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PAVEMENT DESIGN & PERFORMANCE STUDY

PHASE B: DEFLECTION STUDY

Interim Report No. 4

Evaluation of Sandwich Layer System of Flexible Pavements in Virginia

by

Dr. N. K. Vaswani
Highway Research Engineer

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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SUMMARY

The use of a weak sandwich layer in a four-layer system is common in the construction of flexible pavements, but the use of a sandwich layer in a three-layer system is in the experimental stage in Virginia.

Theoretical and field studies have been carried out to determine how sandwiched layers affect the design and performance of pavement systems. It has been determined that a flexible sandwiched layer can be economically used in a four-layer system by providing an optimum thickness of the sandwiched material. The optimum thickness as determined in this investigation is the minimum thickness that will: (1) act as a cushion to prevent cracking in the soil cement subbase from reflecting to the surface, and (2) permit compliance with the density specifications. For crushed stone this thickness is 4". Use of this thickness should increase pavement life and reduce construction costs. It has also been shown that the four-layer system pavements can be evaluated through elastic layered theory.

A three-layer sandwich system of economical design and based on traffic requirements is recommended for low traffic volumes. In this case it has been determined that the optimum thickness is that which will (1) prevent reflection cracking through the untreated aggregate from the 6-inch soil cement layer, and (2) satisfy the density specification. These requirements can be met with a 3" to 4" layer of crushed stone with a prime and double seal.

The evaluation of the four-and three-layer systems has shown that the strains and the resulting pavement life can be predicted from dynaflect deflections.

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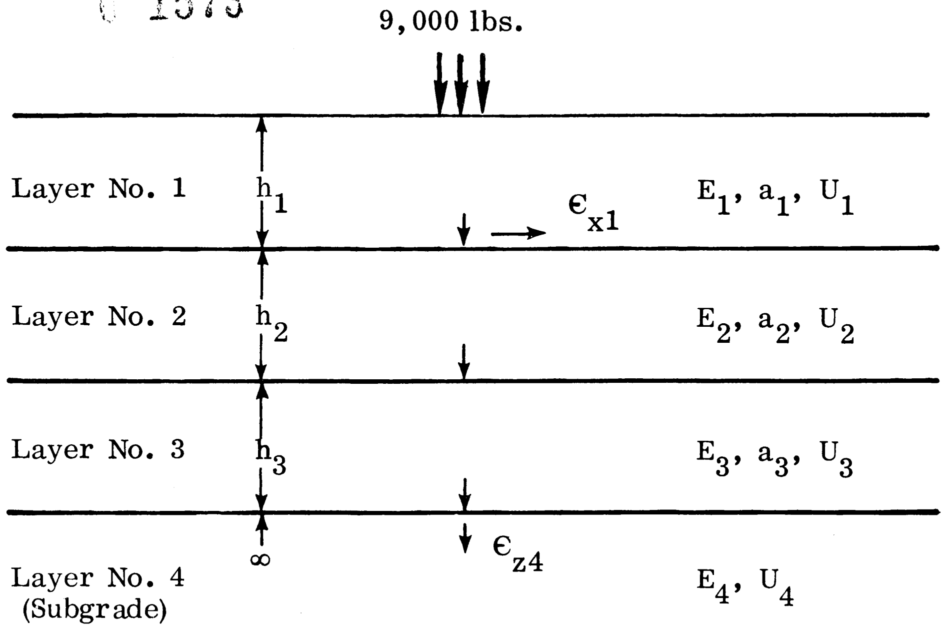
INTRODUCTION

The sandwich layer system was introduced into Virginia when poor resilient subgrades in the Piedmont area had to be stabilized with cement to provide support for heavy construction equipment. The layers overlying the cement treated subgrade have been used in different combinations.

With experience, the use of treated subgrades and sandwiched layers has increased. The object of the investigation reported here was to determine theoretically, as well as by field evaluation of satellite projects, an economical design for pavements containing the sandwiched layers.

PHYSICAL EVALUATION

Various investigators consider two parameters as critical to pavement stability against fatigue under a given traffic volume. These parameters are (1) the maximum vertical compressive strain of the subgrade (ϵ_{z4}) and (2) the maximum radial tensile strain in the bottom of the top or its underlying pavement layer (ϵ_{x1}). This is diagramatically shown in Figure 1. McCullough, et al.[1] in NCHRP Report 1-11 also used these criteria along with maximum deflections to determine the thickness equivalency values for different materials.



ϵ_{x1} = Maximum radial tensile strain in the bottom of the top layer.

ϵ_{z4} = Maximum vertical compressive strain over the subgrade.

Figure 1. Strains in the layer system.

By an empirical correlation with AASHO results, Dorman and Metcalf(2) have shown that the relation between ϵ_{z4} and the log of load applications sustained to failure is a straight line. This relationship is shown in Figure 2. The subgrade strain values leading to fatigue failure for traffic ranging from 10^3 to 10^8 load repetitions are given in Table 1.

Henkelman and Klomp(3) have shown that under repeated loadings, fatigue strain is best presented as a function of the number of load repetitions and the dynamic elastic modulus of the bituminous base course materials. They have shown that for a given modulus of elasticity of the base material, the relationship between the log of ϵ_{x1} and the log of load repetitions is a straight line. This relationship is also shown in Figure 2, while the fatigue radial strain values for a traffic range of 10^3 to 10^8 load repetitions are given in Table 1. The values in Figure 2 and Table 1 have been extrapolated from the graph given by Henkelman and Klomp.

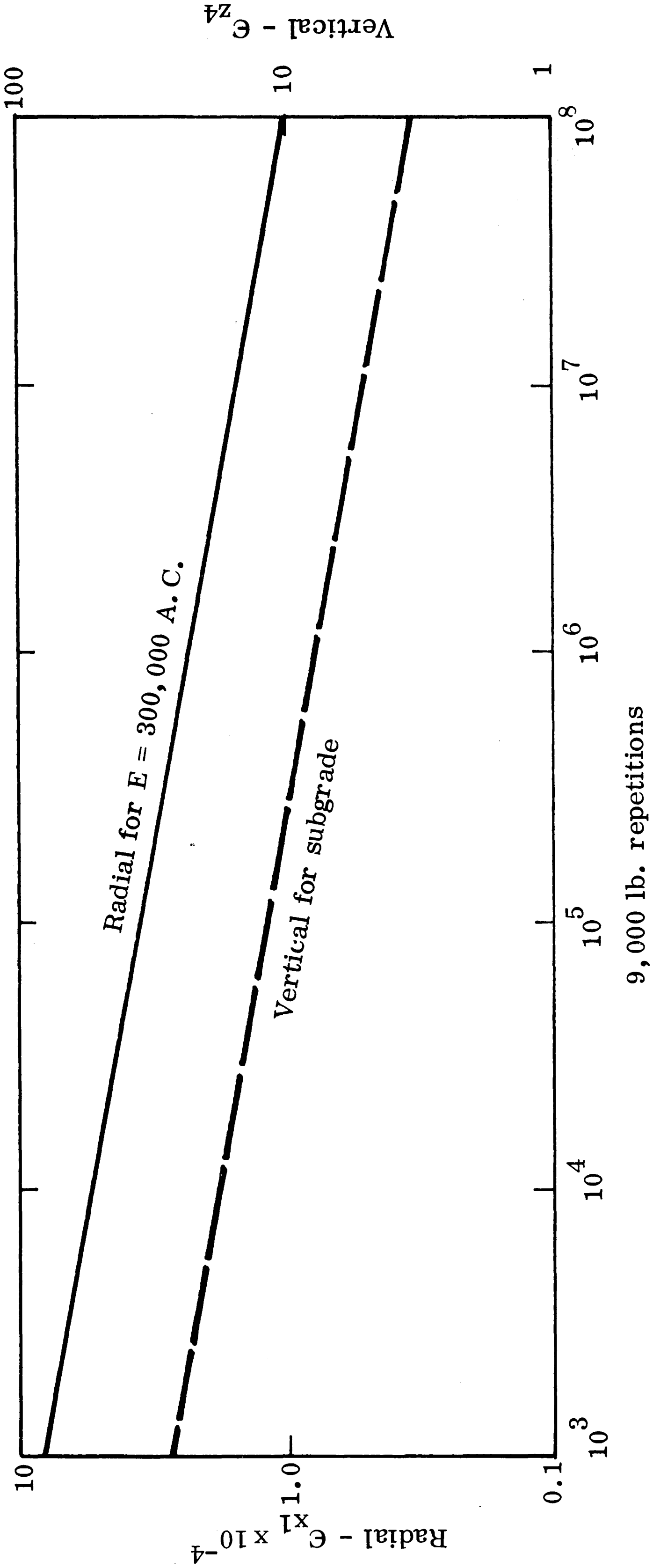


Figure 2. Strain vs. maximum permissible load repetitions.

TABLE 1

TOTAL TRAFFIC VERSUS FATIGUE STRAINS

Number of 18-kip equivalents	Fatigue subgrade strain ϵ_{z4}	Fatigue radial strain ϵ_{x1}
10^3	25.0×10^{-4}	9.9×10^{-4}
10^4	17.0×10^{-4}	6.2×10^{-4}
10^5	10.5×10^{-4}	2.3×10^{-4}
10^6	6.5×10^{-4}	1.5×10^{-4}
10^7	4.2×10^{-4}	0.92×10^{-4}
10^8	2.6×10^{-4}	0.58×10^{-4}

To determine these strains (ϵ_{x1} and ϵ_{z4}), the elastic properties of the materials in the layered system must be known. Also, as shown by Huang(4) and Dehlen(5), the elastic properties of the materials in the satellite projects can be evaluated from the deflection and curvature of the pavement surface. The evaluation of elastic properties, deflection, and curvature is discussed below.

ELASTIC PROPERTIES OF MATERIALS

The design method used in Virginia is a result of extensive research carried out in Virginia, and it is based on AASHO Road Test Results. This method uses the thickness equivalencies of paving materials as determined from deflection tests and performance studies of innumerable satellite pavement projects in Virginia.

As a result of these investigations it was found that the thickness equivalency value so obtained for a given material was a function of (1) the strength properties of the material, and (2) the location of the material with respect to the other layers in the pavement system. Table 2 gives the thickness equivalency values of some of the materials used in Virginia.

To enable the application of elastic theory to design, an investigation was carried out to determine the elastic moduli of materials to which thickness equivalency values had been assigned. The method for this conversion has been previously reported by the author.(6) This work comprised a model study of layered systems under a static load.

TABLE 2

THICKNESS EQUIVALENCY, ELASTIC MODULUS AND POISSON'S RATIO OF MATERIALS

Material	Thickness Equivalency 'a'	Elastic Modulus 'E'	Poisson's Ratio 'U'
Asphaltic concrete	1.0	300,000	0.4
Untreated aggregate	0.35	30,000	0.4
Cement treated aggregate	1.00	300,000	0.13
Soil cement or soil lime	0.45	300,000	0.13
Poor subgrade soil	—	5,000	0.4

Theoretical studies were carried out by means of the Chevron program[7] for two elastic layered systems. Subgrade moduli of E = 2,500 and 5,000 psi and a Poisson's ratio (U) of 0.4 were assigned. The overlying materials were assumed to have U values = 0.4 and 0.47. Based on the method described by the author in reference 6, a correlation between the modulus of elasticity (E) of a layer, overlying a subgrade, and the thickness equivalency value (a) of the material in the layer as determined from elastic layered theory is shown in Figure 3. This relationship is given by the equation

$$\log E = 5.5 + 2.4 \log a \quad (1)$$

Based on this equation, the composite effective elastic modulus (E_{eff}) or thickness index (D_V) of two or more layers could be obtained as follows:

$$(h_1 + h_2 + \ldots.) \log E_{eff} = h_1 \log E_1 + h_2 \log E_2 + \ldots.$$

or

$$\log E_{eff} = \frac{h_1 \log E_1 + h_2 \log E_2 + \ldots.}{h_1 + h_2 + \ldots.} \quad (2)$$

Introducing equivalent values of log E (equation 1) in equation 2, we get

$$(h_1 + h_2 + \ldots.) \log E_{eff} = 5.5 (h_1 + h_2 + \ldots.) + 2.4$$

$$(h_1 \log a_1 + h_2 \log a_2 + \ldots.) \quad (3)$$

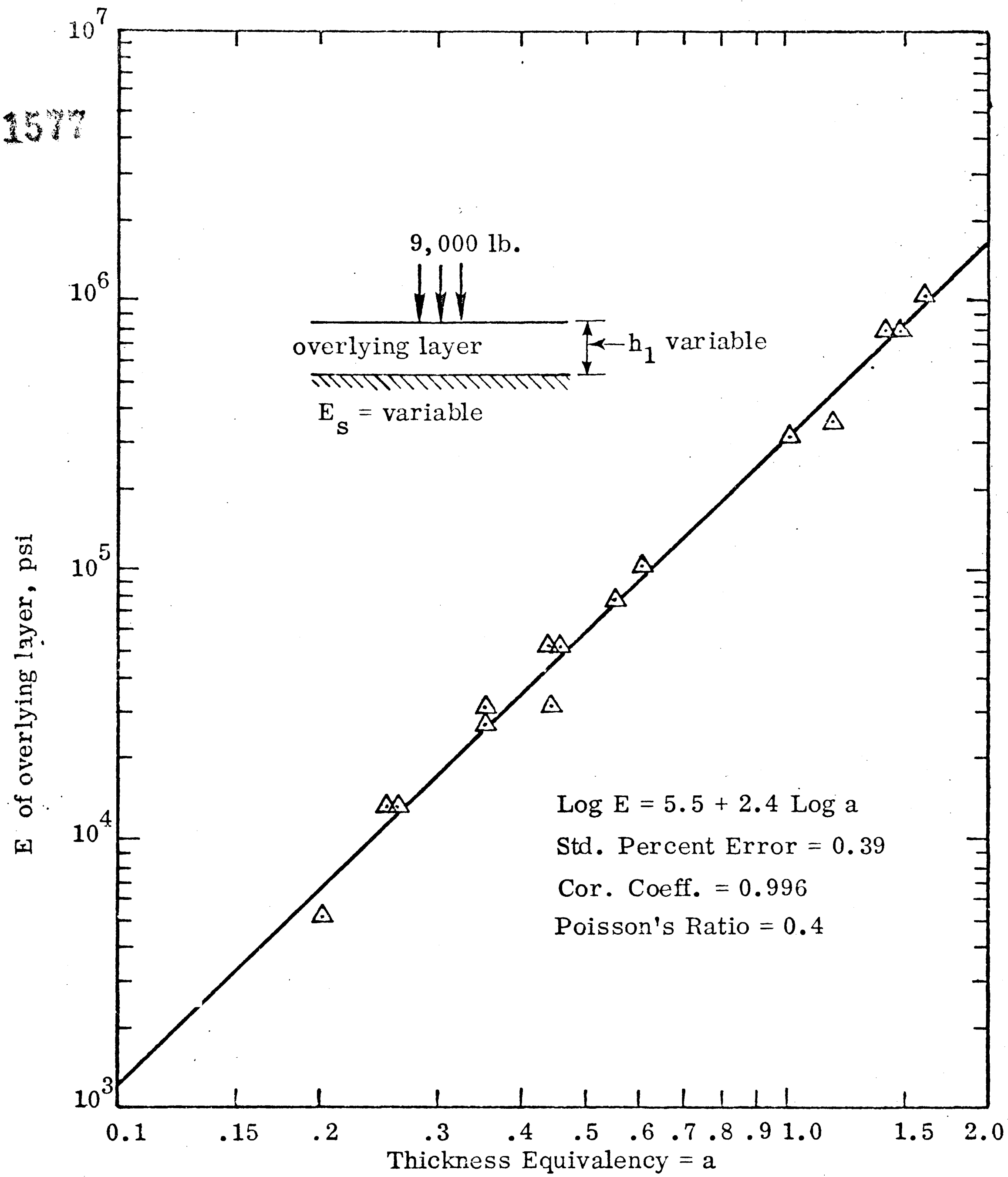


Figure 3. Thickness equivalency vs. elastic modulus of a pavement layer.

Thus equations (1) and (3) show that given the thickness equivalency value (a) and the thickness (h) of each layer, the modulus of elasticity (E) of each material and also the effective modulus of elasticity (E_{eff}) of the whole pavement can be determined.

Also, we have the AASHO model equation as follows:

$$\text{Thickness index, } D_v = a_1h_1 + a_2h_2 + \ldots \quad (4)$$

Thus, use of the effective modulus or thickness index would be an acceptable approach for the evaluation of pavements. This approach has been used in evaluating the sandwich layer system discussed later.

By means of Figure 3 or equation 1, the elastic modulus of the material — whose thickness equivalency is known — could now be determined. The materials and their elastic properties as adopted in this investigation are discussed below.

1. Asphaltic concrete: The thickness equivalency of asphaltic concrete in Virginia is equal to 1. From Figure 3, the elastic properties of this material therefore are E = 300,000 psi and U = 0.4. Kallas and Riley[8] have also determined a value of E = 300,000 psi and U = 0.4.

2. Untreated aggregate: The thickness equivalency of untreated aggregate in Virginia is equal to 0.35. From Figure 3, the elastic properties of this material therefore are E = 30,000 psi and U = 0.4. Based on the work by McCullough[1] and Kallas[8], the values obtained for untreated aggregate in this investigation are justified.

3. Cement treated stone: The thickness equivalency of cement treated stone in Virginia is equal to 1. This value is based more on the performance studies than on the deflection results. If based on deflection results, this value should be higher. From Figure 3, the elastic properties of this material therefore would be E = 300,000 psi and U = 0.4. However, since cement treated stone is a brittle material its Poisson's ratio is much lower than that of flexible materials such as asphaltic concrete and should be close to that of portland cement concrete. Balmer[9] found that the value of U for soil cement was 0.12 to 0.14. Ferguson and Hoover's[10] arguments justify these values. The elastic values of this material are therefore assumed as E = 300,000 psi and U = 0.13.

4. Cement or Lime Treated Soils: The thickness equivalency of these materials in Virginia is 0.4. This low value is taken only because this material is used as a subbase course, which reduces its effective modulus. If this material is used in the base or subbase course its elastic modulus is E = 300,000 psi. (See Figure 3.) Since it is brittle, as stated above for cement treated stone, its U value would be 0.13.

Balmer found that for sand-loam soil cement mixtures the elastic modulus varied from 200,000 psi for 2% cement to 2,000,000 psi for 14% cement, and that the silty-loam soil had E values of from 200,000 psi at 4% cement to 760,000 psi at 16% cement.

The adoption of E = 300,000 and U = 0.13 would, therefore, be reasonably safe for cement treated soils.

5. Subgrade soil: A soil classification chart by the author[11] gives the subgrade modulus (E_s) of poor soil (in confined state) as about 5,000 psi. McGhee,[12] who used the author's charts for determining the E_s values of the subgrade soils under pavements (subgrade in confined state) in the Piedmont area of Virginia, found that the values varied from 4,000 to 10,000 psi.

McCullough assumes that the subgrade modulus varies from 3,000 to 15,000 psi. Kallas takes a subgrade modulus of from 4,000 to 16,000 psi and a U of 0.4. Thompson[13] found that the E_s value of the poor soils (which needed soil stabilization) varied from 5,200 to 8,600 psi.

In this paper, the evaluations for E_s = 5,000 psi and E_s = 10,000 psi are separately reported. The Poisson's ratio used is 0.4.

METHOD OF EVALUATING DEFLECTION AND CURVATURE

In Virginia, dynaflect equipment is used for measuring deflections under the load and at 12", 24", 36" and 48" distances from the load. Studies in Virginia have shown that the Benkelman beam deflection for an 18,000 lb. axle load can be obtained by multiplying the maximum dynaflect deflection by 28.6.

For determining the radius of curvature (R) of the deflected basin, the basin between 0 and 12" was assumed to have either a sinusoidal, circular, or bell shape. The radii of curvature obtained from these three curves were correlated. It was found that a definite correlation existed between the radii of the three curves for various combinations of layered systems. Since the radius of the circular curve is easiest to calculate, this curve was adopted for use. The radius is obtained from the equation $2R\,(d_0 - d_{12}) = r^2$, where d_0 and d_{12} are the deflections at 0 and 12" from the applied load and r = 12".

DESIGN AND EVALUATION OF A FOUR-LAYER SYSTEM

In Virginia, a four-layer system is commonly used for primary, interstate and arterial roads. In this system — due to limitations of the construction equipment — the soil cement overlying the subgrade is always 6" thick. The thickness of the top asphaltic concrete layer varies from 4.5" to 10". Between the soil cement and the asphaltic concrete a layer of untreated aggregate, 4" to 8" deep, is provided.

Figure 4 shows a theoretical relationship (based on the elastic layered theory) between (1) the radial strain at the bottom of the top layer (ϵ_{x1}), (2) the vertical subgrade strain (ϵ_{z4}), (3) the thickness of the sandwiched layer (h_2), (4) the thickness of the asphaltic concrete layer (h_1), and (5) the maximum permissible traffic in terms of 18-kip equivalents.

The relation between the thickness of the layers, strains, and the maximum permissible traffic is also shown in Table 3. Figure 4 and Table 3 show the following:

(1) As the thickness of the sandwiched layer increases the subgrade compressive strain decreases, hence the permissible traffic increases. This shows that with increased pavement thickness, the tendency of ϵ_{z4} to control pavement design is reduced.

Except for one case, that of a thin pavement (h_1 = 3" and h_2 = 4"), ϵ_{x1} and not ϵ_{z4} controls the design.

(2) As the thickness of the sandwiched layer increases the radial strain increases, hence the permissible traffic decreases. Thus, an increased thickness of the sandwich layer results in reduced efficiency and increased construction cost. The maximum thickness of the sandwich layer that could be economically required is 4". This thickness is also capable of preventing cracks in the cement treated subgrade from reflecting through the untreated aggregate, and is approaching the minimum thickness practical with conventional construction techniques. Thus for a 4" or greater thickness of the asphaltic concrete layer, a 4" untreated sandwiched layer is the optimum for design.

(3) As the thickness of the asphaltic concrete layer increases the radial strains decrease, hence the permissible traffic increases. Thus, for increased traffic the asphaltic concrete thickness should be increased, not that of the sandwiched layer. The reasoning is that the untreated aggregate behaves as a resilient material with lower moduli of elasticity as its thickness increases, thus it provides an increasingly weaker support for the asphaltic concrete layer.

Detailed theoretical analysis in which the elastic modulus of the material in the sandwiched layer was varied (not given here) showed that as this modulus decreases the radius of curvature at the top of the pavement decreases, and the radial tensile stress at the bottom of the top layer increases.

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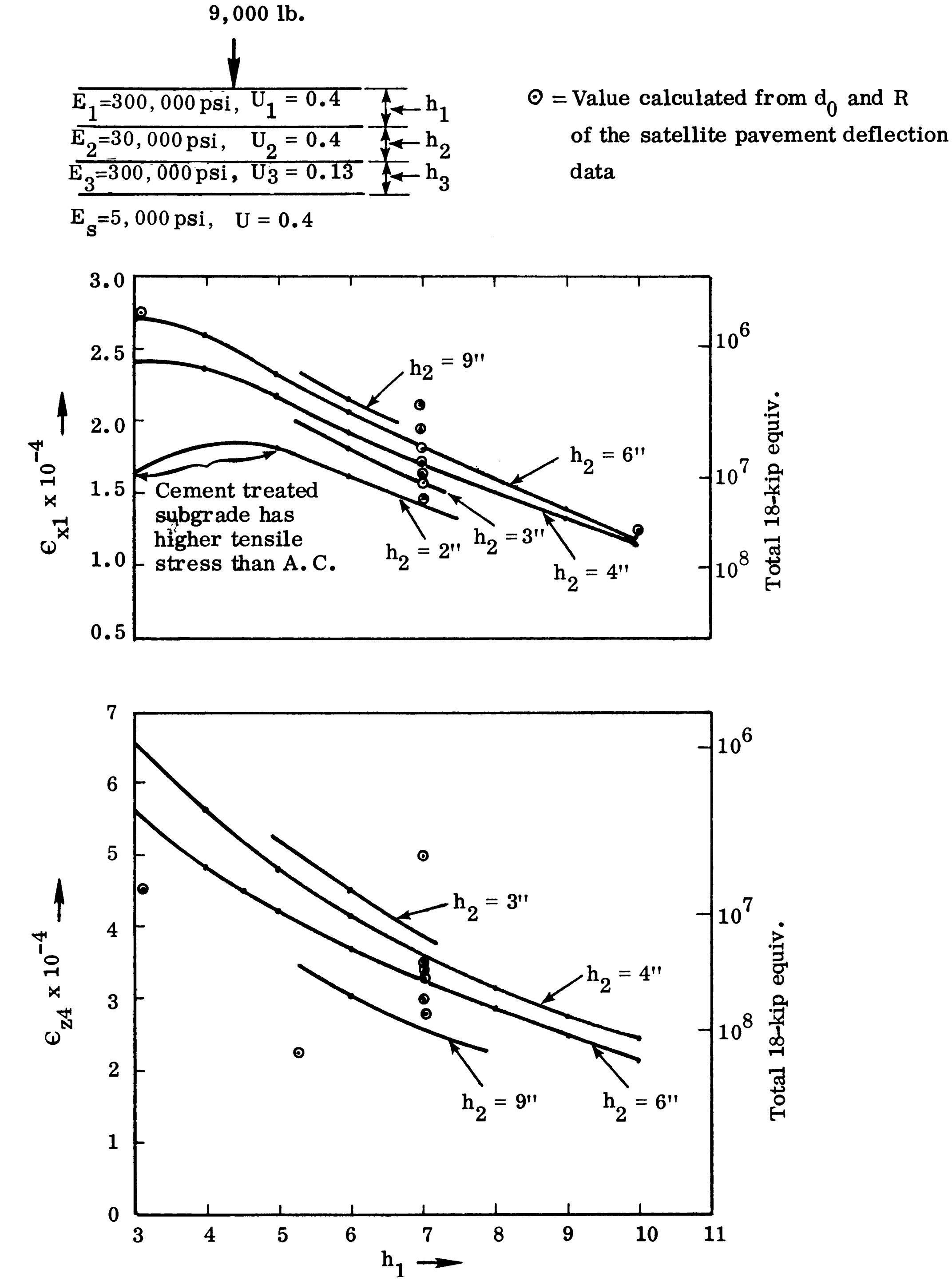


Figure 4. Four-layer system — ϵ_{x1} and ϵ_{z4} vs. total 18-kip loads, (theoretical and field evaluations).

TABLE 3

MAXIMUM PERMISSIBLE TRAFFIC IN A FOUR-LAYER SYSTEM FOR VARYING THICKNESSES OF THE TOP AND SANDWICHED LAYERS (THEORETICAL ANALYSIS)

Bottom sandwiching layer of soil cement 6" thick (h_3 = 6") having E = 300,000 psi and U_3 = 0.13; E_s = 5,000 psi and U_s = 0.4.

Top h_1 (in.)	Sandwich h_2 (in.)	Maximum Permissible Load Repetitions for Limiting Values of Strain			
		Radial Tensile Strain		Vertical Compressive Strain	
		ϵ_{x1}	Load Repetition	ϵ_{z4}	Load Repetitions
3	4	2.40×10^{-4}	1.1×10^{6}	6.59×10^{-4}	1.0×10^{6}
3	6	2.76×10^{-4}	4.5×10^{6}	5.59×10^{-4}	2×10^{6}
5	4	2.17×10^{-4}	2×10^{6}	4.87×10^{-4}	5×10^{6}
5	6	2.35×10^{-4}	1.4×10^{6}	4.2×10^{-4}	9×10^{6}
7	4	1.72×10^{-4}	6×10^{6}	3.65×10^{-4}	1.7×10^{7}
7	6	1.81×10^{-4}	5×10^{6}	3.2×10^{-4}	3.2×10^{7}
9	4	1.33×10^{-4}	2.2×10^{7}	2.81×10^{-4}	7.5×10^{7}
9	6	1.39×10^{-4}	1.2×10^{7}	2.50×10^{-4}	1.4×10^{8}

The effective change due to increasingly weaker sandwiched layers is so rapid that in four satellite experimental pavements — given in Table 4 (Serial No. 5) — with poor sandwiched layer material, the structural strength offered by the soil cement and the sandwiched layer had to be considered as zero in order to reconcile the radii of curvature and C_{x1} values with other parameters. The values plotted in Figures 4 and 5 for this experimental project are for its asphaltic concrete and cement treated aggregate layers only.

It is therefore very essential that high grade untreated aggregate be provided as the sandwiched layer.

TABLE 4

PERFORMANCE OF FOUR-LAYER SANDWICH SATELLITE PAVEMENTS

S. No.	Satellite Project	Pavement Section	D_v	Performance Data			Theoretical Evaluation (based on D_v value)		Theoretical Evaluation (based on d_0 and R of field data)		Estimated Life in Traffic
				Date	d_0 $x10^{-3}$	R $x10^3$	d $x10^{-3}$	R $x10^3$	ϵ_{x1} $x10^{-4}$	ϵ_{z4} $x10^{-4}$	
1	0058-017	7"A. C. +6"Agg. +6"CTS	11.7	4/27/67	22.7	16.1	21.4	15.4	1.62	3.6	8×10^6
3	7220-033	7"A. C. +6"Agg. +6"CTS	11.7	5/22/68	22.6	15.3	21.4	15.4	1.80	3.57	5×10^6
4	0304-041	7"A. C. +6"Agg. +6"CTS	11.7	4/19/67	22.2	14.1	21.4	15.4	1.94	3.45	3.5×10^6
5	Exp. Proj. Rte. 360										
	Section A	7"A. C. +4"Agg. +6"Sel. mat. +6"CTS	7.0	4/12/67	33.5	6.7	30.0	8.3	Weak sandwich layer = Two layer system with sandwich layer as sub-grade.		
	Section B	4.5"A. C. +6"CTA+ 6" Sel. mat. +6"CTS	10.5	4/12/67	24.3	10.3	23.0	13.5			
	Section C	3"A. C. +4"CTA+ 4"Agg. + 6"Sel. mat. +6"CTS	7.0	4/12/67	33.6	5.2	30.0	7.3			
	Section D	4.5"A. C. +6"Agg. +6" Sel. mat. +6"CTS	4.5	4/12/67	38.5	4.1	40.7	4.9			
6	Exp. Proj. Rte. 7360										
	Section A	7"A. C. +6"Agg. +6"CTS	11.7	5/7/68	27.9	12.3	21.4	15.4	2.19	5.0	2×10^6
	Section B	3"A. C. +8"Agg. +6"CTS	8.4	4/11/67	25.1	8.1	26.5	10.4	2.76	4.5	6×10^5
	Section C	7"A. C. +4"Agg. +6"CTS	11.0	4/11/67	19.6	16.9	22.3	14.3	1.60	3.0	1×10^7
7	0095-042	10"A. C. +6"Agg. +6"CTS	14.7	4/4/67	13.6	19.3	14.5	19.5	1.22	--	3.5×10^7
8	0095-016	10"A. C. +6"Agg. +6"CTS	14.7	4/10/69	16.4	23.5	14.5	19.5	--	--	$> 3.5 \times 10^7$
9	0236-029	7"A. C. +6"Agg. +8"CTS	12.6	4/30/68	18.0	20.6	20.0	16.4	1.41	3.0	2×10^7

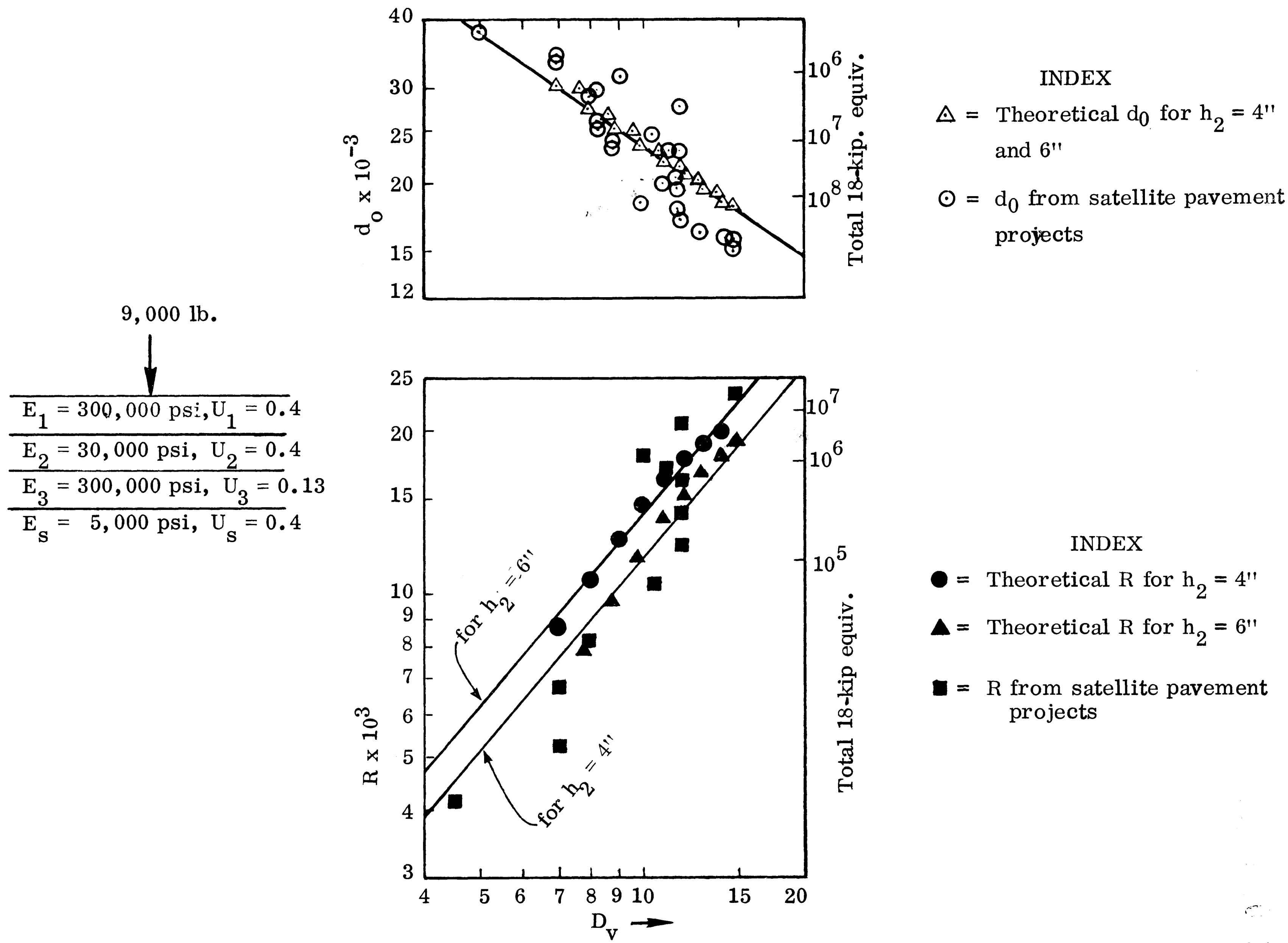


Figure 5. Four layer system-thickness index vs. surface deflection, d_0, and radial curvature, R, (theoretical and field evaluations).

To determine whether the elastic theory could be applied to the satellite projects, theoretical curves for the thickness index (D_V) vs. the maximum deflection (d_0), and also vs. the radius of curvature (R), were drawn. The D_V, d_0, and R values obtained through field testing of the satellite projects were projected on these curves, as shown in Figure 5. The values of d_0 and R as obtained from the field data and as theoretically obtained from the D_V values of the satellite projects are shown in Table 4. The values in Table 4 and in Figure 5 clearly show that the satellite projects do satisfy the theoretical evaluation.

In order to determine ϵ_{x1} and ϵ_{z4} for the satellite projects, a theoretical correlation was established between (1) R vs. ϵ_{x1}, and (2) d0 vs. ϵ_{z4}. These correlations are shown in Figure 6. From these correlations, the values of ϵ_{x1} and ϵ_{z4} were determined for the satellite projects, using the values of R and surface deflection obtained from the performance data. These values are shown adjoining the theoretical curves in Figure 5. This figure shows that the field data satisfy the theoretical ϵ_{x1} values in 5 cases out of 8 and the ϵ_{z4} values in 6 cases out of 8. In 2 cases ϵ_{x1} is higher and in 1 case lower than the theoretical value. In 1 case ϵ_{z4} is higher and in other cases lower than the theoretical value. The reasons for these variations could be many, such as environmental, construction, etc.; however, it is obvious that this method does evaluate the pavement strength.

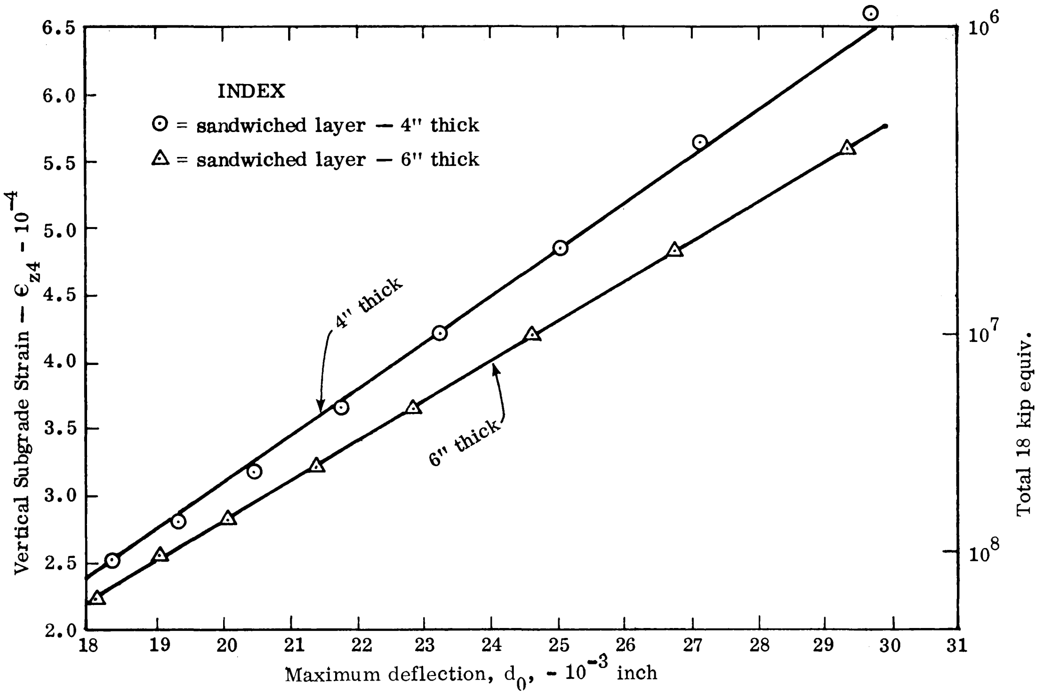
Table 4 gives the values of ϵ_{x1} and ϵ_{z4} for each satellite project. It also gives the estimated life in terms of traffic obtained by use of Figure 4.

DESIGN AND EVALUATION OF A THREE-LAYER SYSTEM

In Virginia three-layer systems are used for higher type secondary and subdivision roads. The design usually consists of a strong layer of asphaltic concrete over a weaker layer of untreated aggregate. The use of a strong sandwiched layer consisting of soil cement over a weak subgrade, with an untreated aggregate over the soil cement, has been used in some cases.

Figure 7 shows a theoretical relationship between (1) the subgrade compressive strain (ϵ_z), (2) the radial tensile strain in the bottom of the strong layer (ϵ_x), (which is the maximum in the pavement system), (3) D_V, and (4) the traffic in terms of 18-kip equivalents. Table 5 shows the strain and traffic values for maximum and minimum D_V values for E_S = 5,000 and 10,000 psi. Figure 7 and Table 5 show that ϵ_z controls the design because failure due to subgrade compressive strain takes place under lower traffic than does the failure due to radial tensile strain. Note that ϵ_z controls in the case of both a strong sandwich layer and a stronger layer over a weaker layer.

Additionally, Figure 7 shows that for the same D_V value (i.e., the same materials of given thicknesses but interchanged layers) the system with the strong sandwiched layer (i.e., untreated aggregate over soil cement) has a lesser subgrade strain for any layered combination than the system with a stronger layer over a weaker layer (i.e., asphaltic concrete over untreated aggregate). In addition, soil cement is much less expensive than asphaltic concrete. For these two reasons, it would always be advantageous to use soil cement to stabilize poor and average quality subgrade soils.



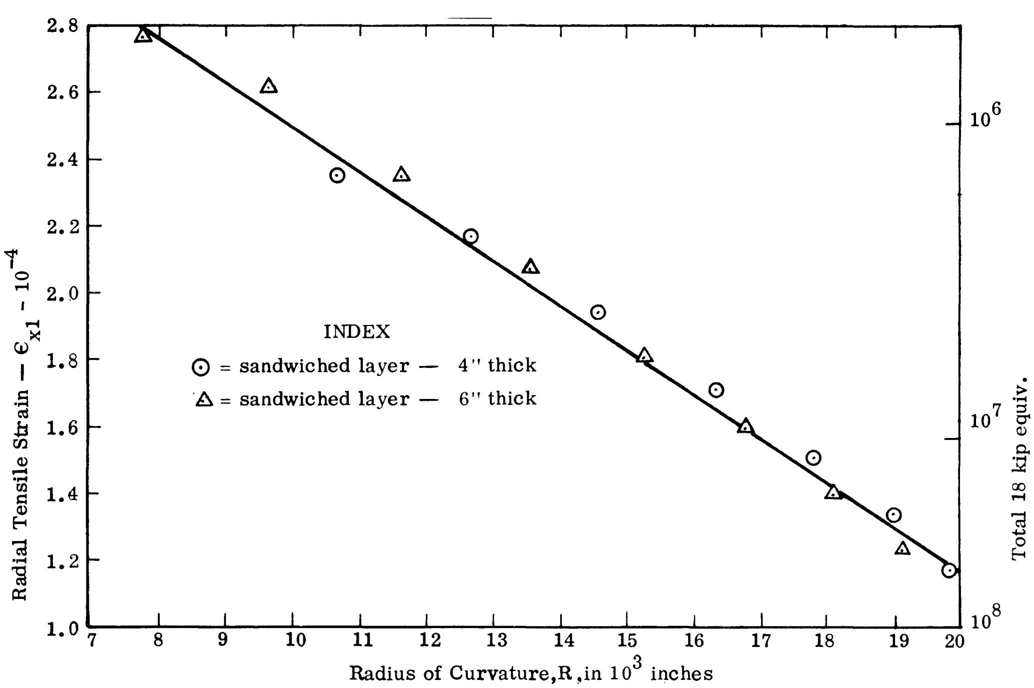


Figure 6. Four-layer system (i) surface deflection (d_0) vs. subgrade strain (ϵ_{z4}); (ii) radius of curvature (R) vs. radial tensile strain (ϵ_{x1}), (theoretical evaluation).

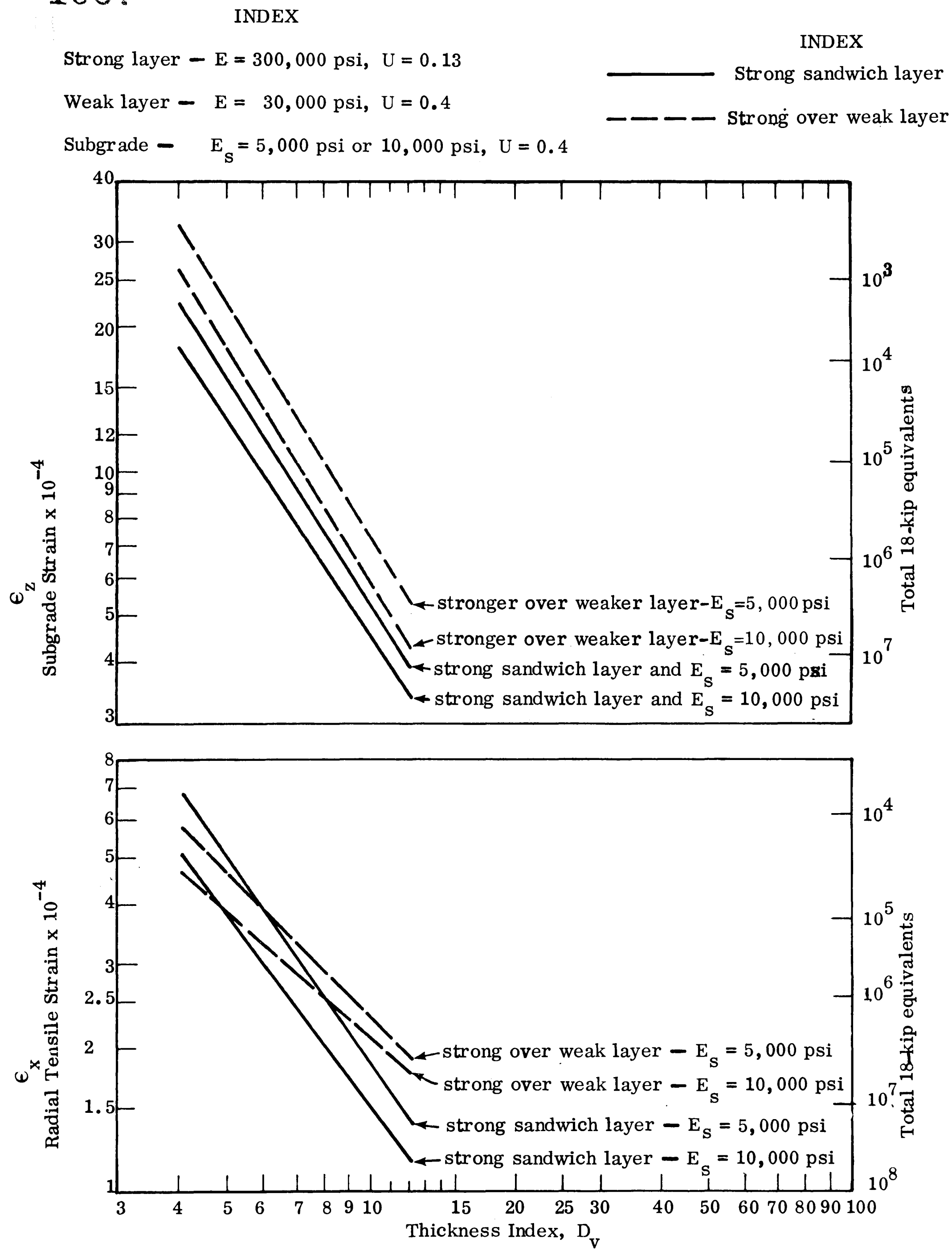


Figure 7. Three-layer system — thickness index vs. subgrade compressive strain and radial tensile strain, (theoretical evaluation).

TABLE 5

MAXIMUM PERMISSIBLE TRAFFIC IN THREE-LAYER SYSTEM FOR SANDWICH AND STRONG LAYER OVER A WEAKER LAYERED SYSTEM (THEORETICAL ANALYSIS)

System	Thickness Index	E_s	Maximum permissible load repetitions for limiting values of strain			
			Radial Tensile Strain		Vertical Compressive Strain	
	D_v		ϵ_x	Load Repetitions	ϵ_z	Load Repetitions
Strong	4.08	5,000	5.73	1.5×10^4	30.84	800
layer	4.08	10,000	4.68	5×10^4	21.28	5×10^3
over	11.16	5,000	2.72	7×10^5	8.25	3×10^5
weaker	11.16	10,000	2.54	10^6	6.01	10^6
layer						
Strong	4.08	5,000	6.81	8×10^3	25.19	10^3
layer	4.08	10,000	5.08	3×10^4	17.82	10^4
sandwiched	11.16	5,000	1.74	8×10^6	5.34	3×10^6
system	11.16	10,000	1.43	2×10^7	4.17	10^7

Figure 7 also shows that for a D_V value greater than 5 or 6, the radial tensile strains in the strong sandwiched layer (i.e., with a soil cement subbase) are lower than for a strong layer over a weaker layer (i.e., with the asphaltic concrete layer on top). Since the thickness of the soil cement is 6", which provides a D_V of 6, this figure proves that both the radial and vertical strains would be lower in soil cement subgrades.

In order to evaluate the satellite projects in terms of the elastic layer theory, it was necessary to determine whether a theoretical correlation existed between the pavement deflection data, the radial strain in the strong layer, and the subgrade compressive strain. Figures 8 and 9 show that in the case of a strong layer over a weak layer system a good correlation exists, while in the case of a strong sandwich layer system the correlation is poor. Thus, in the case of a strong sandwich layer system it might be erroneous to determine the strains from the pavement deflection data.

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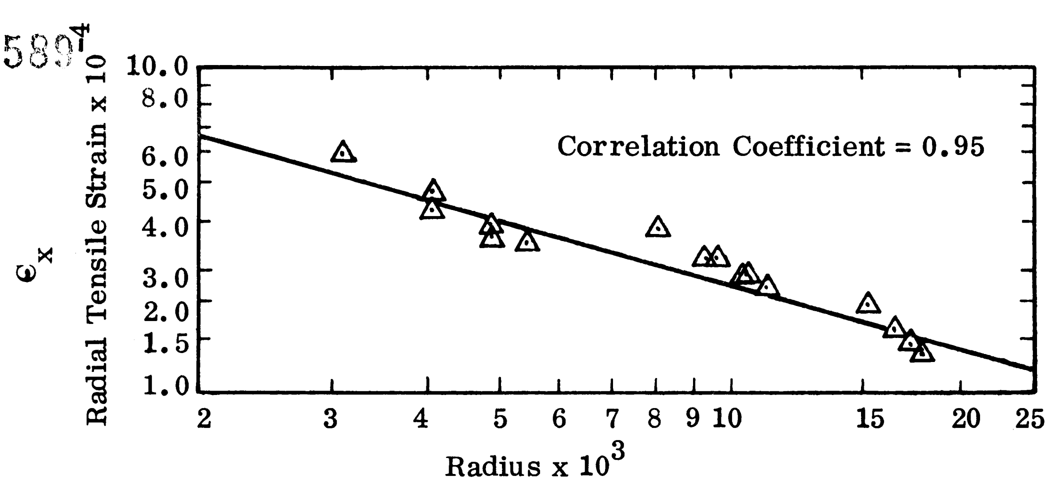
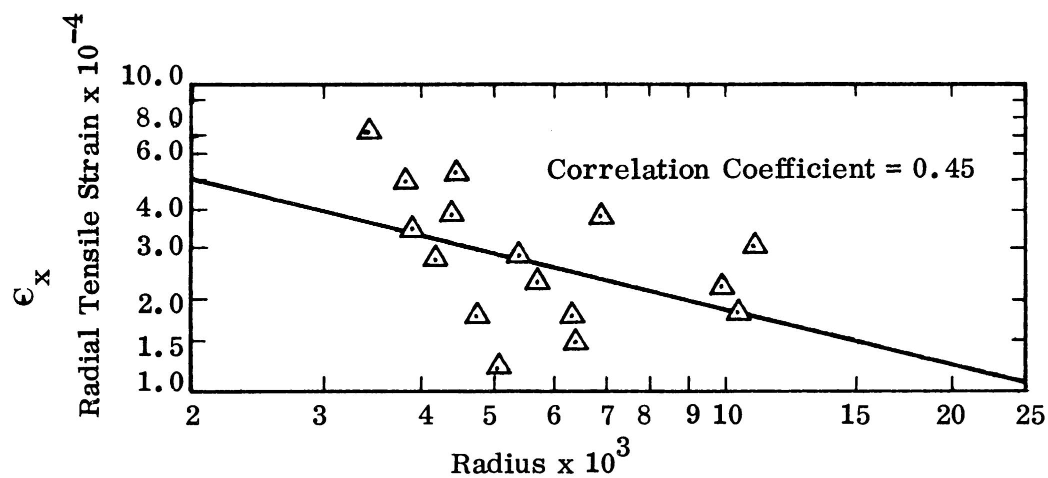


Case 1. Stronger layer over weaker layer.



Case 2. Strong sandwiched layer.

Figure 8. Three-layer system vs. radial tensile strain in the strong layer, (theoretical evaluation).

1590

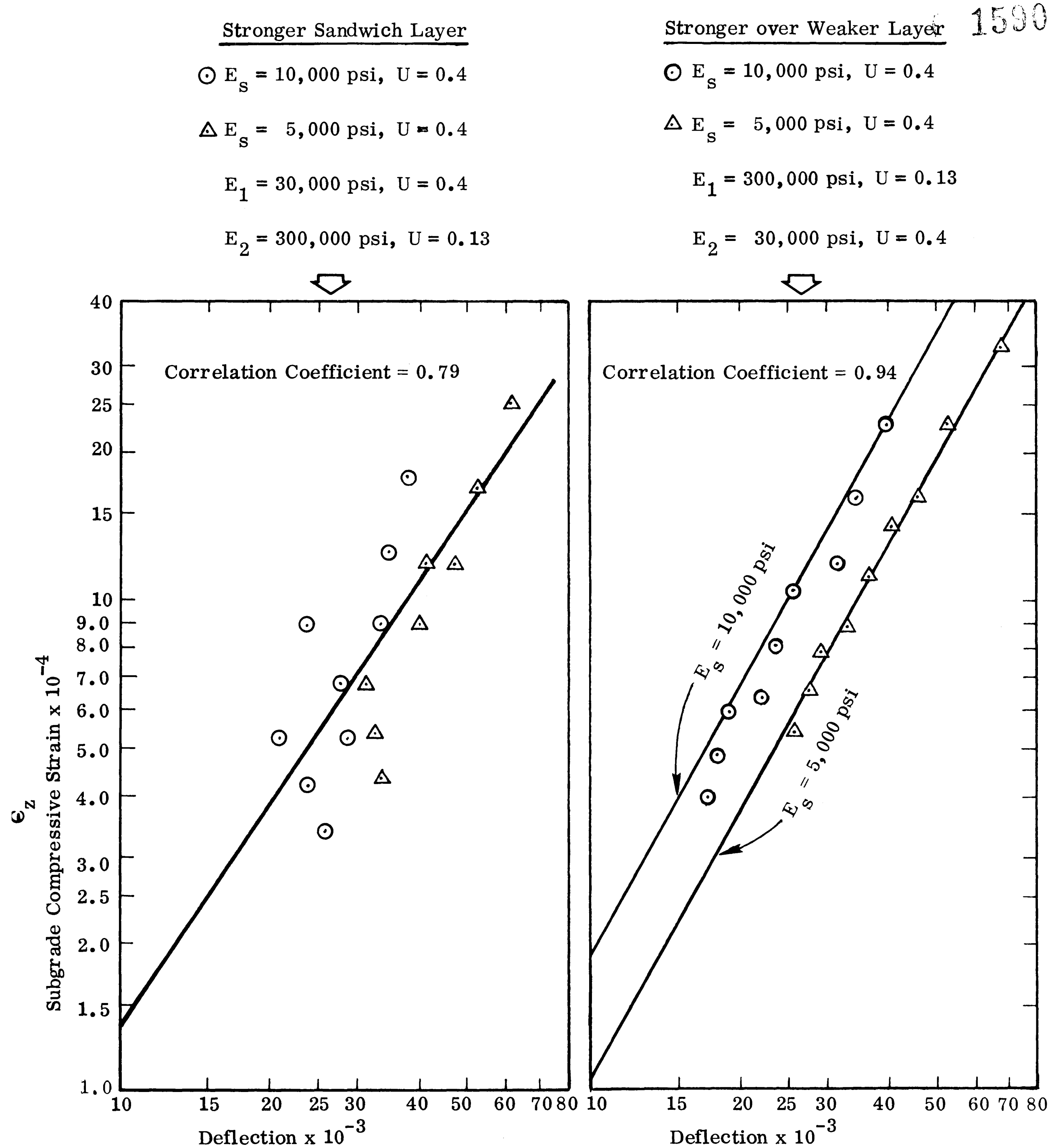


Figure 9. Three-layer system — pavement deflections vs. subgrade compressive strain for stronger sandwich layer and stronger over weaker layer, (theoretical evaluation).

Therefore, the only alternative to evaluating the strains in a strong sandwiched layer is to determine the correlation of the pavement deflection with the thickness index for a given three-layer system. In Virginia, for a strong sandwiched layer system in secondary roads, a 6" layer of soil cement between the subgrade and the untreated aggregate is the most likely choice. The thickness of the overlying layer of untreated aggregate would vary depending on the traffic. Based on this pattern of design, Figure 10 has been drawn. This figure gives the relationship between (1) the thickness of the untreated aggregate layer over 6" of soil cement, (2) the deflection, (3) the radius, (4) the subgrade strain, (5) the radial strains at the bottom of the strong sandwiched layer, (6) the total 18-kip equivalent, and (7) the average daily traffic.

Since the strong layer consists of soil cement, which is very brittle, the maximum permissible total traffic for a given tensile strain has been reduced to half for higher traffic categories. The average daily traffic has been calculated on the basis of the W4-(06) tables of the Virginia Truck Weight Study for Secondary Roads. These tables give an average of sixty 18-kip equivalents for every 1,000 trucks. Fifteen percent trucks (including panel and pickup) have been assumed for calculating the average daily traffic and 20 years has been assumed as the life of the pavement.

To determine the application of the strong sandwiched layer on an experimental project, a secondary road with 8" of stone over 6" of soil cement subbase was taken. The deflection data give $d_0 = 0.024"$ and $R = 8,860"$. Based on these deflection data, as shown in Figure 10, the pavement behaves theoretically as if it were comprised of a 3" layer of aggregate over 6" of soil cement (of $E_2 = 300,000$ psi) on a subgrade of $E_s = 10,000$ psi. Thus, a total allowable traffic of 7×10^5 18-kip equivalents, or an average of 2,700 vehicles per day (vpd) for the 20 year assumed life, is indicated. The present traffic on the road is below 1,000 vpd, and after 5 years of service the pavement is in excellent condition. In practice, the minimum thickness of the untreated layer for proper consolidation is considered to be 4". In a similar manner, other satellite pavements could be evaluated.

Figure 10 shows that as the thickness of the overlying aggregate increases, both the radius and the radial tensile strain decrease. Yet according to the elastic layer theory the radius must increase and the maximum radial tensile strain must decrease as the thickness of the overlying layer increases. This anamoly is a warning against possible erroneous evaluations of pavements in this sandwich layer system where the radius of curvature is a criterion. Hence the evaluation could be carried out as per the example given above.

Figure 10 also shows that the deflection decreases for 0" to 3" of untreated aggregate and then increases. Increased deflections in this system are likely to cause rutting. Thus, we find that for the best design about 3" to 4" of untreated aggregate over 6" of soil cement would carry as many as 2,000 vehicles per day for 20 years. Such an untreated aggregate layer should also be sufficient to prevent reflective cracking from the cement treated soils. This design might prove more economical than many non-sandwich layer system designs.

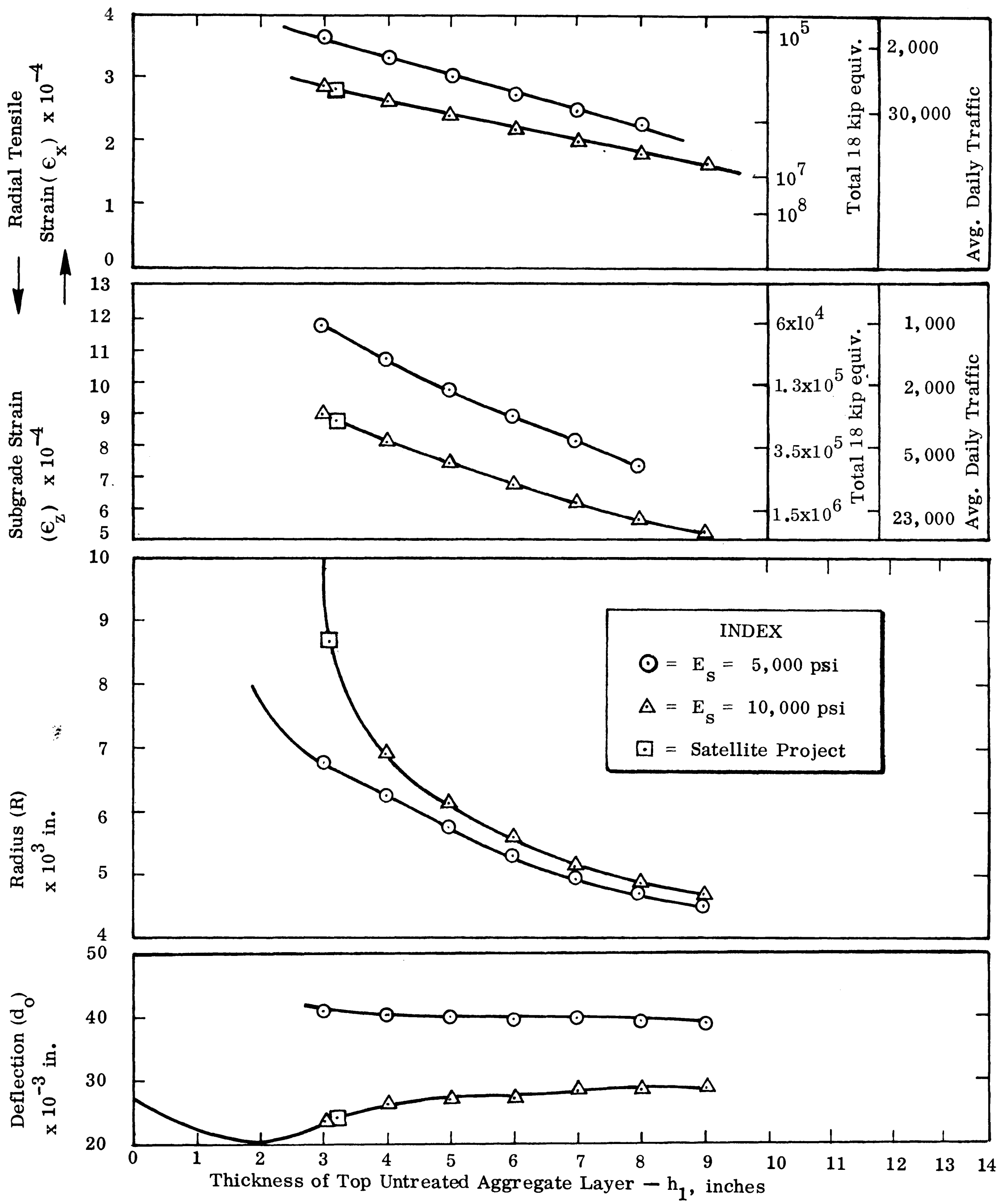


Figure 10. Three-layer strong sandwich layer system — thickness of untreated aggregate layer over 6" soil cement vs. deflection, radius, subgrade strain and radial tensile strain.

CONCLUSIONS

1. The flexible pavements in Virginia satisfy the elastic solid layer theory.

2. In thinner sections of four-layer systems and in all three-layer systems the subgrade strain controls the design, while in four-layer systems, usually used for high type roads, the radial strains control the design.

3. Thin sandwiched layers would provide more life than thick sandwiched layers. Thus for facility of construction and the prevention of crack transfer from the soil cement subbase, a 4" sandwich layer of untreated aggregate is considered to be the optimum in terms of both the design and economy.

4. In a three-layer sandwich system, a 3" to 4" untreated aggregate layer over 6" of soil cement would carry traffic volumes as high as 2,000 vpd (assuming a 20 year pavement life); hence this design would be the most economical.

5. In four-layer sandwich systems the total pavement strength is reduced out of proportion to the reduction in the quality of material used in the sandwiched layer. A good quality stone therefore should be used for the sandwiched layer.

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