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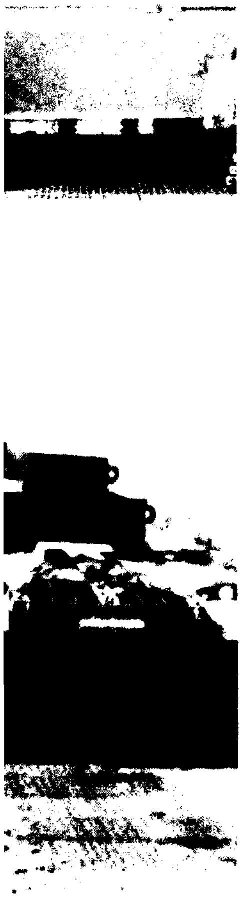

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DEVELOPMENT OF FAILURE CRITERIA OF FLEXIBLE PAVEMENT THICKNESS REQUIREMENTS FOR MILITARY ROADS AND STREETS, ELASTIC LAYERED METHOD

by

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13. ABSTRACT *(Maximum 200 words)*

The current design procedures for flexible pavements for military roads, streets, and open storage areas were reviewed. The computer program used in the current and the elastic layered method was described. The development of the procedure using the elastic layered method and the discrepancies between the two procedures are presented.

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PREFACE

The work reported herein was funded by the US Army Corps of Engineers (USACE), under the FIS-CS, Technical Support. Mr. G. W. Hughes, USACE, was the Technical Monitor.

The study was conducted from January 1987 to July 1988 by the US Army Engineer Waterways Experiment Station (WES), Geotechnical Laboratory (GL), by Dr. Y. T. Chou, Pavement Systems Division (PSD). The work was under the general supervision of Dr. W. F. Marcuson III, Chief, GL, WES, Mr. H. H. Ulery, Jr., (retired), and Dr. G. M. Hammitt II, Chief, PSD. This report was written by Dr. Chou.

COL Larry B. Fulton, EN, was Commander and Director of WES. Dr. Robert W. Whalin was Technical Director.

CONTENTS

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

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

Multiply	By	To Obtain
feet	0.3048	metres
inches	2.54	centimetres
kips (force)	4.448222	kilonewtons
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
square inches	6.4516	square centimetres

DEVELOPMENT OF FAILURE CRITERIA OF FLEXIBLE PAVEMENT THICKNESS REQUIREMENTS FOR MILITARY ROADS AND STREETS, ELASTIC LAYERED METHOD

PART I: INTRODUCTION

Background

1. The conventional procedure for the thickness design of flexible pavements for military roads and streets (Headquarters, Departments of the Army and the Air Force 1980) is based on the California Bearing Ratio (CBR) equation (Turnbull and Ahlvin 1947). In recent years, the elastic layered method (Burmister 1943, 1945; Mehta and Veletsos 1959; Michelow 1963; Peutz 1968; Koninklijke/Shell Laboratorium 1972) has been used in the Corps of Engineers (Brabston, Barker, and Harvey 1975; Barker and Brabston 1975; Parker et al. 1979) for the design of pavements for military roads, streets, walks, and open storage areas.

Scope

2. This report contains the theoretical development that is the basis of the design criteria for flexible pavement for military roads and streets reported in Technical Manual "Pavement Design for Roads, Streets, and Open Storage Areas, Elastic Layered Method."* For convenience of discussion, the design procedure using the conventional method is reviewed, and the superiority of the elastic layered method over the conventional method is presented.

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* Headquarters, Department of the Army, "Pavement Design for Roads, Streets, and Open Storage Areas, Elastic Layered Method," Technical Manual, in preparation.

PART II: CONVENTIONAL DESIGN PROCEDURES

3. The flexible pavement design procedure for roads and streets based on the CBR equation is presented (Headquarters, Departments of the Army and the Air Force 1980). The background development of the procedure is also presented (US Army Engineer Waterways Experiment Station 1961). The design traffic is represented by the design index, and the design thickness is selected using the CBR equation based on the subgrade CBR value.

Design Index

4. The design index ranges from 1 to 10 with greater design index corresponding to heavier traffic, depending upon the frequencies and compositions of the design traffic. Traffic composition is grouped into eight categories with the first five categories representing rubber-tired wheels and the last three categories representing tracked and forklift vehicles. The frequency of traffic is represented by the number of vehicles per day. Based on the frequency and category, the design index is determined.

Design Curves

Equivalent basic 18,000-lb single-axle, dual-wheel loadings

5. The loading used as a base for comparing all other vehicles was 18,000 lb on a single axle equipped with dual wheels. The wheel spacing selected was 13.5 by 58.5 by 13.5 in.* The center-to-center spacing of the two sets of dual wheels was 72 in. Tire contact pressure was 70 psi.

6. Table 1 shows the relationships between the flexible pavement design index and the number of equivalent passes of the basic loading.

Design curves

7. The CBR equation for flexible roads and streets is presented in Equation 1

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

$$t = 0.85\,[0.23 \log_{10}(coverage) + 0.15]\sqrt{\frac{P}{8.1\,CBR} - \frac{A}{\pi}} \qquad (1)$$

where

t = pavement thickness, in.

P = single-wheel load (or the equivalent single-wheel load (ESWL) in the case of multiple-wheel loads)

CBR = California Bearing Ratio of the subgrade soil

A = tire contact area, sq in.

Table 1

Relationship Between Flexible Pavement Design Index and Equivalent Passes of the Basic Loading

Flexible Pavement Design Index*	Passes of the 18,000-lb Basic Loading*
1	3,100
2	13,500
3	59,000
4	260,000
5	1,150,000
6	5,000,000
7	22,500,000
8	100,000,000
9	440,000,000
10	2,000,000,000

* Note that the relationships between the design index and the coverages of the 18,000-lb basic loadings are different for rigid and flexible pavements.

8. Equation 1 is used to determine the required pavement thickness for the 18,000-lb single-axle, dual-wheel loadings. The ESWL of the 18,000-lb basic loading is determined from Figure 1 based on the pavement thickness. The pavement thicknesses are computed at pass levels as shown in Table 1 which corresponds to the 10 design index numbers. The computations are made for various subgrade CBR values, and the relationships are plotted in Figure 2.

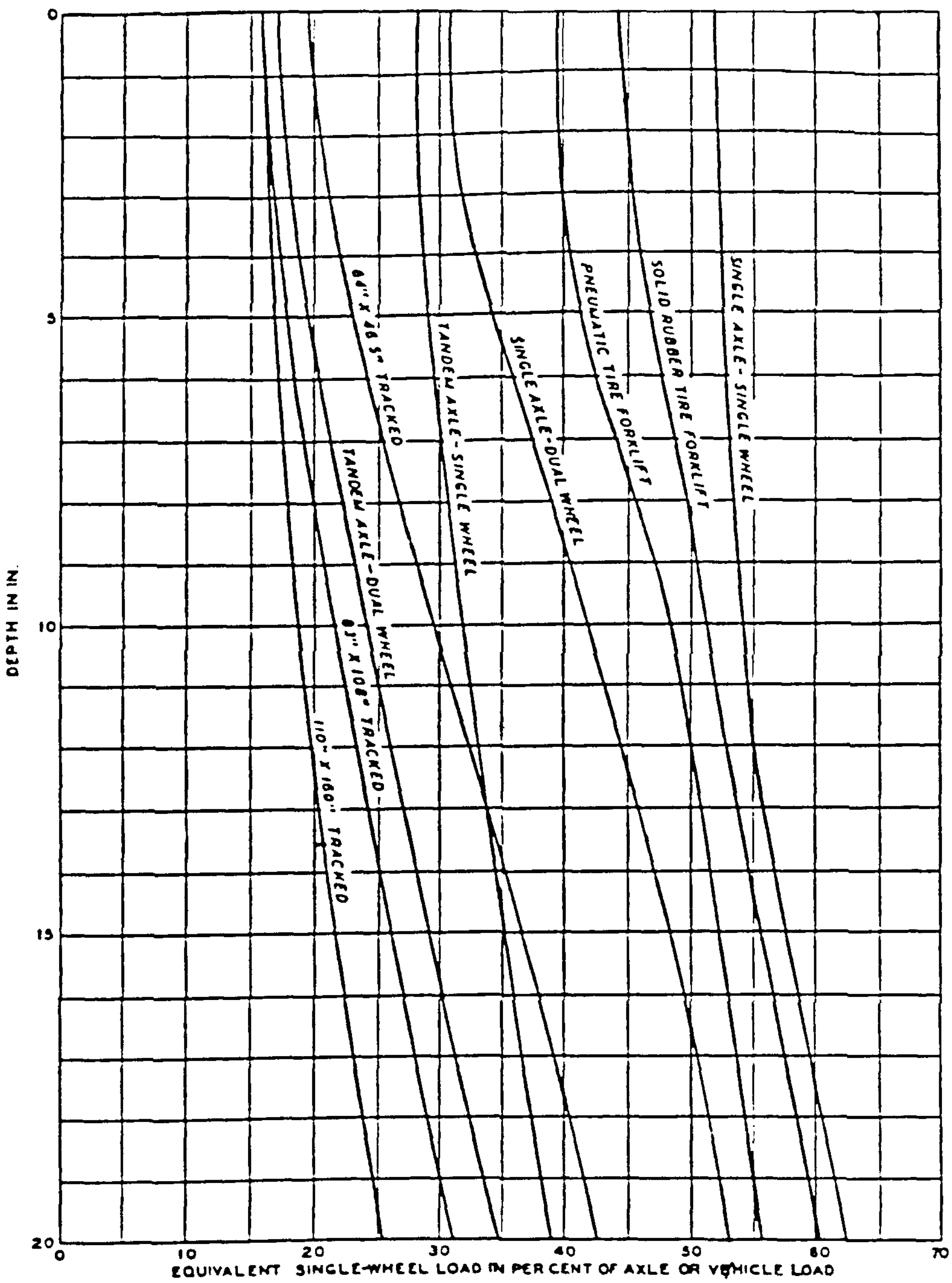

Figure 1. Equivalent single-wheel load in percent of axle or vehicle load versus depth

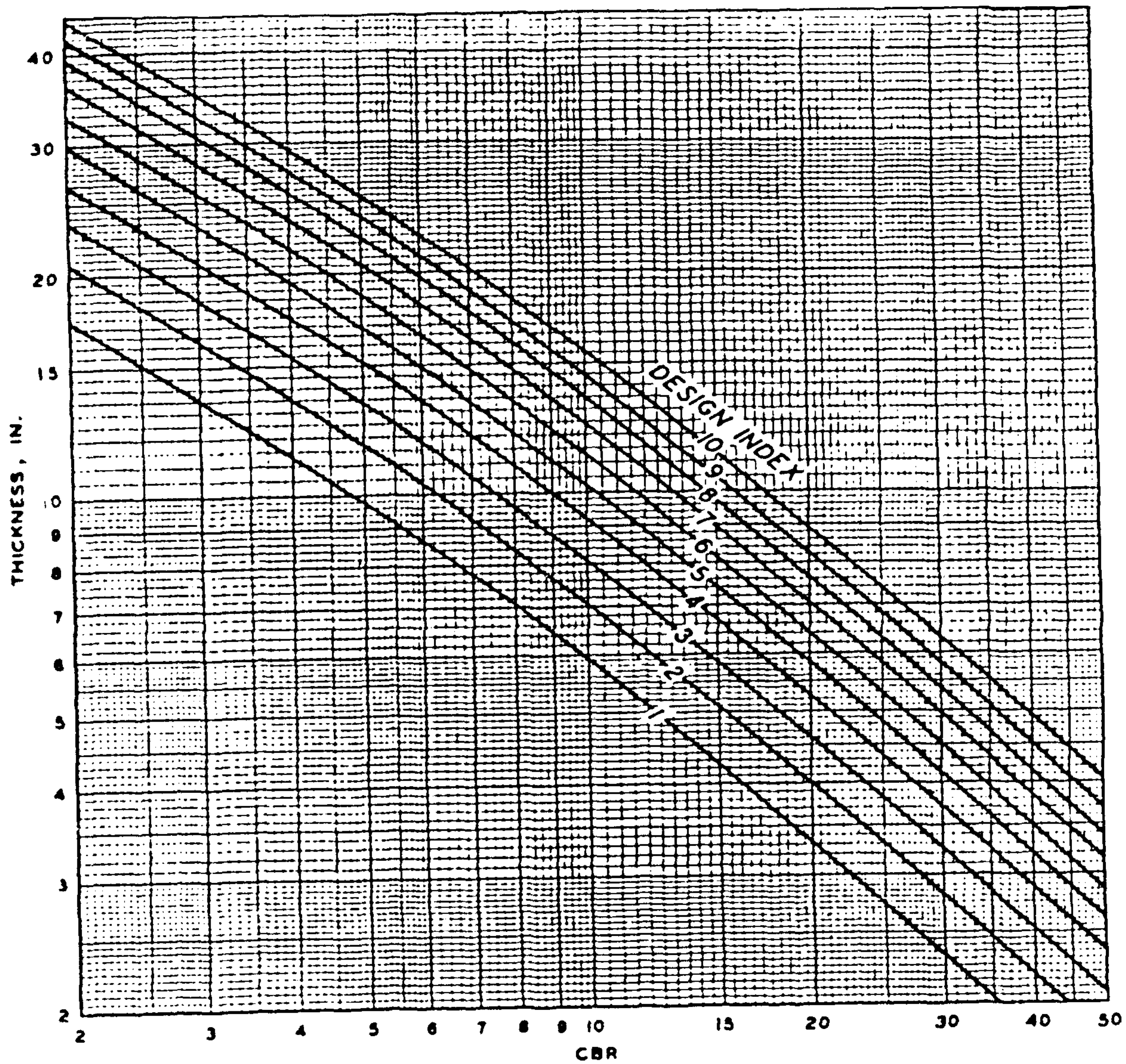

Figure 2. Flexible pavement thickness design requirements, roads and streets

9. The relative loading equivalencies between the basic 18,000-lb axle loading and all other vehicle loadings were established through the development of "Equivalent Coverage Factors." The factors for various vehicle types are tabulated in Plate 8 of Technical Report 3-582 (US Army Engineer Waterways Experiment Station 1961). Essentially, these factors represent the equivalent number of coverages of the basic loading that is applied by a single operation of the various representative configurations at their design loadings. The term "coverage" is defined as the number of maximum stress repetitions that occur at the critical location in the pavement as a result of the single operation of a particular vehicle load. The pass-per-coverage ratios, i.e., the number of passes (or operations) required to produce one coverage for various types of vehicle, are located in Table 7 of Technical Report 3-582 (US Army Engineer Waterways Experiment Station 1961). In the case of 18,000-lb single-axle dual-wheel loading, the pass-per-coverage ratio is 2.64. It takes statistically 2.64 passes of the loaded axle to produce one maximum stress at a certain critical location of the pavement. In a 12-ft wide highway pavement lane, this critical location may be 0 to 4 ft away from the edge of the lane where the pavement experiences most traffic. Table 2 shows representative axle configuration data of the vehicles.

10. Essentially, the design of flexible pavements for military roads and streets using the current design procedure is as follows:

a. Determine the design index number based on the design traffic distributions.

b. Determine the required flexible pavement thickness from Figure 2 based on the subgrade CBR value.

Table 2

Representative Configuration Data*

Configuration	Load Range kips	Tire or Grouser Contact Area sq in.	Average Tire Width** in.	Average Wheel Spacing† in.
Passenger Cars, Trucks, Buses, etc.				
Pneumatic tires				
Single axle, single wheels	0-5	39	7.5	62.0
	5-10	42-46	9.5	72.0
Single axle, dual wheels	0-10	46-50	9.0	70.0†
	10-20	46-50	9.6	72.0
	20-30	46-50	10.5	72.0†
Tandem axle, single wheels††	0-10	50	7.5	72.0
	10-15	50	10.0	76.0
Tandem axle, dual wheels††	10-15	50	7.5	67.5
	15-20	50	11.0	72.0
	20-50			
Forklift Truck				
Pneumatic tires				
Single axle, dual wheels	10-35	--	7.5	72.0
Solid rubber tires				
Single axle, single wheels	0-5	19-42	5.0	28.0
	5-10	19-42	6.0	28.0
	10-20	19-42	7.0	28.0
Tracked Vehicles				
Solid rubber grousers	0-20	28	15.0	64.0
	20-35	28	16.0	83.0
	35-50	--	16.0	99.0
	50-70	54	19.0	100.0
	70-120	54	23.0	110.0

* Based on characteristics of military vehicles.

** Width of track for tracked vehicles.

† Distance between center lines of single wheels or tracks; distance between center lines of dual wheels.

†† Wheel spacings are 13-1/2 × 58-1/2 × 13-1/2 in. Tandem-axle spacing is 48 in.

PART III: ELASTIC LAYERED COMPUTER PROGRAM

11. The layered elastic computer program has been used extensively at the WES for computing the interior stresses in pavement system. The elastic solution for two- and three-layer axisymmetric systems was first developed by Burmister (1943, 1945) and later extended by Mehta and Veletsos (1959) to multilayered systems. For multiple-wheel problems, tire prints are assumed to be circular uniformly loaded areas, and the method for superposition is used. The solution of the problem is based on the theory of elasticity. The material in each layer is assumed to be weightless, homogeneous, isotropic, and linearly elastic. The lowermost layer is considered to be of infinite extent in both the horizontal and vertical directions. A continuous surface of contact between layers is assumed, and the interfaces are considered to be either rough or smooth. Across a rough interface there is no relative displacement in the horizontal direction, and the shearing stress is continuous. At a smooth interface, there is no shearing stress, and the radial displacements on either side of the common surface of contact are generally different.

12. Several computer programs have been developed based on the multilayer elastic theory to solve stress conditions in pavements. The most commonly used ones are CHEVRON (Michelow 1963), BISAR (Koninklijke/Shell Laboratorium 1972) and JULIA and WESLEA developed at WES. CHEVRON is limited to a single-wheel load and the others can be used for multiple-wheel loads. The CHEVRON program was later extended by Chou (1976) and Ahlborn (1972) to account for the effect of the nonlinear properties of pavement materials on pavement responses. The BISAR program was also adopted by Baker and Brabston (1975) and Parker et al. (1979) for the design of rigid pavements. For overlay design the BISAR and JULIA programs can assume the interface condition to be either smooth (unbonded) or rough (bonded); the program also has the capability of analyzing conditions that cannot be classified as either smooth or rough.

13. In using the layered elastic computer program, the elastic moduli and Poisson's ratio of each layer of the pavement structure are needed for input. The applied loads to the pavement are considered as static, circular, and uniform over the contact areas. The interfaces between layers are assumed to be continuous, i.e., the frictional resistance between layers is greater than the developed shear forces.

PART IV: FAILURE CRITERIA, ELASTIC LAYERED METHOD

Design Principles

14. The basic principle for the design procedure is to select a pavement thickness to limit the vertical strains (compressive) in the subgrade and the horizontal (tensile) strains at the bottom of the bituminous concrete induced by design vehicular traffic loads at select levels. The former limit is used to prevent the subgrade from experiencing shear failure, and the latter limit is used to prevent the bituminous surface course from cracking. The use of a cumulative damage concept permits the rational handling of variations in the bituminous concrete properties and subgrade strength caused by cyclic climatic conditions. The strains used for entering the criteria are computed by using Burmister's solution for multilayered elastic continuum. The solution of Burmister's equations for most pavement systems requires the use of computer programs and the characterization of the pavement materials by the elastic constants of the modulus of elasticity and the Poisson's ratio. The computer program used in this study is JULIA.

Asphalt Strain Criteria

15. It is recommended that the asphalt strain criteria be established based on the repetitive load flexural beam test on laboratory-prepared specimens. Several tests are run at different stress levels and different sample temperatures such that the number of load repetitions to fracture can be represented as a function of temperature and initial stress level. The initial stress is converted to initial strain to yield criteria based on the tensile strain of the bituminous concrete.

16. An alternate method for determining values of limiting tensile strain for bituminous concrete is the use of the provisional laboratory fatigue data employed by Heukelom and Klomp (1964). These data are presented in the form of a relationship between stress, strain, load repetitions, and elastic moduli of bituminous concrete. The data may be approximated by the equation

$$\text{Allowable strain repetitions} = 10^{-X} \quad (2)$$

where

$X = 5 \log S_A + 2.665 \log (E/14.22) + 0.392$

S_A = tensile strain of asphalt, in./in.

E = elastic moduli of the bituminous concrete, psi

Subgrade Strain Criteria

17. The subgrade strain criteria were developed by the WES from the CBR Equation 1. The computations were made for truck loads of 18,000-lb single-axle dual wheels, 32,000-lb tandem-axle dual wheels, forklift load of 25,000-lb single-axle dual wheels, and 60,000-lb track load. Table 2 shows configuration data for the vehicular axles. The criteria are developed as follows:

a. Determination of the flexible pavement thickness.

(1) For a given loading configuration and magnitude, the thickness is computed using Equation 1 for a given coverage level. The ESWL P in the equation is determined from the curves shown in Figure 1 which are based on the predetermined thickness. Iterative procedures are used in the process.

(2) The computations are done for several subgrade CBR values and several coverage levels.

b. Computations of subgrade strains.

(1) Based on the computed total pavement thickness, the thicknesses of each layer are determined. Depending upon the pavement thickness, the thickness of the asphalt surface layer varies from 1.5 to 4 in. The thickness can be estimated from Table 2 of TM 5-822-5/AFM 88-7, Chapter 3 (Headquarters, Departments of the Army and the Air Force 1980). The maximum thickness of the base course used in computations is 6 in.

(2) The elastic modulus of the asphalt layer used in the computation is 200,000 psi. The modulus values of the granular layers are determined from Figure 3 based on the modulus values of the underlying layers. The subgrade modulus is determined from the subgrade CBR value using the equation $E = 1{,}500$ CBR . The Poisson's ratios of the asphalt layer, granular layers, and the subgrade soil

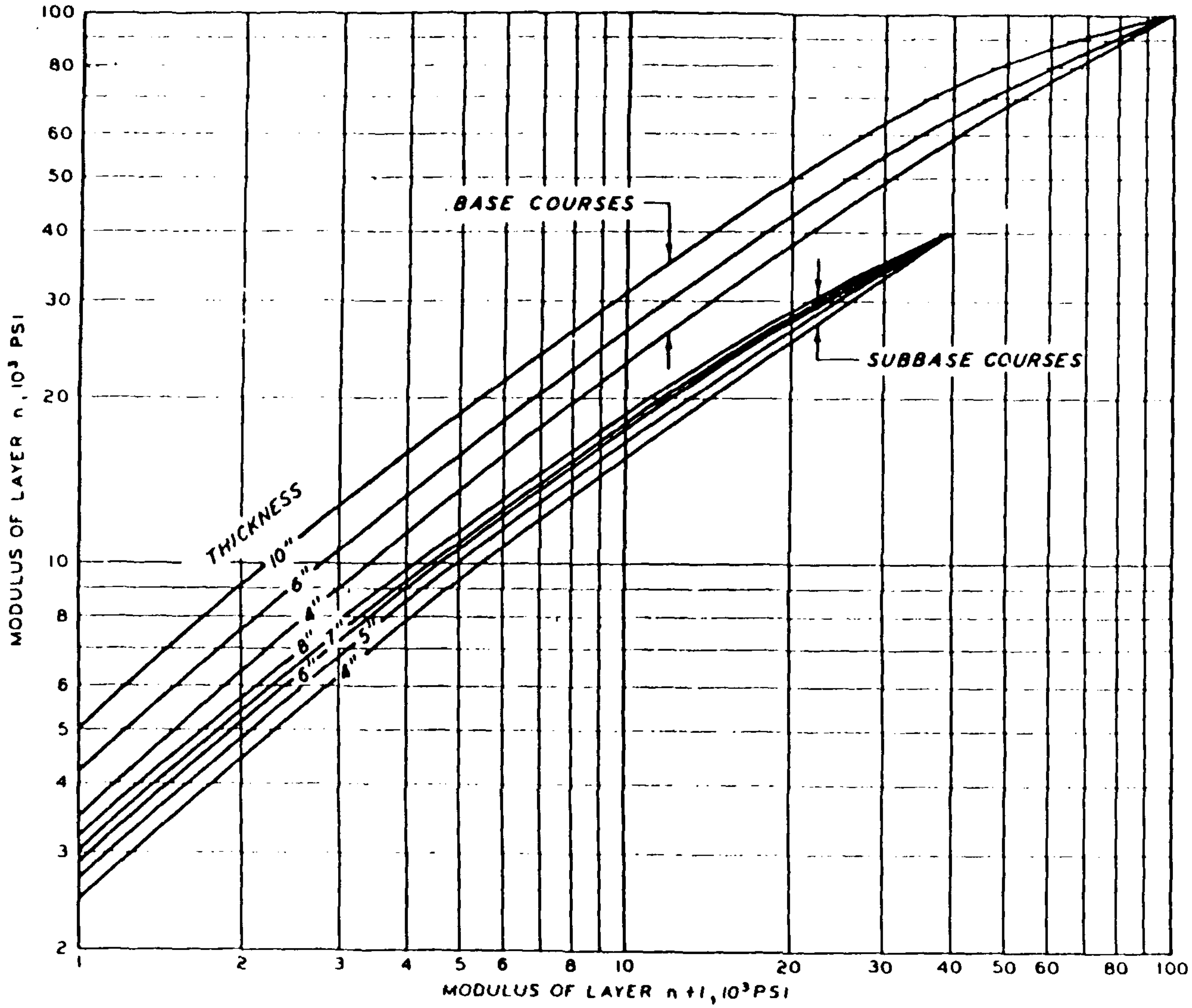

Figure 3. Determination of modulus values of granular materials

used in the computations are 0.5, 0.3, and 0.4, respectively.

(3) The subgrade strains are computed using the JULIA computer program. For pneumatic tires, the maximum strains are directly under one wheel or between wheels. The maximum strain in a tracked vehicle is always at the center of one track. To use the JULIA computer program, it was necessary to convert the track load into several, equaling the number of bogies, uniformly distributed circular loads. Each load has a diameter equaling the effective width of the track.

Development of the Subgrade Strain Criteria

18. Tables 3 through 5 present the computed subgrade vertical strains of many hypothetical pavement sections. The computations were made following the procedures presented earlier. The relationships between the subgrade vertical strain and coverage for subgrade modulus values of 3,000, 6,000, 10,000, and 15,000 psi are plotted in Figure 4; the lines are drawn according to gear configurations. However, this is not desirable for design purpose because when a pavement is designed for a given coverage level, the allowable subgrade strain for the dual-axle dual-wheel load would be smaller than that for the single-axle load. Thus, the required thickness is smaller for the former than for the latter. It is believed that this discrepancy is caused by the method of computing ESWL.* This is explained in the following paragraphs.

19. In the present design criteria for flexible pavements, the ESWL is evaluated based on vertical deflections computed by the Boussinesq homogeneous elastic theory; i.e., the pavement structure is assumed to be composed of a homogeneous linearly elastic medium, and the maximum deflection resulting from the multiple-wheel load is equal to that resulting from the ESWL. However, the computed deflection basins are generally flatter than those measured, and consequently, the computed ESWL's for multiple-wheel heavy gear loads, such as the Boeing 747 and C-5A, become so large that the current criterion is too conservative. This may be explained by the ESWL curves shown in Figure 1.

20. Equation 1 is used to compute the required pavement thicknesses at a coverage level of 10,000 for a 32-kip dual-axle, dual wheels and for a

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* A comparison of ESWL computed with deflection and vertical strain is presented in Appendix A.

Table 3

Flexible Pavements for Roads and Streets, Tandem-Axle Dual Wheels*

Coverage c	Thickness t, in.	Thickness, in. AC	Thickness, in. Base	Thickness, in. Subbase	Modulus, psi Base	Modulus, psi Subbase	Modulus, psi Subgrade	Computed Subgrade Strain in./in.
2,000	11.8	1.5	4.0	6.3	25,000	12,000	6,000	0.135 E -2
10,000	14.6	2.0	6.0	6.6	30,000	12,000	6,000	0.990 E -3
500,000	24.0	4.0	6.0	14.0	47,000	23,000 (7.0 in.) 14,000 (7.0 in.)	6,000	0.401 E -3
2,000	6.1	1.5	4.6	--	31,500		15,000	0.136 E -2
60,000	9.1	2.0	4.0	3.1	38,000	20,000	15,000	0.824 E -3
200,000	10.2	2.0	4.0	4.2	42,000	22,500	15,000	0.708 E -3
1 E +7	14.6	3.0	6.0	5.6	47,000	22,500	15,000	0.452 E -3
5 E +9	23.3	4.0	6.0	13.3	71,000	49,000 (7.0 in.) 23,500 (6.3 in.)		0.215 E -3

* The wheel configurations are 13.5 × 48 × 58.5 in. Tire contact pressure is 70 psi and the gear load is 32-kips.

Table 4

Flexible Pavements for Road and Streets, Single-Axle Loads

Coverage c	Thickness t, in.	Thickness, in. AC	Base	Subbase	Modulus, psi Base	Subbase	Subgrade	Computed Subgrade Strain in./in.
10,000*	10.4	2	4	4.4	24,000	11,000	6,000	0.134 E -2
100,000*	13.0	2	4	7.0	26,000	13,000	6,000	0.942 E -3
1,000,000*	15.4	2	6	7.4	32,000	13,000	6,000	0.667 E -3
10,000**	22.0	4	6	12.0	34,000	14,000 (6 in.) 7,000 (6 in.)	3,000	0.861 E -3
2,000**	11.5	2	4	5.5	28,000	12,500	6,000	0.145 E -2
10,000**	14.1	2	6	6.1	30,000	12,000	6,000	0.112 E -2
50,000**	16.8	3	6	7.8	32,000	13,500	6,000	0.846 E -3
500,000**	20.6	3	6	11.6	42,500	20,000 (6 in.) 12,500 (5.6 in.)	6,000 6,000	0.606 E -3
10,000**	10.0	2	4	4.0	31,500	15,500	10,000	0.111 E -2
500,000**	14.6	2	6	6.6	39,000	17,500	10,000	0.714 E -3
10,000,000**	18.5	3	6	9.5	42,500	20,000	10,000	0.498 E -3

* Single axle and single wheel with gear load of 9 kips. Tire contact pressure is 70 psi.

** Single axle and dual wheels. The wheel spacings are 13.5 × 58.5 × 13.5 in., and the gear load is 18 kips. Tire contact pressure is 70 psi.

Table 5

Flexible Pavements for Roads and Streets, Forklift and Track Loads

Coverage c	Thickness t, in.	Thickness, in. AC	Thickness, in. Base	Thickness, in. Subbase	Modulus, psi Base	Modulus, psi Subbase	Modulus, psi Subgrade	Computed Subgrade Strain in./in.
50,000*	21.5	3	6	12.5	42,000	20,000 (6.5 in.) 12,000 (6 in.)	6,000	0.858 E -3
500,000*	25.0	4	6	15.0	46,000	22,500 (8 in.) 13,000 (7 in.)	6,000	0.628 E -3
50,000*	11.4	2	4	5.4	41,000	22,500	15,000	0.121 E -2
500,000*	14.3	2	6	6.3	45,000	23,000	15,000	0.87 E -3
2,000*	24.2	4	6	14.2	44,000	22,000 (7 in.) 13,000 (7.2 in.)	6,000	0.826 E -3
10,000**	16.1	3	6	7.1	35,000	14,500	15,000	0.607 E -3

* Pneumatic forklift truck, single axle, dual wheels, and the wheel spacings are 9 × 63 × 9 in. and the gear load is 25 kips.
** 60-ton tank.

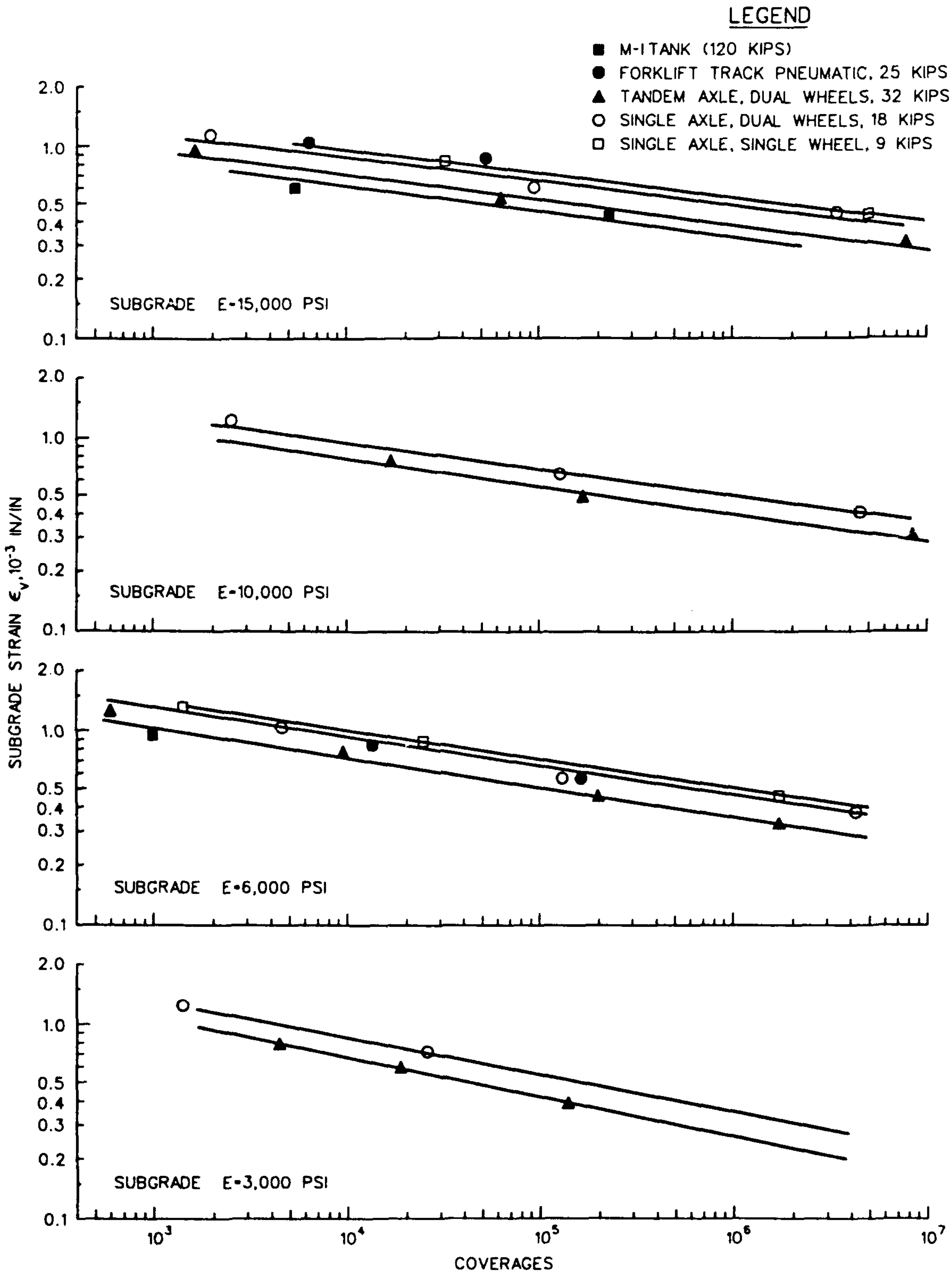

Figure 4. Subgrade strain criteria for roads and streets, elastic layered method

18-kip single-axle, dual wheels. The computed thicknesses are 14.6 and 14.1 in. and the ESWL's are 8,960 and 8,460 lb, respectively. The heavier load (32-kips) results in larger ESWL's and thus requires thicker pavement. When these two pavements are analyzed using the JULIA computer program, the computed subgrade strains are 0.00099 and 0.00122 in./in. under the 32- and 18-kip loads, respectively. It is seen that smaller strain is computed under the 32-kip load. Consequently, the line for 32-kip load (twin-tandem axle) is drawn beneath the 18-kip load (single axle) in Figure 4. The reason for smaller strain under the multiple-axle load is partly because of its thicker pavement, i.e., 14.6 in., and partly due to the reason explained below.

21. When the layered elastic method is used to analyze a flexible pavement, multiple-axle gear loads do not always result in severe loads. For instance, for an 18-kip single-axle, dual-wheel load, the subgrade strains are primarily induced by one set of dual wheels (each wheel weighing 4,500 lb), since the other set of dual wheels is far away (72 in.). For the 32-kip dual-axle, dual-wheel load, the two sets of twin-tandems are far apart (72 in.), and one set has no effect on the other. Since the two sets of dual wheels in the twin tandem are also far apart (48 in.), the subgrade strains are primarily induced by one set of dual wheels (each wheel weighing only 4,000 lb). This is the other reason why the subgrade strains computed for the 32-kip dual-axle, dual-wheel load are smaller than those computed for the 18-kip single-axle, dual-wheel load. In the computation of ESWL, the deflections under one set of dual wheels are affected by other wheels of the dual-axle, dual-wheel load, but the subgrade strains under one set of dual wheels computed by the layered elastic method are not affected by the other wheels. The numerical example presented in the next paragraph will illustrate this point.

22. JULIA was used to compute the vertical strains and deflections in the top of the subgrade of a 5-layer flexible pavement subjected to a 4,500-lb circular load with a radius of 4.52 in. The layer thicknesses were 4, 6, 6, and 6 in., and the corresponding moduli were 200,000, 34,000, 14,000, 7,000, and 3,000 psi. The computed values at various distances are presented in Table 6. For comparison, the strains and deflections were normalized as the percent of the value at the center of the load. The percentages are presented in parentheses in Table 6. It is seen that the deflection basin is much flatter than the strain basin. For instance, at a point 20 in. away from the load, the deflection is 80 percent of the maximum, but the strain is

Table 6

Deflections and Strains at the Top of the Subgrade Under a Single-Wheel Load

Offset	0	5	10	20	30	40	50	60	70
Deflection × 10^{-3}, in.	17.7 (100)*	17.3 (98)	16.5 (93)	14.2 (80)	11.9 (67)	9.96 (56)	8.39 (47)	7.4 (40)	6.15 (35)
Strain × 10^{-3}, in./in.	0.488 (100)*	0.455 (93)	0.375 (77)	0.209 (43)	0.107 (22)	0.0542 (11)	0.0259 (5)	0.0108 (2)	0.003 (1)

* The values in parentheses are the normalized values in percent which is the value at a given offset divided by the value directly under the wheel load in percent. For instance, at an offset distance of 30-in., the normalized deflection is 67 percent which is the ratio of 11.9 to 17.7 in percent.

43 percent of the maximum. The current criterion of determining the ESWL is based on the deflection basin, but the layered elastic method for the design of flexible pavement is based on the strain basin. Discrepancy in results can be expected when two procedures are used together.

23. The representative curve for each subgrade modulus value is drawn near the single-axle single wheel loads shown in Figure 4, the resultant curves for various subgrade modulus values are plotted in Figure 5 which is the subgrade strain criteria for flexible pavements for military roads and streets. For design purpose, a single curve drawn near the $E_s = 10{,}000$ psi and $E_s = 15{,}000$ psi curves is used which may be approximated by the equation

$$\textit{Allowable coverage} = 10^{A} \qquad (3)$$

where

$A = -(2{,}408 + \log \epsilon_v)/0.1408$

ϵ_v = vertical strain at subgrade surface, in./in.

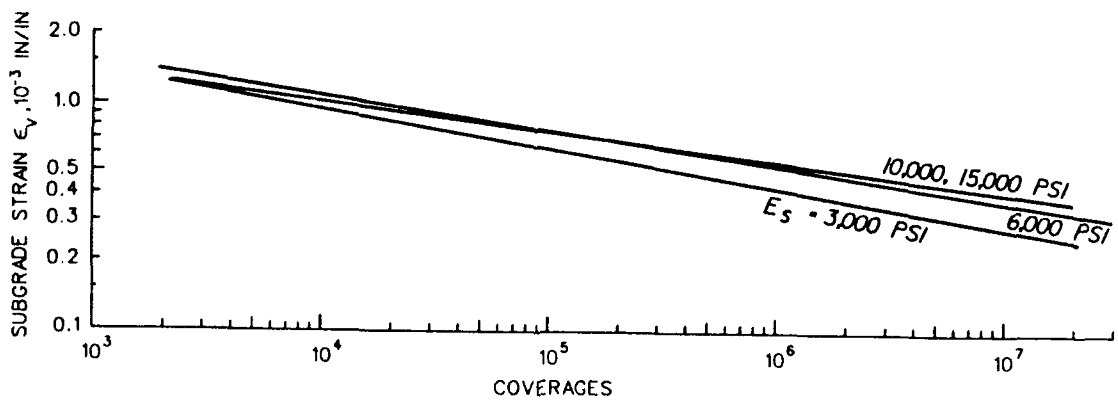

Figure 5. Subgrade strain criteria for roads and streets, elastic layered method

PART V: DISCREPANCY BETWEEN THE CURRENT PROCEDURE AND THE ELASTIC LAYERED METHOD

24. In the current design procedure, the magnitude and compositions of traffic are accounted for by the design index together with the concept of equivalent 18,000-lb basic loading, and the thickness design is completely based on the CBR design equation for flexible pavements. Design index is not used in the elastic layered method, and the thickness design is completely based on the computed subgrade strains induced by the traffic loads using the BISAR program. In general, thickness designed by the two procedures are very close except in certain conditions where the elastic layered method is more reasonable. These conditions are explained as follows:

- a. When traffic is characterized by design index numbers, the pavement thickness may vary greatly when the traffic is in the neighborhood of changing from one index number to the other. This is not the case for the elastic layered method since the traffic is directly input into the computation and the result varies smoothly with number of coverages.
- b. The design index method has another drawback. When the pavement is designed for two different types of vehicles, the heavier vehicle is the governing one as it requires the highest design index and the effects of other lighter vehicles are not considered. In the case of the layered elastic design, the vehicles at a lower design index are not canceled in determining the pavement thickness. Each group of traffic is input into the analysis, and the design is based on the sum of the effects of all the traffic, regardless of the weights or types.

PART VI: CONCLUSIONS

25. The current CBR based design method for flexible pavements for roads, streets, and open storage areas was reviewed. The development of a design procedure using the elastic layered methods is presented, and the discrepancies between the two procedures are discussed.

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APPENDIX A: COMPARISON OF ESWL COMPUTED WITH DEFLECTION AND VERTICAL STRAIN

Vertical strains and deflections are computed in an elastic homogeneous soil under a 9,000-lb dual wheel load. The wheels are 13.5-in. apart and have a constant pressure of 70 psi. The maximum strains and deflections computed at various depths are presented in Table A1. The strains and deflections computed under a 4,500-lb single wheel load are also presented. The computed ESWLs with respect to deflection and vertical strain are thus computed. It is seen that the ESWL based on deflection is much greater than that based on vertical strain. It indicates that if the ESWL based on vertical strain is used in the Corps of Engineers design procedure (Equation 1) the lines shown in Figure 4 will be closer to each other.

Table A1

ESWL Computed with Deflection and Vertical Strain

	9,000-lb Dual Wheels		4,500-lb Single Wheel		ESWL*, lb	
Depth in.	Vertical Strain × 10^{-2} in./in.	Deflection in.	Vertical Strain × 10^{-2} in./in.	Deflection in.	Vertical Strain	Deflection
0	0.3270	0.1040	0.327	0.0887	4,500	10,530
10	0.2950	0.0511	0.282	0.0336	9,450	13,680
20	0.1290	0.0327	0.856	0.0180	13,590	16,380
30	0.0691	0.0232	0.396	0.0121	15,660	17,280
40	0.0417	0.0178	0.226	0.0091	16,650	17,550
50	0.0276	0.0144	0.145	0.0073	17,100	17,730

* The ESWL is computed as the product of the ratio of the computed value of the 9,000-lb dual wheel to that of the 4,500-lb single wheel and the 9,000-lb load.