AD-A171 808 REVIEW OF RIGID PAVEMENT DESIGN FOR CONCRETE FLOOR SLABS ON GRADE(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS GEOTECHNICAL LAB J C POTTER 1/1

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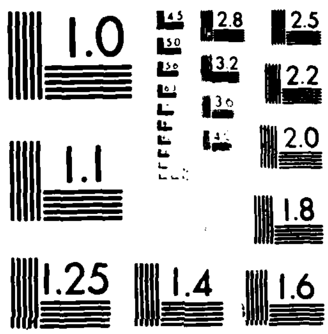

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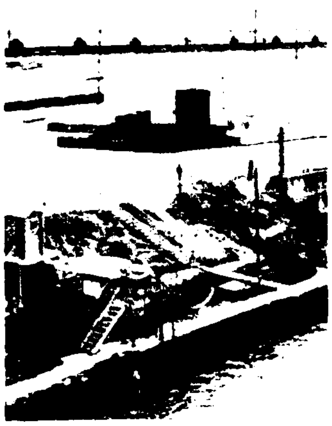

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MISCELLANEOUS PAPER GL-86-23

REVIEW OF RIGID PAVEMENT DESIGN FOR CONCRETE FLOOR SLABS ON GRADE

by

John C. Potter

Geotechnical Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

August 1986

Final Report

Prepared for

DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

GEOTECHNICAL LABORATORY

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

ADA171808

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704 0188
Exp Date Jun 30 1986

1a REPORT SECURITY CLASSIFICATION: Unclassified

1b RESTRICTIVE MARKINGS:

2a SECURITY CLASSIFICATION AUTHORITY:

2b DECLASSIFICATION / DOWNGRADING SCHEDULE:

3 DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.

4 PERFORMING ORGANIZATION REPORT NUMBER(S): Miscellaneous Paper GL-86-23

5 MONITORING ORGANIZATION REPORT NUMBER(S):

6a NAME OF PERFORMING ORGANIZATION: USAEWES Geotechnical Laboratory

6b OFFICE SYMBOL (If applicable): WESGP-EC

7a NAME OF MONITORING ORGANIZATION:

6c ADDRESS (City, State, and ZIP Code): PO Box 631, Vicksburg, MS 39180-0631

7b ADDRESS (City, State, and ZIP Code):

8a NAME OF FUNDING / SPONSORING ORGANIZATION: US Army Corps of Engineers

8b OFFICE SYMBOL (If applicable):

9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

8c ADDRESS (City, State, and ZIP Code): Washington, DC 20314-1000

10 SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO	PROJECT NO	TASK NO	WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification): Review of Rigid Pavement Design for Concrete Floor Slabs on Grade

12 PERSONAL AUTHOR(S): Potter, John C.

13a TYPE OF REPORT: Final report

13b TIME COVERED: FROM 1984 TO 1985

14 DATE OF REPORT (Year, Month, Day): August 1986

15 PAGE COUNT: 20

16 SUPPLEMENTARY NOTATION: Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

17 COSATI CODES

FIELD	GROUP	SUB-GROUP

18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number): Floor slabs; Pavement design; Rigid pavement; Slab on grade

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

This paper documents changes to Technical Manual (TM) 5-809-12, "Concrete Floor Slabs on Grade Subjected to Heavy Loads." Changes to design criteria for thickness determination concerned impact factor, percent standard thickness versus coverage relationship, thickness reduction for high-strength subgrades, and design life. Requirements for use of reinforcing steel and the associated allowable thickness reductions have been revised to provide more flexibility and economy. Joint details and slab sizes used for rigid pavement for airfields, roads, streets, and open storage areas have been adopted as appropriate. The steel-fiber-reinforced concrete pavement design procedure from TM 5-824-3, "Rigid Pavements for Airfields Other Than Army," including the most recent changes to the design factor versus coverage relationship and maximum joint spacing, has been added. These changes establish a rational and consistent basis for the US Army Corps of Engineers' design of rigid pavements.

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS

21 ABSTRACT SECURITY CLASSIFICATION: Unclassified

22a NAME OF RESPONSIBLE INDIVIDUAL:

22b TELEPHONE (Include Area Code):

22c OFFICE SYMBOL:

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

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PREFACE

The investigation reported herein was sponsored by the Office, Chief of Engineers, under the work effort "Review of Rigid Pavement Design for Concrete Floor Slabs on Grade," of the Facilities Investigation and Studies Program.

The study was conducted at the US Army Engineer Waterways Experiment Station (WES) from November 1984 through September 1985 by the Pavement Systems Division (PSD) of the WES Geotechnical Laboratory (GL).

The review was conducted and the report was written by Dr. John C. Potter, PSD. The study was under the supervision of Mr. H. H. Ulery, Jr., Chief, PSD; Mr. Hugh Green, Chief, Engineering Analysis Group; and Mr. D. M. Ladd, Chief, Criteria Development Unit. The work was conducted under the general supervision of Dr. W. F. Marcuson III, Chief, GL.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
inches	2.54	centimetres
kips (force)	4.448222	kilonewtons
miles (US statute)	1.609347	kilometres
pounds (force) per square inch	6.894757	kilopascals
pounds (mass) per cubic inch	27.6799	grams per cubic centimetre

REVIEW OF RIGID PAVEMENT DESIGN FOR CONCRETE FLOOR SLABS ON GRADE

PART I: INTRODUCTION

Background

1. This paper documents changes to the design criteria used in Technical Manual (TM) 5-809-12 (Headquarters, Department of the Army 1977). The April 1977 edition of the TM recommends that concrete floor slabs on grade subjected to heavy loads be designed based on criteria developed in the late 1960's and early 1970's (Rice, Eberhardt, and Varga 1974). Since then, experience with test sections and with in-service pavements has added to the knowledge of pavement mechanics, and the old criteria appear conservative. The old criteria are also inconsistent with current US Army Corps of Engineers (USACE) design criteria for other types of rigid pavements. The treatment of impact, traffic intensity, subgrade strengths, steel reinforcement, and joints for rigid pavements is consistent within the USACE, except for the old floor slab criteria.

Purpose and Scope

2. The purpose of this review was to investigate the potential for reducing floor design thicknesses based on information developed since the early 1970's. Topics given particular attention were (a) impact, (b) coverage versus thickness relationship, (c) effects of high-strength subgrades, (d) maximum modulus of soil reaction, (e) design service life, (f) requirements for reinforcing steel, (g) joint details and slab sizes, and (h) a steel-fiber-reinforced concrete design procedure.

3. These changes reflect current trends being pursued in rigid pavement design and make the USACE design philosophy for rigid pavements consistent.

PART II: CHANGES

Design Criteria for Thickness Determination

4. The design criteria for concrete floor slabs on grade have been modified in the areas of impact, coverage versus thickness relationship, effects of high-strength subgrades, maximum allowable modulus of soil reaction, and design service life.

5. Tests have shown that test vehicles on pavements experience impact effects. However, the pavements themselves do not. The axle loads of a moving truck cause smaller stresses in rigid pavement slabs than those of a stopped truck. In a Maryland road test (Highway Research Board 1952), stresses were measured at pavement edges and transverse joints for speeds up to 40 mph. Stresses at the outside edges decreased 30 percent when truck speeds were raised from a creep to 40 mph. Stresses at transverse joint edges decreased by 15 percent at 40 mph compared with those at rest. Stresses were decreased even more when 3/4-in. boards were placed on the pavement to simulate joint faulting. Similar results were reported from the American Association of State Highway Officials (AASHO) road test (Highway Research Board 1962). This agrees with USACE experience and with the current philosophy for the design of airfield pavements, roads, streets, and open storage areas. Therefore, the use of an impact factor is not justified.

6. Previously, the standard thickness (for 5,000 coverages) was calculated using a combined design factor of 1.55. This included a 25 percent increase in the static load for impact and a 30 percent increase for load repetition. Eliminating the impact factor reduces the combined design factor to 1.3, giving a thickness reduction of about 11 percent.

7. The percent standard thickness versus coverage relationship has been eliminated, and a design factor versus coverage relationship has been established. This allows the actual, rather than the standard, design thickness to be calculated from the thickness equation by replacing the old standard thickness design factor of 1.3 with the design factor determined from the new design factor versus coverage relationship. Using the new design factor versus

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

coverage relationship for airfield pavements (revised under the USACE Facilities Investigation and Studies Program work effort "Review of Rigid Pavement Design Criteria") incorporates data not included in the development of the percent thickness versus coverage relationship and preserves the consistency between the airfield and nonairfield rigid pavement design criteria.

8. The change in thickness of concrete floor slabs on grade resulting from this modification depends upon the design traffic-coverage level. For low-coverage levels, the design thickness is not changed. For high-coverage levels, the thickness is increased by as much as 19 percent.

9. Current airfield pavement design includes a thickness reduction for high-strength subgrades. This reduction is based on USACE experience, and its validity is illustrated by the performance of concrete block pavements on high-strength subgrades. This same reduction (Hutchinson 1966) has been applied for concrete floor slabs on grades. The amount of thickness reduction depends upon the value of the modulus of soil reaction k. For k values above 100 pci, the reduction in design thickness varies from 0 percent (at $k = 200$ pci) up to a maximum of 19.2 percent (at $k = 500$ pci).

10. The maximum allowable k value has been changed from 300 to 500 pci to take full advantage of thickness reductions for high-strength subgrades. This change is appropriate since improvements in compaction equipment and construction procedures have provided a means of reliably achieving k values larger than 300 pci.

11. The traffic-coverage level is based on a design life of 25 years rather than 50 years. This makes the floor slab service life consistent with that of roads, streets, walks, and open storage areas. This 50 percent reduction in trafffic over the design service life will result in a thickness reduction in the range of 5 percent.

12. The cumulative decrease in design thickness depends upon the coverage level and subgrade strength and varies from 0 percent (where the minimum design thickness must still be used) up to a maximum of 40 percent (for moderate forklift loads on weak subgrades).

13. The design curves in Figures 1 and 2 of TM 5-809-12 (Headquarters, Department of the Army 1977) are hereby revised by substituting those shown in Figures 1 and 2. An explanation of each figure is as follows:

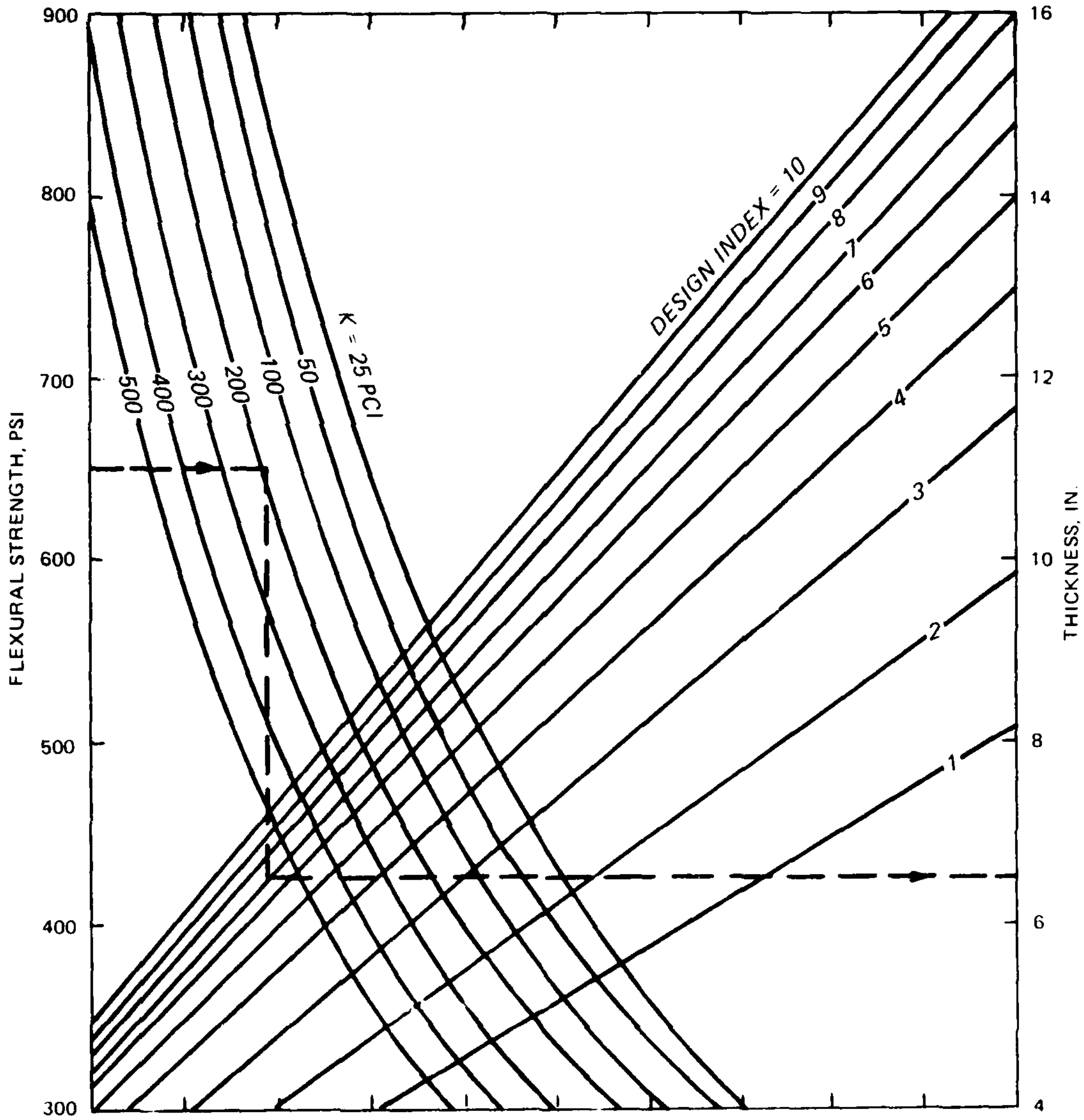


Figure 1. Design curves for concrete floor slabs by design index

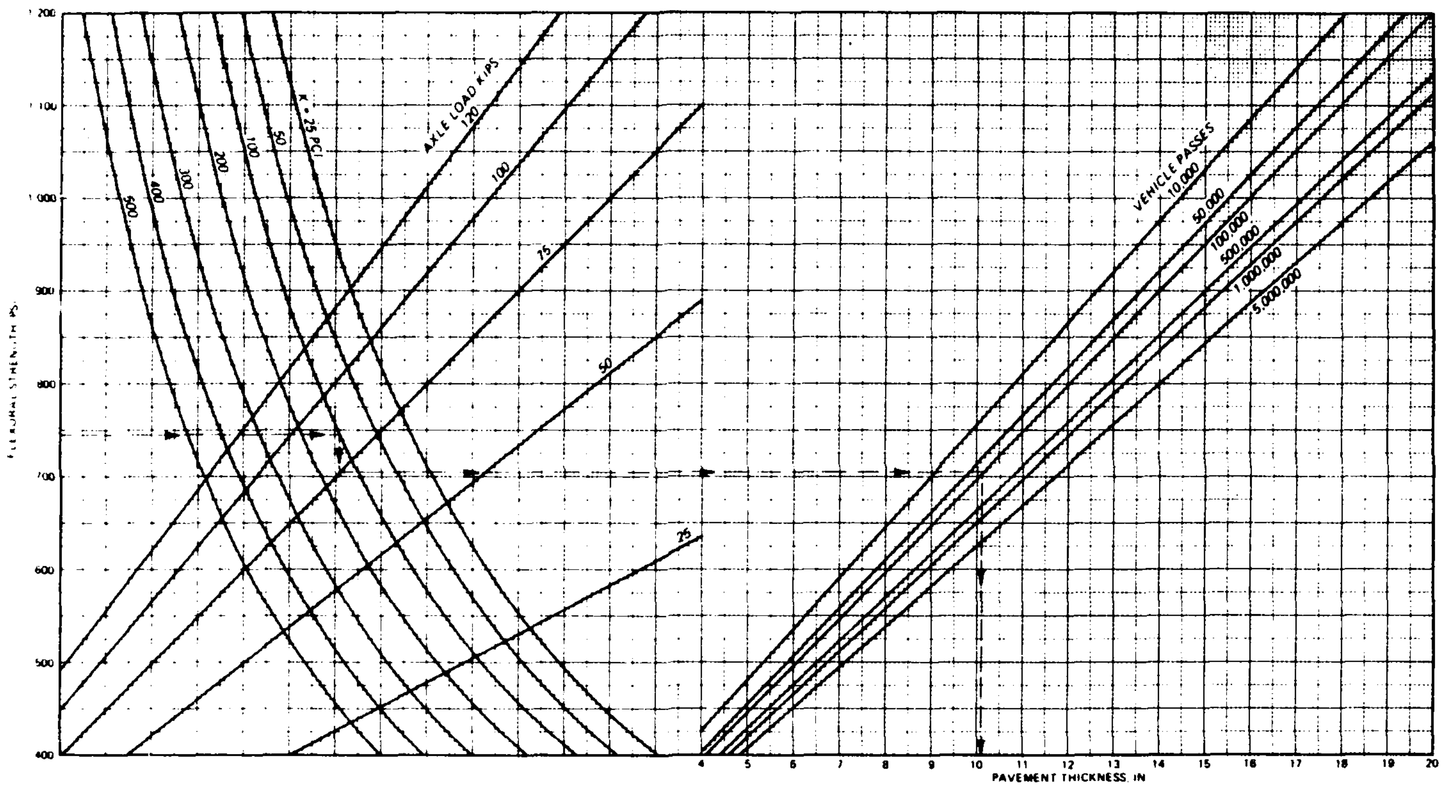


Figure 2. Design curves for concrete floor slabs for heavy forklifts

a. Figure 1 is the design chart for vehicular parking areas. The design indexes shown are for rigid pavement roads and streets as defined in TM 5-822-2 (Headquarters, Department of the Army, in preparation). The original floor slab design indexes 1 to 4, developed from four typical small forklift traffic mixes, are now represented by design indexes 4, 5, 7, and 8, respectively.

b. Figure 2 is the design chart for large forklifts having axle loads between 25 and 120 kips. For pavements designed to carry these large loads, vehicles having axle loads less than 25 kips (trucks, cars, buses, and small forklifts) do not significantly affect the required slab thickness. They are therefore ignored for the purpose of thickness determination.

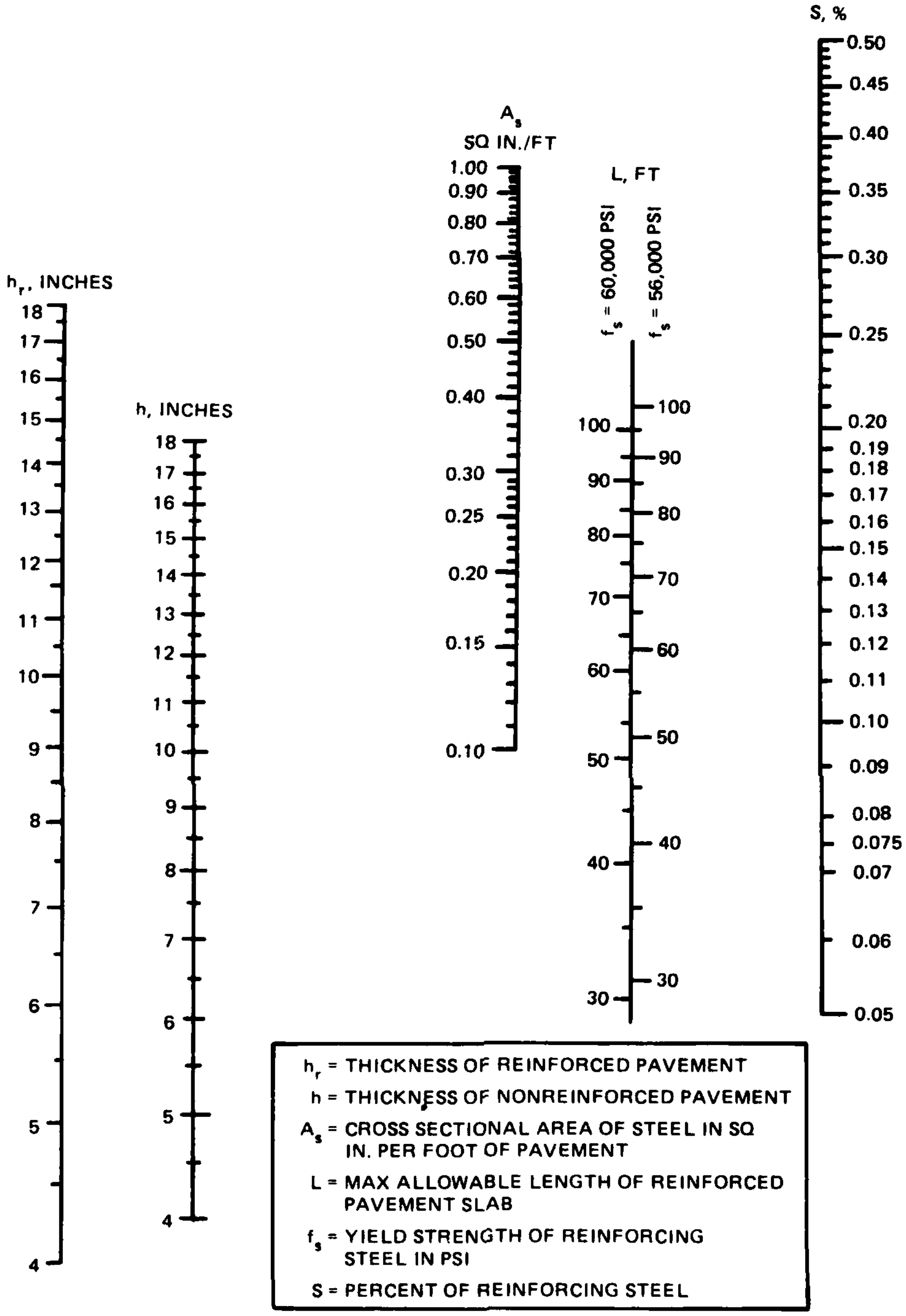
Requirements for Use of Reinforcing Steel

14. The requirements for the use of reinforcing steel and the associated allowable thickness reductions have been revised. These changes provide for more flexibility and economy in the design and construction of floor slabs, resulting in a consistent reinforced concrete pavement design philosophy for USACE rigid pavements.

15. Unreinforced slabs (containing no steel) are now allowed provided that a relatively short joint spacing is acceptable. The old requirement for a minimum of 0.1 percent reinforcing steel in all slabs (with no thickness reduction for reinforcing steel) has been eliminated.

16. For reinforced slabs, thickness reductions for reinforcing steel are now allowed for as little as 0.05 percent steel. The same maximum of 0.5 percent reinforcing steel for thickness reduction is retained. This change is implemented by incorporating the nomograph of the March 1984 draft of TM 5-822-6, (Headquarters, Department of the Army, in preparation). This nomograph is shown in Figure 3.

17. The procedure for adding reinforcing steel to compensate for nonuniform subgrade support is overly conservative, restricts design options, and has been eliminated. Allowing selection of varying slab thicknesses and/or percentages of reinforcing steel throughout the job gives the engineer increased flexibility and allows bid options for more competitive procurement.



NOTE: MINIMUM THICKNESS OF REINFORCED RIGID PAVEMENT WILL BE 6 IN.

Figure 3. Design thickness for reinforced floor slabs (from TM 5-822-6)

Joint Details and Slab Sizes

18. The joint details and slab sizes used for rigid pavements for airfields, roads, streets, and open storage areas have been adopted, as appropriate, for concrete floor slabs. Specifically, the paragraphs, tables, and figures for joint design from the March 1984 draft of TM 5-822-6 (Headquarters, Department of the Army, in preparation) have been incorporated in the new draft of TM 5-809-12 (Headquarters, Department of the Army 1977). This draws on successful USACE experience with these pavements and enhances the consistency of USACE design criteria.

Steel-Fiber-Reinforced Concrete Design Procedure

19. The steel-fiber-reinforced concrete pavement design procedures from TM 5-824-3 (Headquarters, Department of the Army 1979) have been added, providing even more options to the design engineer. These procedures include the most recent changes to the design factor versus coverage relationship and maximum joint spacing recommended in the draft technical report "Field Performance of Fiber-Reinforced Concrete Airfield Pavements" (Rollings, in preparation).

20. The thickness design curves for use with steel-fiber-reinforced concrete slabs are shown in Figures 4 and 5. Deflections are determined from Figure 6 and checked against Figure 7. Note that axle loads less than 25 kips do not produce deflections in excess of those allowed by Figure 6, and therefore do not require a deflection check.

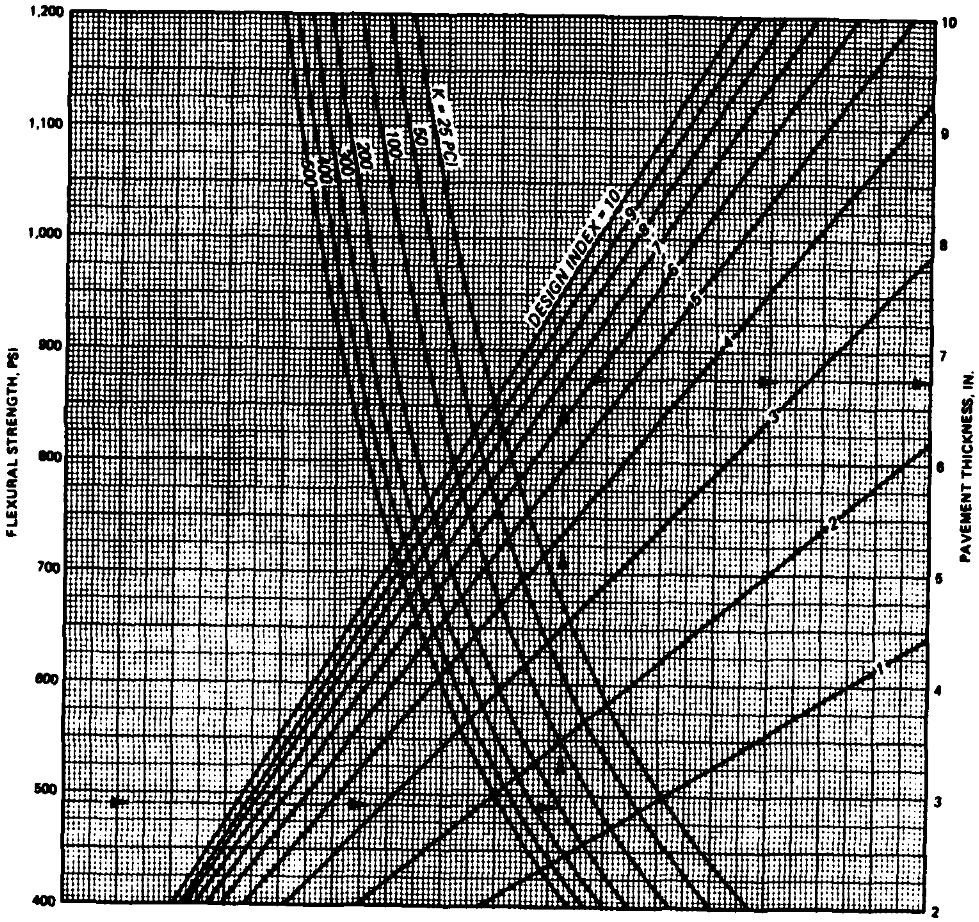


Figure 4. Design curves for steel-fiber-reinforced concrete floor slabs by design index

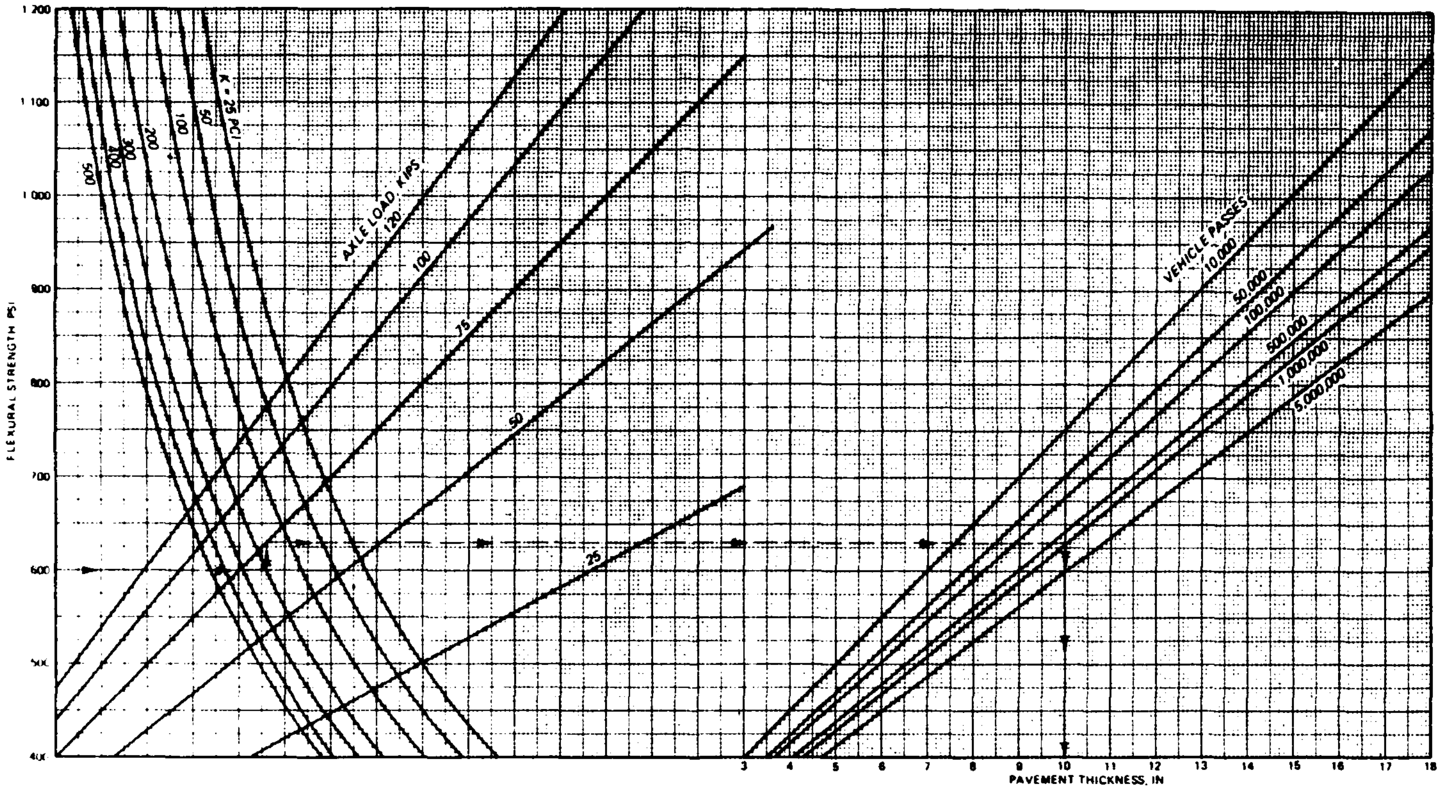


Figure 5. Design curves for steel-fiber-reinforced concrete floor slabs for heavy forklifts

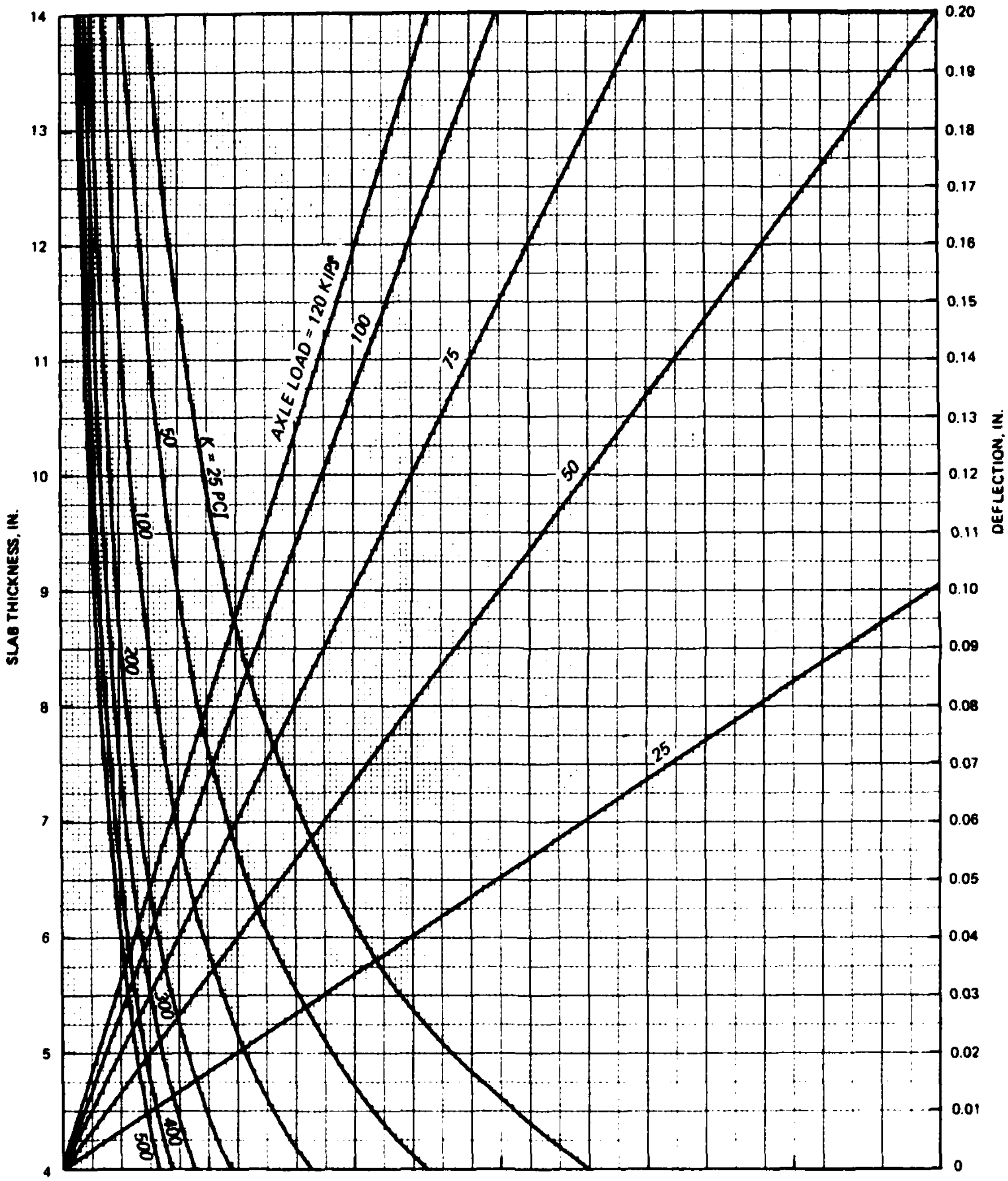


Figure 6. Deflection curves for steel-fiber-reinforced concrete floor slab

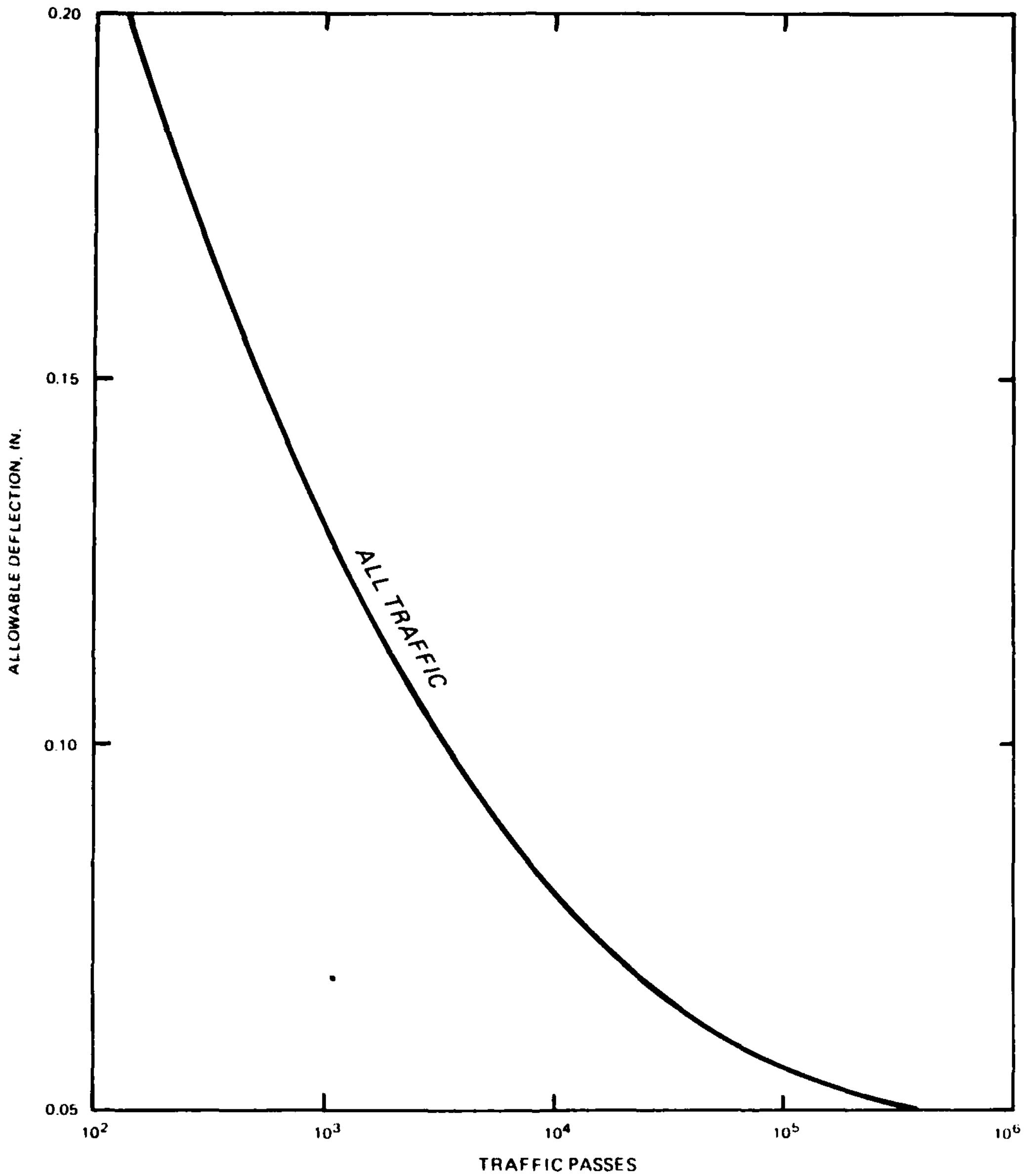


Figure 7. Allowable deflection for jointed steel-fiber-reinforced concrete floor slabs

PART III: SUMMARY

21. These changes to the design criteria include modifications to eliminate the impact factor, use a design factor based on new and reevaluated test section data, provide for thickness reductions for high-strength subgrades, and assume a 25-year design service life. The requirements for the use of reinforcing steel and the associated allowable thickness reductions have been revised to provide more flexibility and economy. Joint details and slab sizes used for rigid pavements for airfields, roads, streets, and open storage areas have been adopted, as appropriate. The steel-fiber-reinforced concrete pavement design procedure from TM 5-824-3 (Headquarters, Department of the Army 1979), including the most recent changes to the design factor versus coverage relationship and maximum joint spacing, has been added.

22. The actual cumulative reduction in design thickness is limited by the range in reasonable values of material properties and by the minimum allowable thicknesses for concrete floor slabs, as specified in TM 5-809-12 (Headquarters, Department of the Army 1977). However, for moderate forklift loads on weak subgrades, the thickness reduction may be as great as 40 percent.

23. These changes establish a consistent basis for USACE design of all rigid pavements and reflect the current doctrine and state of the art.

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