A Thickness Design Method for Concrete Pavements

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The thickness of portland cement concrete pavement and the underlying cement-treated layer was formerly based on California's Traffic Index, which was developed for use in flexible pavement design. Because the Traffic Index is computed from all predicted truck axle loadings, its use is not necessarily valid for rigid pavement designs. A design method was adapted from previous design work published by the Portland Cement Association, and adjusted empirically to fit past experience with satisfactory concrete pavements. A new method of predicting truck traffic from loadometer data and classified truck counts was developed. The design method is sensitive to variation in support value of the underlying soil, thickness of granular subbase, thickness of cement-treated base, modulus of rupture of the concrete, and truck traffic predicted for the design life of the pavement.

•THE design of pavements and their supporting layers is recognized as a gray area inhabited by specters of uncertainty and ghosts of old broken pavements. The only guiding light is past experience, which may be partially obscured by incomplete records of road life and maintenance.

Uncertainties result because it is often cheaper to overdesign instead of investing a large sum in an exhaustive soil survey. Engineers know that it is uneconomical to process natural deposits until aggregates have the uniformity of a factory product. They have experienced the frustrations that occur when trying to get uniform compaction on a project with varying soil types, bad weather, or inexperienced personnel.

The worst uncertainty is the prediction of future traffic that will use the pavement during its design life. Even if reliable classified truck counts are available on existing highways in the area, there are problems of assignment of this traffic to the new facility and expansion of the assigned traffic to the total volumes expected during the design period.

Despite the difficulties cited, it is not believed desirable to leave the determination of the structural elements of the roadbed entirely to rules in a manual or to the judgment of individuals. Engineering judgment is a necessary element in all good design, but in the interest of consistency and uniformity a definite design method should be used as a basic tool. Departures from the results of the strict use of a design process will have to be made on some individual projects, but such modifications should be justified in each instance.

California has adhered to these principles for many years in the design of flexible pavements, but the thicknesses of portland cement concrete pavements have been selected by a set of rules. In recent years, thicknesses were chosen that corresponded

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to the depths of standard side forms. With almost all concrete pavement construction in the state now being performed by the slip-form method, there is no reason to be limited to any particular pavement thickness.

Previously, concrete pavement thickness and depth of cement-treated base was determined by rule from California's Traffic Index. The Traffic Index is calculated from total 5000-lb equivalent wheel loads, and this total is computed from estimated future truck traffic using axle weights of all trucks. This is an acceptable process in flexible pavement design, but it is not necessarily valid for rigid pavement determinations, which should be based only on those loads that produce a stress ratio in excess of 0.50. In this context, stress ratio is the stress produced by a given load divided by the modulus of rupture of the concrete determined by third-point loading at 28 days.

In the selection of concrete pavement thickness from the Traffic Index, no adjustment was made for variation in the support value of the natural soils encountered unless they were expansive. When the soils were expansive, the granular subbase layer was increased to provide sufficient weight in the total structural section to prevent future expansion of the underlying material with resulting loss in stability.

A design method was desired that would be sensitive to the support value of any natural materials that might be found when the soil survey was made for each project, and also would show the increase in support provided by the use of subbases and cement-treated bases. A minimum 0.50-ft thickness of granular subbase has been used when the R-value of the underlying soil is less than 40. Cement-treated bases have been used under nearly all concrete pavements for about 20 years. The purpose was to prevent erosion of the subgrade by pumping, and to provide extra support at the joints.

Another objective was to have a design method that would use the same loadometer data, soil survey reports, and classified truck counts used for flexible designs. Such a method would not be limited in range, and could result in either thicker or thinner designs than were previously considered. This would enhance the validity of the economic comparison made to determine the choice between rigid and flexible pavement for a given project.

After review of the literature, it was concluded that the simplest approach to developing a concrete design method would be to adapt the design data previously published by the Portland Cement Association to the traffic and soil survey information available for all California highway projects. It was also indicated that one or more factors in the new design method would have to be empirically adjusted to correlate the new designs and past experience with satisfactory concrete pavements.

DESIGN METHOD DEVELOPMENT

Fordyce and Packard (1) proposed a concrete highway pavement design procedure based on three major elements: analysis of stress due to moving loads, fatigue resulting from stress ratios exceeding 0.50, and load safety factors. They had prepared charts for single and tandem axle loads that gave stress relationships to axle loads, k-values (Westergaard's modulus of subgrade reaction), and slab depths. These charts were based on influence charts developed by Pickett and Ray (2) from Westergaard's theoretical analysis of concrete slab behavior. In order to use these stress charts, it was proposed to develop a procedure for determining k-values from the soil survey data obtained for each project. This will be discussed later in detail. The stress charts reproduced here as Figure 4 and Figure 5 have been redrawn with slab thickness lines for 0.05-ft increments instead of ½-in. increments. This was done to correspond to our standard practice of designing depths of flexible pavements and the underlying layers to the nearest 0.05 ft. This eliminates the need of converting inches to feet in quantity, profile, and construction staking calculations.

Fordyce and Packard (1) had proposed a new PCA fatigue curve for concrete pavements subject to flexural stresses. From this curve they had prepared a table of allowable stress repetitions to failure vs stress ratio as previously defined. This table was extended from the curve and used without further modification. It is presented here as Table 1.

TABLE 1

ALLOWABLE LOAD REPETITIONS FOR VARIOUS STRESS RATIOS

Stress Ratio	Allowable Repetitions	Stress Ratio	Allowable Repetitions
0.51	400,000	0.71	1,500
0.52	300,000	0.72	1,100
0.53	240,000	0.73	850
0.54	180,000	0.74	650
0.55	130,000	0.75	490
0.56	100,000	0.76	360
0.57	75,000	0.77	270
0.58	57,000	0.78	210
0.59	42,000	0.79	160
0.60	32,000	0.80	120
0.61	24,000	0.81	90
0.62	18,000	0.82	70
0.63	14,000	0.83	50
0.64	11,000	0.84	40
0.65	8,000	0.85	30
0.66	6,000	0.86	23
0.67	4,500	0.87	17
0.68	3,500	0.88	13
0.69	2,500	0.89	10
0.70	2,000	0.90	8

A later publication by the Portland Cement Association titled "Thickness Design for Concrete Pavements" (3) defined the entire design procedure.

R-Value vs k-Value

Soil surveys are made for all major projects with samples being obtained from various depths in the proposed cuts. R-values are determined for all of the soil types encountered using the Hveem Stabilometer and the procedures described in test method No. Calif. 301-F.

It was desired to establish a relationship between R-value and k-value for various soils in order to use the data normally available, and to avoid making plate bearing tests.

Such a relationship is shown in chart form in Figure 9 on page 36 of the "PCA Soil Primer" (4), but it is believed that this chart was constructed by comparing k-value and R-value with California Bearing Ratio (CBR). An investigation to establish a direct relationship was considered desirable, and there was no literature available indicating that this had ever been done.

This investigation was sponsored by the Bureau of Public Roads. The Portland Cement Association cooperated by sending their truck-mounted plate bearing test equipment to California from their laboratory at Skokie, Illinois. They performed tests and established k-values of basement soils at 20 locations. The test sites were compacted embankments with a minimum height of 6 ft, all located on going California highway contracts.

Standard ASTM D1196-64 procedure with static loading for highways was used with the preload modification used at the AASHO Road Test. The preload was sufficient to produce 0.01-in. deflection and was repeated four times. The Ames dials were then set with no load, and test loading procedure commenced.

R-value tests were performed on samples from each test site by the Materials and Research Department; k-values of the clay soils were corrected for eventual saturation by factors developed from consolidometer tests. The method used was Corps of Engineers Military Standard 621 A, Method 104.

When k-value was plotted vs R-value, no direct correlation was found as had been predicted. However, we were able to develop a curve which lies at or below the minimum k-values measured for various R-values. This curve is shown in Figure 1.

The use of this curve in the design of the structural sections for rigid pavements was consistent with our use of minimum R-values for flexible designs. The proposed method was not extremely sensitive to variations in k-value and any inaccuracies would result in more conservative designs.

Design k-Value

It was still necessary to develop a method of obtaining a design k-value which would indicate the increase in support provided by the use of granular subbases and cement-treated bases. The PCA published two charts for this purpose based on Burmister's method for analysis of two-layered systems (5). Both charts are conservative with respect to laboratory and field data. These charts were recomputed and redrawn so that they could be read to the nearest 0.05 ft in line with our other design practices. They are shown as Figures 2 and 3.

These charts are used one at a time to raise the k-value of the underlying soil to a new value at the top of the subbase, and then raise this value to the design k-value at

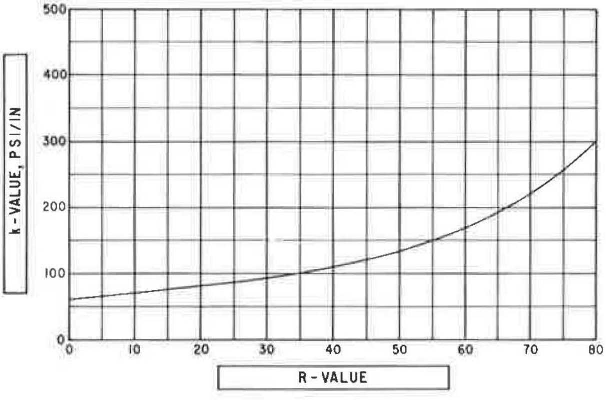

Figure 1. k-value vs R-value.

the top of the cement-treated base. If no subbase is used because of high k-value for the basement soil, just the second chart (Fig. 3) is used to obtain the design k-value.

Estimated Axle Load Repetitions

Loadometer surveys are made every year in California and truck counts, classified by the number of axles, are also made on a statewide basis.

Data from these two sources are used to compute total estimated 5000-lb equivalent wheel loads (EWL) for each project for a 20-year design period extending ahead from the estimated date of project completion. Traffic index is derived from this total EWL figure and used in the design of flexible pavements.

In developing EWL constants from loadometer data, it had been found expedient to use California Table W-4, All Main Rural and Urban (reproduced in the Appendix as Table 2), because the differences in truck traffic patterns between main rural and urban were insignificant for state highways. It also had been determined that despite

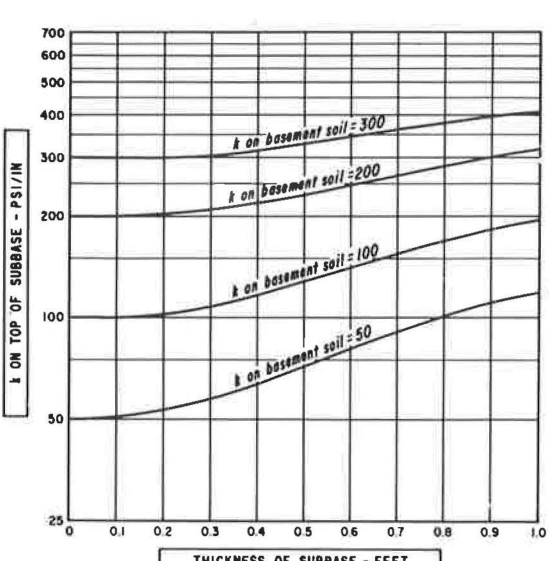

Figure 2. Effect of various thicknesses of granular subbases on k-values.

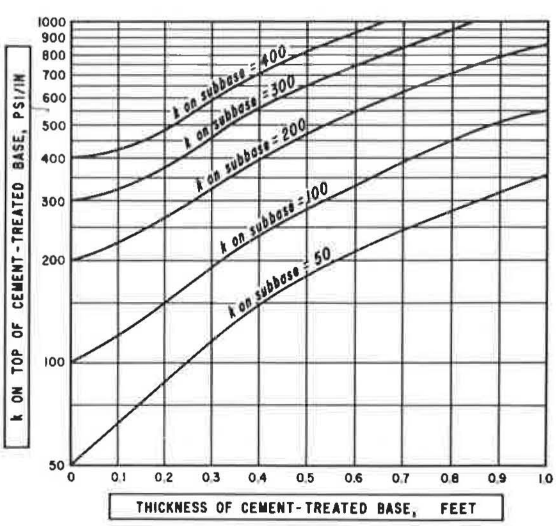

Figure 3. Effect of various thicknesses of cement-treated bases on k-values.

annual variation, averaging the last three years of loadometer data resulted in constants that had very little variation from year to year. Using four-, five-, and six-year averages did not make any significant difference, and one set of constants could be used for several years.

Truck traffic data are expanded to give the estimated average daily truck traffic for each axle type for the midyear of the design period for each project. These figures are multiplied by EWL constants to give the EWL for each truck type and these products are added to give the total EWL for the midyear of the design period. This total multiplied by the number of years gives the total EWL for the design period.

For rigid pavement design, it was logical to make use of the same estimated average daily truck figures. It also was desirable to use the same latest three years of loadometer data to develop constants for computing the total number of axle load repetitions expected during the design life period. These constants would have to be separated by axle classification to use the same traffic data, and by weight of axle increments to use the PCA stress charts.

The method developed for computing the repetition constants is outlined step by step as follows:

1. The numbers of axles weighed shown in each column of the loadometer sheets are expanded to the probable number by the ratio of axles counted to axles weighed. This is done for each weight category for both single and tandem axles.
2. All of the columns for each truck classification for three years are added across to give the total probable number of axles in each weight category for each truck type.
3. The proportion that each weight category bears to each truck type total for single axles is computed, and the same process is repeated for tandem axles.
4. The proportional figures for single axles in each truck type are multiplied by the ratio of number of single axles to number of trucks counted. The same type of computation is made for tandem axles.
5. To use the constants with average daily truck traffic figures, they are multiplied by 365 to give the repetitions for one year.
6. Because the traffic counts are reported for two-way traffic, the above figures are divided by two.
7. The final step is to multiply all the figures by 20 or whatever number of years is to be covered by the design life period.

An example of this computation is shown in detail for three-axle trucks in the Appendix. The final constants are shown in Table 4 in the Appendix, which is used to compute the total estimated axle load repetitions for each 2000-lb weight category for single and for tandem axles.

EVALUATION AND ADJUSTMENT

At this point, a complete design method had been developed, but it was necessary to evaluate the results and make any necessary empirical adjustments. Current data were obtained for four projects from each of the 11 highway districts. Considering inside and outside lanes separately where there were more than two lanes in each direction, it was possible to make 57 designs for comparison with results by the old procedure, asphalt concrete designs based on the same data, and the designs of existing satisfactory portland cement concrete pavements.

As previously mentioned, a minimum 0.50-ft thickness of granular subbase had been used when the R-value of the underlying soil was less than 40. This provides extra support, improved drainage, and a layer of material less susceptible to pumping than the basement soil. It was decided to continue this practice.

A 0.35-ft depth of cement-treated base was considered the practical minimum, and it was decided to use this value in the design process. A nominal thickness of 0.45 ft will be shown on the plans to take care of allowable construction tolerances. Variation in the depths of subbase and base can be accommodated by the method to take care of unusual situations, but these two depths were used in the comparisons.

Safety factors are usually used in concrete pavement design, and these have been referred to as load impact factors. Fordyce and Packard (1) suggest that in reality they are load safety factors and that term is used here. They suggested values ranging from 1.0 to 1.2 depending on the type of street or highway and the expected truck traffic characteristics. These same load safety factors are shown in the PCA's "Thickness Design for Concrete Pavements" (3).

These load safety factors were used in the first trial designs to evaluate the new method. The comparison showed lighter designs than had been used in pavements with a satisfactory road life of 20 to 35 years before resurfacing or replacement. An adjustment had to be made, and it was decided that changing the load safety factors was the best way to accomplish this since these factors are empirical judgments.

The load safety factors and types of facility finally were designated as follows:

LSF = 1.3 for the outside lanes of Interstate highways and other multilane projects with high predicted truck traffic;

LSF = 1.2 for the inside lanes of Insterstate highways and other multilane projects with high predicted truck traffic, and for all lanes of projects with moderate predicted truck traffic; and

LSF = 1.1 for minor highways, frontage roads or streets with low predicted truck traffic.

In the PCA publications, the 1.0 value is suggested for residential streets or rural roads carrying similar traffic. This category is outside state highway practice, and our adjustment expanded the two higher traffic categories to three classifications.

Another adjustment was made in the axle load values used to enter the stress charts. Originally the average value of the load increment was used, but this did not result in designs as heavy as past experience indicated were necessary. Using the top value of the increment, as shown in the PCA method, gave the desired results when combined with the increases in the load safety factors.

The final comparison indicated close agreement with many past designs using 0.75-ft depth of concrete pavement. In the heaviest traffic patterns for which 0.67-ft thickness had been used, the new method indicated 0.75-ft despite a 0.10-ft increase in the depth of cement-treated base. For the heaviest truck traffic reported, the new depth of pavement would be 0.80 ft. Finally, the new method provided a procedure for designing thinner pavements for lighter traffic patterns than had been considered previously for the use of portland cement concrete pavement.

DESIGN PROCEDURE

The project data required for the design process are the type of facility, number of lanes, minimum R-value of the basement soil, expected modulus of rupture of the concrete, and estimated average daily trucks for the midyear of the design period. With these data, the design procedure consists of the following steps, listed in order:

1. Determine the k-value of the basement soil.
2. Find the increased k-value due to the use of a granular subbase.
3. Determine the k-value at the top of the cement-treated base.
4. Choose a load safety factor and apply it to the design axle loads.
5. Select a trial thickness of pavement, and determine the stresses for each axle load for both single and tandem axle loads.
6. Compute the stress ratios by dividing each stress value by the modulus of rupture of the concrete.
7. Record the allowable axle load repetitions for each stress ratio.
8. Compute the estimated numbers of axle load repetitions for the design period.
9. Determine the percent each estimated number of repetitions bears to the allowable repetitions, and add these values to obtain the total percent fatigue resistance used.

Several pavement thicknesses should be tried and that trial thickness selected which shows the nearest to 100 percent fatigue used, but not to exceed 125 percent. The 125 percent upper limit is allowed because a change of 0.05 ft in pavement thickness results in a large change in percent fatigue used, and also because a conservative approach was used throughout the development of the method. Examples of this are the use of minimum k-values, the determination of modulus of rupture from 28-day specimens with third-point loading, and the use of high load safety factors.

To make it easy to follow the design procedure, an example is worked out in detail in the Appendix.

SUMMARY

This new method of portland cement concrete pavement design is sensitive to all of the variables now reflected in California's flexible pavement designs. It uses the same soil survey data, predicted truck traffic, and loadometer survey data. It provides structural sections that result in more valid economic comparisons with flexible designs for selection of pavement type. It produces designs that are nearer optimum and this should result in some economies. It provides extra thickness where unusual conditions of foundation or traffic are encountered.

It is believed that the adoption of this method of rigid pavement design eliminates the inadequacies of designing by arbitrary rules and raises the professional level of California's structural design activities.

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Appendix

PROCEDURE FOR COMPUTING LOAD REPETITION CONSTANTS

The following example, which is shown for three-axle trucks only, illustrates the procedure for computing load repetition constants. The expansion of loadometer data is further limited to the year 1965, but the method is the same for each year of loadometer data used.

1. A portion of a loadometer Table W-4, All MR and U, is reproduced here, designated as Table 2. All three-axle truck columns are used and these are marked (A), (B), and (C). The numbers of axles weighed in the current column are expanded by the ratio of axles counted to axles weighed. In column (A), this would be 2805 divided by 765 equals 3.66667 for both single and tandem axles. This probable number factor is multiplied by the sum of the numbers of axles under 16 kips and each following number in the column. The figures are entered in column (7) on the work sheet designated Table 3. The same computation is made for tandem axles and the process is repeated for columns (B) and (C), using the appropriate probable number factors, and entered in columns (8) and (9). The same type of calculation was made for the years 1963 and 1964 and entered in columns (1) to (6) in Table 3.

2. The horizontal lines are added across to give the total probable numbers of axles in each weight category. These sums are recorded in column (10).

3. The proportion that each weight category of single axles bears to each single axle truck type total is computed, and the same process is repeated for tandem axles. In column (10), the first figure, 30,807.6, is divided by 32,586.0, and the quotient, 0.94542, is recorded as the first figure in column (11). This is repeated for every figure in column (10) for single axles. For tandem axles the divisor would be 6687.0.

4. The proportional figures for single axles in each truck type are multiplied by the ratio of number of single axles to number of trucks counted. In this example from column (10), 32,586 would be divided by 15,320 to give a factor of 2.12702. This factor multiplied by the proportional figures in column (11) gives the products recorded in column (12) for each weight category. The same type of computation is made for tandem axles, dividing 6687 by 15,320.

5. To use the constants with average daily truck traffic figures, they are multiplied by 365 to give the repetitions for one year.

6. Because the traffic counts are reported for two-way traffic, the figures are divided by two. Steps 5 and 6 are combined and all of the figures in column (12) are multiplied by 365 divided by 2 and recorded in column (13).

7. The final step is to multiply all of the figures by 20 or whatever number of years is to be covered by the design life period. These final constants are shown in column (14).

The final constants for all truck types and weight categories are shown in Table 4, which is used to compute the total estimated axle load repetitions for each 2-kip increment of axle loading.

DESIGN PROCEDURE

The design procedure is illustrated by an example with basic data assumed as follows:

- Minimum R-value of basement soil = 10
- Modulus of rupture of the concrete = 550 psi
- Outside lanes of Interstate 8-lane divided construction
- Expanded average daily trucks as tabulated below:

Vehicle Type	Outside Lanes
2-axle trucks	1870
3-axle trucks	1090
4-axle trucks	460
5-axle trucks	3480
6-axle trucks	110

1. Determine the k-value of the basement soil from Figure 1. Intersect the vertical line for an R-value of 10 with the curve, and read the k-value of 70 on the vertical scale reading to the nearest 5 units.

2. Assuming that there will be no problems with expansion, a 0.50-ft thickness of subbase will be used. In Figure 2, the k-value of 70 determined for the basement soil is interpolated logarithmically on the vertical line for 0.50 ft. The new k-value of 90 is read horizontally to the left on the vertical scale.

3. Determine the final design k-value from Figure 3. Using the k-value of 90 determined previously and the minimum cement-treated base thickness of 0.35 foot, a design k-value of 195 is read from the vertical scale on the left.

TABLE 2

S I N G L E   A X L E S

AXLE LOADS IN POUNDS AND 18 KIP AXLE EQUIVALENCY ITEMS	18 KIP AXLE EQUIVALENCY FACTOR RIGID PAVEMENT P=2.5 D=9	FLEXIBLE PAVEMENT P=2.5 SN=5	SINGLE UNIT TRUCKS: PANEL - PICKUP (UNDER ONE TON) CUR	PRI	2 - AXLE, 4 - TIRE CUR	PRI	2 - AXLE, 6 - TIRE CUR	PRI	(A) 3 - AXLE CUR	PRI	4 - AXLE CUR	PRI	SINGLE UNIT TRUCKS TOTAL PROBABLE NOS. CURRENT	PRIOR	TRACTOR (B) 3 - AXLE CUR	PRI	4 - CUR
UNDER 3000	0.0002	0.0002	7042	4781	293	411	621	419	5	1			116430	106930	13	3	9
3000- 6999	0.005	0.005	966	487	220	234	4849	3414	242	149			41357	33423	917	669	332
7000- 7999	0.026	0.032	4	2	2	5	550	361	135	119			3025	2834	371	268	197
8000-11999	0.082	0.087	1	2	4		1106	720	276	195			5990	5327	720	504	378
12000-15999	0.341	0.360	1				418	301	89	47		4	2189	2057	349	269	172
1 16000 18000	0.783	0.796			1		139	97	15	19			688	676	109	93	107
18001-20000	1.260	1.240					44	25	3	2			206	161	30	24	23
20001-21999	1.926	1.826					1	5		1			4	35	2		1
22000-23999	2.818	2.513						2						12			1
24000-25999	3.976	3.533															
26000-29999	6.289	5.389															
30000-34999	11.395	9.432															
~~UNKNOWN~~													~~12~~				
TOTAL SINGLE AXLES WEIGHED			8014	5272	520	650	7728	5344	765	533		4			2511	1830	1220
TOTAL SINGLE AXLES COUNTED			22952	11624	9990	5014	34142	32224	2805	2579	12	14	169901	151455	10662	10515	5624

1/CALIF LEGAL LIMIT. SINGLE AXLE 18000 POUNDS

T A N D E M   A X L E S

AXLE LOADS IN POUNDS AND 18 KIP AXLE EQUIVALENCY ITEMS	18 KIP AXLE EQUIVALENCY FACTOR RIGID PAVEMENT P=2.5 D=9	FLEXIBLE PAVEMENT P=2.5 SN=5	SINGLE UNIT TRUCKS: PANEL - PICKUP (UNDER ONE TON) CUR	PRI	2 - AXLE, 4 - TIRE CUR	PRI	2 - AXLE, 6 - TIRE CUR	PRI	3 - AXLE CUR	PRI	4 - AXLE CUR	PRI	SINGLE UNIT TRUCKS TOTAL PROBABLE NOS. CURRENT	PRIOR	TRACTOR 3 - AXLE CUR	PRI	4 - CUR
UNDER 6000	0.010	0.010							5	2			18	10			16
6000-11999	0.010	0.010							266	167			976	808			219
12000-17999	0.062	0.044							224	146			821	706			118
13000-23999	0.253	0.148							74	72			271	349			122
24000-29999	0.729	0.426							94	62			345	300			93
2 30000-32000	1.305	0.753							68	51			249	246			30
32001-33999	1.700	0.970							28	25			103	121			7
34000-35999	2.165	1.230							6	4			22	20			2
36000-37999	2.721	1.533															2
38000-39999	3.373	1.885								1		2		11			1
40000-41999	4.129	2.289								1				5			
42000-43999	4.997	2.749								1				5			
44000-45999	5.987	3.001															
46000-49999	7.725	4.170								1				5			
50000-54999	10.160	5.100															
~~UNKNOWN~~													~~6~~				
TOTAL TANDEM AXLES WEIGHED									765	533		2					610
TOTAL TANDEM AXLES COUNTED									2805	2579	6	7	2811	2586			2812

2/CALIF LEGAL LIMIT. TANDEM AXLES 32000 POUNDS

A L L   A X L E S

AXLE LOADS IN POUNDS AND 18 KIP AXLE EQUIVALENCY ITEMS	18 KIP AXLE EQUIVALENCY FACTOR RIGID PAVEMENT P=2.5 D=9	FLEXIBLE PAVEMENT P=2.5 SN=5	SINGLE UNIT TRUCKS: PANEL - PICKUP (UNDER ONE TON) CUR	PRI	2 - AXLE, 4 - TIRE CUR	PRI	2 - AXLE, 6 - TIRE CUR	PRI	3 - AXLE CUR	PRI	4 - AXLE CUR	PRI	SINGLE UNIT TRUCKS TOTAL PROBABLE NOS. CURRENT	PRIOR	TRACTOR - 3 - AXLE CUR	PRI	4 - AX CUR
UNDER 3000			7042	4781	293	411	621	419	26	8			116507	106964	13	3	45
3000- 6999			966	487	220	234	4849	3414	904	559			43785	35407	917	669	871
7000- 7999			4	2	2	5	550	361	291	220			3596	3322	371	268	264
8000-11999			1	2	4		1106	720	581	445			7109	6537	720	504	697
12000-15999			1				418	301	385	259		4	3274	3082	349	269	382
1 16000 18000					1		139	97	98	95			992	1045	109	93	148
18001-20000							44	25	10	6		4	232	194	30	24	30
20001-21999							1	5		5			4	54	2		1
22000-23999								2		2				22			1
24000-25999																	
26000-29999																	
30000-34999																	1

STATE OF CALIFORNIA

ABLE W-4 (ALL MR AND U)-- NUMBER OF AXLE LOADS OF VARIOUS MAGNITUDES OF LOADED AND EMPTY TRUCKS AND TRUCK COMBINATIONS OF EACH TYPE WEIGHED, THE PROBABLE NUMBER OF SUCH LOADS, AND THE EIGHTEEN KIP AXLE EQUIVALENTS OF EACH GENERAL TYPE AND OF ALL TYPES COUNTED AT 19 STATIONS FROM JUN. 15 TO AUG. 5, 1965, COMPARED TO CORRESPONDING DATA FOR 1964

SINGLE AXLES

- SEMITRAILER COMBINATIONS							TRUCK AND TRAILER COMBINATIONS										TWO-TRAILER COM					
AXLE	5 - AXLE		6 - AXLE OR MORE		TRACTOR-SEMI-TRAILER TOTAL PROBABLE NOS.		(C) 3 - AXLE		4 - AXLE		5 - AXLE		6 - AXLE OR MORE		TRUCK-TRAILER TOTAL PROBABLE NOS.		4 - AXLE		5 - AXLE		6 - AXLE	7
PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI
3	8	1		1	140	45			16	4	10	6	2		193	75	1		67	12	4	5
275	132	106	3	8	6163	6071	7	1	65	63	892	658	14	17	5545	5192	3		2679	2080	51	33
168	394	284		1	4609	4396	1		17	11	283	232	9	5	1641	1696	2		1085	869	22	16
259	1402	1037	6	15	12417	11493	2	1	24	24	794	609	42	34	4382	4634			1506	1191	49	30
135	23	11	1		2408	2338	2		22	17	257	194	10	15	1642	1554	5		1150	1064	20	17
67	2	1		1	966	902		1	9	11	701	525	1	1	3515	3745	1		1757	1526	2	6
26	1				239	276			3	6	235	175			1177	1236			299	220		2
1					13	5					2	1			10	7			5	5		1
					5															1		
934	1962	1440	10	26			12	3	156	136	3174	2400	78	72			12		8548	6968	148	110
4960	10586	9933	88	118	26960	25526	984	270	1346	1164	15552	16248	223	457	18105	18139	132	56	53442	51164	790	734

TANDEM AXLES

- SEMITRAILER COMBINATIONS							TRUCK AND TRAILER COMBINATIONS										TWO-TRAILER COM					
XLE	5 - AXLE		6 - AXLE OR MORE		TRACTOR-SEMI-TRAILER TOTAL PROBABLE NOS.		3 - AXLE		4 - AXLE		5 - AXLE		6 - AXLE OR MORE		TRUCK-TRAILER TOTAL PROBABLE NOS.		4 - AXLE		5 - AXLE		6 - AXLE	7
PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI
9	33	17		1	253	170							2	3	5	20					1	2
166	1033	667	3	9	6646	5523				1	347	260	28	20	1771	1910			3	1	14	7
99	582	466	3	6	3731	3767					100	72	14	5	526	520					10	6
88	412	298		4	2800	2541			1	1	26	28	17	12	174	288					7	6
73	891	740	3	4	5295	5510			3		249	183	13	24	1258	1396					6	12
21	548	405	1	1	3123	2909					238	184	4	4	1175	1272			2		2	1
5	276	178		1	1531	1259					81	59			396	400			1			1
5	66	76			368	551					12	9		1	59	67						
1	21	16			123	116					7	5			34	34						
	3	4			21	27																
	5	2			27	14																
	3	1			16	7																
	4				22																	
	2				11																	
467	3879	2870	10	26					4	2	1060	800	78	69					6	1	40	35
2480	21067	19796	88	118	23967	22394			9	38	5184	5416	205	453	5398	5907			9	3	241	212

ALL AXLES

SEMITRAILER COMBINATIONS							TRUCK AND TRAILER COMBINATIONS										TWO-TRAILER COM					
LE	5 - AXLE		6 - AXLE OR MORE		TRACTOR-SEMI-TRAILER TOTAL PROBABLE NOS.		3 - AXLE		4 - AXLE		5 - AXLE		6 - AXLE OR MORE		TRUCK-TRAILER TOTAL PROBABLE NOS.		4 - AXLE		5 - AXLE		6 - AXLE	7
PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI	CUR	PRI
24	124	64	1	3	944	600			16	4	15	8	8	9	228	148	1		67	12	7	10
661	2681	1861	8	29	22521	20322	7	1	65	65	1694	1245	79	60	9613	9484	3		2685	2082	84	50
252	764	544	3	4	6962	6649	1		17	11	341	279	18	9	1940	2044	2		1085	869	31	21
481	2566	1910	10	28	20276	18752	2	1	28	26	903	709	84	65	5040	5543			1506	1191	66	48
313	2546	2026	7	10	17114	17227	2		26	17	1110	828	42	60	5922	6145	5		1153	1064	38	39
104	884	675	1	4	5948	5761		1	9	11	962	737	3	6	4788	5216	1		1760	1526	2	9
37	124	89			938	922			3	6	270	193		1	1346	1366			299	220		2
1	16	9			100	67					4	1			19	7			5	5		1
	12				70						1				5					1		
	2	2			11	14																
	1				5																	
					5																	

TABLE 3

CALCULATIONS OF CONSTANTS FOR LOAD REPETITIONS FOR 20 YEARS FOR ONE VEHICLE - ADT (TRUCKS)

		LOADOMETER SURVEY DATA, TABLE W-4, ALL MR & U, PROBABLE NUMBERS												
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
TRUCK CLASS		3-AXLE									TOTAL	PRO-PORTION	× 2.12702	× 365/2	× 20
YEAR		1963			1964			1965							
PROB. NO. FACTOR		2.58531	2.31034	2.41667	4.60549	5.72792	73.00000	3.66667	4.24612	82.00000					
SINGLE AXLE LOADS-Kips	Under 16	1191.8	3890.6	84.6	2583.7	9124.6	146.0	2739.0	10063.8	9840	30807.6	0.94542	2.01093	366.9947	7339.894
	16-18	5.2	247.2	—	87.5	469.7	73.0	55.0	462.8	—	1400.4	0.04298	0.09142	16.6842	333.684
	18-20	—	83.2	2.4	9.2	131.7	—	11.0	127.4		364.9	0.01120	0.02382	4.3472	86.944
	20-22		—	—	4.6	—		—	8.5		13.1	0.00040	0.00085	0.1551	3.102
	22-24				—				—		—	—	—	—	—
	24-26														
	26-28														
	28-30														
	30-32														
	32-34														
	34-35														
TOTAL PROBABLE NO.		1197.0	4221.0	87.0	2685.0	9726.0	219.0	2805.0	10662.0	9840	32586.0	1.00000	2.12702	388.1812	7763.624
PROB. NO. FACTOR		2.58531	—	—	4.60549	—	—	3.66667	—	—	—	—	× 0.43649	—	—
TANDEM AXLE LOADS-Kips	Under 24	873.8	—	—	2031.0	—	—	2086.3	—	—	4991.1	0.74639	0.32579	59.4567	1189.134
	24-26	47.4			96.7			114.9			259.0	0.03873	0.01691	3.0861	61.722
	26-28	47.4			96.7			114.9			259.0	0.03873	0.01691	3.0861	61.722
	28-30	47.4			96.7			114.9			259.0	0.03873	0.01690	3.0843	61.686
	30-32	106.0			216.5			249.3			571.8	0.08551	0.03732	6.8109	136.218
	32-34	54.3			106.0			102.7			263.0	0.03933	0.01717	3.1335	62.670
	34-36	12.9			23.0			22.0			57.9	0.00866	0.00378	0.6898	13.796
	36-38	2.6			—			—			2.6	0.00039	0.00017	0.0310	0.620
	38-40	2.6			4.6						7.2	0.00108	0.00047	0.0858	1.716
	40-42	2.6			4.6						7.2	0.00108	0.00047	0.0858	1.716
	42-44	—			4.6						4.6	0.00069	0.00030	0.0548	1.096
	44-46				—						—	—	—	—	—
	46-48				2.3						2.3	0.00034	0.00015	0.0274	0.548
	48-50				2.3						2.3	0.00034	0.00015	0.0274	0.548
TOTAL PROBABLE NO.		1197.0	—	—	2685.0	—	—	2805.0	—	—	6687.0	1.00000	0.43649	79.6596	1593.192
TOTAL AXLES											45960				
TOTAL VEHICLES											15320				

TABLE 4

CALCULATION OF 20-YEAR AXLE LOAD REPETITIONS

Dist.-Co.-Rte. 00-XX-00 P.M. 0.0/00.0 Exp. Auth. 000000 Inside Lanes ______ Outside Lanes X

Axle Loads Kips		2-Axle ADTT = 1870		3-Axle ADTT = 1090		4-Axle ADTT = 460		5-Axle ADTT = 3480		6-Axle ADTT = 110		Total 20-year Repetitions
		Constant	Repetitions	Constant	Repetitions	Constant	Repetitions	Constant	Repetitions	Constant	Repetitions	
SINGLE AXLE	35							0.09	313			313
	34							0.17	592			592
	32							0.17	592	—	—	592
	30							—	—	14.3	1,573	1,573
	28							—	—	14.3	1,573	1,573
	26	—	—			—	—	—	—	28.7	3,157	3,157
	24	1.75	3,273	—	—	3.72	1,711	0.44	1,531	—	—	6,515
	22	5.91	11,052	3.10	3,379	9.20	4,232	6.28	21,854	27.4	3,014	43,531
	20	40.4	75,548	86.9	94,721	202.	92,920	419.	1,458,120	60.4		
	18	128.		334.		611.		2060.		349.		
TANDEM AXLE	50			0.55	600			0.55	1,914			2,514
	48			0.55	600			0.55	1,914			2,514
	46			—	—			1.50	5,220			5,220
	44			1.10	1,199			1.75	6,090			7,289
	42			1.72	1,875	—	—	3.80	13,224			15,099
	40			1.72	1,875	5.66	2,604	3.29	11,449	—	—	15,928
	38			0.62	676	-9.09	4,181	22.6	78,648	28.8	3,168	86,673
	36			13.8	15,042	12.1	5,566	78.3	272,484	61.4	6,754	299,846
	34			62.7	68,343	35.4	16,284	262.	911,760	62.9		
	32			136.		145.		576.		272.		
	30			61.7		164.		292.		462.		
	28			61.7		164.		292.		462.		
	26			61.7		164.		292.		462.		

4. For this example, a load safety factor of 1.3 is appropriate for outside lanes. On the work sheet (Table 5), the axle load designations in column (1) are multiplied by 1.3 and the resulting figures are entered to the nearest 0.1 kip in column (2).

5. Stresses are determined from Figure 4 (a) for single axle loads and Figure 4 (b) for tandem axle loads. A trial thickness of pavement is first selected and then the charts are entered with each axle load in column (2) of the work sheets. The load line is followed to the horizontal line for the design k-value, thence vertically to the trial thickness line, and then horizontally to the stress scale on the left. The stress values are entered in column (3) of the work sheet to the nearest 5 psi.

To illustrate from the example, a trial depth of 0.75 ft was chosen for the outside lanes. The first axle load in column (2) is 45.5 kips. This value is interpolated in Figure 4(a) and followed up to the combined k-value of 195 which also must be interpolated. From this point proceed vertically to an intersection with the 0.75-ft curve, thence horizontally left to the scale where a stress of 370 psi is read and recorded on the work sheet. Stresses are determined for each axle load in column (2) for single axles, and in the same manner for tandem axles using Figure 4(b).

TABLE 5
WORK SHEET

Dist.-Co.-Rte. 00-XX-00 P.M. 0.0 / 00.0

Outside Lanes 2 Inside Lanes — Exp. Auth. 000000

Load Safety Factor (L.S.F.) 1.3 Basement Soil R-Value 10

Subbase Depth 0.50' Cement-treated Base Depth 0.45'

k-Values: Basement 70 Subbase 90 C.T.B. 195

Modulus of Rupture (M.R.) 550 Trial Depth PCC 0.75'

(1) Axle Load Kips	(2) Axle Load x L.S.F. Kips	(3) Stress psi	(4) Stress Ratio Col. 3 / M.R.	(5) Allowable Repetitions No.	(6) Estimated Repetitions No.	(7) Fatigue Resistance Used %
SINGLE AXLE LOADS						
35	45.5	370	0.67	4,500	313	7
34	44.2	360	0.65	8,000	592	7
32	41.6	345	0.63	14,000	592	4
30	39.0	330	0.60	32,000	1,573	5
28	36.4	315	0.57	75,000	1,573	2
26	33.8	300	0.55	130,000	3,157	2
24	31.2	280	0.51	400,000	6,515	2
22	28.6	260	< 0.50	—	—	—
20	26.0					
18	23.4					
TANDEM AXLE LOADS						
50	65.0	340	0.62	18,000	2,514	14
48	62.4	330	0.60	32,000	2,514	8
46	59.8	320	0.58	57,000	5,220	9
44	57.2	310	0.56	100,000	7,289	7
42	54.6	295	0.54	180,000	15,099	8
40	52.0	285	0.52	300,000	15,928	5
38	49.4	275	0.50	—	—	—
36	46.8					
34	44.2					
32	41.6					
30	39.0					
28	36.4					
					Total % Fatigue Used	80

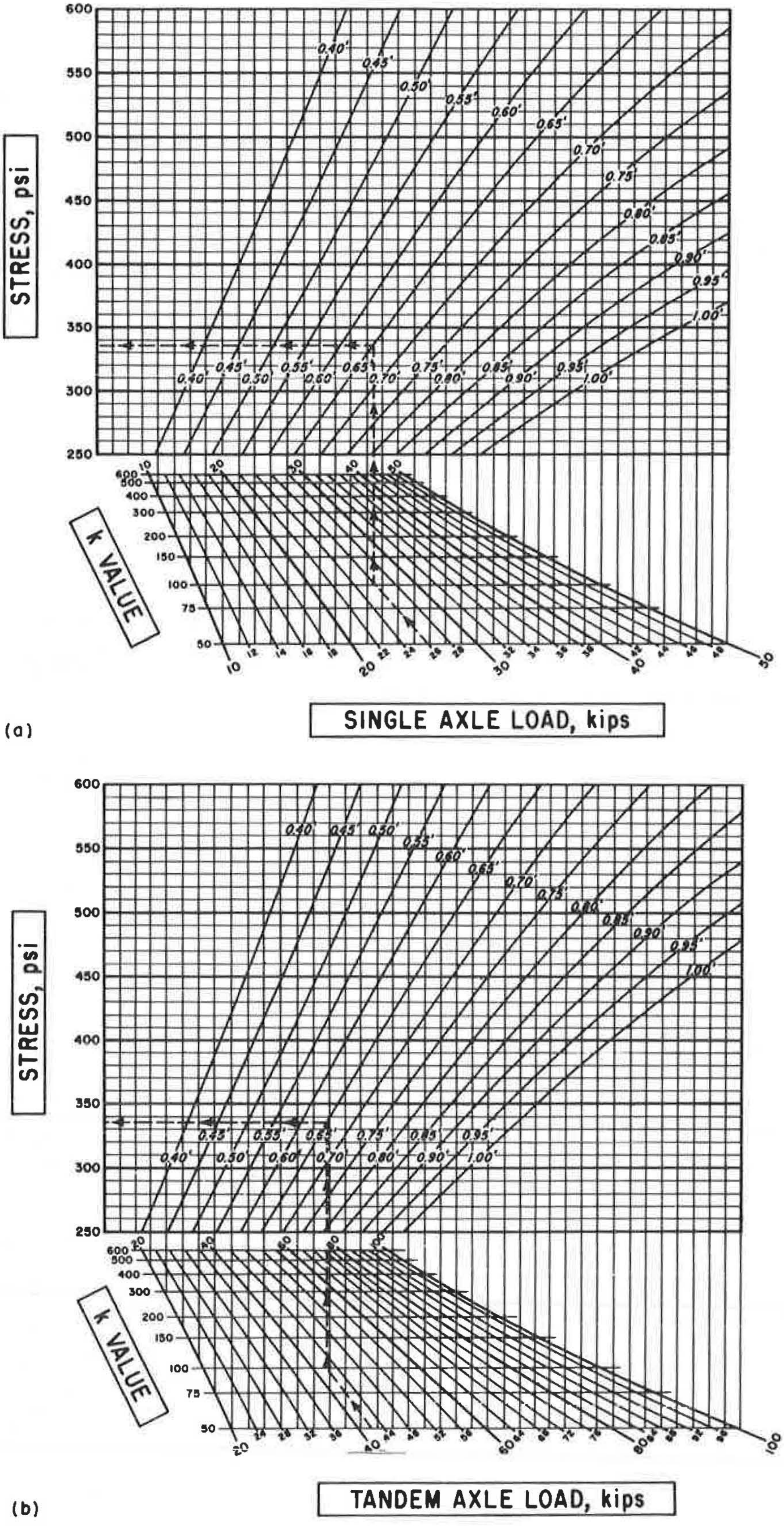

Figure 4. (a) Stress chart for single axle loads and (b) stress chart for tandem axle loads.

6. Each stress value is divided by the modulus of rupture (MR) and the ratios recorded to the nearest 0.01 in column (4) of the work sheet. No values less than 0.51 are used because allowable repetitions are unlimited for stress ratios of 0.50 or less. It can be seen from this that no stress values less than half the modulus of rupture need be determined in the preceding step.

7. Allowable repetitions are taken from Table 1 for each stress ratio and recorded in column (5).

8. Estimated numbers of axle load repetitions for 20 years are calculated on the form represented by Table 4. For this example, the expanded average daily trucks for each vehicle type are entered in the column headings. The average daily truck figure for each vehicle type is multiplied by each constant for that type and the repetition figure entered to the right of the constant. By adding the repetition figures on each horizontal line, the probable number of repetitions for each weight classification is obtained. The total 20-year repetitions are then entered in column (6) on the work sheet, Table 5.

9. For the final step, the estimated repetitions in column (6) are divided by the allowable repetitions in column (5) and multiplied by 100, which gives the percent fatigue resistance used. These figures are recorded to the nearest one percent in column (7) of the work sheet. Column (7) is totaled and the total percent fatigue used is recorded. Several thicknesses are tried and that trial thickness is selected which shows the nearest to 100 percent fatigue used but not to exceed 125 percent. With experience only two trials are necessary.

In this example, only the calculations for the finally selected design thickness of 0.75 ft for the outside lanes are shown to illustrate the method. A trial thickness of 0.70 ft also was used, but this lesser thickness showed a "fatigue resistance used" far in excess of 125 percent.