A COMPOSITE PAVEMENT DESIGN PROCEDURE

T. J. Larsen, P.E., Florida Department of Transportation

Conditions of economy, ecology, and energy have made it mandatory to review concepts and procedures in the orothodox methods of constructing and designing rigid pavement systems. The pavement concept proposed herein has the potential of providing a system which addresses the postulated requirements, particularly in areas where quality aggregates have become sparce or depleted. The system proposed consists of an econocrete base with a relatively thin layer of quality concrete bonded to it. Econocrete has found wide application in pavement construction but primarily as a subbase for a concrete pavement. However, the properties of econocrete are better utilized when the econocrete layer is bonded to the pavement and becomes an integral part of the system. To take full advantage of the econocrete layer in this manner, an appropriate design procedure must be provided which will take due account of material characteristics of the composite layers. For this purpose a design procedure is proposed, taking advantage of the theoretical work presented by S. D. Kohn in "Structural Design of Composite Pavements." The procedure contained herein establishes a method to estimate the shear stress at the interface between the composite layers. A limiting shear stress at the interface provides the necessary criterion for a rational estimate of layer thickness. This presentation provides a rational procedure, taking due account of traffic and material properties, for the design of a composite pavement system. Although the procedure has general application, it is specifically intended to find use in the design of a rigid pavement using a high quality thin concrete wearing course bonded to an econocrete composite base structure.

In 1977-78 the Florida Department of Transportation (FDOT) constructed a composite pavement test road. The base structure for all experimental sections was a nine-inch econocrete base using three different strength levels. All concrete pavements were three inches thick. Those sections where the concrete wearing course was bonded to the econocrete have shown consistently high serviceability ratings. To permit further use of composite pavements where a relatively thin pavement is put on a sturdy base, it is necessary to provide a rational procedure of design taking account of load frequency and intensity as well as characteristics of the materials of the composite layers.

The procedure proposed in this presentation follows that of S. D. Kohn. ["Structural Design of Composite Pavements." Thesis presented to the University of Illinois, 1976.] The thesis makes use of the Miner's hypothesis and the concept of zero maintenance pavement in the selection of a design criterion as was developed by Drs. Darter and Barenberg.

In addition to the thickness design procedure contained in the reference, an additional requirement was introduced to limit the shear between the composite layers. The limiting shear stress at the interface provided the necessary criterion for a rational estimate of layer thicknesses.

Low strength econocrete 5.52 MPa (800 psi) has been used as a subbase for concrete pavements. The benefit of this layer in design is the increased subgrade reaction value which may reduce the concrete pavement thickness slightly. In the construction the econocrete subbase furnishes a rigid working platform for the paving itself. However, the maximum advantage of econocrete in pavement design is attained when the econocrete becomes an integral part of the pavement system. To take advantage of the concrete/econocrete composite design, an appropriate rational design procedure must be established.

DESIGN PROCEDURE

The procedure outlined is an iterative process which involves selecting the total thickness of the composite pavement, estimate stresses imposed by the various axle loads and repetitions, establish the fatigue ratio and fatigue consumption for each axle load, and finally establish the total accumulative fatigue damage to the pavement. This value is compared to the allowable fatigue damage selected on the basis of the concept of zero maintenance pavement. If the computed value of fatigue damage differs substantially from the selected value, a new thickness is assumed and the computations repeated.

With the total thickness known, the criterion of a limiting shear at the interface of the two materials is used to establish the thickness of the individual layers. Details of the procedure are provided herein. Additional details and references are cited in the thesis referred to previously.

Traffic Estimate

The first step in the design is to estimate the traffic distribution. This is established from a W-4 form. The traffic distribution for each axle load group in this example is in Table 1.

The projection of the average annual daily traffic (AADT) over the design period may be predicted and used to calculate the total traffic in Table 1. In predicting the total loads for each group, the average of the first and final AADT may be used or the average AADT may be computed. By each procedure the AADT are 67,800 and 65,200, respectively. In the specific example to be analyzed, the AADT of 65,200 will be used.

The number of trucks in the heaviest traveled lane for a six-lane urban freeway may be estimated as

$$LD = 60.76 - 0.0004V + 1.317T \quad (1)$$

where

LD - percent of trucks in the heaviest traveled lane

V - traffic volume in one direction

T - percent trucks of AADT

For the given AADT and for T = 14 we have,

$$LD = 60.76 - 0.0004\ (32{,}600) + 1.317\ (14)$$
$$= 62.2$$

[Alexander, M. M., and Graves, R. A., "Determina- of Lanal Distribution of Truck Traffic on Freeway Facilities." State Highway Department of Georgia, 1971.]

Hence, about 62 percent of the total truck traffic will be in the heaviest traffic lane. For an eight-lane, two-way urban freeway, the percent truck traffic in the heaviest traveled lane ranges between 40 and 60. In the example to be used, the truck lane traffic will be conservatively estimated at 60 percent. The directional distribution is assumed normal at 50 percent.

Because each truck may have more than two axles, it is of interest to establish the number of axles per truck. This information is obtained from the W-4 form and is 2.70 in the specific example used.

The distance of the outside wheel from the pavement edge has a significant influence on the fatigue damage of a composite pavement slab. A relation between distance from pavement edge and to outside wall of wheel, versus percent of trucks producing edge load, was developed by Darter and Barenberg in FHWA Interim Report No. FHWA-RD-76-105. When this distance is 30.5 cm (12 in) the truck-producing edge load is 34 percent

Fatigue Damage

The Miner accululative damage model is used. The number of loads of a given load level to cause failure, N_i, is computed and expressed as a ratio of (n_i/N_i) where n_i is the actual load repetitions. Hence, the total fatigue damage (FD) is

$$FD = \sum_{i=1}^{i=m} \left(\frac{n_i}{N_i}\right) \quad (2)$$

where m is the total number of axle groups. The value of n_i is computed from traffic data using the expression,

$$n_i = (AADT)\ (365)\ (DP)\ (T)\ (DF)\ (LD)\ (A) \quad (3)$$
$$(P)\ (EL)\ (CON)$$

where

DP - design period, years

T - percent trucks as a ratio

DF - directional factor, ratio

LD - lane distribution factor, ratio

A - mean number of axles per truck

P - percent axles in i^{th} load group as ratio

EL - percent axles causing edge load conditions

CON - 1 for single axles and 2 for dual axles.

In the example

$$n_i = (65{,}200)\ (365)\ (40)\ (0.14)\ (0.50)$$
$$(0.60)\ (2.70)\ (0.32)\ (P)\ (CON)$$
$$= 34.54 \times 10^6\ (P)\ (CON)$$

The number of axle loads to cause failure is based on the Zero-Maintenance curve, representing a probability of failure of 24 percent. The equation for the curve is

$$\log N_d = 16.61 - 17.61R \quad (4)$$

where,

N_d = load applications to failure

R = ratio of flexual stress to strength.

The flexual stress is computed from the selected thickness, H, the elastic properties E_1 and E_2, the subgrade reaction modulus, k, and the stress producing axle load being considered. Such stresses have been determined by finite element procedure and are presented in nomographic form in the referenced thesis. Because the stresses produced are directly proportional to the axle load, only one stress needs to be determined and all other stresses may be computed using the ratio of the axle load considered and the axle load for the referenced stress,

$$\sigma_s = \sigma_r \frac{P_s}{P_r} \quad (5)$$

where,

σ = stress

P = axle load

r = reference

s = selected

The fatigue stress ratio is,

$$R = \frac{\sigma_s}{MR} \quad (6)$$

The summation for FD as shown in Equation 2 for all axle load groups, is compared to a limiting FD value developed by Drs. Darter and Barenberg for Zero-Maintenance Design.

The total FD may be computed using the program developed later in this paper using a TI Programmable 57 calculator.

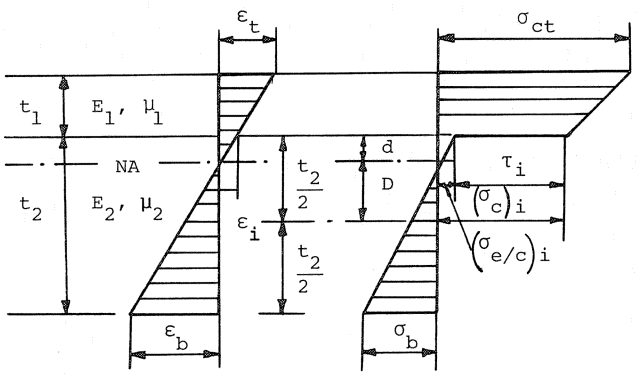
Selection of Limiting Fatigue Damage Value

According to Report No. FHWA-RD-76-105 which relates a cracking index to the FD, the limiting FD value may be selected based on the projected traffic volume for the road. It is appropriate to incorporate environmental consideration based on records or experience in the selection of the limiting fatigue damage value.

SELECTION OF LAYER THICKNESSES

The tensile edge stress at the bottom fiber of the composite pavement is minutely influenced by the thickness combination of the two layers. The thickness of the wearing course or pavement layer may, therefore, be selected based on practical considerations as far as edge stresses are concerned. However, a second criterion was developed which limits the shear stress at the interface of the two layers. The following consideration applies with the notation shown.

Figure 1. Strain-Stress Relation.



The shear stress considered in this case is the differential stress at the interface due to the differences in elastic moduli of the two layers and is

$$\tau_i = \left(\sigma_c - \sigma_{e/c}\right)_i = \varepsilon_i\left(E_1 - E_2\right) \tag{7}$$

The value D is determined using the first moment of the transformed area.

$$D = \frac{\left(\frac{t_1 + t_2}{2}\right) \cdot t_1}{t_1 + t_2 \frac{E_2}{E_1}} \tag{8}$$

and

$$d = \frac{t_2}{2} - D \tag{9}$$

The rate of strain is,

$$\frac{\varepsilon_b}{\frac{t_2}{2} + D} \tag{10}$$

hence, the strain at the interface is

$$\varepsilon_i = \frac{\varepsilon_b}{\frac{t_2}{2} + D} \; d \tag{11}$$

and the corresponding shear stress may be computed.

The maximum fiber strain of the econocrete is,

$$\varepsilon_b = \frac{\sigma_b}{E_2} \tag{12}$$

therefore,

$$\varepsilon_i = \frac{\sigma_b d}{(2D + d)\, E_2} \tag{13}$$

and,

$$\tau_i = \frac{\sigma_b . d}{(2D - d)\, E_2}\left(E_1 - E_2\right) \tag{14}$$

Equation 14 may be rewritten as

$$\frac{2D + d}{d} = \frac{\sigma_b}{\tau}\,\frac{E_1 - E_2}{E_2} \tag{15}$$

where the left side of the equation expresses physical dimensions and the right side mechanical properties of the two materials. Substituting for d and defining the ratio r as,

$$r = \frac{t_1}{t_2} \tag{16}$$

and

$$n = \frac{E_1}{E_2} \tag{17}$$

Equation 15 becomes

$$\frac{r^2 + 2r + \frac{1}{n}}{-r^2 + \frac{1}{n}} = \frac{\sigma_b}{\tau}(n-1) \tag{18}$$

The stress ratio may be determined for any level of load and will remain unchanged. For any given load, physical dimension, and elastic properties producing σ_b, there is a proportional shear stress, τ, at the interface. If it is assumed that the shear fatigue progresses similar to the fatigue in bending, then, the shear fatigue is inadvertently accounted for in this development. Hence, only the ratio of the two stresses becomes important. According to the previous discussion and using the stresses at failure,

$$MR = 0.15\sigma'_c$$

and

$$\tau_a = 0.03\sigma'_c$$

hence,

$$\frac{MR}{\tau_a} = \frac{\sigma_b}{\tau} = \frac{0.15\sigma'_c}{0.03\sigma'_c} = 5 \qquad (19)$$

which may be substituted in Equation 18.

Equation 18 may now be solved for r when the elastic ratio, n, of the two materials is known.

A computer program using a Tl Programmable 57 calculator was developed for Equation 18 to solve the ratio or r.

From the definition of r

$$r = \frac{t_1}{t_2}$$

and,

$$H = t_1 + t_2$$

therefore,

$$t_2 = \frac{H}{1 + r} \qquad (20)$$

Thus, for inputs of the elastic ratio of the two materials, n, the allowable bending stress, MR, the corresponding shear stress, τ_a, and the total thickness of the pavement, H , the computer program will solve for the thickness, t_2.

For practical purposes, and excluding the fatigue assumption for shear stress, it is conservative to place the neutral axis at the interface of the two layers. In that case, the shear stress due to the difference in mechanical properties of the two materials is zero since the strain is zero.

Setting D in Equation 8 equal to $t_2/2$, gives

$$r = (n)^{-1/2} \qquad (21)$$

This equation may be used instead of Equation 15 when the neutral axis is located at the interface of the two layers.

DETAILS AND EXAMPLE OF DESIGN

Fatigue Damage Program TI Programmable 57 Calculator

This program computes stress σ_a as a function of axle load $\left(\sigma_a = P_a/P_{18}.\sigma_{18}\right)$, stress ratio $\left(R = \sigma_a/MR_d\right)$, allowable load repetitions N_i $(\log_{10}N_i = 16.61 - 17.61R)$, fatigue damage $f_d\left(f_d = \frac{n_i}{N_i}\right)$ and sums iterative values of F_d to total the fatigue damage.

To operate the program follow the steps outlined.

1. Make sure your TI Programmable 57 is fully charged or on a charger.
2. Enter the program exactly as follows.
   Swith calculator OFF to ON.
   Press following keys in sequence (either gold or white letters).

1.	LRN	21.	R/S	41.	+	
2.	0	22.	STO	42.	16.61	
3.	EE	23.	4	43.	=	
4.	0	24.	÷	44.	INV	
5.	STO	25.	18	45.	2nd	
6.	6	26.	=	46.	log	
7.	R/S	27.	x	47.	÷	
8.	STO	28.	RCL	48.	RCL	
9.	1	29.	1	49.	3	
10.	R/S	30.	=	50.	=	
11.	STO	31.	STO	51.	1/x	
12.	2	32.	5	52.	STO	
13.	2nd	33.	÷	53.	5	
14.	NOP	34.	RCL	54.	SUM	
15.	2nd	35.	2	55.	6	
16.	LBL	36.	=	56.	GTO	
17.	1	37.	x	57.	1	(should show step 48)
18.	R/S	38.	17.61			
19.	STO	39.	=	58.	LRN	
20.	3	40.	+/-	59.	RST	

To check the program go through the following routine.

Input	Press	Display
-	R/S	0.00
σ_{18}	4.2 (60), R/S	4.2 01 (6.0 02)
MR_d	19.0 (270), R/S	1.9 01 (2.7 02)
n_i	35,000, R/S	3.5 04 (3.5 04)
P_a	24, R.S	1.33163 -07 (1.41855 -07)

kg/cm^2 (lb/in^2)

1.33163×10^{-7} (1.41855×10^{-7}) is the fatigue damage (fd) for the first iteration, continue by entering n_2, P_2, and n_3, P_3, etc.

n_2	35,000, R/S	
P_a	24, R/S	1.33163 -07(1.41855 -07)
FD = Σfd	RCL, 6	2.66326 -07(2.8371 -07)

the value 2.66326×10^{-7} $\left(2.8371 \times 10^{-7}\right)$ is the Σfd for i = 1 and i = 2. To restart the program press RST then R/S. The display will show 0.000. The accumulator is now cleared and the problem can be reentered.

Determination of Layer Thickensses for Composite Pavement

The program provided solves Equation 18

$$\frac{r^2 + 2r + \frac{1}{n}}{-r^2 + \frac{1}{n}} = \frac{\sigma_b}{\tau}(n-1)$$

for the dependent variable, r, as defined by Equation 16 and the thickness of the bottom layer of the composite section, t_2, as defined by Equation 20. The independent variables, n, (see Equation 17) and MR/τ_a (Equation 19) are used as input in the computer program together with the total pavement thickness, H, established based on fatigue damage consideration.

The program may be entered on a TI Programmable 57 calculator. In step seven the ratio of MR/τ_a has been entered as five. However, this ratio may be changed if desired at the time the program is entered.

Press

1.	On-Off	27.	=
2.	LRN	28.	x
3.	STO 1	29.	2
4.	-	30.	=
5.	1	31.	STO 4
6.	=	32.	RCL 3
7.	x	33.	-
8.	5	34.	2
9.	=	35.	=
10.	STO 2	36.	÷
11.	x^2	37.	RCL 4
12.	-	38.	=
13.	1	39.	STO 1
14.	=	40.	R/S
15.	÷	41.	STO 2
16.	RCL 1	42.	RCL 1
17.	x	43.	+
18.	4	44.	1
19.	+	45.	=
20.	4	46.	÷
21.	=	47.	RCL 2
22.	$\sqrt{}$	48.	=
23.	STO 3	49.	1/x
24.	RCL 2	50.	R/S
25.	+	51.	LRN
26.	1	52.	RST

To operate after the program has been loaded:

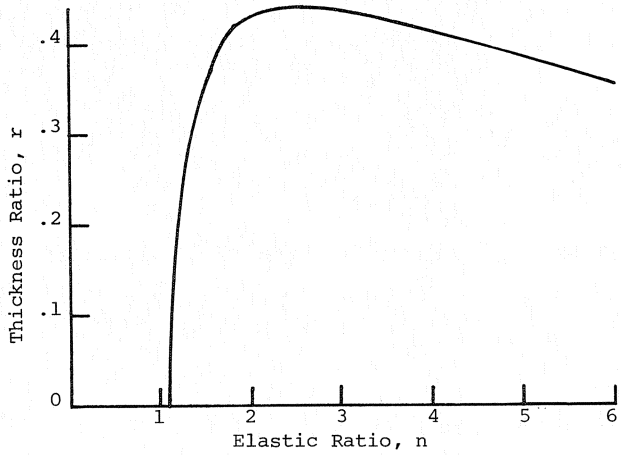
1. Enter value of n and press R/S
   - the calculator will display value of r
2. Enter total thickness, H, and press R/S
   - the calculator will display value ot t_2
3. To restart, press RST and continue as in step 1.

The program is tested by entering n = 4 and press R/S. The calculator should display 0.4010124 which is the value of r. Next, enter 46 (18), the values of H and press R/S. The display should show 32.833399 (12.847852) which is the value of t_2 in this specific case.

The relation between the elastic ratio, $n = E_1/E_2$ and the thickness ratio of the layers $r = t_1/t_2$ was developed in Equation 18 and has been graphed on this page. For the ratio, n, to increase with the properties of the wearing course concrete fixed, as expressed by E_1, a decrease is required in strength properties of the econocrete base layer, as expressed by E_2. For given traffic data, the total thickness would then increase. Consequently, for given conditions, with E_2 the only variable, the total thickness, H, increases when the elastic ratio, n, increases. The variation in r as a function of n is shown in the graph. In studying the graph it is first noted that as n approaches 1, which means similar properties for the materials of the two layers, the thickness ratio approaches infinite. This means that the thickness of the base approaches zero. Within the practical range of n-values between two and six, the corresponding r-values vary between 0.44 and 0.38. Inside this range of r-values the thickness of the wearing course is 1/3 or less of the total thickness. Hence, when H is 45.7 cm (18 in) the wearing course is 15.2 cm (6 in) or less.

Design Example

The following example applies to interstate, rural, and eight-lane divided highway with a final PSI rating of 3.5 at the end of a 40-year traffic period. The traffic details were discussed previously.



CORRELATION BETWEEN RATIOS
OF ELASTICITY AND THICKNESS

The necessary input data are listed in the Design parameter for Urban Freeway and are discussed to the extent they were not covered previously.

E_1 - Small variations have no influence on stresses. A reasonable range of E-values is 26 to 33 x 10^3 MPa (3.75 to 4.75 x 10^6 psi) on the conservative side.

E_2 - For large values of the total thicknesses, H, the influence of E_2 on edge stresses is small. For the specific aggregates intended used on this project, it is expected that the E-value will vary between 6.9 - 10.3 x 10^3 MPa (1.0 - 1.5 x 10^6 psi). The lower conservative value was selected.

MR - Greatly influences thickness requirement. Because the critical stress exists at the bottom fiber, only the modulus of rupture of the lower layer is required. The design strength of the econocrete is specified at 13.8 MPa (2000 psi). The modulus of rupture is assumed at 17 percent of this value or about 2.3 MPa (340 psi). Reducing this value for statistical variability, a value of 2.1 MPa (300 psi) is obtained.

k - Edge stresses may decrease substantially as the k-value increases from 270-810 MPa/cm (100 to 300 pci). Because the water table may be close to the pavement, a high degree of saturation may be expected for the subgrade soil. The best evidence indicates that for this road an A-2-4 soil may be expected. At 70 percent degree of saturation a k-value of 410 MPa/cm (150 pci) would be reasonable. Without better evidence of soil type and saturation, a subgrade reaction modulus of 270 MPa/cm (100 pci) was conservatively estimated.

Other input variables have been discussed and evaluated previously in this report.

Design Parameter for Urban Freeway

		Notation	Value
1.	Elastic Modulus of surface layer, MPa	E_1	27.6 x 10^3
2.	Elastic Modulus of base layer, MPa	E_2	6.9 x 10^3
3.	Design Modulus of Rupture of base layer, MPa	MR_d	2.1
4.	Modulus of Subgrade Reaction, MPa/cm	k	210

5.	Design Period, years	DP	40
6.	Average AADT		65,200
7.	Trucks of AADT, %	T	14
8.	Trucks in design lane, %	LD	60
9.	Directional distribution, %	DF	50
10.	Mean axles per Truck	A	2.70
11.	Mean distance from slab edge, cm		27.9
12.	Axles causing edge load conditions, %	EL	32
13.	Axle load distribution	see Table 1	

Computation of Thickness, H

The following input data are used with the fatigue damage program.

$$n = \frac{E_1}{E_2} = \frac{27.6}{6.9} = 4$$

σ_{18S} = 0.42 MPa (60 psi)

σ_{36T} = 0.37 MPa (54 psi)

k = 270 MPa/cm (100 pci)

The total thickness is assumed at 45.7 cm (18 in).

Calculations show that for the selected variables

$$FD = 9.069 \times 10^{-4} \simeq 10^{-3}$$

which is compared to the allowable FD_a according to the criteria for Zero Maintenance Pavements,

$$FD_a = 10^{-3} - 10^{-4}$$

Consequently, the total thickness selected meets the fatigue damage criterion at the maximum selected value.

When H is selected at 50.8 cm (20 in), the fatigue damage is 1.306×10^{-4} or close to the lower value of the criterion selected.

Computation of Layer Thickness t_1 and t_2

These values are computed by the aid of the computer program for solving Equations 18 and 20 using these input data.

H = 45.7 cm (18 in)

$n = E_1/E_2$

$\sigma_b = 0.15\ \sigma_c$

$\tau_a = 0.03\ \sigma_c$

hence,

$$\sigma_b/\tau_a = \frac{0.15}{0.03} = 5$$

The output indicates that t_2 = 32.44 cm (12.772 in) or for practical purposes 32.38 cm (12 3/4 in) and the pavement or surface course thickness, t_1, is 13.3 cm (5 1/4 in). The neutral axis is then located about 1.9 cm (3/4 in) below the interface of the two layers.

With the neutral axis placed at the interface the layer thickness, according to Equations 20 and 21, are t_1 = 15.2 cm 96 in) and t_2 = 30.5 cm (12 in).

If the thickness, H, is selected as 50.8 cm (20 in), the layer thicknesses are t_1 = 14.6 cm (5 3/4 in) and t_2 = 36.2 cm (14 1/4 in).

In considering the environmental condition of the area where the road is to be located, it is suggested that the higher fatigue damage criterion be used with the total thickness of 45.7 cm (18 in). Another factor in favor of selecting the smaller thickness is the use of rigid shoulder pavements attached to the mainline pavement and thereby reducing edge stresses.

Reinforcement

The design provided incorporates a low fatigue damage consumption and may suggest that the pavement is still intact at the end of the design period. An estimate of joint faulting at 30 years of service and for the assumption and design selected, indicates about 3.2 - 6.4 mm (1/8 - 1/4 in). Hence, the PSI of 3.5 at the end of the design period may not be attained. To assure a pavement quality of 3.5 PSI at the end of the design period, dowels should be used. The dowels serve a two-fold purpose of aligning slabs as well as providing additional shear strength at the joint. Conventional dowels should be placed at the mid-depth of the pavement, 22.8 cm (9 in) from the top.

If further assurance of non-faulting and low maintenance cost of joints is desired, elastic dowels may be used. This principle was applied in the test road in conjunction with bonded/unbonded interface. The latter was employed to assure crack development without sawing joints and to reduce initial cost. Because the cracks did not develop simultaneously, the crack widths varied from joint to joint with some cracks being of the hairline nature and others up to 3.2 mm (1/8 in) wide. The wider joints have been sealed. To obtain uniformity in crack width, it is required that all joints be cut or preformed using plastic strips.

The elastic dowels may be designed to maintain a narrow joint width and provide bending moment resistance at the joint in addition to the common functions of dowels to maintain alignment and provide shear resistance. A steel percentage of dowels of 0.4 with 2/3 of the dowels placed near the bottom face and 1/3 near the top face would provide a bending moment transfer capacity of 37100 Nm/m (100 in - kip/ft) width of the pavement. The use of elastic dowels would ensure a high serviceability rating of the pavement at the end of the design period. It is recommended that the use and type of dowels be considered to extend a high serviceability rating of the pavement.

Comparision of Design with Thicknesses Derived by Other Procedures

The monolithic design requires 30.5 cm (12 in) of concrete and 15.2 cm (6 in) of econocrete subbase for a total thickness of 45.7 cm (18 in). Without the econocrete subbase, and with the pavement placed directly on the subgrade, the thickness required by AASHTO design procedure is 35.6 cm (14 in). Hence, the econocrete subbase corresponds in strength to 5.1 cm (2 in) of concrete.

Using the translation technique proposed by T. J. Larsen (2) as a tentative design procedure for composite econocrete pavements, and assuming the monolithic concrete pavement to be H = 35.6 cm

(14 in), the composite section is t_1 = 15.2 cm (6 in), t_2 = 35.6 cm (14 in) or H = 50.8 cm (20 in). For selected value of t_1 = 12.7 cm (5 in) the base thickness t_2 = 38.1 cm (15 in) and H = 50.8 cm (20 in). A translation procedure suggested by R. G. Packard (3) also yields thicknesses of t_1 = 12.7 cm (5 in) and t_2 = 38.1 cm (15 in).

The design provided is compatible with that obtained by other procedures and induces confidence that the proposed design is rational, taking proper account of traffic frequencies and intensities as well as material characteristics.

Table 1. Axle Load Distribution Eight-Lane Urban Freeway.

Axle Load Group (kN)	Design Axle Load percent	Distribution Total M n_1
	Single Axle	
0 - 13.3	37.616	12.93
13.3 - 31.1	15.077	5.21
31.1 - 35.6	4.885	1.69
35.6 - 53.4	6.168	2.13
53.4 - 71.2	1.188	0.41
71.2 - 80.0	0.689	0.24
80.0 - 89.0	0.625	0.22
89.0 - 97.9	0.336	0.12
97.9 - 106.8	0.086	0.03
106.8 - 115.6	0.005	0.002
	Tandem Axle	
0 - 26.7	0.826	0.57
26.7 - 53.4	9.062	6.26
53.4 - 80.0	5.062	3.50
80.0 - 106.8	4.336	3.00
106.8 - 133.4	7.629	5.27
133.4 - 142.3	2.213	1.53
142.3 - 151.2	1.397	0.97
151.2 - 160.1	1.025	0.71
160.1 - 169.0	0.925	0.64
169.0 - 177.9	0.589	0.41
177.9 - 186.8	0.299	0.21
186.8 - 195.7	0.099	0.07
195.7 - 213.5	0.027	0.02
213.5 - 222.4	0.018	(14,840)*
> - 222.4	0.009	(7,420)*

*The mega (M) notation does not apply to numbers in parentheses.

References

1. S. D. Kohn. Structural Design of Composite Pavements. Thesis presented to the University of Illinois, Urbana, 1976.

2. T. J. Larsen. Econocrete in Pavement Design. Florida Department of Transportation Technical Report, Gainesville, 1976.

3. R. G. Packard. Federal Highway Administration Notice N5080.34, Attachment B. Washington, DC, 1975.