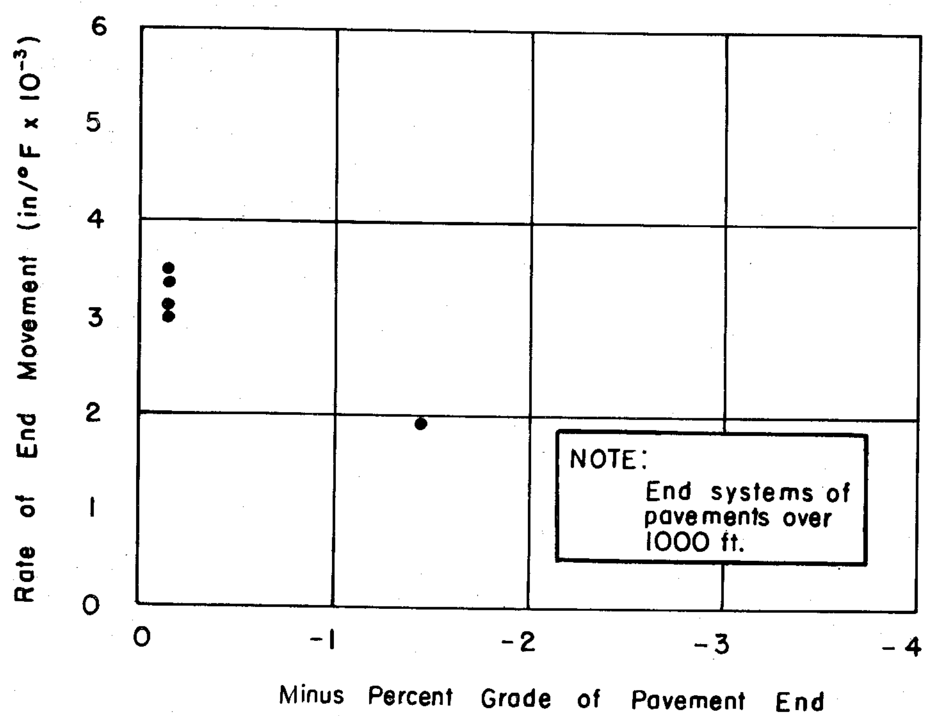
Per Cent Grade

To evaluate the effect of per cent grade on the rate of end movement, the study must be carried out in parts. The difference in plus and minus grades is investigated, and then the effect of per cent grade on end systems with different subbases is studied. All of the pavements in excess of 1000 feet can be used in this study, as it has been found that variable pavement lengths in excess of 1000 feet do not continue to effect the rate of end movement.



EFFECT OF PLUS PERCENT GRADE ON TERMINAL MOVEMENT

Fig. 4.2



EFFECT OF MINUS PERCENT GRADE ON TERMINAL MOVEMENT

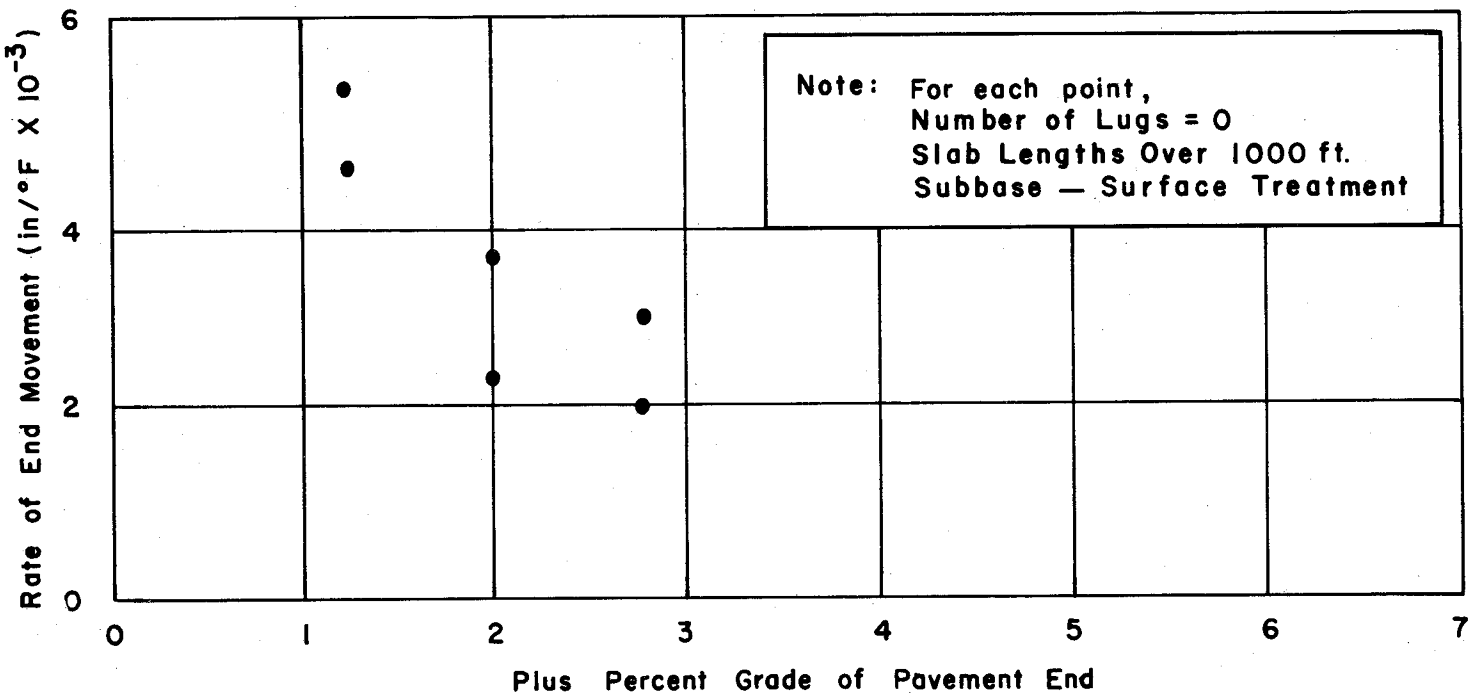
Fig. 4.3

Plus and Minus Per Cent Grades. Figures 4.2 and 4.3 show the rate of movement in terms of plus per cent grade and minus per cent grade respectively. These end systems were taken from Section A of Table 4.1 and all utilize an asphalt treated subbase and five rigid lugs.

These two graphs indicate that an end system having a minus per cent grade experiences slightly less movement per degree change in temperature than one having a plus per cent grade, considering all other variables constant. It is also evident that the rate of end movement of each pavement decreases as their corresponding grades increase.

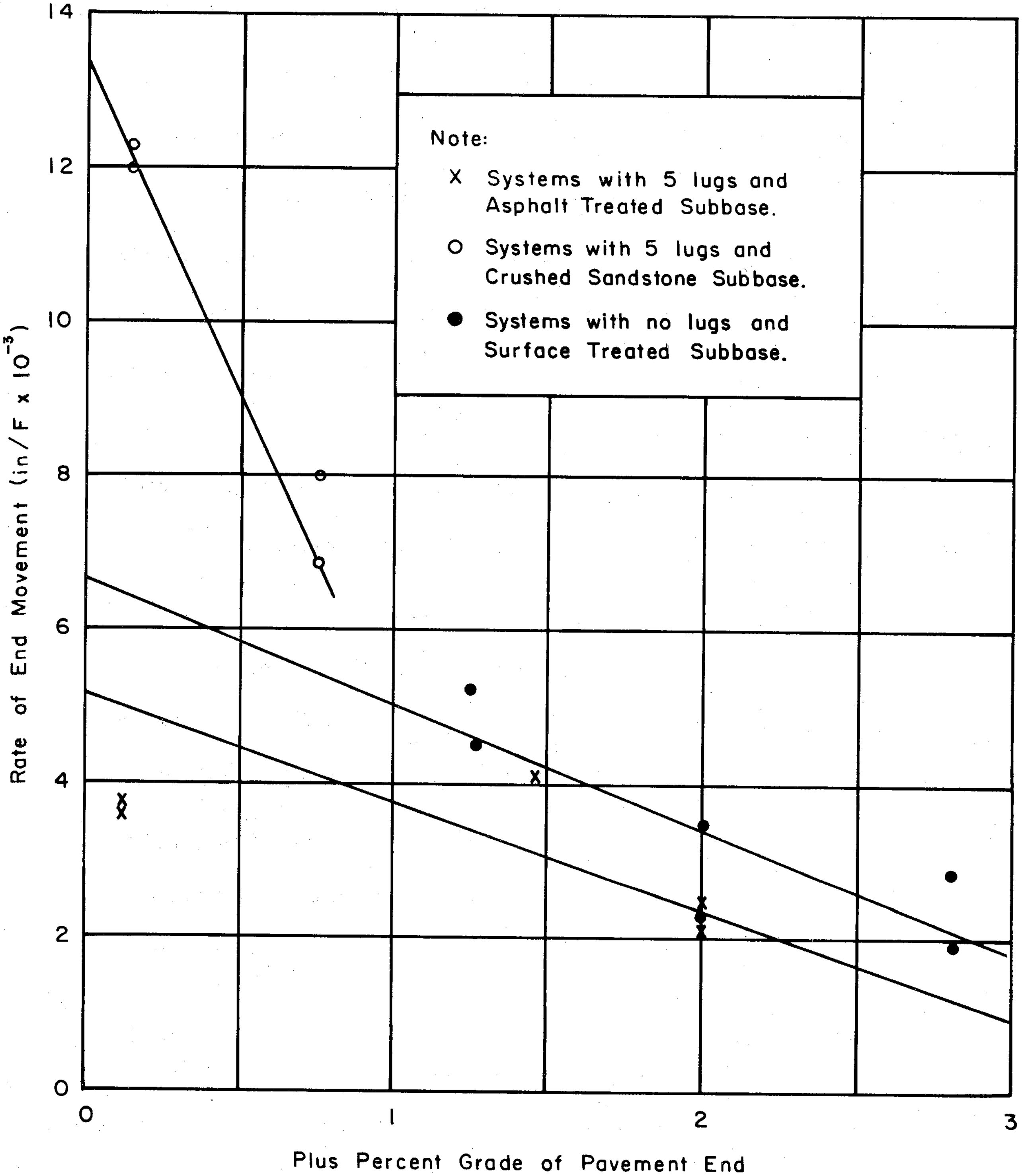
Per Cent Grade with Surface Treated Subbase. Figure 4.4 is a graph showing the rate of end movement for pavements with a plus per cent grade, resting on surface treated subbase, and using no lugs. These end systems were chosen from Section B of Table 4.1. The graph shows as was the case previously, that as the per cent grade of each pavement end increased, the pavement's rate of end movement decreases.

Summary. The preceeding discussion shows that the rate of end movement decreases as the per cent grade increases. This trend is true for pavements having a plus or minus per cent grade, a variable number of lugs, or different type subbases.



EFFECT OF PLUS PERCENT GRADE ON TERMINAL MOVEMENT OF PAVEMENTS WITH SURFACE TREATED SUBBASES

Fig. 4.4



PERCENT GRADE VERSUS TERMINAL MOVEMENT FOR DIFFERENT TYPE SUBBASES

Fig. 4.5

Coefficient of Subbase Friction

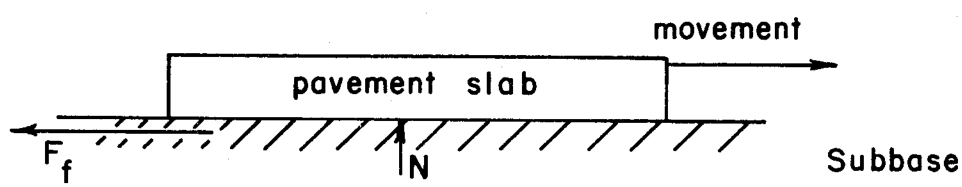
The preceeding discussion on per cent grade shows the relationship of per cent grade and end movement for several types of subbase. The next logical step is to examine the slope and the relative vertical position of the trend lines on the per cent grade--rate of end movement plots in terms of subbase type and number of lugs. Figure 4.5 allows a relative comparison of the various trend lines. (The end systems with cement stabilized base are deleted due to the short slab lengths.)

Crushed Sandstone and Asphalt Treated Subbases. Figure 4.5 indicates that pavements with crushed sandstone subbase have a higher rate of end movement than ones with asphalt treated subbase. Since both of the subbase types are accompanied by five lug systems. Rational analysis indicates the major contributing factor in the difference of end movement is the type subbase.

Surface Treated Subbase. Figure 4.5 also shows at zero per cent grade, a pavement resting on a surface treated subbase has about the same rate of end movement as one on an asphalt stabilized subbase. The pavements on asphalt stabilized subbase utilize five lugs, whereas, the one on surface treated subbase has no lugs. Since the lugs reduce end movement, it may be conjectured that a pavement having a surface treated subbase would have a lower rate of end movement than one using asphalt treated subbase if all other parameters were constant.

Summary. From this discussion it can be seen that subbases with surface treatment have a higher coefficient of friction than an asphalt stabilized subbase. Also, crushed sandstone subbase has a coefficient of friction less than either surface treatment or asphalt stabilized subbases.

This is true because as the rate of end movement decreases, holding other variables constant, the frictional force opposing end movement increases. For the frictional force to increase the coefficient of friction must increase. Figure 4.6 shows this relationship.

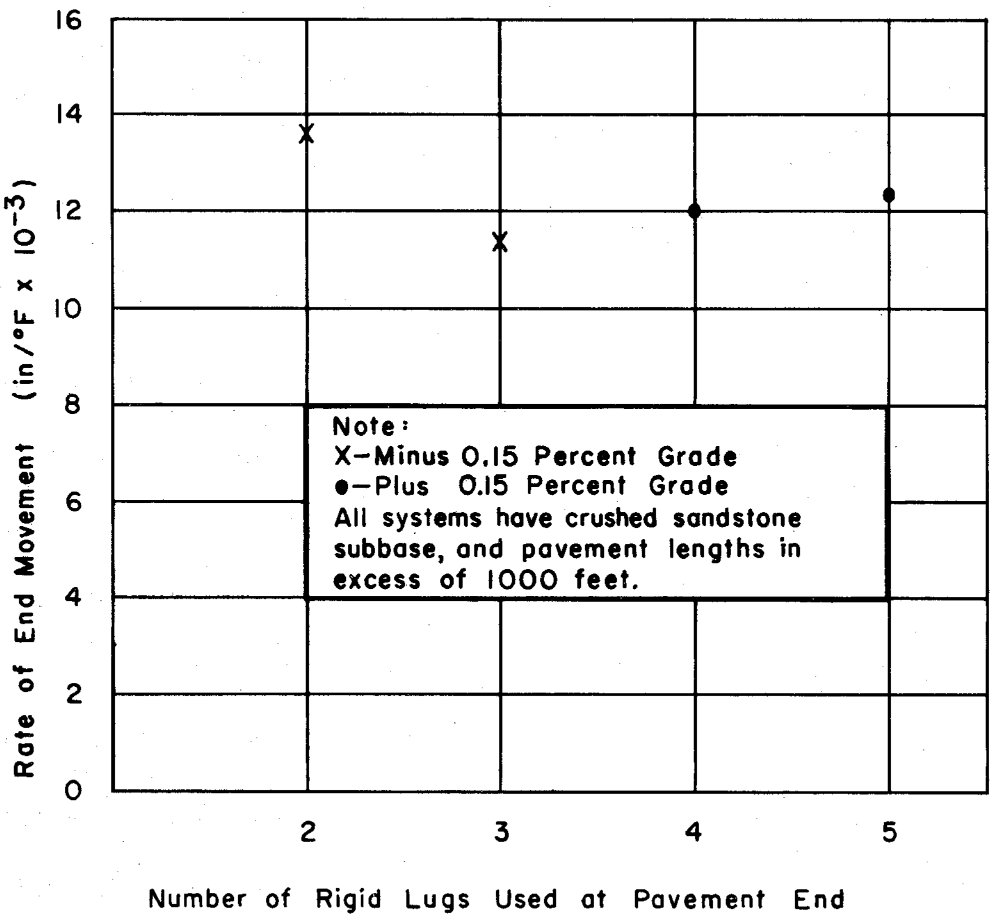


$$F_f = \mu N$$

where:
μ = coefficient of subbase friction
N = normal force due to slab weight
F_f = frictional force

FRICTIONAL FORCE DUE TO COEFFICIENT OF FRICTION

FIGURE 4.6



EFFECT OF NUMBER OF LUGS
ON TERMINAL MOVEMENT

Fig. 4.7

Number of Lugs

Section C of Table 4.1 consists of a cross section of systems using a variable number or rigid lugs. All of these terminal anchorage systems have pavement lengths in excess of 1000 feet; therefore, pavement length will be considered constant. Also, all of the lug systems in this factorial have the same type subbase. To get a range of number of lugs, the two and three lug systems were chosen with a -0.15 per cent grade, while the four and five lug systems were chosen with a +0.15 per cent grade.

Figure 4.7 shows a plot of these different lug systems versus their rate of end movement. As would be expected, the two lug systems experience the greatest rate of end movement. It was found earlier that pavements with plus per cent grade experienced slightly higher rates of end movement than ones with minus per cent grade. Taking this difference in grade into consideration, the four and five lug systems would have a lower rate of end movement than shown. Assuming this fact, the four and five lug systems would have about the same rate of end movement as the three lug systems.

Although the two lug systems experience 0.014 inches of movement per degree temperature change, this would only amount to 1.4 inches of movement for a 100° F temperature change. With the present use of expansion joints and bridge approach slabs, this magnitude is not sufficient to cause any detrimental effects to the bridge.

V. DERIVATION OF AN EMPIRICAL DESIGN EQUATION

The data analysis in the preceding chapter indicated that air temperature change, pavement length, per cent grade, subbase friction, and number of lugs affected the movement of pavement terminals. In this chapter, an empirical equation is developed to solve for terminal movement in terms of the above mentioned parameters. A statistical analysis is made of the data obtained from the 48 terminal systems to arrive at the correlation constants. The final equation is then displayed in nomograph form to allow a designer to determine the number of terminal anchorage lugs for a given system.

Development of Empirical Equation

It has been shown that as slab length increases up to approximately 1000 feet, the rate of end movement increases. The following proportionality can be stated:

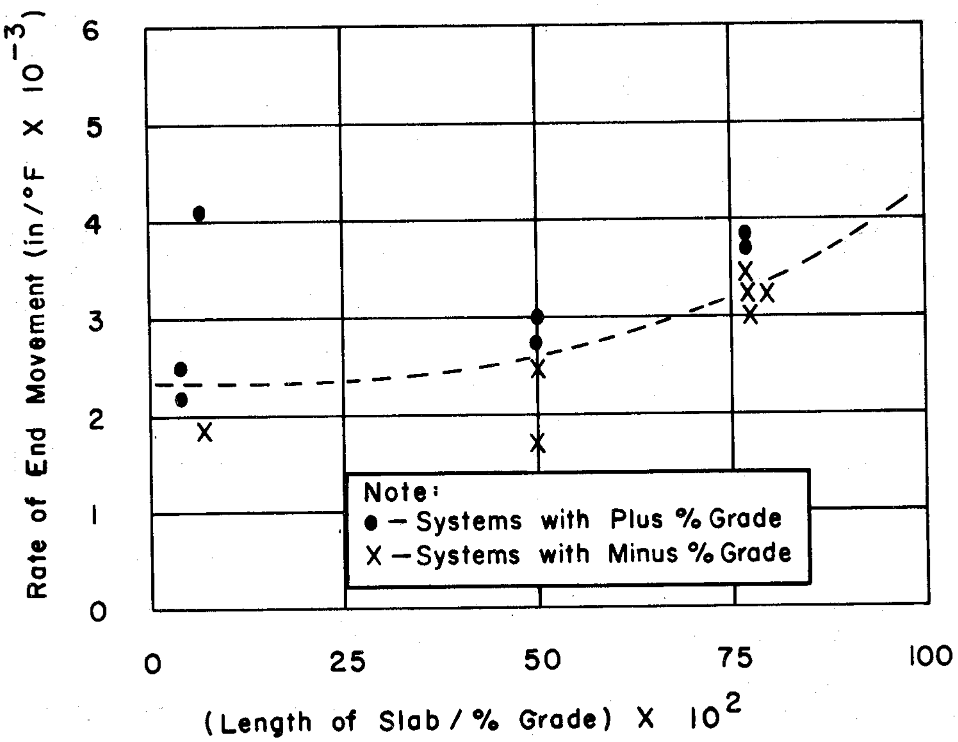
$$b \propto L \quad \ldots\ldots\ldots\ldots \quad 5.1$$

where:

b = rate of end movement (inches/$^{\circ}$ F)

L = length of slab

Also it has been shown that as the per cent grade of different pavements increase, their rate of end movement



LENGTH PERCENT GRADE RATIO VERSUS THE RATE OF TERMINAL MOVEMENT OF PAVEMENTS ON ASPHALT STABILIZED SUBBASE

Fig. 5.1

decreases. Therefore, the following proportionality is stated:

$$b \propto \frac{L}{G} \qquad \text{. . . . . 5.2}$$

where:

G = per cent grade

Equating the rate of end movement in terms of both length and per cent grade and inserting a constant of proportionality, yields the following relationship for slab lengths under 1000 feet.

$$b = A_o \frac{L}{G} \qquad \text{. . . . . 5.3}$$

where:

A_o = constant of proportionality

For pavement lengths in excess of 1000 feet, the length in equation (5.3) will remain a constant of 1000.

Figure 5.1 is a graphic illustration of this equation obtained from an in-service pavement. Rate of end movement is plotted as the dependent variable, and length divided by grade is plotted as the independent variable. The variables in the equation were taken from Table 4.1 using both positive and negative grades. This was done by using the absolute value of per cent grade. Although the length divided by negative grade follows a lower band, for all practical purposes positive and negative grades can be plotted on the same graph, and the difference in the result would be negligible.

Figure 5.1 indicates that equation (5.3) is parabolic. Therefore, it is probably true that the equation takes on the following form:

$$b = A_o \left(\frac{L}{|G|}\right)^{A_1} \quad \ldots\ldots\ldots\ldots 5.4$$

where:

A_1 is some power of $\left(\frac{L}{|G|}\right)$, not equal to 1.

Also, it was previously shown that when per cent grade was zero the length of the slab continues to contribute to the rate of end movement. Therefore, the following mathematical expression must be used:

$$b = A_o \left(\frac{L}{|G| + 1}\right)^{A_1} \quad \ldots\ldots\ldots\ldots 5.5$$

Earlier in the report, it was pointed out that the rate of pavement end movement was also influenced by different types of subbase and the number of lugs. Since these factors are inversely related, they are introduced into the equation as follows:

$$b = \frac{A_0 \left(\frac{L}{|G|+1}\right)^{A_1}}{K^{A_2} (n+1)^{A_3}} \quad . \; . \; . \; . \; . \quad 5.6$$

where:

$(n+1)$ = The number of lugs plus one

K = The subbase coefficient of friction

In the above equation $(n+1)$ is used in place of n because as n becomes zero the equation must continue to be real. Consequently, equation (5.6) should apply to any pavement considering the fact that "K" and "n" will change with a different set of conditions. To make the equation simplier to plot and analyze, it is put into the form:

$$\text{Log } b = \text{Log } A_0 + A_1 \text{ Log}\left(\frac{L}{|G|+1}\right) - A_2 \text{ Log } K - A_3 \text{ Log}(n+1) \quad . \; . \quad 5.7$$

This equation encompasses all the variables studied in this report that might influence the rate of terminal movement.

Development of Design Equation

The correlation constants A_0, A_1, A_2, A_3 can be determined by a statistical analysis using the values of the parameters of each of the 48 systems. All of the parameters for each system were known with the exception of the values for different coefficients of subbase friction.

A literary search was conducted and it was found that the K values for the four subbase types have been evaluated by other investigators as follows.[8,9]

Subbase	Cement	Asp. Stab.	Surf. Treat.	Sandstone
K	3.00	1.75	2.25	1.35

These values were in the range of what might be expected on the basis of the preceding analysis with the exception of surface treated subbases. It was felt on the basis of comparing data that the "K" value for surface treatment should be higher than indicated. Therefore, a multiple correlation was run once using the values of K shown above, and once using "K" for surface treatment of 2.65.

Table 5.1

Run No.	A_0	A_1	A_2	A_3	Avg. Diff.
1	.0000060	1.339	-1.634	-.739	.00161
2	.0000482	1.164	-2.506	-1.058	.00148

Table 5.1 shows the results of these two runs. After each of the correlations were run, the data from each of the 48 systems were plugged back into the resulting equation and

"b" was computed. The average difference in Table 5.1 is the average of all the computed "b"s minus the actual "b" for each of the 48 systems.

For either run in Table 5.1 the average difference is approximately 0.0015 inches. This means the equation would predict an expected end movement for a given temperature differential and set of conditions within 0.0015 in /°F. However, run 2 yields the closest correlation to the actual, therefore it is felt that a "K" of 2.65 more nearly approximates the coefficient of subbase friction for surface treatment.

Using the correlation constants obtained in run 2 yields the following equation.

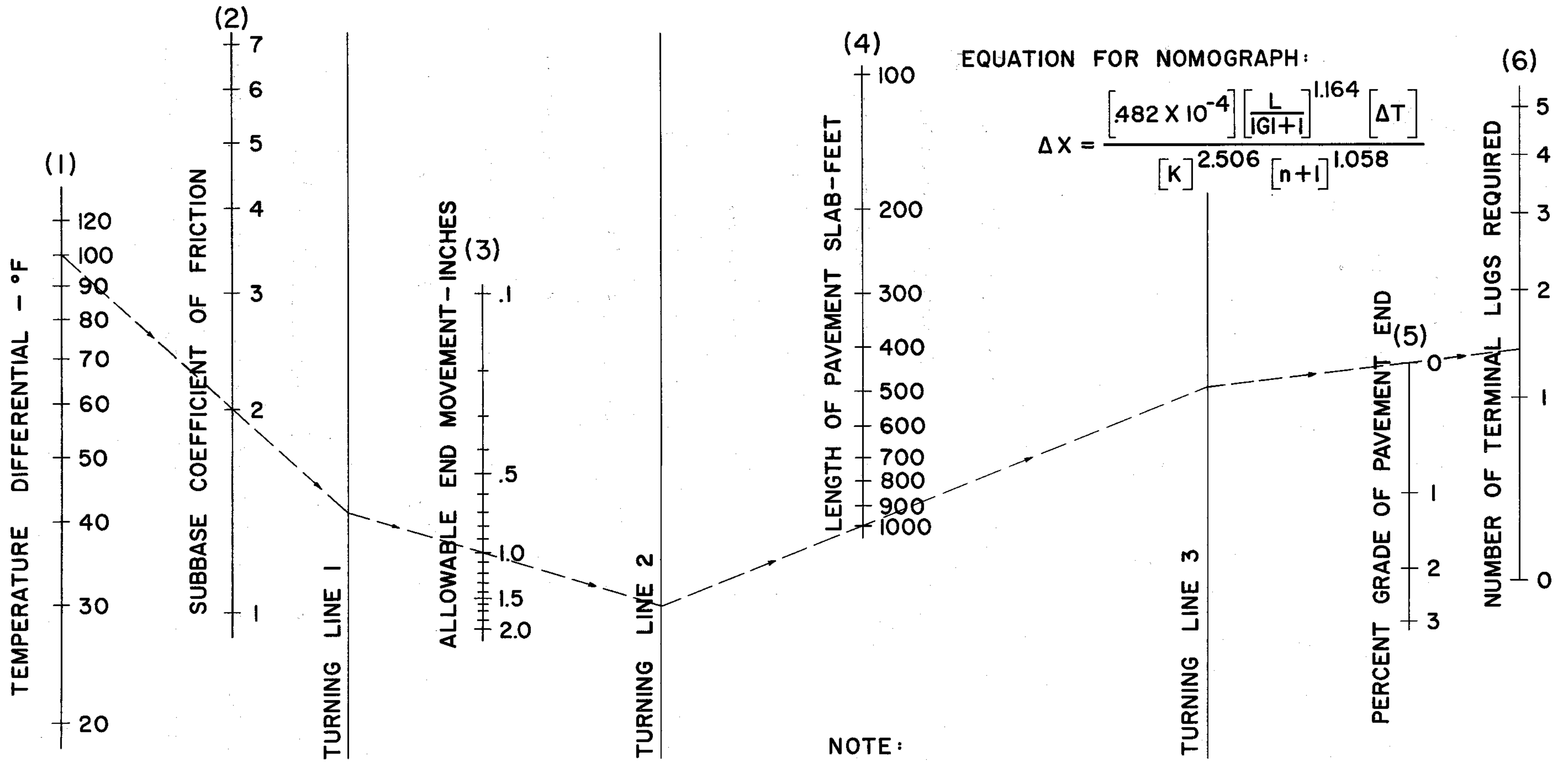
$$\text{Log } b = \text{Log}(.0000482) + 1.164 \text{ Log}\left(\frac{L}{|G|+1}\right) - 2.506 \text{ Log } K - 1.058 \text{ Log } (n+1) \qquad \ldots\ldots\ldots 5.8$$

But $b = \dfrac{\Delta X}{\Delta T}$

Where ΔX = the change in pavement length

ΔT = the change in temperature

Therefore, equation 5.8 could be expanded into the following form, which would account for a maximum yearly change in temperature.



EQUATION FOR NOMOGRAPH:

$$\Delta X = \frac{\left[.482 \times 10^{-4}\right]\left[\frac{L}{|G|+1}\right]^{1.164}\left[\Delta T\right]}{\left[K\right]^{2.506}\left[n+1\right]^{1.058}}$$

NOTE:

(A) Use the maximum seasonal variation of temperature for temp. differential

(B) For pavement slab lengths in excess of 1000 ft. use 1000

(C) Use absolute value of percent grade

(D) Design Chart is applicable only to eight inch pavements

EXAMPLE PROBLEM

ΔT = 100°F = Temp. differential

K = 2 = Subbase coefficient of friction

ΔX = 1.0 in. = Allowable end movement

L = 10,000 ft. = Length of pavement slab

|G| = 0% = Absolute percent grade of pavement end

Answer: n = 2 = Required number of terminal lugs

TERMINAL ANCHORAGE DESIGN CHART
FOR
CONTINUOUSLY REINFORCED CONCRETE PAVEMENT

AUGUST – 1964

FIGURE 5.2

$$\text{Log } \Delta X = \text{Log}(.482 \times 10^{-4}) + 1.164 \text{ Log}\left(\frac{L}{|G|+1}\right) - 2.506 \text{ Log } K - 1.058 \text{ Log}(n+1) + \text{Log } \Delta T$$

Taking the anti-log of both sides yields

$$\Delta X = \frac{\left[.482 \times 10^{-4}\right] \left[\frac{L}{|G|+1}\right]^{1.164} \left[\Delta T\right]}{\left[K\right]^{2.506} \left[n+1\right]^{1.058}} \qquad \text{. . . . . 5.9}$$

When designing a pavement end, the constant for the type subbase to be used, per cent grade, pavement length, temperature range for climatic region, and the maximum end movement that could be tolerated would be known. Therefore, the number of lugs needed could be determined from equation 5.9. Since the complexity of this equation makes its use for design impractical, a nomograph has been developed for solving the equation. Figure 5.2 is an example of this nomograph. The nomograph is entered on the left and is solved in the direction of the arrows using the given parameters.

Since the nomograph is strictly an empirical solution, caution should be used in extrapolating beyond the parameter magnitudes used in this statistical derivation. Furthermore, soil conditions would be another factor to consider, although the subsoil for the various anchorage systems used in this report varied from sand to clay.

VI. CONCLUSIONS

On the basis of this study, the following conclusions are warranted:

1. The terminal movement of a continuously reinforced concrete pavement is directly related to pavement length and temperature change, and inversely related to pavement grade, subbase friction, and the number of lugs.

2. An empirical equation can be derived that enables a designer to determine the number of lugs required for a pavement terminal in terms of the above enumerated parameters.

3. The derived equation can be used as a design guide for determining the required number of lugs for terminal anchorage systems used with an eight inch continuously reinforced concrete pavement.

4. Only the last 500 feet of a continuously reinforced concrete pavement contributes to the end movement experienced at an expansion joint.

5. The TA(CRCP)-62 design detail used by the Texas Highway Department should be revised to provide for the reduction of the number of lugs for certain subbases and geometric conditions.

6. With certain combinations of subbase coefficient and per cent grade, the number of terminal lugs for CRCP can be reduced to zero.

7. In order to further verify the empirical relationship presented in the report, observations will be continued for another year on the terminal anchorage systems. Furthermore, gauge plugs will be installed on several more terminal anchorage systems to further analyze the effect of subbase friction and pavement length.

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