RIGID PAVEMENT DESIGN FOR ROADS AND STREETS ELASTIC LAYERED METHOD

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The current design procedure of rigid pavements for military roads, streets, walks, and open storage areas was reviewed. The two computer programs used in the current and the elastic layered method were described. The development of the procedure using elastic layered method and the discrepancies between the two procedures are presented. Design example was given illustrating the procedure for designing rigid pavement for military roads and streets.

Introduction

At present, thickness designs for concrete airfield pavement are generally done by fatigue analyses. Tensile stresses at the bottom of the concrete slab are calculated and then related to passes of the design aircraft through a fatigue relationship. The most widely used concrete airfield design procedures in the United States were developed originally by the US Army Corps of Engineers (CE) using the Westergaard edge load model.(6,35-39) and the Portland Cement Association (PCA) using the Westergaard interior load model. (21) The CE approach is used by the US Army, the US Air Force, and the Federal Aviation Administration (FAA); the PCA approach is used by the US Navy and a number of commercial designers. In recent years, the elastic layered method (7-8,15,16,18,23) has been used in the CE for the design of both rigid and flexible airfield pavements (4,5,22) and for the design of both rigid and flexible pavements for military roads, streets, walks, and open storage areas. (11,12)

The use of elastic layered method, rather than the Westergaard edge load model, for concrete pavements is not because the stresses computed by the former are more accurate than the latter. Rather, it is for the sake of consistency, i.e., one computer code for both rigid and flexible pavements. Since the CE procedure is based on edge stresses and the elastic layered method computes only interior stresses, adjustments need to be made in using the elastic layered method. This report contains the theoretical development of the design criteria for rigid pavement for military roads and streets reported in the technical manual "Rigid Pavements for Roads, Streets, Walks, and Open Storage Areas, Elastic Layered Method". (12)

Conventional Design Procedure

Basic Loading and Design Index

The design procedure of rigid pavement for roads and streets based on the Westergaard solution is presented in Reference 13. The background development of the procedure is given in Reference 19. The procedure consists of two essential parts:

1. the design traffic is converted into the equivalent basic 18,000-lb single-axle, dual-wheel loading based on the equivalent coverage factors, and
2. the concrete slab stresses are computed using the Westergaard solution, and the thickness is selected based on the design index (DI) which is a function of the traffic.

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." 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 the particular vehicle load. The equivalent coverage factors were determined based on the fatigue criterion developed from full-scale accelerated traffic tests on airfield pavements and required thickness computation using the Westergaard solution (edge load condition).

The overall range in the number of equivalent coverages of the 18,000-lb basic loading for the 25-year design life is from a minimum of 1 to a maximum of 182,500,000. To simplify the design procedure, this range of equivalent coverages was expressed in terms of a numerical scale defined as the Rigid Pavement Design Indexes. This index extends from one through ten, with an increase in the index number corresponding to an increase in the number of equivalent coverages of basic loading. Table 1 shows the number of equivalent coverages of the basic loading for each value of the

Rigid Pavement Design Index. To design a rigid pavement, the entire range of vehicle types, loadings, and traffic intensities anticipated during the design life of pavements for the various classifications of military roads and streets was expressed in terms of an equivalent number of coverages of the basic loading.

Design Chart

In Reference 19, an impact factor 1.25 and a coverage factor 1.3 were used. The coverage factor was used to account for the reduction of design stresses for 5,000 coverages. Explaining in another manner, the coverage factor 1.3 extends the design life from 1 coverage to 5,000 coverages. The impact factor is not used anymore in current design of rigid pavement for roads and streets, and the coverage factor is replaced by the following equation (30)

$$DF = R/\sigma_e = 0.5 + 0.25 \log_{10}(\text{coverage}) \qquad k \leq 200 \text{ pci} \tag{1}$$

where

DF = the design factor;
R = flexural strength of the concrete; and
σ_e = free edge stress.

It is to be noted that for 5,000 coverages the design factor is close to 1.42.

Condition surveys of active airfields and the performance of the accelerated traffic section revealed that slabs on a high-strength foundation continued to perform well after a single crack is formed in the concrete slab. To take advantage of this performance, slab thickness requirements were reduced as shown in Table 2 (14) to allow some cracking to develop.

In military roads and streets load transfer is provided at longitudinal and transverse joints. Since the vehicular loads travel very close to the free edges of the concrete slab, load transfer is thus not considered in the design. Figure 1 is the design chart for rigid pavement of military roads and streets. For parking and storage areas where load transfer is considered, the required flexural strength is reduced 25 percent.

Computer Programs

H-51 (Westergaard solutions) and BISAR (elastic layered solution) computer programs have been used extensively at the Waterways Experiment Station (WES) for computing free edge stresses in rigid pavement and interior stresses at the center of rigid or flexible pavements, respectively. The free edge stresses are generally greater than the interior stresses.

Westergaard's Solution

The Westergaard solution is derived based on the analogy of an elastic plate on dense-liquid foundation (Winkler Foundation). The theory was first formulated by E. Winkler in 1867, who assumed the intensity of the reaction of the foundation at any point was proportional to the deflection of the plate at that point. The settlement of the foundation at any point on its surface was assumed to be proportional to the pressure between the plate and the foundation at the same point, and consequently to be independent of the pressure elsewhere. This corresponds physically to the problem of a plate on a liquid base. It is also necessary to assume that the reactive pressures are vertical only; frictional forces are developed, but they are neglected.

Closed-form solutions were developed for stress conditions in a concrete slab resting on a dense-liquid foundation by Westergaard (35-39) and for temperature-induced stresses by Westergaard (5) and Bradbury. (6) Westergaard's formulas were then employed by Pickett and Ray (26) for developing influence charts, which have been used by the Portland Cement Association (27,28) for the design of highway and airport pavements. The H-51 computer program is used at WES for Westergaard-type solutions. (33) In his original work, Westergaard considered three cases of loading;

1. corner load,
2. edge load, and
3. interior load.

H-51 program considers only the edge load condition as it is most serious in a concrete pavement. The salient feature of the theory of plates is that it yields a two-dimensional solution. Because the plates are thin and the deflection is small, the assumption that the deformations at the surface and at the bottom of the plate at a line normal to the plane of the plate are equal is qualified.

Elastic Layered System

The elastic solution for two- and three-layer systems was first developed by Burmister (7,8) and later extended by Mehta and Veletsos (16) to multi-layered systems. Although the method was developed for a three-dimensional problem, it is essentially two-dimensional because of the restriction of axial symmetry. For multiple-wheel problems, the method of 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, isotopic, and linearly elastic. The lowest layer is considered to be of infinite extent in both the horizontal and the 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.

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 (18) and BISAR. (15) The former is limited to a single-wheel load, and the latter can be used for multiple-wheel loads. The CHEVRON (18) program was later extended by Chou (9) and Ahlborn (1) to account for the effect of the nonlinear properties of pavement materials on pavement responses. The BISAR (15) program was also adopted by the US Army Corps of Engineers for the design of rigid pavements. (4,22)

The disadvantage of using the multilayer elastic theory for rigid pavement design is that the slab is assumed to be finite in extent in the horizontal plane, and consequently only the interior load case can be analyzed. Corner and edge stresses and joint conditions cannot be analyzed. For overlay design the BISAR program can assume the interface condition to be either smooth (unbonded) or rough (bonded); the program also has the capability of analyzing conditions in between.

Failure Criteria, Elastic Layered Method

Accelerated traffic tests (2,17,24,25) conducted by the CE provided the basis for development and validation of the concrete design thickness and the relation between the traffic coverages and the design thickness. (32) These traffic tests defined three failure levels:

1. initial failure when a slab contains a single crack;
2. shattered slab when cracking divides the slab into six pieces; and
3. complete failure when cracking divided the slab into approximately 35 pieces.

Air Force requirements for performance with minimum maintenance established the failure criterion for design as an initial crack.

Pavement thickness requirements were expressed as a percent of standard thickness for varying subgrade k values. (20) The 100 percent standard thickness is taken at 5,000 coverages. The reduction of percent thickness for higher k values is based on values shown in Table 2. Similar plots are available for shattered slab and complete failure conditions. (20)

Recently, Rollings (30) reexamined the CE traffic test data and found that there were a number of test sections in which traffics were applied very close to the free edges and construction joints of the concrete slabs. Failures occurred in these areas earlier than areas where good load transfers were provided. Rollings concluded that lesser coverages then deserved in these test sections were recorded. When higher coverages were assigned to these test sections, Rollings found that the correlation between slab thicknesses and observed pavement performance were improved greatly. However, the correction was not incorporated into Equation 1. In Equation 1 the design factor, DF , defined to be the ratio of concrete flexural strength R to maximum edge stress, σ , was used instead of the percent thickness. The graphic presentation of Equation 1 is shown as the top line of Figure 2. Dr. Walter Barker at the US Army Engineer Waterways Experiment Station incorporated Equation 1 with higher k values. The results are presented in Figure 2. For subgrade modulus k higher than 200 psi, the percent reduction of pavement thickness is presented in Table 2. Equation 1 and Table 2 form the basis of the structural design of concrete pavement for aircraft and vehicular loads based on Westergaard solution calculations.

Design Criteria

Parker (22) analyzed the CE full-scale accelerated traffic test data using the elastic layered method. The relationship between the design factor and failure coverage plotted by Parker is shown in Figure 3. The pavement information, calculated values, and failure coverages are tabulated in Table 4.1 of Reference 10.

The salient features of Figure 3 are

1. all the test sections had used doweled or keyed construction joints and contraction joints on short joint spacings that develop good aggregate interlock. Consequently, all of the relationships in the proposed design procedure are only valid for pavements that use these standard joints and develop typical levels of load transfer;
2. the stresses σ_{LT} are the maximum interior stresses computed using the BISAR computer program based on elastic layered method;
3. most test sections have subgrade modulus k values close to or less than 200; the DF is equal to R/σ_{LT} , where R is the flexural strength of the concrete measured from beam specimens cut from test concrete slabs; and a straight line is drawn through the data points on a semilogarithmic scale.

Although all the test sections were failed at coverage levels less than 10,000, it is justified to extend the relation into higher coverage levels; its justification is presented later in this section.

When the best fit line shown in Figure 3 is plotted together with the line for Equation 1, the relationship is shown in Figure 4. Note that the two criteria are developed based on the same test data but the stresses are computed by the Westergaard solution (edge stresses) in one criterion and by the elastic layered solution (interior stresses) in the other.

In the design of military roads and streets, tie bars are used between lanes, and dowel bars are used at transverse joints. Therefore, good load transfer is provided in the concrete slabs. However, since vehicular loadings travel very close to pavement edges, edge load conditions with no consideration of load transfer are employed in the design. Nevertheless, neither of the two criteria shown in Figure 4 is suitable for the design of military roads. Because the lower line shown in the figure is strictly for Westergaard solution and is thus not suitable for this purpose and while the other line is developed using the elastic layered method, the requirement of good load transfer precludes its use for this study. It is clear that the stresses computed using the elastic layered solution, i.e., interior stresses, are too conservative to simulate the actual free edge loading condition and can result in under-design of the pavement due to unreasonably large design factor R . To remedy the situation, the layered elastic calculated stresses should be increased. The proposed method is determined based on two different approaches explained as follows.

Stress Ratios

From Figure 4, the ratios of the DF associated with elastic layered solution to the DF associated with Westergaard solution at various coverage levels are tabulated in Table 3. Since DF = R/σ , the ratios are also the ratios of maximum edge stress σ_w to maximum interior stress σ_{LE} . Table 3 shows that for coverage levels ranging from 500 to 1,000,000 an average value of the ratio is about 1.33 which happens to be the reciprocal of 0.75, or 1.33 = 1/(1-0.25), where 0.25 happens to be the load transfer capability (25 percent) used by the CE for rigid pavements. It should not be construed however that for a given pavement, the maximum edge stress is always 1.33 times greater than the maximum interior stress. The two straight lines shown in Figure 4 are "statistically" the best-fit lines going through many test points and the points, plotted are rather scattered as shown in Figure 3.

Rollings' Procedure

Rollings (29) developed a procedure for the design of rigid overlays for airfield pavements. The analytical model Rollings chose was the elastic layered method. The following information was cited by Rollings.

"To account for the effect of varying degree of load transfer capability in the base slab, a multiplying factor X was proposed to adjust the layered elastic calculated stresses. To obtain more information on the relation between Westergaard and layered elastic stresses, both stresses were calculated for 60 hypothetical pavements. The aircraft loadings include F-4, B-707, B-723, B-747, and C-141 with modulus of subgrade reactions ranging from 50 to 400 pci and thickness ranging from 6 to 40 in. The stresses (Table C.2 of Reference 29) together with the stresses (Table C.1 of Reference 29) computed by Parker (22), were plotted in Figure 5. Least square regression analysis was tried for the 120 data points. A simple power relationship as shown below was developed.

$$\sigma_{LE} = 0.64\,\sigma_w^{0.972} \qquad (2)$$

where

σ_{LE} = stress from elastic layered analytical model; and

σ_w = stress from Westergaard edge loaded analytical model.

Equation 2 can be modified as

$$\gamma\sigma_{LE} = 0.64(\beta\sigma_w)^{0.972} \qquad (3)$$

where

β = the proportion of the Westergaard stress used in design to account for load transfer, i.e., $1.0-\alpha$, where α is the load transfer to adjacent slab;

γ = equivalent proportion of elastic layered stress to account for load transfer in the Westergaard stress.

It is apparent that γ is simply β raised to the 0.972 power. All the models and relationships developed for use were based on joints meeting the common 25 percent load transfer assumption. Normalizing the relation between γ and β for the standard 25 percent load transfer resulted in a multiplier, X , for the layered elastic stress as shown in Figure 6. The equation for the multiplier, X , is

$$X = \frac{(1-\alpha)^{0.972}}{0.7561} \qquad (4)$$

This multiplier accounts for load transfer different from the standard 25 percent. If the load transfer meets or exceeds 25 percent, then no adjustment in stresses should be made. If the load transfer is lower than this value, the layered elastic calculated stresses in the base slab should be increased by multiplying them by the appropriate X from Figure 6. For instance if the measured load transfer is 10 percent, the layered elastic calculated stresses in the concrete slab should be multiplied by 1.2."

It is important to note that at zero percent load transfer, the multiplier is 1.33 which is the value (1.33 = 1/0.75) derived previously for the ratio of the maximum edge stress to the maximum interior stress.

Design Procedure

From the previous discussion, it seems to be reasonable to design rigid pavements for military roads and streets where load transfer is not considered using the elastic layered procedure with the following procedure:

1. compute the maximum interior stress in the concrete slab using the elastic layered method (i.e., BISAR program), i.e., σ_{LE} ;

2. multiply the layered elastic calculated stress with the factor 1.33 and determine the design factor DF = $R/(1.33\,\sigma_{LE})$;

3. determine the allowable coverage from the fatigue relationship

for $k \leq 200$ pci (5)

$$DF = 0.58901 + 0.35486 \log_{10}(\text{coverage})$$

(graphically shown in Figure 3)

for $k > 200$ pci use Table 2 and Equation 5.

It is to be noted that the use of the multiplier 1.33 for this problem is not analytically all correct. Continued research effort should be conducted to obtain a possibly better solution.

Attempts were made to check if the relation between Westergaard and layered elastic stresses under aircraft loadings (Figure 5) also holds true for vehicular loadings. More computations were made to obtain additional information for pavements under vehicular loadings. It was found that the relation between the computed Westergaard and layered elastic stresses was very close to that for aircraft loadings shown in Figure 5, indicating that the multiplying factor 1.33 derived from aircraft loadings can also be used for the design of rigid pavements for roads and streets.

Justifications For Design Factor DF Less Than and Equal to 1

Equation 5 is used for the design of rigid pavements for military roads and streets. However, one important feature which is connected to the development of the failure criteria needs to be explained.

Design factor DF is the ratio of the flexural strength of the concrete R to the maximum stress σ induced by the load. For DF = 1 , the maximum stress is equal to the flexural strength of the concrete, i.e., the concrete slab will very likely experience its first crack during the first application of the load. However, the fatigue relationship at the top of Figure 4 shows that the allowable coverage is about 17 for a design factor DF of 1. In other words, when the maximum interior stress is equal to the flexural strength of the concrete, the pavement can withstand 17 coverages of the loading before the first crack is developed in the concrete slab. In the case of edge loading, the fatigue relationship at the bottom of Figure 4 shows that when the maximum edge stress is equal to the flexural strength of the concrete, the pavement can actually withstand 100 coverages of the edge load before the first crack is developed in the concrete slab. This is obviously an anomaly but there is not a rational explanation available; the following clarification only provide some perceptions.

Equation 5 (or Equation 1) is determined as statistically the best-fit line plotted through numerous data points, which correlates the design factor and coverage. The coverages are determined from full-scale accelerated traffic tests at the traffic level when the first structural crack at the surface of the concrete slab is "visually" observed. The flexural strength of the concrete R is determined from specimens cut from the pavement and tested in a simple-supported beam test. The maximum interior stress σ is a numerical number computed using the BISAR program based on input elastic modulus E and Poisson's ratio ν of the concrete and the subgrade k modulus. However, the actual stresses in the slabs in the field are variable depending on the placement of the load, rate of loading, load transfer of joints, temperature and moisture gradients, etc. Consequently, the stresses calculated from the analytical models are nominal stresses reflecting the relative effect of imposed traffic loads rather than actual stresses. Also, it is likely that neither the laboratory determined flexural strength R represents the true flexural strength of the concrete nor the traffic level at which the initial structural crack noticeable to naked eyes in the concrete slab surface is exactly the traffic level at which the initial crack really starts. The CE tests defined failure as occurring when one-half or more of the trafficking slabs have one or more structural cracks. The discussions presented in the last paragraph suggest that it is not an anomaly having design factors less than one corresponding to failure coverages greater than one.

Discrepancy Between the Current Procedure and the Elastic Layered Method

In the current design procedure, the magnitude and compositions of traffic are accounted for by the DI together with the concept of equivalent 18,000-lb basic loading. The DI is not used in the elastic layered method. In general, thickness designed by the two procedures are very close except in certain conditions where the elastic layered method is more reasonable. These are explained as follows:

1. When traffics are characterized by DI numbers, the concrete thickness may vary greatly when the traffics are in the neighborhood of changing from one index number to the other. This is not the case for elastic layered method since the traffics are directly input into the computations. This is particularly true when the index number is increased by more than one;

2. The DI method has another drawback. When the pavement is designed for two different types of vehicles, the heavier vehicles are the governing ones as it requires the highest DI. In this case the vehicles that require lower DI are discarded in determining the pavement thickness. This is not the case in the elastic layered design procedure as each group of the traffic is input into the computation, and the design is based on the sum of the effects of all the traffic, regardless of their magnitudes.

Design Examples

As an example of the application of the design procedures, design a plain concrete pavement for a road to carry the following traffic

Passenger cars	2,000 per lane per day
Panel and pickup trucks	1,300 per lane per day
Trucks, 2-axle	150 per lane per day
Trucks, 3-axle	50 per lane per day

For each type of vehicle, the operations per coverage ratios are obtained from Table 4-1 of Reference 12 according to axle configurations. The computed design coverages for each axle type are tabulated in Table 4.

Assuming an E value of 10,000 psi (equivalent to K = 100 psi in Figure 3.1 of Reference 12) for the subgrade soil, four concrete thicknesses were selected and the maximum stresses were computed for all the axle configurations. The stresses are tabulated in column 4 of Table 5. Since load transfer is not considered in roads and streets for rigid pavements as wheel and track loads travel along the concrete slab edges, stresses computed with BISAR (interior stresses) do not simulate the edge stress condition and thus the computed stresses will be multiplied by a factor of 1.33. The modified stresses are shown in column 5 of Table 5. Assuming a 28-day flexural strength R for the concrete of 675 psi, the allowable coverages were computed using Equation 5. The damages, computed as the design coverage n_i to the allowable coverage N_i, are presented in column 8 of Table 5; the damage for design thicknesses of 6, 7, 8, and 10 in. are 18.35, 0.46, 0.01 and 0.0, respectively. For a damage value of 1, the required concrete thickness is 6.7 in. This thickness value would be rounded off to 7.0 in. for design.

Summary

The current design procedure of rigid pavements for military roads, streets, walks, and open storage areas was reviewed. The development of the procedure using elastic layered method and the discrepancies between the two procedures are presented.

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Table 1. Relationship Between Rigid Pavement Design Index and Equivalent Coverages of the Basic Loading.

Rigid Pavement Design Index	Percent Thickness for 5,000 Coverages	Coverages of the 18,000-lb Basic Loading
1	82.0	11
2	90.5	175
3	99.0	3,250
4	107.5	45,000
5	116.0	350,000
6	124.5	1,750,000
7	133.0	7,000,000
8	141.5	25,000,000
9	150.0	70,000,000
10	158.5	180,000,000

Table 2. Reduction in Pavement Thickness for High-Strength Foundations.

Subgrade Modulus, k (kPa/cm)	Reduction in Thickness (%)
540 (200 psi/in.)	0.0
810 (300 psi/in.)	4.6
1,090 (400 psi/in.)	10.6
1,360 (500 psi/in.)	19.2

Note: 1 kPa/cm = 0.369 lb/in.^{3}.

Table 3. Design Factor Ratios and Stress Ratios (from Figure 4).

Coverage Level	(Design Factor, Elastic Layered) ÷ (Design Factor, Westergaard) = Stress σ_w ÷ Stress σ_{LE}
10	1.26
50	1.29
80	1.30
100	1.30
200	1.31
600	1.32
1,000	1.32
1,500	1.33
2,000	1.33
3,000	1.33
5,000	1.33
8,000	1.34
10,000	1.34
20,000	1.34
50,000	1.35
100,000	1.35
500,000	1.35
1,000,000	1.36

Table 4. Computed Design Coverages.

Vehicle Type	Configuration	Load[a] kips	Operations Per Lane Per Day	Operations Per Coverage	Coverage Per Lane Per Day	Coverage[b] Per Lane 25 years
Passenger cars	Single axle, single wheels	1.5	4,000	9.59	417.1	3,806,037
Panel and pick-up truck	Single axle, single wheels	3.0	2,600	9.59	271.1	2,473,787
Truck 2-axle	Single axle, single wheels	9.0	150	6.25	24.0	219,000
	Single axle, dual wheels	18.0	150	2.64	56.8	518,300
Truck 3-axle	Single axle, single wheels	9.0	50	6.25	8.0	73,000
	Tandem axle, dual wheels	32.0	50	2.06	24.3	221,737

[a]Some loads are assumed values.

[b]Values are obtained by multiplying 25 × 365 to the value of coverages per lane per day.

Table 5. Computations of Cumulative Damages.

Axle Type (1)	Load Kips (2)	Slab Thickness in. (3)	Maximum Stress σ_{max} psi (4)	1.33 × σ_{max}[a] psi (5)	Allowable[b] Coverage N_i (6)	Design Coverage n_i[c] (7)	Damage n_i/N_i (8)
Single axle single wheel	1.5	6	28.2	37.6	Too large	3,806,037	0.0
	1.5	7	21.7	29.0	Too large	3,806,037	0.0
	1.5	8	17.2	22.9	Too large	3,806,037	0.0
	1.5	10	11.4	18.0	Too large	3,806,037	0.0
Single axle single wheels	3.0	6	56.3	70.1	Too large	2,473,787	0.0
		7	43.3	57.7	Too large	2,473,787	0.0
		8	34.3	45.7	Too large	2,473,787	0.0
		10	22.8	50.4	Too large	2,473,787	0.0
Single axle single wheels	9.0	6	169.0	225.3	6,066,571	30,200	0.0
		7	130.0	173.3	Too large	30,200	0.0
		8	103.0	137.3	Too large	30,200	0.0
		10	68.5	91.3	Too large	30,200	0.0
Single axle dual wheels	18.0	6	233.0	311.0	28,604	518,300	18.1
		7	185.0	246.6	1,131,619	518,300	0.46
		8	150.0	199.5	74,953,400	518,300	0.01
		10	104.0	138.6	Too large	518,300	0.0
Tandem axle dual wheels	32.0	6	87.5	249.9	895,038	221,737	0.25
		7	150.0	199.5	74,953,400	221,737	0.0
		8	123.5	164.6	7,877,901,000	221,737	0.0
		10	89.0	118.6	Too large	221,737	0.0

[a]1.33 is the factor to account for zero load transfer at pavement joints.

[b]Computed from Equation 5.

[c]Values obtained from Table 4.

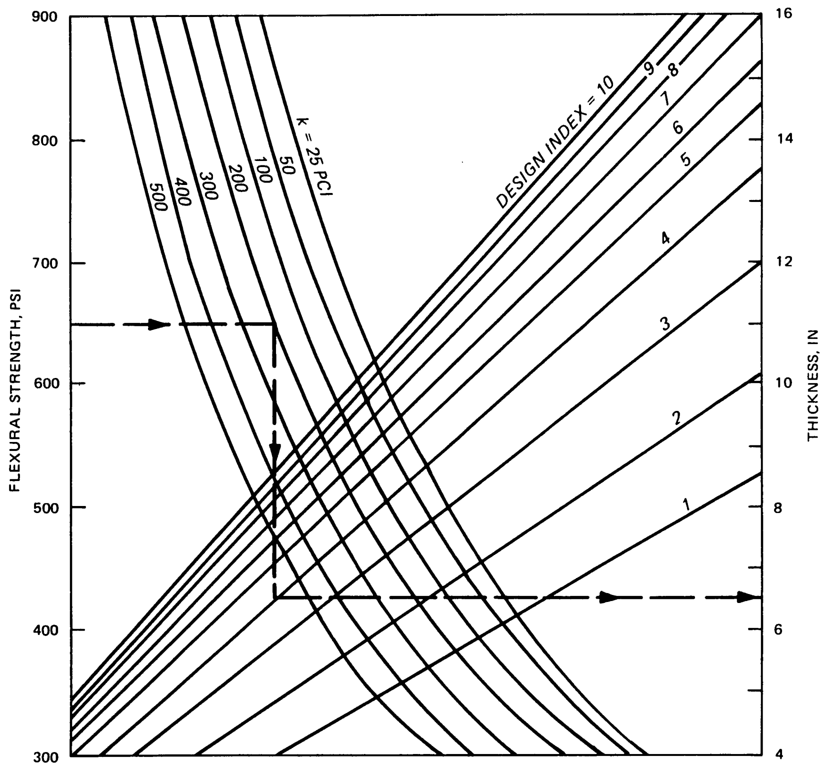

Figure 1. Relationships between flexural strength R and pavement thickness h for roads and streets.

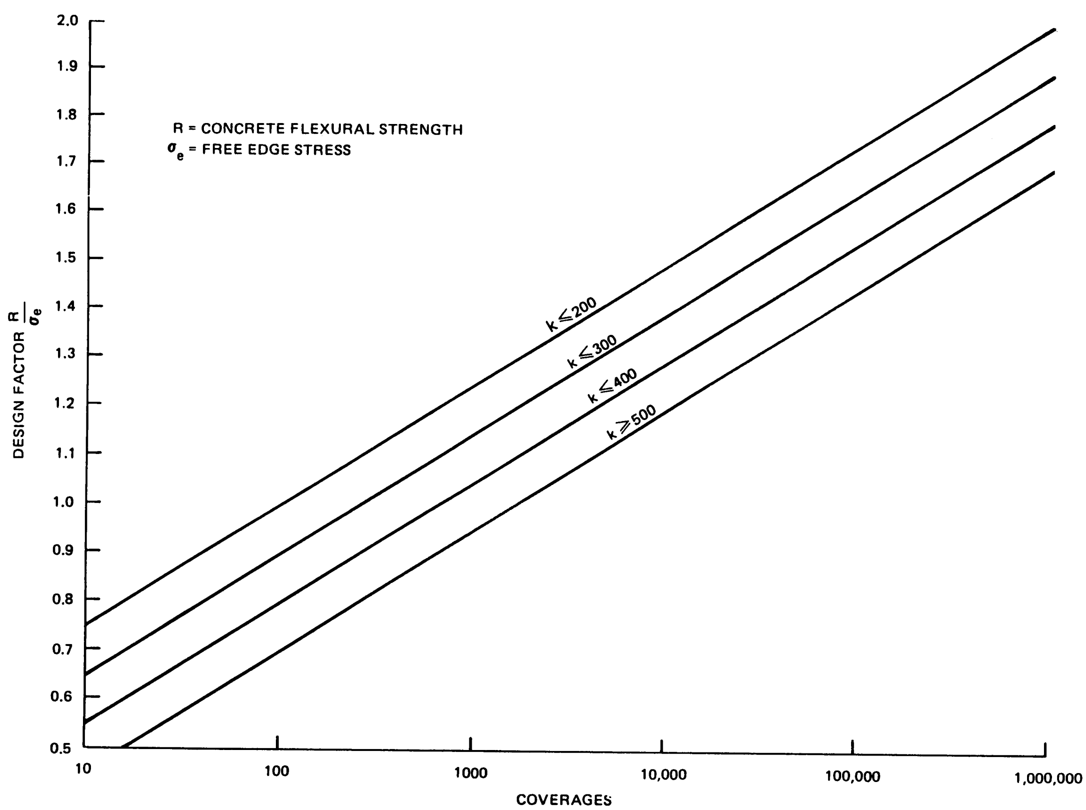

Figure 2. Fatigue relationships for concrete pavements, Westergaard solution.

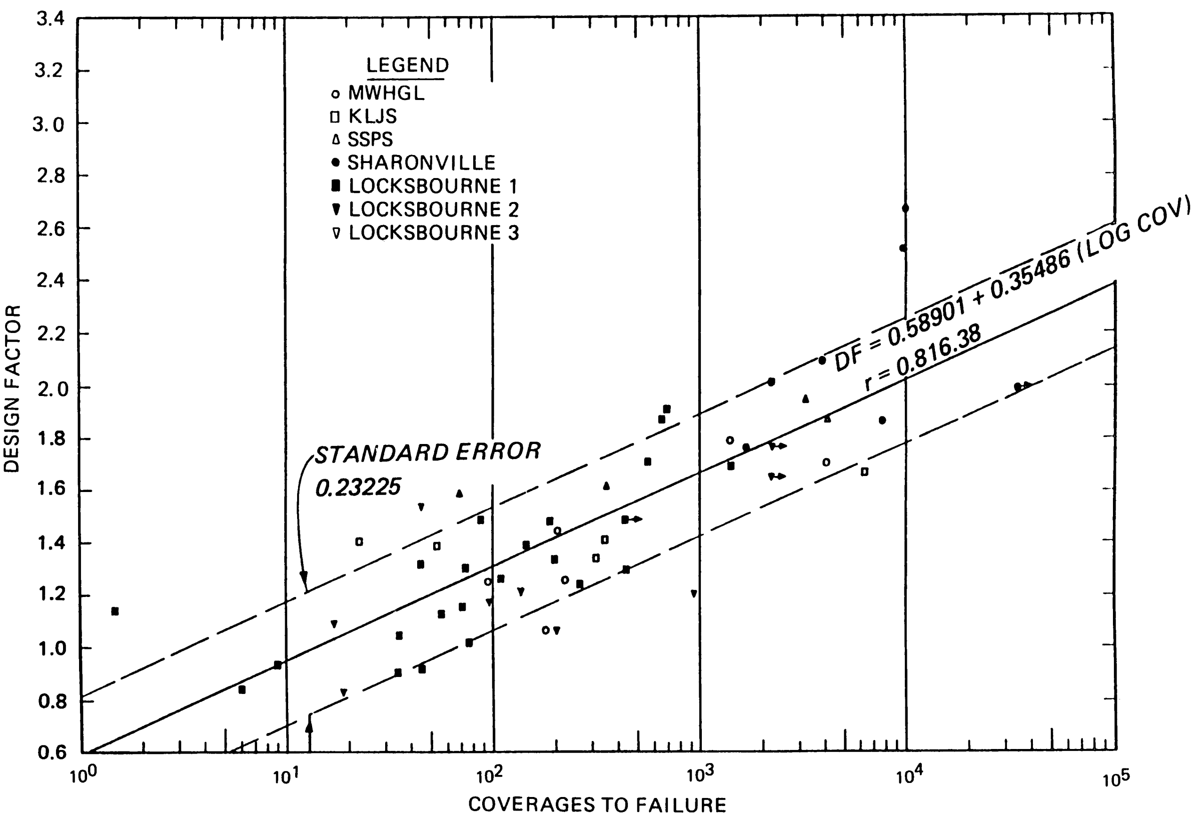

Figure 3. Performance criteria for rigid pavements, elastic layered method. (from reference 22)

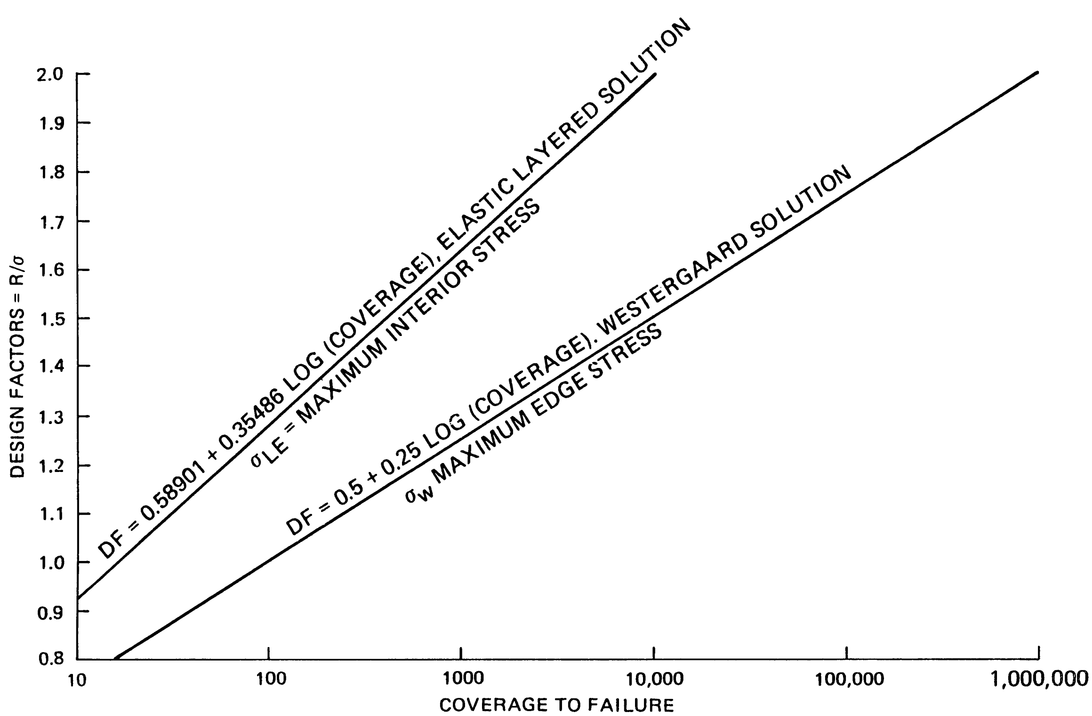

Figure 4. Comparison of failure criteria, Corps of Engineers test data.

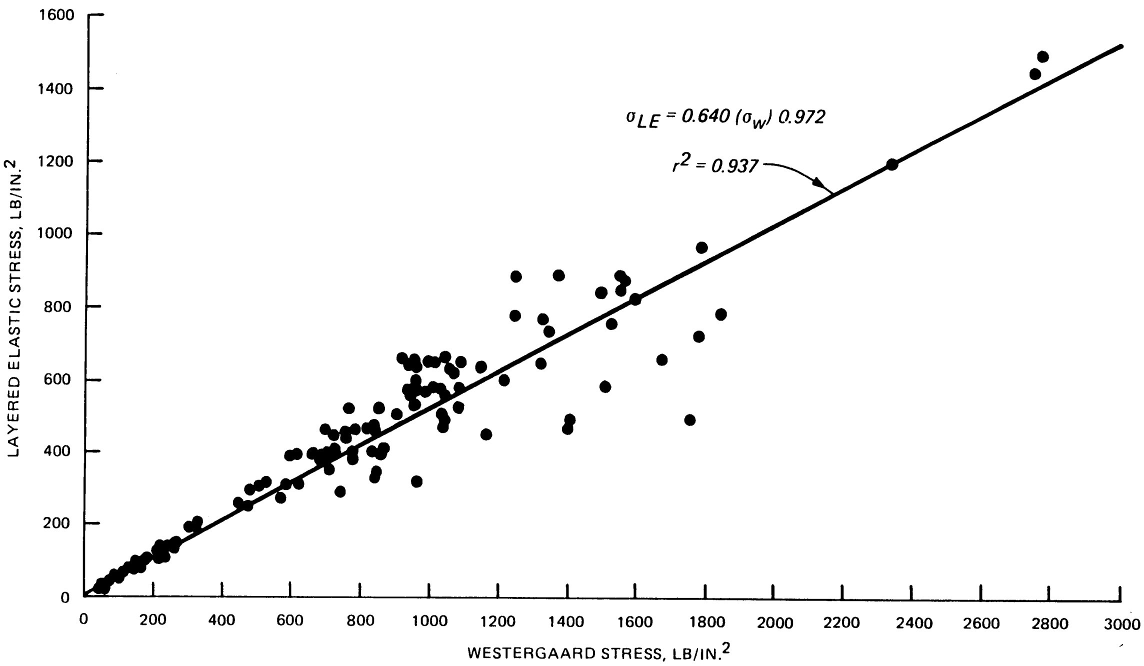

Figure 5. Relation between Westergaard and layered elastic calculated stresses, aircraft loadings. (from reference 29)

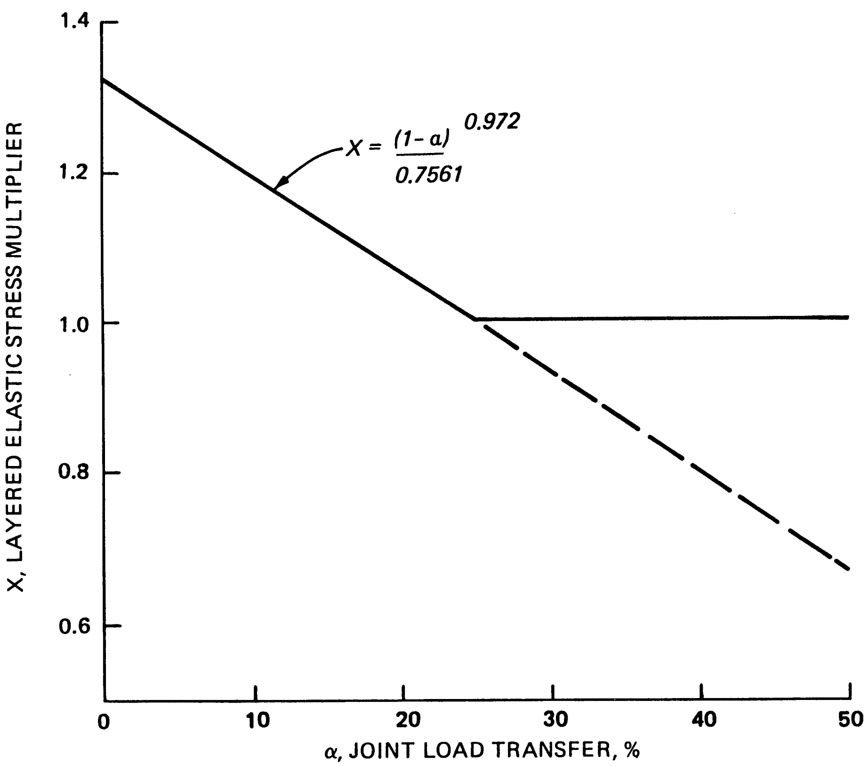

Figure 6. Multiplier for layered elastic stresses to account for load transfer (from Reference 29).