Asphalt Concrete Pavement Design—A Subsystem to Consider the Fatigue Mode of Distress

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In this paper a working model is presented for a subsystem to consider the fatigue mode of distress for asphalt concrete pavements. The design subsystem is divided into three general sections—(a) preliminary data acquisition, (b) materials characterization, and (c) analysis and evaluation. In developing a particular design with this subsystem, use is made of traffic and wheel load distributions, environmental conditions based on available weather records for the vicinity of the proposed design, multilayer elastic theory, resilient response of untreated granular materials and fine-grained soils, stiffness and fatigue characteristics of the asphalt concrete, and a cumulative damage hypothesis based on the simple linear summation of cycle ratios. To expedite the design process, the majority of the design computations have been programmed for use with a high-speed digital computer.

An example shows the use of the design procedure for a structural pavement section consisting of asphalt concrete resting directly on the subgrade soil. The design developed is shown for conventional materials and traffic to result in a thickness that is quite reasonable based on comparisons with other design methods. This particular subsystem would appear to have some advantages, however, in that it can be extended to consider loading conditions and material characteristics for which experience is not available.

•PROPER DESIGN of asphalt concrete pavements requires consideration of a number of complex and interrelated factors. Recent efforts have been made to formulate, in a systematic manner, pavement design systems that attempt to bring these factors together as the first step in the development of a more rational method of design (1, 2). Such a system is shown in Figure 1. Although the design of an asphalt concrete pavement in the manner suggested by this system is not presently possible, each of the considerations shown within it is real and should be included in some way in the design of every modern pavement.

One of the distress mechanisms included as a part of the rupture mode of distress shown in the limiting response block of Figure 1 is that of fatigue of asphalt concrete. It is the purpose of this paper to define considerations that are required to develop a subsystem to consider this mode of distress within the framework suggested in Figure 1. From these considerations, a working model is presented and illustrated by the design of a pavement structure to show the applicability and reasonableness of the method in current pavement design technology.

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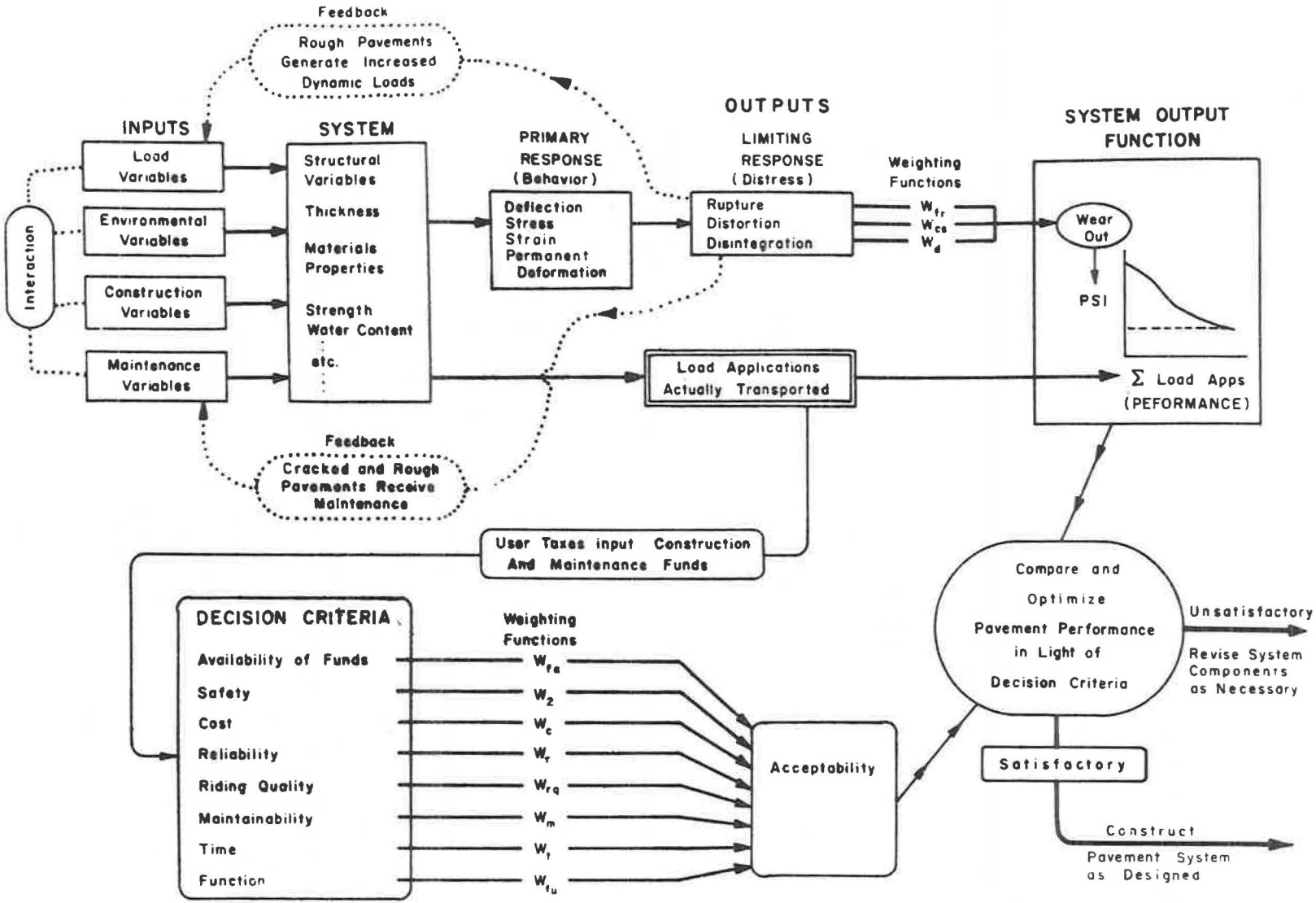

Figure 1. Block diagram of the pavement system (after Finn et al, 1).

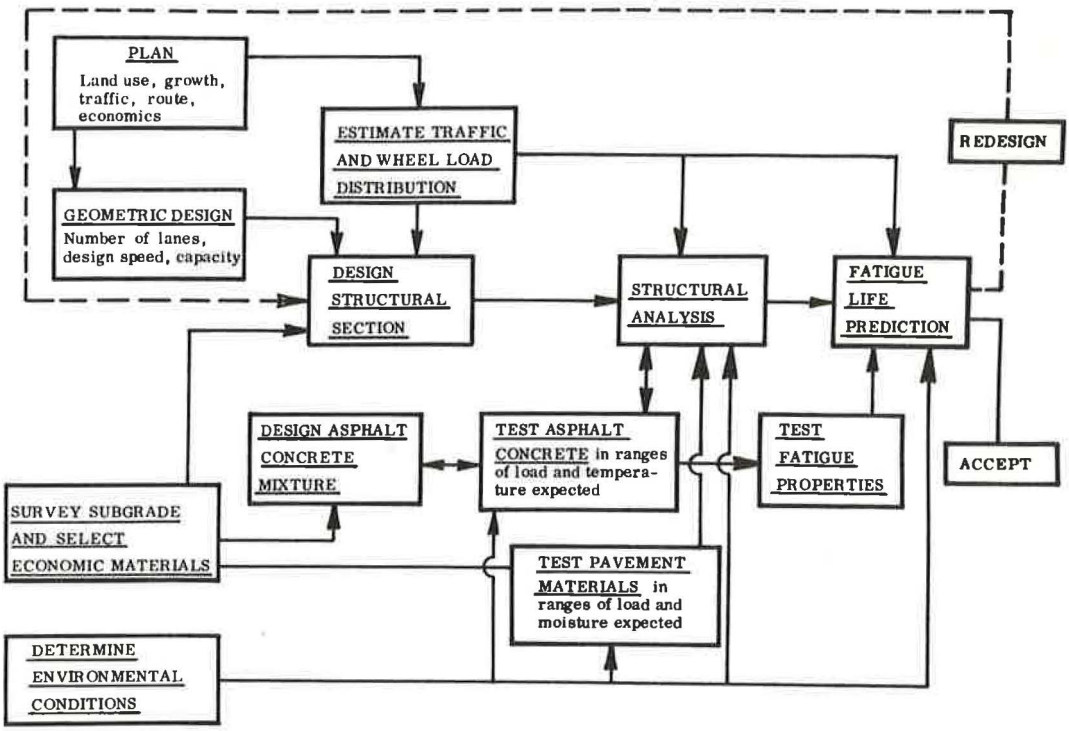

Figure 2. Block diagram of the fatigue subsystem.

THE FATIGUE SUBSYSTEM

A form that a design subsystem can take to consider fatigue is shown in Figure 2 in block diagram form. It should be noted that this fatigue subsystem constitutes only a small part of the whole system (Fig. 1).

The fatigue subsystem shown in Figure 2 can be seen to parallel the classical structural engineering approach, in which a structure is designed, its behavior under its anticipated service conditions analyzed, and its adequacy with respect to some distress criterion determined. This approach is employed because it is realized that the fatigue of asphalt concrete is only one mechanism of a number that can lead to distress within an asphalt concrete pavement structure. Other causes of distress can be analyzed using a similar line of reasoning and their study would form other subsystems to consider—for example, such distress modes as distortion, distintegration or low temperature fracture.

Considering the design subsystems shown in Figure 2, it will be noted that it divides itself naturally into three sections:

1. Preliminary data acquisition—(a) Estimate traffic and wheel load distribution to be served by the proposed facility on the basis of the type of highway, the nature of the area served, and the expected growth of the area; (b) survey subgrade soils traversed by the proposed route and perform routine identification tests; (c) select the most economic materials to be used in the construction of the highway; (d) determine the environmental conditions from available weather records for the vicinity of the proposed highway; and (e) design the asphalt concrete mixture to be used.

2. Materials characterization—(a) Test the asphalt concrete, subgrade soil, and any granular materials to be included in the section to determine their "elastic" properties in the range of service conditions expected in the life of the highway; and (b) test the fatigue properties of the asphalt concrete mixture.

3. Analysis and evaluation—(a) Define the seasonal variation in the stiffness of the asphalt concrete and the moisture content of the subgrade soil; (b) determine the expected response of the asphalt concrete layer in the trial design section to the action of the range of wheel loads and climatic environment; (c) predict the fatigue life of the trial design under the action of the expected traffic volumes; and (d) evaluate the trial design with respect to the adequacy of the section in providing an adequate design life for fatigue. If necessary, select another trial section and reanalyze.

It should be reemphasized that the design procedure is meant to consider only distress that might be caused by fatigue. Protection against other modes of distress must at present be embodied in the selection of the trial structural design.

APPLICATION OF PAVEMENT DESIGN PROCEDURE

The example to be presented is concerned with the design of the structural section for the widened portion of the Ygnacio Valley Road between Walnut Avenue and Oak Grove Road in the city of Walnut Creek and the unincorporated area of Contra Costa County, California. The proposed reconstruction includes the overlay of the existing two-lane pavement plus the widening of the facility to four lanes by the addition of new 12-ft wide traffic lanes on each side of the present roadway.

A full-depth asphalt concrete section was considered for the new construction involved in the widening primarily to alleviate the problems that would be encountered if excavation were required for a thicker structural section. Because the surface grade elevation is fixed by the existing roadway, a conventional structural section could be accommodated only by excavating into the silty clay subgrade soil whose water content increased with depth. It was the previous experience of the Materials Division of the Public Works Department of Contra Costa County that both excavation and compaction difficulties would be met in this situation. A thinner all-asphalt concrete section would not require this excavation, and the anticipated construction problems could be avoided.

A second factor, not considered during the selection of the design section, but nevertheless important to the design deliberations, is the possibility of the occurrence of saturated base conditions if a conventional section were constructed. The reconstruction involves consideration of the use of a landscaped median strip that would be irrigated. Because of the flat topography of the area and the characteristics of the subgrade soil, it is possible that any water reaching the base from the irrigation operation would remain in the section unless expensive positive drainage facilities were provided. A full-depth asphalt concrete section may thus be useful in such a situation.

The steps followed in the design and analysis of the structural section for this project will be briefly presented and ordered insofar as possible to conform to the fatigue subsystem presented here.

Traffic and Wheel Load Distribution

Initially, the only traffic information available for the project was a traffic index of 9.5 (3) that had been estimated by the Engineering Department of the city of Walnut Creek to represent the traffic that could be anticipated for a 10-year period following construction. Using this traffic index, a conventional structural section consisting of 0.50 ft of asphalt concrete, 0.85 ft of untreated aggregate base, and 1.05 ft of untreated aggregate subbase was selected. This thickness of structural section would have required considerable excavation into the silty clay subgrade, as noted earlier. Accordingly, it was deemed appropriate to consider a full-depth asphalt concrete section as an alternative.

Although the design subsystem utilized herein can accommodate detailed traffic data, it was necessary initially to use the estimate provided by Walnut Creek to make a preliminary selection for a full-depth asphalt concrete section to determine whether or not it would be worthwhile to pursue further the design of this type of pavement for the particular circumstances. The traffic index of 9.5 corresponds to 18,000,000 repetitions of a 5-kip wheel load, according to California pavement design procedure (3).

TABLE 1

MONTHLY WHEEL LOAD FACTORS BASED ON W-4 LOADOMETER STUDIES, CALIFORNIA, 1961 to 1966

Axle Load (kips)	2-Axle	3-Axle	4-Axle	5-Axle	6 or More Axles
under 3	2.354	0.224	1.230	0.422	2.104
3 to 7	18.871	16.438	22.275	20.873	23.805
7 to 8	2.127	6.126	7.200	7.062	7.687
8 to 12	4.135	12.700	15.480	16.029	28.362
12 to 16	1.752	6.830	9.210	15.899	21.024
16 to 18	0.569	2.228	3.570	12.402	5.957
18 to 20	0.168	0.397	0.930	2.165	0.973
20 to 22	0.015	0.046	0.075	0.084	0.192
22 to 24	0.008	0.007	0.015	0.029	0.087
24 to 26	0.001	0.004	—	0.008	0.148
26 to 30	—	—	—	0.006	0.198
30 to 35	—	—	—	0.001	—

This value was converted to an equivalent number of passages of an 18-kip axle load (9-kip wheel load) using the equivalent wheel load (EWL) concept of the State of California (3), and resulted in a traffic prediction of 1,600,000 applications of an 18-kip axle load in the 10-year design period. As will be seen, the preliminary full-depth asphalt concrete section selected utilizing these data (approximately 1 ft in thickness) suggested that it would be worthwhile to pursue this approach further. Accordingly, additional traffic data were obtained as planning for the project progressed.

Data obtained for the detailed analysis of the pavement section showed a present ADT of 16,500 vehicles per day, including 185 2-axle trucks, 107 3-axle trucks, 2 4-axle trucks, 126 5-axle trucks, and none with 6-axles or more. The figures represent the results of a traffic count taken on the existing facility. Using these daily figures of truck traffic and monthly wheel load factors determined from the statewide loadometer surveys from 1961 to 1966 (Table 1), the number of applications per month of each of the axle load groups was estimated. These values are given in Table 2.

Several other features of the traffic on the new facility were also estimated on the basis of available information. Because it was known that the major source of truck traffic on this road would be two quarries providing aggregate for construction in the surrounding areas, some consideration was given to the operations in these quarries to obtain the daily and seasonal variations in the traffic. This led to the assumption that the daily variation shown on the California Interstate general purpose route (Fig. 3) would adequately represent the anticipated pattern. The seasonal variation expected was one in which higher traffic volumes would be handled during the summer months, and to include this expectation the monthly traffic numbers given in Table 2 were proportioned accordingly. The values were increased to 1.2 times those shown in May to September inclusive and reduced to 0.8 times those shown in November to March inclusive. At the same time it was concluded that the assumption of a 5 percent annual growth rate in the truck traffic would be consistent with the expected development of the area.

This more detailed breakdown of the anticipated traffic was also analyzed to determine its degree of correspondence with the original estimate. Applying the EWL concept of the California pavement design procedure to the new data results in an actual traffic index for a 10-year design period of about 9.2. In the standard practice this value would be "rounded-up" to T.I. = 9.5, and thus the new data are shown to be consistent with the estimate used in the preliminary design.

TABLE 2

ESTIMATED AXLE LOAD DISTRIBUTION, YGNACIO VALLEY ROAD

Axle Load Group (kips)	Axle Load (kips)	Number per Month	Axle Load Group (kips)	Axle Load (kips)	Number per Month
under 3	3	515.1	18 to 20	19	348.2
3 to 7	5	7924.6	20 to 22	21	18.4
7 to 8	7.5	1955.7	22 to 24	23	5.9
8 to 12	10	4174.5	24 to 26	25	1.6
12 to 16	14	1816.6	26 to 30	28	0.8
16 to 18	17	1913.4	30 to 35	32.5	0.1

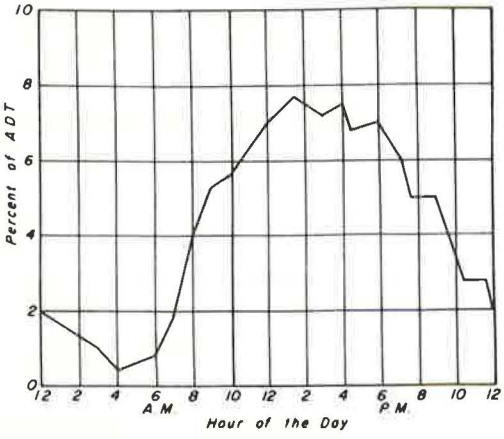

Figure 3. Hourly traffic variation, California general purpose Interstate route.

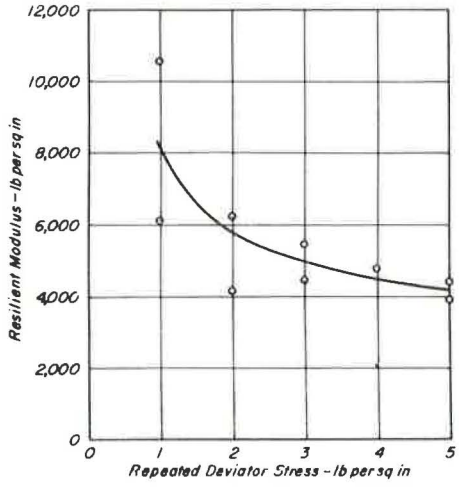

Figure 4. Results of repeated load tests, Ygnacio Valley Road subgrade soil.

Subgrade Soil Survey

The subgrade soil survey was conducted by the Materials Division of the Contra Costa County Public Works Department. Density, water content, and undisturbed samples were obtained at seven locations within the length of the project, including one location beneath the existing pavement. These tests indicated that a uniform subgrade soil—a silty clay—existed throughout the entire length.

Environmental Conditions

A composite weather record for the location was determined from several sources. The average air temperatures and daily ranges were taken from records kept at Buchanan Air Field, which is within 5 miles of the project location. The average wind velocity, solar insolation, and sky cover were obtained from the monthly records at San Francisco Airport and at Concord. The data used in the pavement temperature simulation are given in Table 3

Test Pavement Materials

The selection of a full-depth asphalt concrete section simplified this phase of the procedure to the determination of the properties of the subgrade soil. Resilient modulus

TABLE 3

WEATHER DATA USED IN THE SIMULATION OF PAVEMENT TEMPERATURES, YGNACIO VALLEY ROAD

Month	Average Air Temperature (F)	Daily Range (F)	Average Wind Velocity (mph)	Solar Insolation (Langleys per day)	Sky Cover (sunrise to sunset)
Jan.	46	18	6.2	182	7.0
Feb.	48	21	7.0	287	6.0
Mar.	52	23	8.8	426	5.5
April	59.5	26	9.3	547	4.8
May	61.5	28	9.9	642	3.8
June	66	31	9.8	701	2.0
July	69	33	9.1	685	0.9
Aug.	72	33	8.9	621	1.1
Sept.	66.5	31	7.7	506	1.4
Oct.	62.5	27	6.6	374	3.3
Nov.	54	21	5.8	248	5.3
Dec.	44.5	13.5	5.8	157	7.2

TABLE 4

COMPUTED STRAINS IN PAVEMENT SECTIONS IN AUGUST

Thickness (in.)	Subgrade Vertical Compressive Strain, ϵ_V (in. per in. x 10^{-4})	Asphalt Concrete Tensile Strain, ϵ_T (in. per in. x 10^{-6})
8	5.72	350
12	2.94	167
16	1.90	99

determinations were made over a range in deviator stresses on undisturbed samples recovered from beneath the existing pavement. The resilient modulus is determined from the expression

$$M_R = \frac{\sigma_d}{\epsilon_r}$$

where

M_R = modulus of resilient deformation, psi;
σ_d = repeatedly applied deviator stress, psi; and
ϵ_r = resilient (recoverable) axial strain, in. per in.

Each of the samples was subjected to approximately 40,000 repetitions of each of five repeated deviator stress levels (duration, 0.1 sec; frequency, 20 repetitions per min), and the resilient modulus determined using the resilient deflection corresponding to 25,000 repetitions. The data obtained are shown in Figure 4.

It was assumed that the conditions of density and moisture content at which these samples existed in the field would be those conditions that could be expected to exist under the proposed pavement, and that these conditions would be relatively stable. The results were thus used to characterize the subgrade throughout the entire year.

Poisson's ratio, ν, for the silty clay was not determined in the laboratory; however, for the analyses to be presented subsequently, ν was assumed equal to 0.5. This value would appear reasonable for the expected conditions of the soil in situ.

Design Structural Section

Temperature simulation for this pavement using the data in Table 3 and the method developed by Barber (4) indicated that the highest monthly averages would be experienced in August. Using typical properties of the materials under these conditions, strains were calculated for 8-, 12-, and 16-in. thick layers of asphalt concrete under a 9-kip wheel load with dual tires using layered system elastic theory (5). An iterative procedure was used to ensure compatibility of the vertical compressive stresses at the subgrade and the modulus of the subgrade (Fig. 4). Table 4 indicates the levels of strains obtained in these calculations.

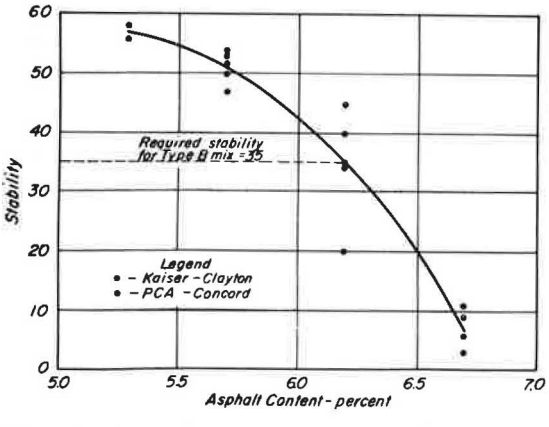

Figure 5. Results of stabilometer tests, Ygnacio Valley Road.

The vertical compressive strain at the subgrade level should be kept below about 6.5 x 10^{-4} in. per in., according to the Shell analysis of pavements designed according to the CBR procedure (6). From Table 4 it can be seen that each of the trial thick-

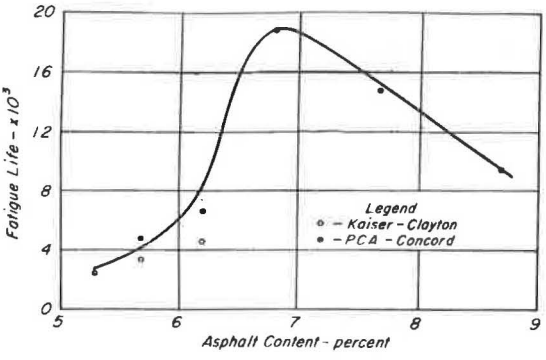

Figure 6. Results of controlled stress fatigue tests at 150-psi tensile stress showing effect of asphalt content, Ygnacio Valley Road.

nesses provides sufficient thickness to achieve this level during the month when the mixture stiffness is at a minimum.

The fatigue behavior of the asphalt concrete is assumed to be controlled by the horizontal tensile strain on the underside of the asphalt bound layer. A strain level of about 150×10^{-6} in. per in. was considered to be a reasonable maximum value based on previous experience because fatigue lives of at least 10^6 repetitions are obtained at this strain level (7). (As noted earlier, the estimated design traffic index of 9.5 corresponds approximately to 1.6×10^6 repetitions of the 9-kip wheel load.) The value of strain for the 12-in. thickness (Table 4) is sufficiently close to this value. Accordingly, this thickness was selected for more detailed analysis.

Design Asphalt Concrete Mixture

Special consideration was given to the design of the asphalt concrete mixture to be used in this pavement to provide a compromise between the stability requirements and requirements for best fatigue resistance.

A mixture was first designed using the standard California stabilometer procedure by the Materials Division of Contra Costa County. The results of the tests are shown in Figure 5. Although tests were performed on mixes fabricated using aggregates from each of the two major sources in the area, the results were treated as one set of data, these aggregates being almost identical in terms of petrography, surface texture, and shape throughout the range of sizes. A 60-70 penetration grade asphalt cement supplied by the Chevron Asphalt Company was incorporated in the design mixture to take advantage of the higher stiffness and consequent longer fatigue life that it would afford in this situation (7). Figure 5 shows that the asphalt content satisfying the stability requirement for Type B mixes (i.e., stability 35 at 140 F) is 6.2 percent. In line with standard California practice, this value is reduced by 0.3 percent to allow for expected field variation, and the design asphalt content is quoted as 5.9 percent.

At the same time, fatigue test specimens were prepared in the laboratory, containing the same aggregates and with asphalt contents ranging from 5.3 to 8.7 percent. Controlled-stress fatigue tests were performed on these specimens. Figure 6 shows the mean fatigue lives determined in these tests at a stress level of 150 psi and indicates that the best fatigue performance would be provided by a mixture containing an asphalt content of 6.7 percent.

The elements of the necessary compromise can be seen by comparing the two mixture designs, i.e., 5.9 percent vs 6.7 percent. The selection of the optimum design, however, takes some other facts into consideration. The stability requirement is based on the necessity of providing adequate resistance to deformation at the highest temperatures to be experienced by the pavement. This criterion, in general, places a maximum on the amount of asphalt that can be incorporated into the mixture. Consideration of the pavement temperature simulation, however, indicates that the lower portion of a full-depth asphalt concrete section will not attain the high maximum temperatures experienced at the surface. Higher asphalt contents can then be tolerated in the lower portion without sacrificing the stability of the layer.

Increase in the asphalt content of a mixture will also provide additional benefits in terms of increased ease of compaction and increased resistance to weathering. Thus, the decision to suggest a higher asphalt content for the mixture to be used in the lower portion of the layer is based on some other criteria in addition to the provision of the

TABLE 5

TRAFFIC WEIGHTED-MEAN STIFFNESS VARIATION, YGNACIO VALLEY ROAD, 10^3 PSI

Month	0 to 4 in.	4 to 8 in.	8 to 12 in.	Month	0 to 4 in.	4 to 8 in.	8 to 12 in.
Jan.	1,720	1,840	1,890	July	175	230	270
Feb.	1,410	1,570	1,640	Aug.	162	210	244
Mar.	1,030	1,250	1,280	Sept.	267	342	389
April	580	700	770	Oct.	480	580	636
May	430	535	600	Nov.	1,030	1,170	1,225
June	245	316	365	Dec.	1,880	1,980	2,020

best resistance to fatigue. On these grounds it was recommended that the uppermost 3 in. of the section be produced of an asphalt concrete containing 5.9 percent asphalt with the lower portion of the layer containing 6.2 percent.

Structural Analysis

The asphalt concrete layer was represented for the purposes of the layered elastic system calculations as three 4-in. layers. The traffic weighted-mean stiffness of each of these layers was obtained by a procedure outlined in the Appendix. The monthly variation of these stiffness values is given in Table 5.

The complete structural analysis of this pavement is greatly simplified by the fact that the tensile strain in the asphalt concrete can be represented as a linear function of wheel load magnitude for any given condition of asphalt concrete stiffness. In this pavement the only layer whose modulus is a function of stress level, and hence wheel load, is the subgrade soil. The variation in stress level in this material is greatly attenuated by the action of the 12-in. asphalt concrete layer. This leads to only small variation in the subgrade modulus with changes in the wheel load, especially when compared with the constant values of stiffness of the asphalt concrete layers in any given month. The number of individual representations of the pavement for the purposes of calculation of the tensile strain in the asphalt concrete need not be compounded by the number of wheel load magnitudes being considered.

The results of the calculation of the tensile strain in the asphalt concrete for the August traffic weighted-mean stiffness values are shown in Figure 7. These calculations were performed taking into account the variation of the subgrade modulus with stress level using an iterative method for solving the stresses in a multilayered elastic system (13). It can be seen from this figure that the results may be represented in terms of the slope of the line relating the tensile strain in the asphalt concrete to the axle load magnitude. This slope has been termed the normalized strain, B, such that

$$\epsilon = BW \qquad (1)$$

where

ϵ = the tensile strain in the asphalt concrete;

W = the axle load magnitude; and

B = the normalized strain, which is a function of the stiffness of the asphalt concrete in the month under consideration.

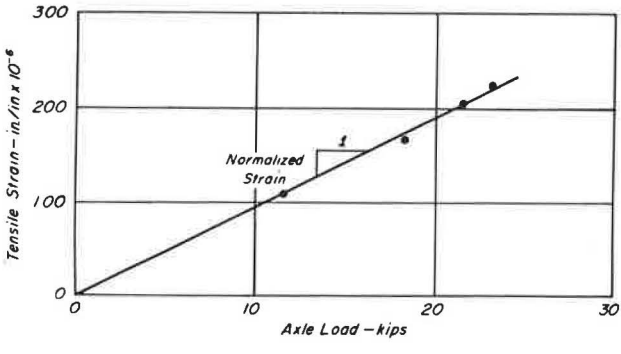

Figure 7. Tensile strain against axle load, Ygnacio Valley Road, August.

Figure 8 shows the results of the structural analysis calculations for the Ygnacio Valley Road pavement presented in terms of normalized strain.

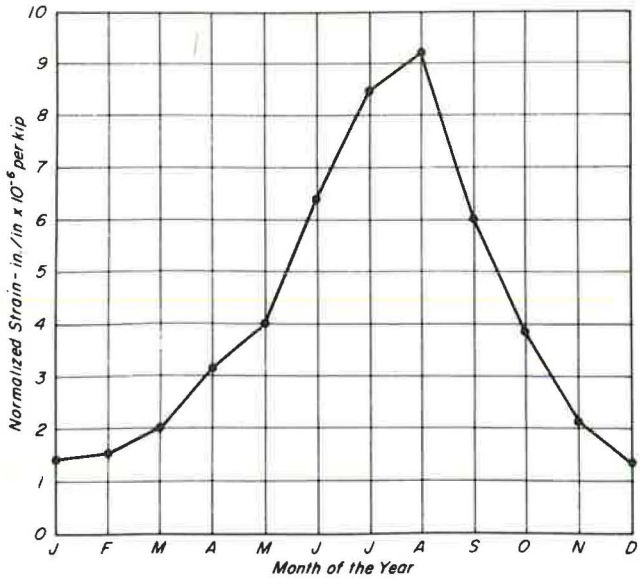

Figure 8. Seasonal variation in normalized strain, Ygnacio Valley Road.

It should be noted that this simplification is not generally applicable, especially where untreated granular materials are included in the structural section. The variation in modulus of base and subbase materials with stress level requires that the iterative procedure be applied for each wheel load magnitude (8).

Test Fatigue Properties

Controlled-stress fatigue tests were performed on laboratory-prepared specimens of the asphalt concrete mixture containing 6.2 percent asphalt. This is the mixture suggested for the lower portion of the asphalt concrete layer where the maximum tensile strains will occur in the field. These tests, performed at a time of loading of 0.1 sec and a frequency of stress applications of 100 per minute (9), yielded the following fatigue equation:

$$N_f = 1.33 \times 10^{-7} \frac{1}{\epsilon_{mix}}^{3.222} \tag{2}$$

where

N_f = number of applications to failure at strain level, ϵ_{mix}; and
ϵ_{mix} = mixture strain, in. per in.

with a standard error of estimate of 0.212.

Fatigue Life Prediction

Prediction of the fatigue life was made using a form of the linear summation of cycle ratios. This compound-loading hypothesis suggests that fatigue failure occurs when

$$\sum \frac{n_i}{N_i} = 1 \tag{3}$$

where

n_i = number of applications at strain level i, and
N_i = number of applications to cause failure in simple loading at strain level i.

Fatigue life prediction simply becomes determination of the time at which this sum reaches unity. A computer solution developed to facilitate computation is summarized as follows:

1. The tensile strain vs stiffness relationship for each axle load was stored (in this case the normalized strain data shown in Figure 7 simplified this step).
2. The tensile strain under each wheel load magnitude was obtained from the appropriate relationship by a numerical interpolation procedure at the stiffness value representing the month under consideration.
3. The fatigue life that would be expected under simple loading at that strain level was determined from the fatigue curve developed for the asphalt concrete. At the same time, the fatigue life corresponding to a 90 percent confidence level was obtained, assuming a logarithmic normal distribution of fatigue life at any strain level (13).
4. The cycle ratio for each of the strain levels (axle load groups) was formed using the number of applications per month of each axle load group (n_i) shown in Table 2 and the fatigue life at each strain level determined from Eq. 3.
5. The sum of the cycle ratios per month was taken and the process repeated for consecutive months until, first, the sum at the 90 percent confidence level reached unity, and then, the sum at the mean level reached unity. This process included the seasonal variation in monthly traffic and the annual rate of increase noted earlier.
6. The fatigue life predictions at the two levels of confidence were taken as the times at which these values were obtained.

The following predictions resulted:

1. The mean fatigue life will be 11.7 years.
2. At a 90 percent confidence level, the shortest probable fatigue life will be 6.6 years.

These predictions indicate that the 12-in. section considered should have adequate resistance to fatigue distress to provide for the 10-year design life required in this highway.

DISCUSSION OF FINDINGS

The reasonableness of the recommended 12-in. asphalt concrete layer can be seen by comparing it with thicknesses indicated by use of other design methods:

Method	Reference	Thickness (in.)
State of California, A	(3)	19.3
State of California, B	(16)	13.5
Asphalt Institute	(10)	13
Shell Group Method	(11)	11
AASHO Interim Guide	(12)	9.5

The State of California design B shown was provided by the Materials and Research Department of the Division of Highways (16) and was based, in part, on deflection predictions based on Dynaflect measurements taken on the subgrade soil at this location.

These comparisons indicate that the design section selected through the use of the fatigue subsystem corresponds reasonably with thicknesses obtained using a number of existing design methods. Because these existing procedures probably embody resistance to other modes of distress as well as fatigue, some confidence that the proposed design is adequate with respect to these other modes is also obtained.

At this point it should be emphasized, however, that an advantage of this design subsystem, as compared to existing procedures, is that it permits detailed consideration of the particular set of conditions under which the pavement is expected to perform because fatigue life is predicted as a function of anticipated traffic, subgrade and asphalt concrete material properties, and environmental variables, and their expected interaction at a specific location.

SUMMARY

In this paper a working model has been presented for a subsystem to consider the fatigue mode of distress. This proposed method permits incorporation of realistic material properties into the design process within the framework of elastic layer theory to define the potential for cracking of the pavement structure under repetitive traffic loading. The subsystem has been shown for conventional materials and traffic to result in thicknesses that are quite reasonable, based on comparisons with other existing design methods. This particular subsystem would appear to have some advantages, however, when compared to existing procedures in that it can be extended to consider loading conditions and material characteristics for which experience is not now available. Moreover, as other subsystems considering additional distress modes become available, this subsystem can be incorporated within the general systems framework shown in Figure 1 because a specific mode of failure has been delineated.

ACKNOWLEDGMENTS

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The fatigue test data were obtained by Dr. J. A. Epps, a former research assistant at the Soil Mechanics and Bituminous Materials Laboratory of the University of California.

Mr. George Dierking of the Institute of Transportation and Traffic Engineering staff prepared the figures.

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Appendix

TRAFFIC WEIGHTED STIFFNESS

Both temperature and traffic vary with hour of the day. Some account of this may be taken through the use of the concept of traffic weighted-mean stiffness (13). The calculation of this weighted mean has been programmed for the computer and a brief outline of the flow of the program will indicate the operations performed.

1. The weather data for the locality, the variation of the traffic with hour of the day, and the mixture properties are stored. Mixture properties include properties of recovered asphalt (penetration and ring and ball softening point), asphalt content, aggregate specific gravity, percent air voids, and volume concentration of aggregate.
2. The temperature at 12 midnight is calculated using Barber's procedure (4).
3. Mixture stiffness using the procedure developed by the Shell investigations (14, 15) is computed corresponding to this temperature and a specified time of loading.
4. The procedure is repeated for each hour of the succeeding 24 hours.
5. The arithmetic mean value of the two hourly values for the stiffness of the asphalt concrete is taken as the hourly mean stiffness, S_i.
6. The traffic weighted-mean stiffness, S_{tr}, is calculated from

$$S_{tr} = \frac{\sum_{i=1}^{i=24} S_i \cdot tr_i}{100}$$

where tr_i = traffic, in percent ADTT, in the hour i.

Stiffnesses calculated in this way have already been given in Table 5 for each month of the year and for the depth considered. The variation of mixture stiffness with depth (at a time of loading of 0.015 sec) is shown in Figure 9. Figure 10 shows the range of stiffnesses that can be expected throughout the year.

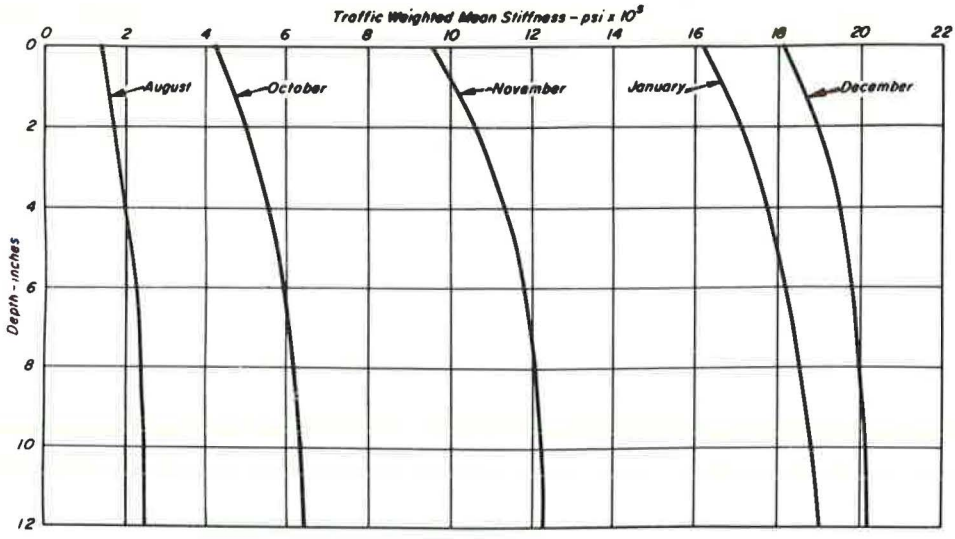

Figure 9. Traffic weighted-mean stiffness of asphalt concrete vs depth for various months during the year.

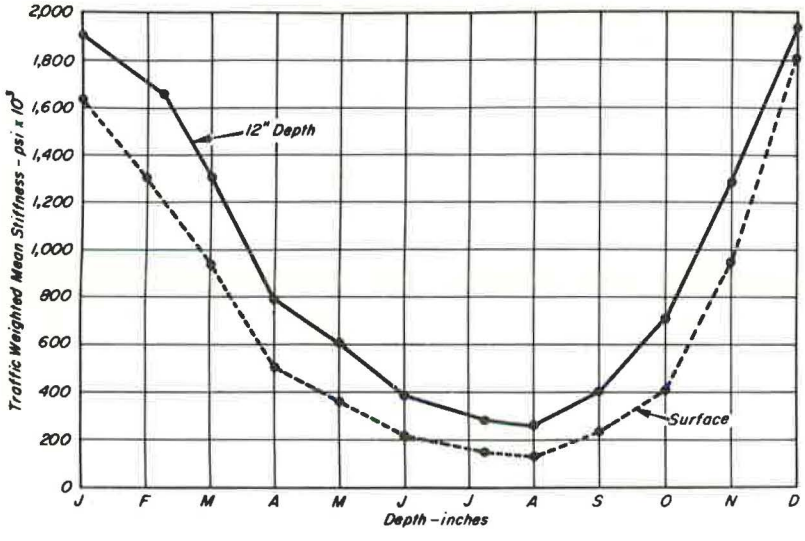

Figure 10. Variation of traffic weighted-mean stiffness of asphalt concrete throughout the year, both at surface and 12-in. depth.