AN EVALUATION OF TERMINAL ANCHORAGE INSTALLATIONS ON RIGID PAVEMENTS

by

B. F. McCullough
Supervising Design Research Engineer

T. F. Sewell

Highway Design Division
Texas Highway Department

In Cooperation with
U. S. Department of Commerce
Bureau of Public Roads

Report No. 39-4(F)
Research Project 1-8-63-39
Evaluation of Terminal Anchorage
Installations on Rigid Pavements

September 1966

ACKNOWLEDGMENT

The research reported in this paper was conducted under the supervision of Mr. M. D. Shelby and then Mr. Robert L. Lewis, Research Engineer, and under the general supervision of Mr. T. S. Huff, Chief Engineer of Highway Design.

The authors are indebted to Messrs. Harold Hans, Garlon Lawrence, and George West of the Highway Design Division, Research Section for their assistance throughout the investigation.

TABLE OF CONTENTS

Page No.

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

This report is a summary of research on rigid pavement terminal anchorage installations that was conducted by the Texas Highway Department over a period of three and one-half years. A total of 152 anchorage systems on jointed concrete pavement and 186 units on continuously reinforced concrete pavement were used in this analysis.

The findings indicate a terminal anchorage system such as used by the Texas Highway Department is a feasible method for preventing pavement volume change forces from damaging an overpass or bridge structure. Several failures were experienced with terminal anchorage systems on jointed pavement due to a deficiency in transferring the pavement growth forces from the anchorage system to the soil mass. A new design detail was prepared by the Texas Highway Department to offset the deficiencies found in a diagnostic investigation of these failures.

On continuous pavement the terminal movement was found to be directly related to pavement length up to 1,000 feet and temperature change and indirectly to pavement grade, subbase coefficient and number of lugs. An empirical expression expressing movement in terms of these variables was derived in this report. This equation, considering the boundary conditions, could be used as a design equation.

An experimental installation in connection with this project has revealed the feasibility of connecting the terminal of a continuous pavement directly to the bridge structure.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of this research project - Evaluation of Terminal Anchorage Installations on Rigid Pavements - which was conducted over a period of three and one-half years by the Texas Highway Department the following conclusions are warranted:

Jointed Concrete Pavements

1. A terminal anchorage system such as used by the Texas Highway Department is a feasible method for preventing pavement growth forces from damaging an overpass or bridge structure if the anchor system is properly designed and constructed.

2. The failures experienced on terminal anchorage systems constructed in the coastal area can be attributed to a deficiency in transferring the pavement growth forces from the anchorage system to the soil mass. On site excavations of failure areas revealed a soil shear failure along a horizontal plane at the bottom of the lug members.

3. In each of the areas where a diagnostic investigation was conducted of the failure, there were no cases where failure could be attributed to the concrete structural members of the anchor slab or lug extensions.

4. The presence of transverse cracks in the anchor slab is not a sign of alarm, but indicative that the anchor system is performing satisfactorily.

5. The design detail contained herein that is presently being used by the Texas Highway Department for anchorage systems on jointed concrete pavement was prepared on the basis of findings of this study.

Continuously Reinforced Concrete Pavement

1. The terminal movement of an eight inch continuously reinforced concrete pavement is directly related to pavement length and temperature change, and indirectly to pavement grade, subbase coefficient, and number of lugs. An empirical expression expressing movement in terms of these variables is presented herein. It may be used as a basis for design.

2. The terminal movement of an eight inch CRCP with terminal anchorages and without such anchorages was found to be independent of pavement age and envirnomental location.

3. The study indicated that only the last 500 feet (or less) of a CRCP contributes to end movement experienced at an expansion joint.

4. Care should be taken in using the empirical equation derived herein for design purposes. Parameters should not be used that are outside the limits of this 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, as the values do not follow what might logically be expected.

There is a possibility that part of the values derived herein are due in part to the type of soil mass acting against the lug as well as the imposing force due to surface friction. Since 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 subbase apply to this empirical design equation.

5. With certain combinations of subbase coefficient and per cent grade, the number of terminal lugs for CRCP can be reduced to zero. A satisfactory performance over a period of seven years to fifteen years in one case verifies this.

6. An experimental project in Central Texas has revealed the possibility of connecting the terminal of a continuous pavement directly to the abutment bent of a bridge structure.

Although problems were experienced with the experimental installation, it is felt that proper design along with good construction procedures will reveal this concept to be completely feasible in the near future.

I. INTRODUCTION

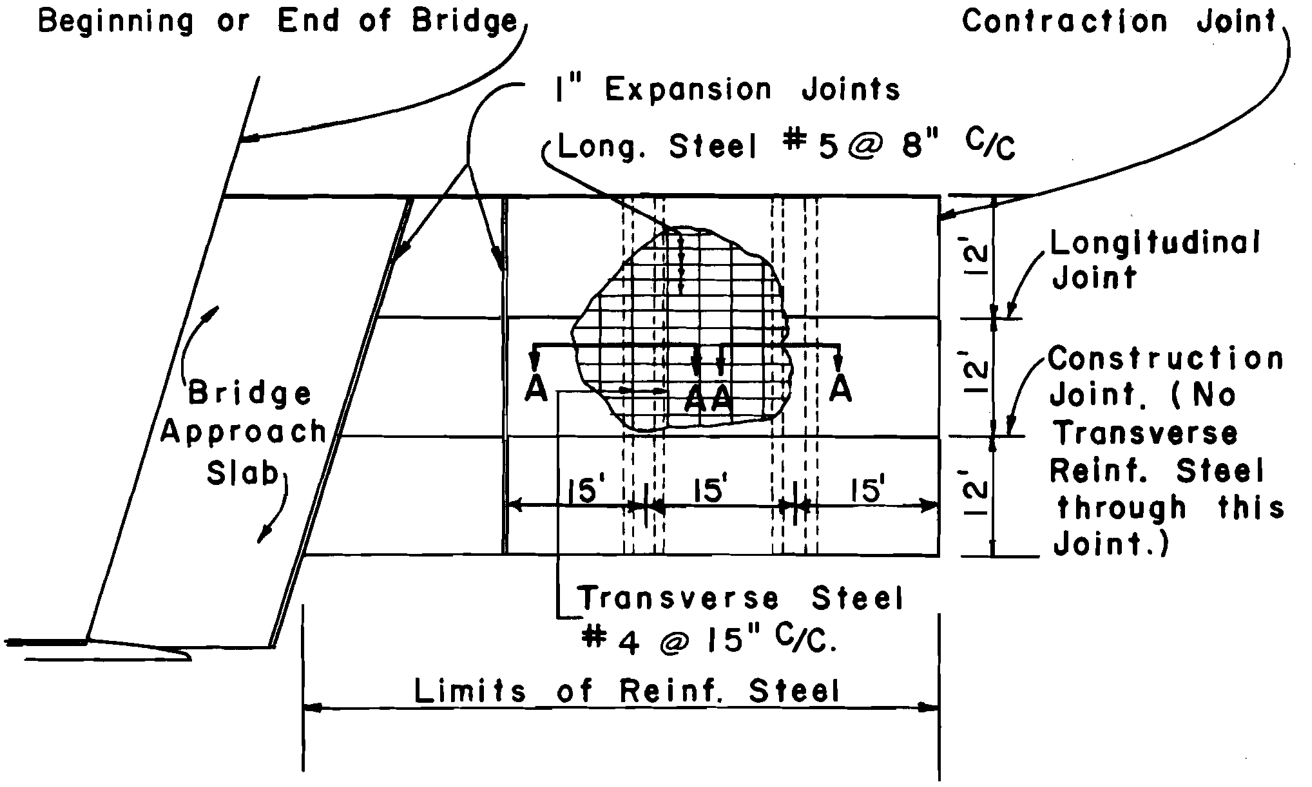
Background

In the late 1950's, numerous jointed concrete pavements (JCP) on the Texas highway system were experiencing an alarming amount of pavement growth, especially along the coastal area. As a result of concrete pavement growth, internal forces are built up in the slab producing 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.

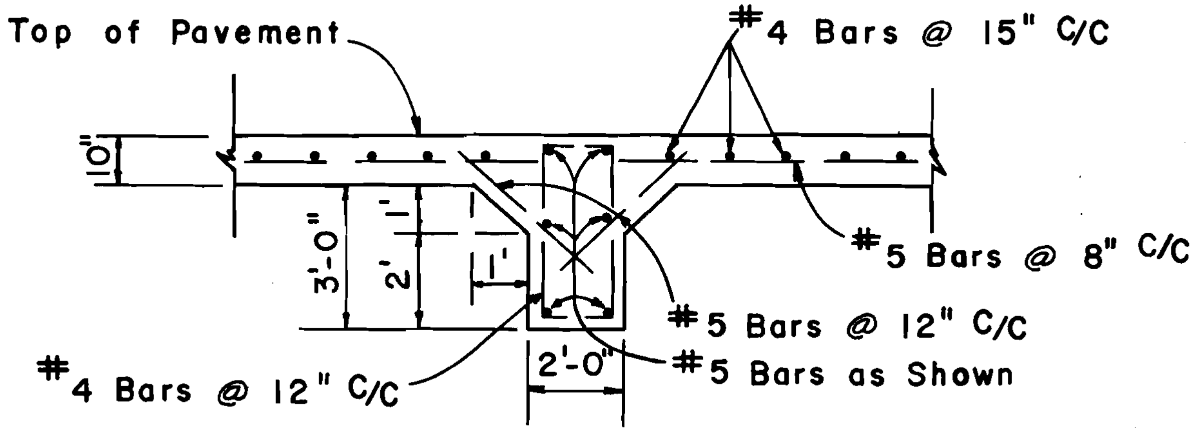
About the same time these anchorage installations were being installed on jointed concrete pavement, the Texas Highway Department initiated the use of continuously reinforced concrete pavement (CRCP) on a widespread scale throughout the state. By logically transposing the experience with the growth problem experienced on jointed concrete pavements to continuous pavements along with that reported in other states, it was felt that continuous pavements would also require an extensive anchorage system.

Design

Messrs. Shelby and Ledbetter in their treatis, on terminal anchorages, enumerated the basic concepts and assumptions employed in designing the terminal anchorage system which was initially used by the Texas Highway Department.[1] Basically, the anchorage system for jointed concrete pavement consists of two anchor lugs, three feet deep and two feet wide at each pavement terminal. Figure 1.1 shows the details of the anchor



PLAN VIEW



SECTION "A - A"

FIGURE 1.1 TYPICAL LUG DESIGN- JOINTED PAVEMENT (1959-1965) slab. As can be seen, 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. In design, 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.

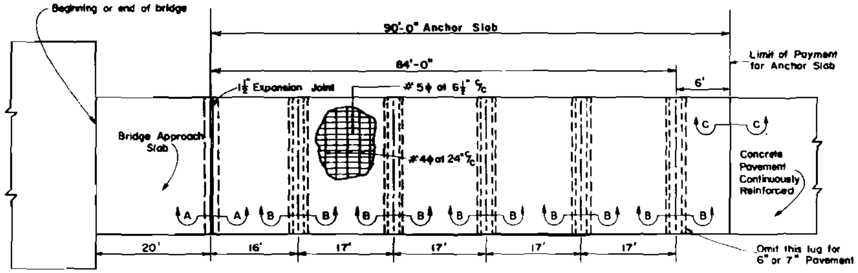
The design for the anchorage system on continuous pavements was basically the same as those for jointed pavements with the exception that five anchor lugs were used which resulted in a longer anchor slab (90 feet). Figure 1.2 shows the details of the anchorage system originally used with CRCP.

Referring again to Figure 1.1, 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, with the one nearest the structure being considered as the front lug.

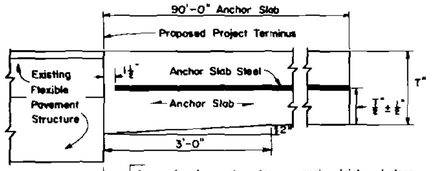
Performance

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 in 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 being experienced. The only adverse comment with CRCP anchorage systems was the excessive cost required to construct them at each pavement terminal. As a result of

FIGURE 1.2 TYPICAL LUG DESIGN - CONTINUOUSLY REINFORCED CONCRETE PAVEMENT (1959-1965)



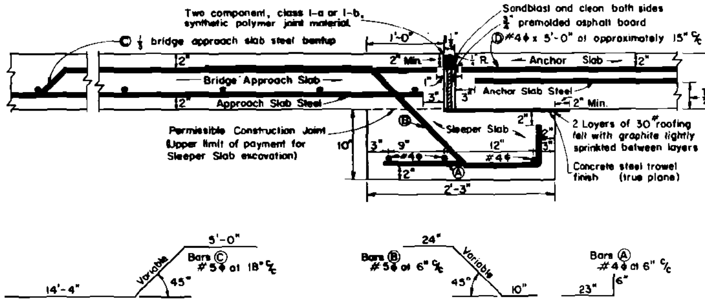
PLAN VIEW



An anchor lug system, less expansion joint and sleeper slab, shall be installed in accordance with these plans for the specified type of proposed pavement. Sixteen ft. from terminus to center of first anchor lug.

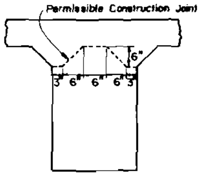
PAVEMENT TERMINUS DETAIL FOR JUNCTURE WITH EXISTING FLEXIBLE TYPE PAVEMENT STRUCTURE

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

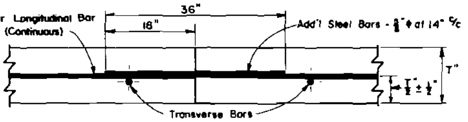


SECTION "A-A"

EXPANSION JOINT AND SLEEPER SLAB DETAIL

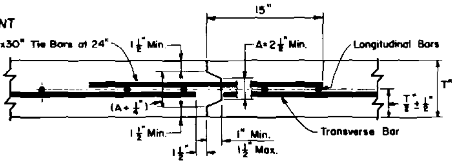


LUG ANCHOR DETAIL SHOWING PERMISSIBLE CONSTRUCTION JOINT



SECTION "C-C"

PERMISSIBLE TRANSVERSE CONSTRUCTION JOINT



LONGITUDINAL CONSTRUCTION JOINT

(Tongue and Groove with Tie Bars)

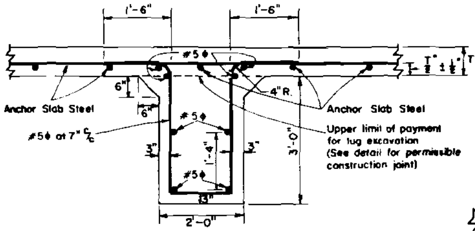
ESTIMATED QUANTITIES FOR ONE 24 FOOT WIDE TERMINAL ANCHORAGE

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

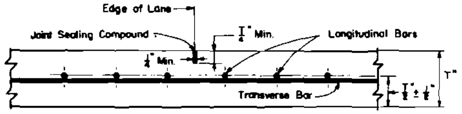
b. Four lug anchors required

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)

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.

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

DN WBL	DRAWING	DATE	FED. RD. DIV. NO.	STATE	FEDERAL PROJECT NO.	SHEET NO.
CK DN MDS	Original	July 1961	6	TEXAS		
DW			STATE DIST. NO.	COUNTY	CONT. SECT. JOB	HIGHWAY NO.
CK DW						
TR						
CK TR						

these two facts, a research project was initiated in March 1963 to evaluate terminal anchorage installations on rigid pavements.

Objectives of Study

The objectives of this study were to determine the cause of anchor distress and perform the field observations necessary to re-evaluate the lug anchorage designs. In addition long term observation and measurements were performed on a number of existing terminal anchorage systems for both jointed and continuous concrete pavements.

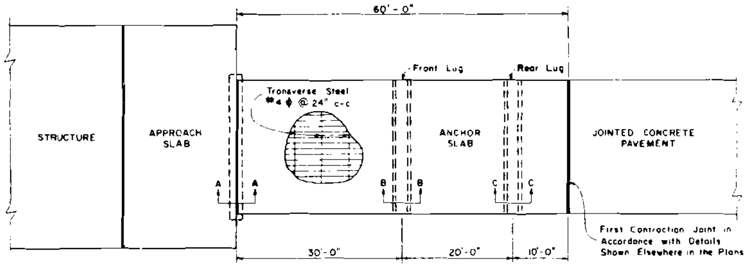
Research Reports

During the course of this research project, four basic reports were prepared. A brief discussion of each is presented in each of the paragraphs below.

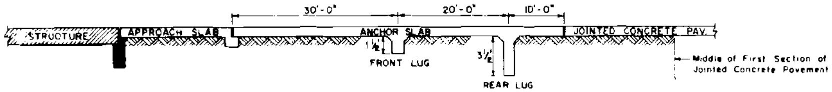
Research Report 39-1 contains the analysis and presentation of data taken in connection with the study of terminal anchorage systems on jointed concrete pavements.[2] In summary, a total of 152 anchorage systems were inspected and data collected concerning each. In addition, an excavation was performed adjacent to three separate units to determine the primary rational of failure. The failures were attributed to an inadequacy in the method of transferring the pavement's growth forces to the soil mass. Strength tests of the soil and visual observations indicated the soil had sheared along a horizontal plane at the lower extremities of the anchor lugs. The pertinent conclusions of Research Report 39-1 are presented herein. The design detail that is now being used by the Texas Highway Department for terminal anchorage systems on jointed concrete pavements is presented in Figure 1.3.

Research Report 39-2 was a preliminary progress report on factors influencing terminal movement on continuously reinforced concrete pavements.[3] To evaluate terminal anchorage systems for CRCP, data was obtained on

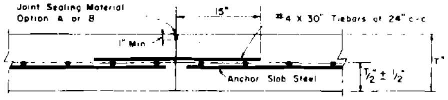
FIGURE 1.3 TYPICAL LUG DESIGN JOINTED PAVEMENT (PRESENT)



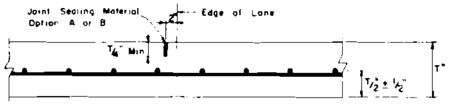
PLAN VIEW



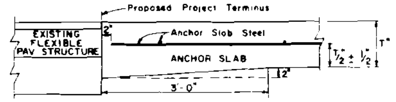
SECTION



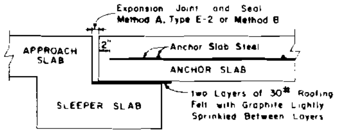
LONGITUDINAL CONSTRUCTION JOINT



GROOVED LONGITUDINAL JOINT



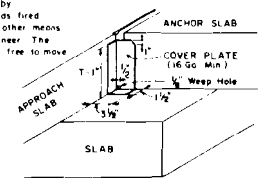
PAVEMENT TERMINUS DETAIL FOR JUNCTURE WITH EXISTING FLEXIBLE TYPE PAVEMENT STRUCTURE



PAVEMENT TERMINUS DETAIL FOR JUNCTURE WITH APPROACH SLAB AND STRUCTURE

SECTION A-A

NOTE The Stainless Steel Cover Plate shall be fastened to the Approach and Slab by means of Bolts or Studs fired into the Slab or by other means approved by the Engineer. The Anchor Slab shall be free to move



STAINLESS STEEL JOINT COVER PLATE

(Required for use with Compression Seal)

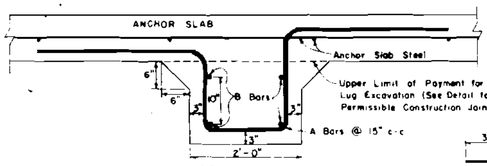
GENERAL NOTES

1. THE DETAILS OF THE BRIDGE APPROACH SLAB ARE SHOWN ELSEWHERE IN THE PLANS.
2. THE LOCATIONS OF THE TERMINAL ANCHORAGE SYSTEMS AND NUMBER OF LUGS PER SYSTEM SHALL BE AS SHOWN ELSEWHERE IN THE PLANS.
3. DETAILS AS TO PAVEMENT SLAB WIDTH, THICKNESS, AND CROWN CROSS-SLOPE SHALL BE AS SHOWN ELSEWHERE IN THE PLANS.
4. THE CONCRETE PAVEMENT SLAB SHALL CONTINUE ACROSS THE ANCHOR LUGS AS SHOWN. ALL REQUIREMENTS AS TO CONSTRUCTION, MEASUREMENT, AND PAYMENT FOR THE PAVEMENT SLABS SHALL BE MADE UNDER THE ITEM "CONCRETE PAVEMENT (CONTINUOUSLY REINFORCED
5. REINFORCING STEEL THAT IS NOT A PART OF THE STANDARD PAVEMENT SLAB REINFORCEMENT SHALL BE OF THE SIZE AND SPACING NOTED HEREON AND SHALL BE PAID FOR UNDER THE ITEM "TERMINAL ANCHORAGE (CONCRETE PAVEMENT)". STRUCTURAL GRADE, INTERMEDIATE GRADE OR ANY GRADE OF REINFORCING STEEL APPROVED UNDER THIS ITEM WILL BE PERMITTED EXCEPT THAT STEEL THAT REQUIRES BENDING SHALL BE STRUCTURAL GRADE OR INTERMEDIATE GRADE BARS.
6. SPLICES IN STRUCTURAL OR INTERMEDIATE GRADE STEEL SHALL BE A MINIMUM OF 20 TIMES THE DIAMETER OF THE BAR. SPLICES IN OTHER GRADES OF STEEL SHALL BE AS NOTED ON THE PAVING DETAIL THAT PERMITS ITS USE.
7. DETAILS OF LONGITUDINAL JOINTS (TRANSVERSE JOINTS IF NECESSARY) AND REQUIRED JOINT SEALS ARE SHOWN ON THE APPROPRIATE PAVING DETAIL SHEET.
8. TRANSVERSE CONSTRUCTION JOINTS WILL NOT BE PERMITTED WITHIN THE LIMITS OF THE ANCHOR LUGS EXCEPT IN AN EMERGENCY STOPPAGE OF THE CONCRETE PLACEMENT AND WITH THE APPROVAL OF THE ENGINEER.
9. THE PERMISSIBLE TRANSVERSE CONSTRUCTION JOINT SHALL BE AS DETAILED ON THE PAVEMENT DETAIL SHEET, BUT MAY BE DELETED IF THE CONTRACTOR ELECTS TO PLACE THE ENTIRE PAVEMENT SLAB IN A SINGLE OPERATION.
10. EXCAVATION FOR, AND CONCRETE USED IN THE ANCHOR LUG SHALL BE PAID FOR UNDER THE ITEM "TERMINAL ANCHORAGE (CONCRETE PAVEMENT)".
11. FOR FURTHER INFORMATION REGARDING THE PLACEMENT OF CONCRETE AND REINFORCING STEEL, REFER TO THE ITEM "TERMINAL ANCHORAGE (CONCRETE PAVEMENT)".
12. DIMENSIONS SHOWN FOR THE SEAT OF THE PREFORMED COMPRESSION SEAL MAY BE MODIFIED TO MORE EFFECTIVELY ACCOMMODATE THE SEAL APPROVED BY THE ENGINEER AND FURNISHED BY THE CONTRACTOR PROVIDED PRIOR APPROVAL IS OBTAINED FROM THE ENGINEER FOR THIS MODIFICATION.
13. IN THE PLANE OF THE STEEL PARALLEL TO THE NEAREST SURFACE OF CONCRETE, BARS SHALL NOT VARY FROM PLAN PLACEMENT BY MORE THAN ONE-TWELFTH OF THE SPACING BETWEEN BARS.

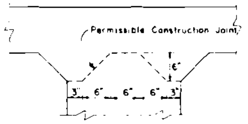
ESTIMATED QUANTITIES FOR ONE
24 FOOT WIDE TERMINAL ANCHORAGE

ITEM	PAVEMENT THICKNESS T(IN.)	CONCRETE (CU. YD.)	STEEL (LBS.)	EXCAVATION (CU. YD.)
FRONT ANCHOR LUG	ALL	2.67		2.67
REAR ANCHOR LUG	ALL	6.22		6.22
ANCHOR SLAB	8	35.6 #		0
	9	40.0 #		0
	10	44.4 #		0

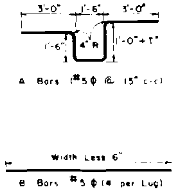
For pavement terminus with existing flexible pavement structure, the concrete quantity should be increased by 0.2 C.Y. to include the thickened end detail.



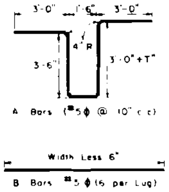
FRONT LUG
SECTION B-B



LUG ANCHOR DETAIL SHOWING PERMISSIBLE CONSTRUCTION JOINT

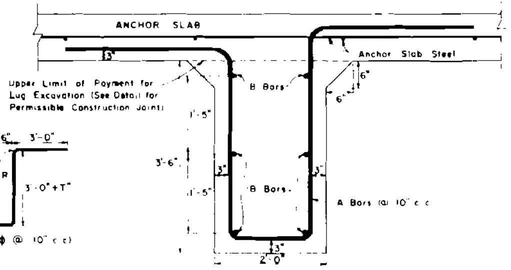


FRONT LUG



REAR LUG

REINFORCING STEEL DETAIL



REAR LUG
SECTION C-C

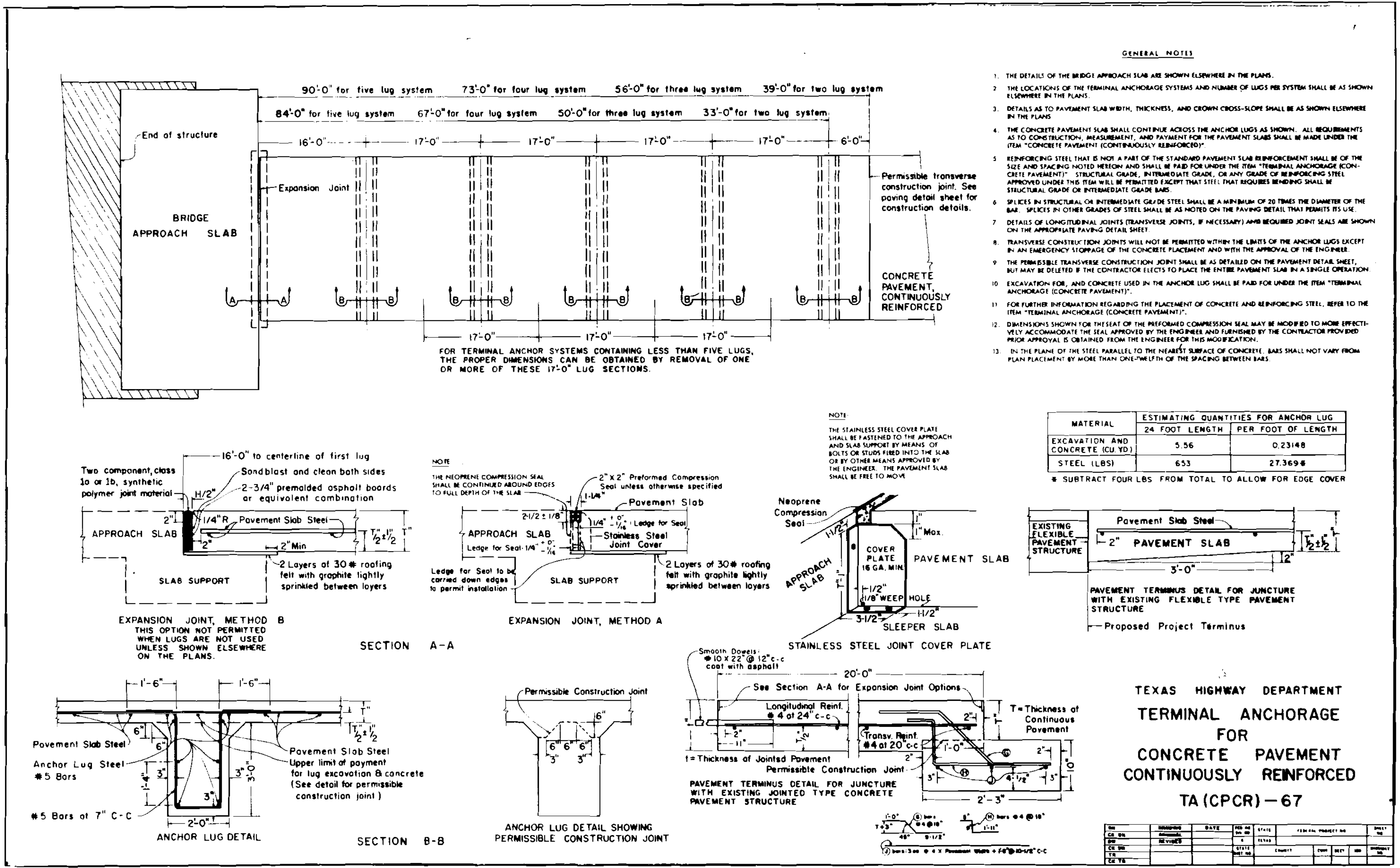
TEXAS HIGHWAY DEPARTMENT
TERMINAL ANCHORAGE
FOR
CONCRETE PAVEMENT
JOINTED
TA(CPJ) - 67

48 terminal anchorage systems for a period of 2 1/2 years and then analyzed to evaluate the influence of each of the parameters considered on terminal movement. This study indicated that pavement length, per cent grade, temperature change, and subbase type had a definite effect upon the number of lugs required to restrain terminal movement. This study was expanded and continued.

Research Report 39-3 pertained to an experimental installation in Central Texas where the terminals of CRCP were connected directly to a continuous slab span bridge.[4] This report and study was made at the request of the Bureau of Public Roads. In connection with this study, it was found that this type of connection is feasible and provides an excellent riding quality that eliminates the expansion joint system generally used in connection with concrete pavements and bridges.

This report (Research Report 39-4F) is the final report on this project. In the conclusions and recommendations the summary of the findings from the above three studies is presented. Furthermore, in this report, an extension of the previous study outlined in Research Report 39-2 is presented. In this study additional anchorage units were used (a total of 186 units) in order to aid in filling in missing elements in the experiment plan used in the previous study, and also to make a study of regional effect. Most of the data presented herein represents a period of approximately 5 years, but in some cases it extends up to 7 years of age and in one case, the pavement age is fifteen years.

FIGURE 1.4 TYPICAL LUG DESIGN- CONTINUOUSLY REINFORCED CONCRETE PAVEMENT (PRESENT)



GENERAL NOTES

1. THE DETAILS OF THE BRIDGE APPROACH SLAB ARE SHOWN ELSEWHERE IN THE PLANS.
2. THE LOCATIONS OF THE TERMINAL ANCHORAGE SYSTEMS AND NUMBER OF LUGS PER SYSTEM SHALL BE AS SHOWN ELSEWHERE IN THE PLANS.
3. DETAILS AS TO PAVEMENT SLAB WIDTH, THICKNESS, AND CROWN CROSS-SLOPE SHALL BE AS SHOWN ELSEWHERE IN THE PLANS
4. THE CONCRETE PAVEMENT SLAB SHALL CONTINUE ACROSS THE ANCHOR LUGS AS SHOWN. ALL REQUIREMENTS AS TO CONSTRUCTION, MEASUREMENT, AND PAYMENT FOR THE PAVEMENT SLABS SHALL BE MADE UNDER THE ITEM "CONCRETE PAVEMENT (CONTINUOUSLY REINFORCED)".
5. REINFORCING STEEL THAT IS NOT A PART OF THE STANDARD PAVEMENT SLAB REINFORCEMENT SHALL BE OF THE SIZE AND SPACING NOTED HEREON AND SHALL BE PAID FOR UNDER THE ITEM "TERMINAL ANCHORAGE (CONCRETE PAVEMENT)" STRUCTURAL GRADE, INTERMEDIATE GRADE, OR ANY GRADE OF REINFORCING STEEL APPROVED UNDER THIS ITEM WILL BE PERMITTED EXCEPT THAT STEEL THAT REQUIRES BENDING SHALL BE STRUCTURAL GRADE OR INTERMEDIATE GRADE BARS.
6. SPLICES IN STRUCTURAL OR INTERMEDIATE GRADE STEEL SHALL BE A MINIMUM OF 20 TIMES THE DIAMETER OF THE BAR. SPLICES IN OTHER GRADES OF STEEL SHALL BE AS NOTED ON THE PAVING DETAIL THAT PERMITS ITS USE.
7. DETAILS OF LONGITUDINAL JOINTS (TRANSVERSE JOINTS, IF NECESSARY) AND REQUIRED JOINT SEALS ARE SHOWN ON THE APPROPRIATE PAVING DETAIL SHEET.
8. TRANSVERSE CONSTRUCTION JOINTS WILL NOT BE PERMITTED WITHIN THE LIMITS OF THE ANCHOR LUGS EXCEPT IN AN EMERGENCY STOPPAGE OF THE CONCRETE PLACEMENT AND WITH THE APPROVAL OF THE ENGINEER.
9. THE PERMISSIBLE TRANSVERSE CONSTRUCTION JOINT SHALL BE AS DETAILED ON THE PAVEMENT DETAIL SHEET, BUT MAY BE DELETED IF THE CONTRACTOR ELECTS TO PLACE THE ENTIRE PAVEMENT SLAB IN A SINGLE OPERATION.
10. EXCAVATION FOR, AND CONCRETE USED IN THE ANCHOR LUG SHALL BE PAID FOR UNDER THE ITEM "TERMINAL ANCHORAGE (CONCRETE PAVEMENT)".
11. FOR FURTHER INFORMATION REGARDING THE PLACEMENT OF CONCRETE AND REINFORCING STEEL, REFER TO THE ITEM "TERMINAL ANCHORAGE (CONCRETE PAVEMENT)".
12. DIMENSIONS SHOWN FOR THE SEAT OF THE PREFORMED COMPRESSION SEAL MAY BE MODIFIED TO MORE EFFECTIVELY ACCOMMODATE THE SEAL APPROVED BY THE ENGINEER AND FURNISHED BY THE CONTRACTOR PROVIDED PRIOR APPROVAL IS OBTAINED FROM THE ENGINEER FOR THIS MODIFICATION.
13. IN THE PLANE OF THE STEEL PARALLEL TO THE NEAREST SURFACE OF CONCRETE, BARS SHALL NOT VARY FROM PLAN PLACEMENT BY MORE THAN ONE-TWELFTH OF THE SPACING BETWEEN BARS.

MATERIAL	ESTIMATING QUANTITIES FOR ANCHOR LUG	
	24 FOOT LENGTH	PER FOOT OF LENGTH
EXCAVATION AND CONCRETE (CU. YD.)	5.56	0.23148
STEEL (LBS)	653	27.369#

\# SUBTRACT FOUR LBS FROM TOTAL TO ALLOW FOR EDGE COVER

NOTE

THE STAINLESS STEEL COVER PLATE SHALL BE FASTENED TO THE APPROACH AND SLAB SUPPORT BY MEANS OF BOLTS OR STUDS FIRED INTO THE SLAB OR BY OTHER MEANS APPROVED BY THE ENGINEER. THE PAVEMENT SLAB SHALL BE FREE TO MOVE

NOTE

THE NEOPRENE COMPRESSION SEAL SHALL BE CONTINUED AROUND EDGES TO FULL DEPTH OF THE SLAB

TEXAS HIGHWAY DEPARTMENT

TERMINAL ANCHORAGE
FOR
CONCRETE PAVEMENT
CONTINUOUSLY REINFORCED
TA (CPCR) — 67

II. EXPERIMENT DESIGN AND DISCUSSION OF DATA

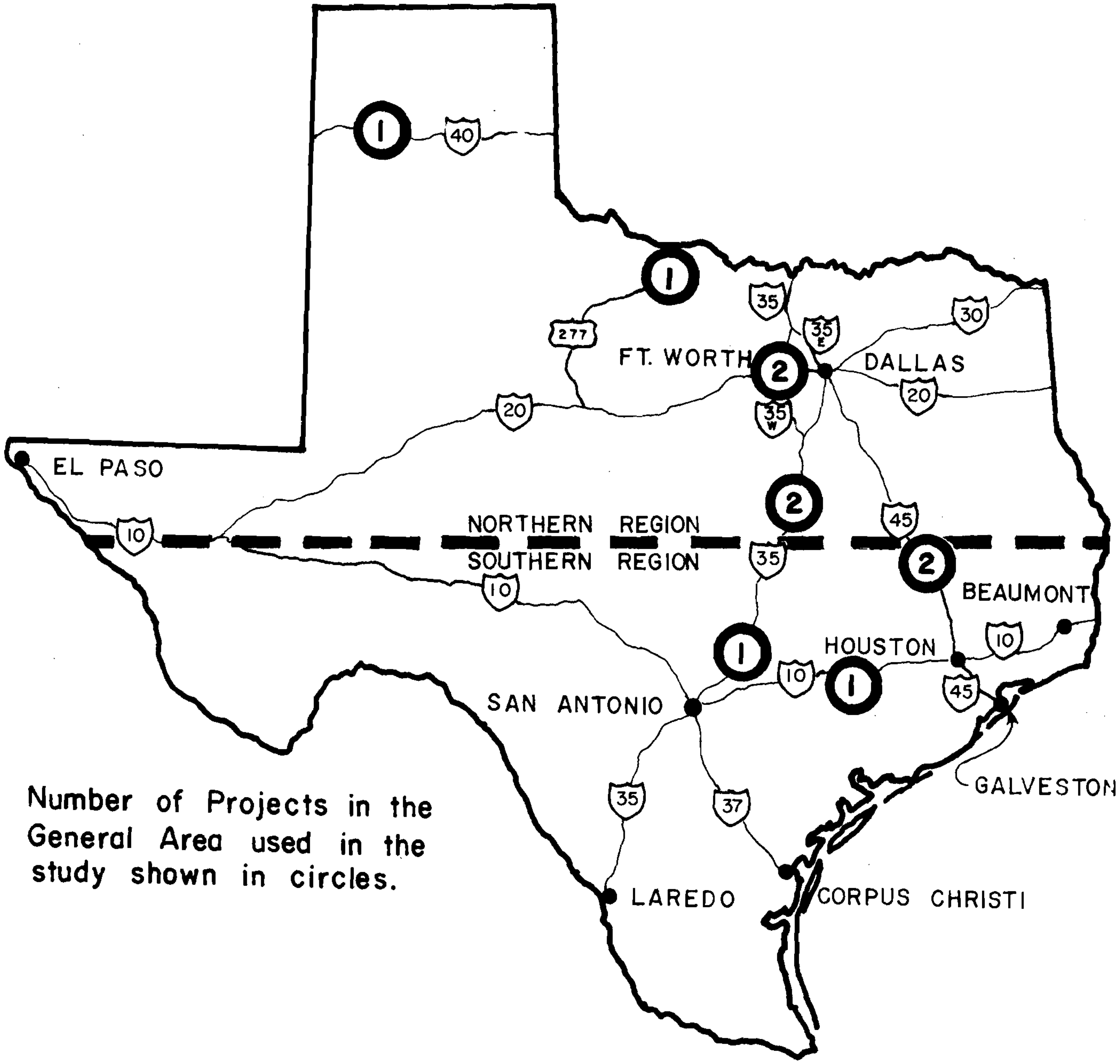
The first phase of this study consisted of a reappraisal of the factorial arrangement of test sections presented in Research Report 39-2. On the basis and the availability of other continuously reinforced concrete pavements over the state, sections were added as necessary to make a full factorial insofar 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. Figure 2.1 is a map showing the division line arbitrarily selected for cutting the state into northern and southern parts. The counties in which field data were obtained are indicated on the map. Locations could not be selected any farther south than shown since no concrete pavements are constructed in that area of the state.

Data were taken as before on all sections for an additional year. This data were then analyzed in the same manner as the procedure outlined in Research Report 39-2.

Layout of Experiment

Tables 2.1 through 2.8 show the factorials of sections for eight different subbase types. For the purpose of this report, four new subbase types were added to acquire a wider range of subbases (see Tables 2.5 through 2.8). Research Report 39-2 covered sections with cement stabilized, asphalt stabilized, surface treated, and crushed sandstone subbases. This study will encompass these same subbases plus crushed river gravel, rounded river gravel, crushed limestone and lime stabilized subbases.

Also sections in North Texas were added to the factorials of three of the original subbase types for the weather environment study (see Tables 2.1 through 2.3). These sections were chosen in a manner so that variables such as number of lugs, slab length, and per cent grade for both north and south sections would be approximately the same.



DIVISION OF THE STATE ON THE BASIS OF WEATHER CONDITIONS

FIGURE 2.1

Table 2.1

FACTORIAL OF LENGTH, PERCENT GRADE, NUMBER OF LUGS FOR PAVEMENTS HAVING ASPHALT STABILIZED SUBBASE

NUMBER LUGS	5												0
SLAB LENGTH % GRADE	650	1150	2000	3050	4100	4500	5000	6440	7700	12150	22900	31440	400
+.13	SS	SS							SS				
−.13	SS	SS										SS SS	
−.30				NN			NN						
+1.00					NN		NN						NN
−1.00			N										NN
+1.20				NN									
+1.46									SS				
−1.46											SS		
+2.00			NN		NN	NN		SS					
+2.70										NN NN			
+3.00						NN							

Note: N-Sections in North Texas S-Sections in South Texas

Table 2.2

FACTORIAL OF LENGTH, PERCENT GRADE, NUMBER OF LUGS FOR PAVEMENTS HAVING CEMENT STABILIZED SUBBASE

NUMBER LUGS	0						3				5						
SLAB LENGTH % GRADE	300	575	665	700	780	1254	1247	1602	1712	1830	1350	2698	2950	3800	7900	10400	29400
+.10								SS									
+.20							SS										
+.40				N	SSSS SSSS	SS		SS	S	S	N	SSSS					SS
−.50															NN		
+.92							SS										
+1.30	N		SS														
−1.30			SS	N													
+1.80																NN	
+2.00						SS								SS			
+2.50													SS	SS		NN	
+3.00		N	N						S	S					NN		
−3.00		N	N														

Note: N−Sections in North Texas S−Sections in South Texas

Table 2.3

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

SLAB LENGTH % GRADE	410	520	620	2200	3500	5050	5200	5400	7550
+.38									N
−.38		N							
+.47	SS		NN						
+1.26					SS				
+1.50				NN					
−1.60									NN
+1.95								SS	
−1.95							SS		
+2.00							SS		
+2.80			NN	NN		NN		SS	
+3.25						NN			
+4.10				NN					

Note: N−Sections in North Texas S−Sections in South Texas

Table 2.4

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

NUMBER LUGS	2	3	4		5	
SLAB LENGTH	2325	2325	11873	45725	11873	45725
% GRADE						
+.15				S		S
−.15	S	S				
+.75				S		S
−.75			S		S	

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

Table 2.5

FACTORIAL OF LENGTH, PERCENT GRADE, NUMBER OF LUGS FOR PAVEMENTS HAVING CRUSHED RIVER GRAVEL SUBBASE

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

Table 2.6

FACTORIAL OF LENGTH, PERCENT GRADE, NUMBER OF LUGS FOR PAVEMENTS HAVING ROUNDED RIVER GRAVEL SUBBASE

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

Table 2.7

FACTORIAL OF LENGTH, PERCENT GRADE, NUMBER OF LUGS FOR PAVEMENTS HAVING CRUSHED LIMESTONE SUBBASE

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

Table 2.8

FACTORIAL OF LENGTH, PERCENT GRADE, NUMBER OF LUGS FOR PAVEMENTS HAVING LIME STABILIZED SUBBASE

NUMBER OF LUGS	0				
SLAB LENGTH	2700	3085	4030	4750	9594
% GRADE					
+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

The sections in South Texas with a one-course surface treatment on the subbase and a crushed sandstone subbase were used to study the age factor (see Tables 2.3 and 2.4). These sections were chosen because data had been taken on them for a period of approximately seven years.

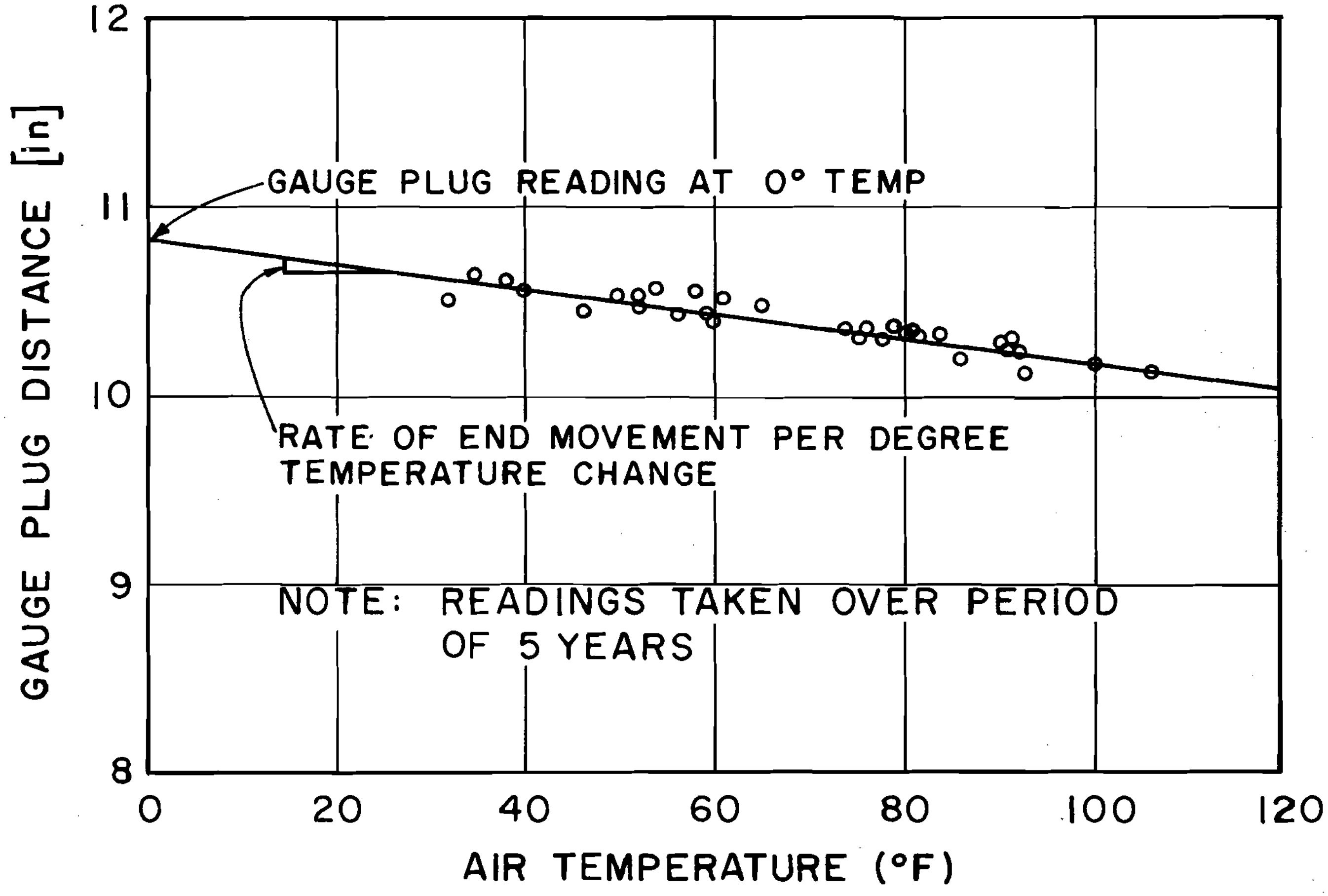
Data Analysis

Data analysis for this report was carried out in the same manner as was used in Research Report 39-2.[3] First, rates of end movement per degree temperature were obtained for each section, and these were used as a comparison basis. 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, per cent 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 creep 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 at zero degrees temperature and any major change in thermal coefficient would affect the rate of end movement per degree temperature change.

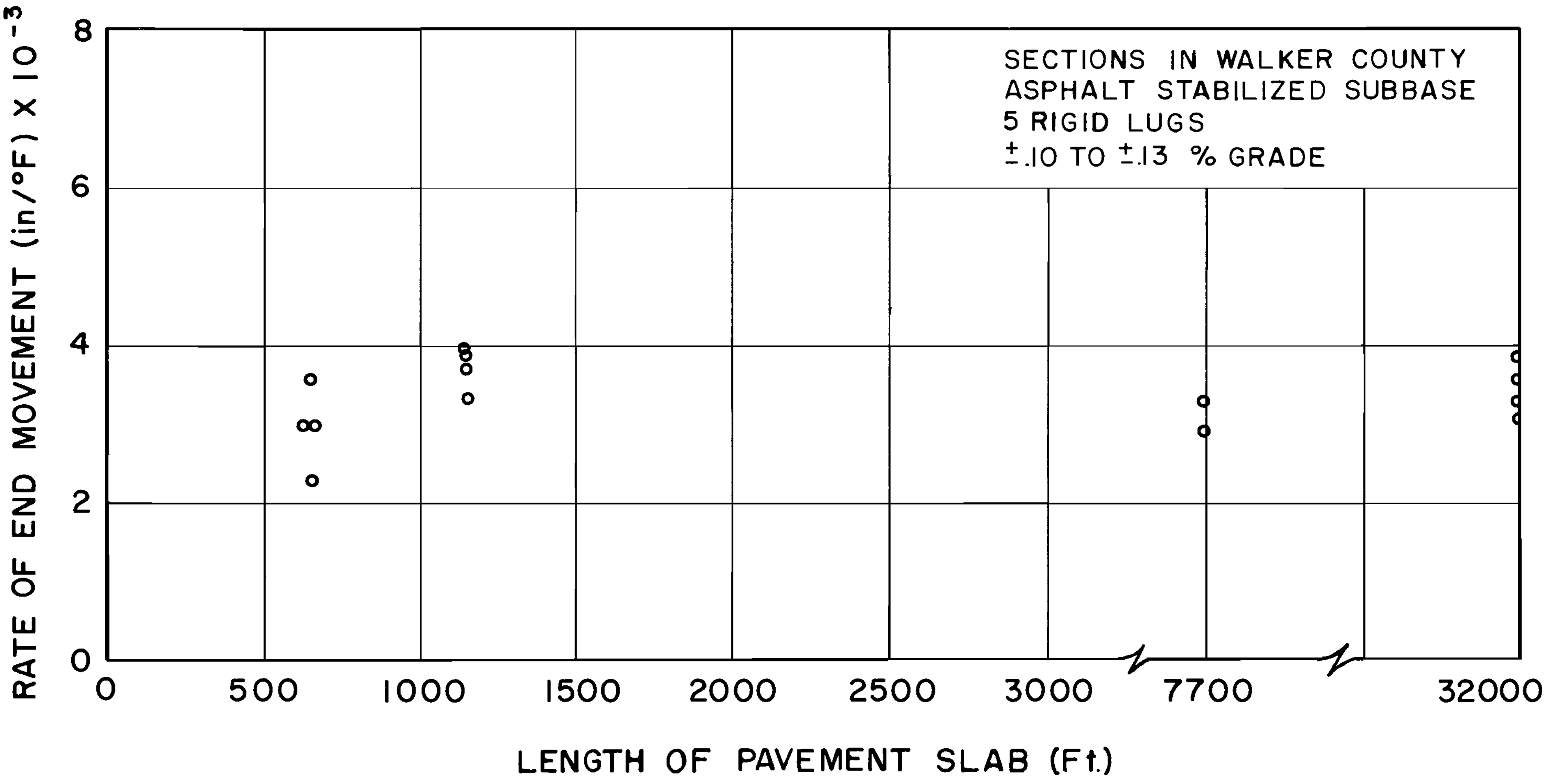
Figure 2.2 shows gage plug reading versus air temperature for a typical section used in the age study. As can be seen all points fall on the same line. Since these points represent data taken for the past seven years, it could be said that pavement age has not affected the rate of end movement or gage plug distance at zero degrees temperature for this section. Similar plots for all other sections of the age study have shown this same relationship.

Effect of Slab Length on End Movement. Earlier research on this project revealed that pavement lengths in excess of 1,000 feet do not influence end movement more than lengths of 1,000 feet. Figure 2.3 shows the rates of end movement for sections from Walker County with all variables as constant as possible plotted



EFFECT OF PAVEMENT AGE ON END MOVEMENT

FIGURE 2.2



EFFECT OF SLAB LENGTH ON END MOVEMENT

FIGURE 2.3

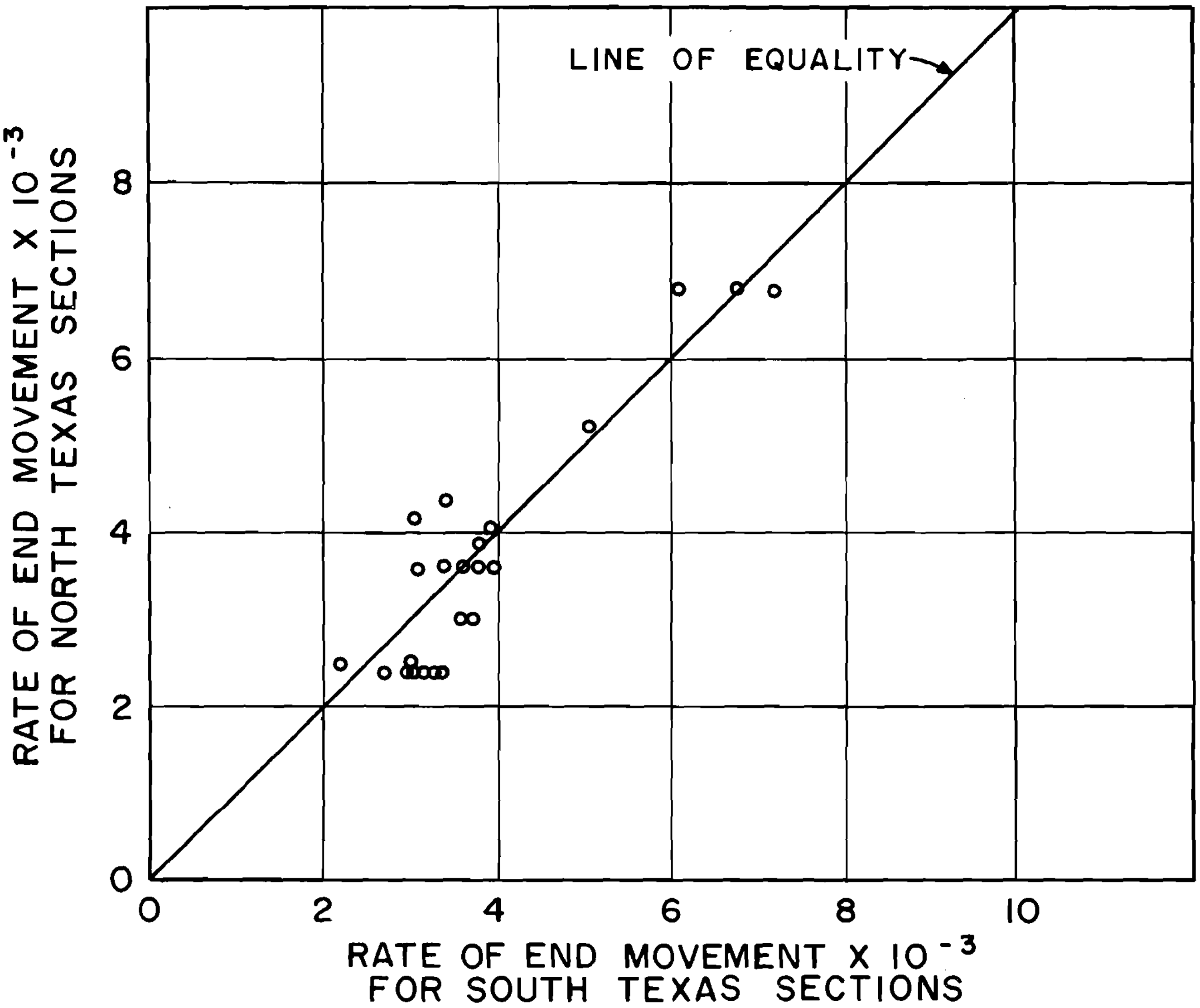
versus the length of slab. This graph bears out the earlier findings that slabs in excess of 1,000 feet do not contribute to end movement more than slabs of 1,000 feet. From this it may be conjugated that approximately a maximum of 500 feet contributes to end movement on each end of the pavement slab. With pavements longer than 1,000 feet the center portion of the slab is restrained by the frictional force from the subbase.

Environmental Location. To study the effect of weather conditions on end movement, temperature has to be excluded so that north and south sections can be compared. Therefore, a logical approach is to look at rates of end movement of north and south sections that have all other factors equal except geography. Rates of end movement for north sections can be plotted versus replicate south sections that have equal parameters such as subbase type, per cent grade, length of slab and number of lugs. Ideally, if there were no difference between north and south sections the points would result in a 45 degree line. Figure 2.4 shows a plot of this type. It should be noted that all sections with a slab length in excess of 1,000 feet are considered equal as far as slab length, on the basis of the preceeding discussion. Also, all per cent grades less than 0.30 per cent were considered equal as it was felt that per cent grades less than this would be inconsequential.

Although the points in Figure 2.4 do not fall exactly on the 45 degree line of equality 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 due to environmental location within the state.

Length and Per Cent Grade. In Research Report 39-2 the following relationship was found to exist between the rate of end movement, slab length and per cent grade, while holding other variables constant.

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



END MOVEMENT IN SOUTH TEXAS VS. END MOVEMENT IN NORTH TEXAS

FIGURE 2.4

Where:

b = Rate of end movement, in/° F.
L = Length of slab contributing to end movement, ft.
$|G|$ = Absolute value of per cent grade
A_4 = Arbitrary constant
A_5 = Constant dependent upon subbase type and number of lugs.

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

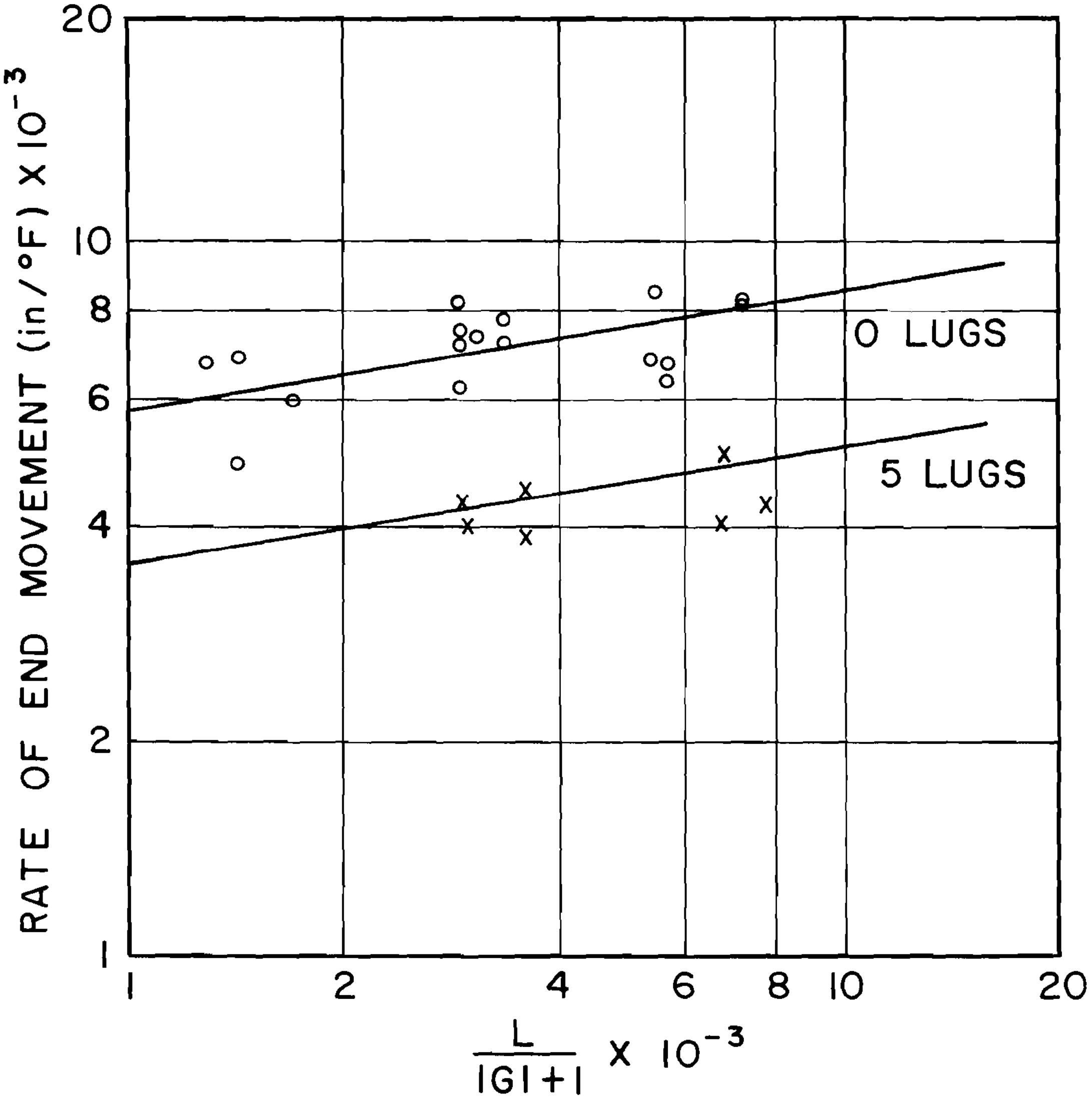
Since the purpose of this report is to verify the equation format developed in Research Report 39-2, Equation (1) will be used as a starting point for analysis. Figures 2.5 through 2.7 show Log (b) plotted versus Log $\left[\frac{L}{|G| + 1}\right]$ for different subbase types and number of lugs. It should be noted that north and south sections were not separated here and that slab lengths in excess of 1,000 feet were set equal to 1,000 feet on the basis of the preceeding discussions.

From these graphs it can be seen that A_5 changes with subbase type and with number of lugs (see Figures 2.5 and 2.7, Zero Lugs), while A_4 is approximately equal for each. Also, Figures 2.5 and 2.6 show that A_5 changes for each number of lugs with the same subbase while A_4 remains constant.

Therefore, it may be stated that A_4 is an arbitrary constant not dependent upon any of the other variables, while A_5 is dependent upon both subbase type and number of lugs. In conclusion we can say this data bears out this part of the original equation format as presented in Equation (1).

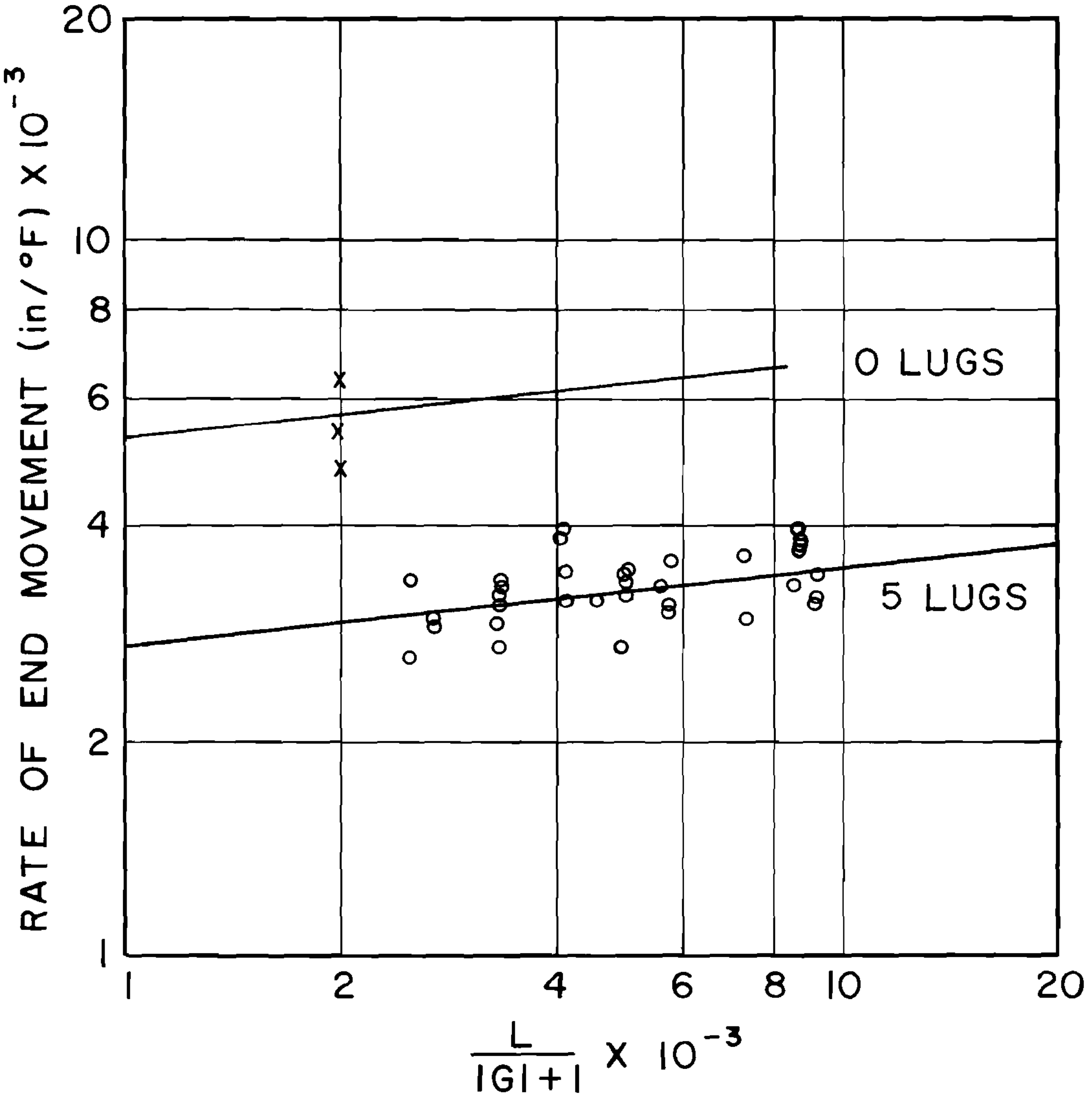
Subbase Coefficient and Number of Lugs. Table 2.9 shows the constant A_5 for each subbase type and number of lug combinations in this experiment. In Research Report 39-2, it was found that the following relationship existed between A_5, subbase coefficient of friction and number of lugs.

$$\text{Log } A_5 = A_1 + A_2 \text{ Log } (K) + A_3 \text{ Log } (N + 1) \quad . \; . \; . \; . \quad (2)$$



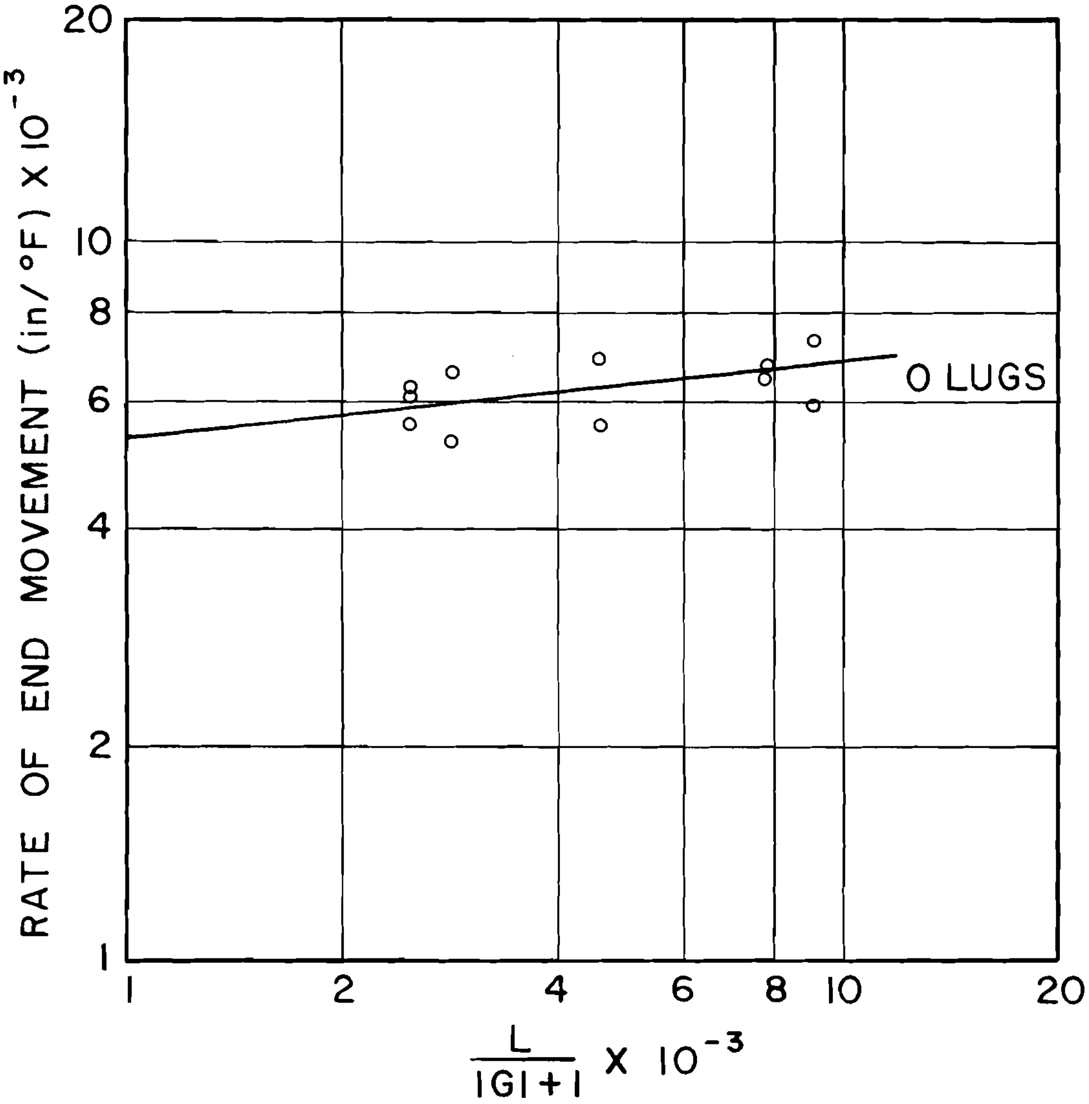
RATE OF END MOVEMENT VS. PAVEMENT LENGTH - PERCENT GRADE TERM FOR CEMENT STABILIZED SUBBASES

FIGURE 2.5



RATE OF END MOVEMENT VS. PAVEMENT LENGTH – PERCENT GRADE TERM FOR ASPHALT STABILIZED SUBBASES

FIGURE 2.6



RATE OF END MOVEMENT VS. PAVEMENT LENGTH - PERCENT GRADE TERM FOR CRUSHED LIMESTONE SUBBASES

FIGURE 2.7

Where:

A_1, A_2, and A_3 are arbitrary constants.
K = Subbase coefficient of friction
N = Number of Rigid lugs

For Research Report 39-2 a literary search was conducted, and a value for each subbase coefficient of 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 cursory 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 subbase may influence the rate of end movement due to different type soil masses acting against the lug surfaces. Therefore, it is felt that the part of A_5 determined by subbase might be more appropriately called subbase coefficient, (K).

Going on this assumption, values of subbase coefficient of friction as such, could not be used for final correlation, and since 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 subbase coefficient so they could be correlated with A_5.

Values of subbase coefficients were obtained by making a linear relationship between (K) for the different subbase types and A_5. This was done by selecting random numbers to represent (K) for the subbase with the lowest rates of movement (surface treated subbase) and the highest rates of 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 (K) for the other subbase types have to fall between 1.35 and 2.65.

To obtain these values Equation (2) was used. This equation contains three unknown constants, therefore, by use of three simultaneous equations of this form, the coefficients A_1, A_2, and A_3 can be determined. These three equations are obtained by use of the A_5 constants from Table 2.9 for sections with surface treated and crushed sandstone subbases and their respective number of lugs. The equations used were as follows:

$$\text{Log }(2.9 \times 10^{-3}) = A_1 + A_2 \text{ Log }(2.65) + A_3 \text{ Log }(0 + 1)$$

$$\text{Log }(9.4 \times 10^{-3}) = A_1 + A_2 \text{ Log }(1.35) + A_3 \text{ Log }(2 + 1)$$

$$\text{Log }(7.0 \times 10^{-3}) = A_1 + A_2 \text{ Log }(1.35) + A_3 \text{ Log }(5 + 1)$$

After solution of these equations for A_1, A_2, and A_3 Equation (2) was used to calculate (K) values for each of the other subbases in Table 2.9 by using their respective number of lugs and A_5. Table 2.10 shows the calculated (K) values for all sections in Table 2.9.

Verification of Equation Format

Substitution of Equation (2) into Equation (1) yields the following relationship:

$$\text{Log } b = A_1 + A_2 \text{ Log }(K) + A_3 \text{ Log }(N+1) + A_4 \text{ Log }\left(\frac{L}{|G| + 1}\right) \quad \ldots\ldots\ldots (3)$$

This equation format is the same as the final equation format derived in Research Report 39-2. Therefore, on the basis of this later data the empirical relationship between end movement and the enumerated parameters is the same.

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

SUBBASE TYPE	NUMBER OF LUGS	$A_5 \times 10^{-3}$
Surface Treatment	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
Round 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

TABLE 2.9

SUBBASE COEFFICIENTS FOR USE IN EMPIRICAL DESIGN EQUATION

SUBBASE TYPE	SUBBASE COEFFICIENT (K)
Surface Treatment	2.65
Lime Stabilization	2.13
Asphalt Stabilization	1.96
Rounded River Gravel	1.95
Crushed River Gravel	1.93
Crushed Limestone	1.93
Cement Stabilization	1.90
Crushed Sandstone	1.35

TABLE 2.10

III. EMPIRICAL DESIGN EQUATION

On the basis of data taken on this project, it has been found that Equation (3) in Chapter II is valid, and furthermore, no factor should be added to compensate for environmental location or pavement age. Therefore, a multiple 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 Equation (3) was determined by multiple regression technique using the values of the parameters of each end system and the values of subbase coefficient determined in Chapter II (see Table 2.10).[5] Results of this regression analysis are as follows:

A_1	A_2	A_3	A_4	R^2	Standard Error
-1.902	0.107	-2.027	-0.312	0.71	0.0008/°F

The resulting empirical design equation is as follows:

$$\Delta X = \frac{0.01253 \left[\frac{L}{|G| + 1}\right]^{0.107} \left[\Delta T\right]}{\left[K\right]^{2.027} \left[\eta + 1\right]^{0.71}} \quad \ldots \text{(4)}$$

Evaluation of Equation

The standard error found in the preceeding paragraph means that Equation (4) would predict an expected end movement for a given temperature change within plus or minus 0.0008 in/°F of what would be measured. 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/°F could be expected from two sections under equal conditions. This replicate error is probably due to randum variation in sampling and the existance of unknown variables.

Although the coefficients found by regression analysis are slightly different from the ones found in Report 39-2 (probably due to much more data encompassing each variable), the standard error here is much better. On this basis 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.

BIBLIOGRAPHY

1. Shelby, M. D. and Ledbetter, W. B., "Experience in Texas with Terminal Anchorage of Concrete Pavement", Highway Research Board Bulletin 332, 1962.

2. McCullough, B. F,, "A Field Survey and Exploratory Excavation of Terminal Anchorage Failures on Jointed Concrete Pavement", Texas Highway Department, Research Report No. 39-1, March 1965.

3. McCullough, B. F. and Sewell, T. F., "Parameters Influencing Terminal Movement on Continuously Reinforced Concrete Pavement", Texas Highway Department, Research Report No. 39-2, August 1964.

4. McCullough, B. F. and Herber, Fred, "A Report on Continuity Between a Continuously Reinforced Concrete Pavement and a Continuous Slab Bridge", Texas Highway Department, Research Report No. 39-3, August 1966.

5. Graybill, Franklin A., "An Introduction to Linear Statistical Models," McGraw-Hill, Volume I, pp. 195-220, 1961.