AD-A008 475

PROCEDURE FOR THE NON-DESTRUCTIVE EVALUATION OF FLEXIBLE AIRFIELD PAVEMENTS

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January 1975

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS
BEFORE COMPLETING FORM

1. REPORT NUMBER
AFCEC-TR-75-1

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER
AD-A008475

4. TITLE (and Subtitle)
Procedure for the Non-Destructive Evaluation of Flexible Airfield Pavements

5. TYPE OF REPORT & PERIOD COVERED
Final Report;
Oct 72 to Jan 75

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
Captain Douglas I. Hanson
Directorate of Laboratories

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Air Force Civil Engineering Center
Tyndall AFB, Florida 32401

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS

12. REPORT DATE
January 1975

13. NUMBER OF PAGES
~~57~~ 58

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release;
distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
US Department of Commerce
Springfield, VA. 22151

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Pavement design, asphalt paving materials, pavement evaluation

PRICES SUBJECT TO CHANGE

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A procedure for the non-destructive evaluation of flexible airfield pavements is presented. The procedure consists of accomplishing a condition survey using a mechanistic procedure and the accomplishment of a deflection study using a Benkelman Beam and an aircraft at close to maximum load. Procedures are developed and presented for use in the prediction of either the allowable aircraft gross load at specified operational levels or the prediction of the allowable coverage levels at specified gross loadings.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

FOREWORD

This report was prepared by the Air Force Civil Engineering Center, Tyndall AFB, FL.

This report summarizes work done between October 1972 and January 1975.

This report has been reviewed by the Information Officer (IO) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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ABSTRACT

A procedure for the non-destructive evaluation of flexible airfield pavements is presented. The procedure consists of accomplishing a condition survey using a mechanistic procedure and the accomplishment of a deflection study using a Benkelman Beam and an aircraft at close to maximum load. Procedures are developed and presented for use in the prediction of either the allowable aircraft gross load at specified operational levels or the prediction of the allowable coverage levels at specified gross loadings.

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I. INTRODUCTION

A. The U. S. Air Force owns enough airfield pavement to be able to build a 200 foot wide runway stretching from the state of Washington to the southern tip of Florida. These airfield pavements are required to support aircraft loads and gear configurations ranging from 750,000 lbs and 24 wheels to 12,000 lbs and two wheels and as many as 150,000 operations per year. Air Force civil engineers are concerned with the expected performance of these pavements, and with the extension of their service life or their rehabilitation. To determine the expected performance of a pavement, a reliable, non-destructive method of pavement evaluation is urgently needed.

B. This paper presents a procedure for the evaluation of flexible pavements which consists of two steps: conducting a comprehensive condition survey of the pavement system by noting any visible surface defects and conducting a deflection survey of the airfield system using a Benkelman Beam and an aircraft (preferably a mission aircraft at as close to maximum gross weight as possible).

II. CONDITION SURVEY

A. A condition survey in one form or another is used by most agencies involved in the design, construction, and maintenance of pavement systems. The condition survey is used by the engineer manager to determine deficiencies in the pavement structure, to record the degradation of a pavement system, and to determine the type and extent of any maintenance or rehabilitation required. It is a combination of a mechanistic and subjective survey of the system. The detailed observation of the performance under the loads it actually carries will provide a general clue of where the distress occurs in a pavement structure, as any distress in the structure will be reflected in the surface condition in such forms as rutting, cracking, etc.

B. Figure 1 presents a mechanistic procedure in the form of a Flexible Pavement Condition Survey Reporting Form. This form is an adaptation of one in use by the Ontario Ministry of Transportation and Communications (Ref 8). In it, the distress manifestations are grouped under three headings: surface defects, permanent deformation, and cracking. The results of the survey are totaled to obtain a total defect score. Then, each pavement is given an overall rating based on the subjective feelings of the inspecting engineer about the condition of the pavement feature. The overall ratings are as follows:

1. GOOD. Pavements in better than average condition with no conspicuous evidence of deformation or incipient failures and few (if any) longitudinal, transverse or shrinkage cracks. All existing defects are properly maintained.

2. FAIR. Pavements with a higher percentage of transverse longitudinal or pattern cracking and minor defects such as weathered or oxidized surface, random cracking and minor deformation or rutting.

3. POOR. Severe surface deformation, such as rutting shear failure, densification, heave or raveling, cracking, or evidence of intrusion of surface water into the moisture-sensitive subsurface layers.

The use of the form results in a mechanistic documentation of the condition of each feature.

III. DEFLECTION SURVEY:

A. BACKGROUND:

1. There is a general agreement among pavement engineers that the measurement of the recoverable resilient deflection of a pavement structure can provide valuable information about the structural capacity of the pavement. Based on a review of the literature, certain observations can be made concerning the deflection of a flexible pavement:

(a) For adequately designed pavements, the deflection taken during the same season of the year remains constant for the life of the pavement, until fatigue failure begins.

(b) There is a tolerable level of deflection which is a function of traffic and which can be established based on the fatigue life of the pavement.

(c) Overlaying a pavement will reduce its deflection and the thickness needed to reduce it to a tolerable level can be established.

2. A typical deflection history curve, representing the performance of a well designed pavement structure is shown in Figure 2. The strength of a pavement undergoes three phases in its behavior:

(a) The initial phase, immediately after construction, in which the pavement structure is further consolidated and strengthened during which the deflection shows a slight decrease.

(b) The functional phase during which the pavement will carry the anticipated traffic without undue deformation and the deflection will remain fairly constant or may show a slight increase.

(c) The failure phase occurring under the repeated stresses of both traffic and environmental factors which cause the deflection to increase rapidly. In this phase, there is a rapid deterioration and resulting failure of the pavement structure.

3. The basic concepts underlying the development of the deflection procedures described in this report are that the pavement deflection for each season of the year remains constant throughout the life of the pavement structure and that most flexible pavements within the Air Force are in the functional phase of their life. Based on these concepts coupled with a capability to predict the life of a pavement structure, it is believed that a non-destructive procedure for the evaluation of the structural capacity of flexible pavements can be developed. The procedure developed involves the use of a Benkelman Beam to measure the deflection of a pavement structure under an aircraft.

B. TEST PROCEDURE. The Benkelman Beam was chosen because it is a versatile, inexpensive piece of equipment that requires little or no maintenance and can be operated by individuals with little prior experience in its use. It has also been found that this equipment could be used to accurately measure deflection. Detailed procedures are included in Appendix A. The beam is used in conjunction with an aircraft loaded as close as possible to its maximum gross weight. Because of the range of aircraft loads, a stiffness procedure was used to normalize the changes in wheel load. Stiffness is calculated by dividing the single wheel-load (SWL) or the equivalent-single-wheel-load (ESWL) by the deflection; thus stiffness is the slope of the load versus deflection plot for the pavement structure.

C. THEORETICAL STUDIES.

1. The theoretical studies were accomplished using a computer program for the analsyis of layered systems under normal surface loads. This program was developed in the late 1960s by the Shell Laboratory in Amsterdam, the Netherlands, and it is commonly known as BISTRO. The program was used to determine the load versus deflection characteristics of flexible pavement structures and to determine what effect changing the tire contact area or pressure has on the deflection of a flexible pavement structure. In all the theoretical studies, a modulus of 350,000 psi was used for the AC surfacing. The moduli of the base course and the subgrade materials were varied. Based on comments by Chou, et. al. (Ref 3) a Poisson's ratio of .4 was used for all asphalt mixtures, a Poisson's ratio of .48 was used for granular base materials. and .4 was used for subgrade materials. Also, an empirical equation for fine grained subgrade materials that relates CBR to modulus of elasticity, E(psi) = 1500 CBR, is presented in ref 3. This relationship was used in the current study.

2. To study the relationship between load and deflection, two pavement structures were used, both with 4 1/2 inches of AC surfacing; the first had a 9 inch base course, the second had an 18 inch base course. A modulus of 80,000 psi was used for the base and a modulus of 22,000 psi (or a CBR of 15) was used for the subgrade. As can be seen from Figure 3, the theoretical

load-deflection curve is linear and the thicker the pavement structure, the flatter the slope of the load-deflection curve, with a stiffness of 684 kip/in for the 9 inch granular base and a stiffness of 813 kip/in for the 18 inch granular base. Thus, the stiffness concept should work for analyzing flexible pavement structures.

3. Another study was conducted to determine the effect of changing the contact area/tire pressure on deflection. Figure 4 presents the results of studies conducted using the same three-layer pavement systems discussed above. Two wheel loads were used: 15,000 lb and 40,000 lbs. The tire pressures were varied from 100 to 300 psi, thereby providing tire contact areas of from 400 square inches to 50 square inches. Contact area is calculated by dividing the wheel load by the tire pressure. The stiffness concept was used to normalize the load-deflection variable. It can be seen that as the contact area of the applied load increases for the same pavement structure there is an increase in stiffness. This occurs with both the 9 inch base and the 18 inch base pavement structures, with the slope being flatter for the 9 inch base course. This indicates that when aircraft with different tire contact areas, even when they have the same wheel load, are used to determine stiffness, a procedure for correcting the stiffness for changes in contact area must be developed and used.

D. STIFFNESS-PERFORMANCE RELATIONSHIPS:

1. To have a valid design or evaluation procedure, the parameter or parameters measured in the field must be tied to the performance of a pavement structure. A relationship developed by A. Joseph and J. Hall (Ref 4) is proposed. That study developed relationships between elastic pavement deflection and the number of traffic applications necessary to cause failure. The basis of their study was past work done on both airfield and highway pavements. Included in the highway studies were the WASHO highway tests, AASHO highway tests, the Arkansas highway tests and the Virginia highway tests. Included in the airfield studies are the Stockdale tests conducted in 1942, the Barksdale tests conducted in 1943, the Stockdale tests conducted in 1945, the Heavy Gear Load Pilot Test Section investigation conducted in 1956 and the Multiple-Wheel Heavy Gear Load (MWHGL) Test Section studies conducted in 1968 and 1969.

2. Joseph and Hall presented four equations in their report that relate elastic deflection, coverages to failure, tire pressure, wheel load, thickness of pavement structure and CBR to one another. The equations were developed using best fit techniques. The following equation is of significance to the current study:

$$C = \frac{0.02106\ P^{1.4433}}{p^{1.7235}\ D^{2.3174}} \qquad \text{(EQ 1)}$$

Where: C = coverages to failure

D = elastic deflection, inches

p = tire pressure, psi

P = single-wheel load, lbs

3. The preceding equation was developed using single-wheel data from airfield test sections and Joseph and Hall reported that the regression analysis had a correlation coefficient of .80.

4. The preceding equation was adapted so that it could be used to compute allowable single-wheel load for various operational levels in coverages, C, when stiffness, S in kips/inch, and contact area, A in sq inches, are used as input. The following is the adapted equation:

$$P = \frac{69.94\ A^{.6368}\ S^{.856}}{C^{.3695}} \qquad \text{(EQ 2)}$$

5. To use the adapted equation to calculate the allowable loadings for multiple-wheel aircraft, the deflection under a load presented by a multiple-wheel aircraft must be equated to that under an equivalent single-wheel. This is accomplished by using the ratio of theoretical deflection factors for a uniform circular load on a homogeneous elastic half-space (Boussinesq analysis). The deflection under a test wheel of a multiple-wheel assembly is increased by a ratio of the deflection factor beneath that point at which the measurement is made to the maximum deflection factor for that multiple wheel assembly. This adjusted deflection is divided into the equivalent-single wheel load (ESWL) for that assembly to obtain stiffness in kips per inch. ESWL is defined as the load on a single wheel of the same contact area as one wheel of the multiple-wheel assembly that produces a maximum deflection equal to that beneath the multiple-wheel assembly. Appendix B contains procedures for computing ESWL.

E. TEMPERATURE-DEFLECTION RELATIONSHIPS. Because of the thermo-viscoelastic nature of asphaltic materials, an important factor in the analysis of the deflection of a flexible pavement structure is the temperature of the bituminous surface. As the surface temperature goes up, the stiffness of the asphalt layer goes down and the deflection goes up.

Therefore, the deflection of a pavement must be adjusted by some factor so that all deflections or stiffnesses are related to a base temperature. The temperature of the pavement surfacing can be adjusted for in one of two ways. The first and preferable method is to develop a temperature-deflection relationship for the specific pavement structure being tested. This can be accomplished by testing the same point at different times throughout the day. If this is not possible, the curves developed by Kingham (Ref 5) shown in Figure 5, give a close approximation for use in adjusting the deflection for temperature changes.

F. SEASONAL VARIATIONS IN DEFLECTION. The load carrying capabilities of a flexible pavement structure vary throughout the year due to the effects of frost, temperature and moisture. This effect on the magnitude of the total deflection of a pavement structure is shown in Figure 6. As pointed out in Reference 9, the annual strength history of a flexible pavement can be divided into four periods: deep frost which is when the pavement is the strongest; when frost is beginning to disappear from the pavement structure, during which the deflection rises rapidly; when the water from the melting frost drains out of the pavement structure and the deflection begins to drop; and the period during which the deflection levels off with a general downward trend as the pavement structure continues to slowly dry out.

G. EXPERIMENTAL STUDIES:

1. Aircraft Comparison Study:

a. At Nellis AFB, Nevada, a study was conducted to compare the deflections obtained under four different single-wheel aircraft with five different pavement structures. All the data were collected in a two-day period during a time of year when the temperature adjustments for the individual data points should be minor. Table 1 presents the results of that study. Note that the stiffnesses vary for each aircraft. For example, in Feature 4, the stiffness for the F-111 is 1510 kips/in and for the A-7 it is 730 kips/in. The reason for this disparity is due to the differences in contact area, as was pointed out to be a possible problem under the previous theoretical discussions.

b. Because of this disparity, a study was conducted using a mathematical relationship that relates deflection to the moduli and thickness of layers in a two layer elastic-layered system. The equation was developed by J. M. Kirk and presented at the Rome International Congress of Roads, and was obtained for this study from a report by Kingham (Ref 5). The equation is given below:

$$d = \frac{1.5pa}{E_s}\left(F_1 + F_2\right), \text{ where:}$$

$$F_1 = \left[1 - \frac{1}{\sqrt{1 + 0.8(t/a)^2}}\right]\frac{E_s}{E_p} \qquad \text{(EQ 3)}$$

$$F_2 = \left[\frac{1}{\sqrt{1 + \left(0.8t/a\,\sqrt[3]{E_p/E_s}\right)^2}}\right]$$

d = pavement deflection, inches.

p = contact pressure, psi

a = radius of contact area, inches

t = pavement thickness, inches

E_p = asphalt pavement modulus, psi

E_s = subgrade modulus, psi

c. Using this equation with a pavement modulus, Ep, of 350,000 psi, a subgrade modulus was computed for each of the pavement structures at Nellis using the deflections and wheel loads for the F-4 aircraft. This subgrade modulus was used with the wheel loads for the other aircraft to compute deflection for the five pavement structures under those aircraft. The data are summarized in Table 2 and the theoretical deflections versus the measured deflections are plotted in Figure 7.

d. A trial and error procedure was used with the BISTRO computer code to determine a base course modulus for the Nellis AFB pavement structures, holding the modulus of the surfacing material constant at 350,000 psi and the subgrade modulus constant at 22,000 psi. A base course modulus was determined that would give a calculated deflection for the F-4 equal to that actually measured in the field. The modulus determined was used to calculate the predicted deflection for each of the test aircraft. The results of these calculations are presented in Table 3 and are plotted in Figure 8. Because of the similarities of feature 3 and 4, feature 3 was not used in this comparison.

e. An analysis of the Nellis data indicates that both the two-layer equation and the BISTRO computer code can be used with a fair degree of accuracy to predict the deflection of simple pavement structures under a single-wheel aircraft when the general nature of the pavement structure is known and a measured deflection from another aircraft is known.

2. Field Studies:

a. In conjunction with destructive pavement evaluation studies accomplished in accordance with standard Air Force procedures, the Benkelman Beam was used to measure deflection under various aircraft. The aircraft included the F-102, F-4, F-111, B-52 and C-130 with most of the work being done with the F-4. The primary purpose of this work was to assist the field pavement evaluation teams in the location of exploratory test pits and to provide data that would be valuable in the analysis of materials testing data. Pavement temperature data were not obtained. Table 4 contains a summarization of the deflections and material properties at each of the Air Force installations included in the test studies.

b. During this work, the field procedures for use of the Benkelman Beam with various aircraft types and gear configurations were worked out. Based on this work the following observations are made:

(1) The procedure can be used very successfully to locate weak and strong points on an airfield system, provided a systematic data collection procedure is used.

(2) At two installations (Luke AFB and Nellis AFB), the use of the procedure located areas on the runway where failures in the form of rutting and surface disintegration occurred shortly after the completion of the study. In both cases, the problem was not manifested in the surfacing at the time of the field work.

(3) The deflections at Clark AB appeared to be large when compared with the base and subgrade strengths. This may be due to a possible difference in the deflection characteristics of a non-plastic versus plastic subgrade, since the subgrade at Clark was predominantly nonplastic and in the other studies the subgrades were mainly plastic.

(4) When a large cargo or bomber aircraft such as the B-52 is used as a loading aircraft, the radius of the deflection basin may exceed the length of the Benkelman Beam probe and two beams set up tail to head are required to measure the deflection.

c. An attempt was made to develop a relationship between deflection and the allowable gross load (AGL) as would be calculated using standard Air Force pavement evaluation procedures (based on the CBR test). To accomplish this, the AGL was computed for the F-4 aircraft for each of the pavement structures presented in Table 4. The resulting AGL is plotted against deflection in Figure 9. Using this data, a simple regression analysis was accomplished. The resulting correlation coefficient was .488 which based on 25 data points indicates that AGL as computed using CBR procedures does not correlate with deflection. This is not surprising when it is considered that the CBR procedure is based on the concept of protecting the weakest layer in the pavement structure from a shear failure and does not totally consider the rigidity of the pavement structure, whereas the deflection is a result of the contribution of each layer in the structure to the structural capacity of the pavement.

IV. PROPOSED EVALUATION PROCEDURE:

A. This section presents the steps that must be followed to evaluate a flexible airfield pavement system using the background developed in this report.

B. The first step is to obtain background data on the airfield system to include the following:

1. Construction History. This is the history of maintenance, repair and reconstruction from time of original construction and should include a description of the components in the pavement structure, material types, thickness and estimated strengths. This data can be obtained from previous evaluation or construction reports.

2. Traffic History. The character and composition of the aircraft traffic should be obtained together with any traffic data peculiar to the aerodrome being evaluated, such as particular taxi patterns, which end of the runway is used for launching aircraft, etc.

3. Miscellaneous. Other information that may affect the evaluation such as weather and precipitation data, drainage facilities and conditions and evidence of frost problems.

C. The second step is to conduct a condition survey of the pavement system. This is done by first dividing the airfield system into features relative to their design and construction history and then using the Flexible Pavement Condition Survey Reporting Form (Figure 1) to record the condition of each pavement feature.

D. The third step is to conduct a deflection survey using a Benkelman Beam and the primary aircraft assigned to the installation. The following steps should be followed:

1. Conduct a deflection survey using the procedure outlined in Appendix A.

2. Compute the average deflection for each feature surveyed.

3. Correct the deflection for temperature by multiplying the temperature adjustment factor times the average deflection.

4. Compute the ESWL (See Appendix B) or Single Wheel Load (SWL) for the test aircraft.

5. Using Kirk's two-layer equation, with the actual thickness of the bituminous layer as obtained from construction history, the ESWL for the test aircraft, the average deflection and an estimated modulus for the bituminous layer, calculate the subgrade modulus, or Figures 10 through 16, can be used.

6. Again, using Kirk's equation or Figures 10 through 16, determine the stiffness for other aircraft types.

7. Determine the allowable gross load for the appropriate operational level using Hall's equations, or by using Figures 17 through 21. If the number of coverages to failure is desired Hall's equations can be used.

V. CONCLUSIONS.

A. A proposed non-destructive pavement evaluation procedure for flexible pavements has been developed that can be used to determine either the operational level (in coverages) or the allowable gross load (in pounds) for any aircraft excluding the C-5A.

B. The procedure developed in this report is probably more applicable to single-wheel aircraft than to complex multiple-wheeled aircraft. This is because the basic equations for converting deflection to performance and for extrapolating deflection of one aircraft type to another aircraft type are based on single-wheel data.

VI. RECOMMENDATIONS.

A. That the study outlined in Appendix C be accomplished to answer the following questions:

1. Is the temperature adjustment curve in Figure 5 correct?

2. Can single-wheel deflections be used to estimate multiple-wheel deflections?

3. Is the basic assumption that the deflection of a pavement is constant from year to year for each season of the year valid?

4. What is the seasonal variation in pavement deflection for various geographical locations throughout the continental United States?

5. Can the deflection from one multiple-wheeled aircraft be used to determine the deflection for another multiple-wheeled aircraft?

B. That a test plan be developed to examine the lower range of accuracy of the Benkelman Beam. Accuracy tests will be required on rigid pavements under aircraft loadings, using devices such as LVDT's to verify deflection readings obtained with the Benkelman Beam.

C. That the proposed procedures outlined in this report be used in appropriate circumstances to supplement procedures currently utilized in the evaluation of Air Force airfield flexible pavement systems.

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2. AFM 88-24, Chapter 2, "Flexible Pavement Evaluation."

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TABLE 1

NELLIS AFB NDPE TEST DATA

FEATURE NUMBER	PAVEMENT STRUCTURE	AVERAGE DEFLECTION AND STIFFNESS FOR EACH AIRCRAFT							
		F-4		F-111		F-105		A-7	
		WL = 21,900 lb TP = 265 psi A = 83 in^2		WL = 36,300 lb TP = 510 psi A = 259 in^2		WL = 19,000 lb TP = 200 psi A = 95 in^2		WL = 13,200 lb TP = 215 psi A = 61 in^2	
		D	S	D	S	D	S	D	S
1	4 1/2"AC/14" GP/CL	.0210	1040	.0263	1475	.0225	880	.0137	960
2	4 1/2"AC/9" SM/CL	.0308	710	.0481	300	.0332	600	.0197	670
3	4 1/2"AC/6" GP/8" GM/CL	.0259	845	.0327	1190	.0258	770	.0187	700
4	4 1/2"AC/18" GP/CL	.0258	850	.0257	1510	.0225	380	.0170	780
5	4 1/2"AC/6" GP/10"GM/CL	.0249	880	.0316	1227	.0223	390	.0195	680

NOTE:
D - DEFLECTION (inches)
S - STIFFNESS (KIPS/IN)
WL - WHEEL LOAD (lbs)
TP - TIRE PRESSURE (psi)
A - TIRE CONTACT AREA (in^2)
AC - ASPHALTIC CONCRETE

Other symbols under "Pavement Structure" refer to base and subbase classification utilizing Unified Soil Classification System.

TABLE 2

PREDICTED VERSUS ACTUAL DEFLECTIONS USING KIRK'S EQUATION

FEATURE NR.	F-4		F-111		F-105		A-7	
	MEASURED	CALCULATED E_s	MEASURED	PREDICTED	MEASURED	PREDICTED	MEASURED	PREDICTED
1	.021	62,500	.0263	.027	.0225	.018	.0137	.014
2	.0308	39,000	.0484	.041	.0332	.027	.0197	.0196
3	.0259	47,750	.0327	.0335	.0258	.0224	.0187	.0165
4	.0258	49,750	.0335	.0225	.0225	.0224	.0170	.0165
5	.0249	52,000	.0716	.0323	.0225	.0216	.0195	.0163
AVERAGE			.0323	.0334	.0253	.0223	.0177	.0165
% DIFF			1.7%		11.8%		6.6%	

NOTE: E_s = Subgrade modulus calculated from deflections and wheel loads for F-4 aircraft using Equation (3).

TABLE 3

PREDICTED VERSUS ACTUAL DEFLECTION USING BISTRO

FEATURE NR.	F-4		F-III		F-105		A-7	
	MEASURED	CALCULATED E_s	MEASURED	PREDICTED	MEASURED	PREDICTED	MEASURED	PREDICTED
1	.021	162,000	.0263	.0314	.0225	.0190	.0137	.0143
2	.0308	89,000	.0484	.0450	.0332	.0271	.0197	.0200
4	.0258	34,000	.0257	.0368	.0225	.0227	.0170	.0169
5	.0249	96,000	.0316	.0362	.0223	.0222	.0195	.0166
AVERAGE	.0256		.0330	.0373	.0251	.0227	.0174	.0169
% DIFF.			13.0%		9.6%		2.9%	

TABLE 4

FLEXIBLE PAVEMENT DEFLECTION SUMMARY

BASE	AIRCRAFT	GROSS LOAD (LBS)	WHEEL LOAD (LBS)	TIRE PRESSURE (psi)	DEFLECTION (inches)	TEST PIT NUMBER	ASPHALTIC CONCRETE THICKNESS (inches)	SOILS DATA
LUKE	F-4	47,700	20,892	265	.022	2	5	9"SP/CBR=100(4%); ML-CL/CBR=30
					.0245	3	5	6"SP/CBR=85(4%); 4"SP/CBR=90(4%); CL/CBR=40
					.036	4	3	11"GP/CBR=25; SC/CBR=10
					.022	8	3	6"GP/CBR=100; 7"SP/CBR=75; ML/CBR=35
					.030	10	6 1/2	6"GP/CBR=75; SP/CBR=35; ML-CL/CBR=15
NELLIS	F-111	81,486	38,700	155	.104	5	5	5 1/2"GP-GM/CBR=60; 3"SC/CBR=35; GC/CBR=25
					.046	6	5	12"GP/CBR=70; CL/CBR=20
	F-4	48,270	21,140	260	.0185	8	5	GRAVEL POCKET - GW/CBR=100
SEYMOUR JOHNSON	F-4	49,650	21,740	265	.0420	2	6	4 1/2" SAND ASPHALT; SP/CBR=30
					.0665	3	5	11"SP/CBR=25; CL/CBR=10
					.028	4	5 1/2	6"GW/CBR=80; 12"SP/CBR=60; SP-SM/CBR=50
MINOT	B-52	458,000	REAR TRUCK 59,540 ESWL 73,136	285	.075	2	5	8"GW/CBR=95; 21"SP/CBR=45; 43"SP/CBR=25; CL/CBR=7
					.088	3	4 1/2	8"SW/CBR=100; 24"SP/CBR=45; 36"SP/CBR=30; CL/CBR=8
					.090	4	5 1/2	9"GP/CBR=100; 30"SP/CBR=85; 28"SW/CBR=20; CL/CBR=7
ANDREWS	C-130	115,000	25,900 ESWL-28,260	95	.036	11	4	8"GP-GM/CBR=50; 8"SM/CBR=30; CL/CBR=16

TABLE 4 CONTINUED

BASE	AIRCRAFT	GROSS LOAD (LBS)	WHEEL LOAD (LBS)	TIRE PRESSURE (psi)	DEFLECTION (inches)	TEST PIT NUMBER	ASPHALTIC CONCRETE THICKNESS (inches)	SOILS DATA
CLARK	F-4	53,000	23,200	265	.031	2	7 1/2	6"SM/CBR=60; SW/CBR=30
					.060	8	8	7"GP/CBR=75; SP/CBR=60
					.047	10	7	2 1/2" SP-SM/CBR=50; 6"SM/CBR=90; SP/CBR=100
VOLK	F-102	31,000	13,950	-	.040	1	7	9"SP/CBR=10; SP-SM/CBR=60
					.018	3	5 1/2	8"SM/CBR=30; SP-SM/CBR=45
					.0165	4	6	6"SP-SM/CBR=24; SP/CBR=32
					.009	7	4	24"GP/CBR=75; SP/CBR=11
					.008	8	8	6"GP-GM/CBR=45; SP/CBR=47
					.016	9	8 1/2	10"SP-SM/CBR=55; SP/CBR=30
					.0205	11	4	6"SP-SM/CBR=70; 4"AC; 14"SP-SM/CBR=20; SP/CBR=4
					.0245	12	7	12"SP/CBR=45; SP-SM/CBR=16
					.0715	13	3	SP/CBR=8

BASE: ______________________ **DATE:** ____________

FEATURE DESCRIPTION: ______________________

TYPE DISTRESS		SEVERITY OF DISTRESS				
		VERY SLIGHT 2	SLIGHT 4	MODERATE 6	SEVERE 8	VERY SEVERE 10
SURFACE DEFECTS	RAVELING					
	OXIDATION					
	FUEL SPILLAGE					
	JET BLAST DAMAGE					
SURFACE DEFORMATION	RUTTING					
	FROST HEAVE					
	SHOVING					
SURFACE CRACKING	LONGITUDINAL					
	TRANSVERSE					
	MAP					
	SHRINKAGE					
	REFLECTION					
	ALLIGATOR					

GENERAL CONDITION

GOOD ______

FAIR ______

POOR ______

SURFACE DRAINAGE

GOOD ______

FAIR ______

POOR ______

IS MAINTENANCE REQUIRE

____

GENERAL COMMENTS

____

____

____

____

____

____

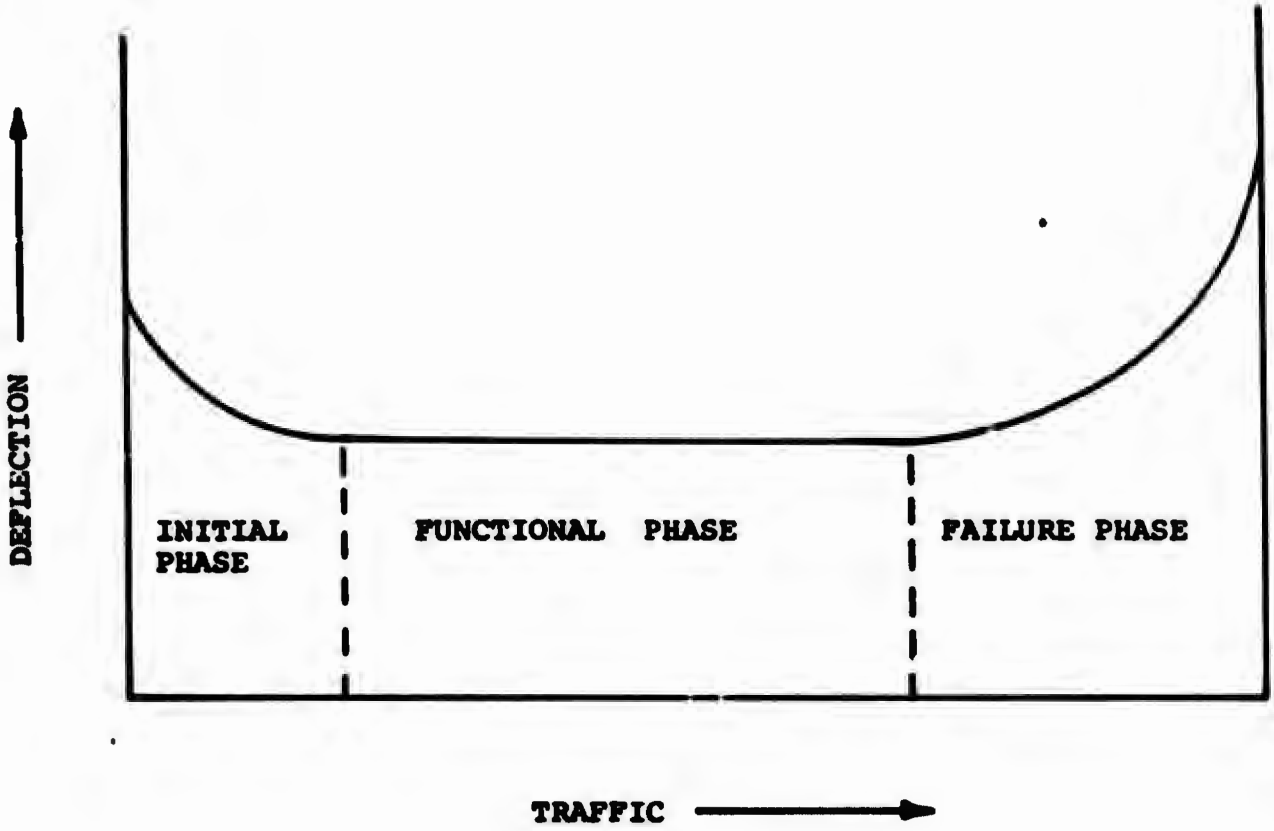
____

____

TOTAL DEFECT SCORE

____

FIGURE 1. FLEXIBLE PAVEMENT CONDITION SURVEY REPORTING FORM



IGURE 2. DEFLECTION HISTORY CURVE FOR WELL DESIGNED PAVEMENT STRUCTURE (Ref

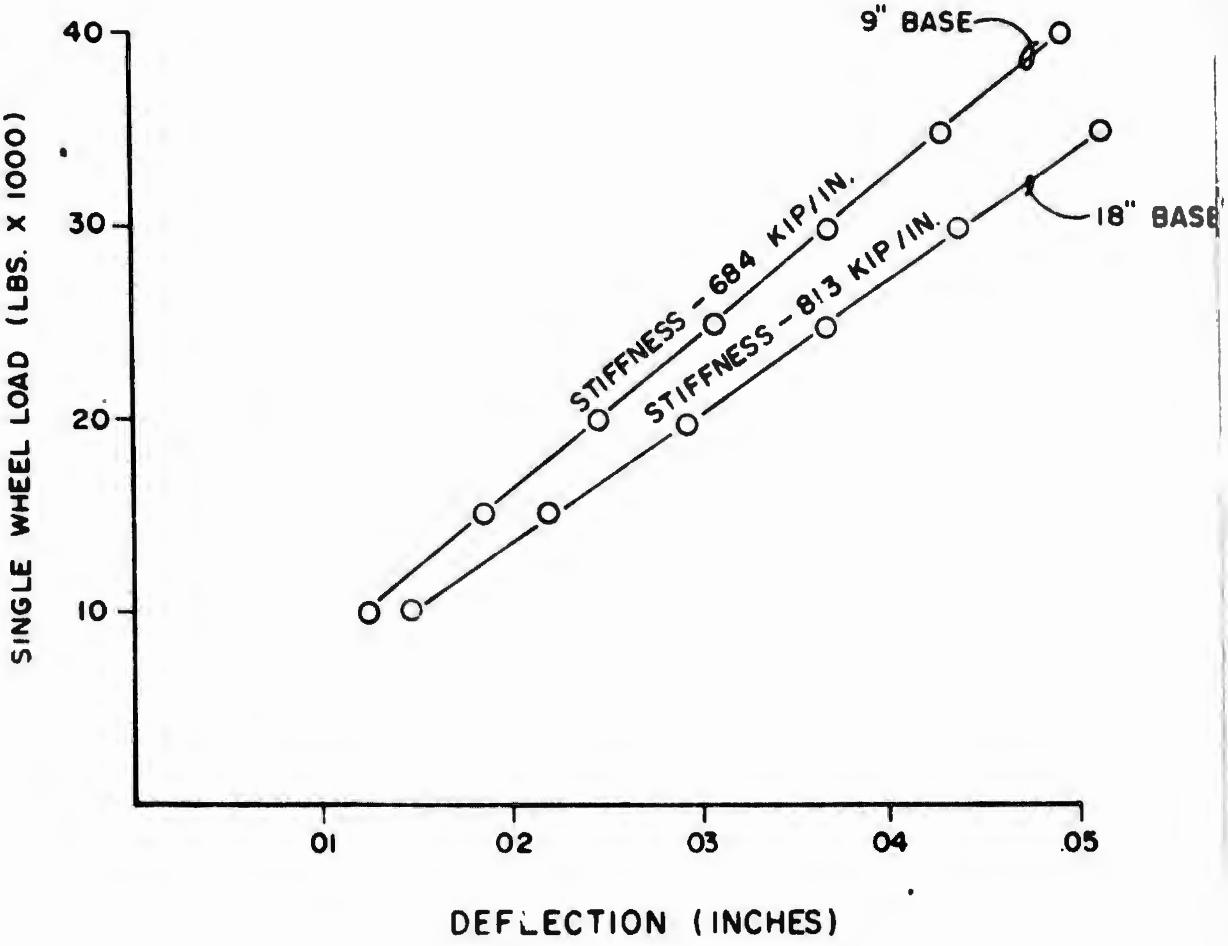


FIGURE 3. THEORETICAL LOAD-DEFLECTION CURVES

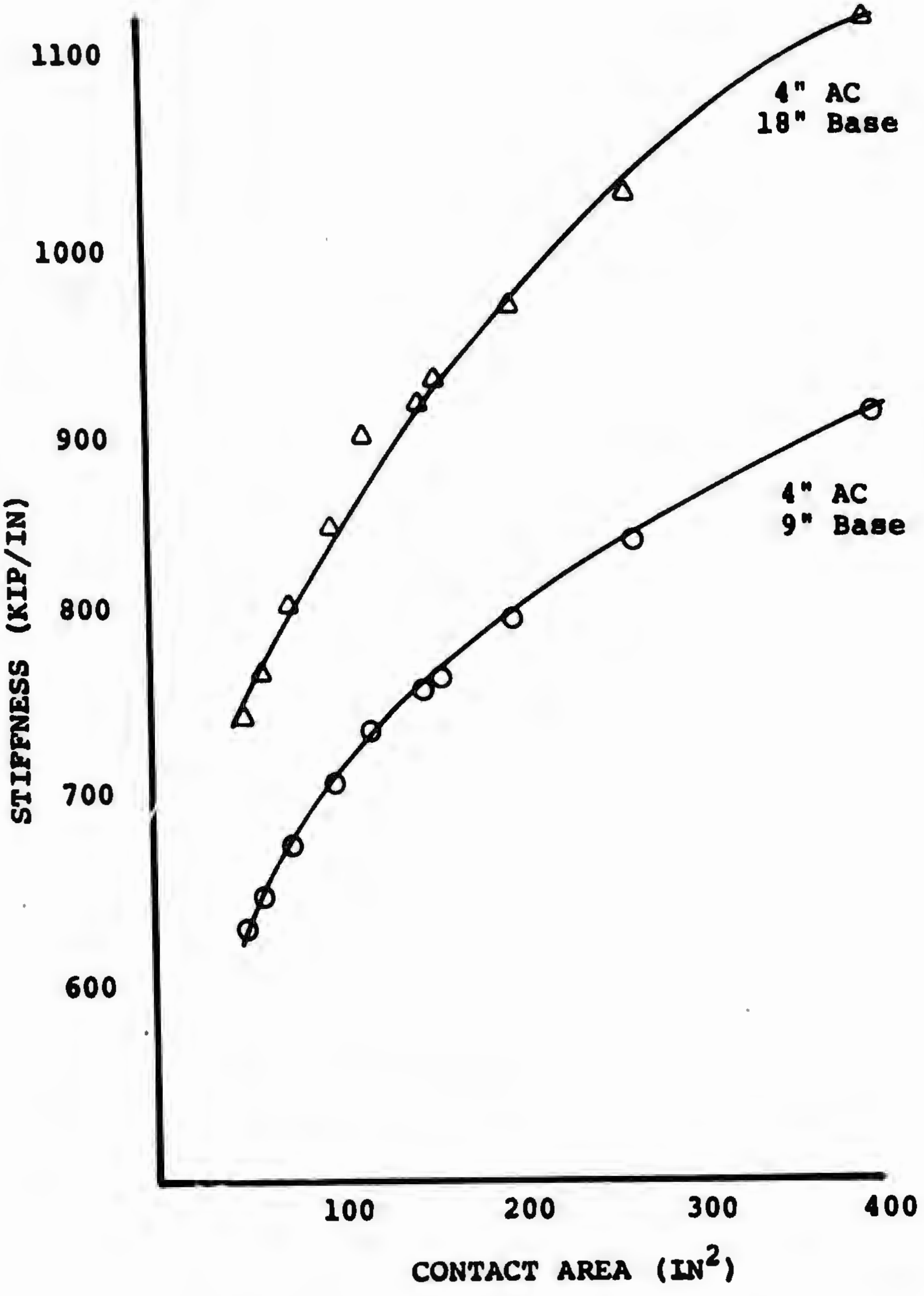


FIGURE 4. THEORETICAL RELATIONSHIP BETWEEN STIFFNESS AND TIRE CONTACT AREA

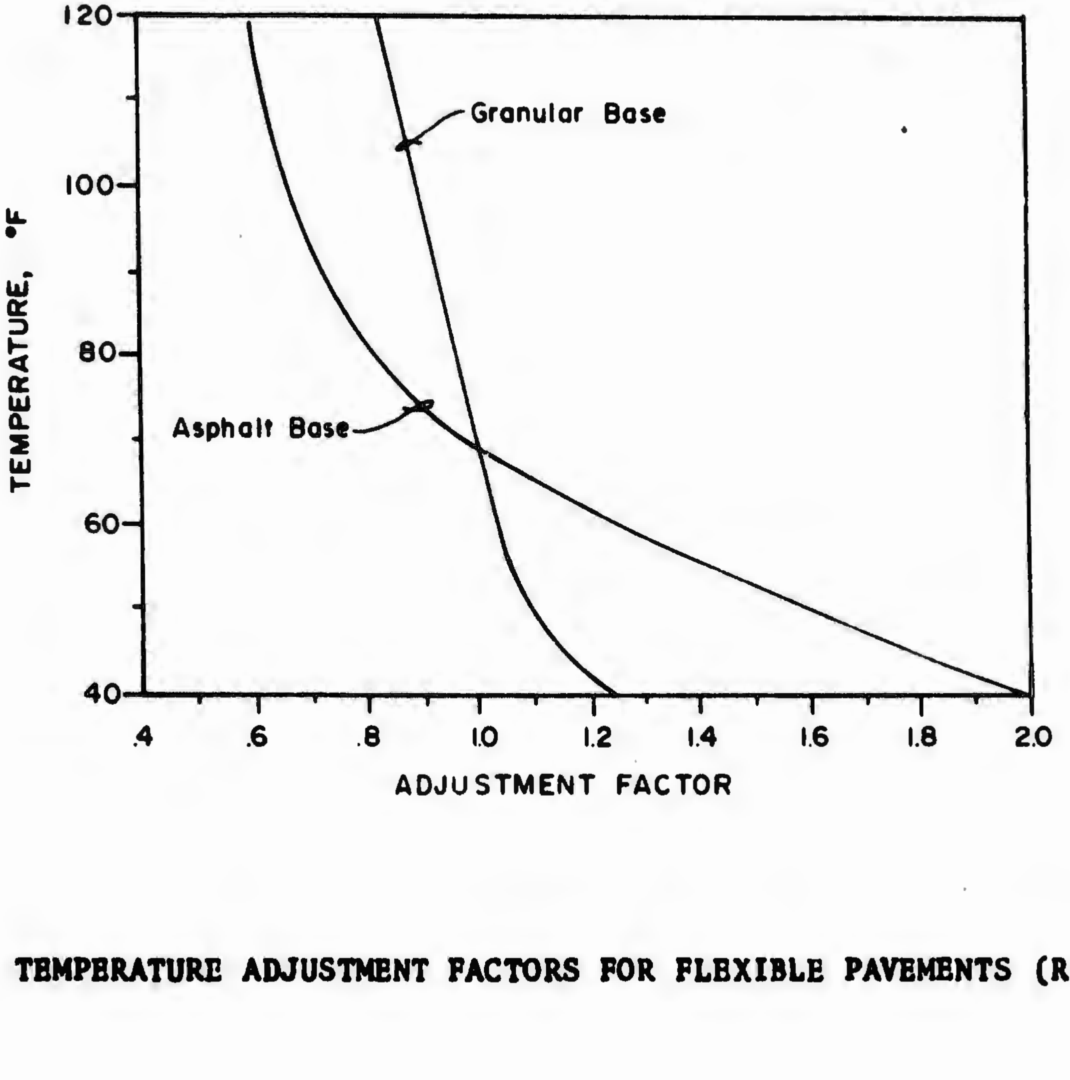
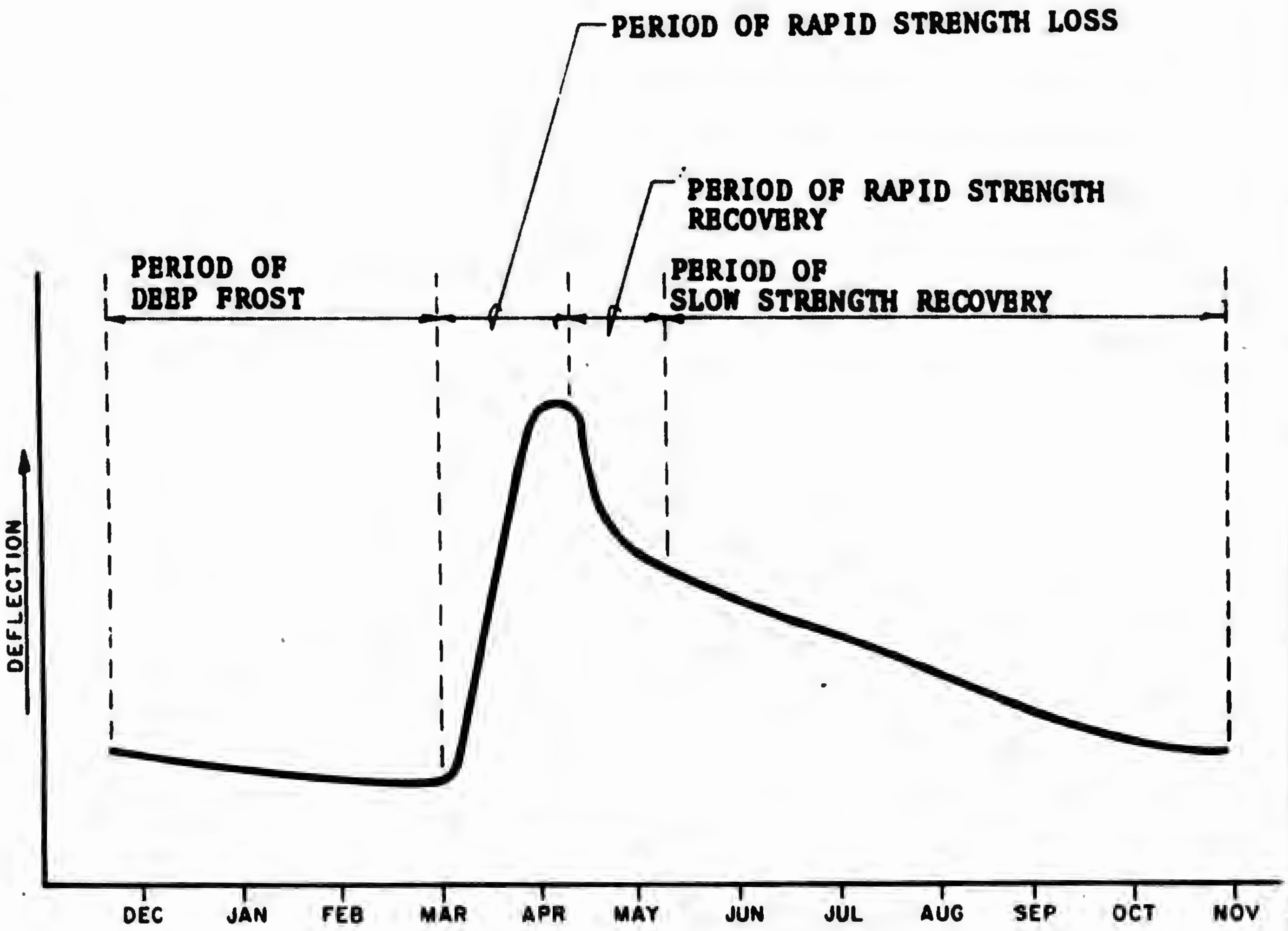


FIGURE 5. TEMPERATURE ADJUSTMENT FACTORS FOR FLEXIBLE PAVEMENTS (Ref 5)



IGURE 6. TYPICAL SEASONAL VARIATIONS IN DEFLECTION (Ref 9)

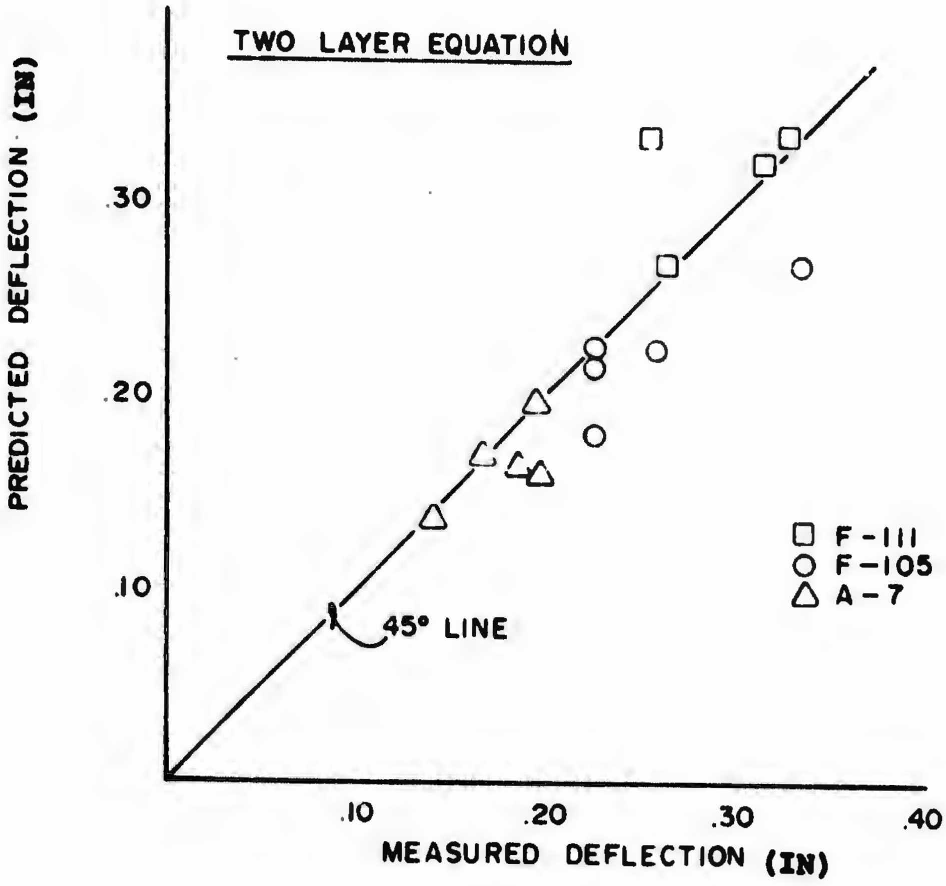


FIGURE 7. PREDICTED VERSUS MEASURED DEFLECTION USING KIRK'S EQUATION

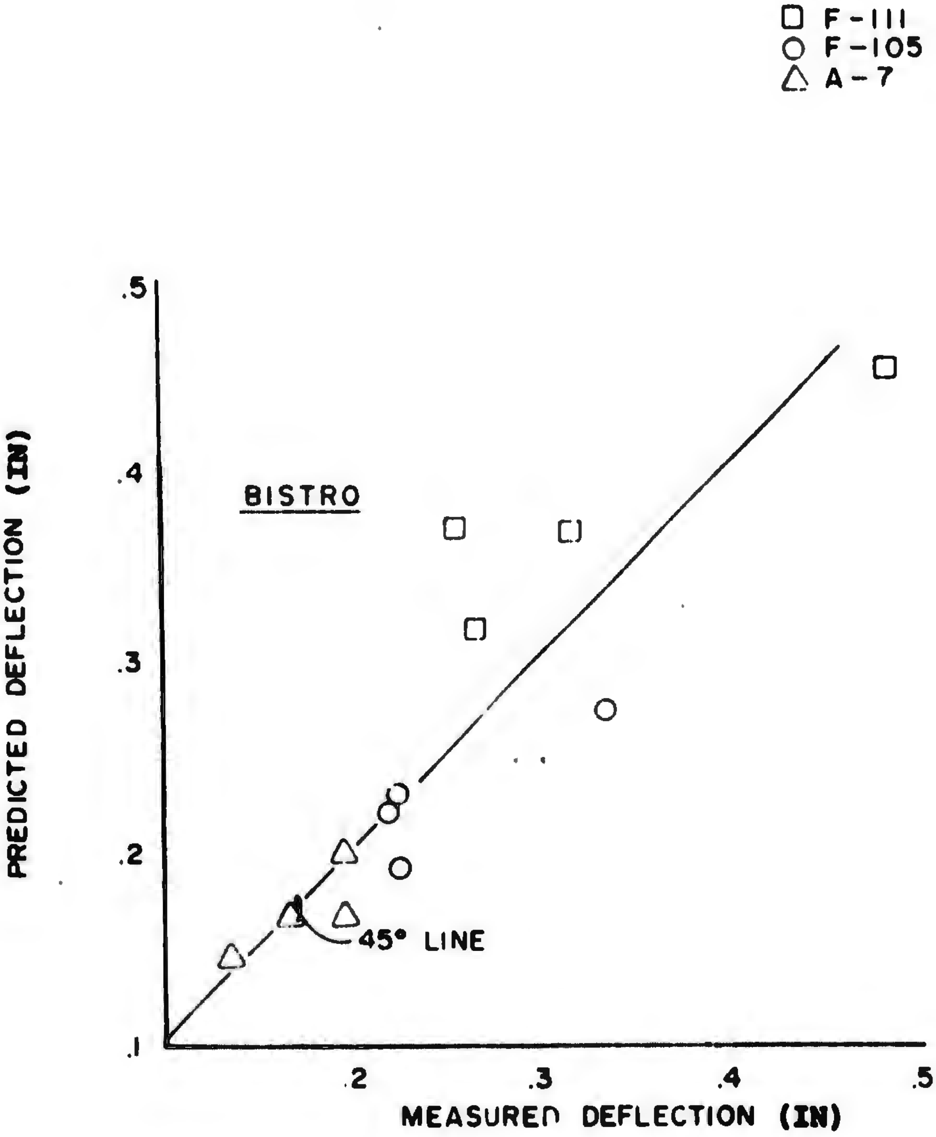


FIGURE 8. PREDICTED VERSUS MEASURED DEFLECTION USING BISTRO

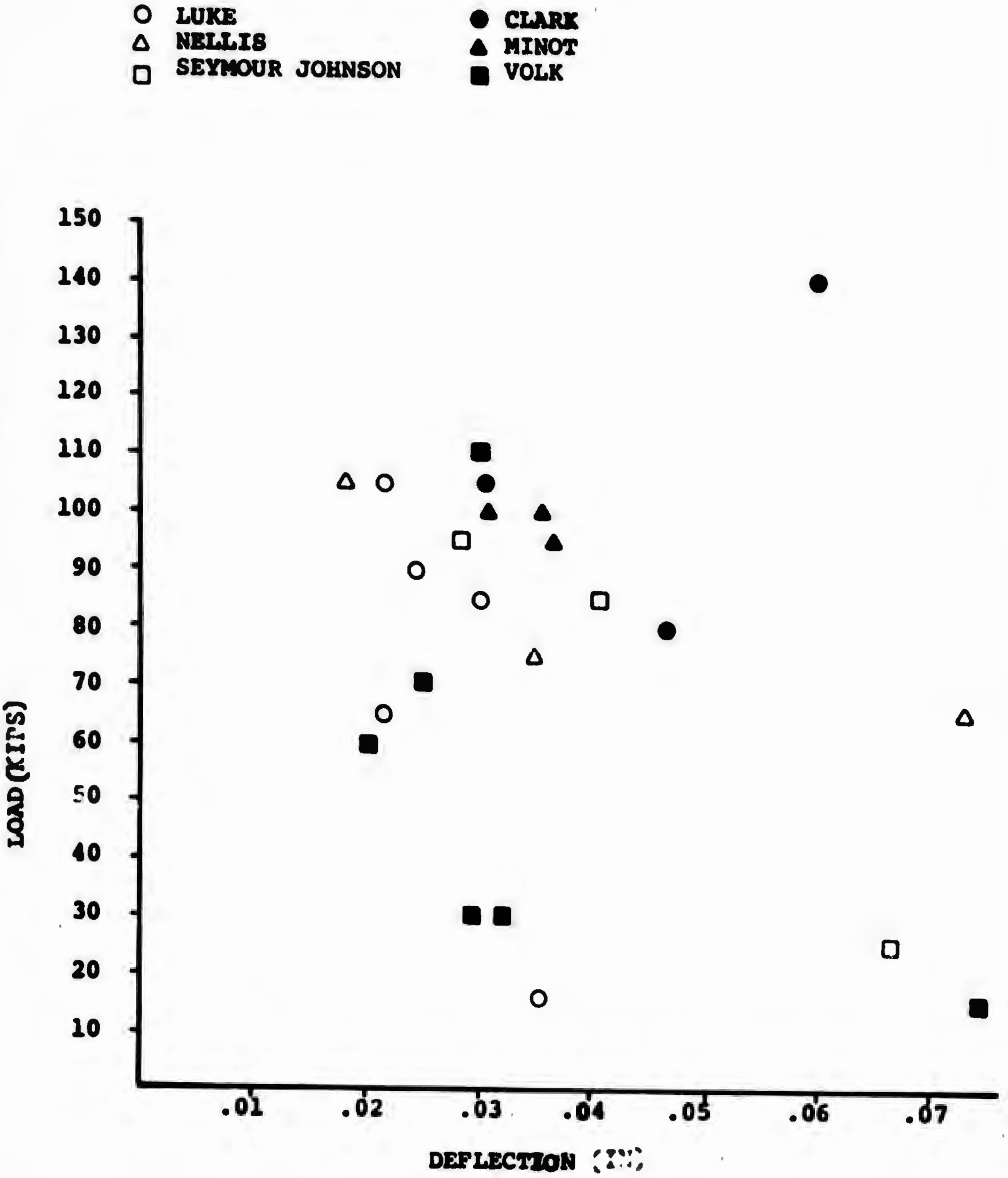


FIGURE 9. ALLOWABLE GROSS LOAD VERSUS DEFLECTION FOR F-4 AIRCRAFT

NOTE:

t = Asphalt thickness in Figures 10 through 16

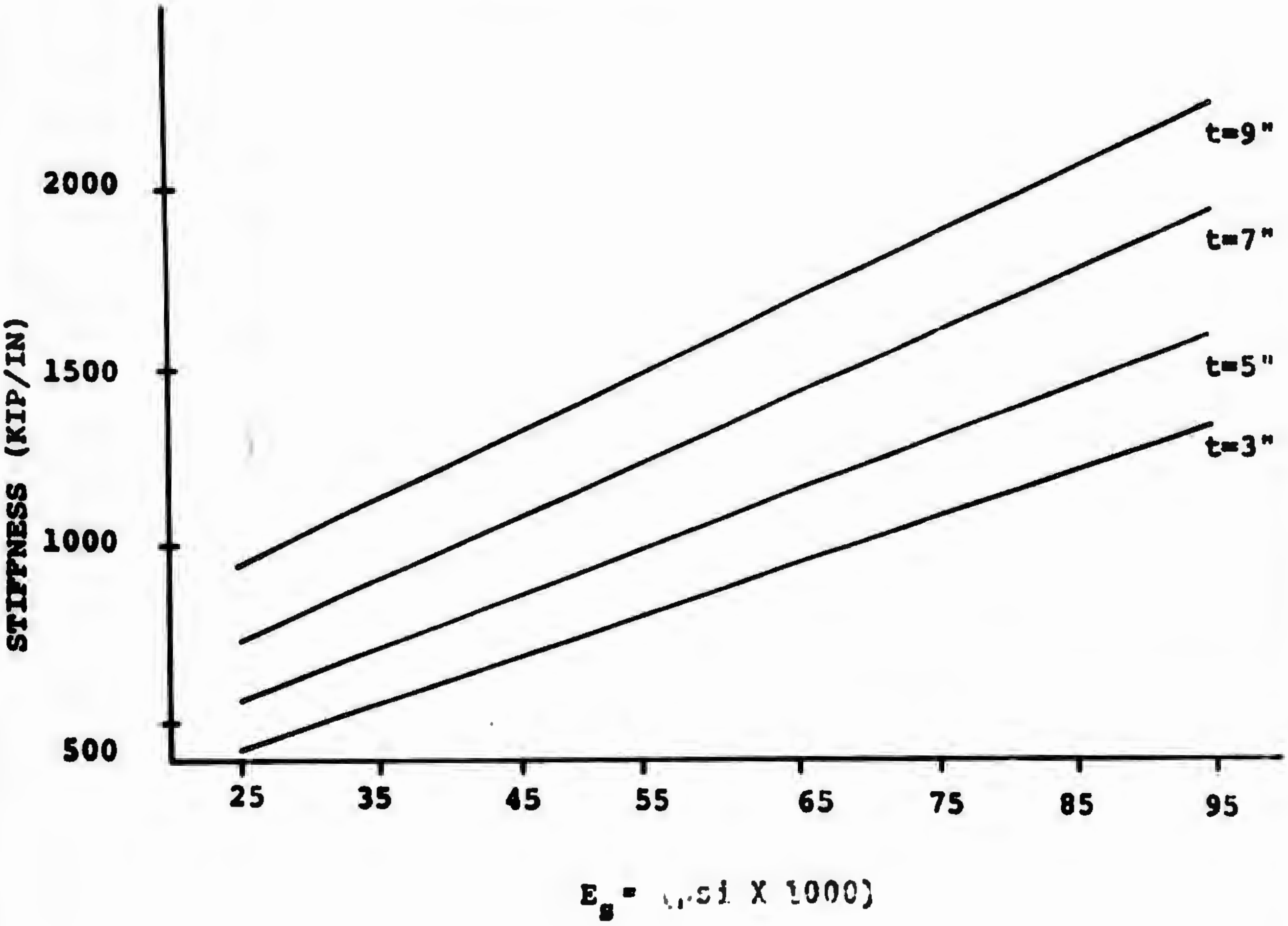


FIGURE 10. STIFFNESS VERSUS SUBGRADE MODULUS (E_s) FOR F-4 AIRCRAFT

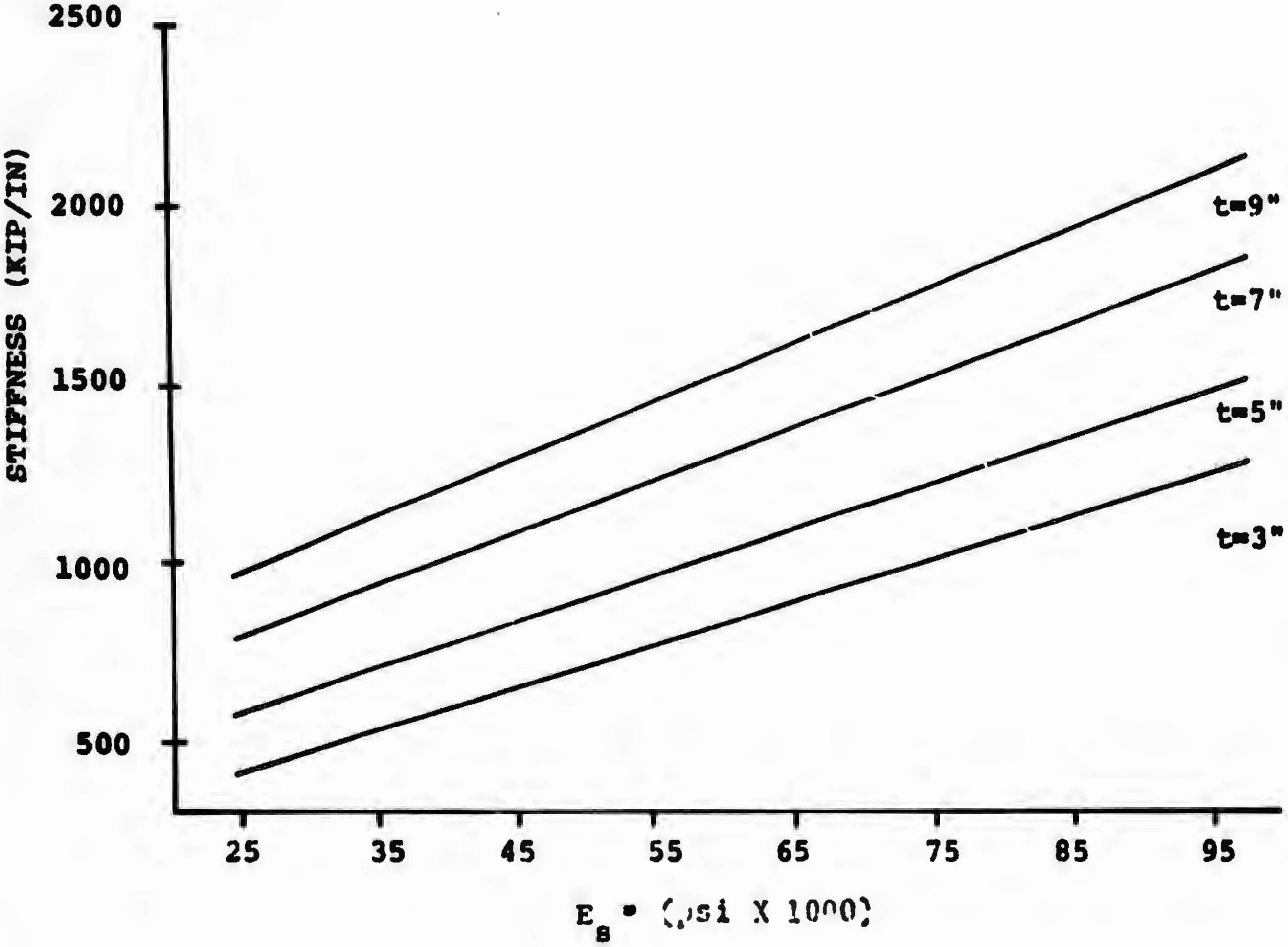


FIGURE 11. STIFFNESS VERSUS SUBGRADE MODULUS (E_s) FOR F-15 AIRCRAFT

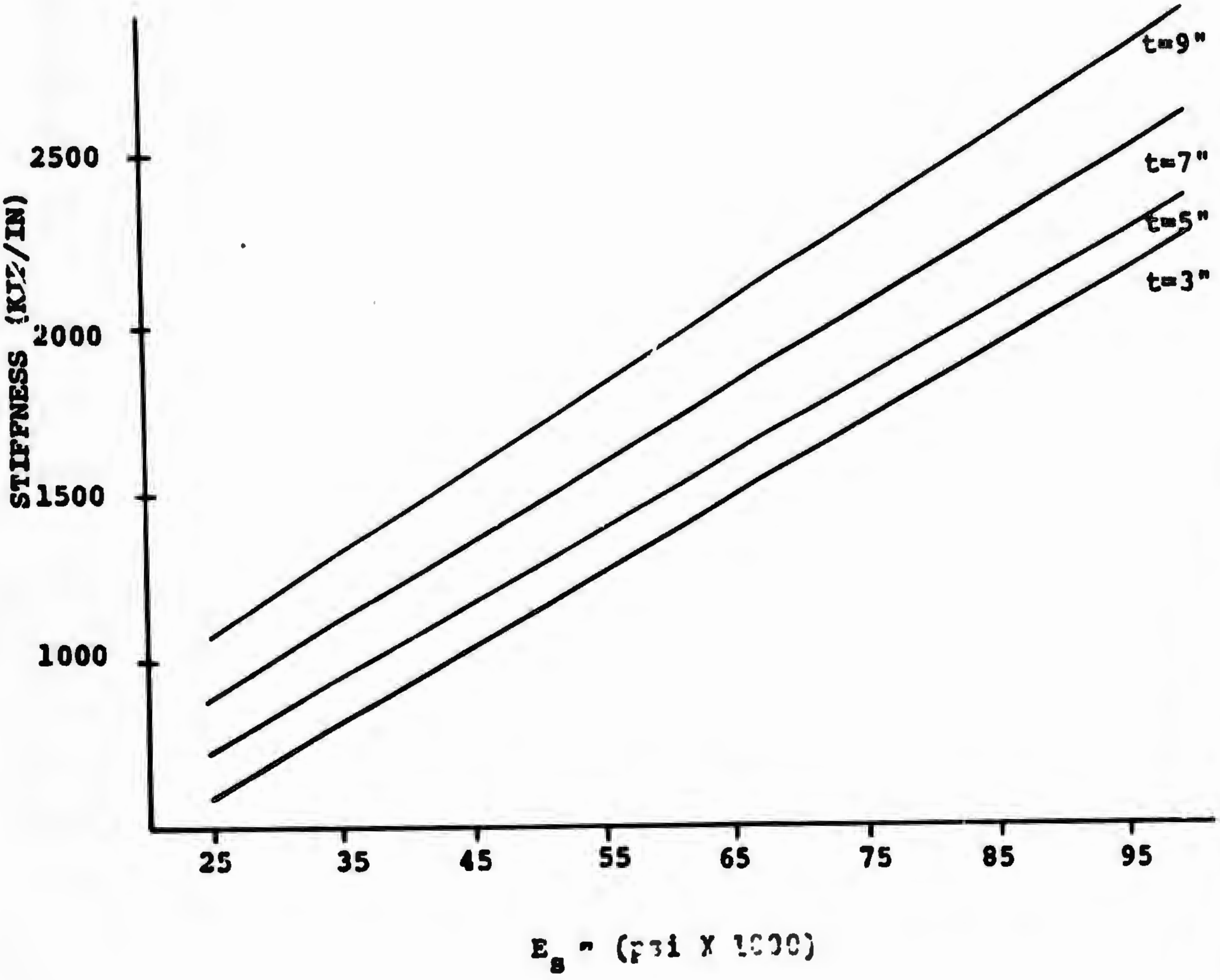


FIGURE 12. STIFFNESS VERSUS SUBGRADE MODULUS (E_s) FOR F-111 AIRCRAFT

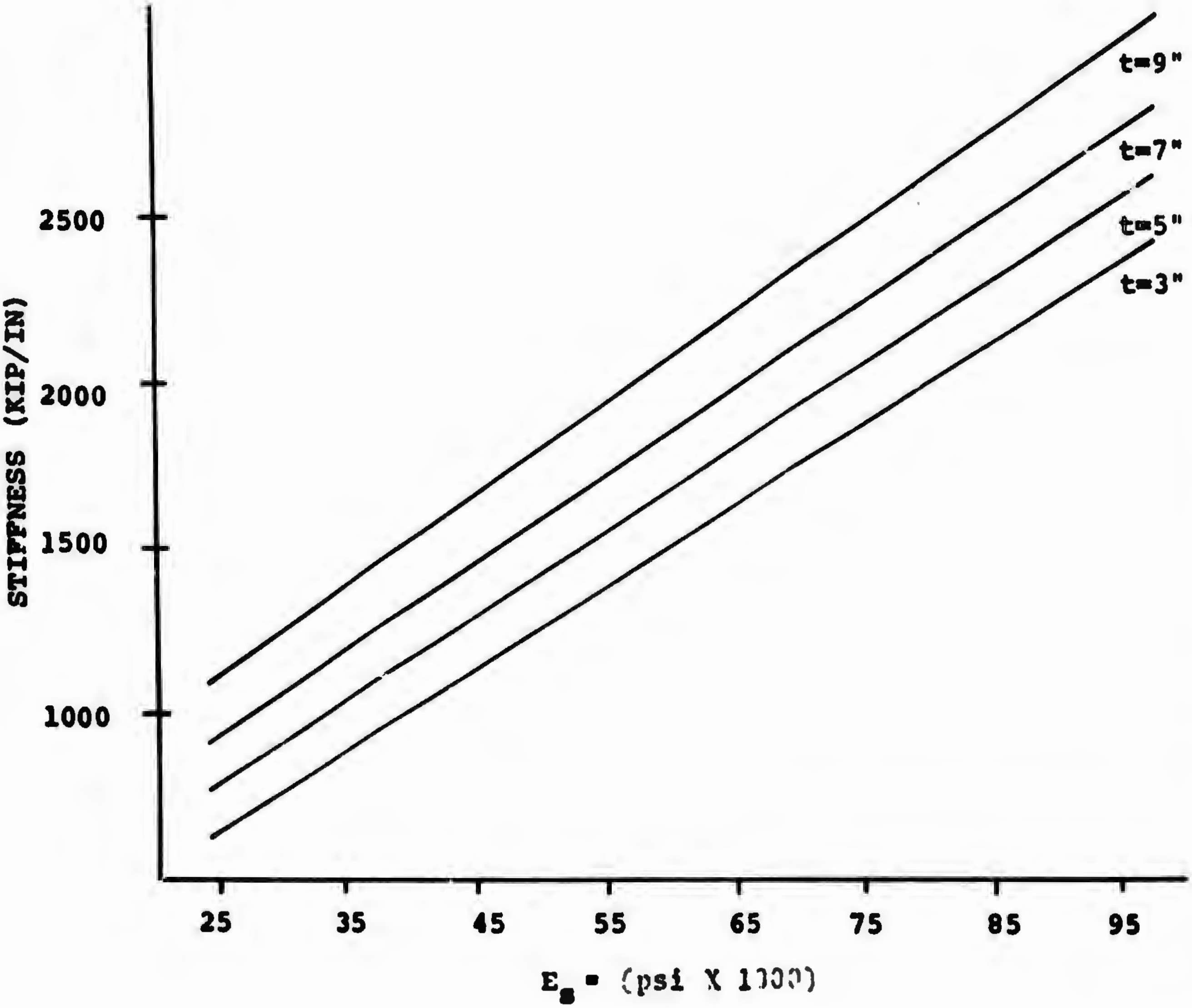


FIGURE 13. STIFFNESS VERSUS SUBGRADE MODULUS (E_s) FOR C-130 AIRCRAFT

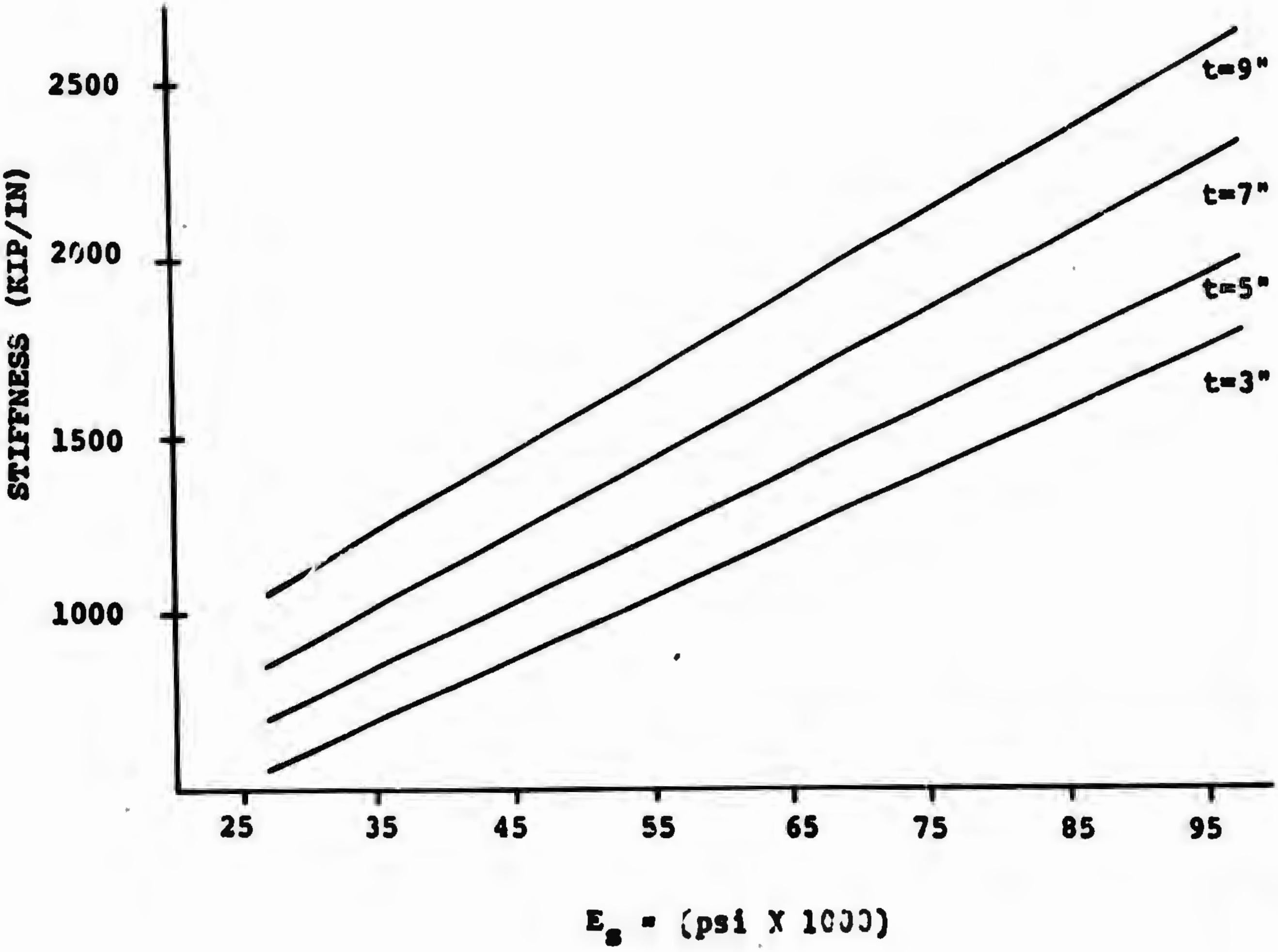


FIGURE 14. STIFFNESS VERSUS SUBGRADE MODULUS (E_s) FOR C-141 AIRCRAFT

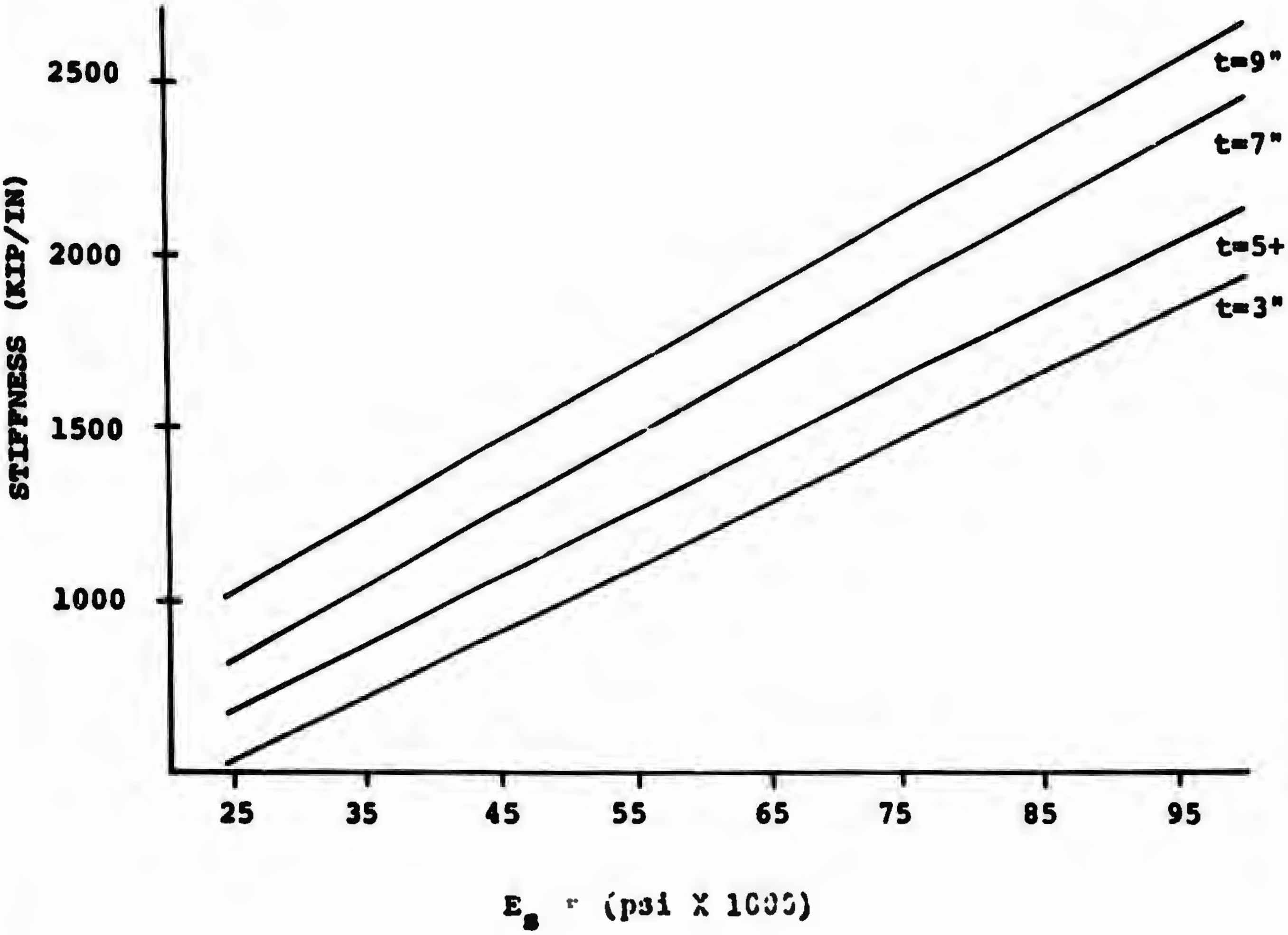


FIGURE 15. STIFFNESS VERSUS SUBGRADE MODULUS (E_s) FOR KC-135 AIRCRAFT

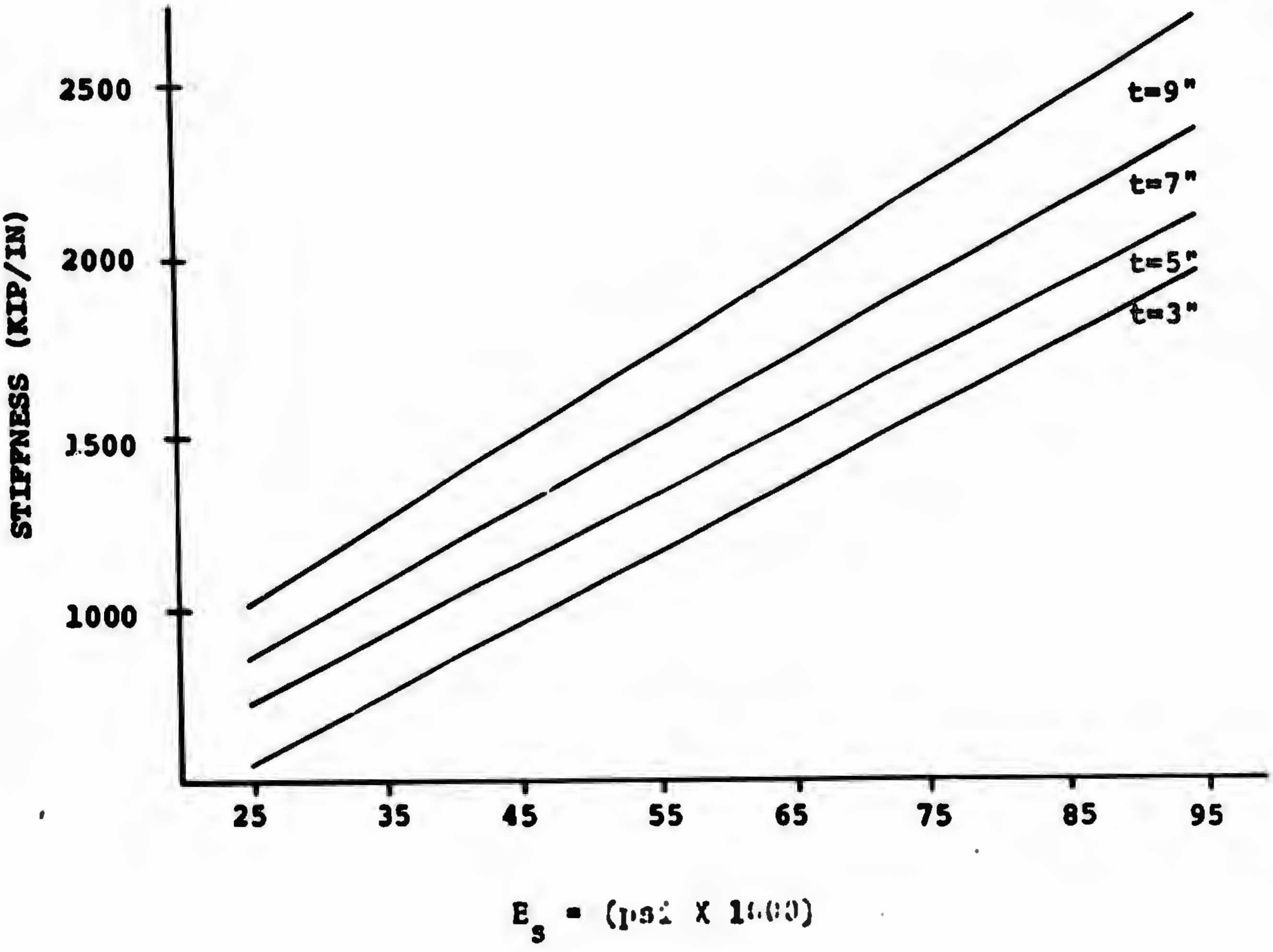


FIGURE 16. STIFFNESS VERSUS SUBGRADE MODULUS (E_s) FOR B-52 AIRCRAFT

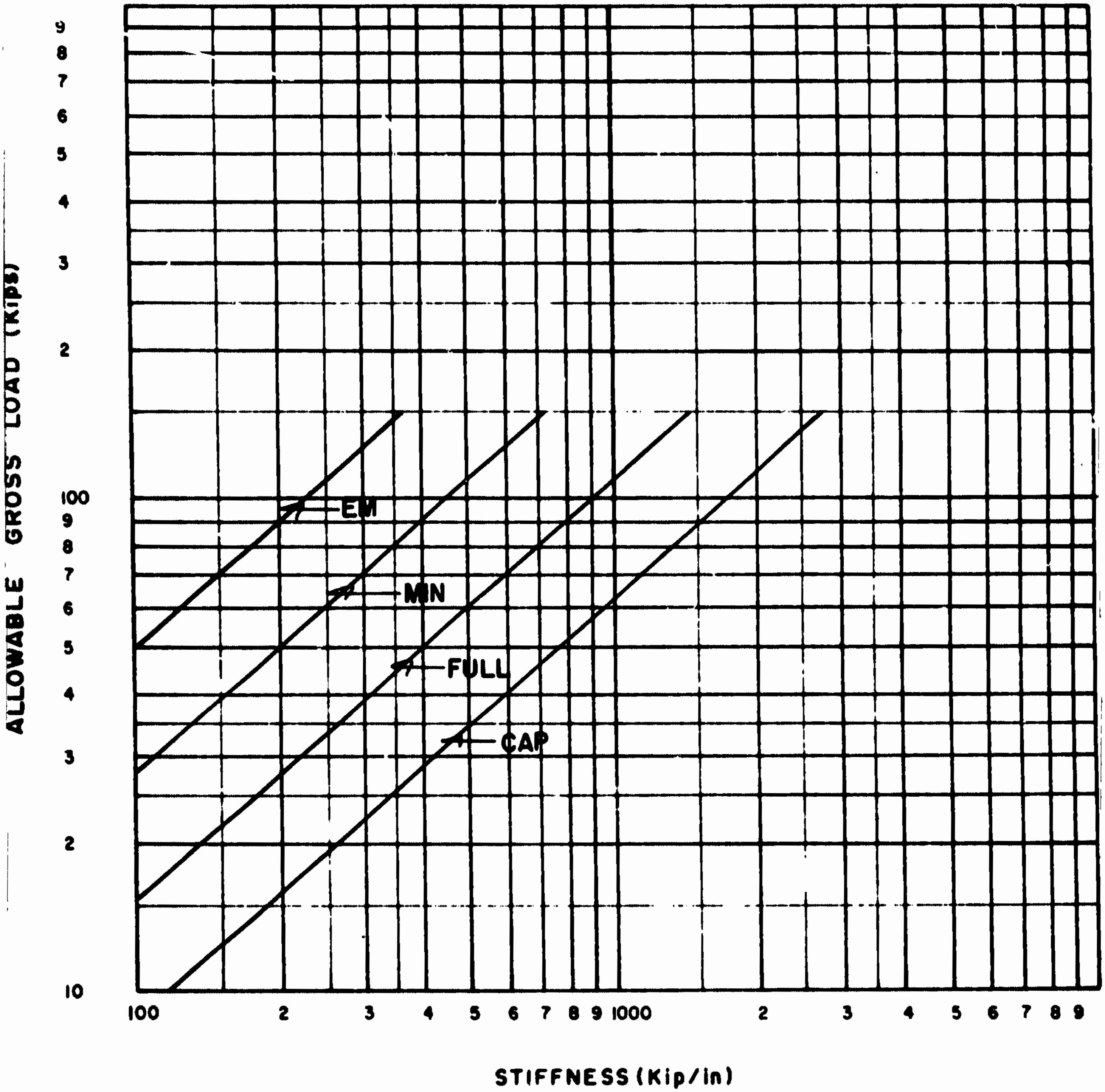


FIGURE 17. ALLOWABLE GROSS LOAD VERSUS STIFFNESS FOR F-4 AIRCRAFT

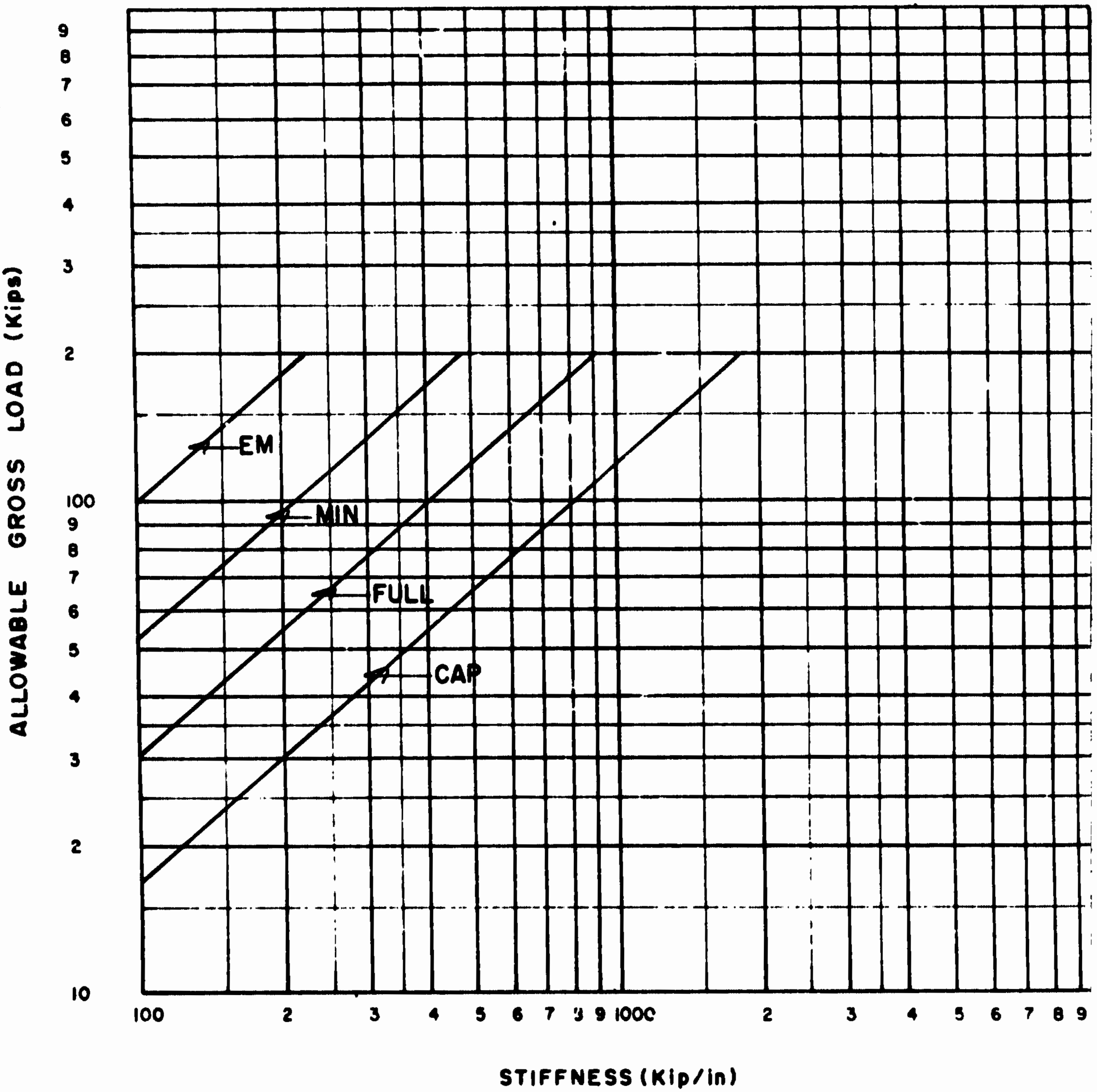


FIGURE 18. ALLOWABLE GROSS LOAD VERSUS STIFFNESS FOR F-111 AIRCRAFT

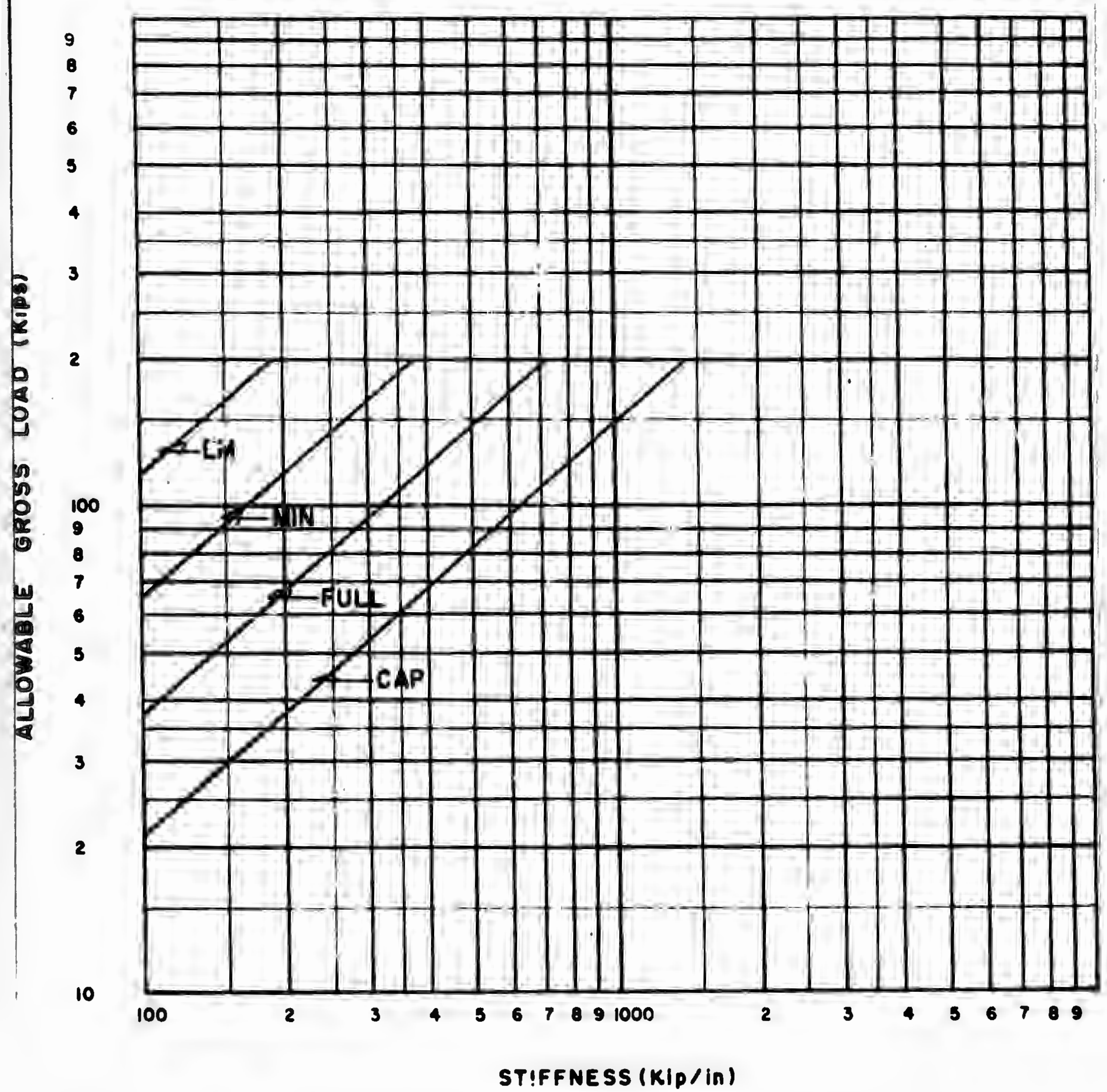


FIGURE 19. ALLOWABLE GROSS LOAD VERSUS STIFFNESS FOR C-130 AIRCRAFT

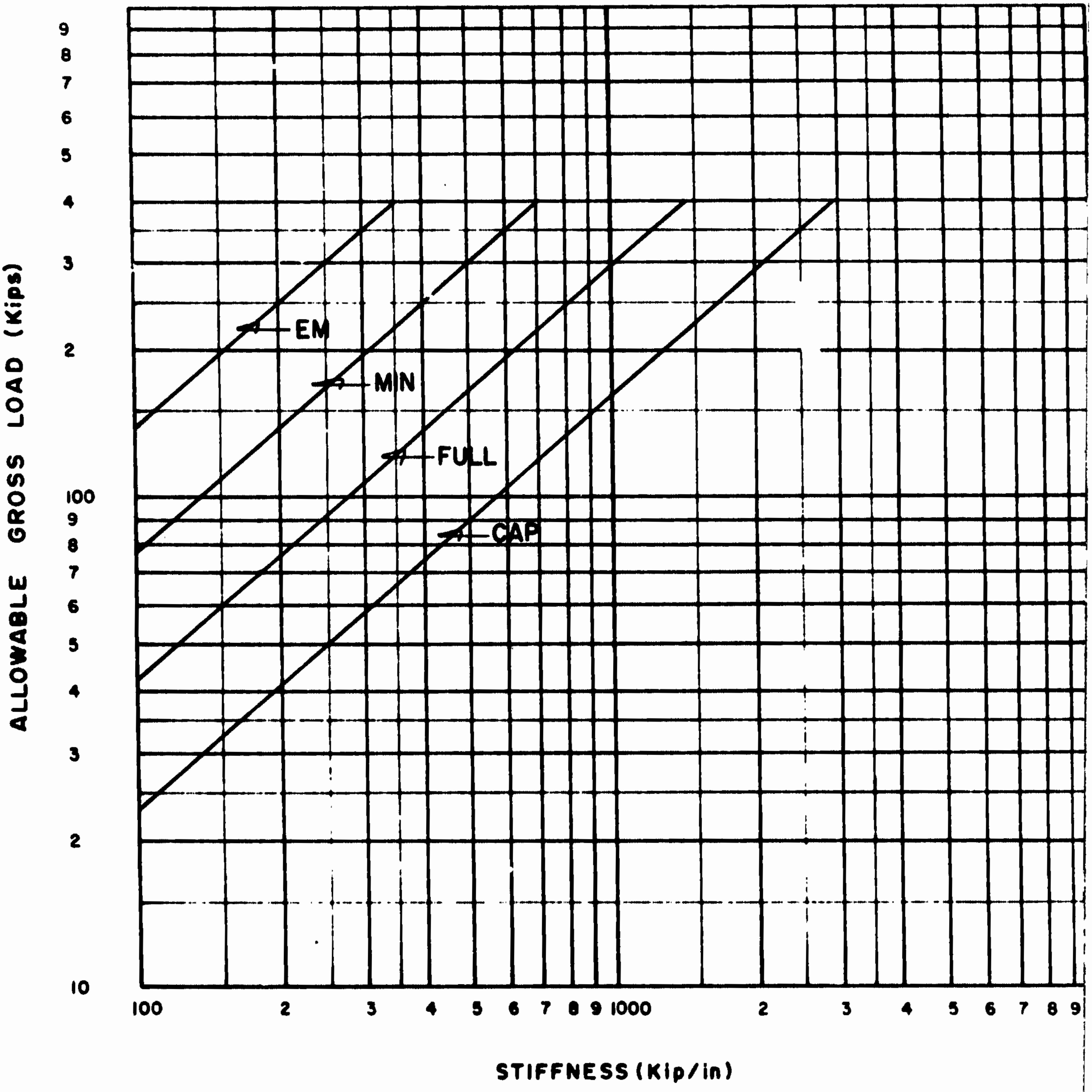


FIGURE 20. ALLOWABLE GROSS LOAD VERSUS STIFFNESS FOR C-141 AIRCRAFT

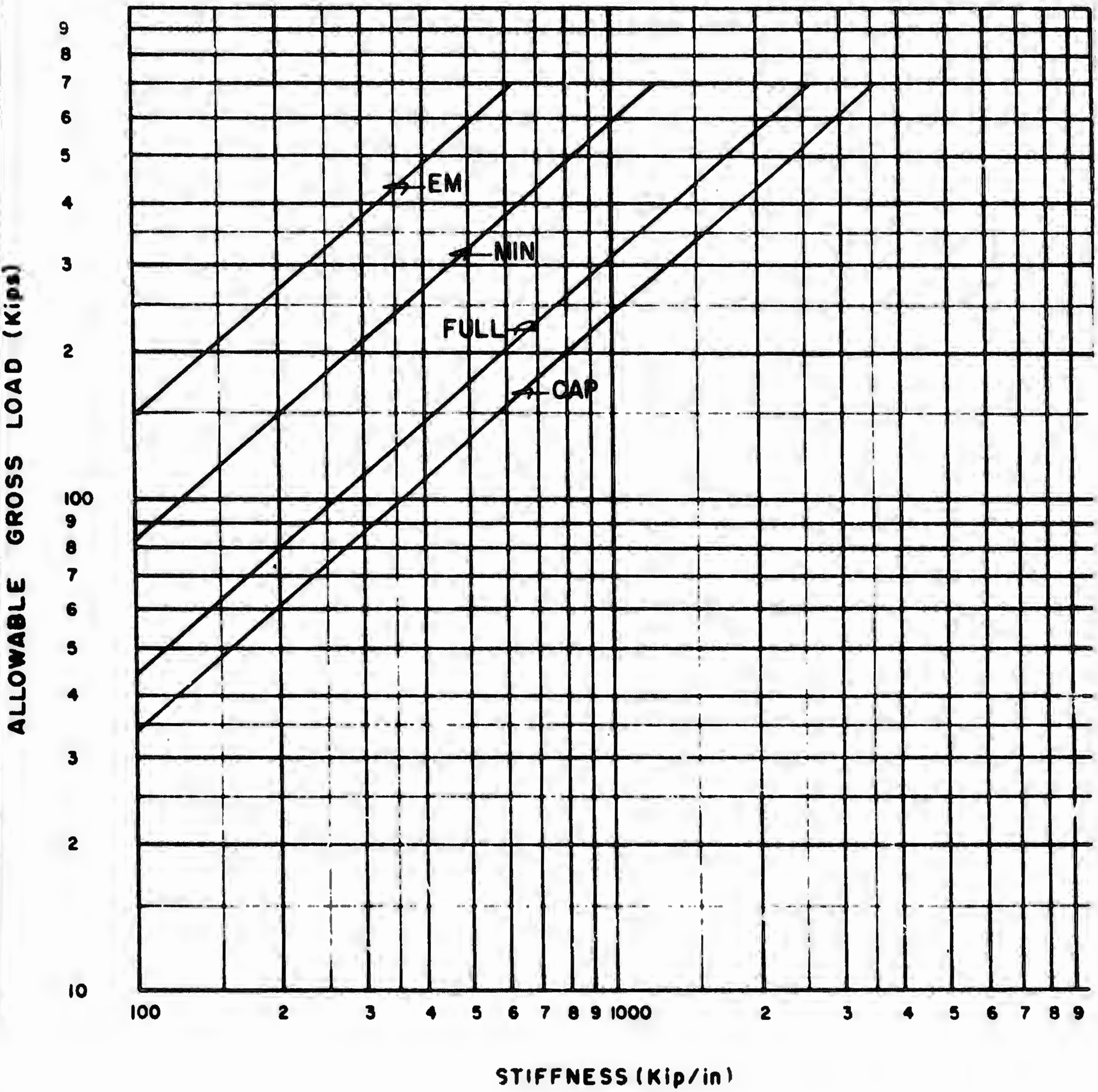


FIGURE 21. ALLOWABLE GROSS LOAD VERSUS STIFFNESS FOR B-52 AIRCRAFT

APPENDIX A

TEST PROCEDURES

1. Apparatus

1.1 Loading Vehicle - The preferable loading vehicle is the mission aircraft for the airfield system being studied. For most airfield systems within the Air Force, one particular type of aircraft is the most critical. If possible, this aircraft should be used at as close to maximum takeoff weight as possible. The maintenance personnel snould be able to provide the total weight of the aircraft to within 1000 lb. Also, it is necessary to know the exact tire pressure at the time the study is conducted. Insure that the maintenance personnel actually measure the tire pressure.

1.2 Benkelman Beam - The Benkelman Beam is a portable, rotating beam-type pavement deflection indicator as shown in Figures A-1 through A-3. It is equipped with a dial micrometer gauge, 1-in range.

2. Preparation of Benkelman Beam

2.1 At the beginning of each test day, accomplish the following steps:

2.1.1 Assemble the probe beam and check all connections for tightness and rigidity.

2.1.2 Inspect the dial micrometer gauge for tightness of all connections and to minimize friction; clean the stem with alcohol.

3. Rebound Deflection of Flexible Type Airfield Pavement Systems

3.1 Select and mark the point to be tested. On runways and taxiways these points should be a maximum of 200 feet apart and should be located in the gear path of the feature being studied. On aprons one point for every 40,000 sq feet is sufficient with a minimum of ten points per apron.

3.2 Align the aircraft parallel to the longitudinal axis of the taxiway or runway or in a convenient direction of travel on an apron. On single wheel aircraft, locate one of the wheels over the point; on multi-wheeled aircraft, locate the rear wheel of one of the trucks over the test point.

3.3 Position the probe beam next to the tire over the test point, at an angle of 90 degrees to the loading vehicle.

3.4 Release the beam locking screw so that the beam is free. This will allow the rear support of the base section to contact the pavement surface.

3.5 Turn the buzzer switch on. Set the dial gauge to zero.

3.6 Have the aircraft move straight ahead to the next data point. The aircraft can be spotted by one of the wing walkers provided by aircraft maintenance with the aircraft.

3.7 Read and record the dial micrometer gauge to the nearest half unit (0.0005 in.).

3.8 Tighten the beam locking screw to protect the dial gauge.

NOTE: On weak flexible pavements, the deflection basin may exceed eight feet in radius which will necessitate the use of an additional Benkelman Beam to insure that the total deflection is measured. The probe on the second beam is inserted between the legs of the first beam and read in the same manner.

Pavement temperature must be determined for flexible pavements. The temperature should be measured at about two hour intervals or more often if deemed necessary. It can be measured as follows: At a point about two feet from the pavement edge, drill or punch a 1/4 to 3/8 inch diameter hole to one-half the depth of the bituminous surface course or a minimum depth of 2 inches. Fill the hole with oil or water and insert the thermometer. Record the temperature to the nearest degree Fahrenheit. Also record the free air temperature.

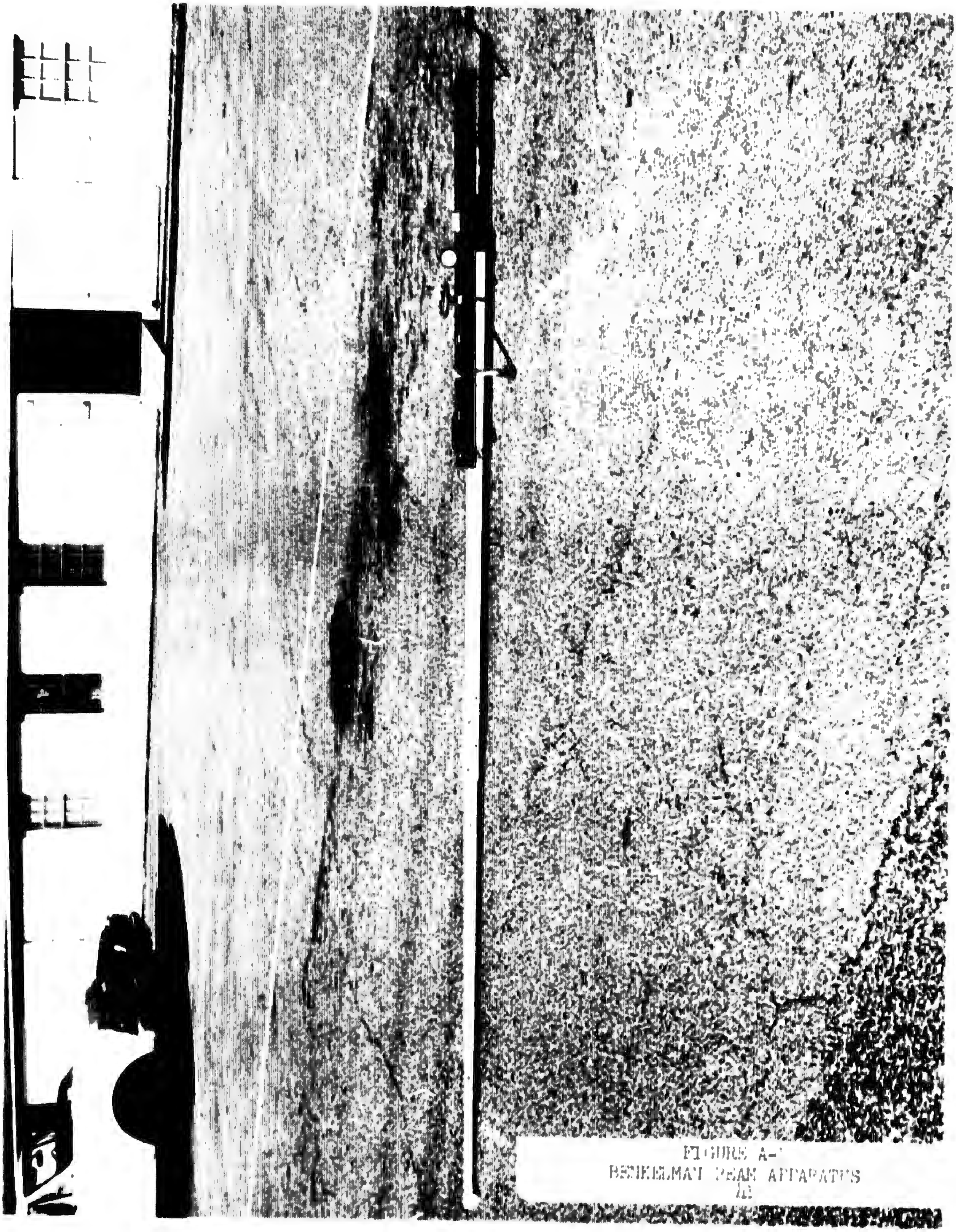
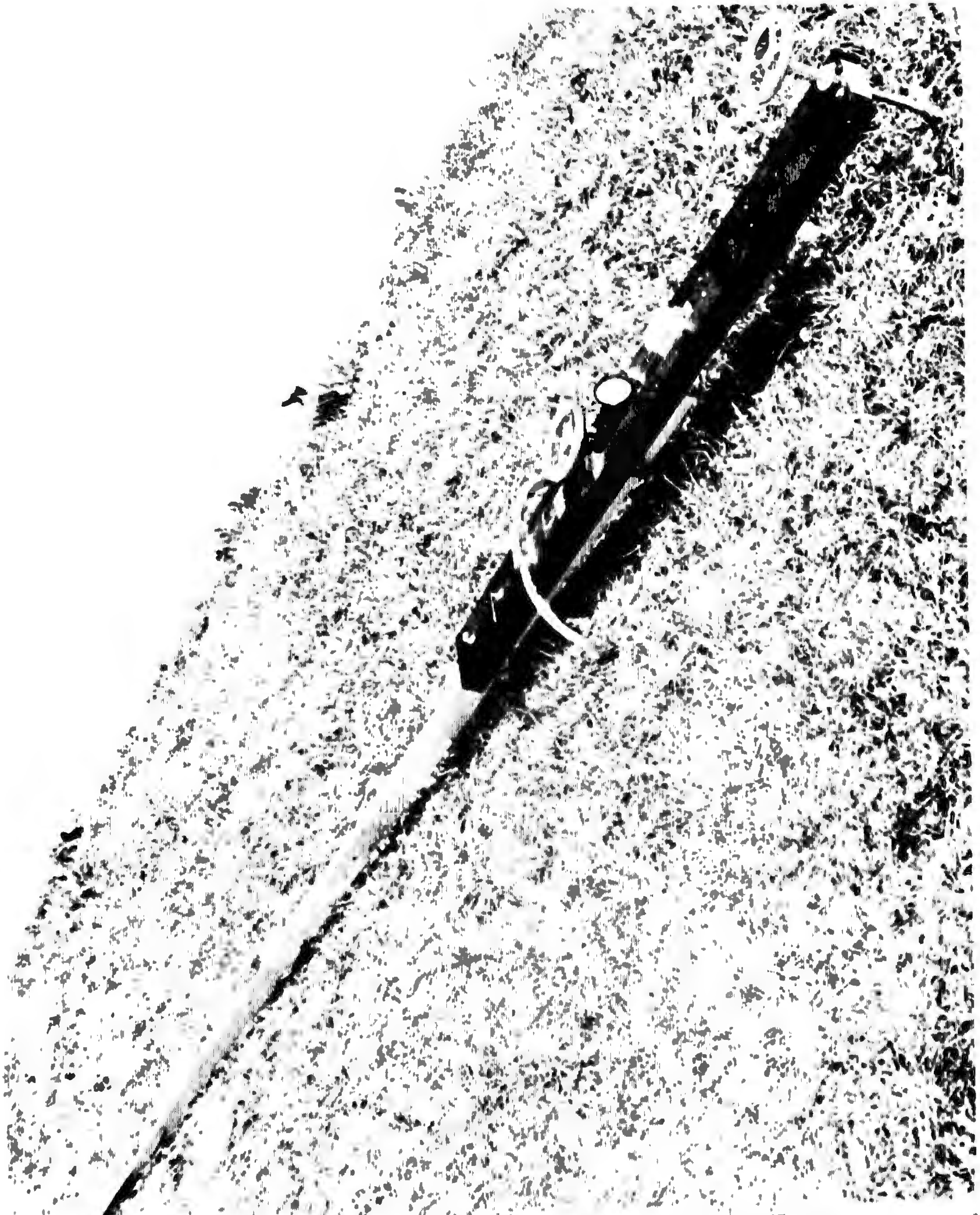


FIGURE A-1
BENKELMAN BEAM APPARATUS



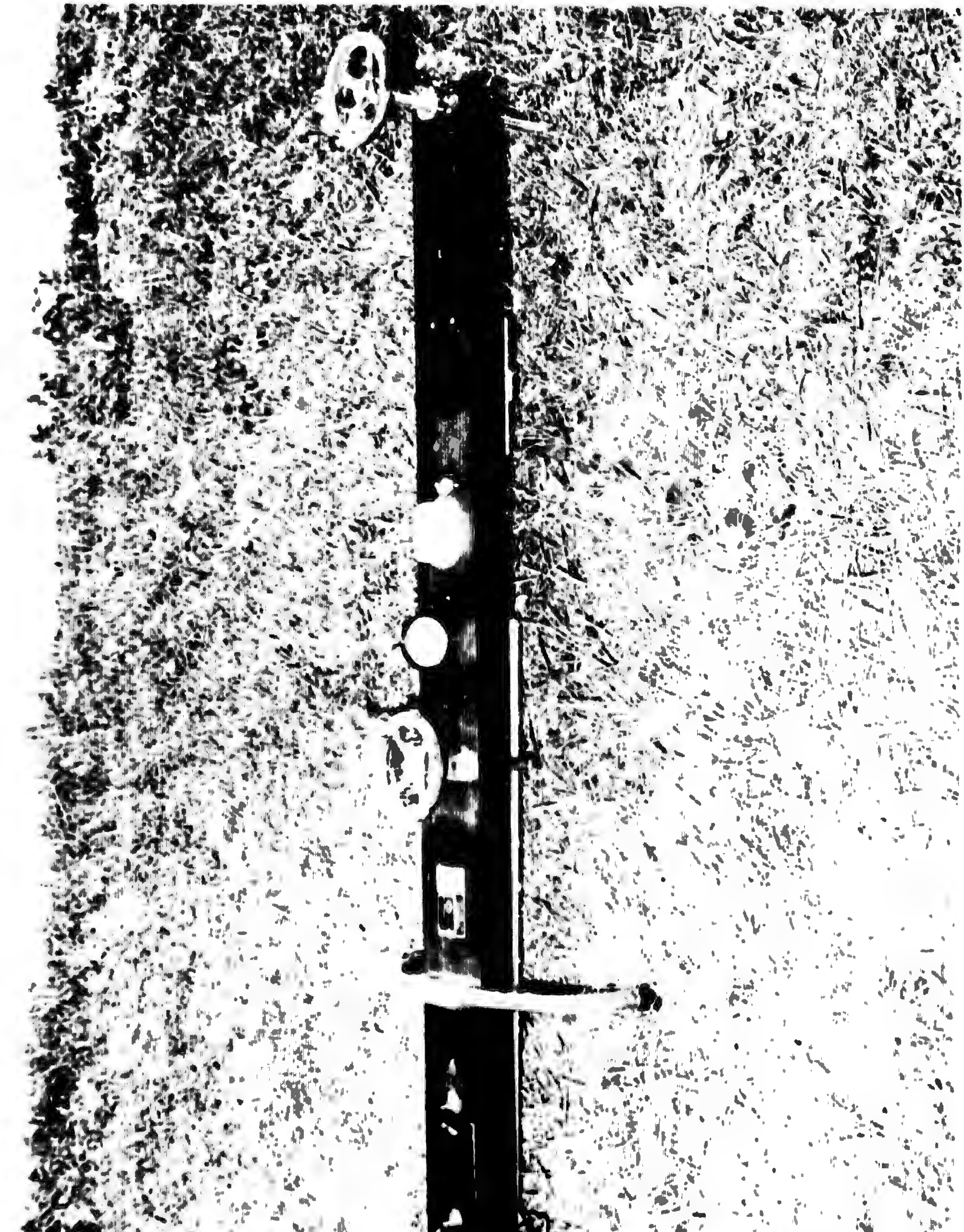


FIGURE A-1 MICROMETER GAUGE, BUZZER AND SWITCH, AIR OUTLET CONTROLS

APPENDIX B

ESWL DETERMINATION FOR FLEXIBLE PAVEMENTS

CBR design and evaluation curves are constructed for a single-wheel loading. CBR design and evaluation curves for multiple-wheeled aircraft can be developed through the use of the equivalent single wheel load (ESWL) concept. ESWL is defined as: the load on a single wheel of the same contact area as the one wheel of a multiple-wheel assembly that will produce a maximum deflection equal to that beneath the multiple wheel assembly is assumed to be equivalent to the multiple wheel loading. The results of relating multiple and equivalent single-wheel loadings can be presented as a curve that relates depth in inches to equivalent single wheel load in percentage of assembly load. Thus, at any given depth or design thickness, a single-wheel load equivalent to a given multiple-wheel load can be determined; and, with the single-wheel load established, the CBR equation can be used to compute thickness.

The following presents an example of the method by which theoretical maximum deflections are developed for single and multiple-wheel assemblies and combined to establish a relation between multiple and equivalent single-wheel loads.

Assume: C-130 aircraft with a single tandem gear; spacing 60 inches and a tire contact area (a) of 400 square inches. (See Figure B-1 for sketch of gear)

Then: radius, $r = \sqrt{A/\pi} = 11.28$ inches
tire spacing in radii $= 60/11.28 = 5.32$

Deflections for a single wheel load may be obtained utilizing the deflection factor, F, such that:

$$\text{Deflection, } W = \frac{PrF}{Em}$$

Where: P = load intensity
Em = modulus of elasticity

The following tabulation of deflection factors is read from a deflection factor chart:

TABLE B-1

DEFLECTION FACTORS OFFSET FROM CENTER OF WHEEL # 1

DEPTH	BENEATH WHEEL # 1	2.66 RADII OR 30 IN	5.32 RADII OR 60 I
0	1.50	.28	.14
10in or .89r	1.11	.31	.16
20in or 1.77r	.78	.31	.16
30in or 2.66r	.51	.29	.16
40in or 3.55r	.40	.27	.16
50in or 4.44r	.32	.25	.16
60in or 5.32r	.28	.20	.16
70in or 6.20r	.26	.19	.15

By the principle of superposition, the deflection beneath one wheel of the twin wheel loading is equal to that beneath that wheel plus that due to the other wheel. Also the deflection beneath the point half-way between the wheels (the center of the gear) is equal to twice that at 30 inches (2.66 radii). Thus by adding the corresponding deflection-factor values shown in Table B-1 in columns 2 and 4 (numbered left to right) and by doubling the values listed in Column 3, the following table of deflection factors is established:

TABLE B-2

DEFLECTION FACTORS

DEPTH (IN)	BENEATH ONE WHEEL OF TWIN	BENEATH CENTER OF TWIN
0	1.64	.56
10	1.27	.62
20	.94	.62
30	.67	.58
40	.56	.54
50	.48	.50
60	.44	.40
70	.41	.38

The maximum deflection beneath one wheel of the dual assembly represents the maximum deflection beneath the dual loading for shallow depths. The maximum deflection midway between the wheels represents the maximum deflection beneath the dual loading at deep depths. The maximum deflection beneath the dual wheels in the transition zone can be determined accurately by superimposing deflections beneath the individual wheels of the duals for all offsets between the wheels and selecting the maximum. A computer program has been developed to accomplish this. The accuracy is not significantly improved; therefore the procedure described here can be used.

The load on a single wheel of the same contact area as one wheel of the dual assembly that produces a maximum deflection equal to that beneath the dual assembly is assumed to be equivalent to the dual loading. The ratio of the equivalent single-wheel to the load on one wheel of the twin assembly is the ratio of the maximum dual-wheel deflection factor to the maximum single-wheel deflection factor for that depth. The following table presents the ratios of dual and equivalent single-wheel loads for various depths:

TABLE B-3

LOAD RATIOS

			LOAD RATIO	
DEPTH (IN) (COL 1)	SINGLE-WHEEL DEFLECTION FACTOR (COL 2)	DUAL-WHEEL DEFLECTION FACTOR (COL 3)	SINGLE TO ONE WHEEL OF DUAL COL 4)	SINGLE TO DUAL ASSEMBLY (COL 5)
0	1.50	1.64	1.09	.546
10	1.11	1.27	1.14	.572
20	.78	.94	1.20	.600
30	.51	.67	1.31	.626
40	.40	.56	1.40	.700
50	.32	.48	1.50	.750
60	.28	.44	1.57	.786
70	.26	.41	1.58	.790

Where: Col 2 is Col 1, Table B-1; Col 3 is the maximum value for each depth from Col 2 and 3, Table B-2; Col 4 is Column 3 divided by Col 2; and Col 5 is Col 4 divided by the number of wheels in the assembly (in this example - n=2).

Tables B-4 and B-5 on the next page contain an example problem for a twin-tandem type gear configuration. Table B-6 presents ESWL factors for selected aircraft versus depth as determined through the use of a computer program developed by the Boeing Company. Figure B-2 contains a sketch of the gear for the KC-135 example problem.

EXAMPLE PROBLEM

AIRCRAFT: KC-135

GEAR CONFIGURATION: TT

SPACING: 36 X 60

TIRE CONTACT AREA: 230

RADIUS = $\sqrt{A/\pi}$: 8.56

TABLE B-4

DEPTH (IN)	RADII	DEFLECTION FACTORS OFFSET FROM CENTER OF WHEEL 1				DEFLECTION FACTOR OFFSET FROM EACH WHEEL TO CENTER OF ASSEMBLY
		BENEATH WHEEL 1	BENEATH WHEEL 2	BENEATH WHEEL 3	BENEATH WHEEL 4	
0	0	1.5	.185	.105	.08	.185
10	1.17	.98	.192	.110	.08	.192
20	2.34	.59	.192	.110	.09	.192
30	3.50	.40	.192	.122	.11	.192

TABLE B-5

DEPTH (IN)	SINGLE-WHEEL DEFLECTION FACTOR	TOTAL DEFLECTION FACTOR		LOAD RATIO	
		BENEATH WHEEL 1	BENEATH CENTER	SINGLE TO ONE WHEEL	SINGLE TO ASSEMBLY
0	1.5	1.87	.37	1.24	.312
10	.98	1.362	.384	1.389	.347
20	.59	.982	.384	1.66	.416
30	.40	.824	.384	2.10	.526

TABLE B-6

FLEXIBLE PAVEMENT ESWL FACTORS

FOR SELECTED AIRCRAFT ASSEMBLY LOADS

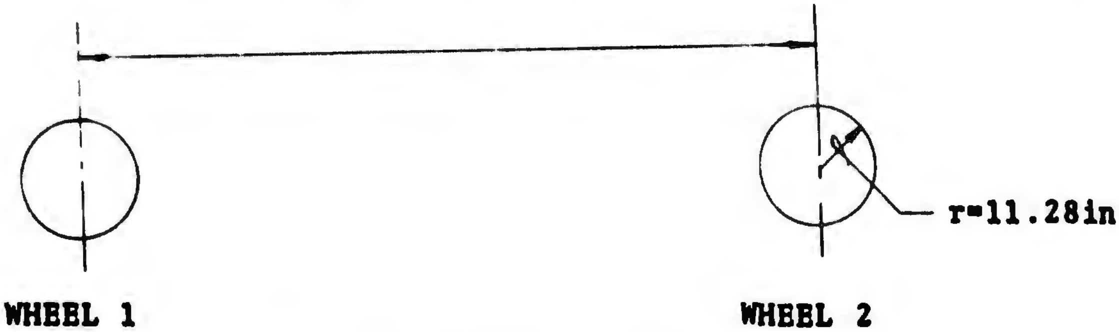
	B-1 TT-37"x56" CA=225	B-52 TW-TW CA=236	KC-135 TT-36"x60" CA=230	C-141 TT-32.5"x48" CA=208	BOEING 747 TT-44"x58" CA=208	DC-8 TT-30"x55" CA=209
0	.314	.307	.314	.320	.307	.320
2	.317	.309	.315	.322	.308	.321
4	.321	.314	.320	.328	.313	.328
6	.330	.320	.328	.338	.320	.337
8	.340	.329	.338	.349	.330	.349
10	.352	.339	.349	.364	.340	.363
12	.365	.350	.362	.379	.352	.379
14	.379	.363	.376	.397	.364	.397
15	.386	.369	.383	.406	.371	.406
20	.428	.405	.425	.456	.405	.455
25	.475	.44	.469	.516	.446	.511
30	.529	.475	.521	.575	.492	.565
35	.579	.510	.569	.630	.540	.611
40	.627	.540	.613	.681	.590	.655
50	.712	.60	.693	.762	.680	.736
60	.777	.65	.760	.818	.749	.790
70	.824	.695	.809	.857	.800	.840
100	.956	.805	.895	.925	.953	.990

	C-9 TW-25" CA=174	C-118 TW-30.7" CA=221	C-121 TW-33" CA=266	C-124 TW-44" CA=630	C-130 ST-60" CA=400	
0	.575	.568	.570	.581	.546	
2	.578	.570	.572	.582	.547	
4	.586	.576	.577	.585	.549	
6	.598	.585	.585	.589	.553	
8	.615	.597	.596	.595	.558	
10	.633	.611	.608	.602	.563	
12	.653	.626	.622	.610	.569	
14	.682	.642	.636	.620	.576	
15	.695	.650	.643	.624	.580	
20	.762	.707	.694	.651	.600	
25	.824	.762	.744	.690	.621	
30	.865	.814	.769	.726	.644	
35	.895	.851	.836	.767	.668	
40	.916	.879	.866	.803	.699	
50	.943	.917	.907	.856	.757	
60	.959	.939	.932	.891	.812	
70	.969	.954	.949	.916	.852	
100	.999	.999	1.000	.991	.972	

CA = Contact area (sq in)

FIGURE B-1

GEAR CONFIGURATION FOR C-130 EXAMPLE PROBLEM

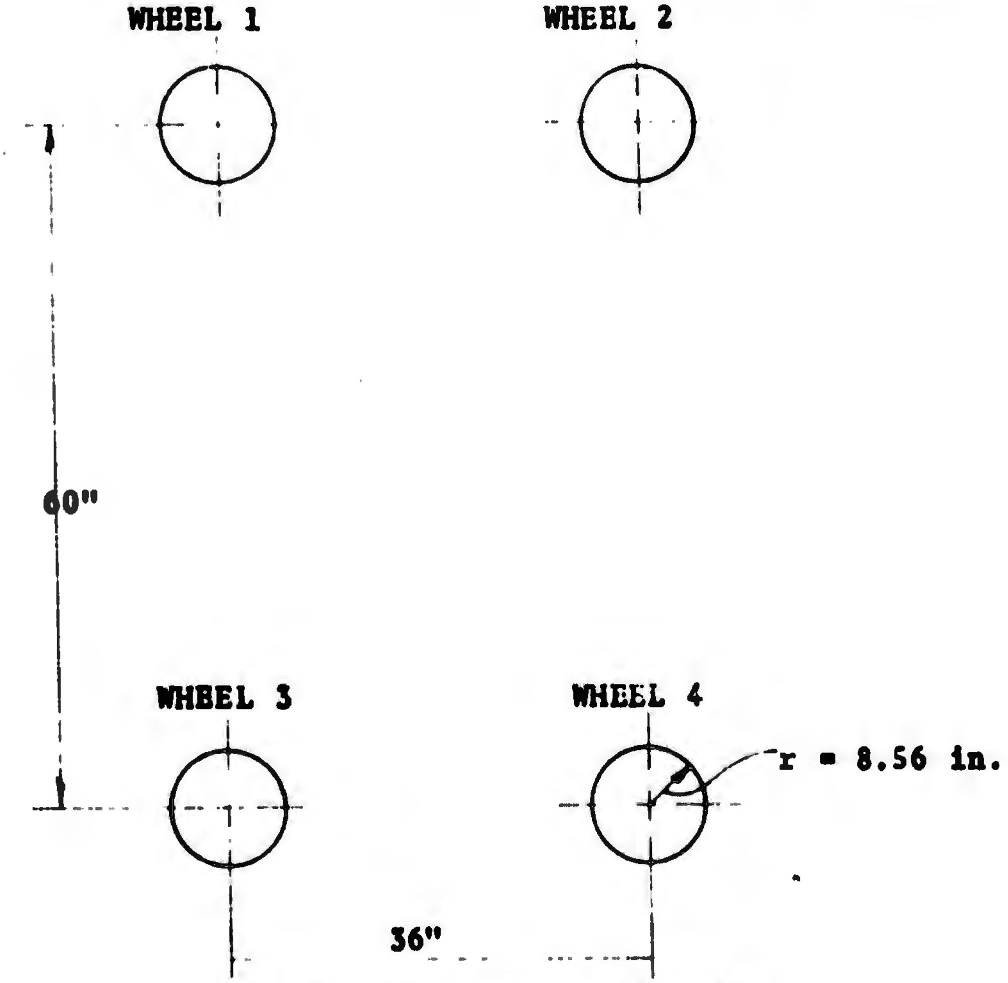


C-130: ST, spacing = 60 in.

Area = 400 sq. in.

FIGURE B-2

GEAR CONFIGURATION FOR KC-135 EXAMPLE PROBLEM



KC-135: TT, spacing 36 x 60

Area = 230 Sq. In.

APPENDIX C

TEST PLAN FOR FOLLOW-ON PROGRAM

1. GENERAL: A non-destructive pavement evaluation procedure is urgently needed to provide the Air Force with a rapid and inexpensive procedure for the evaluation of the load-carrying capacity of airfield pavement structures. The general outline for such a procedure has been developed and it is necessary to evaluate the procedure under field conditions. The procedure consists of conducting a deflection study using a Benkelman Beam and a loaded aircraft. This test plan outlines a study to further expand the data based on the procedure and to evaluate the system under field conditions.

2. SUGGESTED TASK ORGANIZATIONS:

a. Air Force Civil Engineering Center (AFSC) Tyndall AFB, FL.

b. Armaments Development Test Center/DE, (AFSC), Eglin AFB FL.

c. 314th Civil Engineering Squadron (MAC), Little Rock AFB, Arkansas.

d. 57th Civil Engineering Squadron (TAC), Nellis AFB, Nev.

e. 2849th Civil Engineering Squadron (AFLC),Hill AFB, Utah.

f. 91st Civil Engineering Squadron (SAC), Minot AFB, ND

3. TEST OBJECTIVES: To evaluate the use of the Benkelman Beam in the conduct of pavement evaluation studies by field civil engineering squadrons and to develop rated data on the seasonal variation of deflection measurements to ascertain whether deflection can be predicted using different aircraft.

4. RESPONSIBILITIES:

a. The Directorate of Laboratories of the Air Force Civil Engineering Center (AFCEC) is designated as the Test Director and will be responsible for the following actions:

(1) Obtaining the Benkelman Beams for use by each of the respective Civil Engineering Squadrons.

(2) Training personnel at each test location on the test procedure and the use, operation and maintenance of the equipment.

(3) Analyzing the test data submitted from each of the test conductors.

b. The Civil Engineering Squadrons at each of the test locations are designated as the test conductors and are responsible for the following actions:

(1) The conducting of the deflection study and obtaining all of the test data necessary.

(2) The coordination required to obtain the test aircraft from Aircraft Maintenance and access to the test features for the period of time required to accomplish the testing. This includes runway closure as may be necessary.

5. TEST PROGRAM:

a. The test program will consist of gathering pavement deflection data at each of the Air Force bases indicated as test locations, on the pavement features designated as test features. The data collection will consist of:

(1) Measuring the deflections using a Benkelman Beam and the test aircraft at points located 200 feet apart along the centerline of the test feature.

(2) Measuring the pavement temperature at four locations along each test feature at one-half hour intervals throughout the test period.

(3) Obtaining the surface air temperature from the base weather detachment gathered at one-half hour intervals throughout the test period.

(4) Conducting a pavement temperature - deflection study. At two of the locations where thermometers have been placed per paragraph (2) preceding, determine the deflection and temperature at four different times during the test period. This data will be used to develop a relationship between deflection of a pavement structure and the asphalt temperature and to correct the deflections obtained on each test feature for deflection.

(5) Obtaining the aircraft weight and tire pressures at time of test. The weight data is available through aircraft maintenance and is needed to the nearest kip. The test aircraft is to be as heavy as possible without adding munitions.

(6) Obtaining climatological data for the test location to include average daily maximum and minimum air temperatures by week and the average weekly precipitation. This data will be collected throughout the test period.

(7) Obtaining from Base Operations an accurate count of the actual aircraft traffic using the test feature or features.

b. The following is a listing of the test locations, test features and desired test aircraft.

(1) Eglin AFB FL; Runway 12-03 and the NW-SW taxiway; F-111 and C-130 aircraft.

(2) Little Rock AFB, Ark: Flexible pavement portion of runway 06-24 and the assault strip; C-130 aircraft.

(3) Nellis AFB, Nev: Runway 03R-21L; F-4 and F-111 aircraft.

(4) Hill AFB, Utah: Flexible pavement portion of runway 14-32; F-4 or F-105 and C-130 aircraft.

(5) Minot AFB ND: Flexible pavement portion of parallel taxiway; B-52 and KC-135 aircraft.

c. At Eglin AFB, Little Rock AFB and Nellis AFB, the data are to be collected four times per year in May, August, December, and March. At Hill AFB and Minot AFB, the data are to be collected in early May and early September.