Pavement Analysis and Design

TE-503 A/TE-503

Lecture-6
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DESIGN PROCEDURES

Traffic is the most important factor in pavement design. The consideration of traffic should include both the loading magnitude and configuration and the number of load repetitions.

There are three different procedures for considering vehicular and traffic effects in pavement design:

- **Fixed traffic**
- **Fixed vehicle**
- **Variable traffic and vehicle**

DESIGN PROCEDURES-Fixed Traffic

In fixed traffic, the thickness of pavement is governed by a single-wheel load, and the number of load repetitions is not considered as a variable.

If the pavement is subjected to multiple wheels, they must be converted to an equivalent single-wheel load (ESWL) so that the design method based on a single wheel can be applied.

This method has been used most frequently for airport pavements or for highway pavements with heavy wheel loads but light traffic volume.

Usually, the heaviest wheel load anticipated is used for design purposes. Although this method is rarely in use today for pavement design, the concept of converting multiple-wheel loads to a single-wheel load is important.

DESIGN PROCEDURES-Fixed Vehicle

In the fixed vehicle procedure, the thickness of pavement is governed by the number of repetitions of a standard vehicle or axle load, usually the 18-kip (80-kN) single-axle load. If the axle load is not 18 kip (80 kN) or consists of tandem or tridem axles, it must be converted to an 18-kip single-axle load by an equivalent axle load factor (EALF). The number of repetitions under each single or multiple-axle load must be multiplied by its EALF to obtain the equivalent effect based on an 18-kip (80-kN) single-axle load.

A summation of the equivalent effects of all axle loads during the design period results in an equivalent single-axle load (ESAL), which is the single traffic parameter for design purposes. The great varieties of axle loads and traffic volumes and their intractable effects on pavement performance require that most of the design methods in use today be based on the fixed-vehicle concept.

DESIGN PROCEDURES-Variable Traffic and Vehicle

For variable traffic and vehicles, both traffic and vehicle are considered individually, so there is no need to assign an equivalent factor for each axle load. The loads can be divided into a number of groups, and the stresses, strains, and deflections under each load group can be determined separately and used for design purposes.

This procedure is best suited for the mechanistic methods of design, wherein the responses of pavement under different loads can be evaluated by using a computer. The method has long been employed by the PCA with the use of design charts.

EQUIVALENT SINGLE-WHEEL LOAD (ESWL)

The study of ESWL for dual wheels was first initiated during World War II when the B-29 bombers were introduced into combat missions. Because the design criteria for flexible airport pavements then available were based on single-wheel loads, the advent of these dual-wheel planes required the development of new criteria for this type of loading.

Neither time nor economic considerations permitted the direct development of such criteria. It was necessary, therefore, to relate theoretically the new loading to an equivalent single wheel load, so that the established criteria based on single-wheel loads could be applied.

EQUIVALENT SINGLE-WHEEL LOAD (ESWL)

The ESWL obtained from any theory depends on the criterion selected to compare the single-wheel load with multiple-wheel loads.

Using Burmister's two-layer theory, Huang (1969c) conducted a theoretical study on the effect of various factors on ESWL by assuming that single and dual wheels have the same contact pressure.

Similar studies were made by Gerrard and Harrison (1970) on single, dual, and dual-tandem wheels by assuming that all wheels have equal contact radii.

EQUIVALENT SINGLE-WHEEL LOAD (ESWL)

It was found that the use of different criteria, based on stress, strain or deflection, plays an important role in determining ESWL and, regardless of the criterion selected, the ESWL increases as the pavement thickness and modulus ratio increase or the multiple-wheel spacing decreases.

The ESWL can be determined from theoretically calculated or experimentally measured stress, strain, or deflection.

Any theoretical method can be used only as a guide and should be verified by performance. This is particularly true for the empirical methods of design in which the ESWL analysis is an integral part of the overall design procedure.

EQUIVALENT SINGLE-WHEEL LOAD (ESWL)

Five criteria:

- **Equal vertical stress criterion**
- **Equal vertical deflection criterion**
- **Equal tensile strain criterion**
- **Equal contact pressure criterion**
- **Equivalent contact radius criterion**

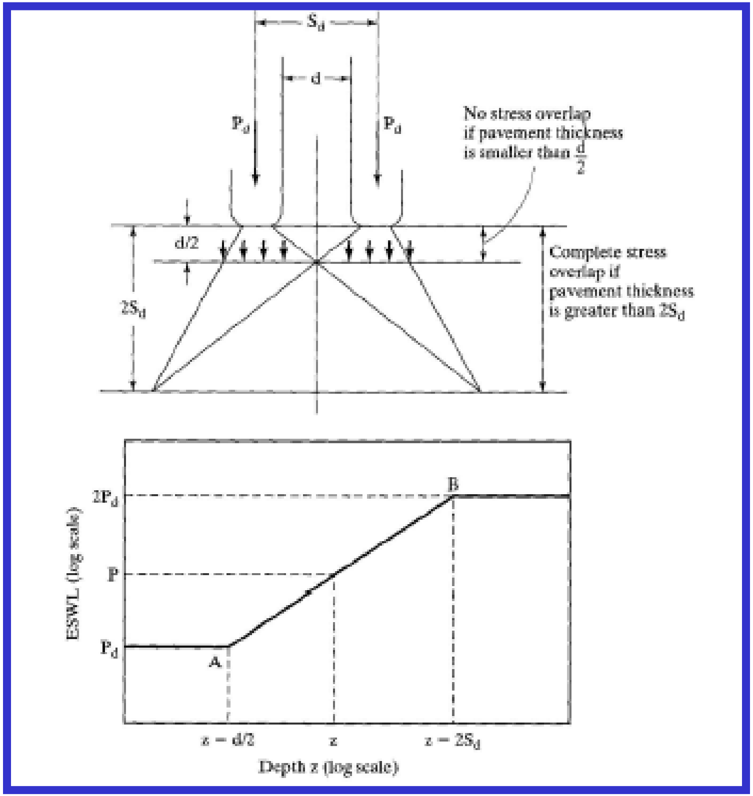
Traffic Loading and Volume

ESWL-Equal vertical stress criterion

Working from a theoretical consideration of the vertical stress in an elastic half-space, Boyd and Foster (1950) presented a semi-rational method for determining ESWL, which had been used by the Corps of Engineers to produce dual-wheel design criteria from single-wheel criteria.

The method assumes that the ESWL varies with the pavement thickness, as shown in Figure.

For thicknesses smaller than half the clearance between dual tyres, the ESWL is equal to one-half the total load, indicating that the subgrade vertical stresses caused by the two wheels do not overlap.



ESWL-Equal vertical stress criterion

For thicknesses greater than twice the center to center spacing of tyres, the ESWL is equal to the total load, indicating that the subgrade stresses due to the two wheels overlap completely.

By assuming a straight line relationship between pavement thickness and wheel load on logarithmic scales, the ESWL for any intermediate thicknesses can be easily determined. After the ESWL for dual wheels is found, the procedure can be applied to tandem wheels.

ESWL-Equal vertical stress criterion

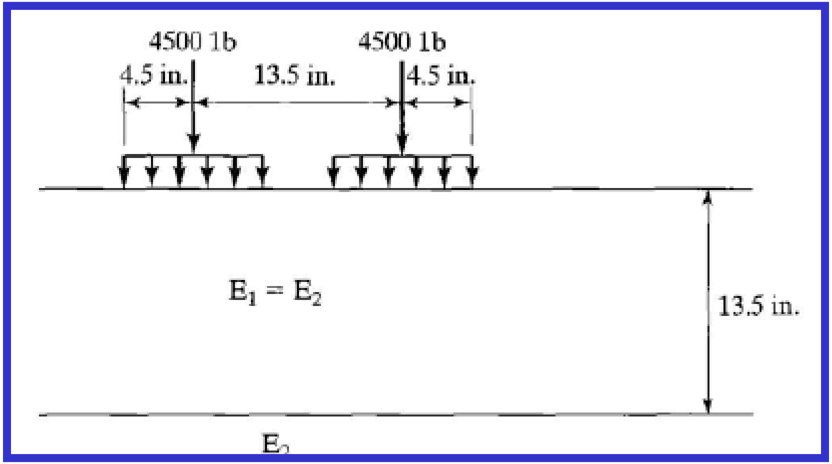
Instead of plotting, it is more convenient to compute the ESWL by:

$$\log(\mathrm{ESWL}) = \log P_d + \frac{0.301 \log(2z/d)}{\log(4S_d/d)}$$

in which P_d is the load on one of the dual tyres, z is the pavement thickness, d is the clearance between dual tyres, and S_d is the center to center spacing between dual tyres.

ESWL-Equal vertical stress criterion-Numerical problem

A set of dual tyres has a total load of 9,000 lb, a contact radius a of 4.5 in., and a center to center tyre spacing of 13.5 in., as shown. Determine the ESWL by Boyd and Foster's method for a 13.5-in.



ESWL-Equal vertical stress criterion-Numerical problem

P_d=4,500lb, S_d =13.5in, z=13.5in, a=4.5 in, d=13.5-9.0=4.5in

$2S_d$ =27.0in.

For $d/2$=2.25in

ESWL= P_d=4,500lb

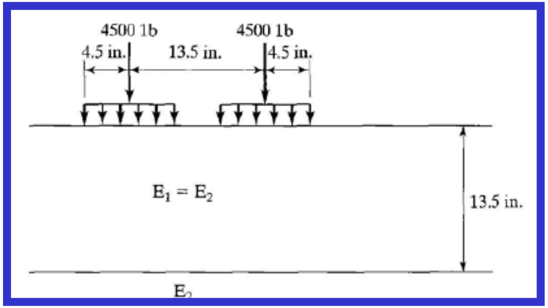
For $2S_d$ =27.0in

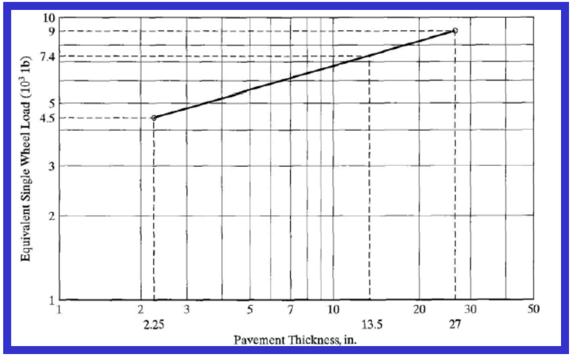
ESWL= $2P_d$=9,000lb

From figure

For 13.5 in

ESWL=7,400 lb.





$$\log(\text{ESWL}) = \log P_d + \frac{0.301 \log(2z/d)}{\log(4S_d/d)}$$

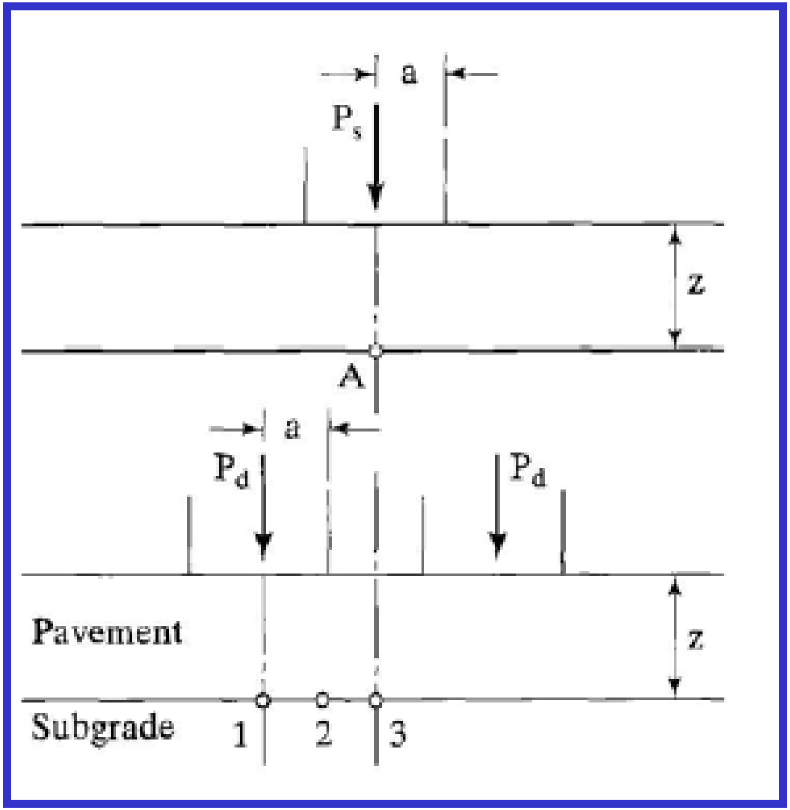
ESWL=7,417 lb

ESWL-Equal vertical deflection criterion

After the application of Boyd and Foster's method and the subsequent completion of accelerated traffic tests, it was found that the design method was not very safe and an improved method was developed by Foster and Ahlvin (1958).

In this method, the pavement system is considered as a homogeneous half-space and the vertical deflections at a depth equal to the thickness of the pavement can be obtained from Boussinesq solutions. A single-wheel load that has the same contact radius as one of the dual wheels and results in a maximum deflection equal to that caused by the dual wheels is the ESWL.

ESWL-Equal vertical deflection criterion



ESWL-Equal vertical deflection criterion

The vertical deflection factor *F* can be used to determine ESWL. Much as in the case of vertical stress, the deflection factor F_s at point A under the single wheel and F_d at points 1, 2, and 3 under the duals, as shown in Figure, are determined. The deflection can then be expressed as:

$$w_s = \frac{q_s a}{E} F_s \qquad\qquad w_d = \frac{q_d a}{E} F_d$$

in which the subscript *s* indicates single wheel and *d* indicates dual wheels. The deflection factor F_d is obtained by superposition of the duals.

ESWL-Equal vertical deflection criterion

To obtain the same deflection,

$$w_s = w_d$$

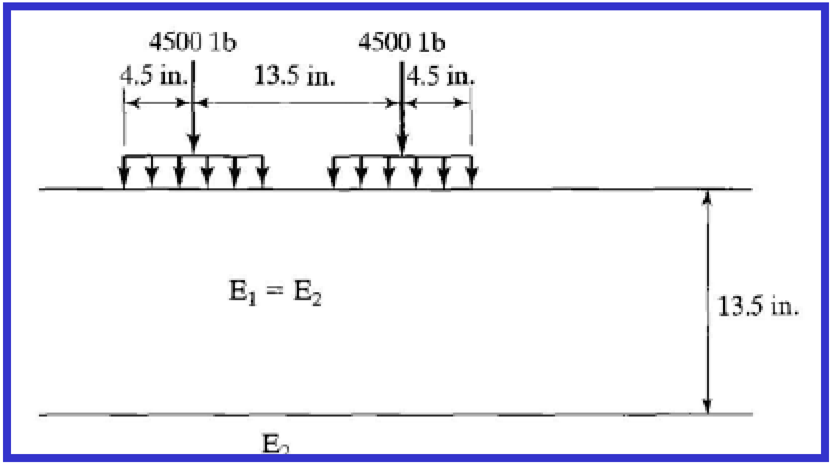
$$q_s F_s = q_d F_d$$

For the same contact radius, contact pressure is proportional to wheel load:

$$\text{ESWL} = P_s = \frac{F_d}{F_s} P_d$$

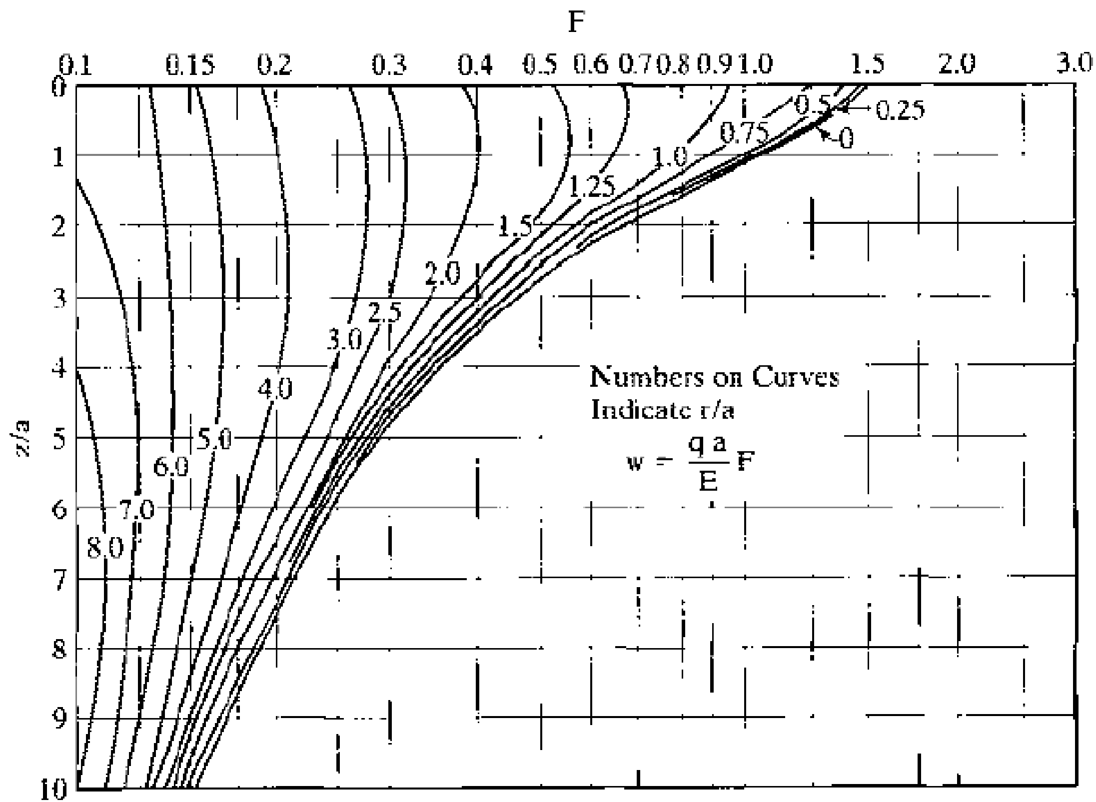
ESWL-Equal vertical deflection criterion-Numerical problem

For the pavement shown, determine the ESWL by Foster and Ahlvin's method.



Traffic Loading and Volume

ESWL-Equal vertical deflection criterion-Numerical problem



ESWL-Equal vertical deflection criterion-Numerical problem

TABLE 6.2 Deflection Factors Under Dual Wheels for a Homogeneous Half-Space

	Left wheel		Right wheel		
Point no.	r/a	F_s	r/a	F_s	Sum F_d
1	0	0.478	3	0.263	0.741
2	0.75	0.443	2.25	0.318	0.761
3	1.5	0.390	1.5	0.390	0.780

$$ESWL = P_d F_d / F_s = 4{,}500 \times 0.780/0.478 = 7{,}343 \text{ lb.}$$

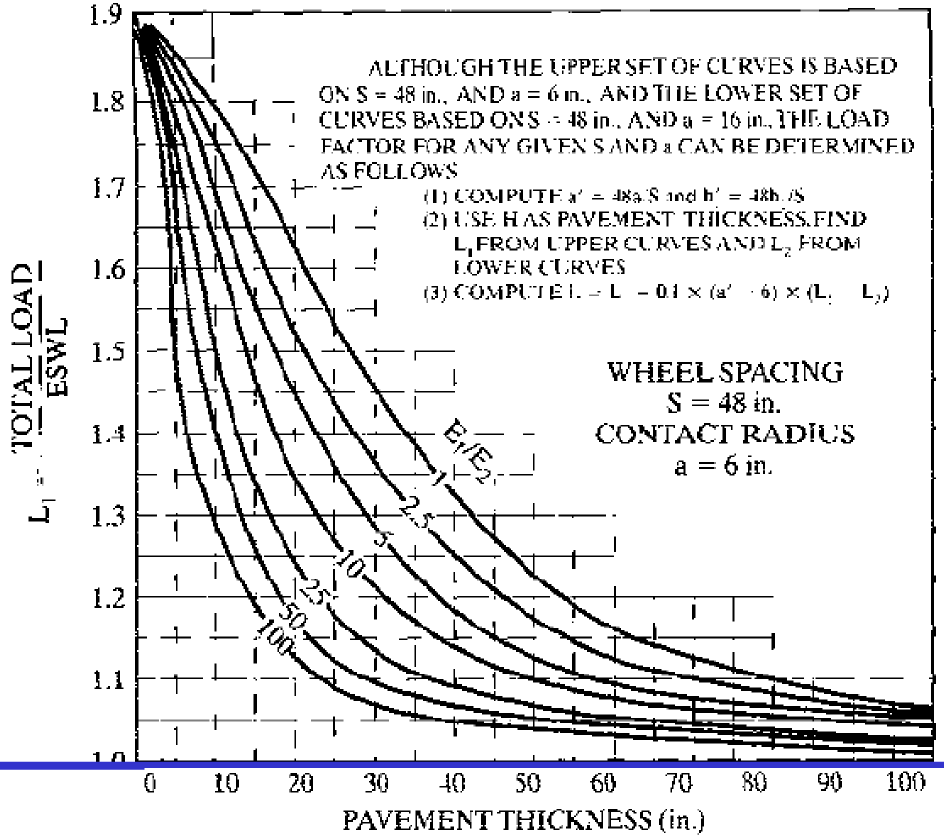
ESWL-Equal vertical deflection criterion-Huang approach

Although the improved method by Foster and Ahlvin results in a larger pavement thickness, which is more in line with traffic data than the earlier method by Boyd and Foster, the assumption of a homogeneous half-space instead of a layered system is not logical from a theoretical viewpoint.

From the data presented by Foster and Ahlvin (1958), Huang (1968b) indicated that the improved method was still not safe, as evidenced by the fact that some of the pavements with thicknesses greater than those obtained by the method were considered inadequate or on the borderline. Since the ESWL for layered systems is greater than that for a homogeneous half-space, Huang (1968b) suggested the use of layered theory and presented a simple chart for determining ESWL based on the interface deflection of two layered systems, as shown in Figure.

Traffic Loading and Volume

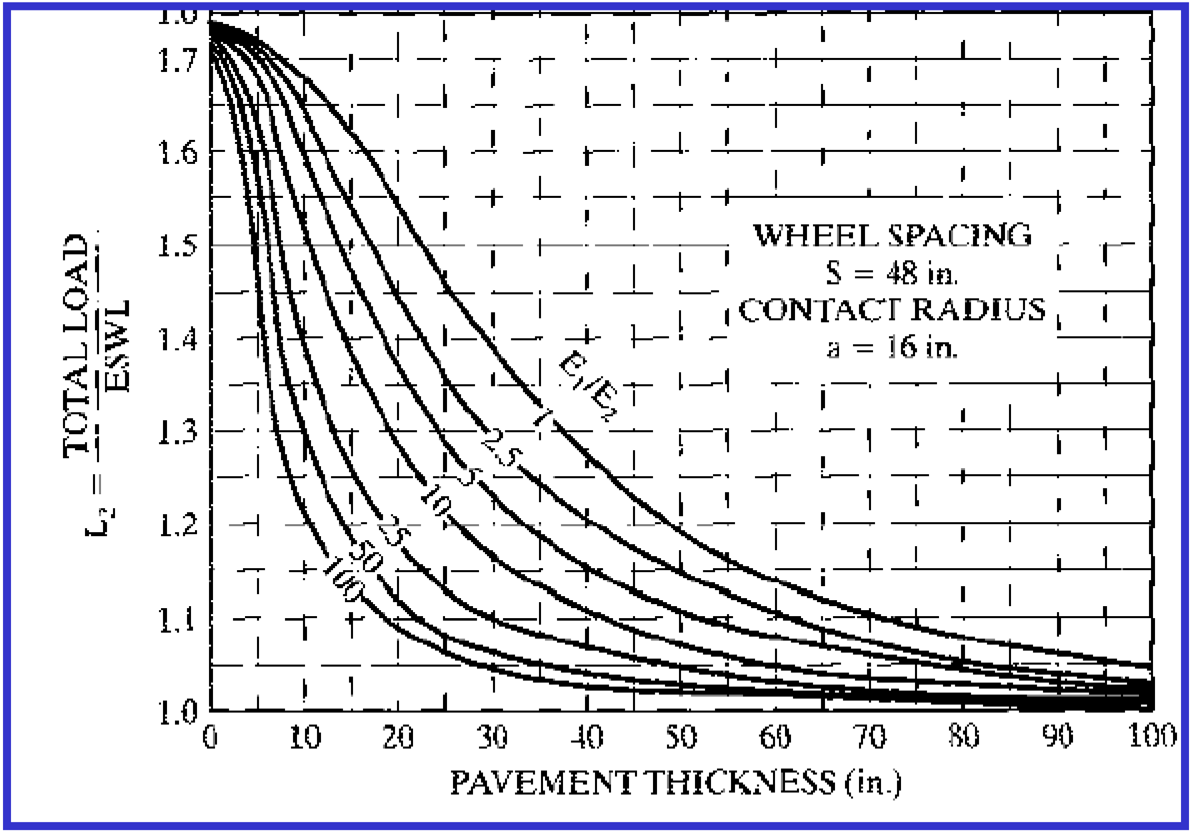
ESWL-Equal vertical deflection criterion-Huang approach



Pavement Analysis and Design

Traffic Loading and Volume

ESWL-Equal vertical deflection criterion-Huang approach



ESWL-Equal vertical deflection criterion-Huang approach

Given contact radius *a*, pavement thickness h_1, modulus ratio E_1/E_2 and dual spacing S_d , the chart gives a load factor:

$$L = \frac{\text{Total load}}{\text{ESWL}} = \frac{2P_d}{P_s}$$

Or

$$\text{ESWL} = \frac{2P_d}{L}$$

But

$$\text{ESWL} = P_s = \frac{F_d}{F_s} P_d$$

$$L = \frac{2F_s}{F_d}$$

This equation was used to develop the charts shown in figure.

ESWL-Equal vertical deflection criterion-Huang approach

The chart is based on a dual spacing S_d of 48 in. If the actual spacing is different, it must be changed to 48 in. and the values of a and h_1 changed proportionally. As long as S_d/a and h_1/a remain the same, the load factor will be the same.

The upper chart is for a contact radius of 6 in. and the lower chart is for a contact radius of 16 in.

The load factor for any other contact radius can be obtained by a straight-line interpolation.

ESWL-Equal vertical deflection criterion-Huang approach

The procedure can be summarized as follows:

1. **From the given S_d, h_1 and a, determine the modified radius a' and the modified thickness h'_1 by:**

$$a' = \frac{48}{S_d} a$$

$$h'_1 = \frac{48}{S_d} h_1$$

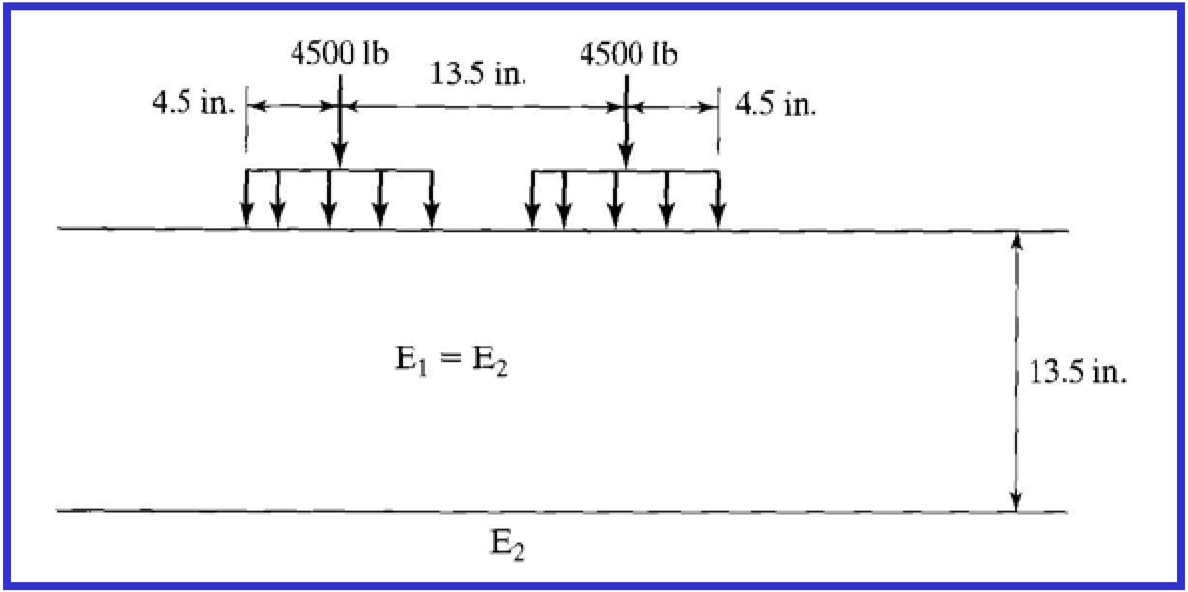
2. Using h'_1 as the pavement thickness, find load factors L_1 and L_2 from the chart.

3. Determine the load factor L from $L = L_1 - (L_1 - L_2)\frac{a' - 6}{10}$

4. Determine ESWL from $\text{ESWL} = \frac{2P_d}{L}$

ESWL-Equal vertical deflection criterion-Huang approach-Numerical problem

For the pavement shown, determine the ESWL by equal interface deflection criterion using Huang approach.



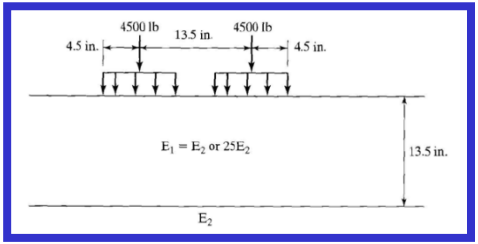
Traffic Loading and Volume

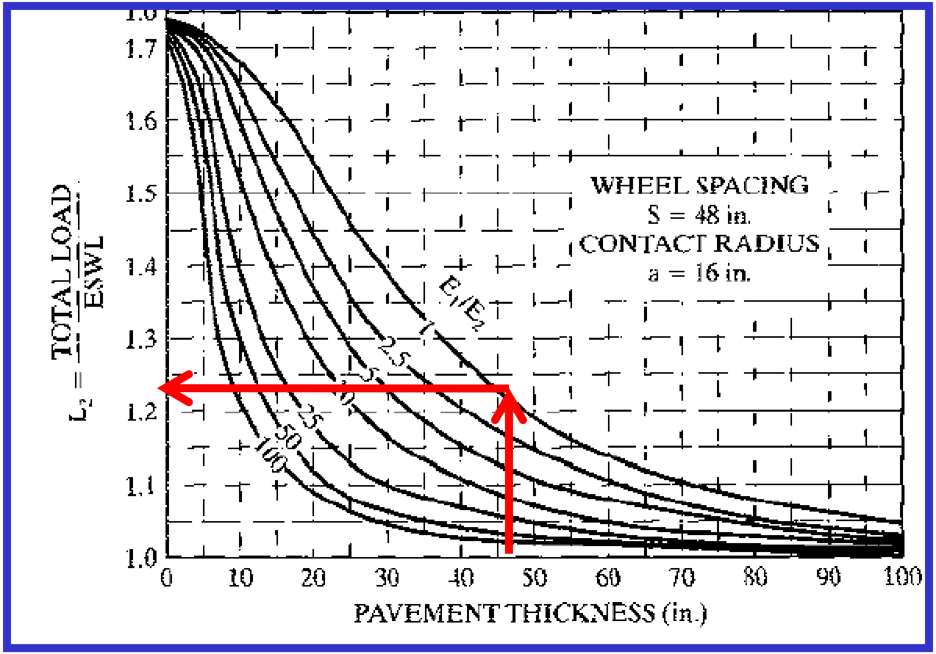
ESWL-Equal vertical deflection criterion-Huang approach-Numerical problem

S_d=13.5 in., h_1=13.5 in., a=4.5in., a'=(48/13.5)4.5=16in.

h'_1=(48/13.5)13.5=48 in. From chart L=1.22

ESWL=2x4500/1.22=7,377lb.





ESWL-Equal tensile strain criterion

The conversion factors presented in Figures 2.23, 2.25, 2.26 and 2.27 can be used to determine ESWL. The tensile strain *e* at the bottom of layer 1 under a single-wheel load is

$$e = \frac{q_s}{E_1} F_e$$

in which q_s is the contact pressure of a single wheel.

The tensile strain under dual or dual-tandem wheels is

$$e = \frac{C q_d}{E_1} F_e$$

in which C is the conversion factor and q_d is the contact pressure of dual or dual tandem wheels.

ESWL-Equal tensile strain criterion

Equating the above equations to obtain the same tensile strain:

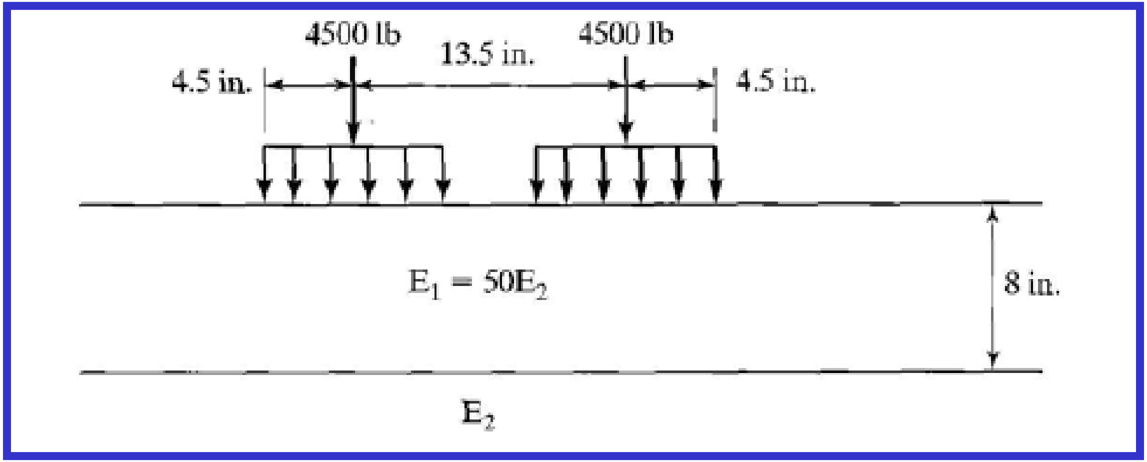
$$q_s = C\, q_d$$

For equal contact radius, contact pressure is proportional to wheel load:

$$ESWL = P_s = CP_d$$

ESWL-Equal tensile strain criterion-Numerical problem

A full-depth asphalt pavement, 8 in. thick, is loaded by a set of dual wheels with a total load of 9000 lb, a contact radius a of 4.5 in. and a center to center wheel spacing S_d of 13.5 in., as shown in Figure. If $E_1/E_2 = 50$, determine ESWL by equal tensile strain criterion.

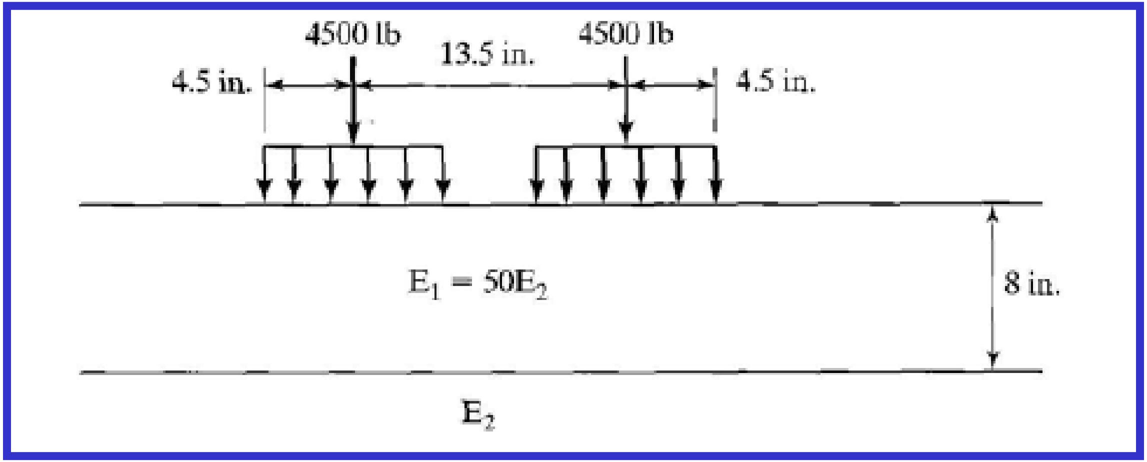


ESWL-Equal tensile strain criterion-Numerical problem

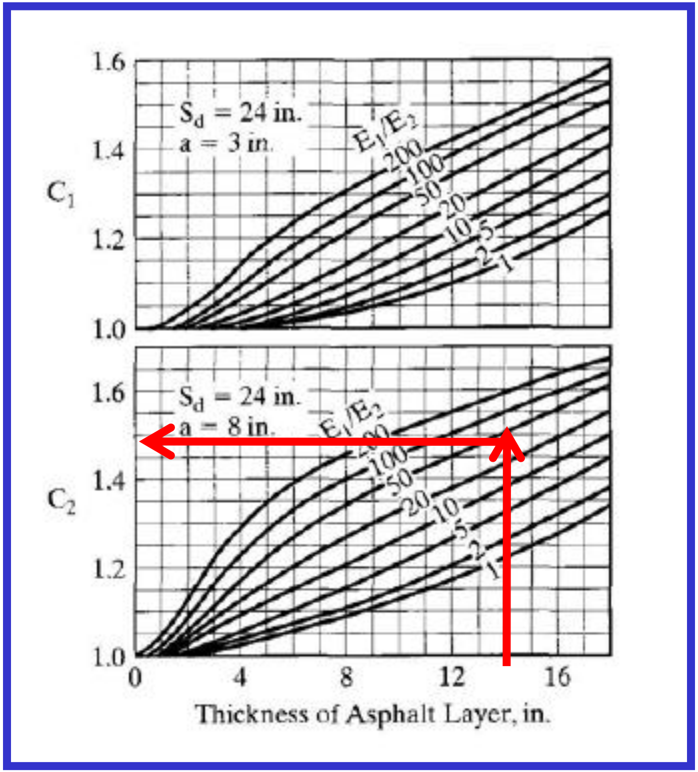
S_d=13.5 in., h_1=8 in., a=4.5in., a´=(24/13.5)4.5=8in.

h'_1=(24/13.5)8=14.2in. From chart C=1.50

ESWL = P_s = CP_d = 1.5x4500=6,750lb.



ESWL-Equal tensile strain criterion-Numerical problem



ESWL-Equal contact pressure criterion

The interface deflections for single and dual wheels with the same contact pressure can be written as:

$$w_s = \frac{qa_s}{E_2} F_s$$

$$w_d = \frac{qa_d}{E_2} F_d$$

in which the subscript *s* indicates single wheel and *d* indicates dual wheels. The deflection factor F_d is obtained by superposition of the duals. To obtain equal deflection, $\omega_s = \omega_d$ or

$$\frac{qa_s}{E_2} F_s = \frac{qa_d}{E_2} F_d$$

ESWL-Equal contact pressure criterion

Since $a_s = \sqrt{\dfrac{P_s}{\pi q}}$ **and** $a_d = \sqrt{\dfrac{P_d}{\pi q}}$

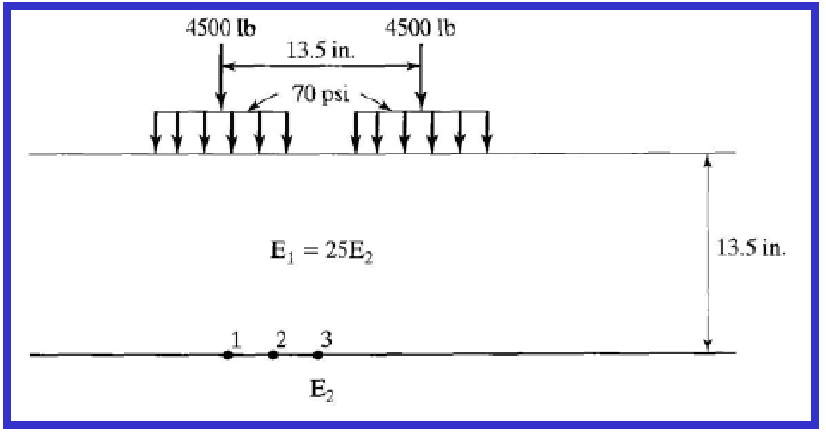
Putting these values in above equation, we get

$$\text{ESWL} = P_s = \left(\frac{F_d}{F_s}\right)^2 P_d$$

If P_d and q are given, a_d can be computed and the maximum deflection factor F_d can be determined. However, the application of above equation presents a difficulty because F_s depends on the contact radius a, which varies with P_s. Consequently, the above equation can be solved only by a trial and error method.

ESWL-Equal contact pressure criterion-Numerical problem

A two-layer system with a thickness h_1 of 13.5 in. and a modulus ratio of 25 is loaded under a set of duals with a total load of 9000 lb, a contact pressure *q* of 70 psi and a center to center tyre spacing 13.5 in. as shown in Figure. Determine the ESWL based on the equal interface deflection criterion with equal contact pressure.



ESWL-Equal contact pressure criterion-Numerical problem

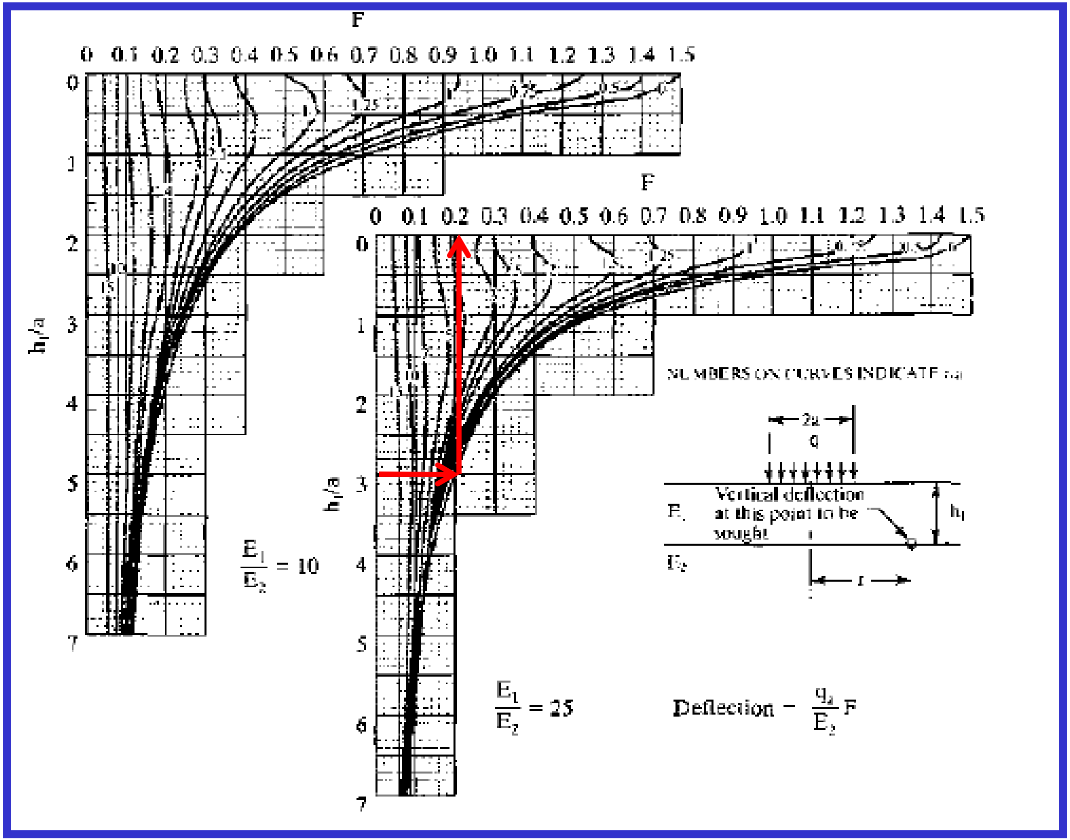
P_d =4,500lb, q=70psi, a_d=4.5in.

With h_1/a_d=3, E_1/E_2=25, using figure 2.19, deflection factors are:

TABLE 6.3 Deflection Factors Under Dual Wheels for a Layered System

	Left wheel		Right wheel		
Point no.	*r/a*	F_s	*r/a*	F_s	Sum F_d
1	0	0.19	3	0.17	0.36
2	0.75	0.19	2.25	0.17	0.36
3	1.5	0.18	1.5	0.18	0.36

ESWL-Equal contact pressure criterion-Numerical problem



ESWL-Equal contact pressure criterion-Numerical problem

Assume P_s =8,000lb, q=70psi, a_s=6.03in.

With h_1/a_s=2.24 and E_1/E_2=25, using figure 2.19

F_s=0.26

$P_s=(F_d/F_s)^2\,P_d=(0.36/0.26)^2$ x4500=8,627lb

Now assume P_s =8,300lb and repeat steps until close value is achieved.

ESWL=P_s

ESWL-Equivalent contact radius criterion

Instead of equal contact radius or equal contact pressure, loannides and Khazanovich (1993) proposed the use of an equivalent contact radius to determine the load equivalency and called this method equivalent single-axle radius (ESAR).

The basic concept is to determine a single wheel load with an equivalent radius that would lead to the same response if loaded by the same total load as the dual-wheel assembly. For example, by the use of statistical regression techniques, they found that the maximum bending stress due to dual tyres in the interior of a concrete slab would be the same as a single tyre with the equivalent radius:

$$a_{eq} = a[1+ 0.241683(S/a)]$$

ESWL-Equivalent contact radius criterion

$$a_{eq} = a[1 + 0.241683(S/a)]$$

in which

a_{eq} = equivalent tyre contact radius,

a = contact radius of each of the dual tyres

S=center-to-center spacing between the dual.

They maintained that it is possible to derive with reasonable accuracy an equivalent radius, a_{eq}, for any arbitrary loading configuration simply as a function of its geometry.

EQUIVALENT AXLE LOAD FACTOR

An equivalent axle load factor (EALF) defines the damage per pass to a pavement by the axle in question relative to the damage per pass of a standard axle load, usually the 18-kip (80-kN) single-axle load.

The design is based on the total number of passes of the standard axle load during the design period, defined as the equivalent single-axle load (ESAL) and computed by

$$\text{ESAL} = \sum_{i=1}^{m} F_i n_i$$

in which

m **is the number of axle load groups**

F_i **is the EALF for the ith-axle load group**

n_i **is the number of passes of the ith-axle load group during the design period.**

EQUIVALENT AXLE LOAD FACTOR

The EALF depends on:

- **The type of pavements**
- **Thickness or structural capacity**
- **The terminal conditions at which the pavement is considered failed.**

Most of the EALFs in use today are based on experience. One of the most widely used methods is based on the empirical equations developed from the AASHO Road Test (AASHTO, 1972).

The EALF can also be determined theoretically based on the critical stresses and strains in the pavement and the failure criteria.

EQUIVALENT AXLE LOAD FACTOR-Flexible pavements

AASHTO equivalent factors

The following regression equations based on the results of road tests can be used for determining EALF:

$$\log\left(\frac{W_{tx}}{W_{t18}}\right) = 4.79\log(18+1) - 4.79\log(L_x + L_2) + 4.33\log L_2 + \frac{G_t}{\beta_x} - \frac{G_t}{\beta_{18}}$$

$$G_t = \log\left(\frac{4.2 - p_t}{4.2 - 1.5}\right)$$

$$\beta_x = 0.40 + \frac{0.081(L_x + L_2)^{3.23}}{(\mathrm{SN}+1)^{5.19}L_2^{3.23}}$$

Note that

$$\mathrm{EALF} = \frac{W_{t18}}{W_{tx}}$$

EQUIVALENT AXLE LOAD FACTOR-Flexible pavements

AASHTO equivalent factors

In these equations,

W_{tx} is the number of x-axle load applications at the end of time t;

W_{t18} is the number of 18-kip (80-kN) single-axle load applications to time t;

L_x is the load in kip on one single axle, one set of tandem axles, or one set of tridem axles;

L_2 is the axle code (1 for single axle, 2 for tandem axles, and 3 for tridem axles);

SN is the structural number, which is a function of the thickness and modulus of each layer and the drainage conditions of base and subbase;

p_t is the terminal serviceability, which indicates the pavement conditions to be considered as failures;

G_t is a function of p_t; and,

β_{18} is the value of β_x when L_x is equal to 18 and L_2 is equal to one.

EQUIVALENT AXLE LOAD FACTOR-Flexible pavements

AASHTO equivalent factors-Numerical problem

Given p_t = 2.5 and SN = 5, determine the EALF for a 32-kip tandem-axle load and a 48-kip tridem-axle load.

$$\log\left(\frac{W_{tx}}{W_{t18}}\right) = 4.79\log(18+1) - 4.79\log(L_x + L_2) + 4.33\log L_2 + \frac{G_t}{\beta_x} - \frac{G_t}{\beta_{18}}$$

$$G_t = \log\left(\frac{4.2 - p_t}{4.2 - 1.5}\right)$$

$$\beta_x = 0.40 + \frac{0.081(L_x + L_2)^{3.23}}{(SN+1)^{5.19} L_2^{3.23}}$$

$$\text{EALF} = \frac{W_{t18}}{W_{tx}}$$

TABLE 6.4 Asphalt Institute's Equivalent Axle Load Factors

Axle load (lb)	Equivalent axle load factor: Single axles	Tandem axles	Tridem axles	Axle load (lb)	Equivalent axle load factor: Single axles	Tandem axles	Tridem axles
1000	0.00002			41,000	23.27	2.29	0.540
2000	0.00018			42,000	25.64	2.51	0.597
3000	0.00072			43,000	28.22	2.76	0.658
4000	0.00209			44,000	31.00	3.00	0.723
5000	0.00500			45,000	34.00	3.27	0.793
6000	0.01043			46,000	37.24	3.55	0.868
7000	0.0196			47,000	40.74	3.85	0.948
8000	0.0343			48,000	44.50	4.17	1.033
9000	0.0562			49,000	48.54	4.51	1.12
10,000	0.0877	0.00688	0.002	50,000	52.88	4.86	1.22
11,000	0.1311	0.01008	0.002	51,000		5.23	1.32
12,000	0.189	0.0144	0.003	52,000		5.63	1.43
13,000	0.264	0.0199	0.005	53,000		6.04	1.54
14,000	0.360	0.0270	0.006	54,000		6.47	1.66
15,000	0.478	0.0360	0.008	55,000		6.93	1.78
16,000	0.623	0.0472	0.011	56,000		7.41	1.91
17,000	0.796	0.0608	0.014	57,000		7.92	2.05
18,000	1.000	0.0773	0.017	58,000		8.45	2.20
19,000	1.24	0.0971	0.022	59,000		9.01	2.35
20,000	1.51	0.1206	0.027	60,000		9.59	2.51
21,000	1.83	0.148	0.033	61,000		10.20	2.67
22,000	2.18	0.180	0.040	62,000		10.84	2.85
23,000	2.58	0.217	0.048	63,000		11.52	3.03
24,000	3.03	0.260	0.057	64,000		12.22	3.22
25,000	3.53	0.308	0.067	65,000		12.96	3.41
26,000	4.09	0.364	0.080	66,000		13.73	3.62
27,000	4.71	0.426	0.093	67,000		14.54	3.83
28,000	5.39	0.495	0.109	68,000		15.38	4.05
29,000	6.14	0.572	0.126	69,000		16.26	4.28
30,000	6.97	0.658	0.145	70,000		17.19	4.52
31,000	7.88	0.753	0.167	71,000		18.15	4.77
32,000	8.88	0.857	0.191	72,000		19.16	5.03
33,000	9.98	0.971	0.217	73,000		20.22	5.29
34,000	11.18	1.095	0.246	74,000		21.32	5.57
35,000	12.50	1.23	0.278	75,000		22.47	5.86
36,000	13.93	1.38	0.313	76,000		23.66	6.15
37,000	15.50	1.53	0.352	77,000		24.91	6.46
38,000	17.20	1.70	0.393	78,000		26.22	6.78
39,000	19.06	1.89	0.438	79,000		27.58	7.11
40,000	21.08	2.08	0.487	80,000		28.99	7.45

Note. 1 lb = 4.45 N

EQUIVALENT AXLE LOAD FACTOR

Theoretical analysis:

In the mechanistic method of design, the EALF can be determined from the failure criteria. The failure criterion for fatigue cracking is given by with f_2 of 3.291 by the Asphalt Institute and 5.671 by Shell:

$$N_f = f_1 (\epsilon_t)^{-f_2} (E_1)^{-f_3}$$

Deacon (1969) conducted a theoretical analysis of EALF by layered theory based on an assumed f_2 of 4 using above equation

$$\text{EALF} = \frac{W_{t18}}{W_{tx}} = \left(\frac{\epsilon_x}{\epsilon_{18}}\right)^4$$

EQUIVALENT AXLE LOAD FACTOR

Theoretical analysis:

in which ε_x is the tensile strain at the bottom of asphalt layer due to an x-axle load and ε_{18} is the tensile strain at the bottom of asphalt layer due to an 18-kip axle load. If W_{tx} is also a single axle, it is reasonable to assume that tensile strains are directly proportional to axle loads, or

$$\mathrm{EALF} = \left(\frac{L_x}{18}\right)^4$$

in which L_x is the load in kip on a single axle. This equation is valid only when L_x is on a single axle.

EQUIVALENT AXLE LOAD FACTOR

Theoretical analysis:

For tandem or tridem axles, a more general equation is

$$\text{EALF} = \left(\frac{L_x}{L_s}\right)^4$$

in which L_s is the load in kip on standard axles which have the same number of axles as L_x. If the EALF for one set of tandem or tridem axles is known, that for other axles can be determined by above equation.

EQUIVALENT AXLE LOAD FACTOR

Theoretical analysis-Numerical problem

Given $p_t = 2.5$ and $SN = 5$, determine the EALF for 5000-lb and 50,000-lb single axles. If the EALF of a 32-kip tandem axle is 0.857, determine the EALF for 15,000-lb and 80,000-lb tandem axles.

For SA

$$\text{EALF} = \left(\frac{L_x}{18}\right)^4$$

For any axle

$$\text{EALF} = \left(\frac{L_x}{L_s}\right)^4$$

EQUIVALENT AXLE LOAD FACTOR

For rigid pavement please see Section 6.3.2 and study yourself.