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TRANSPORTING ABNORMALLY HEAVY LOADS ON PAVEMENTS

TASK FORCE ACTIVITY
Task Force on Transporting Abnormally Heavy Loads on Highways

GROUP 2 - DESIGN AND CONSTRUCTION OF TRANSPORTATION FACILITIES
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PREFACE

This circular contains a report developed by the Task Force to provide guidance criteria for the supporting systems to be used in transporting abnormally heavy loads on highways for the purpose of protecting the highway facility. The scope of the Task Force was limited to considerations involving the pavement system, and the report, therefore, does not consider the effects of abnormally heavy loads on bridges and other structures.

HIGHWAY RESEARCH BOARD
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Page 5, Equation 1 should have a minus sign before $\frac{1}{\rho\pi}$

Page 6, Equation 3 should have a minus sign before $\frac{.15}{.23}$

Page 14, the following reference should be added:

VanVuuren, D. J., "The ESWL Concept and Its Application to Abnormally Heavy Vehicles on Roads," South African Institute of Civil Engineers, August 6, 1969.

Page 15, in Figure 4 in the last column to the right, the Fig. 1 in parentheses should read (Fig. 3).

TRANSPORTING ABNORMALLY HEAVY LOADS ON PAVEMENTS

INTRODUCTION

Abnormally heavy and abnormally sized vehicles traveling under special permits issued by state highway departments are becoming an increasingly common sight on our nation's highways. These heavy and oversized vehicles, necessary, in part, by our advanced technology, have created the potential for rapid deterioration of the highway system. Thus a need exists for the development of a satisfactory method for determining the effects of these vehicles on highway pavements in order that the destructive effects of these overloads may be assessed and/or determine alternative methods of distributing the load such that minimal damage will be experienced by the pavement.

Maximum loads carried on these truck-tractor, jeep, low boy-tractor or dolly types of vehicles can be as high as 1,000,000 pounds with the vehicle possessing 116 wheels. The number and distribution of axles and wheels are varied relative to the loads which the vehicle is to support. Figure 1 and 2 and Table 1 show typical axle and vehicle configurations designed to support an unusually heavy load. Items such as nuclear reactors, electrical generators, transformers, storage tanks and items associated with the petrochemical industry have been transported on similar types of vehicles over our nation's highways.

ESTABLISHMENT OF HIGHWAY RESEARCH BOARD TASK FORCE

During the 1970 Highway Research Board annual meeting a group of interested engineers including representatives from state highway departments, Corps of Engineers, universities and the Highway Research Board met to investigate the need for forming a committee to develop criteria for vehicle flotation on highways. Special Task Force A2T52 (Transporting Abnormally Heavy Loads on Highways) was established prior to the 1971 annual meeting of HRB. This report is a result of this special task force's efforts. The purpose of the report is to formulate guidelines by which states may analyze the effects of unusually heavy loads upon the design life or remaining life of their highways and to indicate satisfactory methods of distributing heavy loads on pavements.

BACKGROUND INFORMATION

One of the key parameters in the design of pavements is the number of equivalent 18-kip loads which the pavement will be expected to support for a given life. Incorporation of this particular data into the design process would appear to be a more or less straightforward act contingent upon proper treatment of projected traffic data. However, the prediction of traffic loads is often confounded by abnormally heavy traffic loads which consume a disproportionate share of the pavement life.

Appropriate methods are not available which accurately predict the number and type of abnormally heavily loaded vehicles which will utilize a pavement. Additionally design methods are not available which allow the engineer to predict the destructive effects of these heavy vehicles on the pavement with a reasonable degree of accuracy. For example accurate methods of predicting the damaging effects of these vehicles in terms of 18-kip equivalent single axle loads are not available. Thus the practicing engineer has been faced with estimating the damaging effects of this type of vehicle on pavements with somewhat empirical design methods which vary considerably from state to state.

Realizing that more rational pavement design methods are under development but are not yet either readily available or accepted, the special task force presents established methods which should be strongly considered by state highway departments and other interested agencies to determine the destructive effects of abnormally heavy wheel loads on highways.

Review of State Practices

Two reports basically summarize state practices with regard to the use of highways by abnormally heavy loads. These reports are:

1. National Cooperative Highway Research Program Report 80; "Oversize-Overweight Permit Operation on State Highways," Prepared by Roy Jorgensen and Associates for the Highway Research Board, 1969.

2. TOR-1001 (S2855-12)-1 "Vehicle-Highway Relationship Study Report," by Robert K. Maddock, August 1966. Technology Division, San Bernardino Operations, Aerospace Corporation, San Bernardino, Calif.

These reports indicate that in most state laws, there is provision made not only to establish maximum legal limits, but also to establish maximum limits allowed by permit. In nearly all of the state laws, the maximums allowed by permit are influenced by the stresses liable to occur in bridges (or other structures) rather than on a roadway's pavement. These limits are usually established by law through application of a bridge formula involving axle loads and spacing rather than application of any roadway capability formulas.

In addition, there is considerable variance not only in the formulas used for the same bridge designs but also in the types and degree of individual analyses performed by bridge department personnel. Accordingly, it is assumed that if there is no kind of uniform methodology existing for bridges, then neither does there exist a uniform methodology for computation of maximum load carrying capabilities for nonbridged sections. Some states allow the maximum size and/or weight to be determined on an individual case basis (by engineering/route analysis, by the director of the highway department, or by some other means); however, most require as a condition to the issuance of any permit that the applicant give bond to indemnify the state against damage to roads or bridges.

There appears to be little uniformity between state laws and/or methodologies used to evaluate abnormally heavy loads on highways, therefore, the methodology presented herein should be particularly useful to state officials, legislators and/or others.

Based on a review of state practices and available pavement design methods the following is presented:

Section I: TRANSPORTING ABNORMALLY HEAVY LOADS ON FLEXIBLE PAVEMENT

Section II: TRANSPORTING ABNORMALLY HEAVY LOADS ON RIGID PAVEMENT

Potential Uses

Potential uses of the proposed systems include establishing the damaging effects of existing vehicles and establishing proper wheel configuration for vehicles to carry specific loads. The damaging effects of specific vehicles can be determined by the proposed methods for both flexible and rigid pavements. It is left to the user of these methods to establish the amount or degree of damage he is willing to accept due to the passage of this vehicle. These methods can also be utilized to classify vehicles according to their destructive effects on certain types of highways and thereby lead to the development of "highway load code maps."

Utilization of these methods for determining proper wheel configuration including axle spacing, wheel spacing, number of axles, number of wheels and tire pressures can be established by series of trial and error solutions. A particular gear configuration can be established and the anticipated damage to the pavement determined. If excessive damage is expected, another wheel configuration can be selected.

Limitation of Methods

No design methods provide guidelines for deciding on the amount of pavement life which may be sacrificed for an abnormally heavy load. Each load must be individually reviewed and a management decision made before these overloads may lawfully pass over our highways. The accuracy of these methods to quantify this loss of road life due to abnormally heavy loads has not been established. Such factors as pavement temperature,moisture content of the pavement materials, the presence or absence of shoulder, the effect of stabilized materials and pavement age may not be considered in an accurate manner to give reliable estimates of pavement damage for all roadway conditions. Nevertheless, the methods presented herein describe the desired relationship to a reasonable degree of accuracy.

Evaluation of pavement systems with unknown sections or unknown traffic present a special problem. Measurement or calculation of current deflections would afford an index as to the probable deflection to be experienced from a given overload. From a general knowledge of pavements, the probable effects of the overload on the pavement could be deduced. Such a system is being utilized in Ontario.

SECTION I
TRANSPORTING ABNORMALLY HEAVY LOADS ON FLEXIBLE PAVEMENTS

INTRODUCTION

A means of determining if an abnormally heavy load could operate on a flexible pavement has been developed based upon the U. S. Army Corps of Engineers flexible pavement design procedures. This design procedure can also be used to indicate what can be done to an abnormally heavy vehicle supporting system in order to permit the vehicle to use a roadway. The methodology presented herein makes use of equivalency factors to relate traffic of an abnormally heavy vehicle to traffic of a standard load. This equivalency will indicate the amount of life that will be used up by the heavy vehicle and provide a basis for determining if the vehicle can be permitted to use the road.

DESIGN METHOD

There are numerous pavement design methods that could have been chosen for use in developing the criteria for application to abnormally heavy loads. The method chosen is the U. S. Army Corps of Engineers (CE) design method. The CE method of pavement design makes use of a formula for determining pavement thickness based upon the strength of the soil, traffic and load. This makes it easy to reverse the design procedure and evaluate an existing road for its capability to carry an abnormally heavy load. Those parameters considered important in pavement design and evaluation are considered by the CE procedures.

PARAMETERS

A definition of the parameters used in this procedure for flexible pavements are as follows:

a. Axle Load - the load on an axle of a vehicle.

b. Tire Load - the load being carried by one tire on a vehicle.

c. Standard Load - an 18-kip load on an axle having dual tires on each end.

d. Equivalent Single Wheel Load - that load on one tire which will have the same effect on a pavement as a load on an axle or group of axles.

e. CBR - a measure of soil strength

f. Tire Pressure - the tire inflation pressure.

g. Tire Contact Area - the area of the tire in contact with the pavement. Contact area is determined by dividing the tire load by the tire pressure.

h. Coverages - a measure of traffic intensity on a road.

i. Radii - the radius of a circle having the same area as the tire contact area.

j. Tire Spacing in Radii - the distance between two tires measured in radii.

k. Equivalency Factor - Ratio of coverages of a standard load to coverages of an abnormally heavy load.

PROCEDURE

CE Design Equation

The Corps of Engineers design equation is the basis for establishing whether an abnormally heavy vehicle can use a particular roadway. This design equation is as follows:

$$t = (.23 \log C + .15) \sqrt{P \left(\frac{1}{8.1\ CBR} \qquad \frac{1}{\rho\pi} \right)} \tag{1}$$

where:

t = thickness of pavement structure in inches.

C = a measure of traffic called coverages.

P = equivalent single wheel load in pounds.

CBR = a measure of soil strength.

ρ = tire pressure in psi.

Equivalent Single Wheel Load

Equivalent single-wheel loads (ESWL) are determined using the curve shown on figure 3. This curve defines the effect one wheel load has on another wheel load and is a plot of spacing between wheels versus the percent increase in ESWL for each adjacent wheel. To obtain an ESWL, it is necessary to determine that load on a single tire (with characteristics equivalent to one tire on the vehicle) which will produce the same effect on the pavement as all the wheels on an axle or axle group. The ESWL will be equal to the load on one tire on the vehicle plus the additional load contributed by each nearby tire. An example of an ESWL determination is shown on figure 4.

Equivalency Factor

As indicated above, the determination of whether a vehicle can use a pavement is based upon use of an equivalency factor, which is simply a ratio of the allowable traffic of a standard load (C_s) to the allowable traffic of an abnormally heavy load (C_a). Thus:

$$F = \frac{C_s}{C_a} \qquad (2)$$

Use is made of the CE design formula to calculate the allowable coverages of the standard axle load, and also to calculate the allowable coverages of each axle or axle group on the abnormally heavy vehicle. This is accomplished by rearranging the CE formula in the following manner and calculating C as indicated for the various axles.

$$\log C = \frac{t}{.23\sqrt{P\left(\frac{1}{8.1\ CBR} - \frac{1}{p\pi}\right)}} - \frac{.15}{.23} \qquad (3)$$

Therefore, the axle equivalency factors are calculated by determining the allowable coverages of the standard axle and dividing by the allowable coverages of the abnormally heavy axle load. The axle equivalency factors are then summed in order to get the vehicle equivalency factor.

The method of assessing the damaging effects of an abnormally heavy load in relation to some standard load (normally the design axle load for the pavement) is as follows:

a. Calculate the equivalency factor for the abnormally heavy vehicle, and the standard axle load.

b. Determine the number of repetitions of the standard axle load (r_s) for which the road was designed.

c. Divide R_s by the equivalency factor to determine the equivalent repetitions (R_s) of the abnormally heavy vehicles.

d. Since the whole service life of the pavement cannot be devoted to the abnormal vehicle, it is necessary to decide on some percentage of the service life that can be used by the abnormal vehicle. The number of repetitions of the abnormal vehicle a road can sustain must then be multiplied by this percent to determine the allowable repetitions of the abnormal vehicle.

Vehicle Adjustments

Should the calculations indicate that the abnormally heavy vehicle cannot use a particular pavement, it is then possible to determine what can be done to the vehicle in order to allow it to use the pavement. The severity of the heavy vehicle can be reduced by reducing the ESWL, i.e. lowering the tire pressure, reducing the load, or increasing the number, and/or spacing of tires. By using the above formulas, the desired number of passes needed can be used to calculate an ESWL that would allow the abnormal vehicle to use a pavement. Then, by using figure 2, it is possible to select tire spacings that reduce the overlapping effect and therefore reduce the ESWL, or it is possible to add additional tires and axles at a distance such that the overlapping effect is minimal. The addition of more tires reduces the load per tire and therefore the ESWL is reduced.

Stabilized Layers

The Corps of Engineers design and evaluation procedures are based upon use of granular materials for base and subbase courses, and no provision is made for use of stabilized layers. However, the procedure presented herein can be applied to stabilized layers by use of equivalency factors which relate a thickness of stabilized material to an equivalent thickness of non-stabilized material. Most highway departments make use of equivalency factors that will be adequate for use with the Corps of Engineers method.

Estimating Parameters

There may be occasion where the physical characteristics of a road such as CBR and thickness are not known. In these cases, it will be necessary to make an intelligent guess as to these values. Although these values may be estimated, the equivalency factors thus produced should still give a reasonable relationship between a standard axle load and the abnormally heavy load.

Where the design traffic is not known, it will be necessary to base the road capability on future anticipated life under standard loadings. This will provide a basis for determining the amount of life the abnormally heavy vehicle will be using.

Limitations

The procedure presented herein provides a reasonable basis for determining whether an abnormally heavy vehicle can use a particular road or for devising a vehicle capable of transporting a very large load with overloading pavements. Obviously due to assumptions made in developing the simplified procedure, the results are not as precise as possible. Where better results are demanded, a more involved and more precise procedure can be used. The CE procedure will give more precise answers if the ESWL is calculated according to procedures set forth in WES Instruction Report No. 4, "Developing a Set of CBR Design Curves," (reference 8) and if the equivalency factor is based upon a ratio of passes rather than coverages. The conversion from passes to coverages is discussed in WES TR 3-582, "Revised Method of Thickness Design for Flexible Highway Pavements at Military Installations," August 1961 (reference 9).

ADDITIONAL METHODS

As indicated earlier, other pavement design methods could be utilized in a simplified manner for determining the effect of abnormally heavy wheel loads on pavements. The most critical problem in adopting these methods is the conversion of loads imposed by the abnormally heavy vehicle to an equivalent typical axle load, such as 18,000 pounds or 5,000 pounds, utilized by most designing agencies. Since a completely satisfactory method is not available, Corps of Engineers experience with airfield pavements whose wheel loads are similar in many respects to those imposed by heavy highway vehicles was utilized.

An approach that does not directly require this relationship is based on elastic theory. It is neither the purpose nor intent of this discussion to be an extensive reference list upon which this method is based. However, it is the considered opinion of this committee that the method briefly described below may be utilized as an indication of the damage created by an abnormally heavy vehicle on the pavement.

Most "elastic" methods of pavement design are, in fact, only analysis techniques for examining real or assumed structural sections. In this same sense, the response of a given pavement structure can be analyzed when subjected to a very heavy load.

Computation Procedure

A simplified approach to this method is outlined in the following steps:

1. Determine the nature and value of the wheel loads to be carried.

2. Determine the cross-section geometry (thickness) and types of material in each layer.

3. Estimate "elastic" parameters (modulus, Poisson's ratio) for each material.

4. Compute stresses, strains, and deflections using an appropriate theoretical method, and

5. Compare these stresses and strains with appropriate failure or performance criteria.

Load Evaluation

Except for complex special cases, the individual wheel loads should be converted to some single value such as described earlier for the ESWL. For most computerized computation methods, the effect of adjacent wheels can be accounted for by superposition. In addition, it may be necessary to examine the pavement system by layers in conjunction with various materials.

Thickness and Materials

Construction and/or maintenance records should provide adequate information. Coring or other detailed measurements should be utilized only as a last resort.

Elastic Parameters

Ideally, the various materials should be tested, but in most instances this would be impractical. Therefore, an estimate of these values can be made using the experience of various researchers as shown in Table 2.

Computation of Stresses, Strains and Deflections

Several computer programs are available, such as the Chevron 5-L or n-layer program, or the Shell BISTRO. Although the BISTRO program is more powerful and flexible, it may be too time-consuming and costly for most overload computations. The input to the Chevron program is limited to a single load, but others can be added by superposition. If computers are not available, computations can be made by using tabulated information such as that in Highway Research Board Bulletin No. 342. Those particular values required for analysis are shown in Table 3.

Comparison With Failure or Performance Criteria

Infrequently applied abnormally heavy loads can cause either excessive permanent deformation (rutting) or cracking of the surface. A single pass may not manifest itself immediately as a "failure," but may substantially decrease the number of normal loads that can be carried before failure occurs. To date, it is somewhat difficult to specify allowable values for stress or strain since these data are not as yet readily available from experience. However, one can use values such as those shown in Table 4, which are only approximate for the materials shown for fatigue type of cracking. Allowable vertical compressive strain in the subgrade for various load repetitions expressed in 18,000 lb. equivalent axle loads are as follows:

Repetitions	Vertical Strain
10,000	400×10^{-6}
100,000	230×10^{-6}
1,000,000	140×10^{-6}

Together, these values provide guidelines for cumulative fatigue damage analysis. In order to preclude permanent deformation at the top of the subgrade, a maximum allowable vertical strain of 650×10^{-4} has been suggested (Shell) for 1,000,000 applications.

Example Problem

A pavement consisting of an asphalt concrete surface, cement stabilized base, and lime stabilized subbase was designated as the pavement which a certain heavy vehicle was to traverse. Appropriate elastic values were estimated for the asphalt concrete, cement stabilized base, lime stabilized subbase and subgrade.

The computer solution indicated that this vehicle would create the following maximum stresses and strains in the pavement section:

asphalt concrete surface tensile strain	850×10^{-6}
cement treated granular base tensile stress	140 psi
lime stabilized subbase stress ratio	0.79*
subgrade compressive strain	400×10^{-6}

Based on these data the fatigue life utilized by the passage of this vehicle is as follows:

asphalt concrete surface	1/1,000	=	0.1 percent
cement stabilized base	1/10	=	10 percent
lime stabilized subbase	1/100	=	1 percent
subgrade	1/10,000	=	0.01 percent

The most critical layer is the cement stabilized material. Thus, 10 percent of the pavement life will be utilized by a single passage of this vehicle.

SECTION II

TRANSPORTING ABNORMALLY HEAVY LOADS ON RIGID PAVEMENTS

INTRODUCTION

A method is described below which will allow the engineer to determine the effect of abnormally heavy loads on existing portland cement concrete highway pavements. This method is intended to be a simplified approach and is based on the use of current technology. New concepts are not utilized, but rather existing pavement design methods have been organized into a framework that can be utilized for the solution of the above stated problem.

BACKGROUND INFORMATION

Many currently used portland cement concrete pavement design methods are based on the theory developed by Westergaard (1). This theory is utilized to calculate the stress in the concrete slab due to a given wheel load. Hogg (2) and Holl (3) working independently also developed a theory suitable for calculating

*The static strength of the lime stabilized subbase is 200 psi and the computed maximum stress in the lime stabilized layer is 158 psi.

the stress in concrete slabs. The major differences in these theories concerns the representation of the subgrade materials. Pickett and Ray (4) have developed influence charts based on Westergaard and Hogg and Holl's theories. These charts* allow these theories to be easily utilized for pavement design purposes where multiple wheel vehicles are encountered.

The Portland Cement Association, utilizing Westergaard's and Pickett and Ray's works together with information developed by the Association, has published design methods for highway (5) and airfield pavements (6).

COMPUTATION METHOD

By use of the above mentioned Westergaard theory and the influence charts developed by Pickett and Ray, one may calculate the stress in a concrete slab due to heavy wheel loads. This stress, when compared with the strength of the slab to determine its expected fatigue life, can be utilized with Minor's hypothesis to determine the percent of pavement damage due to an application of a given load (Figure 5). Details are given below.

Determination of Stress in Pavement

Pickett and Ray (4) have developed influence charts for the following loading conditions:

a. Interior loading - Westergaard theory,

b. Interior loading - Hogg and Holl theory,

c. Edge loading - Westergaard theory and,

d. Near Edge loading - Westergaard theory.

Since Westergaard's theory has been widely utilized and because of the difficulties associated with determining the elastic properties of the materials beneath the concrete slab, influence charts utilizing Westergaard theories will be utilized. The location of the wheel load on the pavement slab for abnormally loaded vehicles may be near the edge of the pavement; thus, it is anticipated that either the edge loading or near edge loading influence chart should be utilized. An example of an influence chart is shown in Figure 6.

To utilize the influence chart values of the elastic modulus of a concrete pavement several factors are required and these include Poisson's ratio of the concrete pavement, the thickness of the pavement, the modulus of subgrade reaction, tire pressure, wheel spacing, wheel loads, and axle spacing.

Elastic Modulus of Concrete

The elastic modulus of concrete is dependent upon such factors as mixture design, aggregate type, age (Figure 7)(7), moisture content, and unit weight.

*Large scale influence charts developed by Pickett and Ray are published by Kansas State University.

In general, the modulus will increase with age, unit weight, and strength. An elastic modulus value of 4,000,000 psi is commonly used for pavement design and unless detailed coring and testing is to be considered, this value should be used.

Poisson's Ratio

Poisson's ratio of concrete is dependent upon such factors as mixture design, aggregate type, age (Figure 8) (7), moisture content among other factors. Values used for pavement design are commonly 0.15 and 0.20. Since a value of 0.15 is more widely used than 0.20, this value is suggested for use although a slightly more conservative answer could be obtained by the use of 0.20.

Thickness of Pavement

The thickness of the existing pavement should be easily obtained from construction and/or design records.

Modulus of Subgrade Reaction

Approximate interrelationships between soil classifications and the modulus of subgrade reaction can be obtained from Figure 9 (5). This Figure may be utilized if laboratory or field test data are not available for the determination of the modulus of subgrade reaction (k value).

Corrections to the k value, if untreated or cement treated subbases are utilized between the slab and subgrade, can be obtained from Tables 5 and 6 (5). Correction to subgrade k values when bituminous stabilized bases are utilized is not well established.

Tire Pressure, Wheel Spacing, Wheel Loads, Axle Spacing

This information could be conveniently obtained from overload permits.

After establishing appropriate quantities as described above, the stress in the slab due to a particular wheel load can be determined as described in references 4 and 6.

FATIGUE LIFE

The amount of fatigue resistance utilized by the passages of a particular vehicle can be determined by use of the method described in reference 5.

The stress ratio or the ratio of the flexural stress in the pavement (created by the wheel load) to the modulus of rupture of the concrete (flexural strength of concrete) must be determined.** The determination of the flexural

**A load safety factor as described by the Portland Cement Association has not been utilized in this method.

stress in the pavement is described above. The flexural strength of the concrete can be determined by sampling from the pavement or by utilizing design values. Design strength utilized in the highway field are usually based on 28 day strengths. Consideration should be given to utilizing higher strength values as the strength will increase with age as shown in Figure 10.

Once a stress ratio is determined, Table 7 may be utilized to determine the allowable repetitions for a particular loading. For example, if a stress ratio of 0.83 is determined, the repetitions allowed prior to predicted failure are 50. Thus, one passage of this vehicle will consume 2 percent of the available fatigue life.

The percent fatigue life utilized due to normal traffic and the overloads must be continually summed. According to the Portland Cement Association, failure can be predicted when the consumed fatigue life reaches a level of 100 to 125 percent.

An example format that could be utilized is shown in Table 8.

CONCLUSION

A simplified method has been developed which will allow the engineer to calculate the effect of abnormally heavy loads on portland cement concrete pavements. This method utilized Westergaard's theory and Pickett and Ray's influence charts together with data developed by the Portland Cement Association.

Appropriate material constants have been suggested where needed for calculation.

Continuous records must be maintained for this method to be effective. Certainly abnormally loaded vehicles are somewhat similar and as experience is obtained by an agency, certain vehicle classes can be grouped and detailed calculations will not be required to determine the flexural stress in the concrete pavement.

This method can be used as a first approximation of the effects of abnormally heavy loads on portland cement concrete pavements; whether or not they are unreinforced, reinforced or continuously reinforced.

REFERENCES

1. Westergaard, H. W., "Stresses in Concrete Pavement Computed by Theoretical Analysis", Public Roads, Vol. 7, No. 2, April 1926, pp. 25-35.

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3. Holl, D. L., "Thin Plates on Elastic Foundations", Proceedings, 5th International Congress for Applied Machanics, John Wiley and Sons, Inc., 1939, pp. 71-74.

4. Pickett, G. and G. K. Ray, "Influence Charts for Concrete Pavements", Transactions, American Society of Civil Engineers, Paper No. 2425, Vol. 116, 1951, pp. 49-73.

5. "Thickness Design for Concrete Pavements", Portland Cement Association, 1966.

6. Packard, R. G., "Design of Concrete Airport Pavements", Portland Cement Association, 1973.

7. Troxell, G. E., H. E. Davis, J. W. Kelly, "Composition and Properties of Concrete", McGraw-Hill Book Co., Second Edition, 1968.

8. Instruction Report No. 4, "Developing a Set of CBR Design Curves", Nov 1959, WES, Vicksburg, Mississippi.

9. TR 3-582 Revised Method of Thickness Design for Flexible Highway Pavements at Military Installations. Aug 1961, WES, Vicksburg, Mississippi.

Table 1. Typical vehicles.

Vehicle Gross Load, lbs	No. of Axles	No. of Wheels	Maximum Axle Load, lbs	Maximum Wheel Load, lbs
120,000	12	76	10,000	2,500
153,000	8	44	24,000	4,075
181,600	12	76	22,300	2,750
180,500	8	44	30,000	4,975
236,245	9	52	50,800	6,365
344,800	12	76	31,400	6,250

Figure 1. Axle configuration for 32 wheels, 125,000 lb.

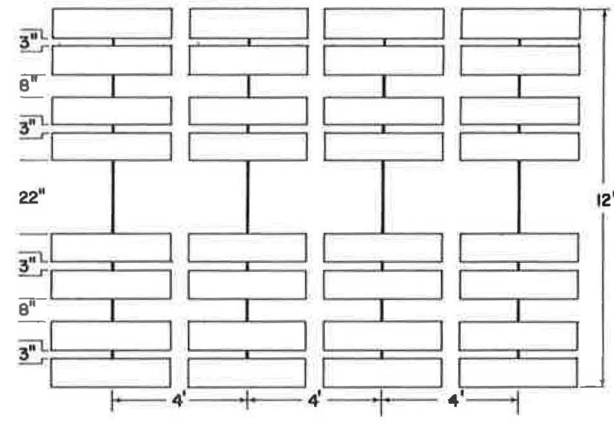


Figure 2. Axle configuration for 12 wheels, 75,000 lb.

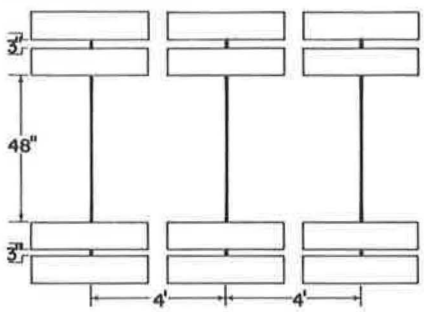


Figure 3. Equivalent single wheel load curve.

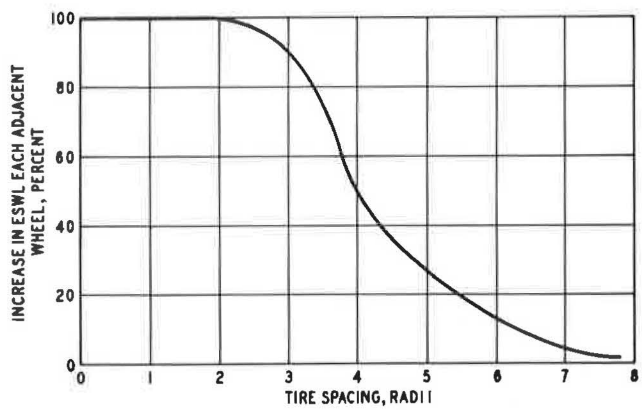
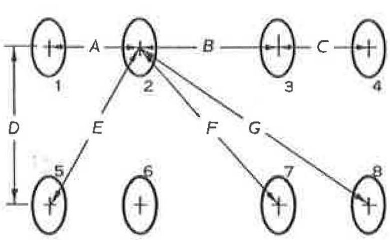


Figure 4. Example equivalent single wheel load calculation.



	WHEEL SPACING INCHES	RADII
A	13.5	2.56
B	58.5	11.10
C	13.5	2.56
D	48.0	9.10
E	50.0	9.45
F	75.9	14.40
G	86.5	16.40

DETERMINATION OF ESWL UNDER WHEEL 2

WHEEL NO.	RADII SPACING	WHEEL INFLUENCE (FIG. 1)
1	2.56	0.961
2	0	1.000
3	11.1	-
4	13.6	-
5	9.45	-
6	9.1	-
7	14.4	-
8	16.4	-
	TOTAL	1.961

NOTE: ESWL = 1.961 × LOAD PER TIRE.

Table 2. Approximate methods for estimating elastic parameters for pavement materials.

Material	Modulus of Elasticity, psi	Poisson's Ratio
Asphalt concrete	200,000 - 600,000	Low stiffness: 0.50 High stiffness: 0.35
Asphalt treated base	100,000 - 600,000	Low stiffness: 0.50 High stiffness: 0.35
Cement treated base	Uncracked: up to 2,000,000 Cracked: down to values for untreated granular base material	Uncracked: 0.20 Cracked: 0.30
Lime treated base	Uncracked: up to 500,000 Cracked: down to values for untreated granular base material	Uncracked: 0.20 Cracked: 0.30
Untreated granular base	2.5 times the value for underlying material	0.30
Subgrade soil	1500 x C.B.R. (psi)	Cohesive: 0.50 Non-cohesive: 0.30

Table 3. Stresses, strains and deflections required for analysis.

Layer	Required Response
Asphalt surfacing and asphalt treated base	Horizontal strain at bottom (only required if untreated base is utilized)
Cement and lime treated base	Horizontal stress at bottom (vertical stress and strain at top)* or stress ratio as shown in Table 7
Untreated granular base	Horizontal stress at bottom (vertical stress and strain at top)*
Subgrade	Vertical strain at top*

*considered for permanent deformation

Table 4. Approximate fatigue relationships for stabilized materials.

Material	Number of Repetitions to Failure					
	10	100	1,000	10,000	100,000	1,000,000
Asphalt stabilized tensile strain x 10^{-6} (dense graded)	4,000	2,000	850	400	140	85
Cement stabilized tensile stress, psi (granular soil)	140	125	105	90	72	51
Cement stabilized tensile stress, psi (silty clay)	92	85	78	70	62	54
Lime stabilized ratio of applied stress to static strength	0.87	0.79	0.72	0.63	0.55	0.47

Figure 5. Determination of fatigue life.

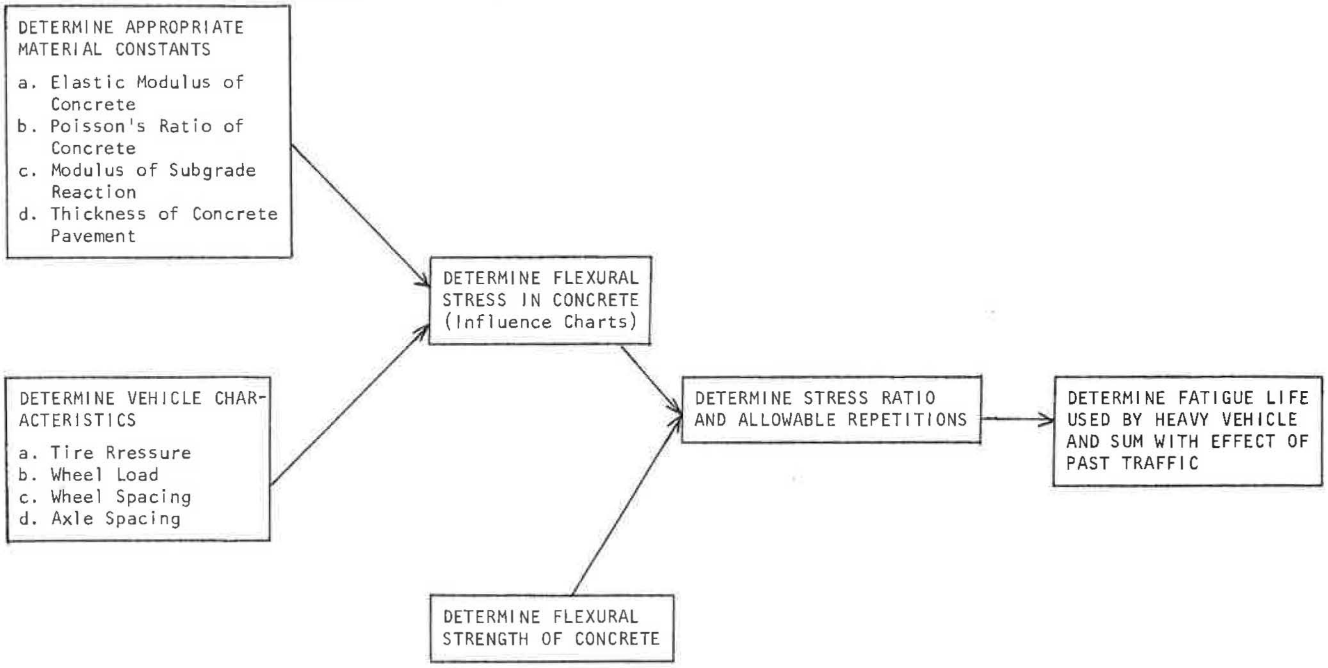


Figure 6. Typical influence chart.

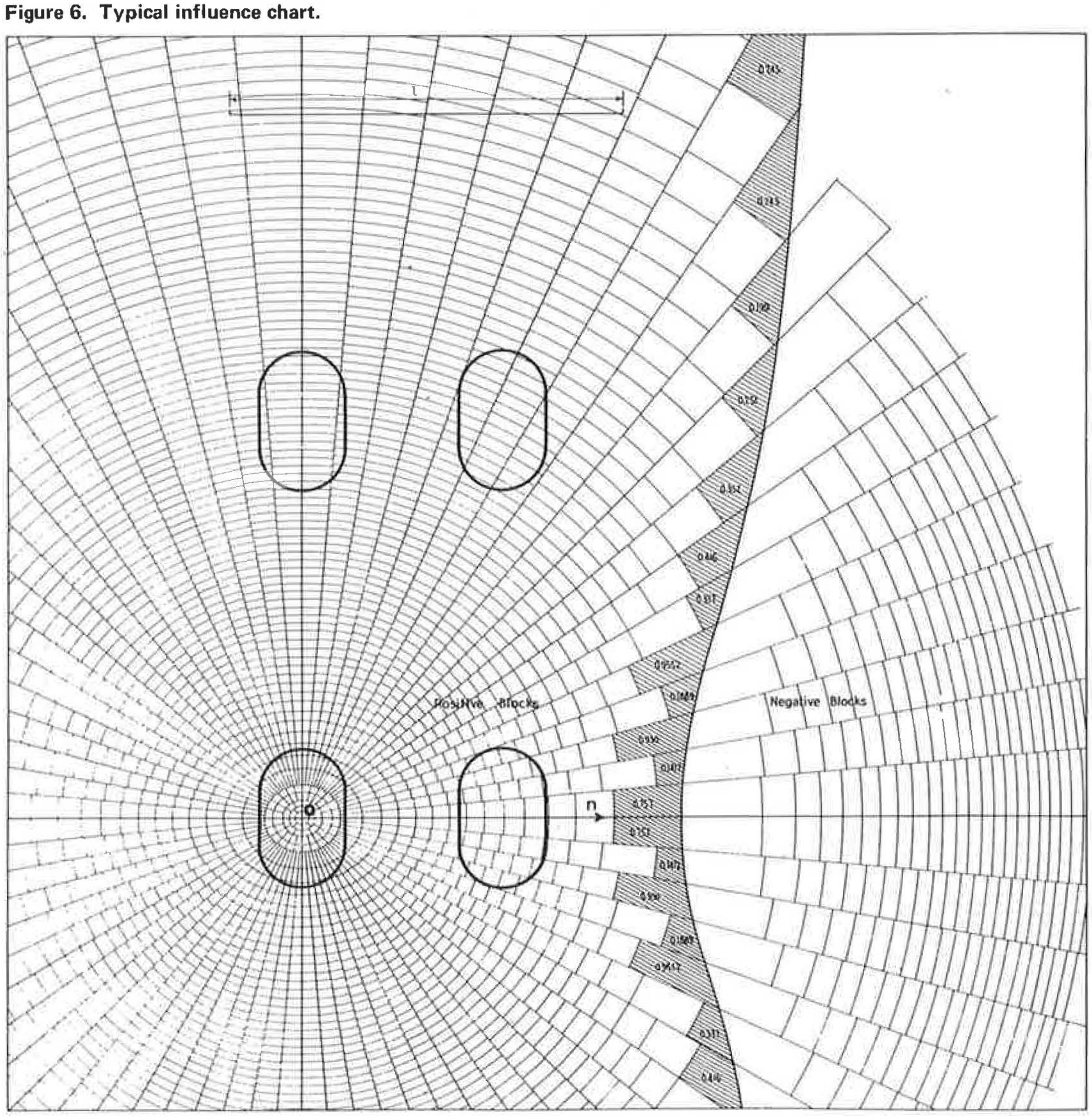


Figure 7. Effect of age, mix and stress upon modulus of elasticity. All mixes had a 1-in. slump and were stored in damp sand. (7)

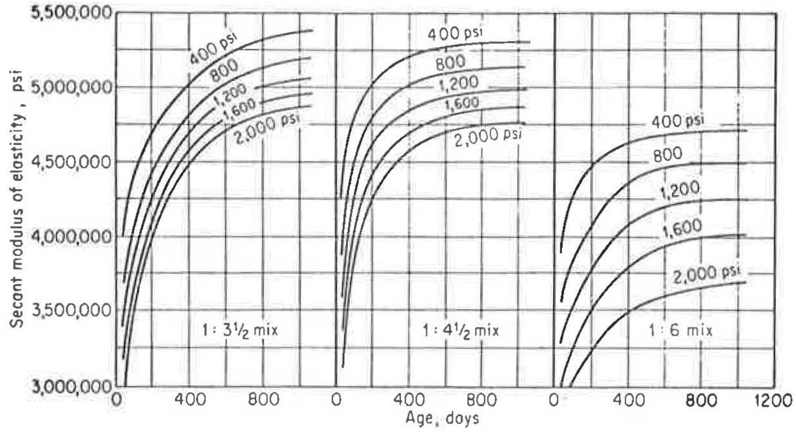


Figure 8. Effect of age on Poisson's ratio for sandstone concrete. (7)

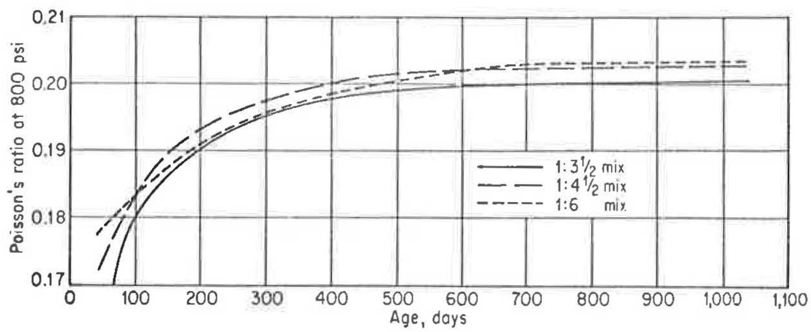
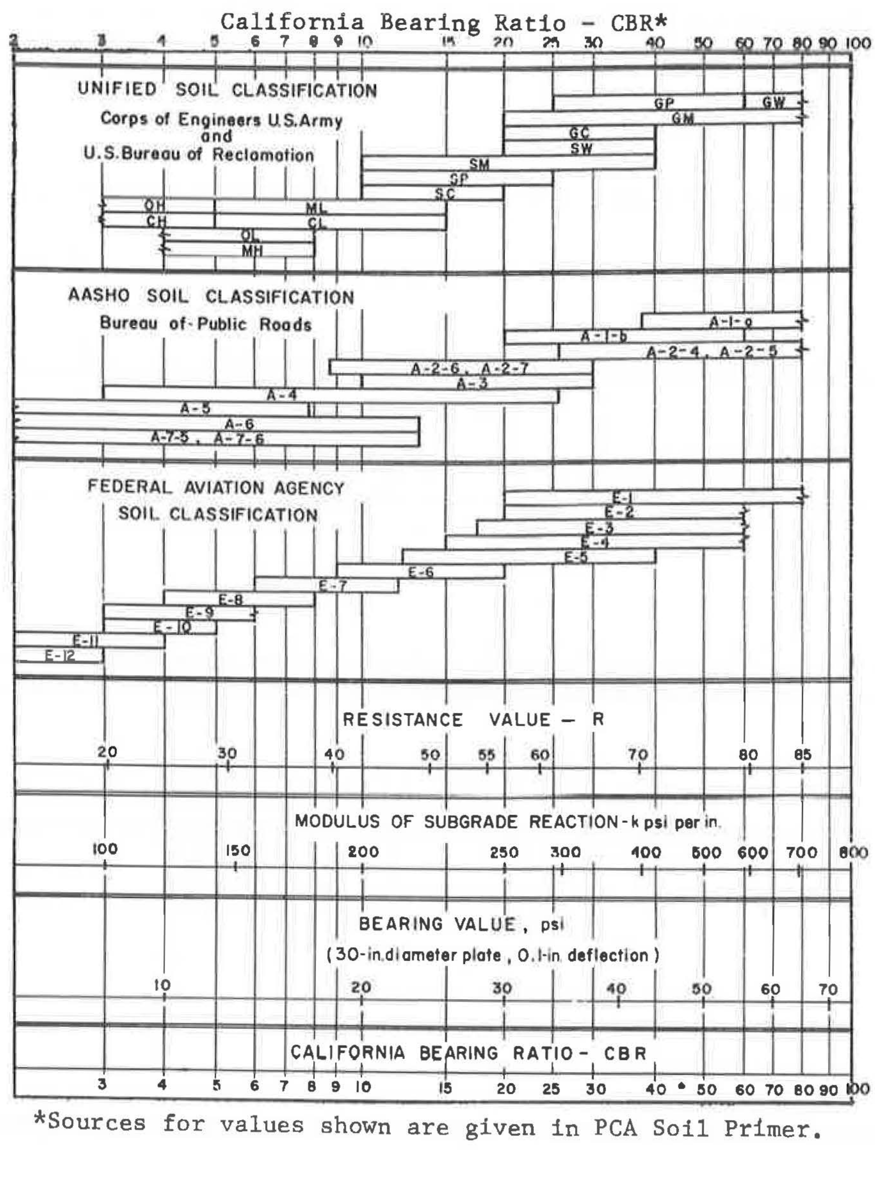


Figure 9. Approximate interrelationships of soil classifications and bearing values.



*Sources for values shown are given in PCA Soil Primer.

Table 5. Effect of untreated subbase on k values, pci.

Subgrade k value	Subbase k value 4 in.	6 in.	9 in.	12 in.
50	65	75	85	110
100	130	140	160	190
200	220	230	270	320
300	320	330	370	430

Table 6. Design k values for cement-treated subbases.

(Subgrade k value -- approx. 100 pci)

Thickness, in.	k value, pci
4	300
5	450
6	550
7	600

Figure 10. Flexural strength, age, and design relationships.

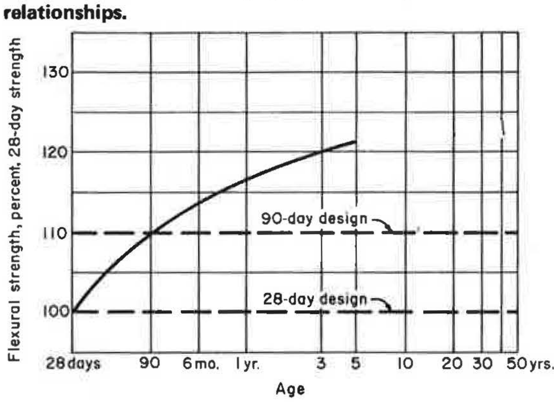


Table 7. Stress ratios and allowable load repetitions.

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

*Load stress divided by modulus of rupture.
**Unlimited repetitions for stress ratios of 0.50 or less.

Table 8. Sample calculation form.

I. General Information

District No. ______ County Bastrop Highway SH 95

Location of Section: From Elgin to Bastrop

Date of Construction September 1965 Traffic Volume 5,000 VPD

II. Material Constants

Elastic Modulus of Concrete 4,000,000 psi Poisson's Ratio of Concrete 0.15

Modulus of Subgrade Reaction 200 psi Design Modulus of Subgrade Reaction 300 psi

Flexural Strength of Concrete 700 psi Thickness of Pavement 9 inches

III. Calculations

Date	Overload Permit Number	Flexural Stress in Concrete	Stress Ratio	Allowable Repetitions	Percent Fatigue Resistance	Fatigue Resistance Used % Cumulative	Remarks
9/1/72						41	Fatigue Life Utilized During First SN Years
10/22/71	10-22-71-107	580	0.83	50	2.000	43	
11/2/71	11-2-71-125	450	0.64	11,000	0.009	43.009	