APPENDIX 2. DEVELOPMENT OF PAVEMENT DESIGN CURVES.

1. BACKGROUND.

a. The pavement design curves presented in this circular were developed using the California Bearing Ratio (CBR) method for flexible pavements and the Westergaard edge loading analysis for rigid pavements. The curves are constructed for the gross weight of the aircraft assuming 95% of the gross weight is carried on the main landing gear assembly and 5% of the gross weight is carried on the nose gear assembly. Aircraft traffic is assumed to be normally distributed across the pavement in the transverse direction. See FAA Research Report No. FAA-RD-74-36, Field Survey and Analysis of Aircraft Distribution on Airport Pavement. Pavements are designed on the basis of static load analysis. Impact loads are not considered to increase the pavement thickness requirements. See FAA Research Report No. FAA-RD-74-39, Pavement Response to Aircraft Dynamic Loads.

b. Generalized design curves are presented in Chapter 3 for single, dual, and dual tandem main landing gear assemblies. These generalized curves do not represent specific aircraft but are prepared for a range of aircraft characteristics which are representative of all civil aircraft except wide body. The aircraft characteristics assumed for each landing gear assembly are shown in Tables 1, 2, and 3.

2. RIGID PAVEMENTS.

a. The design of rigid airport pavements is based on the Westergaard analysis of an edge loaded slab resting on a dense liquid foundation. The edge loading stresses are reduced by 25 percent to account for load transfer across joints. Two different cases of edge loading are covered by the design curves. Figures 3-14 through 3-22 assume the landing gear assembly is either tangent to a longitudinal joint or perpendicular to a transverse joint, whichever produces the largest stress. Figures 3-23 through 3-29 are for dual tandem assemblies and have been rotated through an angle to produce the maximum edge stress. Computer analyses were performed for angles from 0 to 90 degrees in 10-degree increments. Single and dual wheel assemblies were analyzed for loadings tangent to the edge only as the stress is maximum in that position. Sketches of the various assembly positions are shown in Figure 1.

TABLE 1. SINGLE WHEEL ASSEMBLY

Gross Weight lbs.	(kg)	Tire Pressure psi	(MN/m^3)
30,000	(13 600)	75	(0.52)
45,000	(20 400)	90	(0.62)
60,000	(27 200)	105	(0.72)
75,000	(34 000)	120	(0.83)

TABLE 2. DUAL WHEEL ASSEMBLY

Gross Weight lbs.	(kg)	Tire Pressure psi	(MN/m^2)	Dual Spacing in.	(cm)
50,000	(22 700)	80	(0.55)	20	(51)
75,000	(34 000)	110	(0.76)	21	(53)
100,000	(45 400)	140	(0.97)	23	(58)
150,000	(68 000)	160	(1.10)	30	(76)
200,000	(90 700)	200	(1.38)	34	(86)

TABLE 3. DUAL TANDEM ASSEMBLY

Gross Weight lbs.	(kg)	Tire Pressure psi	(MN/m^2)	Dual Spacing in.	(cm)	Tandem Spacing in.	(cm)
100,000	(45 400)	120	(0.83)	20	(51)	45	(114)
150,000	(68 000)	140	(0.97)	20	(51)	45	(114)
200,000	(90 700)	160	(1.10)	21	(53)	46	(117)
300,000	(136 100)	180	(1.24)	26	(66)	51	(130)
400,000	(181 400)	200	(1.38	30	(76)	55	(140)

Specific design curves are presented for wide body aircraft. The aircraft characteristics are shown on the design curves.

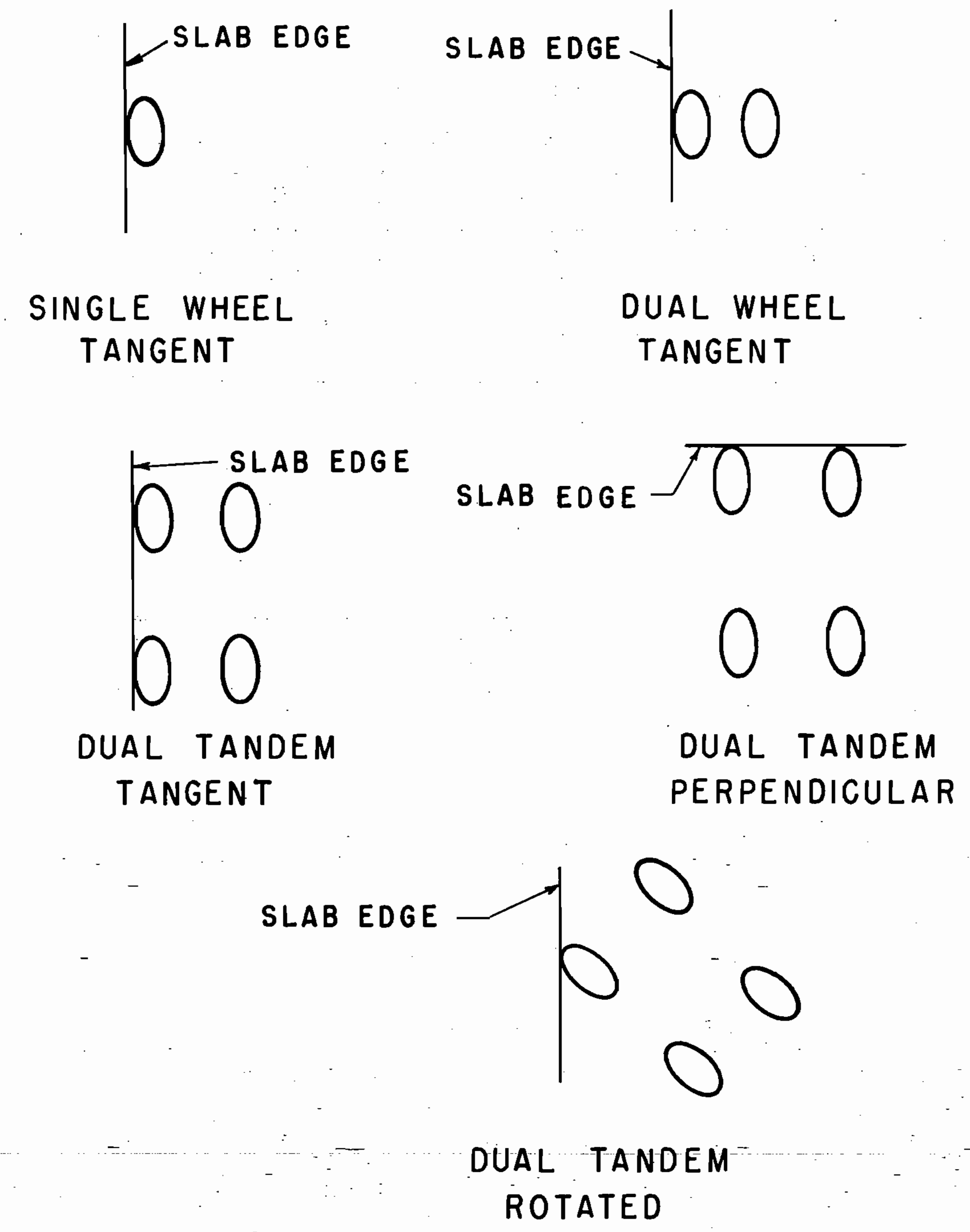

FIGURE 1. ASSEMBLY POSITIONS FOR RIGID PAVEMENT ANALYSIS

b. Fatigue effects are taken into consideration by converting traffic to coverages. The coverage concept provides a means of normalizing pavement performance data which can consist of a variety of wheel sizes, spacings and loads for pavements of different cross sections. For rigid pavements, coverage is a measure of the number of maximum stress applications occurring within the pavement slab due to the applied traffic. One coverage occurs when each point in the pavement within the limits of the traffic lane has experienced a maximum stress, assuming the stress is equal under the full tire print. Each pass (departure) of an aircraft can be converted to coverages using a single pass-to-coverage ratio which is developed assuming a normal distribution and applying standard statistical techniques. The pass-to-coverage ratios used in developing the rigid pavement design curves in Chapter 3 are given in Table 4. Annual departures are converted to coverages assuming a 20-year design life. Coverages are determined by multiplying annual departures by 20 and dividing that product by the pass-to-coverage ratio shown in Table 4.

TABLE 4. PASS-TO-COVERAGE RATIOS FOR RIGID PAVEMENTS

Design Curve	Pass-to-Coverage Ratio
Single Wheel	5.18
Dual Wheel	3.48
Dual Tandem	3.68
B-747	3.70
DC 10-10	3.64
DC 10-30	3.38
L-1011	3.62

c. After the conversion of departures to coverages, the slab thickness is adjusted in accordance with the fatigue curve developed by the Corps of Engineers from test track data and observation of in-service pavements. The fatigue relationship is applicable to the pavement structure; i.e., the slab and foundation are both included in the relationship. The thickness of pavement required to sustain 5,000 coverages of the design loading is considered to be 100 percent thickness. Any coverage level could have been selected as the 100 percent thickness level as long as the relative thicknesses for other coverage levels shown in Figure 2 is maintained.

d. Pavement thickness requirements for 5,000 coverages were computed for various concrete strengths and subgrade moduli. Allowable concrete stress for 5,000 coverages was computed by dividing the concrete flexural strength by 1.3 (analogous to a safety factor). The pavement thickness necessary to produce the allowable concrete stress for 5,000 coverages is then multiplied by the percent thickness shown in Figure 2 for other coverage levels.

3. <u>FLEXIBLE PAVEMENTS</u>.

a. The design curves for flexible pavements in Chapter 3 of this circular are based on the CBR method of design. The CBR is the ratio of the load required to produce a specified penetration of a standard piston into the material in question to the load required to produce the same penetration in a standard well-graded, crushed limestone. Pavement thicknesses necessary to protect various CBR values from shear failure have been developed through test track studies and observations of in-service pavements. These thicknesses have been developed for single wheel loadings. Assemblies other than single wheel are designed by computing the equivalent single wheel load for the assembly based on deflection. Once the equivalent single wheel is established, the pavement section thickness can be determined from the relationships discussed above.

b. Load repetitions are indicated on the design curves in terms of annual departures. The annual departures are assumed to occur over a 20-year life. In the development of the design curves, departures are converted to coverages. For flexible pavements, coverage is a measure of the number of maximum stress applications that occur on the surface of the pavement due to the applied traffic. One coverage occurs when all points on the pavement surface within the traffic lane have been subjected to one application of maximum stress, assuming the stress is equal under

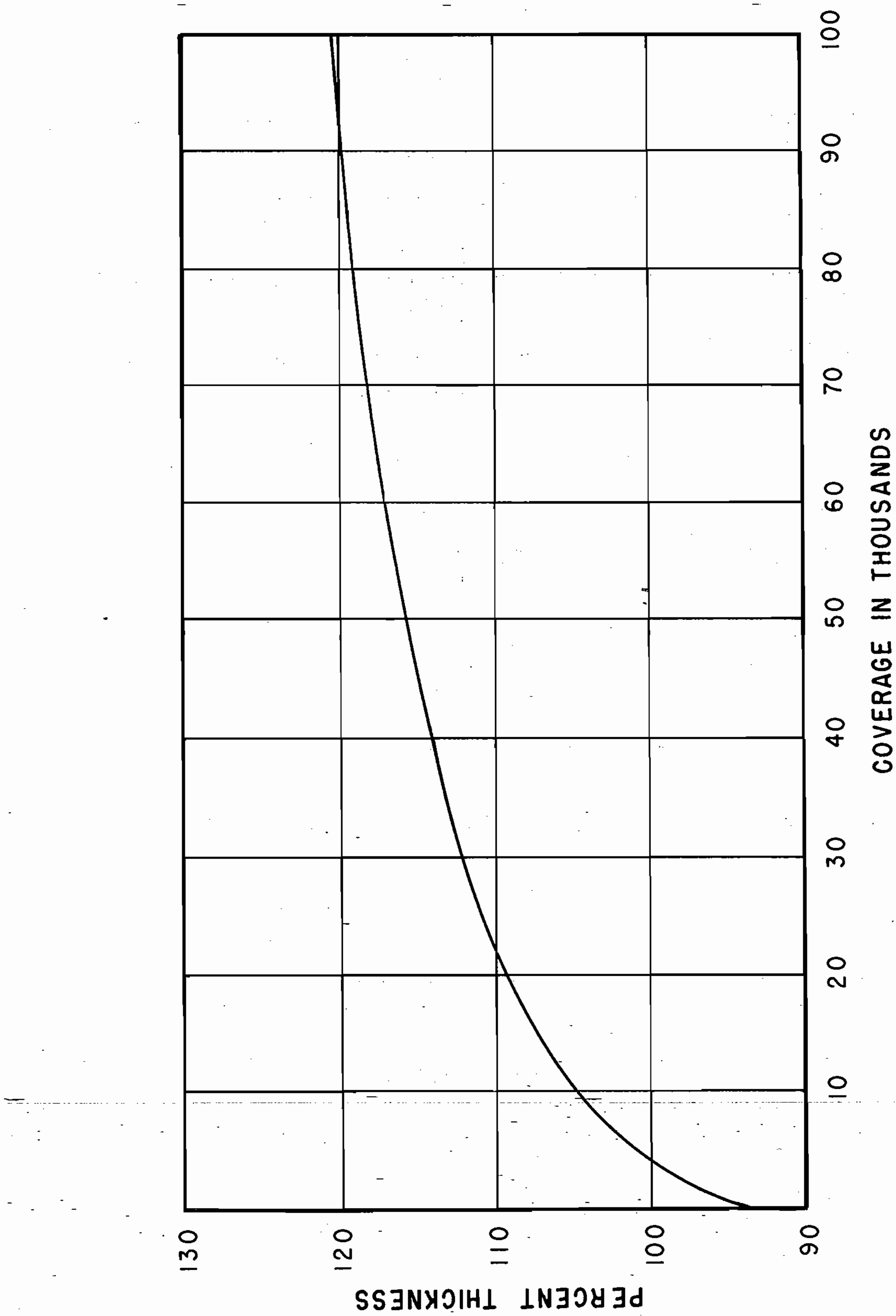

FIGURE 2. PERCENT THICKNESS VS. COVERAGES

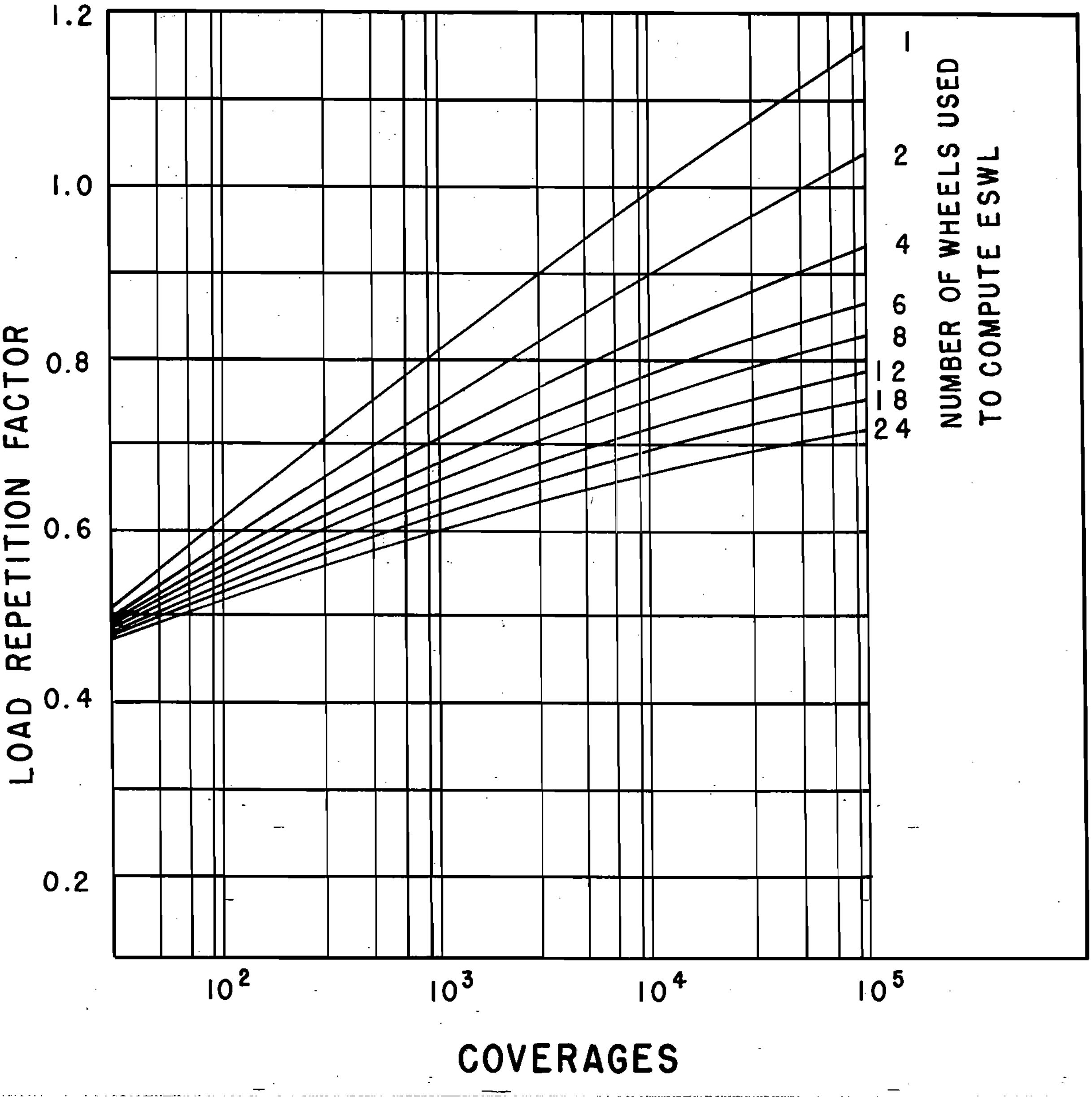

FIGURE 3. LOAD REPETITION FACTOR VS. COVERAGES

the full tire print. Each pass (departure) of an aircraft can be converted to coverages using a single pass-to-coverage ratio which is developed assuming a normal distribution and applying standard statistical techniques. The pass-to-coverage ratios used in developing the flexible pavement design curves in Chapter 3 are given in Table 5. Annual departures are converted to coverages by multiplying by 20 and dividing that product by the pass-to-coverage ratio given in Table 5. Figure 3 shows the relationship between load repetition factor and coverages. The pavement section thickness determined in accordance with paragraph a above is multiplied by the appropriate load repetition factor (Figure 3) to give the final pavement thickness required for various traffic levels.

TABLE 5. PASS-TO-COVERAGE RATIOS FOR FLEXIBLE PAVEMENTS

Design Curve	Pass-to-Coverage Ratio
Single Wheel	5.18
Dual Wheel	3.48
Dual Tandem	1.84
B-747	1.85
DC 10-10	1.82
DC 10-30	1.69
L-1011	1.81