TRI-SERVICE PAVEMENT WORKING GROUP (TSPWG) MANUAL

CONSTRUCTING PAVEMENT DESIGN AND EVALUATION CHARTS

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TRI-SERVICE PAVEMENTS WORKING GROUP MANUAL (TSPWG M)

CONSTRUCTING PAVEMENT DESIGN AND EVALUATION CHARTS

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FOREWORD

This Tri-Service Pavements Working Group Manual supplements guidance found in Unified Facilities Criteria, Unified Facility Guide Specifications, Defense Logistics Agency Specifications, and Service-specific publications. All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and, in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the TSPWG Manual, the SOFA, the HNFA, and the BIA, as applicable. This manual provides guidance on generating charts, curves, and tables for design and evaluation of pavements. The information in this TSPWG Manual is referenced in technical publications on the Whole Building Design Guide. It is not intended to take the place of Service-specific doctrine, technical orders (TOs), field manuals, technical manuals, handbooks, Tactics, Techniques or Procedures (TTPs), or contract specifications, but should be used along with these to help ensure pavements meet mission requirements.

TSPWG Manuals are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction, maintenance, repair, or operations. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Systems Command (NAVFAC), and the Air Force Civil Engineer Center (AFCEC) are responsible for administration of this document. Technical content of this TSPWG Manual is the responsibility of the Tri-Service Pavements Working Group (TSPWG). Defense agencies should contact the preparing activity for document interpretation. Send recommended changes with supporting rationale to the respective Service TSPWG member.

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TRI-SERVICE PAVEMENT WORKING GROUP (TSPWG) MANUAL
NEW SUMMARY SHEET

Document: TSPWG M 3-260-03.22-01, *Constructing Pavement Design and Evaluation Charts*

Superseding: None

Description: This manual provides guidance on generating charts, curves and tables for design and evaluation of airfield pavements.

Reasons for Document:

- The revision of UFC 3-260-03, *Airfield Pavement Evaluation*, implements PCASE software to evaluate pavements and removes previously allowed charts for manually evaluating pavements. This TSPWG manual provides guidance on generating charts to design and evaluate pavements.

Impact: There is no cost impact. The following benefits should be realized.

- Supplemental information on the design and evaluation of pavements will be available to all Services.

- Maintenance and/or upgrading of this supplemental information will include inputs from all Services.

Unification Issues: None.

Note: The use of the name or mark of any specific manufacturer, commercial product, commodity, or service in this publication does not imply endorsement by the Department of Defense (DOD).

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CHAPTER 1 INTRODUCTION

1-1   BACKGROUND.

Evaluation charts are tools that determine allowable loads and allowable passes for a single pavement layer. In rigid pavements, this is the concrete layer. For flexible pavements, analyze each layer in turn to determine the allowable load and passes for the entire pavement structure.

The analytical process calculates pavement responses induced by a mission aircraft for a selected load and number of passes. These pavement responses are inter-related and checked against limiting values defined by performance criteria to determine the allowable gross load (AGL) permitted on a pavement for a set number of evaluation passes.

1-2   PURPOSE AND SCOPE.

This document describes the process to construct flexible and rigid airfield pavement evaluation charts using conventional evaluation procedures. Flexible pavement evaluation uses stress-based performance criteria derived from the Fröhlich single-layer model (CBR-Beta model), while rigid pavement evaluation uses performance criteria derived from the Westergaard medium-plate theory stress model (k-model).

The evaluation charts for flexible and rigid pavement structures graphically represent the entire analysis process incorporated in the Pavement-Transportation Computer Assisted Structural Engineering (PCASE) application. Charts are limited as compared to more precise PCASE calculations. Constructing an evaluation chart involves many variables, including the AGL, number of passes, pavement layer thicknesses, layer strength properties, and traffic areas. These factors contribute to the shape and extent of the evaluation charts. In addition, the extent, curve smoothness, and axis ranges require manual adjustment for each aircraft evaluation chart to accommodate a wider or more narrow range of values in terms of aircraft load, passes, layer strengths, thickness, etc. Therefore, evaluation charts in their final form closely approximate more precise PCASE calculations.

1-3   APPLICABILITY.

This manual applies to rigid and flexible pavements and focuses on airfield pavements as well as pavement subject to other traffic. While manual calculations can generate the data required to construct all curves for an evaluation chart, the large number of points required to obtain smooth curves renders this approach somewhat impractical. Generating the data using software to create the charts is a more practical approach. A customized subset of PCASE algorithms can calculate the allowable load and allowable passes for a given pavement structure necessary to produce the data tables required to generate each curve in an evaluation chart. A basic understanding of the pavement evaluation processes, pavement models, and inherent limitations of the graphical approach is required when generating evaluation charts using these instructions.

1-4 **GLOSSARY.**

Appendix A contains acronyms, abbreviations, and terms.

1-5 **REFERENCES.**

Appendix B contains a list of references used in this document. The publication date of the code or standard is not included in this document. Unless otherwise specified, the most recent edition of the referenced publication applies.

CHAPTER 2 BASIS OF CHART CONSTRUCTION

2-1   DEFINITIONS.

The following definitions are used across the various airfield flexible and rigid pavement evaluation charts. Units of measure are generically provided where required in the following format:

- [F] –   Units of force or weight [lb, N]

- [L] –   Units of length [in, m]

- [F/L^2] –   Units of pressure [lb/in^2 (or psi), MN/m^2]

2-1.2   Mission Aircraft.

The aircraft of interest selected to determine the AGL and allowable passes of that aircraft.

2-1.3   Evaluation Load.

Aircraft gross load used for analysis at the specified number of evaluation passes [F].

2-1.4   Evaluation Passes.

The number of evaluation passes used for analysis at the aircraft evaluation load.

2-1.5   AGL – Allowable Gross Load.

The calculated AGL for the mission aircraft based on the specified evaluation passes on a defined pavement structure at [F].

2-1.6   Allowable Passes.

The allowable number of passes of the mission aircraft based on the specified evaluation load on a defined pavement structure.

2-1.7   P/C – Pass-to-Coverage Ratio.

The number of passes of a specified aircraft required to produce one coverage over a traffic lane. This parameter is a function of pavement type, traffic area (percent load and wander width), aircraft gear geometry, and tire width. See Table 2-1 for examples.

Table 2-1   Sample Aircraft Pass-to-Coverage Ratio

Aircraft	Flexible Pavements		Rigid Pavements	
	Traffic Area A	Traffic Areas B, C, D	Traffic Area A	Traffic Areas B, C, D
B-1B Lancer	1.706	2.815	3.413	5.630
B-52H Stratofortress	1.641	1.962	1.641	1.962
C-5A/B Galaxy	0.810	1.032	1.399	1.643
C-17A Globemaster III	1.380	1.899	1.380	1.899
C-130-J Hercules	2.334	4.528	4.667	9.056
F-15C/D Eagle	9.328	13.812	9.328	13.812
F-15E Eagle	8.102	11.987	8.102	11.987
F-22 Raptor	12.289	21.019	12.289	21.019
KC-10A Extender	1.885	2.800	3.215	5.487
Boeing 747-400	1.810	2.554	3.619	5.107
CV-22 Osprey	4.165	5.172	4.165	5.172
KC-46A Pegasus	1.867	3.022	3.734	6.044
P-3C Orion	3.556	6.615	3.556	6.615

2-1.8   Limiting Vertical Stress.

For flexible pavement structures, the limiting vertical stress represents the maximum vertical stress that the subgrade or a pavement sublayer supports without failing $[F/L^2]$.

2-1.9   CBR – California Bearing Ratio.

The CBR is an empirical measure of soil strength adopted in the conventional design and evaluation of flexible pavements and unsurfaced airfields. For laboratory prepared samples, determine the CBR through ASTM D1883, *Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils*. Although withdrawn in 2018, in the absence of other approved procedures, see ASTM D4429, *Standard Test Method for CBR (California Bearing Ratio) of Soils in Place,* for evaluating soils in the field.

2-1.10 k – Modulus of Subgrade Reaction.

The modulus of subgrade reaction quantifies the support provided by the subgrade or the base beneath a concrete slab when the rigid pavement system is represented as a slab placed on a dense liquid foundation. In the field, the modulus of subgrade reaction is determined using the plate bearing test, CRD-C 655-95, *Standard Test Method for Determining the Modulus of Soil Reaction.* The value of k is incremented according to the procedure delineated in UFC 3-260-02 when there are additional layers between the

concrete slab and the subgrade, such as a base or drainage layer, and is denoted as the effective k. In this case, the effective k depends on the thickness of the base or subbase layers placed over the existing subgrade [(F/L^2)/L]. The effective modulus of subgrade reaction represents the value of k directly beneath the slab and accounts for the support provided by the entire pavement structure beneath the slab. When conducting a plate bearing test (CRD-C 655-95) on top of a layered structure, the test measures the effective k representing the support of the entire layer structure.

The radius of relative stiffness represents the stiffness of the concrete slab in relation to the foundation supporting that concrete slab. It is the distance from the interior load to the point of contraflexure of the slab. The radius of relative stiffness is given by the formula [L].

Equation 2-1.   Radius of Relative Stiffness

$$l = \sqrt[4]{\frac{Eh^3}{12k(1-v^2)}}$$

Where:

h – Thickness of a Concrete Slab [L]
E – Modulus of Elasticity of Concrete [F/L2]
v – Poisson's Ratio of Concrete
l – Radius of Relative Stiffness

2-1.11 R – Concrete Flexural Strength.

The flexural strength of concrete determined by ASTM C78, *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)*, on a simple beam with third-point loading. [F/L^2].

2-1.12 σ_e – Free Edge Stress.

Free edge stress is the maximum free-edge stress acting at the bottom of a concrete slab under an aircraft landing gear using the Westergaard medium-plate theory as implemented by Pickett and Ray to compute the free edge stress [F/L^2]. The free-edge stress calculation assumes that the tire contact pressure remains constant during the analysis. Likewise, previous evaluation charts assumed a constant tire contact area. With constant contact area, the relationship between calculated allowable load and free-edge stress is linear and permits the use of load factor ratios in the evaluation charts. However, the actual contact area under loaded aircraft tires is always changing as the pneumatic tire compresses or decompresses, so the assumption of constant contact pressure better simulates field conditions.

2-1.13   **DF – Design Factor.**

The DF is the ratio of the flexural strength to a design or evaluation maximum edge stress. Equation 2-2 defines the design factor and assumes a 25 percent load transfer across joints.

Equation 2-2.   **Design Factor**

$$DF = \frac{R}{0.75\sigma_e}$$

The design factor is defined for three different failure conditions: first crack, shattered slab, and complete failure. DoD pavement evaluations are only performed for first crack and shattered slab failure criteria, characterized as the point at which 50 percent of the slabs have at least one crack or 50 percent of the slabs are shattered. These are defined by the following two equations:

Equation 2-3.   **First Crack (Standard Evaluation)**

$$DF = 0.7 - 0.001k + 0.25\log_{10} C$$

Equation 2-4.   **Shattered Slab (Extended Life)**

$$DF = 0.5 - 0.00123k + 0.25\log_{10} C$$

Where:

k (or *Effective* k) (lb/in^3), modulus of subgrade reaction entered in Imperial units of measure, is greater or equal to 200 lb/in^3 (54 MN/m^3) and less than or equal to 500 lb/in^3 (136 MN/m^3)

C are coverages.

2-1.14 E_N **– Evaluation Number.**

The evaluation number (E_N) is defined exclusively for rigid pavements and is a normalization number used in the iterative process for determining allowable load and passes. The evaluation number is defined as follows.

Equation 2-5.   **Evaluation Number**

$$E_N = \frac{\frac{R}{0.75DF}}{\left(\frac{l}{h}\right)^2}$$

2-2   **CHART CONSTRUCTION BASIS.**

Evaluation chart construction assumes a relationship between the evaluation variables to construct lines between the appropriate input parameters to generate an intermediate value or a final value, such as AGL or allowable passes. In most cases, a chart's range

and scales (ordinates and/or abscissas) require adjustment to improve readability. This includes adjusting numbers on the scales, spacing out curves and lines evenly, and adjusting the axes ranges to values appropriate to the aircraft in question.

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CHAPTER 3 RIGID PAVEMENT

3-1   RIGID EVALUATION CHART USAGE.

The following example outlines the evaluation process to determine the allowable load and allowable passes for a C-17A Globemaster aircraft given the rigid pavement structure shown below and using Figures 3-1, 3-2, 3-3, 3-4 and Table 3-1.

- 50,000 passes of the C-17A aircraft

- Traffic Area A (channelized full load)

- Slab thickness, h = 14 inches

- Modulus of elasticity of concrete, E = 4,000,000 psi

- Poisson's ratio of concrete, υ = 0.15

- Modulus of subgrade reaction, k = 200 psi/in.

- Flexural strength of concrete, R = 600 psi

- Evaluate for both standard and extended life criteria

3-1.2   Determine the Allowable Gross Load for 50,000 Passes (Steps).

1.   Use Figures 3-1 or 3-2 to determine the design factor (DF) for the required failure criteria. Enter the figure with the evaluation passes of 50,000 and draw a horizontal line that intercepts the C-17A pass-coverage-ratio (see Table 2-1) (*P/C* = 1.38 for Traffic Area A). Draw a vertical line down to the intercept line corresponding to the given k-value (k = 200 psi/in.). Finally, draw a horizontal line to read *DF* from the right scale. For a standard evaluation *DF* = 1.64 and for an extended life evaluation *DF* = 1.40.

2.   Use Table 3-1 to determine the normalized radius of relative thickness, l/h for k = 200 psi/in. and slab thickness h = 14 inches. From Table 3-1, l/h = 3.32; therefore, l = 3.32h = 3.32(14) = 46.5 inches.

3.   Use Figure 3-3 to determine the evaluation number E_N for each failure criteria. Start with l/h = 3.32 from Step 2 on the left vertical axis. Draw a horizontal line to the given flexural concrete strength R = 600 psi. Draw a vertical line to the design factors determined in Step 1, E_N = 44 for a standard evaluation and E_N = 52 for an extended life evaluation.

4.   Enter Figure 3-4 on the x axis with E_N = 44 (standard evaluation) or E_N = 52 (extended life evaluation) from Step 3, draw a vertical line to the radius of relative stiffness, l = 46.5 inches from Step 2, then draw a horizontal line to the y axis to determine the *AGL* = 500,000 lbs for a standard evaluation and *AGL* = 610,000 lbs for an extended life evaluation.

3-1.3   **Determine Allowable Passes for 585,000 lb Load (Reverse Steps).**

1.   Determine the evaluation number E_N from Figure 3-4. Trace a horizontal line from evaluation load = 585,000 lb until it intercepts the curve with $l =$ 46.5 inches. From there, draw a vertical line down to determine $E_N = 50$.

2.   Using Table 3-1, determine the normalized radius of relative stiffness, l/h for $k = 200$ psi/in and slab thickness $h = 14$ inches. From Table 3-1, $l/h =$ 3.32.

3.   Enter Figure 3-3 at the left vertical axis with the values $l/h = 3.32$, draw a horizontal line to $R = 600$, then draw a vertical line. Enter Figure 3-3 on the right vertical axis with the value $E_N = 50$ from Step 1, then draw a horizontal line to the point where it intersects the vertical line described above to determine the design factor *DF* required for the evaluation load. As shown on Figure 3-3, it might be necessary to interpolate between the *DF* curves. The resulting *DF* = 1.45.

4.   With the *DF* = 1.45 from Step 3, enter Figures 3-1 or 3-2 on the right vertical axis, then draw a horizontal line to the given *k* value (200 psi/in.), draw a vertical line to intercept the *P/C* of the C-17A, then draw a horizontal line to the left vertical axis to determine the allowable passes, 10,000 passes for standard evaluation and 80,000 passes for extended life evaluation.

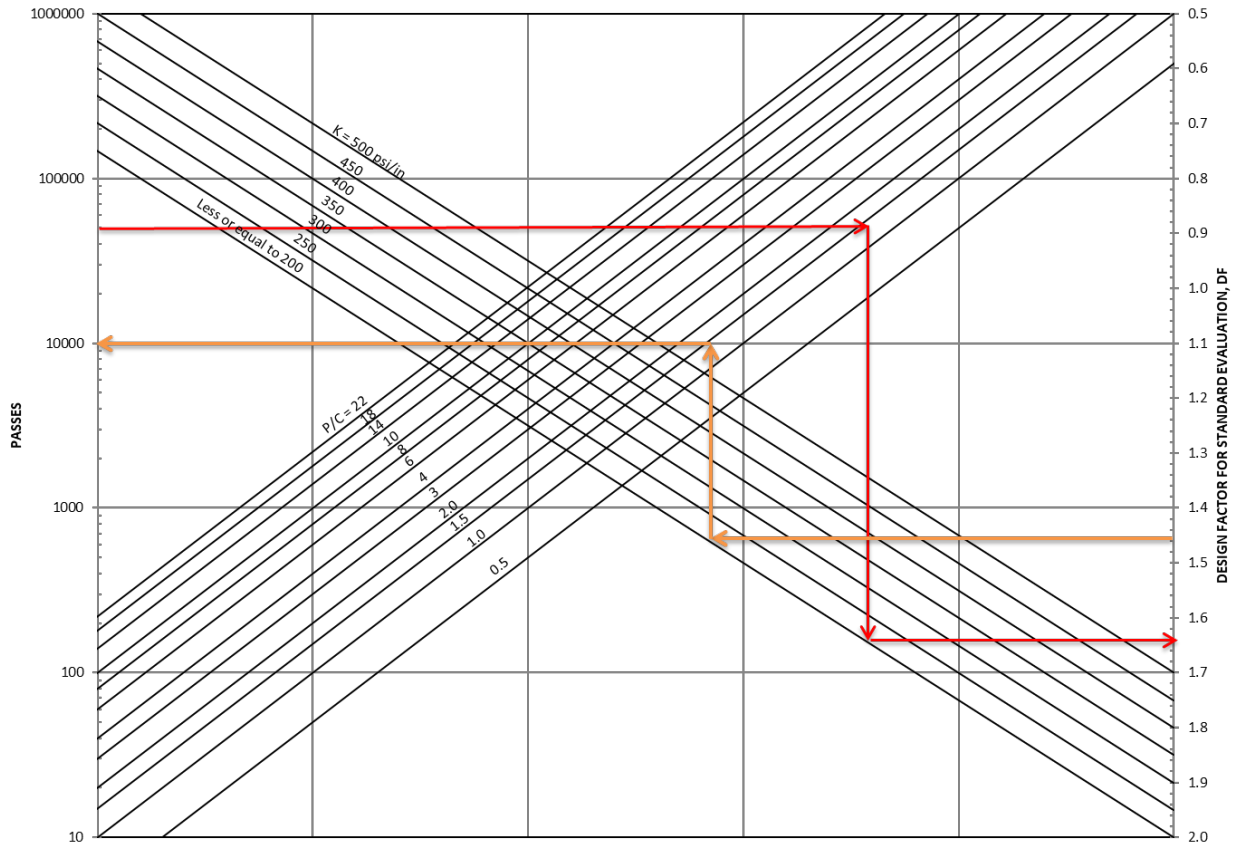**Figure 3-1 Design Factor for Standard Eval (First Crack)**

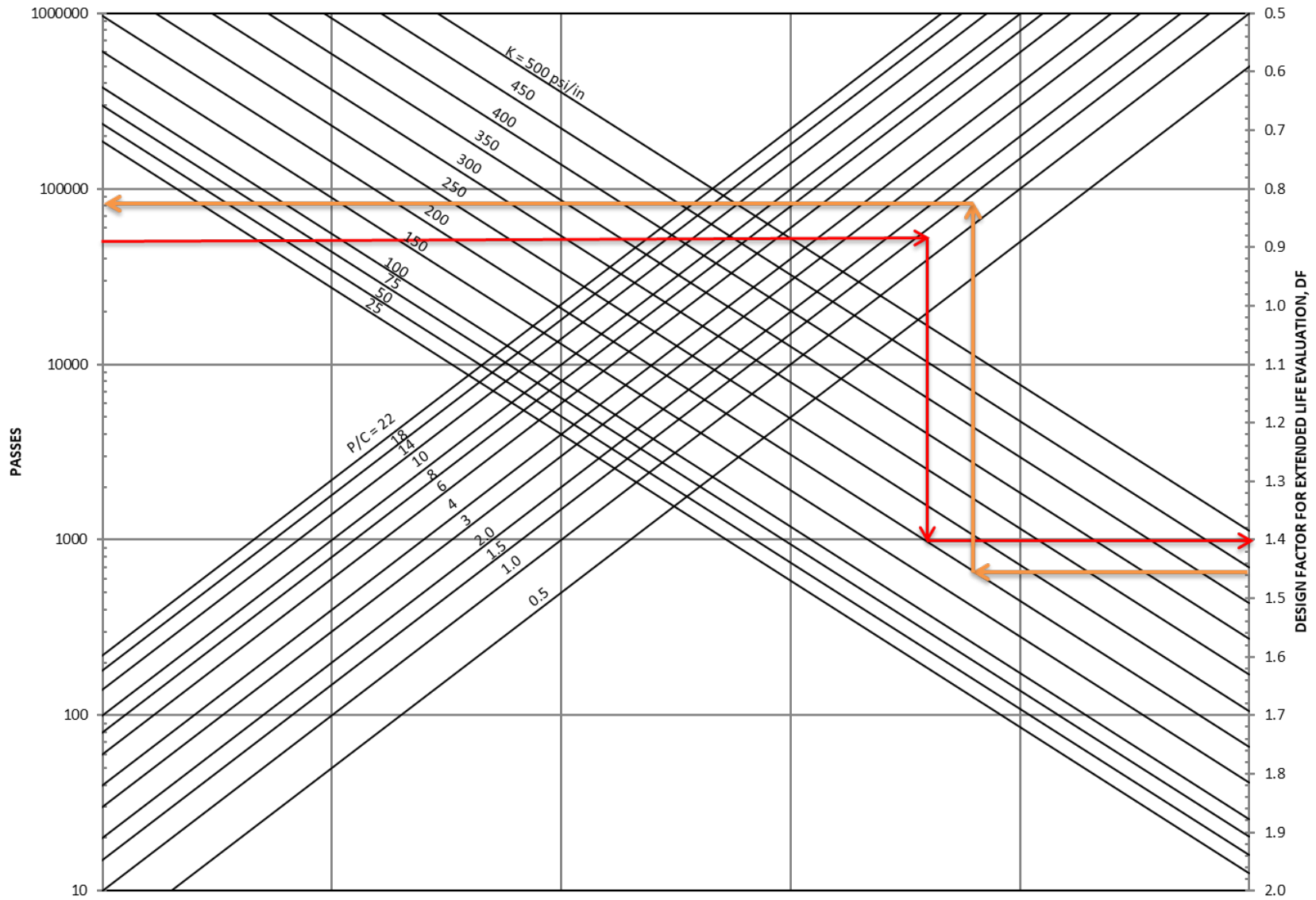**Figure 3-2 Design Factor for Extended Life Evaluation (Shattered Slab)**
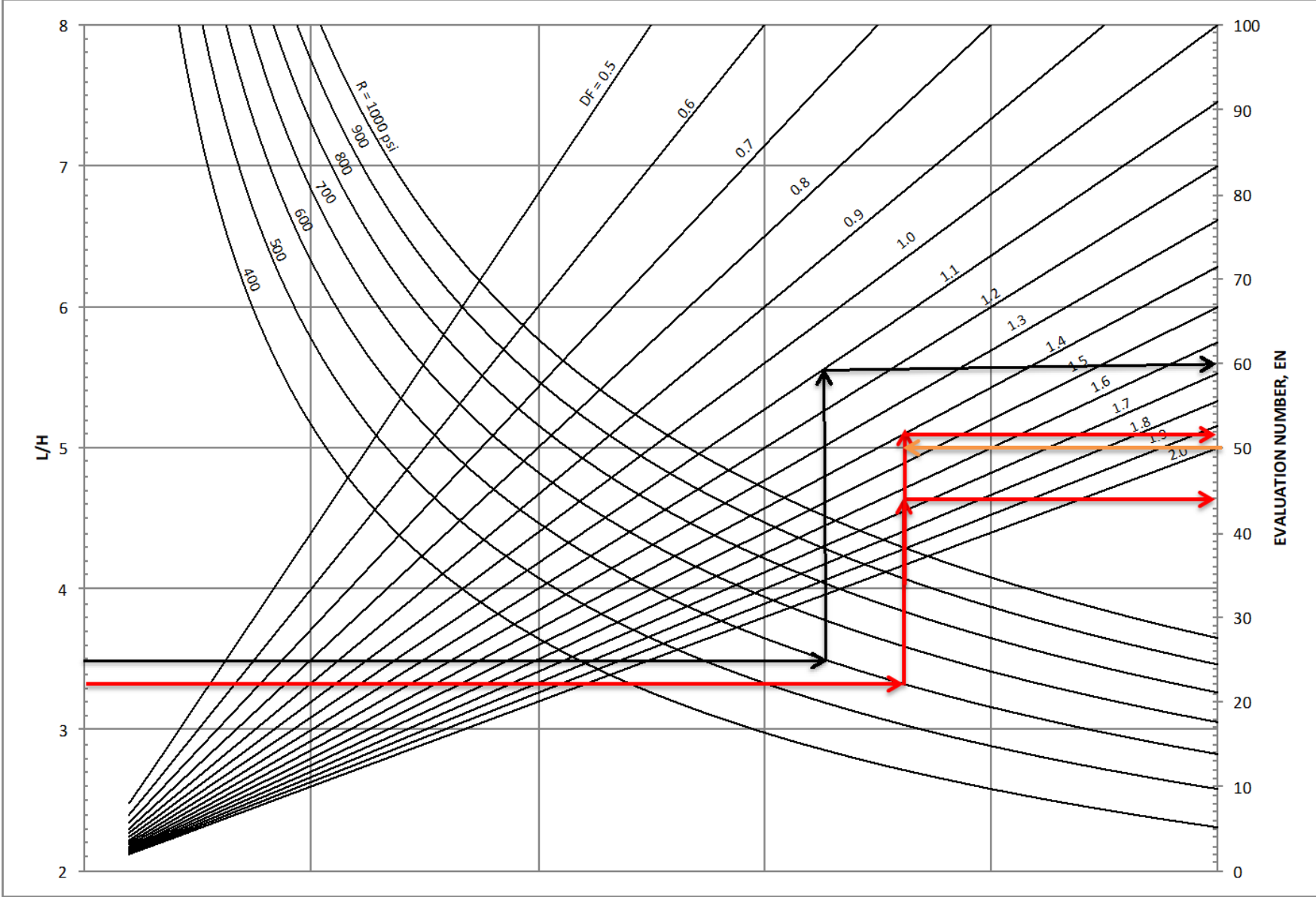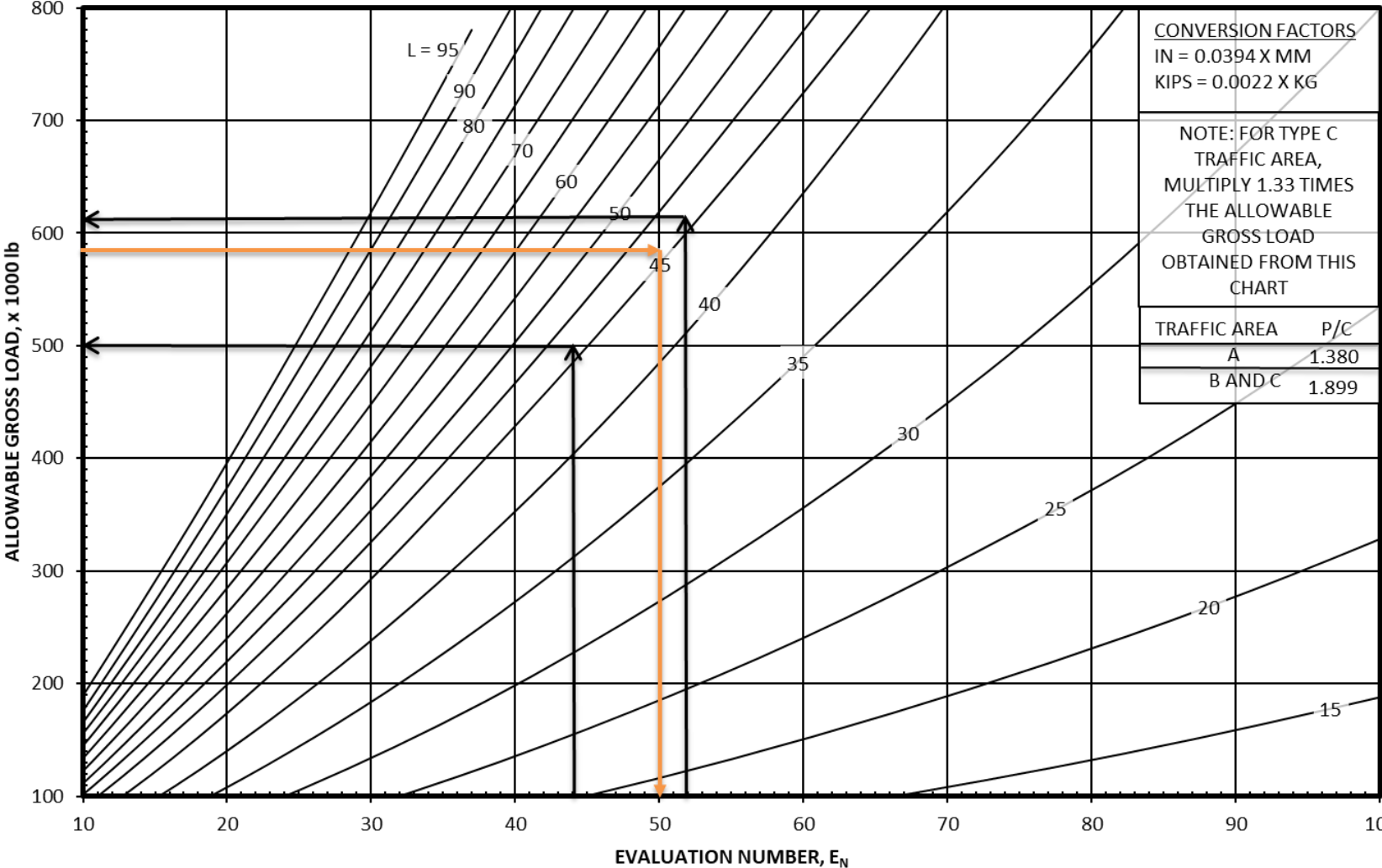
Figure 3-3 Evaluation Number, E_N

Figure 3-4 AGL Evaluation Chart for the C-17A

C-17A GlobeMaster III

Table 3-1 Normalized Radius of Relative Stiffness l/h (E = 4,000 ksi, v = 0.15)

h, in	k=25 lb/in³	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500
1	10.81	9.09	8.21	7.64	7.23	6.91	6.64	6.43	6.24	6.08	5.93	5.81	5.69	5.59	5.49	5.40	5.32	5.25	5.18	5.11
2	9.09	7.64	6.91	6.43	6.08	5.81	5.59	5.40	5.25	5.11	4.99	4.88	4.79	4.70	4.62	4.54	4.48	4.41	4.35	4.30
3	8.21	6.91	6.24	5.81	5.49	5.25	5.05	4.88	4.74	4.62	4.51	4.41	4.32	4.25	4.17	4.11	4.04	3.99	3.93	3.88
4	7.64	6.43	5.81	5.40	5.11	4.88	4.70	4.54	4.41	4.30	4.20	4.11	4.02	3.95	3.88	3.82	3.76	3.71	3.66	3.61
5	7.23	6.08	5.49	5.11	4.83	4.62	4.44	4.30	4.17	4.06	3.97	3.88	3.81	3.74	3.67	3.61	3.56	3.51	3.46	3.42
6	6.91	5.81	5.25	4.88	4.62	4.41	4.25	4.11	3.99	3.88	3.79	3.71	3.64	3.57	3.51	3.45	3.40	3.35	3.31	3.27
7	6.64	5.59	5.05	4.70	4.44	4.25	4.08	3.95	3.84	3.74	3.65	3.57	3.50	3.43	3.38	3.32	3.27	3.23	3.18	3.14
8	6.43	5.40	4.88	4.54	4.30	4.11	3.95	3.82	3.71	3.61	3.53	3.45	3.38	3.32	3.27	3.21	3.16	3.12	3.08	3.04
9	6.24	5.25	4.74	4.41	4.17	3.99	3.84	3.71	3.60	3.51	3.43	3.35	3.29	3.23	3.17	3.12	3.07	3.03	2.99	2.95
10	6.08	5.11	4.62	4.30	4.06	3.88	3.74	3.61	3.51	3.42	3.34	3.27	3.20	3.14	3.09	3.04	2.99	2.95	2.91	2.87
11	5.93	4.99	4.51	4.20	3.97	3.79	3.65	3.53	3.43	3.34	3.26	3.19	3.13	3.07	3.02	2.97	2.92	2.88	2.84	2.81
12	5.81	4.88	4.41	4.11	3.88	3.71	3.57	3.45	3.35	3.27	3.19	3.12	3.06	3.00	2.95	2.90	2.86	2.82	2.78	2.75
13	5.69	4.79	4.32	4.02	3.81	3.64	3.50	3.38	3.29	3.20	3.13	3.06	3.00	2.94	2.89	2.85	2.80	2.76	2.73	2.69
14	5.59	4.70	4.25	3.95	3.74	3.57	3.43	3.32	3.23	3.14	3.07	3.00	2.94	2.89	2.84	2.79	2.75	2.71	2.68	2.64
15	5.49	4.62	4.17	3.88	3.67	3.51	3.38	3.27	3.17	3.09	3.02	2.95	2.89	2.84	2.79	2.75	2.70	2.67	2.63	2.60
16	5.40	4.54	4.11	3.82	3.61	3.45	3.32	3.21	3.12	3.04	2.97	2.90	2.85	2.79	2.75	2.70	2.66	2.62	2.59	2.56
17	5.32	4.48	4.04	3.76	3.56	3.40	3.27	3.16	3.07	2.99	2.92	2.86	2.80	2.75	2.70	2.66	2.62	2.58	2.55	2.52
18	5.25	4.41	3.99	3.71	3.51	3.35	3.23	3.12	3.03	2.95	2.88	2.82	2.76	2.71	2.67	2.62	2.58	2.55	2.51	2.48
19	5.18	4.35	3.93	3.66	3.46	3.31	3.18	3.08	2.99	2.91	2.84	2.78	2.73	2.68	2.63	2.59	2.55	2.51	2.48	2.45
20	5.11	4.30	3.88	3.61	3.42	3.27	3.14	3.04	2.95	2.87	2.81	2.75	2.69	2.64	2.60	2.56	2.52	2.48	2.45	2.42
21	5.05	4.25	3.84	3.57	3.38	3.23	3.10	3.00	2.91	2.84	2.77	2.71	2.66	2.61	2.57	2.52	2.49	2.45	2.42	2.39
22	4.99	4.20	3.79	3.53	3.34	3.19	3.07	2.97	2.88	2.81	2.74	2.68	2.63	2.58	2.54	2.49	2.46	2.42	2.39	2.36
23	4.93	4.15	3.75	3.49	3.30	3.15	3.03	2.93	2.85	2.78	2.71	2.65	2.60	2.55	2.51	2.47	2.43	2.40	2.36	2.33
24	4.88	4.11	3.71	3.45	3.27	3.12	3.00	2.90	2.82	2.75	2.68	2.62	2.57	2.52	2.48	2.44	2.40	2.37	2.34	2.31
25	4.83	4.06	3.67	3.42	3.23	3.09	2.97	2.87	2.79	2.72	2.65	2.60	2.55	2.50	2.46	2.42	2.38	2.35	2.31	2.29
26	4.79	4.02	3.64	3.38	3.20	3.06	2.94	2.85	2.76	2.69	2.63	2.57	2.52	2.47	2.43	2.39	2.36	2.32	2.29	2.26
27	4.74	3.99	3.60	3.35	3.17	3.03	2.91	2.82	2.74	2.67	2.60	2.55	2.50	2.45	2.41	2.37	2.33	2.30	2.27	2.24
28	4.70	3.95	3.57	3.32	3.14	3.00	2.89	2.79	2.71	2.64	2.58	2.52	2.47	2.43	2.39	2.35	2.31	2.28	2.25	2.22
29	4.66	3.92	3.54	3.29	3.11	2.98	2.86	2.77	2.69	2.62	2.56	2.50	2.45	2.41	2.37	2.33	2.29	2.26	2.23	2.20
30	4.62	3.88	3.51	3.27	3.09	2.95	2.84	2.75	2.67	2.60	2.54	2.48	2.43	2.39	2.35	2.31	2.27	2.24	2.21	2.18

3-2   CONSTRUCTING RIGID PAVEMENT EVALUATION CHARTS.

This section describes how to construct the four evaluation charts described in the previous example. The charts in Figures 3-1, 3-2, and 3-3 are independent of the aircraft and are constructed once. Figure 3-4 is prepared for each aircraft.

3-2.1   Constructing Design Factor Charts (Figures 3-1 and 3-2).

The charts in Figures 3-1 and 3-2 are graphical representations of Equations 2-3 and 2-4. They present the linear relationships between *DF*, k, and *log₁₀ C*. Therefore, only two points are required to generate the graphs. Two families of lines are generated on the same chart, as demonstrated in Figure 3-5 for a standard evaluation. The first family of lines relate *DF* on the primary horizontal axis to evaluation passes on the primary vertical axis. The second family of lines relate evaluation passes on the secondary horizontal axis to *DF* on the secondary vertical axis.

To plot the first family of lines, fix k in Equations 2-3 and 2-4 to a convenient value and vary *DF* to solve for the coverages *C.* The example in Figure 3-5 uses k = 200 psi/in. Calculated coverages are converted to passes by multiplying *C* by a preselected set of *P/C* ratios. Sample chart Figure 3-5 uses two *P/C* ratios: *P/C* = 4.0 and *P/C* = 1.0**.**

Use a convenient *P/C* ratio (*P/C* = 1.0) to plot the second family of curves. Solve Equations 2-2 and 2-3 for a new set of design factors (*DF)* and change the k and coverages *C.* Plot these new sets of design factors *DF* on the secondary vertical axis against coverages on the secondary horizontal axis. For less-cluttered charts and to avoid plotting all curves in the same direction, invert the scale of the secondary vertical axis so the two sets of curve families cross each other. Note that the scales for the two *DF* axes and the two passes' axes utilize the same *DF* range (0.5 to 2.0) on both axes and pass range (1 to 1,000,000) on both axes. This is important for the pivot from any *P/C* value other than 1 that represents a line of equality between the two sets of axes. To verify results in the chart, assume passes = 10,000, k = 200 psi/in., and *P/C* = 4.0. From Equation 2-3:

$$DF = 0.7 - 0.001(200) + 0.25\log_{10}(10000/4.0) = 1.35$$

This result matches the *DF* = 1.35 obtained from Figure 3-5.

Figure 3-5 Example of Standard Life Evaluation Design Factor Chart
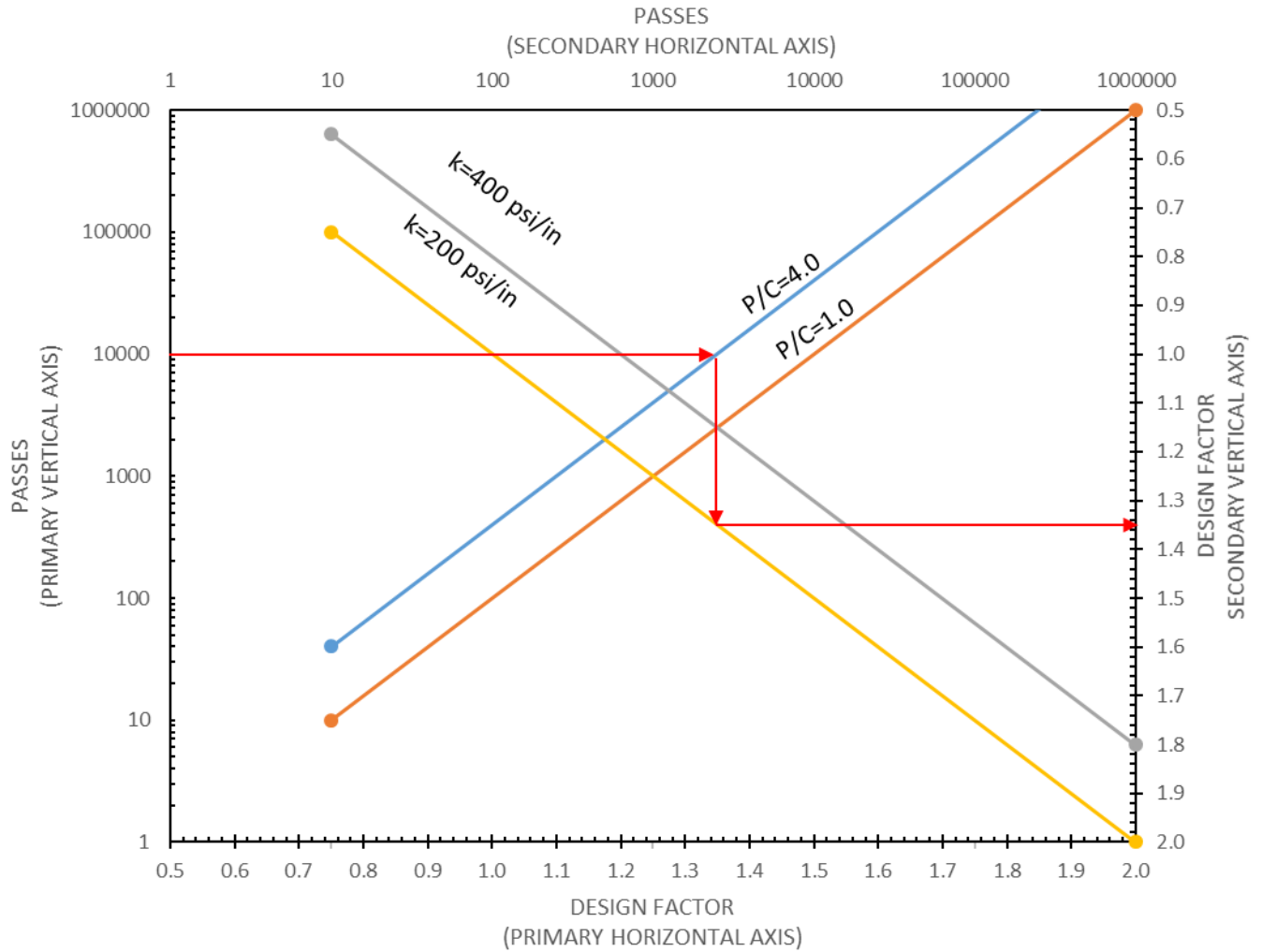
3-2.2 Constructing Evaluation Number Charts (Figure 3-3).

Use a graphical representation of Equation 2-5 to construct the evaluation number (E_N) chart in Figure 3-3. The E_N is linearly proportional to R, inversely proportional to DF, but nonlinear with respect to $(l/h)^2$ since this term is squared. Use one or more of the variables in Equation 2-5 as a reference to construct this chart. This yields a reference set of curves as functions of E_N. Use a convenient design factor ($DF' = 1.0$) as the reference variable. The importance of choosing the reference variable cannot be overstated. The most difficult aspect of constructing these combined charts is understanding that you are choosing this reference DF value to relate to other DF values and their corresponding curves. In other words, the nonlinear curves for different R-values in Figure 3-6 are actually for $DF = 1.0$ and the diagonal lines for different DF values act as pivot points to shift from the curves corresponding to other DF values to those represented by $DF = 1.0$.

Develop the family of curves by relating l/h ratios and E_N in Equation 2-5 for varying values of R. Rewrite Equation 2-5 as Equation 3-1 below to indicate that E'_N values are calculated using *DF'* as a reference value.

Equation 3-1.   Evaluation Number Referencing DF'

$$E'_N = \frac{\frac{R}{0.75DF'}}{\left(\frac{l}{h}\right)^2}$$

Figure 3-6 shows an example for two curves calculated by setting $R = 400$ psi and $R = 600$ psi in Equation 3-1. Plot the calculated values for E'_N along the primary horizontal axis and plot the l/h ratios along the primary vertical axis. Adjust the reference curves by multiplying E'_N by the ratio *DF'/DF* to determine E_N for other values of *DF* using Equation 3-2.

Equation 3-2.   Evaluation Number Using Other DF Values

$$E_N = E'_N \left(\frac{DF'}{DF}\right)$$

Next, apply Equation 3-2 to adjust the E'_N values from the two curves developed for $R = 400$ psi and $R = 600$ psi. Plot the results on the secondary vertical axis to obtain the final E_N values as illustrated in Figure 3-6. The two curves in the example are for design factors *DF* = 1.0 and *DF* = 0.75. To verify the chart results, assume *DF* = 0.75, $l/h = 3.5$, and $R = 400$ psi. From Equation 2-5:

Equation 3-3.   Evaluation Number Calculation Check

$$E_N = \frac{\frac{R}{0.75DF}}{\left(\frac{l}{h}\right)^2} = \frac{\frac{400}{0.75(0.75)}}{(3.5)^2} = 58$$

This result matches the $E_N = 58$ obtained from Figure 3-6.

Figure 3-6 Sample Construction of Evaluation Number Chart

Figure 3-6 Sample Construction of Evaluation Number Chart
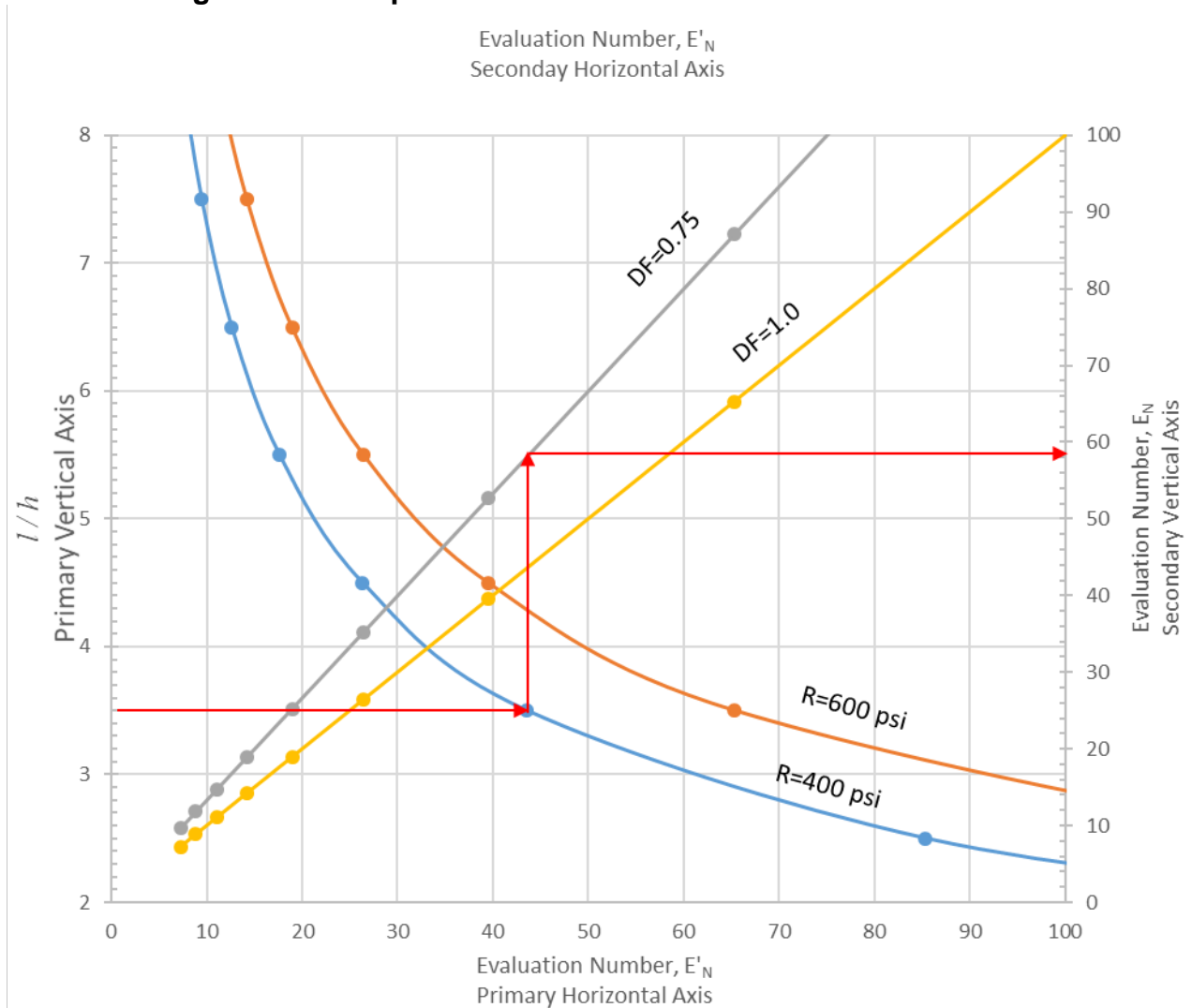
3-2.3 Constructing Allowable Gross Load Charts (Figure 3-4).

There is no prescribed equation to construct the AGL chart of an aircraft. Constructing these charts involves an interactive procedure to calculate the AGL based on a computerized solution of the Westergaard medium-plate theory. This requires large amounts of data to generate smooth curves as functions of both the radius of relative stiffness, l, and the evaluation number, E_N. Equation 3-4 uses Equation 2-5 to solve for the slab thickness, h. It establishes a set of values E_N, l, R, and DF that are input variables to the computerized solution.

Equation 3-4.   Slab Thickness

$$h = l \sqrt{\frac{E_N}{\left(\frac{R}{0.75DF}\right)}}$$

The family of l curves shown in Figure 3-4 results from running the computerized solution for 23 values of E_N ranging from 5 to 100 and 23 values of l also ranging from 5

to 100. This forms a calculation matrix with a total of 529 data points as shown in Table 3-2. Each l column is plotted against the E_N.

Table 3-2   Calculation Matrix to Develop AGL Chart (Figure 3-4)

		Number of l				
		1	2	3	…	23
		Radius of Relative Stiffness, l inches				
Number of E_N	Evaluation Number, E_N	5	10	15	…	100
1	5					
2	10					
3	15					
…	…					
23	100					

Creating this type of table manually using PCASE is very tedious.

CHAPTER 4 FLEXIBLE PAVEMENT

4-1   FLEXIBLE EVALUATION CHART USAGE.

Use the sample flexible evaluation charts shown in Figures 4-1 and 4-2 in conjunction with Table 4-1 to determine AGLs or allowable passes. These example charts are for the C-17A Globemaster aircraft.

In the example below, we evaluate a flexible pavement for the following conditions:

- 50,000 passes of the C-17A aircraft
- Traffic Area A (channelized full load)
- Total pavement thickness above subgrade, T = 36 inches
- CBR = 6

4-1.2   Determine the Allowable Gross Load for 50,000 Passes.

1.   Determine the limiting vertical stress for a *CBR* = 6. Use Table 4-1. The *P/C* ratio for the C-17A from Table 2-1 for Traffic Area A is 1.38.

The limiting vertical stress value (limiting vertical stress / *CBR*) for *P/C* = 1.0 at 50,000 passes = 2.51

The limiting vertical stress value (limiting vertical stress / *CBR*) for *P/C* = 1.5 at 50,000 passes = 2.57

Interpolate between *P/C* = 1.0 and *P/C* = 1.5 to determine the limiting vertical stress for *P/C* = 1.38 and passes = 50,000.

$$2.51 + (2.57 - 2.51)\frac{(1.38 - 1.0)}{(1.5 - 1.0)} = 2.55$$

Compute the limiting vertical stress = 2.55 x *CBR* = 2.55 x 6 = 15.4 psi

2.   Enter Figure 4-1 with limiting vertical stress = 15.4 psi, trace a vertical line to intercept a subgrade CBR = 6. Then draw a horizontal line to intercept a pavement thickness = 36 inches. Draw a vertical line to the allowable load at the bottom horizontal axis. From Figure 4-1, AGL = 627,000 lbs.

4-1.3   Determine the Allowable Passes for 585,000 lb Load:

1.   Enter Figure 4-1, draw a vertical line from the load axis for an evaluation load = 585,000 lbs until it intercepts a pavement thickness = 36 inches. Draw a horizontal line from the thickness curve to intercept the curve corresponding to a CBR = 6. From there, draw a vertical line & read the limiting vertical stress = 14.2 psi.

2.   Enter Figure 4-2 with a limiting vertical stress = 14.2 psi, trace a horizontal line to intercept the curve corresponding to Traffic Area A. Draw a vertical line down to the passes axis and read the allowable passes = 114,000.

Table 4-1   Limiting Vertical Stress vs Passes and Pass-to-Coverage Ratio

Passes	Limiting Vertical Stress (psi) = (Value from this Table) Multiplied By (CBR)[1]														
	Pass-To-Coverage Ratio, P/C														
	0.14	0.25	0.33	0.50	1.00	1.5	2.00	3.00	4.00	6.00	8.00	10.00	14.00	18.00	22.00
1	6.93	7.83	8.34	9.23	11.14	12.60	13.84	15.96	17.81	21.07	23.99	26.72	31.83	36.69	41.41
3	5.66	6.27	6.60	7.18	8.36	9.23	9.95	11.14	12.14	13.84	15.29	16.60	18.95	21.07	23.05
5	5.21	5.72	6.01	6.48	7.46	8.16	8.73	9.68	10.46	11.76	12.86	13.84	15.56	17.10	18.50
10	4.70	5.12	5.34	5.72	6.48	7.02	7.46	8.16	8.73	9.68	10.46	11.14	12.33	13.36	14.29
30	4.07	4.38	4.55	4.82	5.35	5.72	6.02	6.48	6.86	7.46	7.94	8.36	9.07	9.68	10.21
50	3.83	4.11	4.25	4.49	4.95	5.26	5.51	5.91	6.22	6.72	7.12	7.46	8.03	8.52	8.94
100	3.56	3.79	3.91	4.11	4.49	4.75	4.95	5.26	5.51	5.91	6.22	6.48	6.93	7.29	7.61
300	3.20	3.38	3.47	3.62	3.91	4.11	4.26	4.49	4.67	4.95	5.17	5.35	5.66	5.91	6.12
500	3.05	3.22	3.30	3.44	3.69	3.87	4.00	4.20	4.36	4.60	4.79	4.95	5.21	5.42	5.60
1,000	2.88	3.03	3.10	3.22	3.44	3.58	3.69	3.87	4.00	4.20	4.36	4.49	4.70	4.87	5.02
3,000	2.65	2.77	2.83	2.92	3.10	3.22	3.30	3.44	3.54	3.69	3.81	3.91	4.07	4.20	4.31
5,000	2.56	2.67	2.72	2.81	2.97	3.07	3.15	3.27	3.36	3.50	3.61	3.69	3.83	3.95	4.04
10,000	2.45	2.54	2.59	2.67	2.81	2.90	2.97	3.07	3.15	3.27	3.36	3.44	3.56	3.65	3.73
30,000	2.29	2.37	2.41	2.48	2.59	2.67	2.72	2.81	2.87	2.97	3.04	3.10	3.20	3.27	3.33
50,000	2.23	2.30	2.34	2.40	2.51	2.57	2.63	2.70	2.76	2.85	2.92	2.97	3.05	3.12	3.18
100,000	2.15	2.21	2.25	2.30	2.40	2.46	2.51	2.57	2.63	2.70	2.76	2.81	2.88	2.94	2.99
300,000	2.03	2.09	2.12	2.17	2.25	2.30	2.34	2.40	2.44	2.51	2.55	2.59	2.65	2.70	2.74
500,000	1.99	2.04	2.07	2.11	2.19	2.24	2.27	2.33	2.37	2.42	2.47	2.51	2.56	2.61	2.64
1,000,000	1.93	1.98	2.00	2.04	2.11	2.15	2.19	2.24	2.27	2.33	2.37	2.40	2.45	2.49	2.52

[1] Values in this table represent the limiting vertical stress normalized to a CBR = 1.0. To determine the limiting stress for other CBR values, multiply the values from this table by the CBR.

Figure 4-1 C-17A Allowable Gross Load on Flexible Pavements
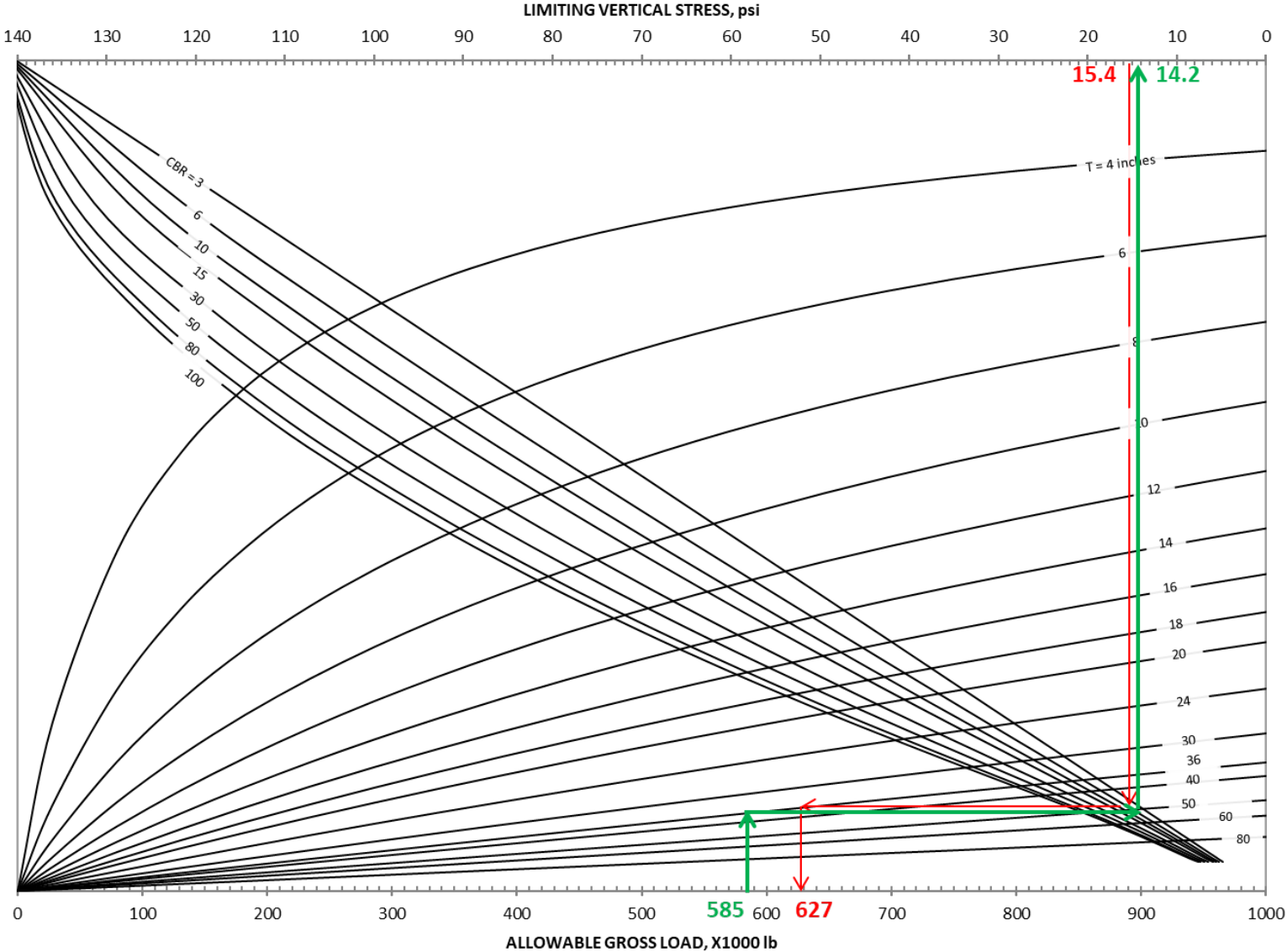
Figure 4-2   Allowable Passes vs Limiting Vertical Stress for C-17A
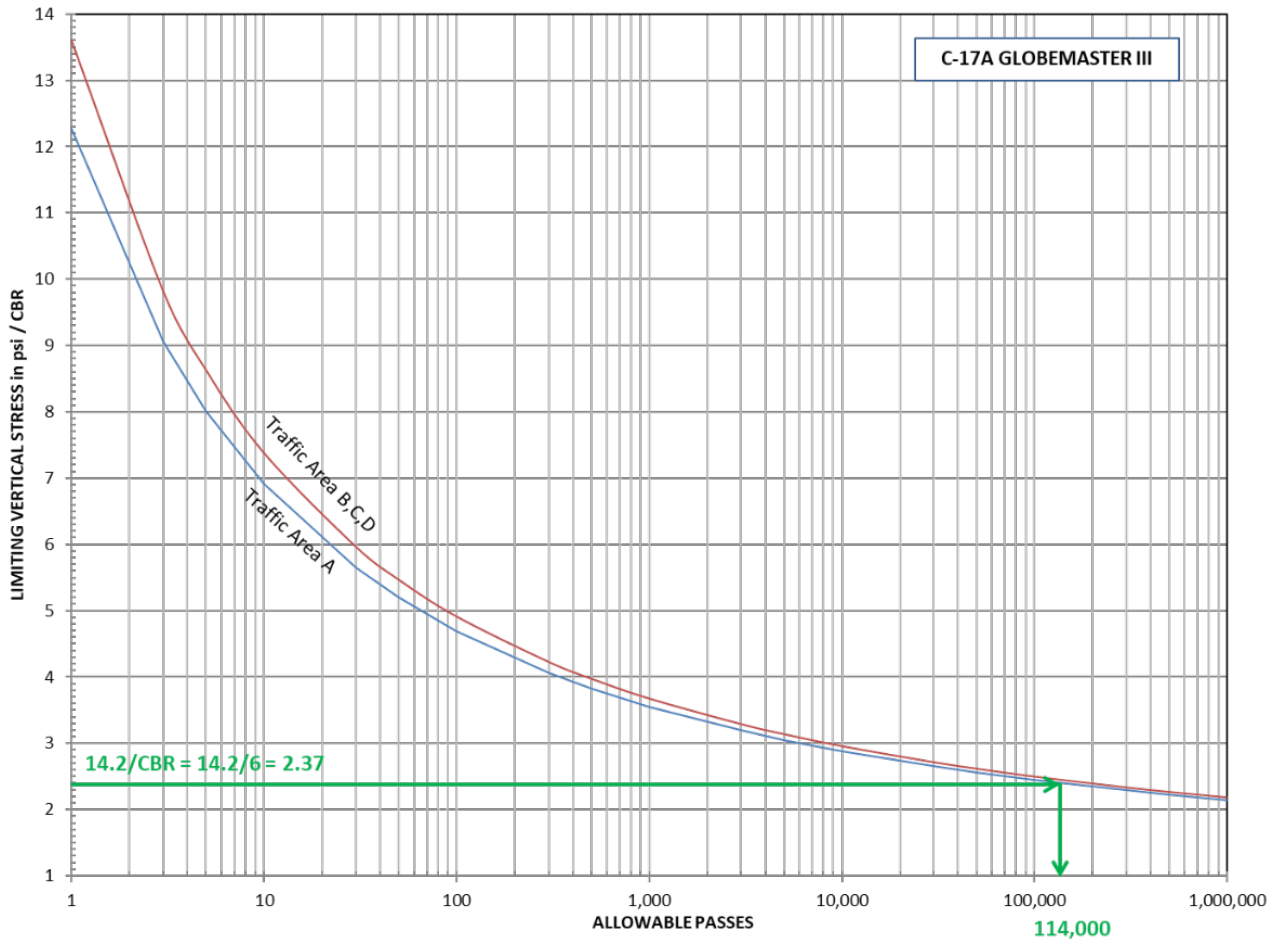
4-2   CONSTRUCTING FLEXIBLE EVALUATION CHARTS/TABLES CBR ≤ 20.

Table 4-1 and Figures 4-1 and 4-2 are based on the implementation of the CBR-Beta flexible pavement criteria. When the *CBR* is less than or equal to 20, use the following procedure to develop evaluation charts.

The CBR-Beta criteria are mathematically expressed by the following equations:

Equation 4-1.   Log₁₀ CBR-Beta Criteria

$$\log_{10} \beta = \frac{1.5441 + 0.073 \log_{10} C}{1 + 0.2354 \log_{10} C}$$

Equation 4-2.   **CBR-Beta Criteria**

$$\beta = \frac{\pi \sigma_z}{CBR}$$

Where:

σ_z = Limiting vertical stress, psi
CBR = California Bearing Ratio of the subgrade
π = 3.1415927

4-2.2   Constructing Limiting Vertical Stress Table (Table 4-1).

Table 4-1 is a tabulation of the limiting vertical stress, σ_z, derived from Equation 4-1 and normalized to a CBR = 1.0. To construct this table, convert a list of passes to coverages by dividing the passes by the P/C ratio to obtain the coverages, C = passes / (P/C). Enter the coverages, C, into Equation 4-1 and solve for the limiting vertical stress, σ_z/CBR, where CBR = 1.0. For this reason, to obtain the actual limiting vertical stress, multiply any Table 4-1 value by the CBR. For instance, where the subgrade CBR = 10, Passes = 10,000, and the P/C = 2.0, the limiting vertical stress value from Table 4-1 is 2.97. To get the limiting vertical stress for a CBR = 10, σ_z = 2.94 x CBR = 2.97 x 10 = 29.7 psi.

Table 4-1 is a generic table that is independent of aircraft; hence, it is constructed once.

4-2.3   Constructing AGL Chart for CBR ≤ 20 (Figure 4-1).

4-2.3.1   The chart in Figure 4-1 is a graphical approximation of the computerized solution implemented in PCASE to determine AGLs for specific aircraft. To construct the portion of the chart in Figure 4-1 dealing with the family of thicknesses above a certain CBR value, calculate maximum vertical stresses by assuming a set of aircraft gross loads ranging from an arbitrary minimum load to approximately twice the maximum load on the aircraft. Divide this load range into a sufficient number of load increments to obtain smooth curves. For the example shown in Figure 4-1 (C-17 aircraft), the load increments are 50,000 lbs. and the maximum load is 1,200,000 lbs. Often it is necessary to adjust the load increments, maximum loads, and the number and thickness increments to accommodate other aircraft.

4-2.3.2   Table 4-2 shows the calculation matrix required for a specific subgrade CBR value. A total of 456 cases (24 load increments x 19 thicknesses) are required to populate this table. The process is repeated for other CBR values. A total of eight tables are generated for CBR = 3, 6, 10, 15, 30, 50, 80, and 100, for the example in Figure 4-1. Therefore, a total of 3,648 total cases (456 x 8) are generated to populate all tables.

Table 4-2   Calculation Matrix (Figure 4-1)

C-17 Aircraft Reference CBR=3						
		Number of Thicknesses				
Number of Load Increments	**Aircraft Gross Load, lb**	1	2	3	…	19
		Thickness, T in inches				
		4	6	8	…	80
1	50					
2	100					
3	150					
…	…					
12	600					
…	…					
24	1200					
Maximum gross load = 585,000 lbs						

4-2.3.3   Once the tables are completed, select a reference *CBR* (i.e., *CBR* = 3) and plot each aircraft gross load against the calculated vertical stress on the primary horizontal and vertical axes. This results in a family of curves relating *AGL* to vertical stress for each pavement thickness at the reference *CBR*.

4-2.3.4   In Equation 4-2, the vertical stress is linearly proportional to the *CBR*; therefore, the vertical stresses for the chosen reference *CBR* can plot directly against any other CBR value as long as the aircraft gross weight is a constant value. To achieve the best results, select an aircraft gross weight near the maximum weight of the aircraft.

4-2.3.5   For this example, the load used in Figure 4-3 is near the maximum weight of the C-17 aircraft (600,000 lb, see Table 4-2). Plot the vertical stresses from the row corresponding to 600,000 lb in Table 4-2 against the same row in the tables developed for *CBR* = 6, 10, 15, 30, 50, 80, and 100. The vertical stresses for each *CBR* are plotted on the secondary horizontal axis and the reference *CBR* (*CBR* = 3) on the primary vertical axis. This generates a family of curves as a function of *CBR*. To avoid having all curves go in the same general direction and to make the chart easier to read, reverse the scale on the secondary horizontal axis.

Figure 4-3 Constructed AGL Chart for the C-17A
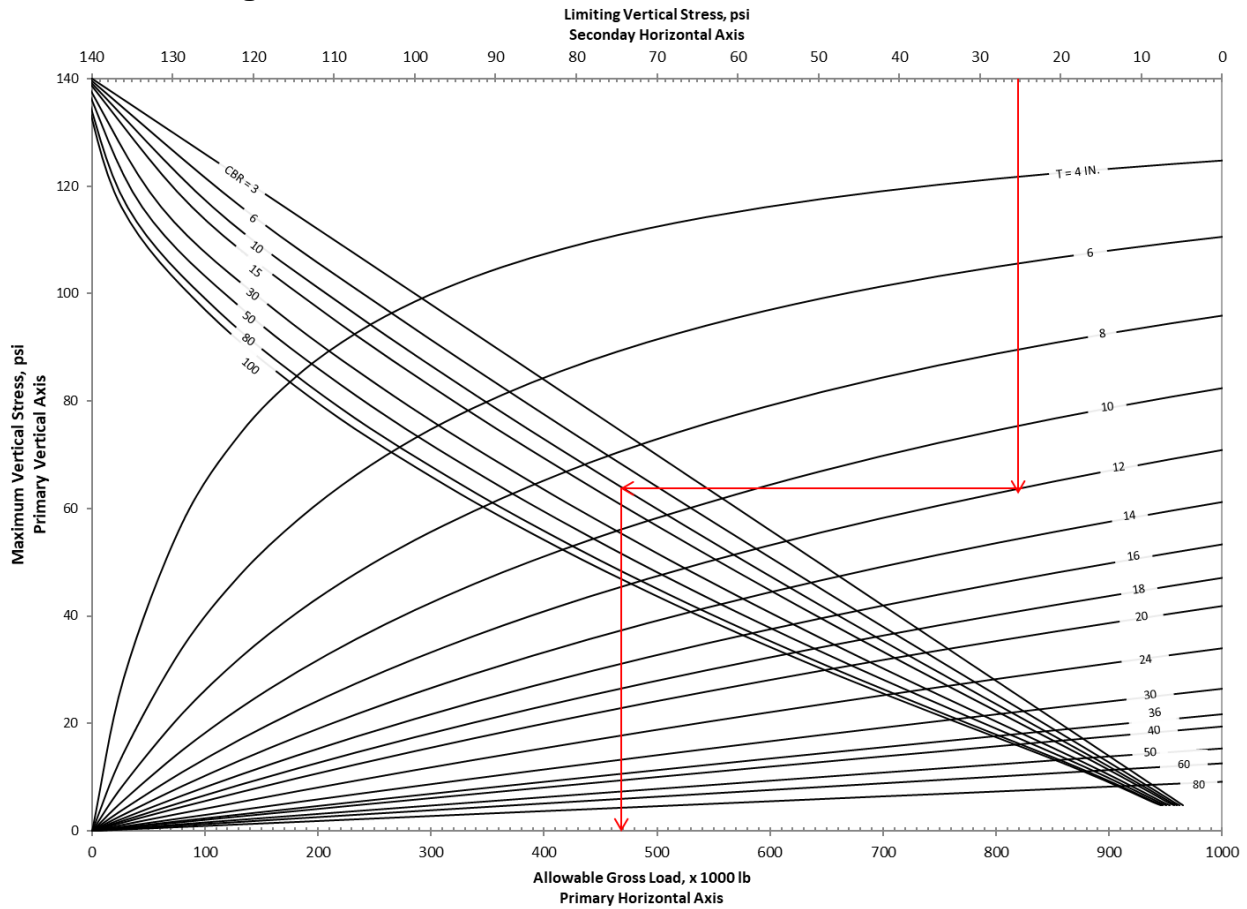
4-2.4   Constructing Allowable Pass Charts for CBR ≤ 20.

Figure 4-2 is a graphical representation of the solution of Equation 4-1 in terms of the allowable number of coverages as a function of traffic areas for a prescribed limiting vertical stress. These allowable coverages must be converted to allowable passes; therefore, charts are developed for each aircraft. Equation 4-1 is rearranged as follows to solve for σ_z.

Equation 4-3.   Limiting Vertical Stress

$$\sigma_z = \left(\frac{CBR}{\pi}\right) 10^{\left(\frac{1.5441+0.073\log_{10}C}{1+0.2354\log_{10}C}\right)}$$

Using Equation 4-3, calculate the limiting vertical stresses for a prescribed set of allowable passes. Plot these allowable passes against the calculated limiting vertical stress for Traffic Area A and Traffic Areas B, C, and D. Note that Figure 4-2 is aircraft-dependent and therefore must be generated for each aircraft.

4-3   CONSTRUCTING AGL CHARTS FOR CBR ≥ 30.

4-3.1   Constructing evaluation charts for subgrade CBR ≥ 30 is based on the legacy CBR-Alpha criteria defined by Equation 4-4.

Equation 4-4.   Thickness

$$t = \alpha \sqrt{\frac{ESWL}{8.1 CBR} - \frac{A}{\pi}}$$

Where:
   t = required thickness above subgrade, inches
   CBR = subgrade California Bearing Ratio
   α = alpha factor
   $ESWL$ = equivalent single wheel load, lb.
   A = tire contact area, in^2

4-3.2   The tire contact area A in Equation 4-4 is a function of load and contact pressure. The $ESWL$ is a function of the aircraft gear geometry and pavement thickness t. The example graph in Figure 4-4 depicts the ESWL factor curve for the C-17A aircraft. The α-factor is a function of coverages as it shows in Figure 4-5.

4-3.3   Solve Equation 4-4 for the $ESWL$ as shown in Equation 4-5 to determine the AGL of an aircraft for a number of evaluation passes over a subgrade CBR with thickness t.

Equation 4-5.   Equivalent Single Wheel Load

$$ESWL = 8.1\ CBR \left[\left(\frac{t}{\alpha} \right)^2 + \frac{A}{\pi} \right]$$

4-3.4   The process to calculate the AGL requires an iterative approach since the tire contact area A changes with tire load. First determine the $ESWL$ factor from Figure 4-4 for a pavement thickness t and a subgrade CBR. Then determine the α-factor for the evaluation passes from Figure 4-5. Convert the passes to coverages by applying the appropriate P/C for the desired traffic area. Then assume an AGL, compute the corresponding tire contact area A, and finally calculate a new AGL using Equation 4-6.

Equation 4-6.   Allowable Gross Load

$$AGL = \frac{\dfrac{\frac{ESWL}{ESWLFactor}}{nt}}{pct}$$

Where:
   nt is the number of tires used to calculate the $ESWL$
   pct is the percent of the aircraft gross load per tire.

4-3.5   Continue this process until the absolute value of the difference (AGL_{New} – $AGL_{Assumed}$) is negligible or less than a tolerance value. This iterative process typically converges within about 10 iterations.

4-3.6   The sample calculations in Table 4-3 are generated for the C-17A aircraft to illustrate constructing *AGL* charts using the CBR-Alpha criteria. First, choose an arbitrary reference pass level that generates reasonable allowable loads for a range of thicknesses. The example in Table 4-3 assumes 50,000 passes. Next, set up a range of thicknesses from 10 to 80 inches. Then, calculate the AGLs for *CBR* = 3, 6, and 10. Normally, a computerized solution generates these calculations using Figures 4-4 and 4-5 and Equations 4-5 and 4-6. Plot the resulting *AGL* values in the primary horizontal axis against the thickness in the primary vertical axis for each *CBR* column. This generates a family of *CBR* curves as shown in Figure 4-6.

4-3.7   Next, choose a reference *CBR* (*CBR* = 6) but vary the passes. Plot the resulting *AGL* as function of passes on the secondary vertical axis versus thickness on the secondary horizontal axis. This forms the second family of pass curves as illustrated in Figure 4-6.

Table 4-3   Data Generated to Construct AGL Chart for CBR ≥ 30

C-17A Globemaster – Traffic Area A					
Reference Passes = 50,000			Reference CBR = 6		
Thickness, in.	AGL, lbs			AGL, lbs		
	CBR=3	CBR=6	CBR=10	Passes=50,000	Passes=10,000	Passes=1,000
10	33,179	68,673	120,210	68,673	79,501	105,593
15	64,066	132,923	231,211	132,923	154,342	204,260
20	100,968	205,417	355,064	205,417	239,451	314,633
25	141,130	284,130	489,805	284,130	328,301	436,003
30	182,846	367,567	633,438	367,567	425,065	568,167
40	273,455	554,480	937,399	554,480	639,683	846,579
50	371,918	755,587	1,268,597	755,587	876,197	1,156,619
60	483,569	976,249	1,632,297	976,249	1,129,142	1,494,424
70	601,769	1,213,099	2,020,676	1,213,099	1,403,256	1,851,948
80	726,241	1,459,217	2,435,780	1,459,217	1,687,027	2,237,219

4-3.2   Constructing Allowable Pass Charts for CBR ≥ 30.

Constructing allowable pass charts is also based on Equation 4-4. Here, the thickness *t* is linearly proportional to the α-factor and therefore to passes. Construct a chart by choosing a reference *CBR* and a reference *AGL* then solving Equation 4-4 either for the AGL for a range of thicknesses or for thickness for a range of passes.

Figure 4-7 is a graphical solution of the process just described. To construct the *CBR* family of curves in Figure 4-7, populate the sample data in Table 4-4 by setting the reference gross load to 585,000 lbs. for *CBR* = 3, 6, and 10. Calculate the thicknesses required for each *CBR* value for a range of passes as shown in Table 4-4. Plot the passes along the primary horizontal axis and the required thicknesses along the primary vertical axis to form the *CBR* family of curves as shown in Figure 4-7.

To construct aircraft gross load curves, assume a reference $CBR = 6$ and compute the required thicknesses at a range of gross loads equal to 400,000 lbs, 585,000 lbs, and 700,000 lbs. Since the relationship between thickness t and the α-factor is linear, plot calculated thicknesses for a reference gross load (585,000 lbs) and reference CBR ($CBR = 6$). In Figure 4-7, the reference thicknesses are plotted on the secondary vertical axis and the thicknesses for the selected aircraft gross load are plotted on the secondary horizontal axis. Reverse the scale for the secondary horizontal axis to make the chart easier to read. This process results in a family of aircraft gross load curves.

4-4   AGL∕ALLOWABLE PASS CHARTS FOR CBR 20 < CBR < 30.

There is no set procedure to develop evaluation charts for subgrade strengths in the range $20 < CBR < 30$. The current DoD pavement design and evaluation procedure is based on a CBR-Beta-Alpha Hybrid procedure that uses CBR-Beta criterion for $CBR \le$ 20 and the CBR-Alpha criterion for $CBR \ge 30$. Previous sections described how to construct and use tables and charts for both procedures. An interpolation method can manually determine the AGL or allowable passes for intermediate CBR values. For instance, to determine the allowable load for $CBR = 23$, first determine the AGL for CBR = 20 (AGL_{20}) and $CBR = 30$ (AGL_{30}). Then use linear interpolation to determine the AGL at $CBR = 23$ (AGL_{23}) as shown by Equation 4-7.

Equation 4-7.   Interpolated Allowable Gross Load

$$AGL_{23} = AGL_{20} + \left(\frac{AGL_{30} - AGL_{20}}{CBR_{30} - CBR_{20}}\right)(CBR_{23} - CBR_{20})$$

The more precise computerized solution generated from PCASE will differ from the manual solution for CBR values between 20 and 30.

Table 4-4   Data Generated to Construct Allowable Pass Chart for CBR ≥ 30

	C-17A Globemaster III					
	Reference Gross Load = 585,000 lbs			Reference CBR = 6		
	Thickness, in.			Thickness, in.		
Passes	CBR=3	CBR=6	CBR=10	AGL = 400,000 lbs	AGL = 585,000 lbs	AGL = 700,000 lbs
100	36.98	22.72	15.90	17.64	22.72	25.76
1,000	50.47	30.62	21.09	23.57	30.62	34.93
3,000	56.17	34.09	23.31	26.13	34.09	38.84
10,000	61.79	37.47	25.52	28.76	37.47	42.63
30,000	66.56	40.26	27.45	30.91	40.26	45.92
50,000	68.65	41.58	28.31	31.86	41.58	47.37
100,000	71.39	43.30	29.42	33.08	43.30	49.31
500,000	77.74	47.16	32.09	36.10	47.16	53.63
5,000,000	87.14	52.97	36.10	40.51	52.98	60.19

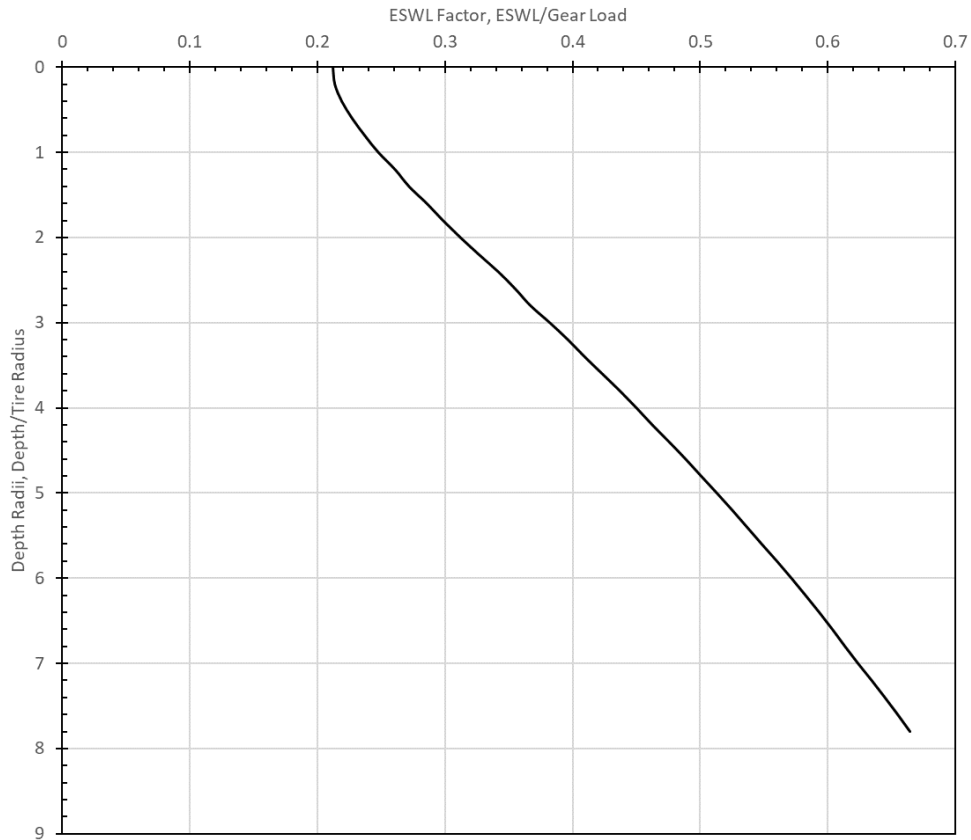**Figure 4-4 ESWL Factor for C-17A**

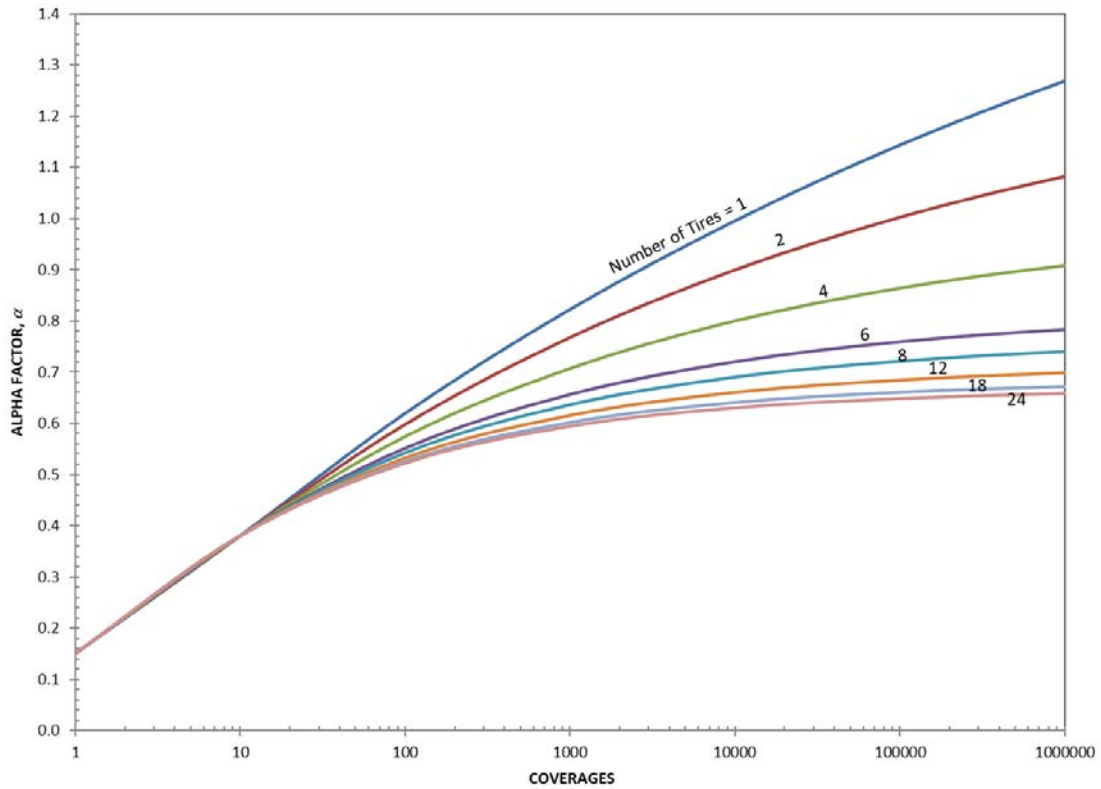**Figure 4-5 Alpha Factors as Function of Coverages**

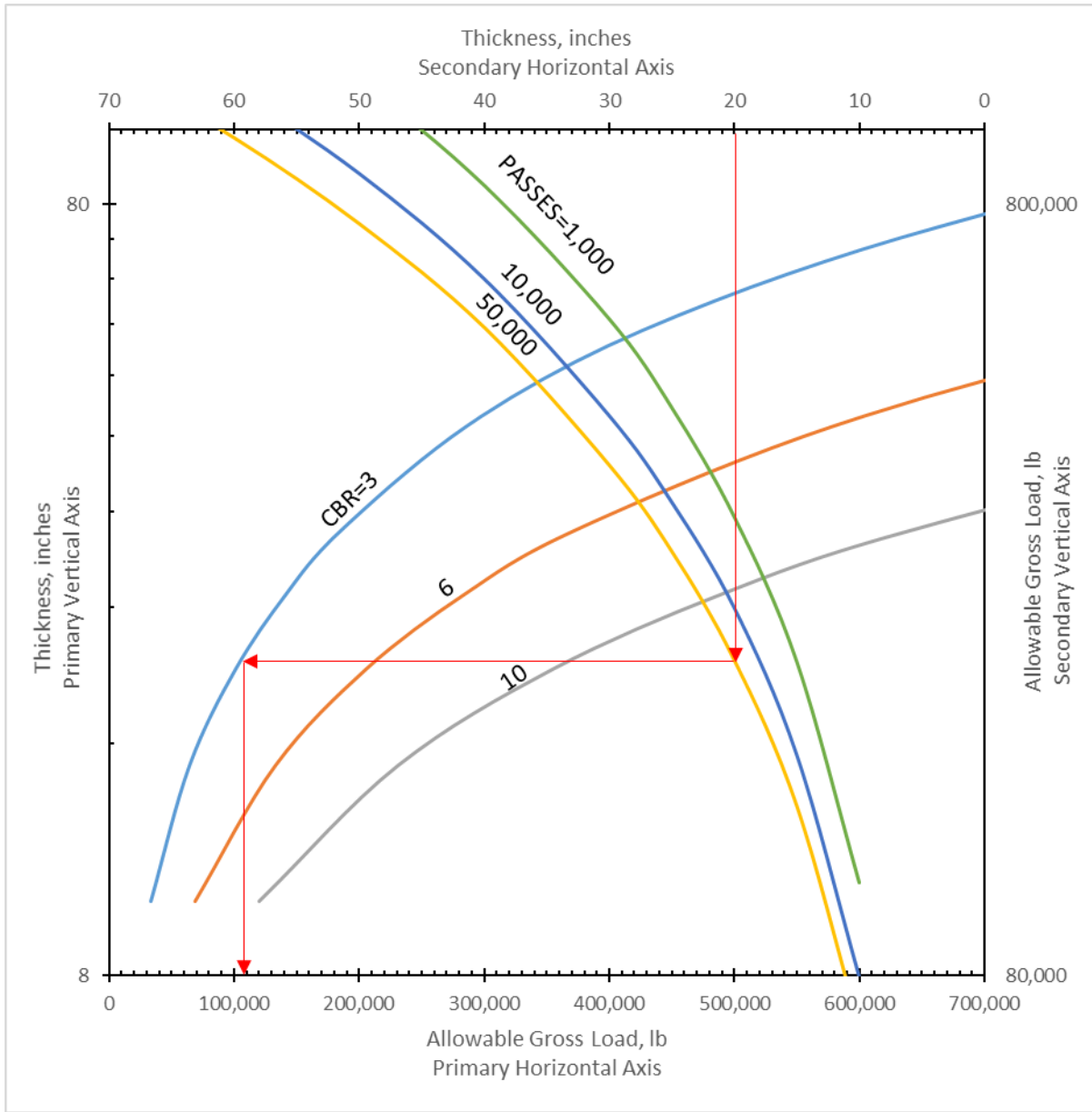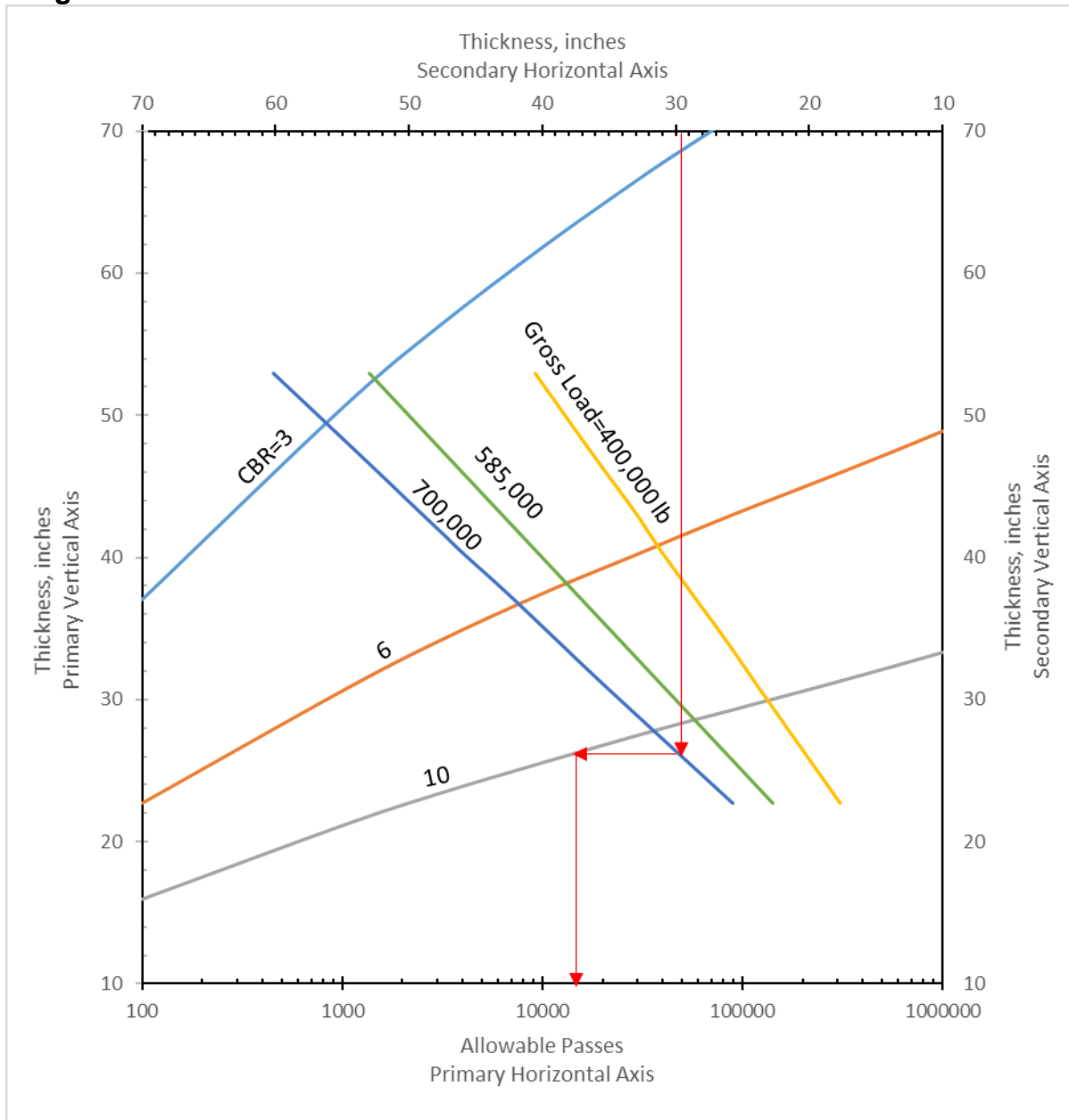### Figure 4-6 Constructed C-17A - Traffic Area A AGL Chart

Figure 4-7 Constructed C-17A - Traffic Area A Allowable Passes Chart

4-5   FINAL REMARKS.

4-5.1   In many cases, the evaluation charts will yield results that compare favorably to the results of more precise calculations. However, there are some innate limitations to the generality of the graphical representations. Some examples of limitations in the graphical solution are:

- Certain variables must be assumed and fixed to generate a plot, meaning it is not applicable in other scenarios.

- The fidelity/number of curves provided in a single plot is limited by readability that requires interpolation and incurs risks.

4-5.2   There are situations where the computerized solutions produce less precise values, generally around the fringes of the acceptable input or output values. For example, heavy aircraft on thin pavements or light aircraft on very strong pavements may yield unstable answers. Possible reasons for these instabilities:

- For heavy aircraft on thin pavements, current criteria are not well-suited for this scenario due to a lack of field data and limitations of the mechanistic-empirical models.

- For light aircraft on strong pavements, the transfer function levels off in this region where small changes in response yield large changes in passes, thus making certain iterative procedures difficult in the computerized solution.

4-5.3   In those cases, the graphical representation may need manual adjustments to eliminate these oddities. Take care when drawing guidelines between families of curves to produce accurate results. This is particularly difficult in plots like Figure 4-6 where both families of curves are nonlinear. Another difficult scenario is extrapolating beyond the established family of curves. (In Figure 4-6, for example, finding the AGL for 75,000 passes for a CBR 12.) In either case, the curves are not spaced evenly apart from one another (see the distance between 1,000 to 10,000 and 10,000 to 50,000).

4-5.4   This manual provides guidance for the process to construct the many charts and tables required to generate a graphical solution and explains many of the assumptions made during their development. It is not a fully step-by-step approach, since generating evaluation charts often requires manual selection of input values and their ranges as well as manipulating chart axes scales and orientation to achieve reasonable results.

APPENDIX A GLOSSARY

A-1   **ACRONYMS**

$[F/L^2]$ Units of pressure [lb/in^2 (or psi), MN/m^2]

[F]   Units of force or weight [lb, N]

[L]   Units of Length [in, m]

AGL   Allowable Gross Load

DoD   Department of Defense

ESWL   Equivalent Single Wheel Load

in.   Inch(es)

in^2 Square Inch(es)

in^3 Cubic Inch(es)

ksi   Kip(s) per Square Inch

lb(s)   Pound(s)

Lb/in2   Pound per Square Inch

Lb/in3   Pound per Cubic Inch

m   Meter

m^2 Square Meter

MN   Meganewton

MN/m2   Meganewton per Square Meter

MN/m^3 Meganewton per Cubic Meter

N   Newton(s)

PCASE   Pavement-Transportation Computer Assisted Structural Engineering

psi   Pound per Square Inch

UFC   Unified Facilities Criteria

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APPENDIX B REFERENCES

ARMY

CRD-C 655-95, *Standard Test Method for Determining the Modulus of Soil Reaction*, https://www.wbdg.org/ffc/army-coe/standards/crd-c655

DEPARTMENT OF DEFENSE

https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc

UFC 3-260-02, *Pavement Design for Airfields*

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

https://www.astm.org/

ASTM C78, *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)*

ASTM D1883, *Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils*

ASTM D4429, *Standard Test Method for CBR (California Bearing Ratio) of Soils in Place*