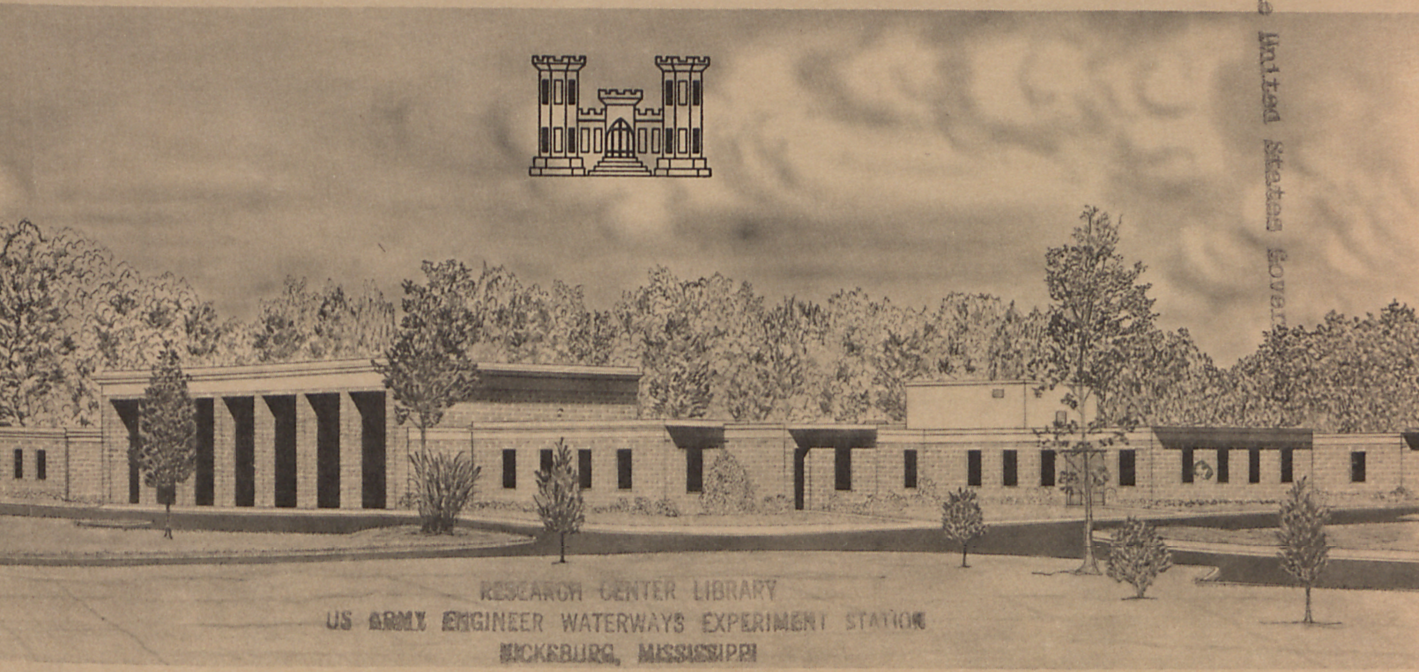
MISCELLANEOUS PAPER S-71-5

AIRFIELD PAVEMENT REQUIREMENTS FOR MULTIPLE-WHEEL HEAVY GEAR LOADS

by

D. N. Brown, J. L. Rice



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Sponsored by Federal Aviation Administration

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PREFACE

Recommended changes to Federal Aviation Administration (FAA) Advisory Circular No. 150/5320-6A, Airport Paving, relative to design and evaluation of airport pavements subject to traffic resulting from operation of the Boeing 747 and/or Lockheed C-5A aircraft, have been prepared in partial fulfillment of FAA Engineering Requirement ER-450-034a, Pavement Investigation for Multiple-Wheel Heavy Gear Loads, and are presented in this report. These criteria were prepared in accordance with procedures developed as a result of a joint engineering investigation, Multiple-Wheel Heavy Gear Load Tests, sponsored by the FAA, U. S. Air Force, and U. S. Army.

The investigation reported herein was conducted from January 1968 to February 1970. Overall supervision of the investigation and all details pertaining to the flexible pavement portion of the testing was provided by the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. The rigid pavement testing was directed by the U. S. Army Construction Engineering Research Laboratory (CERL), Champaign, Ill.

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LIST OF ABBREVIATIONS AND SYMBOLS

A	Measured contact area of one tire, sq in.
AC	Asphaltic concrete
CBR	California Bearing Ratio
E	Concrete modulus of elasticity
ESWL	Equivalent single-wheel load determined as shown in Reference 2
F	Factor that varies with subgrade strength
h	Rigid pavement thickness, inches
h_e	Thickness of existing rigid pavement
k	Subgrade modulus, pci
kip	1000 pounds
lb	Pounds
MWHGL	Multiple-wheel heavy gear load
p_e	ESWL or SWL tire pressure, psi
PCC	Portland cement concrete
pci	Per cubic inch
psi	Per square inch
R	Concrete flexural strength, psi
sq in.	Square inches
SWL	Single-wheel load
t	Total thickness of superior material required above a layer of soil of known strength to prevent shear deformation within this layer of soil, inches
t_b	Required thickness of bituminous overlay
t_f	Required thickness of flexible overlay
t_s	Required thickness of surface course
U	Poisson's ratio of concrete
α_i	Load repetition factor

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
square inches	6.4516	square centimeters
pounds	0.45359237	kilograms
pounds per cubic inch	0.144166	grams per cubic centimeter
pounds per square inch	0.070307	kilograms per square centimeter
miles per hour	1.609344	kilometers per hour

INTRODUCTION

Any community that aspires to greatness must of necessity provide adequate ground facilities for operation of tomorrow's aircraft. The problems related to provision of these facilities are varied and complex. Design and construction of these facilities tend to become more difficult and expensive each year as airline operators continue to seek larger and faster aircraft in an economic battle for survival to provide improved air service to the public. Maintenance of adequate facilities for today's aircraft is difficult enough; however, operators of public airports have the additional problem of more-or-less continuous planning, designing, and rebuilding their facilities in order to provide adequate facilities for new larger, faster aircraft of the future. At the present time, these operators are faced with the immediate problem of providing ground facilities capable of handling the Boeing 747 aircraft, one of the new jumbo jet aircraft of tomorrow that has arrived today. In addition, they must be prepared in the near future to provide facilities for other aircraft of tomorrow, such as the L-500, 2707 (SST), L-1011, and DC-10. It is important to maintain facilities operational at all times and, furthermore, every effort should be made to increase their capacities. To this end, the Federal Aviation Administration (FAA), in concert with the U. S. Army and the U. S. Air Force, has been actively engaged since 1968 in a cooperative investigation (Reference 1) conducted at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi. The purpose was to validate and/or revise as necessary current structural criteria for airfield pavementsto ensure the applicability of these criteria to the design and evaluation of pavements subject to traffic of very heavy aircraft equipped with large multiple-wheel landing gears. This investigation, commonly referred to as multiple-wheel heavy gear load (MWHGL) pavement test (Reference 1), has been completed and a report prepared.

PURPOSE AND SCOPE

This report provides airfield pavement thickness design and evaluation criteria for the Boeing 747 and Lockheed C-5A prepared in accordance with procedures developed in the MWHGL pavement tests report (Reference 1) and other related data relative to the behavior of pavements. Presentation of detailed information from the MWHGL pavement tests is beyond the scope of this report. These details are well covered in Reference 1.

MWHGL PAVEMENT TESTS

With the advent of the jumbo jet aircraft, as represented by the B 747 and C-5A, engineers are faced with providing airfield pavements capable of sustaining traffic of aircraft weighing in excess of three-quarters of a million pounds with a growth potential of 15 to 25 percent. In addition, these aircraft are equipped with extremely large multiple-wheel landing gears. For flexible pavements, this puts added emphasis on the effects of wheel interaction and large deflection basins resulting from these landing gears. For rigid pavements, the distribution of wheels over an area almost as large as a single pavement slab raises doubts as to the adequacy of assumptions of interior (as currently used by FAA), corner, and edge loading on slabs assumed to extend to infinity. Also, it poses questions relative to conventional assumptions of degree of load transfer across joints. In order to obtain information relative to these problems, test sections, surfaced both with flexible and with rigid pavement, were constructed and subjected to full-scale prototype traffic applied with components of the B 747 (Figure 1) and the C-5A (Figure 2) landing gears using the pertinent tire contact area for each. A summary of this investigation is given in the following paragraphs.

PLANNING AND DESIGN

Work was initiated in February 1968. All planning and designing was based on three primary considerations, which were:

(A) Test sections with sufficient surface area to provide adequate room for maneuvering the primary load test cart (Figure 3) on the test section.

(B) Evaluate the behavior of conventional flexible and rigid airfield pavements constructed on a relatively weak subgrade (CBR = 4, k = 100 pci, or F = 9*) and subjected to MWHGL aircraft traffic.

(C) Evaluate the behavior of weak subgrades at relatively deep depths beneath conventional airfield pavements subjected to MWHGL aircraft traffic.

On the basis of these considerations, test sections for both flexible and rigid pavements were designed. Plan and section for the design selected are shown in Figure 5. Additional details relative to the rigid pavement test section are shown in Figure 6. A plan for installation of various instruments to be used in obtaining information relative to the behavior

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* See Figure 4 for CBR-FAA subgrade class comparison.

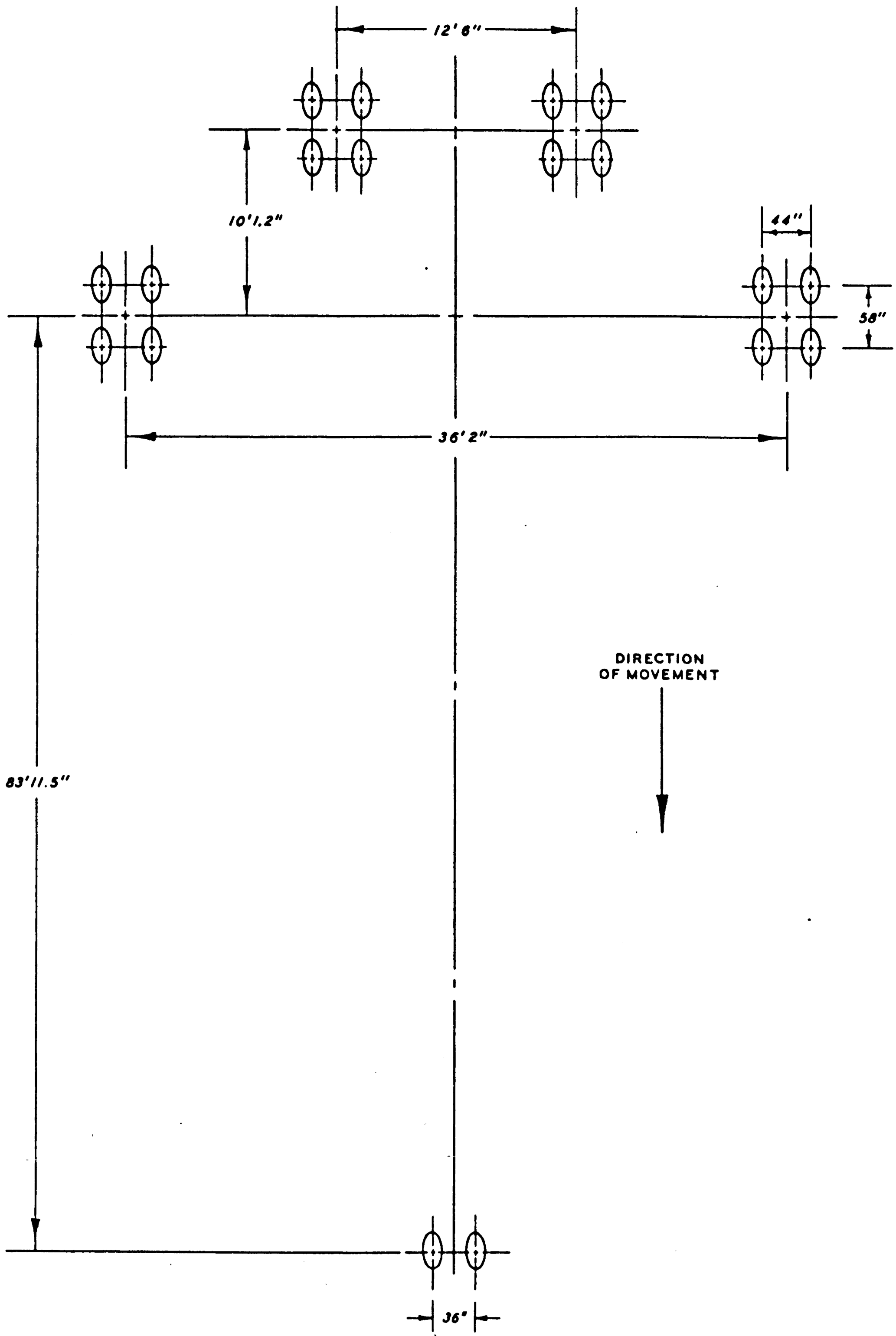


FIGURE 1 - Boeing 747 Gear Configuration

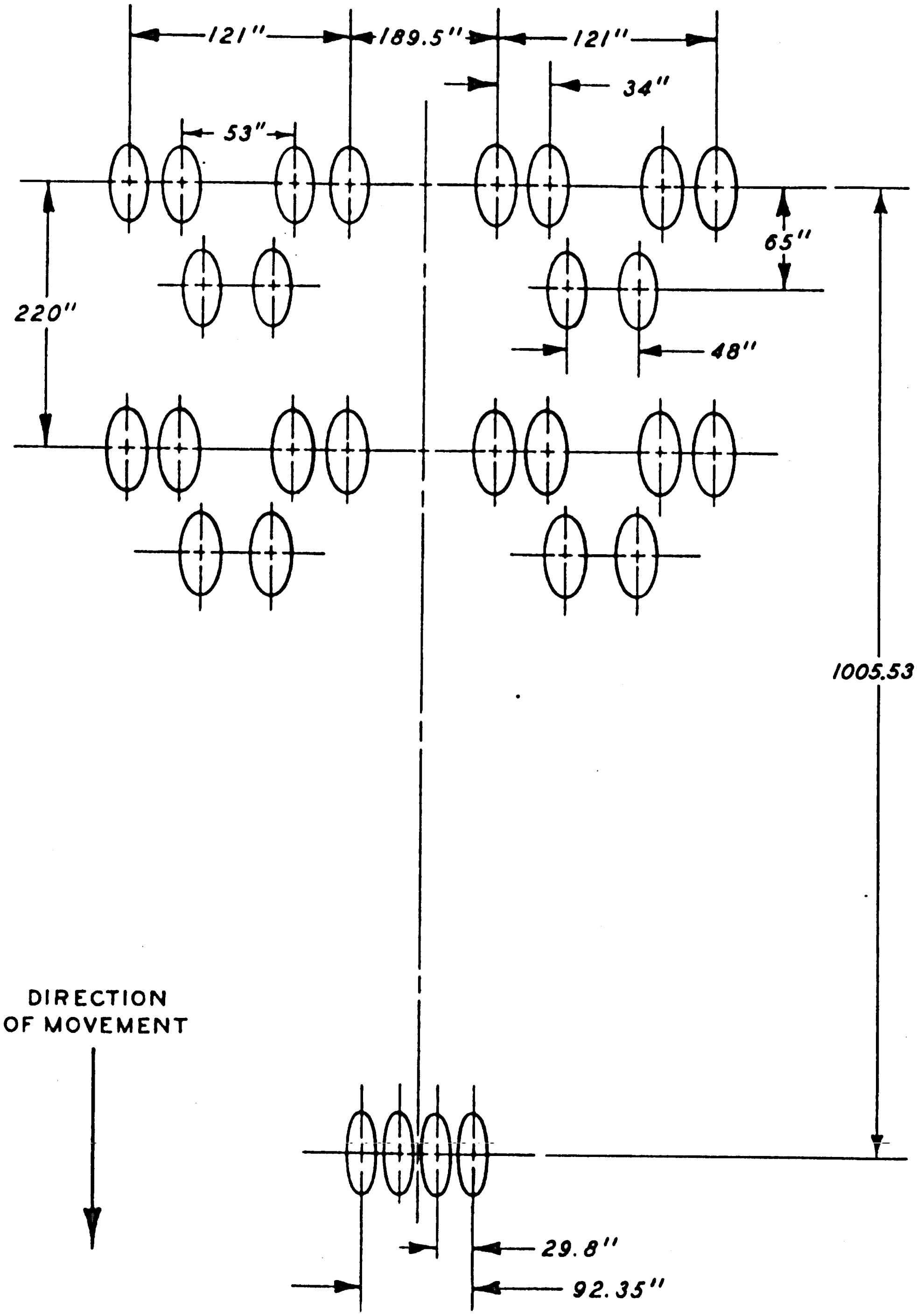


FIGURE 2. C-5A Gear Configuration

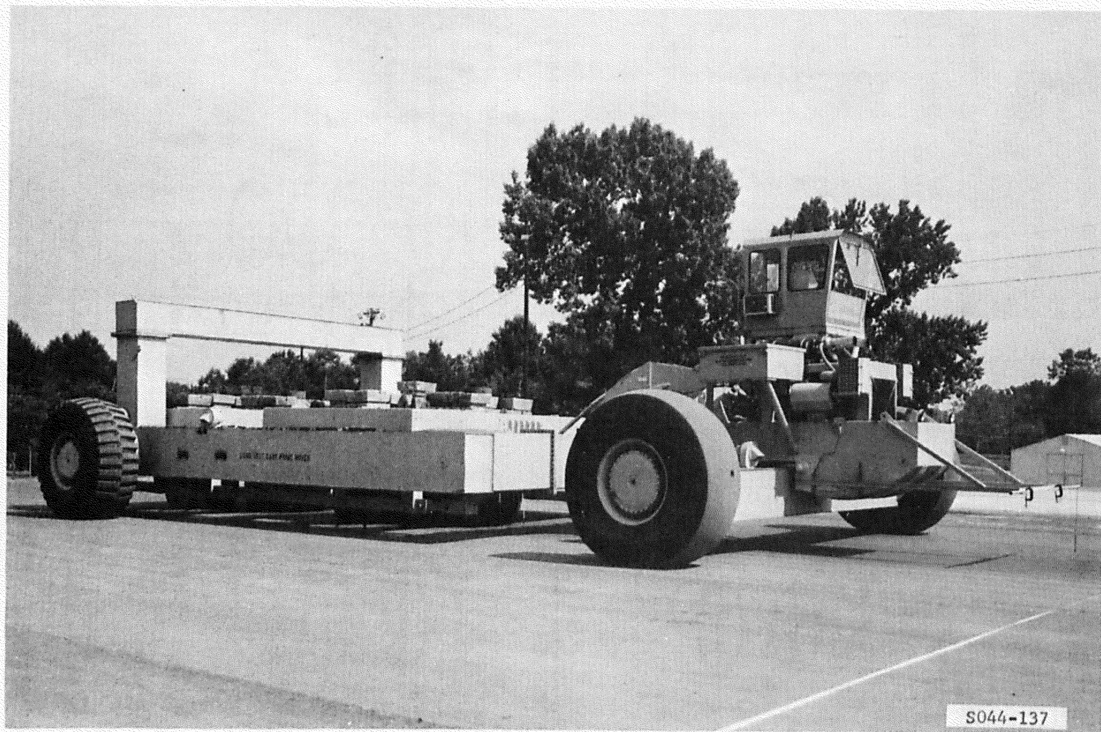


FIGURE 3 - Primary Load Test Cart

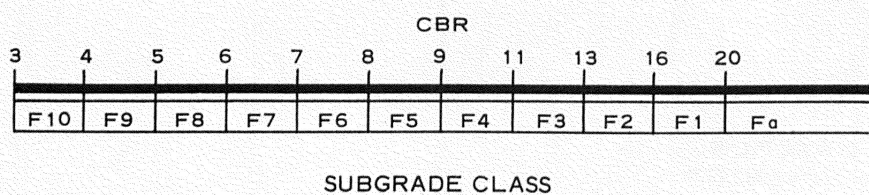


FIGURE 4 - CBR - FAA Subgrade Class Comparison

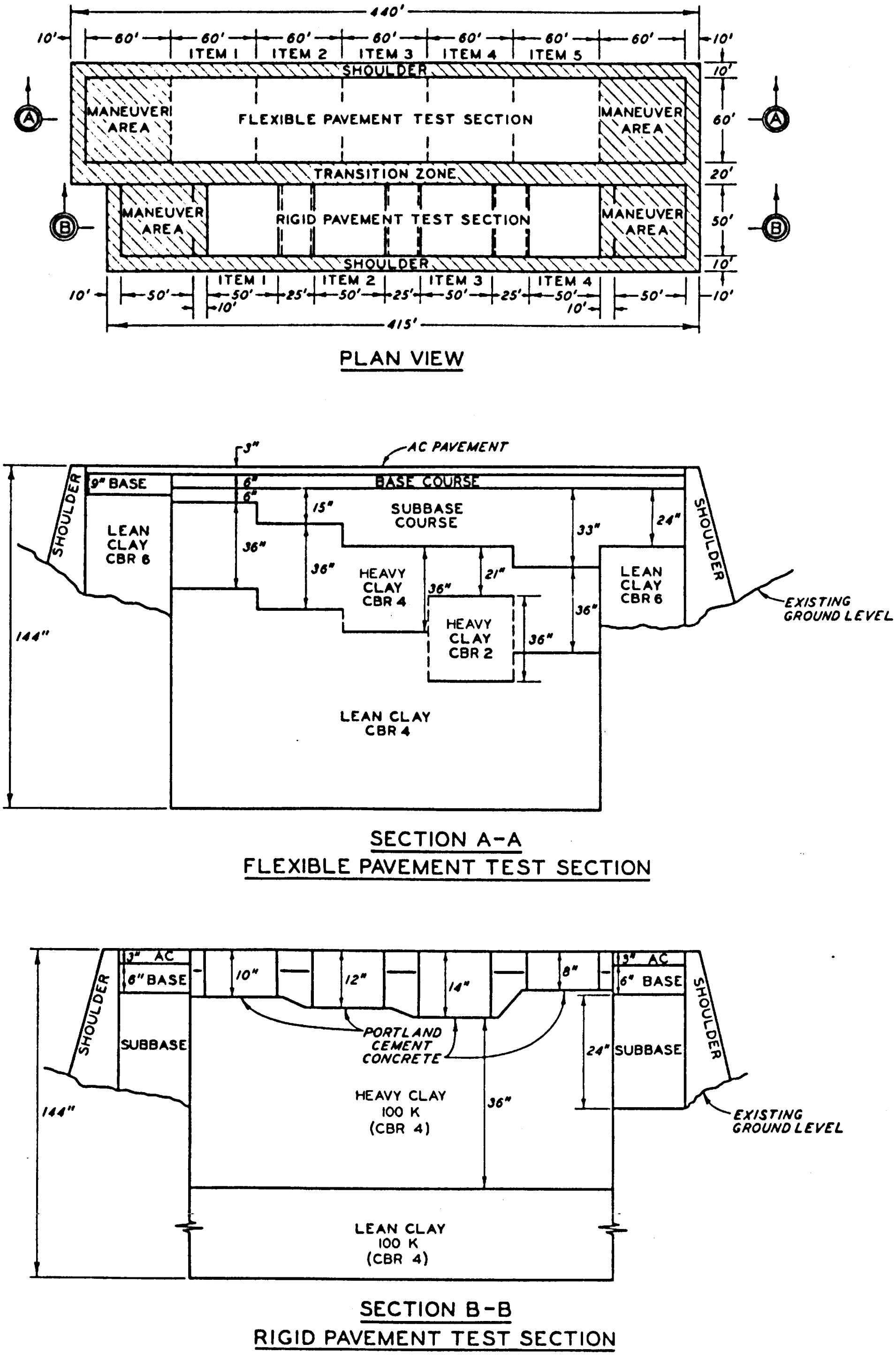


FIGURE 5 - Plan and Profiles of MWHGL Test Sections

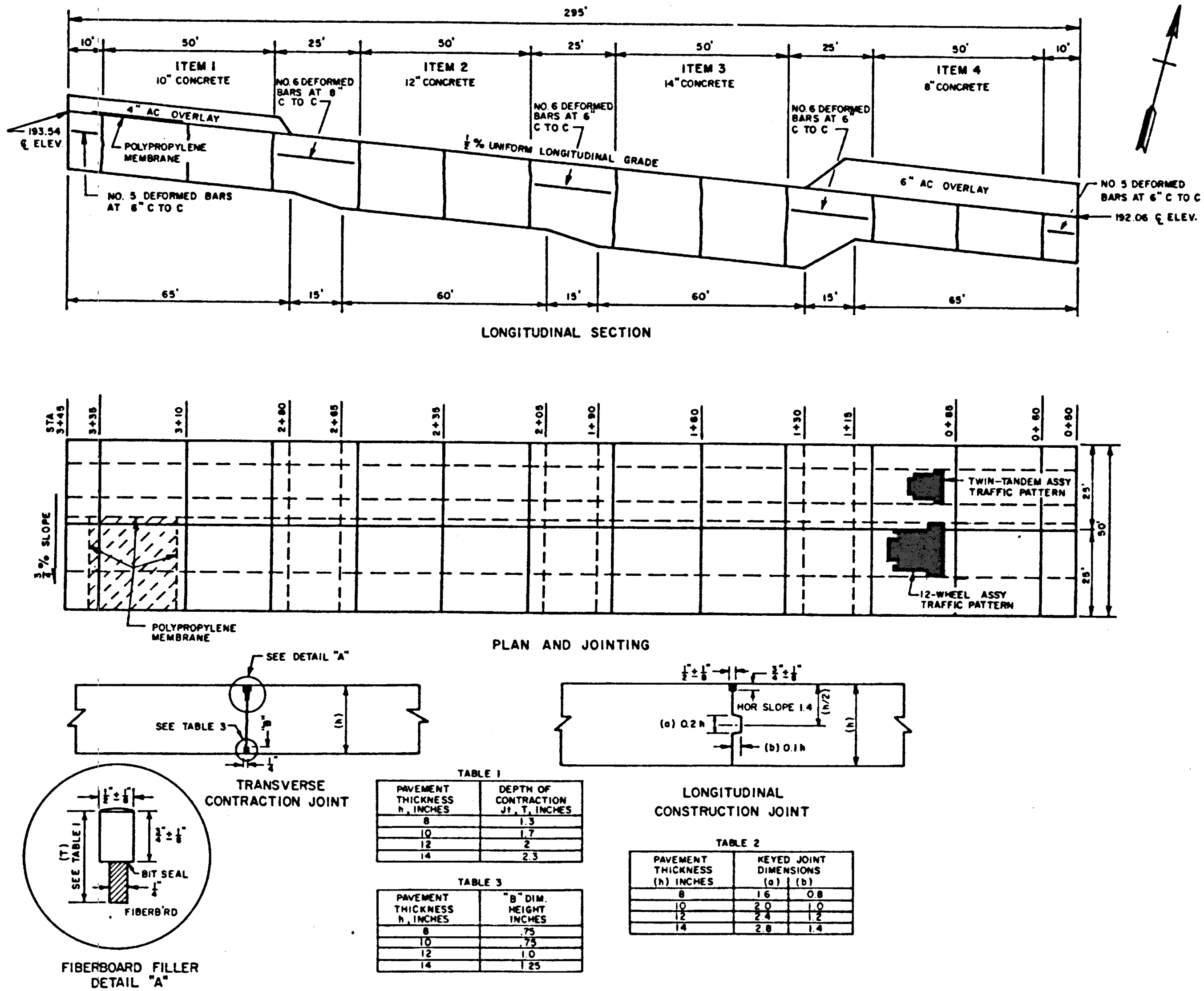


TABLE 1

PAVEMENT THICKNESS h, INCHES	DEPTH OF CONTRACTION Jt, T, INCHES
8	1.3
10	1.7
12	2
14	2.3

TABLE 3

PAVEMENT THICKNESS h, INCHES	"B" DIM. HEIGHT INCHES
8	.75
10	.75
12	1.0
14	1.25

TABLE 2

PAVEMENT THICKNESS (h) INCHES	KEYED JOINT DIMENSIONS (a)	(b)
8	1.6	0.8
10	2.0	1.0
12	2.4	1.2
14	2.8	1.4

FIGURE 6 - Plan, Profile, and Layout of Test Lanes, Rigid Pavement Test Section

of the various materials under load was prepared. Locations of deflection gages, pressure cells, and strain gages within each pavement section are shown in Figures 7 and 8. Planning and designing phases of the investigation were completed by mid-June 1968.

CONSTRUCTION

Construction of the test sections was started in July 1968. The flexible pavement test section was completed in November 1968, and the rigid pavement test section was completed in December 1968. The area within the limits of the test sections was excavated to a depth of 12 ft below finished grade and replaced with material as indicated in Figure 5.

TESTING

(A) Instrumentation Testing - Instrumentation testing was conducted during the period April to July 1969. Instrumentation data were obtained for static and slowly moving loads (up to 10 mph) under various components of the B 747 and the C-5A landing gears including one-quarter of the main gear of the B 747 (4 wheels, twin-tandem), a single wheel from the main gear of the B 747 and the C-5A, one-half of the main gear of the C-5A (12 wheels), and one-quarter of the main gear of the C-5A (6 wheels). Data were obtained for several loads and several speeds by operation of the various gear components over the pavement surface at selected horizontal distances from instruments.

(B) Application of Test Traffic - Traffic was applied to the surface of the test sections with various components of the C-5A and B 747 aircraft along specific tracking lanes as shown in Figures 6 and 9. The particular load, tire pressure, and gear assembly combination used in each specific traffic lane are indicated in Table 1 and 2. Test traffic was applied to the surface of the test section during the period August 1969 to February 1970.

(C) Test Data Obtained - Summaries of relevant test data obtained during the conduct of the MWHGL pavement tests of flexible and rigid pavements, respectively, are shown in Tables 1 and 2.

PERTINENT FINDINGS

Findings as a result of the MWHGL study pertaining to the design of pavements for the MWHGL aircraft are summarized in the following paragraphs.

(A) Flexible Pavement - The actual performance of the flexible pavement test sections under the twin-tandem and 12-wheel-gear traffic was substantially better than had been predicted using flexible pavement design methodology that was in existence prior to the conduct of the MWHGL tests.

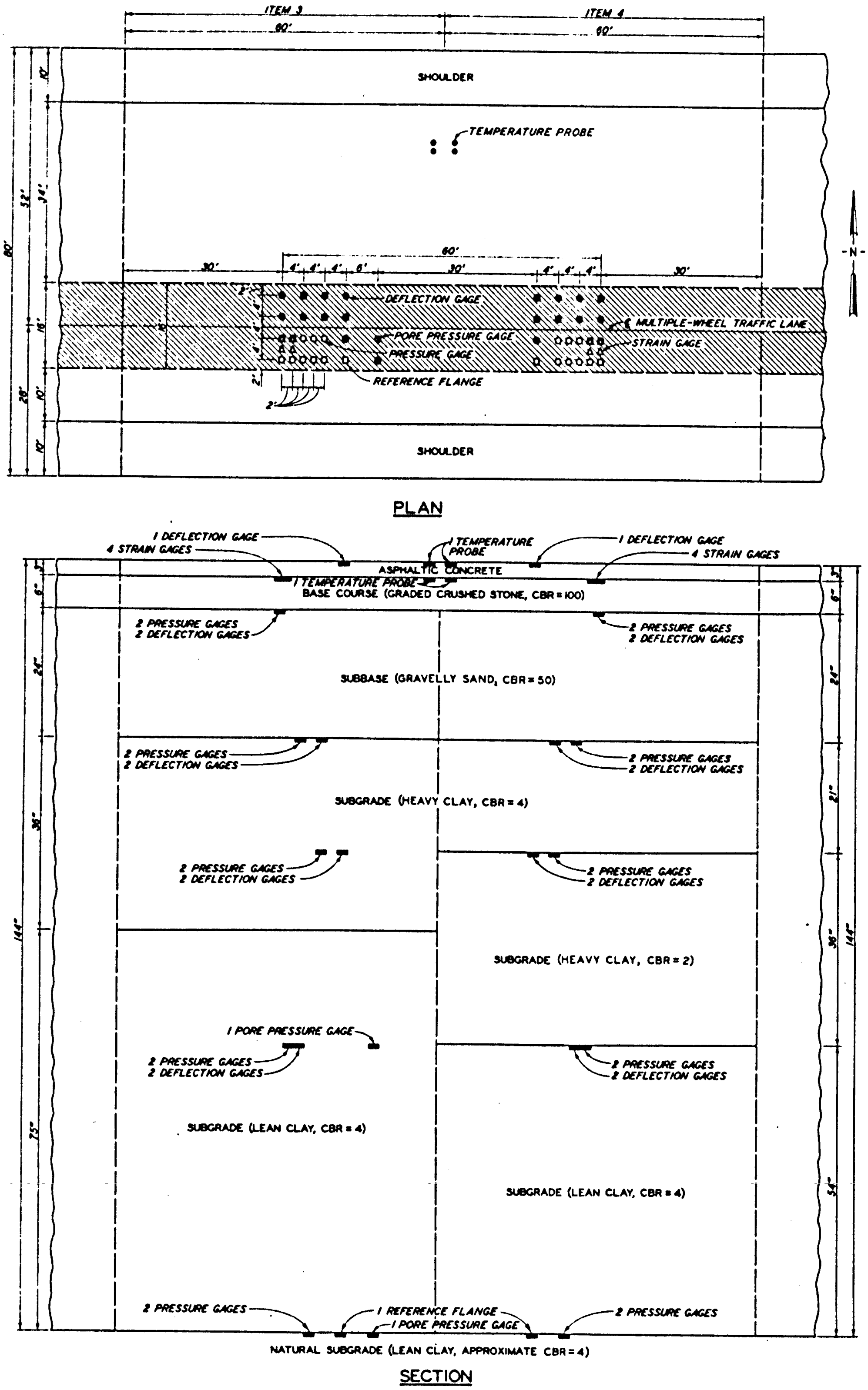


FIGURE 7 - Instrumentation Layout for Flexible Pavement Tests

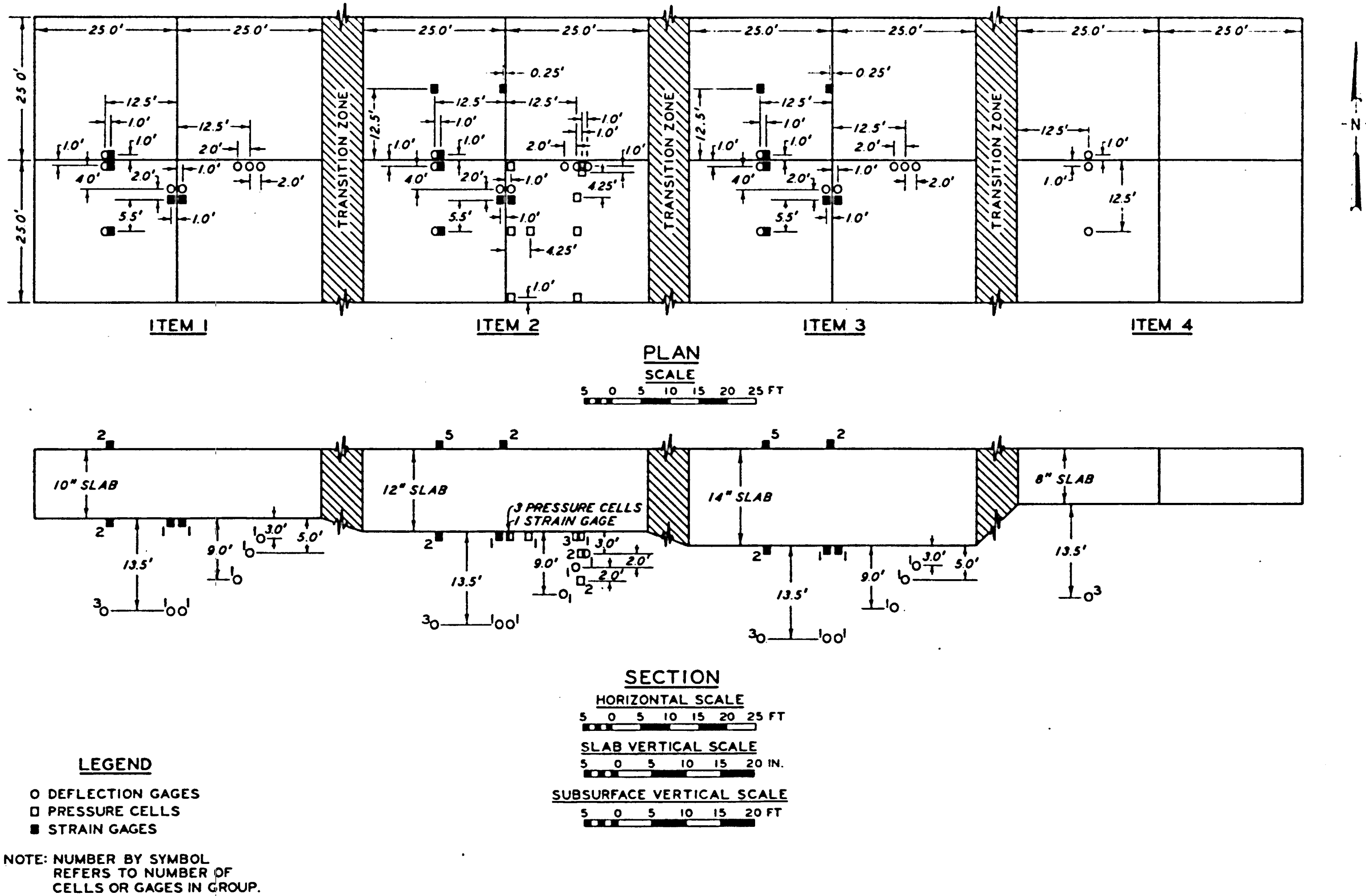
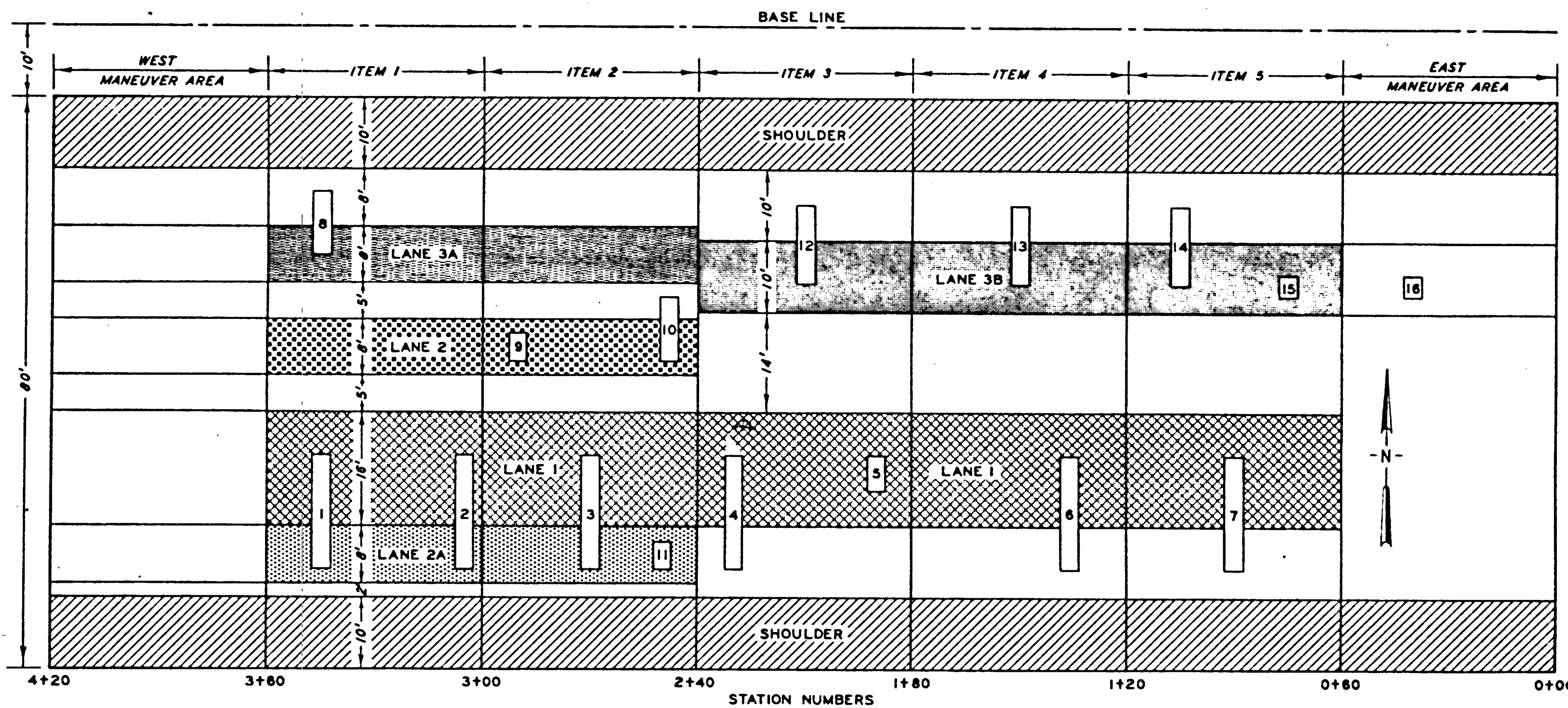


FIGURE 8 - Instrumentation Layout for Rigid Pavement Test Section



LEGEND

CBR PIT LOCATION AND NUMBER

Note: Identification of Test Lanes Given in Table 1.

FIGURE 9 - Layout of Test Lanes, Flexible Pavement Test Section

Table 1

TRAFFIC TEST DATA FOR FLEXIBLE PAVEMENT TEST SECTION

Traffic Lane	Assembly	Load per Tire lb	Tire Inflation Pressure psi	Tire Contact Area sq in.*	Pavement Temperature Range F	Item	Rated Subgrade CBR	Passes	Total Deflection in.	Maximum Permanent Deformation in.	Upheaval in.	Pavement Cracking	Rating of Test Item
1	360 kip 12 wheel	30,000	100	285	90-135	1	3.7	0	0.63	-	-	-	-
							-	5	-	1.8	1.6	Severe	Failed
							-	8	-	3.6	-	Severe	Failed
						2	4.4	0	0.43	-	-	-	-
							-	69	0.53	0.5	0.4	Severe	Failed
							-	132	-	1.1	0.5	Severe	Failed
						3	3.8	0	0.30	-	-	-	-
							-	990	0.31	1.8	0.7	Severe	Failed
							-	2200	-	2.6	1.1	Severe	Failed
						4	4.0	0	0.30	-	-	-	-
							-	990	0.33	1.3	0.5	Severe	Failed
							-	2200	-	2.8	0.7	Severe	Failed
						5	4.0	0	0.27	-	-	-	-
							-	300	-	0.5	0.1	None	Satisfactory
							-	990	0.25	1.1	0.3	Slight	Satisfactory
							-	1557	-	1.4	0.3	Slight	Satisfactory
							-	2541	-	1.7	0.3	Slight	Satisfactory
3A	30 kip Single wheel	30,000	100	285	90-120	1	3.7	0	0.12	-	-	-	-
							-	348	0.26	1.4	0.1	Severe	Failed
						2	4.4	0	0.11	-	-	-	-
							-	1392	0.08	0.8	0.1	None	Excellent
2	50 kip Single wheel	50,000	165	285	90-115	1	3.7	0	0.48	-	-	-	-
							-	17	-	1.2	0.6	Severe	Failed
						2	4.4	0	0.19	-	-	-	-
							-	580	0.47	2.4	0.6	Severe	Failed
2A	50 kip Single wheel	50,000	165	285	60-70	1	3.7	0	0.42	-	-	-	-
							-	17	-	1.5	1.2	Severe	Failed
						2	4.4	0	0.23	-	-	-	-
							-	580	0.47	1.5	0.4	Severe	Failed
3B	240 kip Twin-tandem (44x58)	60,000	225	290	65-85	3	3.8	0	0.56	-	-	-	-
							-	55	0.72	2.4	0.9	Severe	Failed
						4	4.0	0	0.56	-	-	-	-
							-	55	0.72	2.4	1.0	Severe	Failed
						5	4.0	0	0.50	-	-	-	-
							-	55	-	1.3	0.2	Slight	Satisfactory
							-	584	0.74	3.5	0.7	Severe	Failed

* Average measured area.
** No failure developed.

Table 2

TRAFFIC TEST DATA FOR RIGID

PAVEMENT TEST SECTION

Test Item	Slab	Thickness h, in.	Subgrade Modulus k, pci	Concrete Flexural Strength R, psi	Assembly	Passes to Failure: Initial Pred	Initial Act	Shattered Pred	Shattered Act	Complete Pred	Complete Act	Remarks
1	SW	10.6	140	725	360 kip	534	334	5,600	*	16,000	*	
	SE	9.8	140	725	12 wheel	53	256	802	789	5,600	*	
	NW	9.6	169	695	166 kip							Traffic not applied
	NE	9.5	169	695	Twin-tandem							prior to overlay
	S(overlay)	4.2 AC 10.2 PCC	140	725	360 kip 12 wheel	73,500						6,070 passes applied; item not failed
	N(overlay)	3.8 AC 9.6 PCC	169	695	166 kip Twin-tandem	7,500						2,040 passes applied; failure imminent
2	SW	12.0	78	800	360 kip	6,670	5,990	11,350	*	20,000	*	
	SE	12.1	78	800	12 wheel	7,060	5,290	12,000	*	22,700	*	
	NW	11.5	111	700	166 kip	<100	120	1,890	2,040	5,700	*	
	NE	11.3	111	700	Twin-tandem	<100	450	1,350	2,040	4,800	*	
3	SW	14.1	65	760	360 kip	28,000	2,945**	34,700	*	60,000	*	
	SE	13.8	65	760	12 wheel	17,300	789**	24,000	*	42,700	*	
	NW	13.6	115	660	166 kip	525	780	6,600	*	15,000	*	
	NE	14.1	115	660	Twin-tandem	1,500	450	12,600	*	25,500	*	
4	SW	8.2	125	775	360 kip	<100	240	253	320	1,330	*	
	SE	8.2	125	775	12 wheel	<100	242	253	320	1,330	*	
	NW	7.4	128	605	166 kip							Traffic not applied
	NE	7.2	128	605	Twin-tandem							prior to overlay
	S(overlay)	5.4 AC 8.2 PCC	125	775	360 kip 12 wheel	12,000						6070 passes applied; item not failed
	N(overlay)	5.6 AC 7.3 PCC	128	605	166 kip Twin-tandem	660						Failed after 2040 passes

* Traffic was discontinued before test item reached failure condition shown.
** Failure premature due to pumping.

The better-than-predicted performance was proportional to the larger number of wheels on the gear. The better performance dependent upon the larger number of wheels was partially attributed to a degree of confinement afforded by the perimeter wheels on the soil mass under the interior wheels. An additional advantage of the large number of wheels may be that the partial stress reversals imposed within the elastic domain are actually of benefit to the performance of the pavement structure. Based upon these findings, expressions were developed from which the effects of traffic volume can be determined based upon the number of main-gear wheels.*

An equivalent single-wheel loading (ESWL) based upon all main-gear tires on the aircraft generally gave a better correlation with the total flexible pavement thickness requirement than did an ESWL based upon only the main-gear tires for only one of the main landing gears. An analysis of the data did indicate that, depending upon the aircraft main-gear arrangement, the ESWL based upon a number of main-gear tires less than the total may require a greater pavement thickness and, if so, should be used. In this case, the load-repetition factor representing the effects of traffic volume must be determined using the same number of main-gear tires used for the computation of ESWL.

(B) Rigid Pavement - Performance of the rigid and the rigid plus nonrigid overlay test sections under twin-tandem and 12-wheel-gear traffic was close to that predicted by the existing design methodology. Three of the four test items performed closely to the predicted performance with the fourth item failing prematurely because of pumping of the subgrade materials. The analysis of data indicated no need for change to design methodology, which is based upon the Westergaard analysis modified by an appropriate factor (safety factor) to account for the effects of repetitive loading resulting from traffic volume.

Measurements of concrete strain and deflections indicated that loading along the edge of the slab was more severe than loading at the interior of the slab. Performance under the traffic substantiated the strain and deflection measurements as all cracking was observed to initiate at the slab edge and migrate across the slab.

Pumping of the fine-grained subgrade materials under the rigid pavement was much more severe than anticipated. Ordinarily criteria require the use of a filter or base course over the clay subgrade materials as a deterrent to pumping; however, because of the short duration of the tests and the anticipated absence of free moisture, the filter course was deleted in favor of a two-layer system to simplify analysis. The pumping was most severe under the 12-wheel traffic and in the thickest test section (item 3). Because of the manner of design and construction of the

* See equation on page 31 and Figure 10.

test track, moisture migrating in the subgrade or between the subgrade and pavement collected under item 3, making pumping more severe. The performance of item 3 under the 12-wheel traffic was definitely influenced by the pumping, but it is doubtful that pumping at any of the other items under either the twin-tandem or 12-wheel traffic was severe enough to have materially affected their performance. The pumping experienced did emphasize the need for positive protection of fine-grained subgrade materials, especially for pavement that will be subjected to MWHGL aircraft.

Another significant result of the rigid pavement MWHGL tests was the performance of the keyed longitudinal construction joint under the 12-wheel-gear traffic. Traffic was applied parallel and along the keyed longitudinal construction joint between the two paving lanes. Failure of the joint was experienced for the entire length of the test tract in all four test items as well as in the reinforced concrete transition slabs between the test items. The failures consisted of either a shearing of the key or a spalling of the keyway with the types of failure being about even. The volume of traffic causing the keyed-joint failure could not be accurately determined since the failure could not be observed. A faulting of the joint was detected early in the traffic life, which was indicative of the failure. A study of deflection measurements along the joint also indicates an early failure of the joint. Thus, the severity of the MWHGL on joints is obvious, and the need for something better than the keyed joint used is apparent.

Large transient and permanent rigid pavement deformations were experienced under the MWHGL traffic. Permanent deformations of the pavement surface of 0.6 to 1.0 in. were experienced under the traffic. Only a portion of this permanent deformation could be attributed to densification of the foundation materials, and it is probable that the majority of the deformation was due to the plastic flow or lateral movement of the clay subgrade materials directly beneath the concrete slab.

RECOMMENDED CHANGES TO FAA ADVISORY CIRCULAR NO. AC 150/5320-6A, AIRPORT PAVING

As a result of analysis of test data obtained during the conduct of the MWHGL pavement tests (Reference 1), a procedure for preparation of design, construction, and evaluation criteria for airfield pavement to be subjected to aircraft equipped with MWHGL has been developed. Criteria for the B 747 and C-5A aircraft prepared in accordance with this procedure are presented herein.

FLEXIBLE PAVEMENT

The procedure developed for preparation of criteria for flexible pavements in the MWHGL pavement test report (Reference 1) is limited to preparation of thickness and evaluation criteria. The recommended procedure for determining thickness requirements for flexible pavements consists of the following steps which should be included in paragraph 4a(1), Appendix I.

(A) Determine ESWL - The ESWL (Reference 2) is based on the ratio of maximum deflections beneath a multiple-wheel group and one wheel of that group computed assuming a homogeneous, isotropic, half-space loaded by uniformly distributed circular loads. The ESWL varies with depth and is determined at pertinent depths or at sufficient depths to form a curve of ESWL versus depth. An example of ESWL determination can be found in Reference 2. The methodology has been computerized for treatment of complex landing gear geometry and the program is available. The procedure is first applied using all main-gear wheels, which generally results in maximum thickness requirements for a specific aircraft. Where it is found that some combination of wheels other than all main-gear wheels will produce greater thickness requirements, then that combination of wheels will be used to determine the ESWL.

The thickness of superior (stronger) material required above a layer of soil of known strength to prevent shear deformation within this layer of soil will be determined by the following equation:

$$t = \alpha_i \sqrt{A} \left[- 0.0481 - 1.1562 \left(\log \frac{CBR}{p_e}\right) - 0.6414 \left(\log \frac{CBR}{p_e}\right)^2 - 0.4730 \left(\log \frac{CBR}{p_e}\right)^3 \right]$$

where

t = total thickness of superior material required above a layer of soil of known strength to prevent shear deformation within this layer of soil, inches

α_i = load-repetition factor which varies with number of wheels on main gear of aircraft considered and the volume of aircraft traffic, in passes, anticipated as shown in Figure 10

A = measured contact area of one tire, sq in.

p_e = ESWL or SWL tire pressure, psi. For multiple-wheel gear, $p_e = \frac{ESWL}{A}$ where ESWL is determined by the method shown in Reference 2 and for single-wheel gear, $p_e = \frac{SWL}{A}$. This is an artificial tire pressure for multiple-wheel loads consistent with use of contact area of one tire and has no relation to actual tire inflation pressure. However, for single-wheel loads this pressure is the actual average contact pressure and is nominally the same as the tire inflation pressure.

CBR = strength of soil as determined by Test Method 101, Military Standard MIL-STD-621A (Reference 3)

(B) Thickness Requirements - CBR thickness design curves were determined in accordance with the procedure discussed in the preceding paragraph for 100,000 passes of the B 747 and 50,000 passes of the C-5A. These requirements were then converted into equivalent design criteria in terms of FAA subgrade classification (F) through use of Figure 4; i.e., the average value of CBR shown in this figure for a specific F value was used in the conversion (CBR of 3.5 = F 10). The resulting design curves for the B 747 and C-5A are shown in Figures 11 and 12. These have been developed for critical areas and should be included in paragraph 17.

RIGID PAVEMENT

(A) Thickness Criteria - Rigid pavement thickness requirements have been prepared for the B 747 and C-5A aircraft and are presented by Figures 13, 14, and 15 for critical areas. Figure 13 is a revision of Figure 9 of the manual and Figures 14 and 15 should be added to paragraph 37. The thickness requirements depicted by each figure are based upon the Westergaard equations for interior loading. Concrete stresses have been computed using the Portland Cement Association's computer program for airport pavement design, which is based upon the "Influence Charts for Concrete Pavements" developed by Pickett and Ray. The computer program selects the orientation of the gear on the slab that gives the maximum stress.

A safety factor of 2.1 has been selected for the development of the thicknesses shown in Figure 13 and is recommended for use with the curves shown by Figures 14 and 15 when designing concrete pavements for the critical areas. The safety factor value of 2.1 has been selected based upon the MWHGL traffic test study and is the value determined to be necessary when the concrete stress determination is based upon interior loading. The safety factor must be included in paragraph 19b(2) and in paragraph 3b(6) of Appendix I. In reality the safety factor is a load-repetition factor. It is applied to the computed stress to determine the concrete flexural strength that will accept the design volume of traffic. Relations between load-repetition and interior-load stresses have not been developed; therefore, the safety factor (load-repetiton factor) was

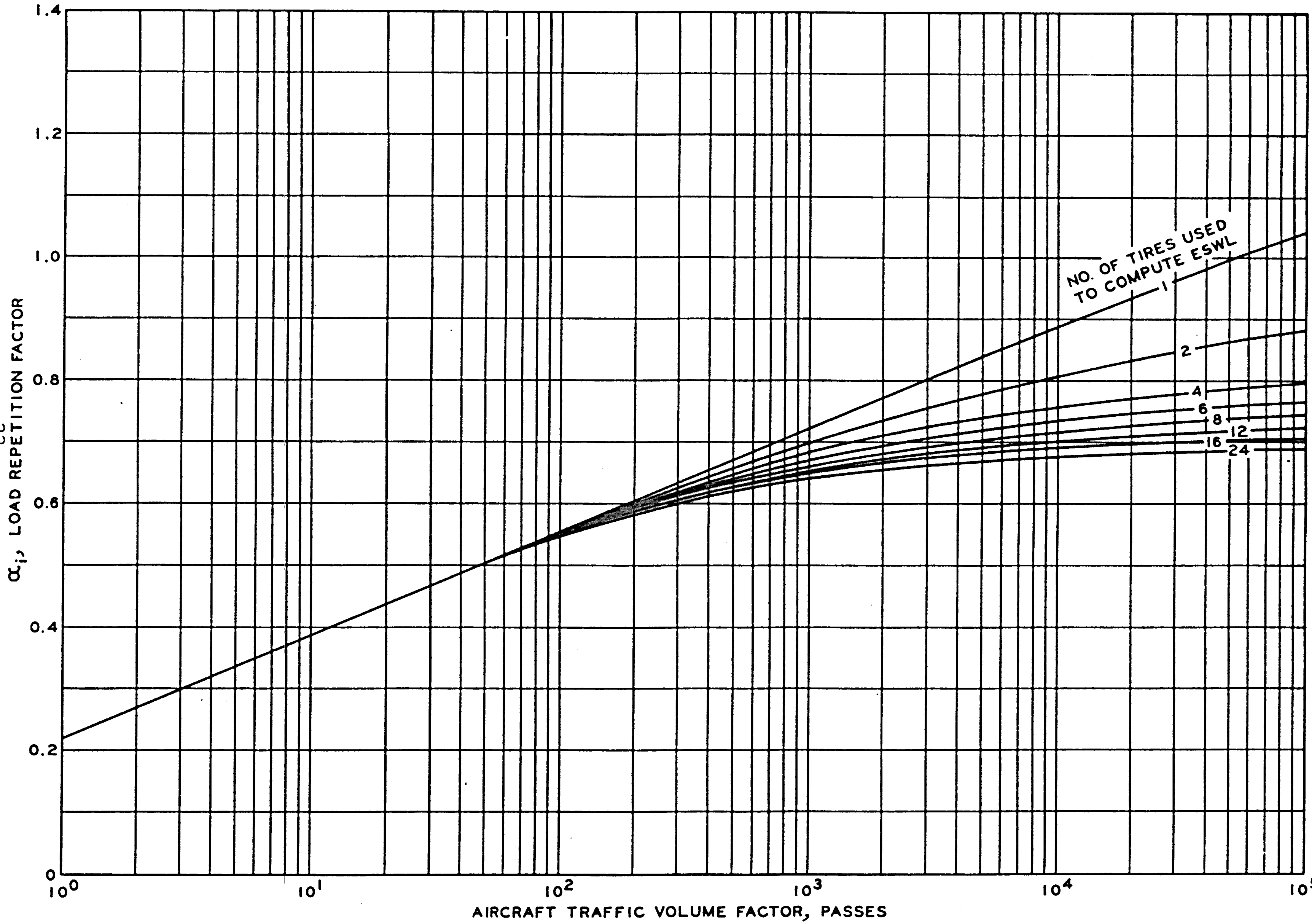


FIGURE 10 - Composite Plot of Load-Repetition Factors Versus Passes

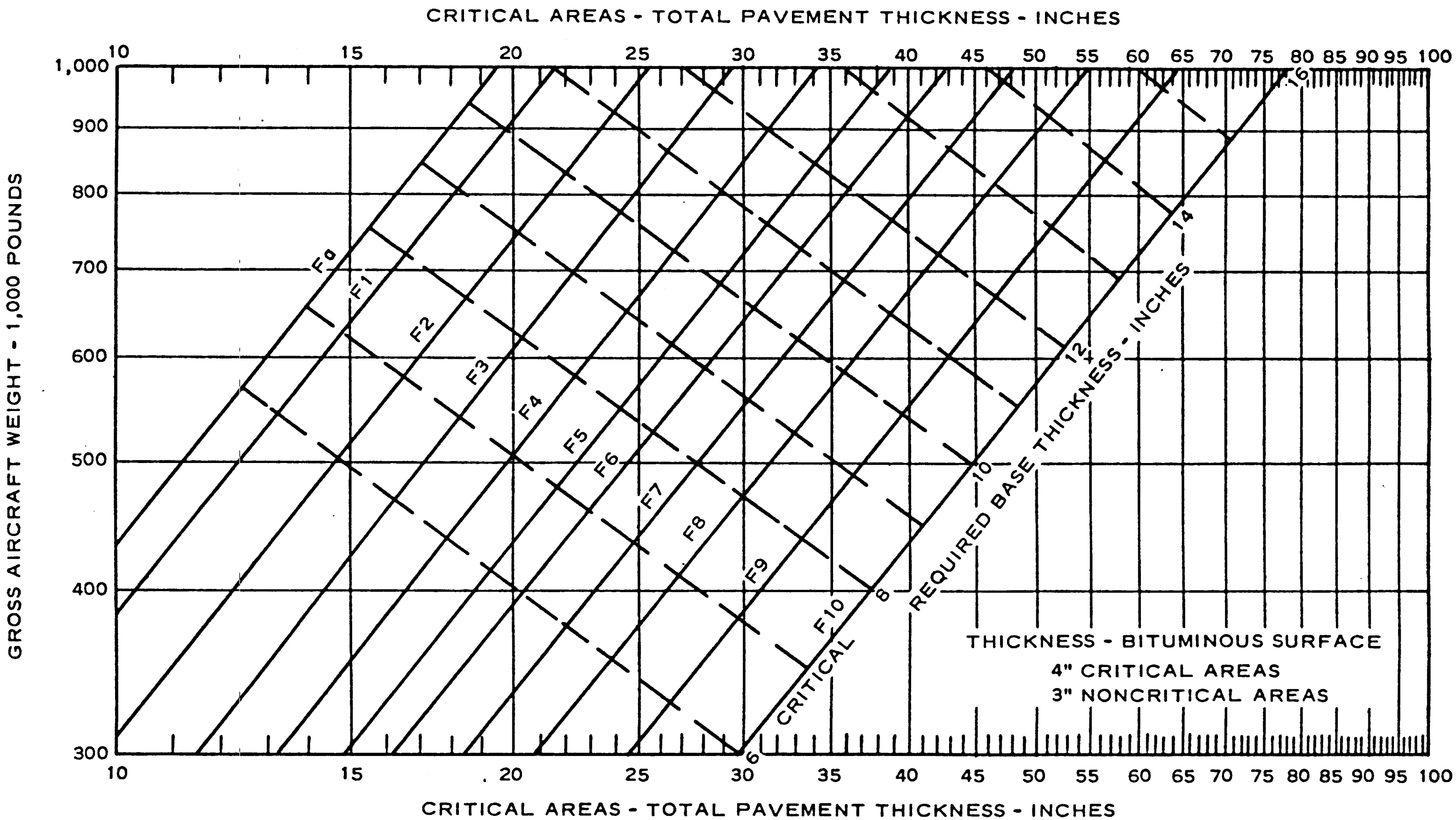


FIGURE 11 - Flexible Pavement Design Curves for Boeing 747 Aircraft (Contact Area 208 sq in.)

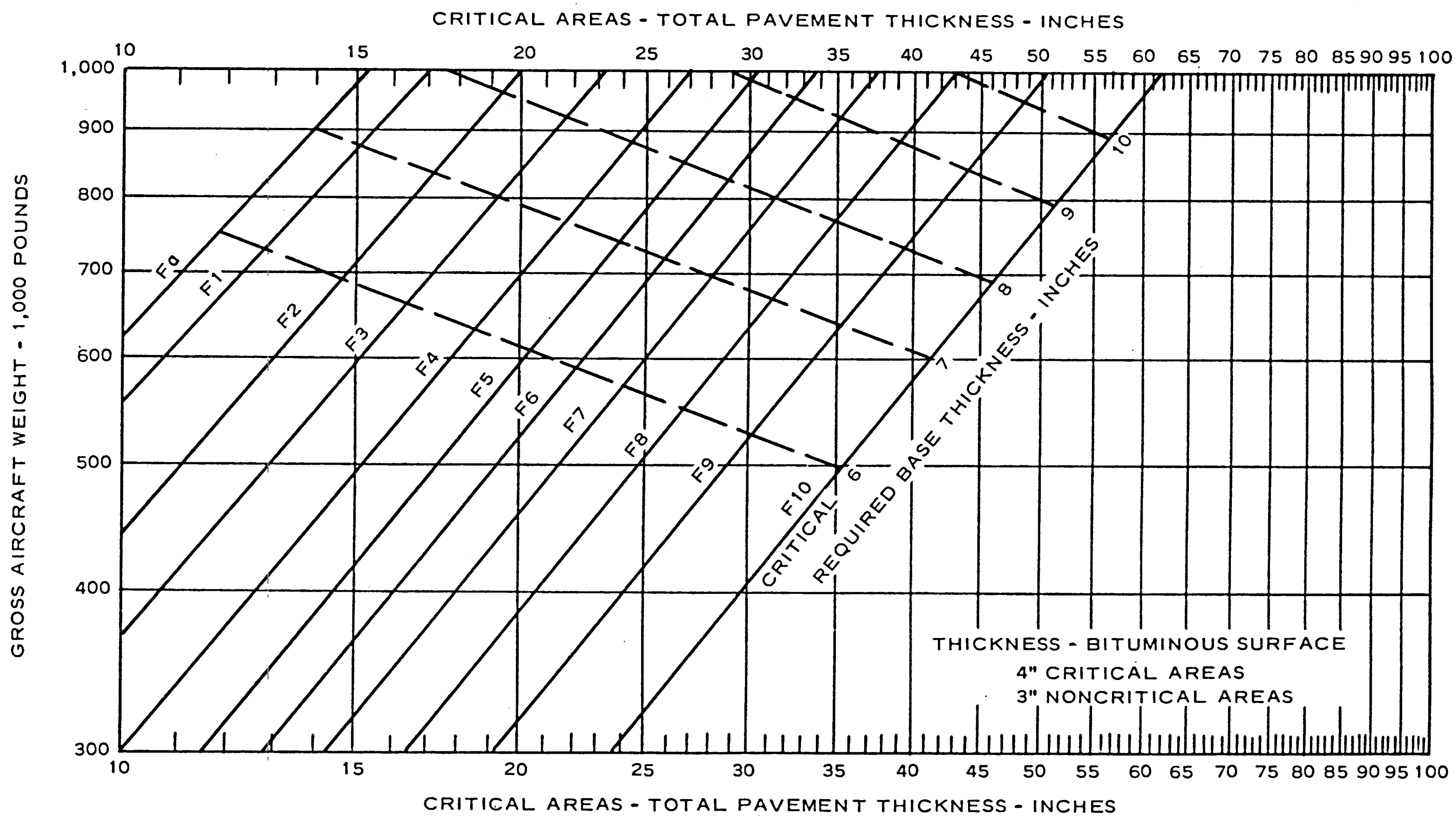


FIGURE 12 - Flexible Pavement Design Curves for C-5A Aircraft (Contact Area 285 sq in.)

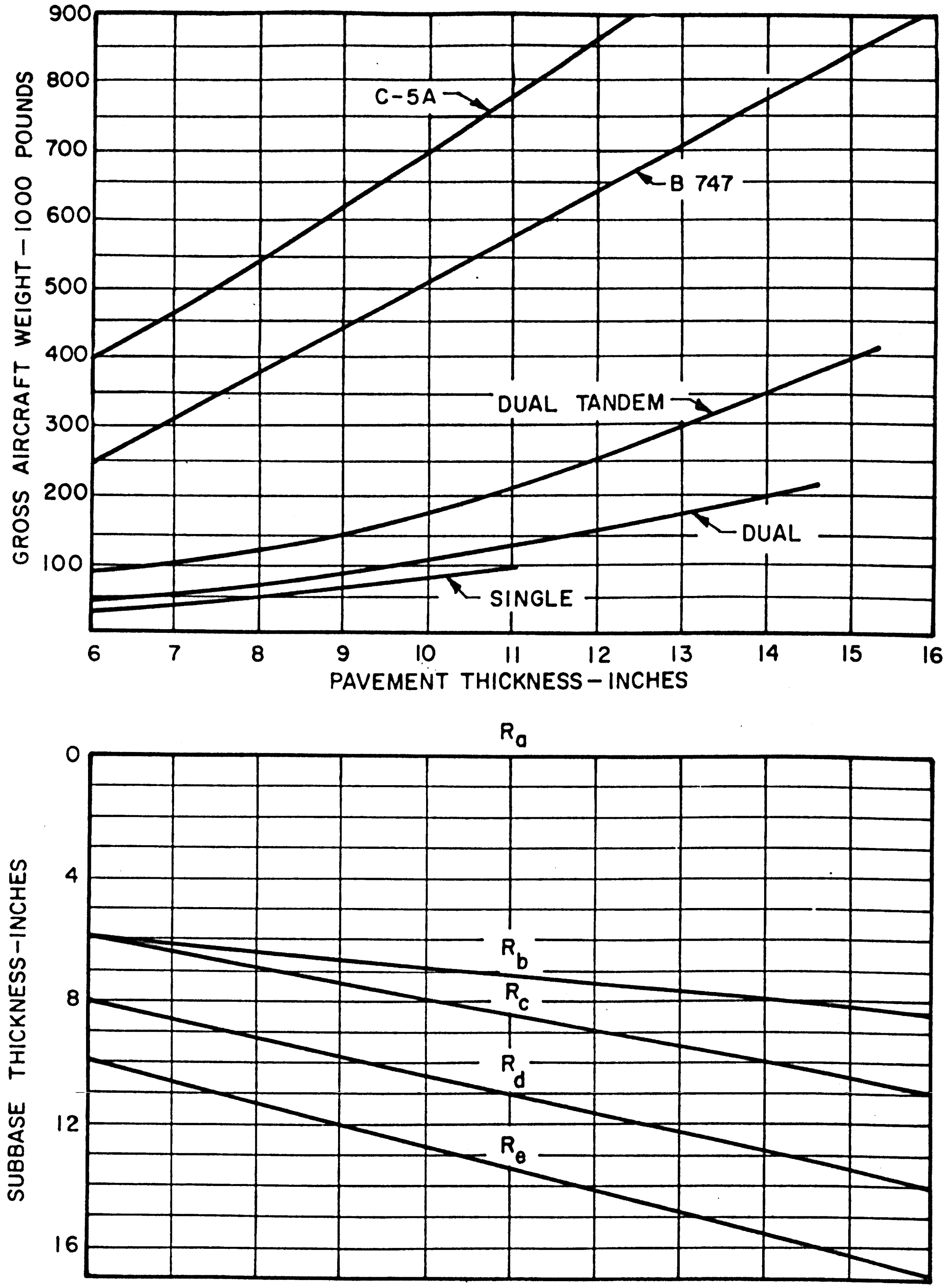


FIGURE 13 - Rigid Pavement Design Curves for Critical Areas

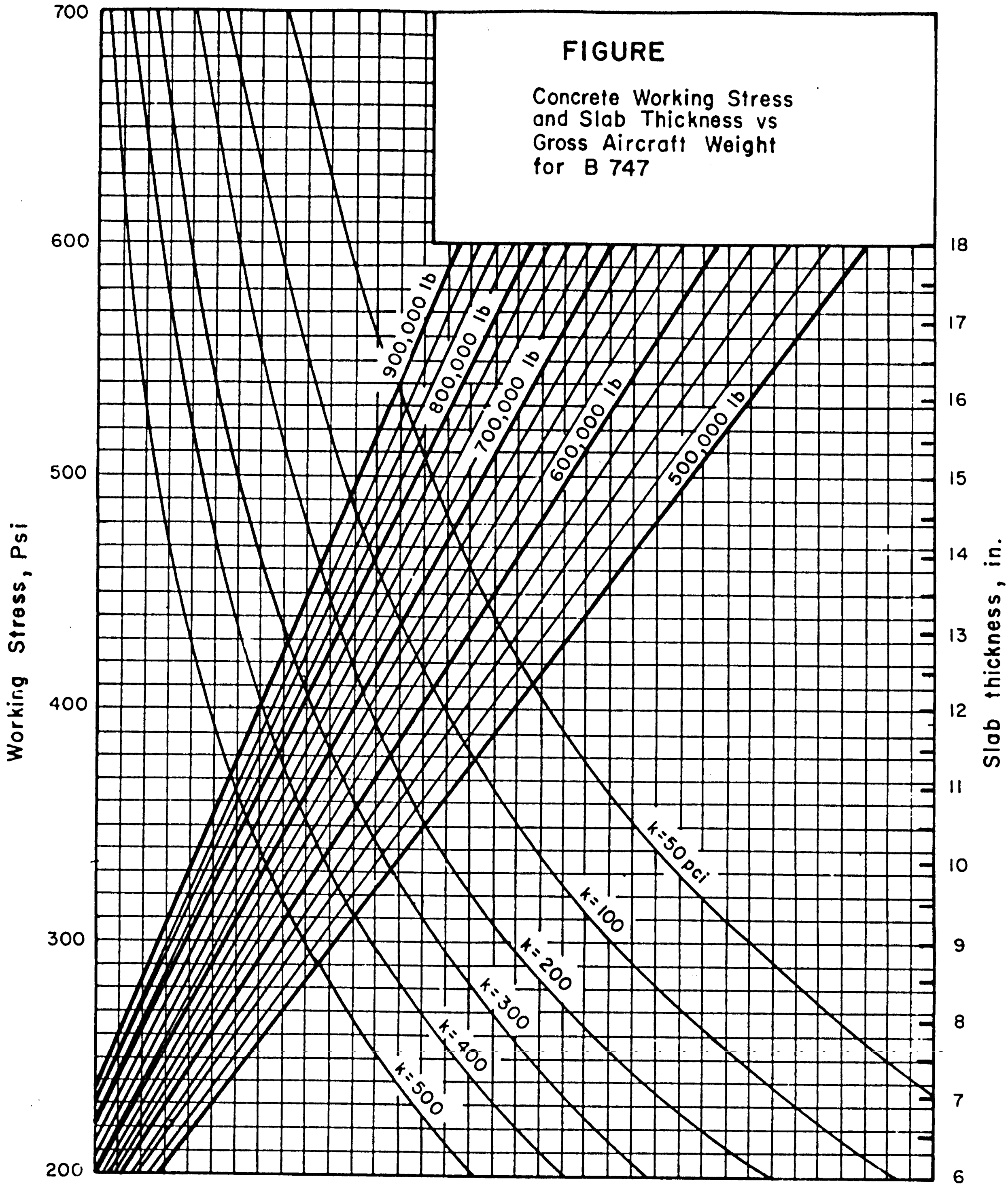


FIGURE 14 - Concrete Working Stress and Slab Thickness Versus Gross Aircraft Weight for B 747

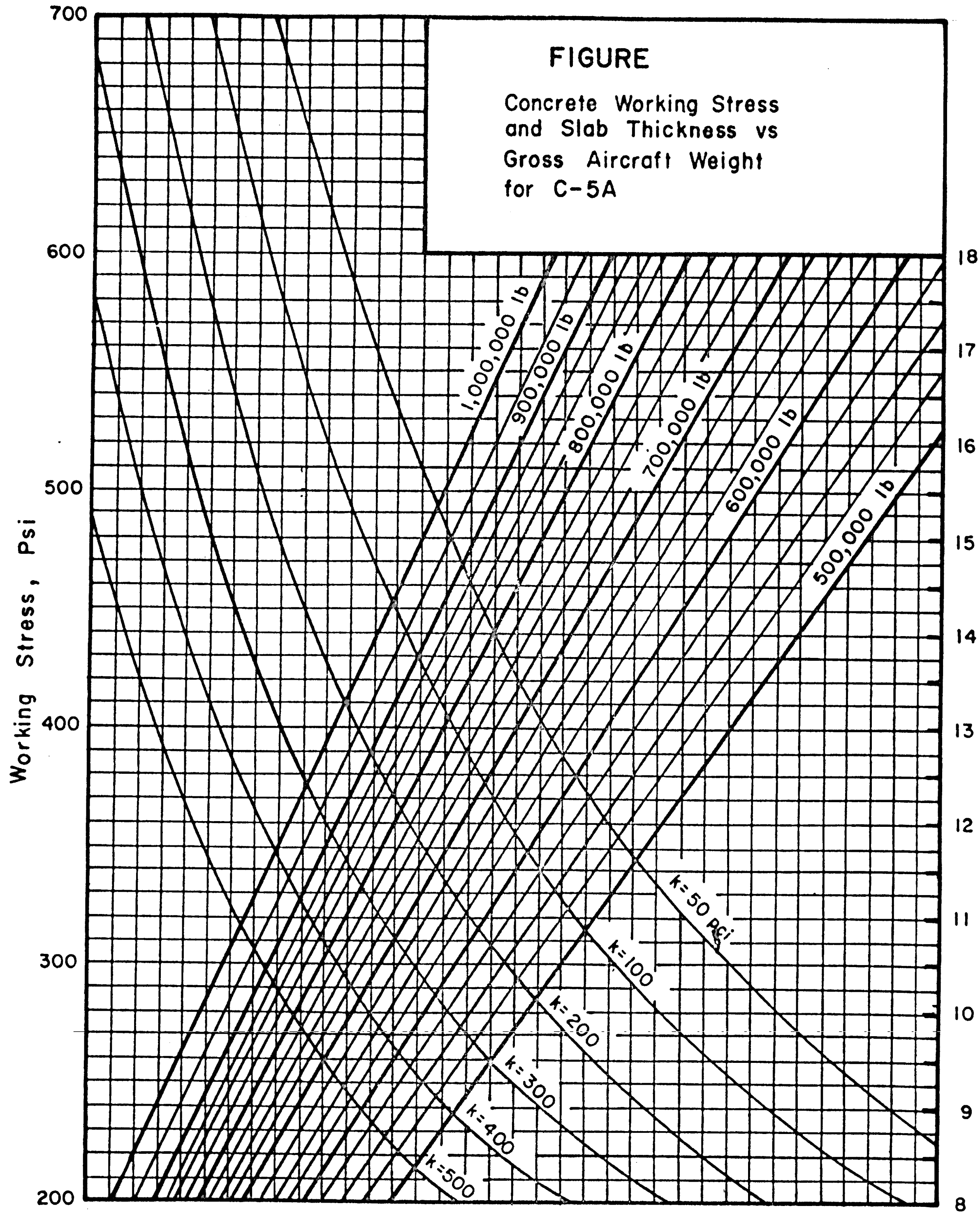


FIGURE 15 - Concrete Working Stress and Slab Thickness Versus Gross Aircraft Weight for C-5A

developed using the relationship between load-repetition and edge-loading stress, which is an acceptable alternate. Pavement thickness requirements based upon edge loading and assuming 25-percent load transfer to the adjacent slab were determined using the Westergaard edge-loading equations and the edge load-repetition factor for 100,000 passes of the B 747 aircraft and 50,000 passes of the C-5A aircraft. These pass volumes have been determined to be applicable for critical areas. The safety factor (load-repetition factor) necessary to adjust the computed interior load stress to yield the thickness required by the edge-load stress and edge load-repetition factors for the B 747 and C-5A aircraft was determined. The resulting safety factor to be used with the interior-load stresses was 2.1.

Rigid pavement thickness versus gross aircraft loading curves have been added to the FAA design curves for critical areas and are presented by Figure 13. The landing gear geometry for the B 747 and C-5A is sufficiently different from each other and from other aircraft landing gears that separate design curves are shown for each aircraft. The parameters used for the development of these curves are as follows and should be included in paragraph 3b of Appendix I.

Working Stress, S = 330 psi

Concrete Modulus of Elasticity, E = 4,000,000 psi

Poisson's Ratio of Concrete, U = 0.15
Modulus of Subgrade Reaction, k = 300 psi
Safety Factor = 2.1

Aircraft Traffic Volume: B 747 - 100,000 passes
C-5A - 50,000 passes

Contact Area per Tire: B 747 - 208 sq in.
C-5A - 285 sq in.

Figures 14 and 15 present the interrelations of interior-load concrete stress, modulus of subgrade reaction, aircraft gross loading, and concrete pavement thickness for the B 747 and C-5A aircraft, respectively. These charts may be used for either design or evaluation of rigid pavements. When used for the design of pavements for critical areas, a safety factor of 2.1 must be used.

(B) Joints in Rigid Pavements - The type-C keyed longitudinal joint shown by Figure 10 of the FAA manual was the type used in the MWHGL test track and is the joint that failed early in the traffic life. The test track was admittedly constructed on a low-strength subgrade without the benefit of a base course; however, it is logical to assume that the same type failure may occur regardless of subgrade strength. This assumption is based upon the fact that an increase in the strength of the subgrade results in a corresponding decrease in slab thickness and consequently a decrease in key and keyway dimensions. Stress conditions in the concrete remain about the same since the thickness design is based upon a limiting stress. Therefore, it is recommended that keyed longitudinal construction joints not be allowed in pavements designed for MWHGL, and the type-C joints in Figure 10 of the manual should be deleted. The MWHGL study did not include studies of the other types of construction joints; however, there are past test track data and actual performance data that indicate that the dowelled construction joint is superior to the keyed joint, and it is probable that a dowelled construction joint would perform satisfactorily under MWHGL traffic. Other types of construction joints that might be considered are the thickened-edge butt joint and the thickened-edge keyed joint. It is recommended that these type joints should be included in Figure 10.

OTHER ITEMS FOR CONSIDERATION

NONRIGID OVERLAY OF RIGID PAVEMENT

The results of the MWHGL study of nonrigid (bituminous) overlay indicated that the existing equation for nonrigid overlay thickness requirements was satisfactory. This equation is:

$$t_f = 2.5 (Fh - h_e)$$

where

t_f = required thickness of nonrigid overlay, inches

F = factor that varies with subgrade strength

h = required thickness of rigid pavement for the design loading if placed directly on the subgrade or subbase.

h_e = thickness of existing rigid pavement

The above equation is used by the FAA for the design of flexible overlays and the results of the MWHGL tests indicate no need for a change. However, the results of the MWHGL tests or previous full-scale nonrigid overlay tests do not support the FAA design criteria for bituminous overlay represented by the equation:

$$t_b = \frac{t_f + 0.5t_s}{1.5}$$

where

t_b = required thickness of bituminous overlay

t_f = required thickness of flexible overlay

t_s = required thickness of surface course

The above equation represents approximately 20- to 25-percent reduction in required flexible overlay thickness if a bituminous overlay is used. There have been some indications that a bituminous concrete pavement performs better than an equal flexible pavement thickness; however, there is some evidence that the difference in performance in the two types of pavement may be a function of load and wheel arrangement. The reduction represented by the FAA equation for bituminous overlay has not been substantiated by traffic tests using aircraft loadings and multiple-wheel gears.

RIGID OVERLAY OF RIGID PAVEMENTS

Rigid overlay of rigid pavements was not a part of the MWHGL study; however, a review of the FAA criteria indicates that it has been developed from past full-scale traffic tests. It is believed that the criteria are still valid when used with the newly developed pavement thickness criteria for the determination of required thickness of an equivalent slab of rigid pavement.

COMPACTION REQUIREMENTS BENEATH RIGID PAVEMENTS

The results of the MWHGL study indicate the need for careful consideration of an increase in compaction requirements with depth. Since density as a function of depth was not a variable in the MWHGL study, the results of the study do not provide data for a change in the requirements. In addition to this, no previous test track studies have included foundation compaction as a variable. The compaction requirements contained in Change 3 to the FAA Advisory Circular 150/5320-6A, dated 1 April 1970, represent a substantial increase for rigid pavements; the MWHGL studies did not provide data with which to evaluate the validity for these requirements. It may be of interest to note that the FAA Change 3 would have required densities of 95 percent of CE 55 maximum density* to a depth of 8 in., 90 percent from 8 to 16 in., 85 percent for 17 to 24 in., and 80 percent from 24 to 32 in. in the foundation for the MWHGL test track. This is contrasted to the densities of about 85 percent of maximum density* actually constructed. Had the FAA density requirements been used, the subgrade modulus would have been higher and the slab thickness for the design traffic volume would have been less. However, it is difficult to say whether performance of the test sections would have been materially different insofar as the joint performance, pumping, and deformations are concerned.

* Maximum density as determined by Test Method 100 (Reference 3).

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13. ABSTRACT

This document presents recommended changes to Federal Aviation Administration (FAA) Advisory Circular No. 150/5320-6A, Airport Paving, relative to design and evaluation of airport pavements subject to traffic resulting from operation of the Boeing 747 and/or Lockheed C-5A aircraft. Criteria for flexible and rigid pavements were prepared in accordance with procedures developed as a result of an engineering investigation of the effects of traffic of multiple-wheel heavy gear loads.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Aircraft landing areas						
Concrete pavements						
Flexible pavements						
Multiple-wheel heavy gear loads						