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16. ABSTRACT

Introduction

The earth's crust, in its many variations, remains as the foundation and source of materials for all present-day roadways. Traffic and weather are the major forces tending to destroy the roadway, forces that the highway engineer must account for and accommodate, both in construction of the roadway and throughout its life. His real problem is not to merely succeed in this accommodation but to do so at least cost.

The modern roadway is designed, among other things, to minimize the undulations of the earth's surface. As a practical matter, one critical element in such design is the highway embankment. Economy usually dictates that the materials for constructing embankments be taken from roadway excavations. Most materials which are taken from roadway excavations and placed in embankments can neither support modern wheel loads nor provide an adequate, all-weather surface. Therefore, a man-made surfacing of imported materials must be constructed over these basement soils.

Structural design of the roadbed is the determination of the thickness of subbase, base and pavement to be placed over the basement soil. Basic to the problem is the selection of the most suitable available materials and their most advantageous use. Their grouping in horizontal layers under the pavement should be such that the most benefit will be derived from the inherent qualities of each material.

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FLEXIBLE PAVEMENT
STRUCTURAL SECTION
DESIGN GUIDE
FOR
CALIFORNIA CITIES AND COUNTIES

Third Edition

January 1979

FLEXIBLE PAVEMENT

STRUCTURAL SECTION

DESIGN GUIDE

FOR

CALIFORNIA CITIES AND COUNTIES

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FOREWORD

This booklet is intended to provide a concise and useful tool to the designer of city streets and county roads.

The information in this guide has been updated since the last printing in January 1973, but the concepts and methods used herein are not new.

The guide is based on the results of extensive studies, tests and numerous reports by various agencies concerning the many factors affecting the structural design of roadway sections.

This guide should prove quite helpful to many cities and counties irrespective of the amount or lack of laboratory facilities and testing equipment.

Suggestions for improvements to this guide may be directed to either the County Engineers Association of California or the League of California Cities.

ACKNOWLEDGMENT

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Appreciation is extended to the Engineers who have contributed to this publication by their suggestions.

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INTRODUCTION

The earth's crust, in its many variations, remains as the foundation and source of materials for all present-day roadways. Traffic and weather are the major forces tending to destroy the roadway, forces that the highway engineer must account for and accommodate, both in construction of the roadway and throughout its life. His real problem is not to merely succeed in this accommodation but to do so at least cost.

The modern roadway is designed, among other things, to minimize the undulations of the earth's surface. As a practical matter, one critical element in such design is the highway embankment. Economy usually dictates that the materials for constructing embankments be taken from roadway excavations. Most materials which are taken from roadway excavations and placed in embankments can neither support modern wheel loads nor provide an adequate, all-weather surface. Therefore, a man-made surfacing of imported materials must be constructed over these basement soils.

Structural design of the roadbed is the determination of the thickness of subbase, base and pavement to be placed over the basement soil. Basic to the problem is the selection of the most suitable available materials and their most advantageous use. Their grouping in horizontal layers under the pavement should be such that the most benefit will be derived from the inherent qualities of each material.

A pavement may be designed to support any traffic density and axle load. It does this by distributing downward and outward the high-intensity stresses imposed by a loaded wheel, reducing these stresses in magnitude until they may be safely carried by the basement soil. The pavement structure is made up of materials of successively higher load-carrying capacity from basement soil to pavement surface. In establishing the depth of each layer, the objective is to provide a minimum thickness of overlaying material that will reduce the unit stress on the next lower layer, commensurate with the load-carrying capacity of the material comprising that layer.

The purpose of this guide is to provide acceptable criteria and methods upon which design of the structural section can be based. The material is slanted towards engineers who need to design roads and streets with standards oriented toward the requirements of the cities and counties rather than the more heavily traveled state highways.

The methods and procedures are not new in concept or theory. They are, however, representative of the thinking of the California Department of Transportation, the County Engineer's Association of California the League of California Cities, and other equally interested groups. This guide is based on the results of extensive studies and tests and on numerous reports by various agencies concerning the multitude of factors affecting the structural design of roadway sections.

SCOPE AND LIMITATIONS

The structural design of flexible pavements is not an exact science and, therefore, it is not possible to formulate one set of design criteria that could meet the requirements of every road everywhere. Traffic conditions, climate and geology, materials of construction, and of course, economics, are the variables that demand from the engineer the fullest application of his professional judgment and engineering skills.

For some time the State of California has been using a structural design formula based on empirical relationships developed from several test tracks and the performance of pavements in actual service. The original formula has been modified as more and better information has become available, and will be modified in the future as continuing research contributes further information.

The basic methods for structural design presented in this guide are based on this formula. Definitions of terms are provided and separate variables in the formula are discussed in detail. Several approaches for approximating the values of the variables are presented. These approaches represent degrees of refinement and are geared to the experience of the engineer.

This guide covers the design of street and highway facilities having Traffic Indices less than 8 based on a 10 year design life. It is felt that the higher magnitude of traffic (T.I.= 8 or more) requires the same criteria used for state highways. The design of structural sections for these highways is adequately covered in the Highway Design Manual of the California Department of Transportation (1). Information on test methods and materials is covered in the Materials Manual (2) which is also published by the California Department of Transportation.

THE STRUCTURAL SECTION AND ITS COMPONENTS -- DEFINITIONS AND USES

Flexible Pavement - Pavement having sufficiently low bending resistance to maintain intimate contact with the underlying structure, yet having the required stability to support the traffic loads; e.g., macadam, crushed stone, gravel, and all bituminous types not supported on a rigid base.

Surface Course - The top layer of a pavement, designed to provide structural value and a surface resistant to traffic abrasion. It should help protect the lower layers in the pavement structure from extreme climatic effects and should be dust-free and skid-resistant.

Base Course - The layer of a two or more course pavement placed directly under the surface course. It is characterized by good load distribution qualities.

Asphalt Concrete (AC) - Used primarily as a surface course, a full-depth pavement, and in some instances as a base course. Paving asphalts are normally specified for this material, and crushed rock or aggregate with high interparticle friction is desirable.

Road-Mixed Asphalt Surfacing - Normally called for when facilities for making asphalt concrete (AC) are not economically available. Liquid asphalts are normally used and the aggregate tends to be variable. It is used on low traffic volume roads where higher types of surfacing are not required for traffic service.

Bituminous Seal-Coat - A bituminous coating with or without aggregate applied to the surface of a pavement for the purpose of waterproofing and preserving the surface, rejuvenating a previous bituminous surface, altering the surface texture of the pavement, providing delineation or, providing resistance to traffic abrasion. Seal coats are suitable for delineating the traveled way. They provide a thin wearing surface and also fill shrinkage cracks in the pavement.

Penetration Treatment - This treatment consists of the application of light liquid asphalt to roadbed material. It is used principally as a dust palliative on detours, medians, and parking areas. It is also used for erosion control on cut and fill slopes.

Tack Coat - (Paint Binder) - The initial application of bituminous material to an existing asphalt concrete surface to insure bond between the superimposed construction and the old surface. It usually consists of an asphaltic emulsion, although paving asphalt is sometimes used.

Prime Coat - The initial application of a liquid bituminous material to an absorbent surface, preparatory to any subsequent treatment, for the purpose of hardening or toughening the surface to retard abrasion under traffic and promote adhesion between it and the superimposed construction. It usually consists of liquid asphalt.

Cement Treated Base (CTB) - A base layer constructed with good quality, well-graded aggregate mixed with up to 6% cement. CTB provides a high slab strength, allowing the imposed load to be spread over a large area. California Standard Specifications require an aggregate prequalification test such that aggregate to be used as CTB shall be of such quality that when mixed with up to 5% cement, the compressive strength (at optimum moisture) of a sample shall not be less than 750 psi after 7 days when tested by Test Method No. Calif. 312. However, due to construction variables, the compressive strength of field cores will be somewhat lower than those obtained in the laboratory. Class "A" CTB is therefore designed to have a minimum compressive strength of 1100 psi in seven days in the laboratory as defined by Test No. Calif. 312 to allow for this difference.

Class "A" CTB is used under asphalt concrete to provide added strength on the heavier travelled roads.

Class "B" CTB is not designed to provide a specific compressive strength. The cement is used primarily to increase the R-value of a material so as to make it suitable for use as a base course under a bituminous surface.

Lime Stabilized Materials - Lime is primarily used to treat clayey materials in the structural section. Response is normally poor when used with granular materials. Application is usually made in the basement soil or subbase layer although the use of lime stabilized material in the base course has been successful on lightly traveled roads. It is necessary to verify that materials can be satisfactorily treated with lime by appropriate testing.

Untreated Aggregate Base - High quality mineral aggregate used only in flexible pavement construction. It normally requires some processing to upgrade quality.

Subbase - One or more courses of soil or aggregate or both, of planned thickness and quality, placed on the subgrade as a foundation for a base. This is used where the basement soil will not support a structural section consisting of pavement and base alone, or where it is more economical to reduce the base thickness requirement by introducing this lower-priced layer.

Borrow - Basement soil obtained outside the roadway prism to make up a deficiency in embankment material. Borrow quality is sometimes specified in the project special provisions, but it is never a part of the structural section.

Basement Soil - The material in excavations, embankments, and embankment foundations immediately below the lowest layer of the structural section and extending to the depth that affects structural design.

Subgrade - The portion of the roadbed surface which has been prepared, as specified, and upon which a layer of specified roadbed material, base, or surfacing is to be placed.

CALIFORNIA DESIGN METHOD

An empirical equation is used by the California Department of Transportation for design of flexible pavement structural sections. This equation has its origin in test track data from the Brighton Test Road (1940-43) and the Stockton Airfield Test Track (1942). The test track constants used to develop this equation have since been modified based on results of the WASHO Road Test and, more recently, the AASHO Road Test. These constants have been adjusted to fit test track data to California pavement experience.

Factors Considered in the Design Equation

A. Effect of traffic - Thickness is a function of this factor (Traffic Index or TI).

B. Resistance value (R-value) of the supporting layer - Thickness is inversely related to the strength of the foundation material as indicated by the stabilometer test (R-value or R).

C. Strength of the pavement structure - Thickness is inversely proportional to the strength factor of the materials in the structural section (Gravel Factor or G_f).

D. The general thickness design equation may be expressed as follows:

$$\text{Thickness} = (\text{constant}) \; \frac{(\text{Effect of Traffic}) \; (\text{Resistance to deformation of supporting layer})}{(\text{Strength factor of layer being designed})}$$

$$\text{Specifically } T = \frac{0.0032(TI) \quad (100-R)}{G_f}$$

For convenience, the relationships expressed in the design equation have been developed in graphical or tabular form, and will be considered in this manner in the further discussions.

EFFECT OF TRAFFIC (TI)

The effect of traffic on a roadway over its design life is expressed by the Traffic Index. To estimate this factor, it is first necessary to reduce the many different types of vehicles and loads to a common denominator. This common denominator is the 18,000 pound equivalent axle load (EAL). The destructive effect of one passage of a given truck is expressed as an equivalent number of passages of an 18,000 pound axle load.

Estimation of the total number of EAL's on a section of road for a given period of time has been simplified by the use of truck constants. A truck constant is a number which represents the total number of 18,000 pound axle loads which would be generated in one year by the passage of one truck per day in one direction. This truck is assumed to be carrying an average load which has been determined through statistical treatment of axle load and frequency data. Each axle classification (e.g., 2-axle, 3-axle, etc.) has a separate truck constant. A method for calculating truck constants is shown in Appendix A for those agencies having unique truck loadings.

If accurate truck constants are desired, they should be calculated for the highway or street under consideration (3). Because of the cost, this would normally be done only for special situations where the engineer feels the traffic is unique and he needs the information to effect a savings or justify a heavier section. For the typical situation, the constants listed in Table A-5 of Appendix A may be used. These constants represent the results of statewide loadometer analyses. The State Highway constants are checked annually and are revised when significant change is noted. Most engineers using this manual will be concerned only with the second column of constants entitled "City Streets and County Roads" which were developed in 1966. The first column should be used in the design of roads and streets with a 10-year T.I. of 8 or more.

To evaluate the destructive effect of traffic for a given project, the total number of EAL's expected on the road during its design life is estimated by using truck constants in conjunction with average daily one-way truck traffic (ADTT) data from classified traffic counts. The data are expanded separately for each axle classification according to the engineer's estimate of the increase or decrease in truck traffic volume expected during the life of the facility. This total anticipated EAL is then converted by formula (Table A-1 in Appendix A), to Traffic Index (T.I.). The Traffic Index is a convenient number to use in designing structural sections as it bears a direct relationship to the thickness of pavement required. Appendix A presents the T.I. calculation in a step by step manner.

The design period or life of a pavement would not normally be less than 10 years. When truck traffic volume approaches that of a state highway, a 20-year design life should be used. Shorter periods are used when the pavement is only temporary construction or when the pavement is to be replaced by new construction before the end of the normal design period.

METHODS FOR OBTAINING TRAFFIC INDEX

The standard method of traffic evaluation provides the most accurate data and should be used whenever possible. This method calls for:

1. Truck constants, either those developed especially for the project or those listed in this text. (Table A-5, Appendix A).

2. A truck traffic count showing truck volume classified according to number of axles per truck and presented as Average Daily Truck Traffic. Counts should be labeled for one-way or two-way traffic as appropriate.

3. Factors to estimate increase or decrease in traffic volume during design life of pavements.

4. Design life of pavement. Normally 10 years. Heavey traffic may indicate consideration of a 20-year design life.

The procedure for calculating T.I. according to this method is found in Appendix A. In general, a T.I. less than 4 should not be used.

Estimation of T.I. by ADT and Percentage of Trucks (10-year design life)

A somewhat less sophisticated and less accurate method of estimating the traffic index is the subject of the graph shown in Figure 1. To estimate T.I. by this method, the engineer needs:

1. A number representing the average daily two-way traffic (ADT) for the proposed facility.

2. Truck volume as a percentage of the ADT.

3. Some idea as to the expected increase in ADT during the design life of the project as well as an idea of anticipated change in the percentage of trucks using the road.

The first step in the estimation of a T.I. by this method is to obtain the ADT and percentage of trucks for the facility. On an existing road, this may be easily done by relatively inexperienced personnel. Counts may be made on a 24-hour basis or by spot checks and should include both directions of traffic.

Vehicles to be counted as trucks include buses and two and more axle trucks. Pickups, panel trucks and cars with trailers are not classed as trucks.

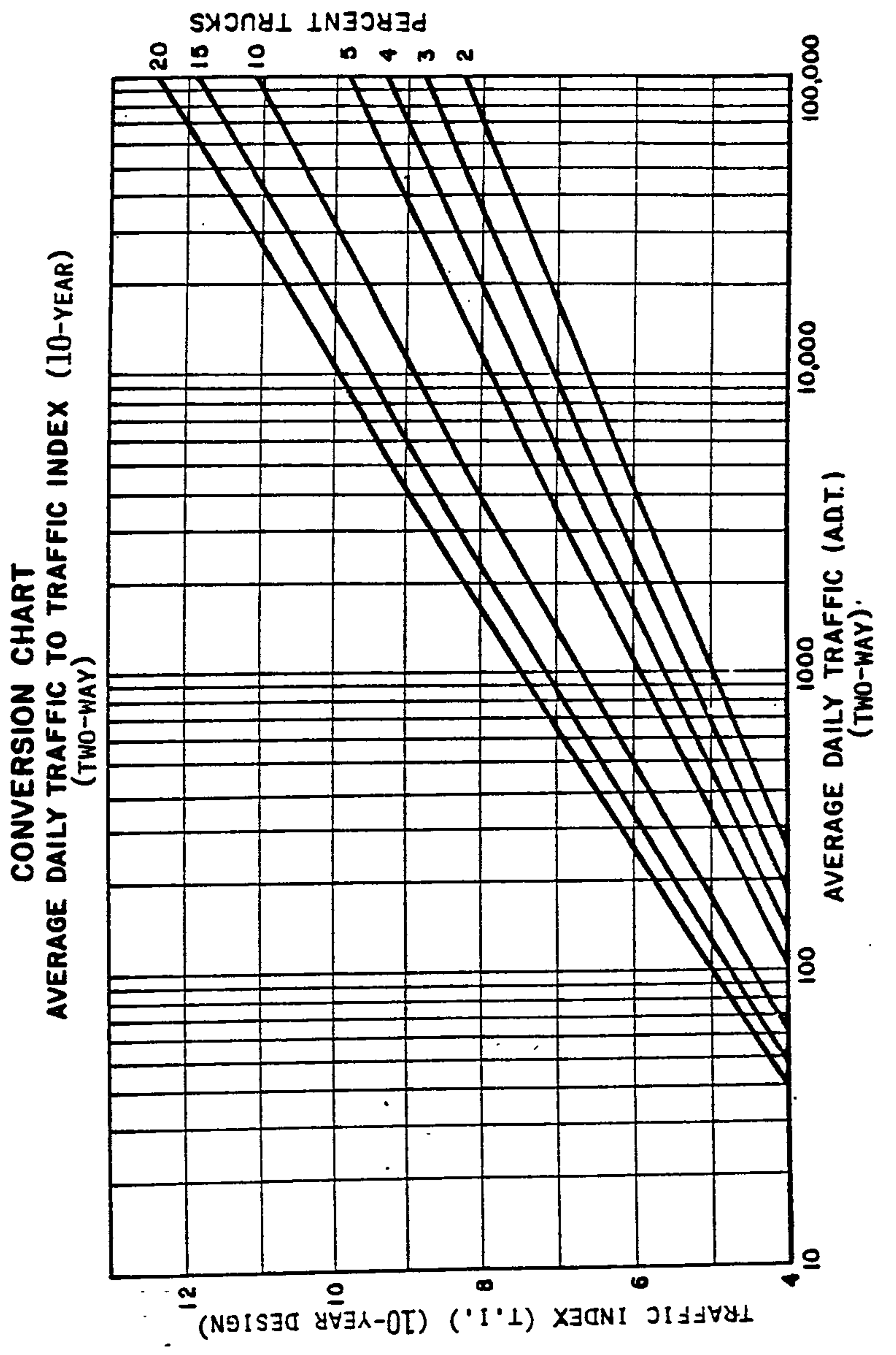
The ADT and percentage of trucks should next be modified to represent the average condition for the design period. If the opening ADT is 1,000 and the anticipated ADT at the end of the design period is 1,400, the chart should be entered with an ADT of 1,200. The same holds true for truck percentage.

The ADT/T.I. chart is based upon a 10-year design life. Data for the chart was taken from the 1963 classified vehicle census and developed using the constants for city streets and county roads shown in this text.

Estimation of T.I. According to Road Type (10-year design life)

In the absence of more detailed knowledge, traffic may be estimated by considering the type of facility to be designed. Estimates of traffic made in this manner tend to be inaccurate and, for this reason, should allow for a safety factor. The estimated Traffic Index should be justified by a description of the facility, the area it serves, and the normal types of traffic carried. The following table lists several road categories and the T.I. which might be expected to correspond with these categories. The last four categories in the table are difficult to estimate. Since roads in these categories are more critical with regard due to heavier traffic, the T.I. should be estimated using either the standard method or the chart shown in Figure 1 if at all possible.

FIGURE I


CONVERSION CHART
AVERAGE DAILY TRAFFIC TO TRAFFIC INDEX (10-YEAR)
(TWO-WAY)
PERCENT TRUCKS
20
15
10
5
4
3
2
10
100
1000
10,000
100,000
AVERAGE DAILY TRAFFIC (A.D.T.)
(TWO-WAY)
4
6
8
10
12
TRAFFIC INDEX (T.I.) (10-YEAR DESIGN)

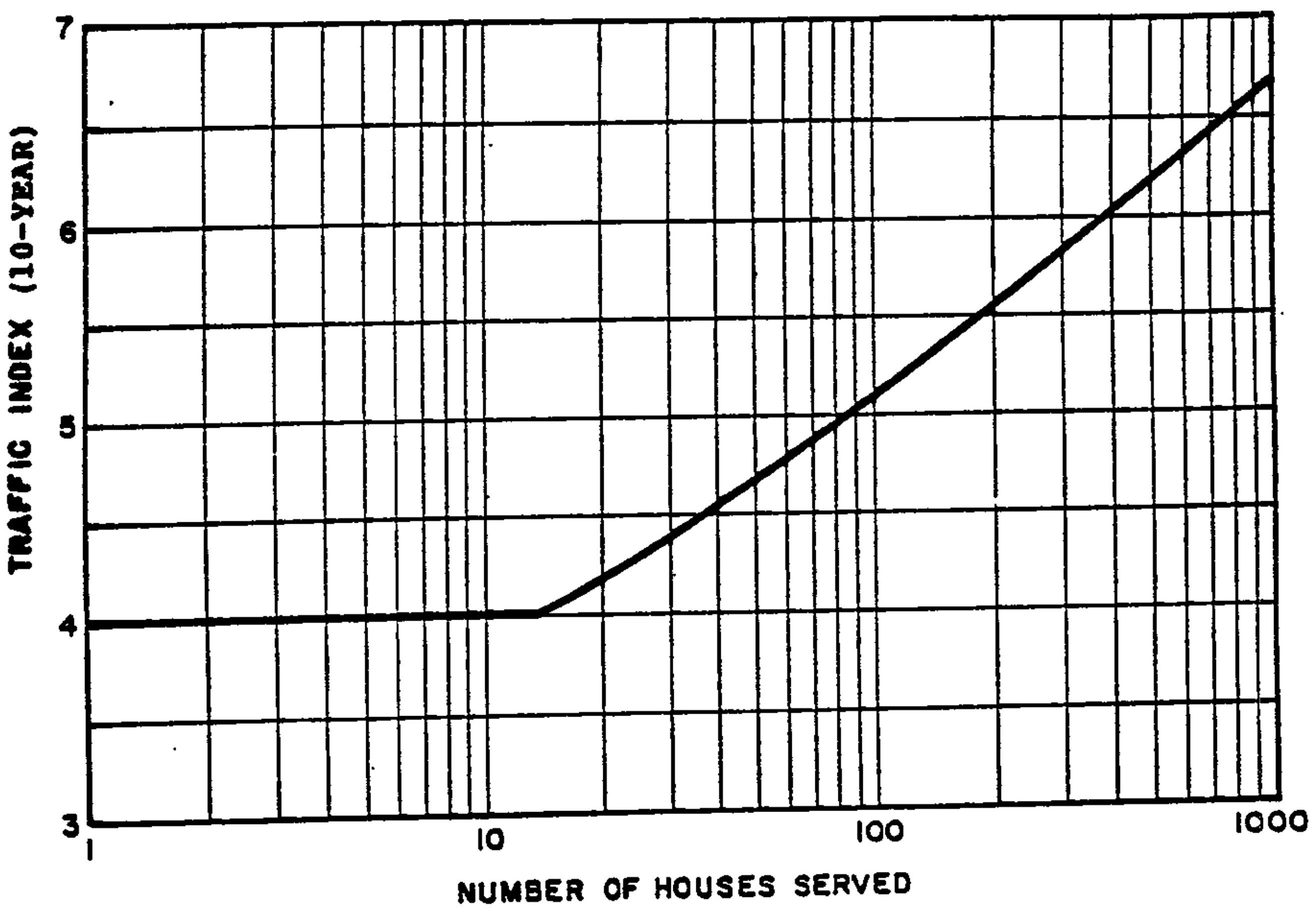
TYPE OF FACILITY	T.I. (10-Year)
Minor residential streets and cul-de-sacs.	4
Average residential streets.	4.5
Residential collectors and minor or secondary collectors.	5
Major or primary collectors providing for traffic movement between minor collectors and major arterials.	6
Farm-to-market roads providing for the movement of traffic through agricultural areas to major arterials.	5 - 7
Commercial roads (arterials serving areas which are primarily commercial in nature).	7 - 9
Connector roads (highways and arterials connecting two areas of relatively high population density).	7 - 9
Major city streets and thoroughfares and county highways.	7 - 9
Streets and highways carrying heavy truck traffic. This would include streets in heavily industrialized areas.	9+

For subdivision traffic only, it is permissible to use the chart shown in Figure 2. This chart relates Traffic Index to the number of houses served. It should be emphasized that this chart applies only to residential and collector streets. Streets carrying other traffic through the subdivision and streets going by a commercial area should not be analyzed by a house count chart.

Prior to the use of this chart, the engineer should consult with the area planners as to future plans for temporarily dead-ended streets. Many times either commercial developments tie into residential collectors, or the collectors are extended to serve much larger areas.

The chart is based upon each residence generating an average eight trips per day. Truck traffic is assumed to be three percent of the subdivision traffic. The truck traffic is assumed to consist, almost exclusively, of 2-axle and 3-axle vehicles. Truck constants

CHART FOR ESTIMATION OF TRAFFIC INDEX
USING A HOUSE COUNT



Notes: For use only within subdivisions for residential and residential collector streets.

Chart is based on a 10-year design life.

of 34 for the 2-axle, and 117 for the 3-axle trucks are based upon the common trucks found on these streets. Truck traffic is assumed to consist of 89% 2-axle, and 11% 3-axle trucks. Traffic Indices are based upon a ten-year design life for the facility.

Estimation of T.I. in Special Situations

Many times a particular road presents a unique situation which demands that the engineer use a little more judgment to arrive at a truly representative Traffic Index. An example of such a situation might occur where a road serves an agricultural or recreational area or has a heavily used rock quarry at some point along the route. Since the rock trucks would haul one way loaded and one way empty, the engineer could use a different T.I. for each direction of travel and effect significant economy in design.

QUALITY OF SUBGRADE SUPPORT (R)

The term "resistance", as used in this guide, refers to the ability of a material to resist lateral deformation when acted upon by a vertical load. When displacement occurs, the soil moves out and away from the applied load. This displacement of soil causes a "wave development" on all sides of the load. The object of the design procedure is to keep this displacement within certain limits, depending on traffic and surfacing.

Measurement of the resistance or R-value is made by means of the stabilometer test. An index of resistance to displacement is arranged on a scale from 0 to approximately 100. Theoretically, water would have an R-value of 0 since it would transmit pressure equally in all directions, while steel would show an R-value of almost 100 since no measurable deformation would occur. Soils and aggregates will range from less than 5 to about 85.

The R-value is determined using soil specimens which are compacted in a manner to approximate the condition of soil in the field. The specimens are tested in a state as near to full moisture saturation as possible. Thus, the R-value represents the worst possible state the soil might attain at the typical field density state.

The procedure also takes into account the fact that some soils are expansive. When a compacted soil expands on exposure to free water, the density and particle arrangement of the mass are disrupted causing a lowering of the stability of the material. This is compensated for in the California design method by determining the expansive tendency of the soil at various water contents. If the expansion is found to be above that tolerable, the data is used to adjust the R-value downward. This results in design of a thicker cover layer because of the lower strength within the supporting soil caused by the water taken on during expansion.

DETERMINATION OF THE R-VALUE

The stabilometer test (Test Method No. Calif. 301) is the standard method for obtaining an R-value. This test method will not be elaborated upon at this point.

If R-value tests have been made in the past on nearby, similar soils, it is sometimes possible to use this information to evaluate the soil in question. To do this, it is necessary to perform simple classification tests on the soil to be evaluated and to compare these results with those obtained on the previously tested nearby soil. If the grain size classification and Atterberg Limits are comparable and if the soil is apparently from the same soil formation, then the probability is high that the R-values will be similar.

Diligence in record keeping will pay dividends, if the records help save the cost of extensive R-value testing.

When sampling areas for new construction, it is essential to use good judgment. If the job includes cut and fill work, it would do no good to sample material at the bottom of the fill sections which will be covered with material from an adjacent cut. The material which will form the basement soil for the project is the material to be sampled. Sufficient samples should be taken to establish the quality of the different soils on the job. Design would normally be based on the lowest expected R-value unless large areas of good and bad material allow the designer to economically change the design at intervals. Changes in structural section design will not always effect a savings if they are made too often. Sometimes it is economically feasible to remove a short section of low R-value material to allow a design based on the higher R-value soil.

Other information useful at this point might include:

1. Identification of soil types from existing soil maps, aerial photographs, and other sources. Agricultural agencies and geological agencies may be able to contribute much information.

2. Investigation of ground water conditions, especially during severe periods (winter, irrigation, etc.).

3. Examination and sampling, when appropriate, of existing roadway cuts and other excavations.

4. Review of the design and construction of existing roads in the vicinity and their present condition.

5. Discussions with maintenance personnel and others who may have personal knowledge of conditions affecting the design.

6. An excellent guide in outline form to items which may be considered for investigation is the "Materials Report Outline," Section 130, California Department of Transportation Materials Manual.

Estimation of R-value Using Soil Classification

Rough estimates of R-value can be made using some simple soil classification tests in conjunction with the sand equivalent (SE) test. Each soil type (e.g. sandy clay, etc.) roughly encompasses a certain R-value range. The R-value range for a soil type may be narrowed by knowing more about the soil's plasticity and by knowing its sand equivalent (SE) value (Test Method No. Calif. 217). Soil classification sheets and a triangular chart (Figures 3 and 4) are included as aids. To classify soils on the triangular chart (Figure 4), a sieve analysis and hydrometer analysis are necessary (Test Method Nos. Calif. 201, 202, and 203).

When the soil classification has been determined from Figure 4, the chart in Figure 5 may be used to approximate the R-value. In this chart, the curves representing the various soil types show a stylized approximate frequency distribution of R-values for that particular type soil.

For fine-grained materials, the upper tail or high R-value portion of the curve represents lower plasticity, relative to the soil type, while the lower tail represents soils of the same type having higher plasticity. The sand equivalent values provide additional subdivisions within the chart.

For a particular SE value, chances are good that the R-value for the same material will be as high or higher than the R-value designated by the corresponding dashed line. The converse, however, is not true since it is possible for a material to have a high R-value with a relatively low SE.

The curves for coarse-grained materials are affected in the same manner, by the presence of clay, with the lower tail representing materials with either more clay or clay with higher activity. In coarse-grained materials with little or no clay, the lower tail represents hard, smooth-surfaced and poorly graded (well sorted) material while the upper tail represents rough-surfaced and well graded material.

The use of the chart must be tempered with good judgment and it should always be borne in mind that R-values obtained in this manner are estimations only. The reasoning behind these estimations should be fully documented in the materials report to provide the reviewers with as much basic data as possible.

FIELD CLASSIFICATION OF SOILS

Minimum Description Required for Classification of Soil in place as sampled

	PROPERTY		FIELD IDENTIFICATION
1.	MOISTURE		Dry-Moist-Wet-Very Wet (very wet means free water evident)
2.	a. COMPACTNESS coarse grained soils		Loose-Dense-Very dense
	b. CONSISTENCY fine grained soils		Very soft — Exudes between fingers when squeezed. Soft — Easily molded in fingers. Firm — Can be molded by strong pressure in fingers Stiff — Cannot be molded in fingers. Hard — Brittle or very tough
3.	COLOR		Indicate range of color: e.g. brown to reddish brown. Use qualifying adjective to indicate cast, as reddish, vs.
4.	SOIL TYPES	SIZE	
Coarse grained non-cohesive	Broken rock	+3"	Angular fragments of rock
Coarse grained non-cohesive	Stone Coarse Medium Fine	 -3" + 1" -1" + 3/8" -3/8" + #10	Crushed or naturally angular rock particles
Coarse grained non-cohesive	Boulders	+6"	Rounded fragments of rock
Coarse grained non-cohesive	Cobbles	-6" + 3"	Rounded
Coarse grained non-cohesive	Gravel Coarse Medium Fine	 -3" + 1" -1" + 3/8" -3/8" + #10	Rounded rock particles
Coarse grained non-cohesive	Sand Coarse Fine	 -#10+ #40 -#40 + #200	Particles visible to naked eye. No cohesion when dry.

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	4. SOIL TYPES CONT'D.	SIZE	FIELD IDENTIFICATION
Fine Grained Cohesive Soils	Silts	-#200 + 5 Micron	Particles mostly -200; barely visible to naked eye. Some plasticity, and exhibits marked dilatancy (Shaking test shows quick or "livery" condition.) Dries mod. quickly and can be dusted off the fingers. Dry lumps possess cohesion, but easily powdered in fingers.
	Loams		Contain sand, silt and clay sizes; possess mod. plasticity.
	Sandy Clay		Mod. to high plasticity and dry strength. No dilatancy.
	Silt-Clay		Fine grained (-200). No dilatancy. Appreciable plasticity.
	Clay	-5 Micron	Smooth to touch and plastic, no dilatancy. Sticks to fingers and dries slowly. Shrinks appreciably on drying. Dry lumps can be broken but not powdered. They disintegrate under water. { Lean clays show these properties to low degree. Fat clays show these properties to high degree. }
Organic	Peats		Fibrous organic matter, usually brown or black in color. Firm — Fibers compressed together. Spongy — Very compressible and open structure.
5. PLASTICITY			Non-plastic; slightly plastic; moderately plastic; highly plastic. Inherent property of soil. Moisten as necessary to evaluate plasticity.

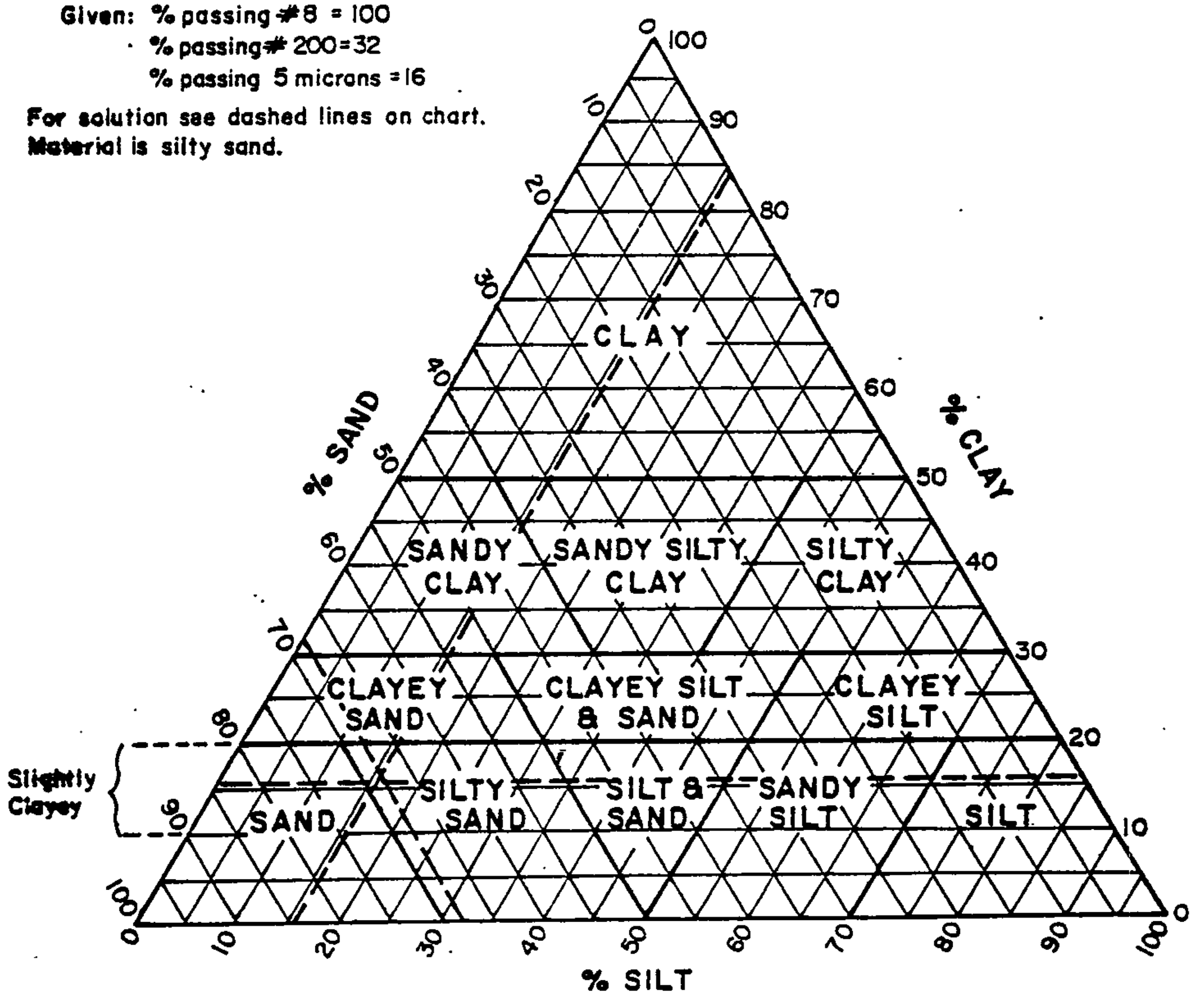
SOIL CLASSIFICATION CHART

% CLAY = % finer than 5 microns
% SILT = % passing #200 − % clay
% SAND = % passing # 8 − % passing # 200

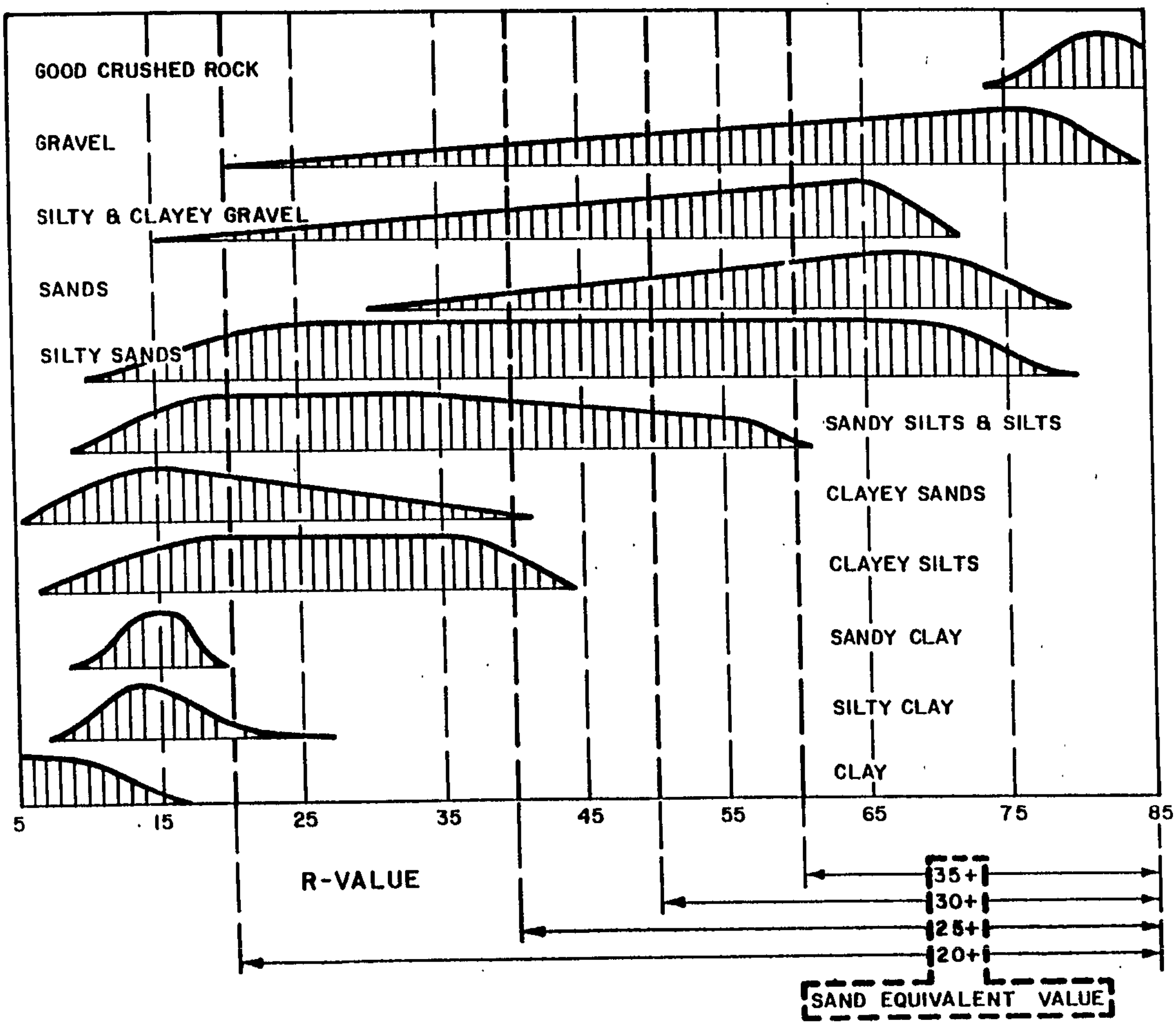
If over 50% is retained on # 8.
sample is gravel-modified by amounts
of other constituents contained. (sand, silt, clay)

EXAMPLE CLASSIFICATION
Given: % passing #8 = 100
% passing # 200 = 32
% passing 5 microns = 16

For solution see dashed lines on chart.
Material is silty sand.



ESTIMATION OF R-VALUE USING SOIL CLASSIFICATION AND SAND EQUIVALENT



STRENGTH OF STRUCTURAL LAYERS (G_f)

The capacity of the structural section layers to resist the forces imposed by traffic is expressed in terms of their "gravel equivalent factor (G_f)". This is an empirical factor developed through research and field experience, which relates the relative strength of a unit thickness of the particular material (AC, CTB, Class 3 AS, etc.) in terms of an equivalent thickness of gravel. It is important to note that the various materials must meet certain quality requirements (grading, R-value, SE, etc.) in order to have the strength assumed for the gravel factor assigned.

G_f values assigned to the various construction materials are tabulated in Figure 8. A graph illustrating the relationship between G_f for asphalt concrete and the Traffic Index is shown in Figure 6. This graph enables interpolation between the values shown in Figure 8 and allows the designer small advantages in economy if he chooses to design by the formula rather than by tables.

STRUCTURAL SECTION DESIGN PROCEDURE

The Standard design procedure is shown in the Highway Design Manual, 7-651. This procedure uses the design formula and allows the designer to design each layer to the most economical thickness. Use of this formula requires three variables: T.I., R-value, and G_f.

The design chart shown in Figure 7 is taken from the Design Manual, and offers a quicker approach to the design problem. Complete instructions for use of the chart are shown in Figure 8.

RELATIONSHIP BETWEEN GRAVEL EQUIVALENT FACTOR FOR ASPHALT CONCRETE AND TRAFFIC INDEX

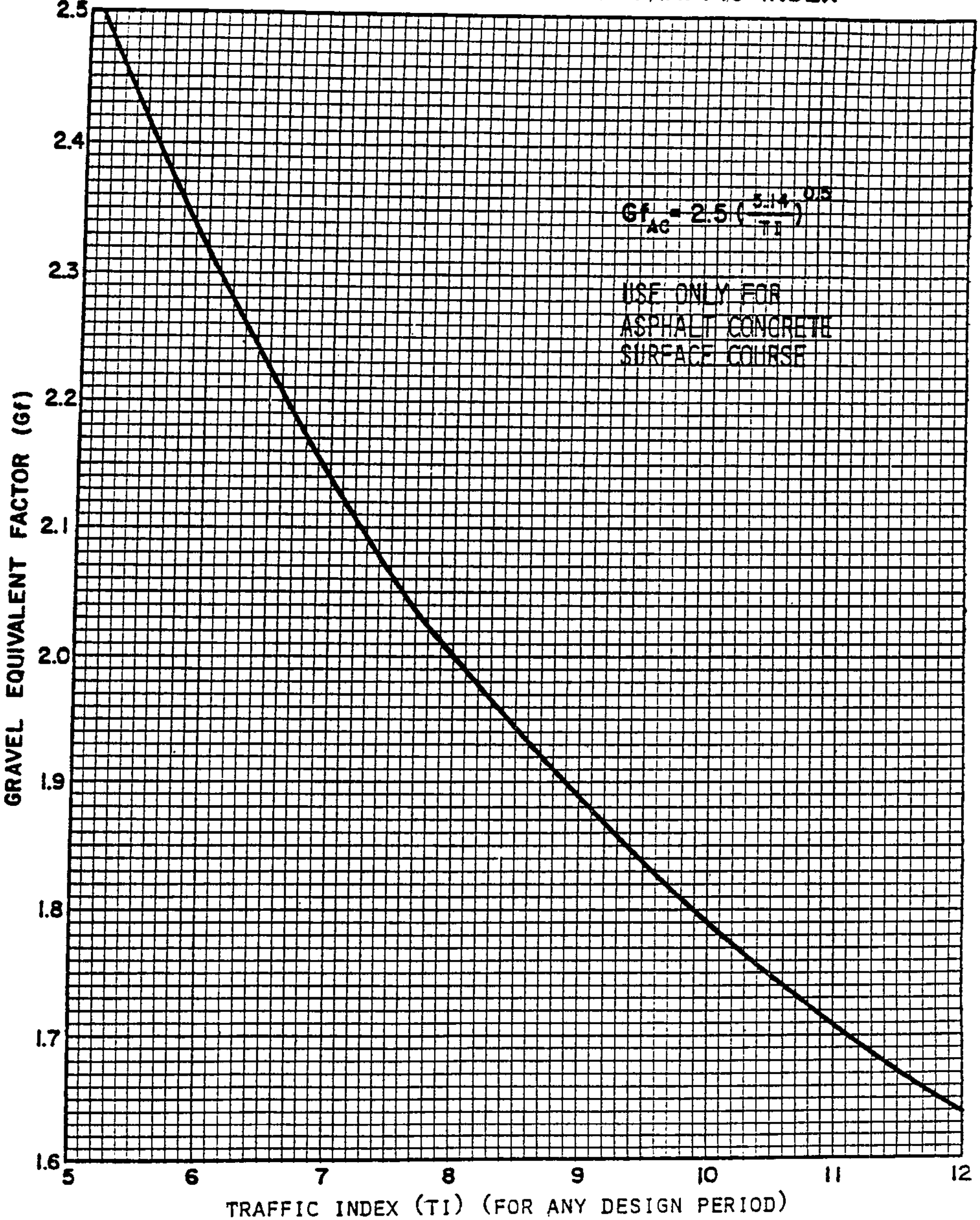
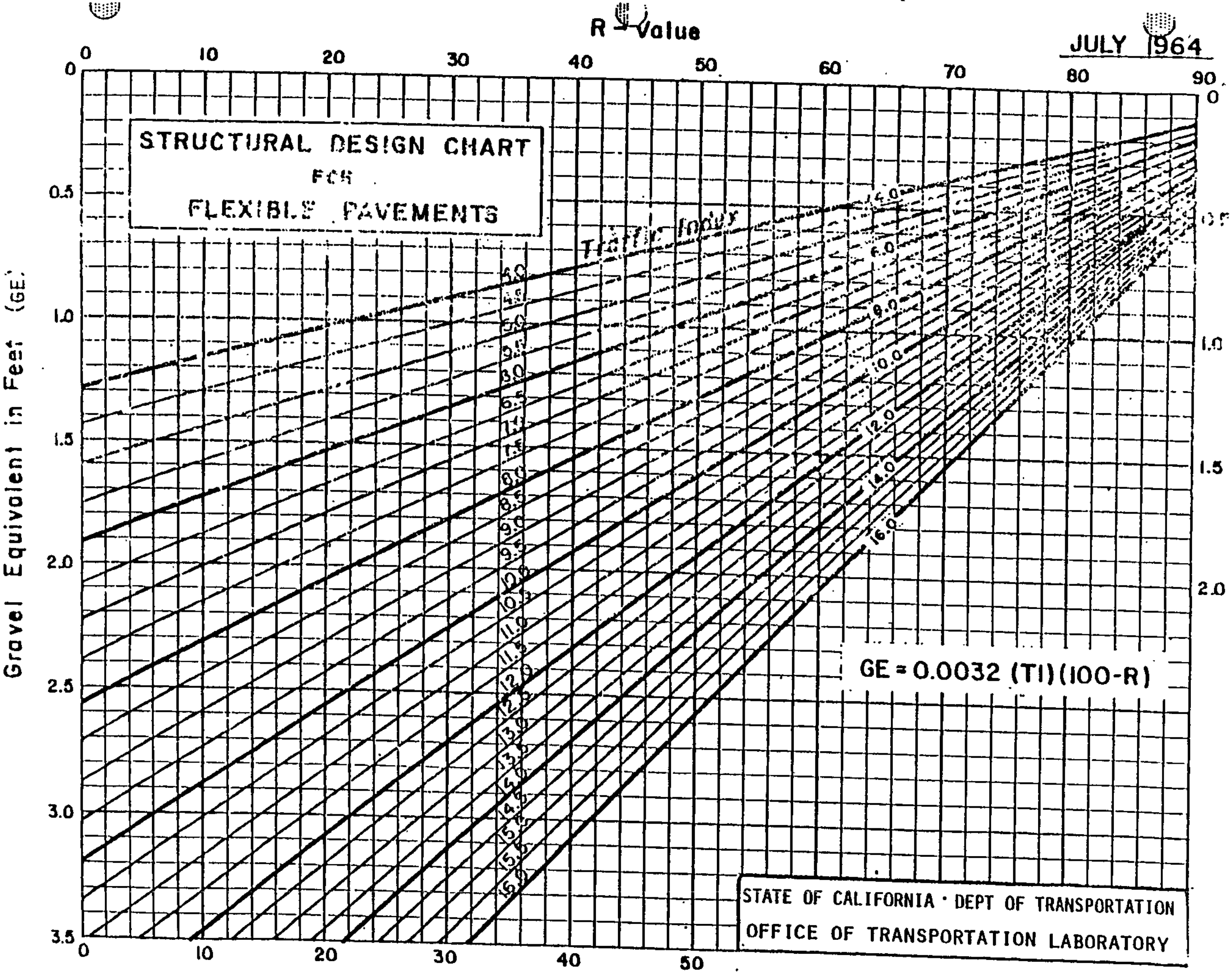


FIGURE 6



STRUCTURAL DESIGN CHART
FOR
FLEXIBLE PAVEMENTS
R - Value
JULY 1964
Traffic Index
GE = 0.0032 (TI)(100-R)
Gravel Equivalent in Feet (GE)
STATE OF CALIFORNIA · DEPT OF TRANSPORTATION
OFFICE OF TRANSPORTATION LABORATORY

FIGURE 8

INSTRUCTIONS FOR USE OF STRUCTURAL DESIGN CHART

1. Find total GE - Intersect TI line with basement soil R-value line and read GE.

2. Select type of base to be used.

3. Find GE of surfacing - Intersect TI line with base material R-value line (Use R-80 for Class "B" CTB) and read GE. For Class "A" CTB select the surfacing thickness from Table III.

4. Find thickness of surfacing - Convert GE to actual thickness using $T = GE/G_f$ or if thickness was found in Table III solve for GE. Round off thickness to the nearest .05 foot or, preferably, to the next highest .05 foot and adjust the GE accordingly.

5. Find GE of surfacing + base - Intersect TI line with subbase material R-value line and read GE.

6. Find thickness of base - Subtract the adjusted GE found in Step 4 from the GE in Step 5 and convert the remainder to thickness using $T = GE/G_f$. Round off the thickness to the nearest .05 foot or, preferably, to the next highest .05 foot and adjust the GE accordingly.

7. Find thickness of subbase - Add the adjusted GE from Step 4 to the adjusted GE from Step 6, and subtract the result from the GE found in Step 1. Round off to the nearest .05 foot or, preferably, to the next highest .05 foot.

TABLE 1

Gravel Equivalents of Structural Layers in Feet

Actual thickness of layer feet	ASPHALT CONCRETE Traffic Index (TI) 5 and below	5.5 6.0	6.5 7.0	7.5 8.0	8.5 9.0	9.5 10.0	10.5 11.0	11.5 12.0	12.5 13.0	13.5 14.0	ETB	LTB	Cement-treated Base Class A	Cement-treated Base Class B	Aggregate Base	Aggregate Subbase
	Gravel Equivalent Factor (G_f)										G_f	G_f	G_f		G_f	G_f
	2.50	2.32	2.14	2.01	1.89	1.79	1.71	1.64	1.57	1.52	1.3	1.2	1.7	1.2	1.1	1.0
0.20......	0.50	0.46	0.43	0.40	0.38	0.36	0.34	0.33	0.31	0.30	0.26	....	....	....	....	....
0.25......	0.63	0.58	0.54	0.50	0.47	0.45	0.43	0.41	0.39	0.38	0.33	....	....	....	....	....
0.30......	0.75	0.70	0.64	0.60	0.57	0.54	0.51	0.49	0.47	0.46	0.39	0.36	....	....	....	....
0.35......	0.88	0.81	0.75	0.70	0.66	0.63	0.60	0.57	0.55	0.53	0.46	0.42	0.60	0.42	0.39	0.35
0.40......	1.00	0.93	0.86	0.80	0.76	0.72	0.68	0.66	0.63	0.61	0.52	0.48	0.68	0.48	0.44	0.40
0.45......	....	1.04	0.96	0.90	0.85	0.81	0.77	0.74	0.71	0.68	0.59	0.54	0.77	0.54	0.50	0.45
0.50......	....	1.16	1.07	1.01	0.95	0.90	0.86	0.82	0.79	0.76	0.65	0.60	0.85	0.60	0.55	0.50
0.55......	....	....	1.18	1.11	1.04	0.98	0.94	0.90	0.86	0.84	0.72	0.66	0.94	0.66	0.61	0.55
0.60......	....	....	....	1.21	1.13	1.07	1.03	0.98	0.94	0.91	0.78	0.72	1.02	0.72	0.66	0.60
0.65......	....	....	....	1.31	1.23	1.16	1.11	1.07	1.02	0.99	0.85	0.78	1.11	0.78	0.72	0:65
0.70......	....	....	....	....	1.32	1.25	1.20	1.15	1.10	1.06	0.91	0.84	1.19	0.84	0.77	0.70
0.75......	....	....	....	....	....	1.34	1.28	1.23	1.18	1.14	0.98	0.90	1.28	0.90	0.83	0.75
0.80......	....	....	....	....	....	1.43	1.37	1.31	1.26	1.22	1.04	0.96	1.36	0.96	0.88	0.80
0.85......	....	....	....	....	....	1.52	1.45	1.39	1.33	1.29	1.11	1.02	1.45	1.02	0.94	0.85
0.90......	....	....	....	....	....	....	1.54	1.48	1.41	1.37	1.17	1.08	1.53	1.08	0.99	0.90
0.95......	....	....	....	....	....	....	....	1.56	1.49	1.44	1.24	1.14	1.62	1.14	1.05	0.95
1.00......	....	....	....	....	....	....	....	1.64	1.57	1.52	1.30	1.20	1.70	1.20	1.10	1.00
1.05......	....	....	....	....	....	....	....	....	1.65	1.60	1.37	1.26	1.79	1.26	1.16	1.05

NOTES: ETB is emulsion treated base constructed with emulsified asphalt.
LTB is lime treated base.
For the design of road-mixed asphalt surfacing, use 0.8 of the gravel equivalent factors (G_f) shown above for asphalt concrete.

SAFETY FACTORS

The basic thickness design formula contains sufficient built-in safety allowance for low-volume roads and streets. Facilities with a T.I. of 8 and over might benefit from use of the safety factors shown in Table II. The factors are particularly needed where ADT and T.I. are high. In this type of situation, traffic density causes hazardous conditions during maintenance operations and prevents closure of the roadway for repairs. It is best in these cases to construct a section with a long, maintenance-free life.

Where desired, the safety factors in Table II, below may be applied to sections designed by the above method. For sections using aggregate bases and Class "B" CTB, add the GE increase to the GE found in Step 5. In each case, convert the new GE to thickness, round off the new thickness and adjust the GE accordingly. Since the addition of the safety factor should not change the total GE, the subbase thickness must be reduced to compensate for the increased thickness of the layer to which the safety factor was applied.

Additional information on the application of the safety factor is shown in the California Department of Transportation Design Manual (1). The safety factors primarily correct for deficiencies in layer thicknesses resulting from permissible construction tolerances.

TABLE II

STRUCTURAL SECTION SAFETY FACTORS

Base Type	Gravel Equivalent Increase in Feet	Layer Applied to
*Class "A" CTB	0.24	CTB
Class "B" CTB	0.18	AC
Aggregate Base	0.16	AC

*When no high subgrade is allowed, the gravel equivalent increase is 0.10 foot for Class "A" cement treated base.

TABLE III

Typical Depths of Pavement and Base Related to TI (R=50)
(Design Period Defined in T.I. Calculations)

Type of base material	Pavement or base layer	Depth of Layer (feet) TI 5.0	TI 6.0	TI 7.0	TI 8.0	TI 9.0	TI 10.0	TI 11.0	TI 12.0	TI 13.0	TI 14.0
Class A CTB	Pavement	....	....	....	0.25	0.30	0.35	0.40	0.45	0.50	0.55
	Base	....	....	....	0.60	0.65	0.70	0.80	0.85	0.90	0.95
Class B CTB	Pavement	....	0.25	0.30	0.35	0.40	....	....	....	....	....
	Base	....	0.45	0.55	0.65	0.70	....	....	....	....	....
Class 1 AB	Pavement	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.65	....
(80R-value)	Base	0.40	0.50	0.60	0.65	0.75	0.85	0.95	1.05	1.10	....
Class 2 AB	Pavement	0.20	0.25	0.30	0.35	0.40	0.50	0.55	0.60	....	....
(78R-value)	Base	0.40	0.50	0.60	0.65	0.75	0.80	0.90	1.00	....	....

NOTES: The above table was made as a guide with the thicknesses based on the TI in each column and the assumption made that subbase with an R-value of 50 would be used. Extra thickness was added for a safety factor as stated above.

The thicknesses shown satisfy the theoretical required thickness. However, common sense and knowledge of construction practice may, in the case of the thinner layers, dictate greater thicknesses of a particular material. In general, it is difficult to obtain good results over an untreated base with less than 0.20 ft. (2-1/2") of asphalt concrete surfacing. It is also very difficult to properly place and compact layers of aggregate base or subbase when these layers measure less than 0.33' (4").

If a design calls for a thin aggregate base layer (less than 0.4') as well as a thin aggregate subbase layer, it might be well to combine the two and place a layer of base equal to the total thickness. This would save placing costs and provide a better design. This discussion applies, of course, to any method of design.

For the design of sections using bases other than aggregate base, it is necessary to go to the standard method or use Figure 7.

Full-depth asphalt concrete pavements can be designed by using Table IV as defined in the following section.

STRUCTURAL SECTION DESIGN EXAMPLE

To illustrate a typical design, the following example is presented. Although the example uses the design formula, it is so structured that the engineer may also follow through with the more approximate methods.

Problem: Design a structural section for a county farm-to-market road based on the following traffic counts and laboratory test data, using a ten year design period. Average daily traffic (ADT) is around 880 with about 10% truck traffic.

Truck Traffic Counts

Truck Category	Present ADTT	
	Two-way	One-way
2-axle	62	31
3-axle	10	5
4-axle	4	2
5-axle	12	6

It is estimated that truck traffic 10 years after construction will be 2.0 times the present truck traffic except for 5-axle trucks which are estimated to increase 1.5 times present traffic in the same period. Estimates were arrived at after consultation with planners and consideration of future land use.

Laboratory Soil Test Data

Test results from:

	Location 1	Location 2	Location 3
Sand Equivalent	5	7	9
R-value	10	12	15
Grading Analysis:			
% Passing No. 8	100	100	100
% Passing No. 200	73	60	39
% Passing 5 Micron	32	26	15

Visual inspection along the route indicates that three main soils are present. The location runs through an old flood plain and the soils are intermingled and hard to delineate.

Solution:

Step 1 - Determine Traffic expansion factors

5-axle trucks $\frac{1 + 1.5}{2} = 1.25$

Other trucks $\frac{1 + 2.0}{2} = 1.50$

Note that this is a "mid-period" factor which, when multiplied by average annual EAL* and number of years in the design period, will yield total EAL. Determination of this factor entails considerable engineering judgment and consideration of overall area development.

*EAL = Equivalent 18,000 pound axle loads

Step 2 - Determine Equivalent 18,000 pound Axle Load Repetitions EAL. The truck counts indicate a normal mixture of farm-to market traffic so that the City-County EAL constants may be used as is.

Truck Category	Present ADT (One-way)	Expansion Factor	Expanded ADT	EAL* Constants	Annual EAL
2-axle	31	1.5	46.5	34	1,581
3-axle	5	1.5	7.5	117	877
4-axle	2	1.5	3	182	546
5-axle	6	1.25	7.5	288	2,160

Total Annual EAL = 5,164

Total 10-year EAL = 10 x 5,164 = 51,640

Step 3 - Convert Total EAL to Traffic Index

$$TI = 9.0\left(\frac{\text{Total EAL}}{10^6}\right)^{0.119}$$

$$TI = 9.0\ (0.0516)^{0.119}$$

$$TI = 9.0 \times 0.703 = 6.33$$

Use TI = 6.5 rounding off to nearest 0.5

Equation 2, Appendix A (or from Table A-1 or Figure A-2)

Step 4 - Interpretation of Laboratory Test Data.

The design method is based on the R-value test data. The sand equivalent values and grading analyses on the same soil samples are used for supplemental information to aid in classifying the material encountered.

An important point to remember is that the samples taken must be representative of material which will lie immediately under the planned structural section.

An R-value of 10 should be used in designing a structural section for this project since it represents the lowest quality material encountered and the materials are so intermingled that it is not feasible to change the design R-value to take advantage of the better material.

* These constants represent average one-way EAL for one truck per day for one year using loadometer data from 1965 on selected city streets and county roads.

It is important to use judgment in selecting the R-value for design with a particular material, so that extreme test results do not unduly influence the results.

Step 5 - With the data obtained thus far, we may now design the structural section using a TI of 6.5 and an R-value of 10 for basement soils.

For illustration purposes, let us assume that it is desired to use Type "B" Asphalt Concrete, Class 2 Aggregate Base, and Class 2 Aggregate Subbase as the materials in the structural section.

Step 5a - Find the equivalent thickness of gravel required (gravel equivalent, or simply GE) for the Asphalt Concrete Pavement which will be placed over Class 2 Aggregate Base (78 Min. R-value material).

GE = 0.0032 (TI) (100-R) From Figure 7
GE = 0.0032 (6.5) (100-78)
GE = 0.46' required

Next, for a Traffic Index of 6.5, we obtain a gravel factor of 2.22 for Asphalt Concrete from Figure 6.

$$\text{Thickness of AC required} = \frac{0.46'}{2.22} = 0.21$$

Rounding to the nearest 0.05', use 0.20' AC

Step 5b - Find the thickness of Aggregate Base required

Class 2 Aggregate Subbase consists of 50 Min. R-value material

GE over 50 R-value material = 0.0032 x 6.5 x 50 = 1.04'
Deduct GE furnished by AC = 2.22 x 0.20' =-0.44'
GE required for Aggregate Base = 0.60'

Next we obtain a gravel factor of 1.10 for AB from Figure 8.

$$\text{Thickness of AB required} = \frac{0.60}{1.10} = 0.55'$$

Use 0.55' Cl. 2 AB

Step 5c - Find the thickness of Aggregate Subbase required over basement soils with an R-value of 10 Min.

GE required over 10 R-value matl. = 0.0032 x 6.5 x 90= 1.87'
GE furnished by 0.20' AC(from above) = 0.44'
GE furnished by 0.55' AB(1.10x0.55) = 0.60' -1.04'
GE of Cl. 2 AS required 0.83'
Gravel factor for Agg. Subbase is 1.0 (from Figure 8)
Hence the thickness of Cl. 2 AS required = 0.83'
Rounding to the nearest 0.05', Use 0.85' Cl. 2 AS

Step 5d - Check to see that adequate overall cover requirements are satisfied.

Total GE required = 1.87' (from page 20)
Total GE furnished with
0.20' AC x 2.22 = 0.44' gravel equivalent
0.55' AB x 1.10 = 0.60' " "
0.85' AS x 1.00 = 0.85' " "
1.89' " "

1.87' required; 1.89' furnished, therefore the structural section furnished is adequate, for each layer of material and for total cover required.

FULL DEPTH ASPHALT CONCRETE DESIGN

For an alternate structural section design solution, a procedure is presented for full depth asphalt concrete using Table IV. The California Department of Transportation has not completed its studies of this method. Initial indications appear good, however, and the method is provided for those that care to use it. Streets and roads designed using this interim method will be approved by the State.

Table IV provides asphalt concrete pavement thicknesses that are a compromise between the present California pavement design procedure and the full depth asphalt concrete design method of The Asphalt Institute (4).

By entering Table IV with a basement soil R-value of 10 and a design Traffic Index of 6.5, a full depth pavement thickness of 0.80' asphalt concrete is indicated for the previous example.

This chart was developed for full depth asphalt concrete pavement design by taking advantage of decreasing stress levels with depth and also increased cohesion provided by reduced temperatures in the lower portion of the pavement.

There are two cases in which the designer should utilize an intervening layer between the basement soil and the full depth asphalt concrete layer. The first case includes provision for a working table to support construction equipment when moist basement soil conditions are encountered. For the second case, economic consideration plays the main role in selection of an intervening layer between a thick asphalt concrete pavement and a low quality basement soil. The intervening layer could consist of basement soil stabilized with either lime, cement or asphalt depending on the materials and conditions encountered. (Note: Effective stabilization usually requires a minimum compacted thickness of 0.5 ft.)

FULL-DEPTH ASPHALT CONCRETE LAYER THICKNESS (FEET)

R-value of Underlying Material

T.I.	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
4.0	.45	.45	.40	.36	.34	.32	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30
4.5	.50	.50	.45	.44	.42	.39	.36	.34	.31	.30	.30	.30	.30	.30	.30	.30
5.0	.60	.60	.50	.48	.46	.43	.41	.38	.35	.31	.30	.30	.30	.30	.30	.30
5.5	.70	.65	.60	.54	.51	.48	.46	.43	.40	.36	.33	.30	.30	.30	.30	.30
6.0	.80	.75	.65	.60	.57	.54	.51	.47	.44	.41	.37	.33	.30	.30	.30	.30
6.5	.85	.80	.75	.67	.63	.59	.56	.52	.49	.45	.42	.37	.33	.30	.30	.30
7.0	.90	.85	.80	.74	.70	.66	.62	.58	.54	.49	.45	.41	.37	.31	.30	.30
7.5	.95	.90	.85	.81	.76	.72	.67	.63	.59	.54	.50	.45	.41	.35	.30	.30
8.0	1.00	.95	.91	.87	.83	.78	.73	.68	.63	.58	.54	.49	.44	.38	.35	.35
8.5	1.07	1.03	.98	.93	.89	.84	.79	.74	.69	.63	.58	.52	.47	.42	.35	.35
9.0	1.15	1.10	1.05	1.00	.95	.90	.85	.80	.74	.68	.62	.56	.50	.44	.40	.40
9.5	1.23	1.18	1.12	1.07	1.01	.96	.90	.85	.79	.73	.66	.60	.54	.47	.40	.40
10.0	1.31	1.26	1.20	1.14	1.08	1.02	.96	.90	.84	.78	.71	.64	.57	.50	.45	.45
10.5	1.39	1.33	1.27	1.21	1.15	1.08	1.02	.95	.89	.83	.76	.68	.61	.54	.45	.45
11.0	1.47	1.41	1.34	1.28	1.21	1.15	1.08	1.01	.94	.87	.80	.73	.65	.57	.50	.50
11.5	1.56	1.49	1.42	1.35	1.28	1.21	1.14	1.07	.99	.92	.85	.77	.69	.60	.50	.50
12.0	1.64	1.57	1.49	1.42	1.35	1.27	1.20	1.12	1.05	.97	.89	.81	.72	.63	.55	.55
12.5	1.72	1.64	1.57	1.49	1.41	1.34	1.26	1.18	1.10	1.01	.93	.85	.76	.67	.55	.55
13.0	1.81	1.73	1.65	1.57	1.49	1.41	1.33	1.24	1.16	1.07	.98	.89	.80	.70	.65	.65
13.5	1.90	1.81	1.73	1.65	1.56	1.48	1.39	1.30	1.21	1.12	1.03	.93	.84	.74	.65	.65
14.0	1.98	1.89	1.80	1.72	1.63	1.54	1.45	1.36	1.26	1.17	1.07	.97	.87	.77	.66	.65

NOTE: These thicknesses are based on a subgrade tolerance of not more than 0.05′ above or below the grade established by the Engineer. Additional thickness is not required to compensate for this allowed construction variation.

An alternate layer construction could consist of placing at least 0.5 foot of aggregate subbase over the basement soil.

For the above cases, some structural benefit must be given to the intervening layer. This could be in terms of a thickness adjustment applied to the full depth asphalt concrete that would be determined according to the following equation:

$$T = T_1 - \frac{t(G_f)}{(G.E._1 - G.E._2)} (T_1 - T_2)$$

where: T = adjusted asphalt concrete thickness (ft.) required over either aggregate subbase or stabilized basement soil.

T_1 = full depth asphalt concrete thickness (ft.) required over basement soil (Table IV).

T_2 = asphalt concrete thickness (ft.) required over either aggregate subbase or stabilized basement soil assumed of infinite depth (Table IV).

t = thickness (ft.) of aggregate subbase or stabilized basement soil.

G_f = gravel factor for aggregate subbase or stabilized basement soil.

$G.E._1$ = gravel equivalent (ft.) required over basement soil (Figure 7).

$G.E._2$ = gravel equivalent (ft.) required over aggregate subbase or stabilized basement soil assumed of infinite depth (Figure 7).

For the previous example with basement soil R=10, T.I. = 6.5 and full depth pavement of 0.80 foot AC, the following adjustment would be made, if aggregate subbase was used:

With 0.50 foot of 40 R-value AS, G_f = 1.0, Table IV indicates T_1 = 0.80 ft. AC and T_2 = 0.52 ft. AC. From Figure 7, $G.E._1$ = 1.87 ft. and $G.E._2$ = 1.25 ft.; therefore:

$$T = 0.80 - \frac{0.5(1.0)}{(1.87-1.25)} (0.80-0.52)$$

$$T = 0.80 - \frac{(0.5)(0.28)}{(0.62)} = 0.80-0.23$$

T = 0.57 foot or rounded to 0.60 foot AC

Use either 0.60 ft. AC over 0.50 ft. of 40 R-value AS or 0.80 ft. AC over 10 R-value basement soil.

The above formula takes into consideration the depth factor adjustments for full depth asphalt concrete pavements. For full depth AC structural sections where R-value by expansion controls (i.e. over expansive material) add sufficient aggregate subbase material under the AC to provide for this potential expansion.

This design method provides a basis for an economic comparison as defined below.

ECONOMIC COMPARISON OF SECTIONS

Many situations allow comparison of several structural sections, each of which meets design criteria. An initial cost analysis may aid in the selection of the best section. It is necessary to determine the construction cost of each alternative.

In addition to initial cost, final selection will also depend upon local practices, construction experience, suitability of the materials for their intended use, expected service life, climatic conditions, future maintenance, depth of utilities, and other considerations.

STAGE CONSTRUCTION

Stage construction of a road is sometimes proposed as an economic expedient or as a device to lengthen the improvement for a particular highway. When stage construction is properly planned and executed, it usually performs as intended.

It is essential to remember that the road be designed for the same criteria which would govern the design of a fully completed facility for that location. The individual layer thicknesses of the design should not be compromised. Full thicknesses of subbase and base should be placed since it is impracticable to add to them later on.

The surfacing is usually the only item in the structural section affected by stage construction. In some cases, the surfacing is deferred for several years and only a road mixed asphalt treatment of the upper portion of the base or placement of a seal coat is provided initially for traffic. Other projects are designed with some portion of the surfacing thickness placed at the time of construction and the rest later on. However, the non-linear relationship between asphalt concrete thickness and design life should be taken into consideration, i.e. 0.10' of asphalt concrete does not last half as long as 0.20' of asphalt concrete.

In any case, a definite time schedule should be fixed for the completion of stage construction. If the surface is allowd to break up, for example, before the final layer is placed, it will probably be necessary to place a thicker than planned final layer.

The project should be carefully watched during the interim period between initial construction and completion and upon the first indication of trouble, should be completed to the full design thickness. Pavement deflection measurements can be utilized in this situation to determine the adequacy of the final construction under actual field moisture conditions. Deflection measurements can also be used to determine the need for additional surfacing prior to appearance of visual distress.

CHANGES TO R-VALUE TEST

It is sometimes suggested that it would be advantageous to determine the R-value in semi-arid parts of California at 400 psi exudation pressure rather than 300 psi as currently specified. This is not a safe practice. The Department of Transportation investigated the relationship between moisture contents under pavements and exudation pressure (5) and concluded that 300 psi more nearly represented field conditions.

If the engineer designing the pavement structure is thoroughly knowledgeable with respect to the pitfalls in structural design, and if he has engineering data to back up his judgment, he might be justified in using an R-value at other than 300 psi exudation pressure. This would apply primarily to areas with low rainfalls where the soils have good drainage characteristics.

The structural section, however, should be designed for the worst moisture condition that can be expected, not the average condition. Moisture tends to concentrate under pavements, even in drier climates. This condition can be aggravated by irrigation water, heavy rains, condensation, and other sources of water.

OVERLAY DESIGN USING PAVEMENT DEFLECTION

The Transportation Laboratory has developed a flexible pavement overlay design method based on non-destructive testing techniques. Test Method No. Calif. 356 describes the equipment and step-by-step procedure utilized to determine overlay thickness requirements based on pavement deflection measurements. This includes provisions for using a Benkelmen Beam, Traveling Deflectometer, Dynaflect, Road Rater, or Dehlen Curvature Meter.

CBR DESIGN METHOD

General

Some agencies do not have access to R-value determination equipment, but do have the facilities or ready access to such equipment necessary to determine CBR (California Bearing Ratio) values. The nomograph (Figure B-1) will provide an approximate means of determining a structural section by converting the known CBR to an equivalent R-value. The nomograph must be used with extreme care since there is no direct correlation between R-value and CBR. The nomograph is more accurate when considering fine-grained soils than it is when working with gravelly soils.

Basic Data

The CBR values should be determined in conformance with procedures set forth in Appendix B.

Comments

The bearing ratio test is used to determine the bearing ratio (relative bearing value compared to that of crushed rock) at optimum moisture and maximum density, after soaking, of material proposed for use on the roadway.

The expansion test is used to determine the expansion of a compacted specimen of material proposed for use, after soaking for a period of four (4) days. The test is made on a compacted specimen used in the bearing ratio test referred to above.

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APPENDIX A

METHOD FOR CALCULATING EQUIVALENT AXLE LOADS, TRUCK CONSTANTS, AND TRAFFIC INDICES

SCOPE

This method describes the procedure for transforming traffic count data into descriptive numbers which are used in calculating the structural thickness of pavement.

DEFINITIONS

Average Daily Truck Traffic (ADTT) - the number of trucks passing a given point on a highway, in both directions, in any 24-hour period. (One-way traffic should be so noted)

Equivalent Axle Load (EAL) - the number of repetitions of an 18,000 pound axle load which would have the same damaging effect as the truck axle or axles being considered.

Truck Constant - (EAL Constant) - a number expressing the total EAL generated by the passage of one truck of a particular type carrying an average load, once a day, in one direction, for a period of one year.

Traffic Index - (TI) - a number or "index" value used in design which represents the cumlative effects of both composition and intensity of truck traffic.

PROCEDURE FOR CALCULATING TRAFFIC INDEX

For structural thickness design purposes, the average daily truck traffic must be converted into a traffic index. Initially, we must convert all axle loads[1] to an equivalent number of 18,000 pound axle loads by using the equation:

$$\text{EAL/Repetition} = \left(\frac{A}{18}\right)^{4.2} \qquad (1)$$

Where: EAL = equivalent 18,000 pound axle loads for one repetition of a particular average axle load

A = Average axle load in kips

The graphical solution to this equation is presented in Figure A-1 along with an example showing that one 18,000 pound axle load would have a constant EAL of 1.0.

To determine total EAL, multiply the repetitions of the axle load by the EAL per repetition.

---

[1] Treat a tandem unit as two single axles each carrying one-half the tandem unit load.

To convert the total EAL to a Traffic Index (TI), use the following equation:

$$TI = 9.0\left(\frac{EAL}{10^6}\right)^{0.119} \qquad (2)$$

This equation is solved graphically in Figure A-2 and is presented in tabular form below:

TABLE A-1

Conversion of EAL to Traffic Index

EAL	TI	EAL	TI
9		1,270,000	
	2.5		9.5
48		1,980,000	
	3.0		10.0
194		3,020,000	
	3.5		10.5
646		4,500,000	
	4.0		11.0
1,850		6,600,000	
	4.5		11.5
4,710		9,490,000	
	5.0		12.0
10,900		13,500,000	
	5.5		12.5
23,500		18,900,000	
	6.0		13.0
47,300		26,100,000	
	6.5		13.5
89,800		35,600,000	
	7.0		14.0
164,000		48,100,000	
	7.5		14.5
288,000		64,300,000	
	8.0		15.0
487,000		84,700,000	
	8.5		15.5
798,000		112,000,000	
	9.0		
1,270,000			

In order to convert mixed truck traffic to equivalent 18,000 pound axle loads, it is necessary to have a sampling of the truck traffic, using the highway, by axle weights and by number of axles. This information, for a state-wide count, is made available every other year by the Federal Highway Administration in its W-4 tables.

TABLE A-2

AN EXAMPLE OF LOADOMETER TRAFFIC COUNT DATA (Several Stations Summed)

Axle Weight Intervals (Kips)	No. Axles Weighed			
Single Axles	2-axle Trucks	3-axle Trucks	4-axle Trucks	5-axle or more Trucks
Under 3.0	11,561	22	43	61
3.0 - 7.0	1,092	1,186	187	2,226
7.0 - 8.0	438	384	27	735
8.0 - 12.0	952	810	59	1,390
12.0 - 16.0	433	464	19	912
16.0 - 18.0	41	108	10	917
18.0 - 20.0	2	8		75
20.0 and Over[2]				
Tandem Axles[1]				
Under 6.0		4	18	28
6.0 - 12.0		282	446	1,894
12.0 - 18.0		262	236	934
18.0 - 24.0		178	162	610
24.0 - 30.0		130	154	1,770
30.0 - 32.0		82	66	1,064
32.0 - 33.0		6	4	66
33.0 and Over[2]				
Total Number Axles	14,519	3,926	1,431	12,682

[1]Treat a tandem unit as two single axles, each carrying one-half the tandem unit load. For this reason the tabulated figures are actually twice the number of tandem axles counted.

[2]All overloads should be included in count data and classified by load intervals according to Federal Highway Administration W-4 tables.

TABLE A-3

CALCULATIONS FOR TRUCK CONSTANTS

Axle Weight Intervals (Kips)	EAL per[1] Repetition	2-axle Trucks	3-axle Trucks	4-axle Trucks	5-axle or more Trucks
Single axles under 3.0	0.000	1[2]	0	0	0
3.0 - 7.0	0.005	5	6	1	11
7.0 - 8.0	0.025	11	10	1	18
8.0 - 12.0	0.085	81	69	5	118
12.0 - 16.0	0.348	151	161	7	317
16.0 - 18.0	0.787	32	85	8	722
18.0 - 20.0	1.255	3	10	0	94
Tandem Axles Under 6.0	0.000[3]		0	0	0
6.0 - 12.0	0.003		1	1	6
12.0 - 18.0	0.025		6	6	23
18.0 - 24.0	0.104		19	17	63
24.0 - 30.0	0.299		39	46	529
30.0 - 32.0	0.534		44	35	568
32.0 - 33.0	0.694		4	3	46
Total EAL's		284	454	130	2,515
Total No. Axles[4]		14,519	3,926	1,431	12,682
Average EAL/Axle[5]		0.020	0.115	0.091	0.198
Truck Constants[6]		14	126	132	362

[1]Calculated from equation (1) or obtained from Table A-1. Use medium axle load for the load class.

[2]EAL/Repetition multiplied by number of axles. (No. of axles from Table A-2)

[3]These constants calculated for one-half of the medium tandem axle load

[4]From Table A-2.

[5]Total EAL's divided by Total No. of Axles.

[6]EAL/Axle x 365 days x No. Axles on each truck.

In practice, the calculations for TI are made by using truck constants for trucks in the following categories: 2,3,4, and 5 or more axle trucks. Buses are also considered as trucks, and pickups are not included. These constants are derived as follows:

1) Obtain loadometer data - (axle weight for all trucks listed by truck category) - and a classified traffic count. Both are included in Table A-2.

2) Separate the axle weights in each truck category into axle weight intervals as shown in Table A-2. Overloads should also be considered and classified by load intervals as shown.

3) Calculate the mean axle load for each weight interval and convert to average EAL/repetition by the relationship

$EAL = (A/18)^{4.2}$ (Table A-3). This average EAL/repetition is then

multiplied by the number of axles in each weight interval. This yields a total EAL for each truck category in each weight interval for the period encompassed by the loadometer survey.

4) The EAL's in each truck category are then summed up.

5) From the total EAL's and the total number of axles for each truck category, the average EAL/axle can be calculated for each category.

6) The truck constant for each truck category is then obtained by multiplying the average EAL/axle by 365 days and by the number of axles on one truck in that category. Constants have been calculated by the Department of Transportation from the statewide traffic count and are listed in Table A-5. The statewide constants should only be used in cases where more accurate truck traffic data is not available.

7) To calculate annual EAL, the truck constants for each truck category are multiplied by the average daily truck traffic in one direction for each axle day and the anticipated increase factor to the mid year of the design period. The resulting totals for each truck category are summed up to obtain the total average annual EAL's in one direction as shown in Table A-4.

8) For use in the thickness design equation, the total annual EAL's are multiplied by the number of years in the design period and are then converted to Traffic Index (TI) by the relationship shown in Equation (2).

TABLE A-4

CALCULATION OF ANNUAL EAL

Truck Category	One Way Average Daily[1] Truck Traffic	x	Truck[2] Constants	x	Anticipated[3] Increase Factor	=	EAL By Truck Category
2-axle	169		14		2.30	=	5,400
3-axle	91		126		1.90	=	21,800
4-axle	47		132		1.75	=	10,750
5-axle or more	158		362		2.10	=	120,000
					Total Average Annual EAL's	=	157,950

Computing the total design EAL for 20 years:

$$EAL_{20\ yr.} = 157{,}950 \times 20 = 3{,}160{,}000^{4}$$

Traffic Index (TI) is calculated from the EAL by the use of equation (2), Table A-1, or from Table A-2.

$$TI = 9.0 \left(\frac{EAL}{10^6}\right)^{0.119}$$

$$= 9.0 \left(\frac{3{,}160{,}000}{10^6}\right)^{0.119}$$

$$= 9.0\ (3.16)^{0.119}$$

$$= 9.0\ (1.15)$$

$$= 10.35 \text{ use a TI of } 10.5$$

This value of 10.5 for Traffic Index can now be used in the pavement structural thickness design equation, as explained in Test Method No. Calif. 301.

---

[1] One-way count.

[2] These constants are for this example only and are not to be used in any actual calculations. Use the constants given in Table A-5 if applicable.

[3] This factor converts average daily truck traffic from the present count to the anticipated average count for the mid-year of the design period.

[4] Three significant figures are adequate for the accuracy of the method and data.

STATEWIDE TRUCK CONSTANTS

TABLE A-5

EAL Constants for Duel-tired Commercial Vehicles
(Use only with one-way traffic counts)

	Annual Design EAL for One Vehicle per Year	
Type of Vehicle	State Highways	City Streets and County Roads
2-axle truck	51	34
3-axle truck	156	117
4-axle truck	224	182
5-axle truck or more	689	288

The annual EAL constants in Table A-5 represent the best available factors from California statewide truck weighings. They are used for calculating the Traffic Index where traffic conditions are considered typical of the statewide average. Use of these constants avoids the expense of calcualting individual road truck constants.

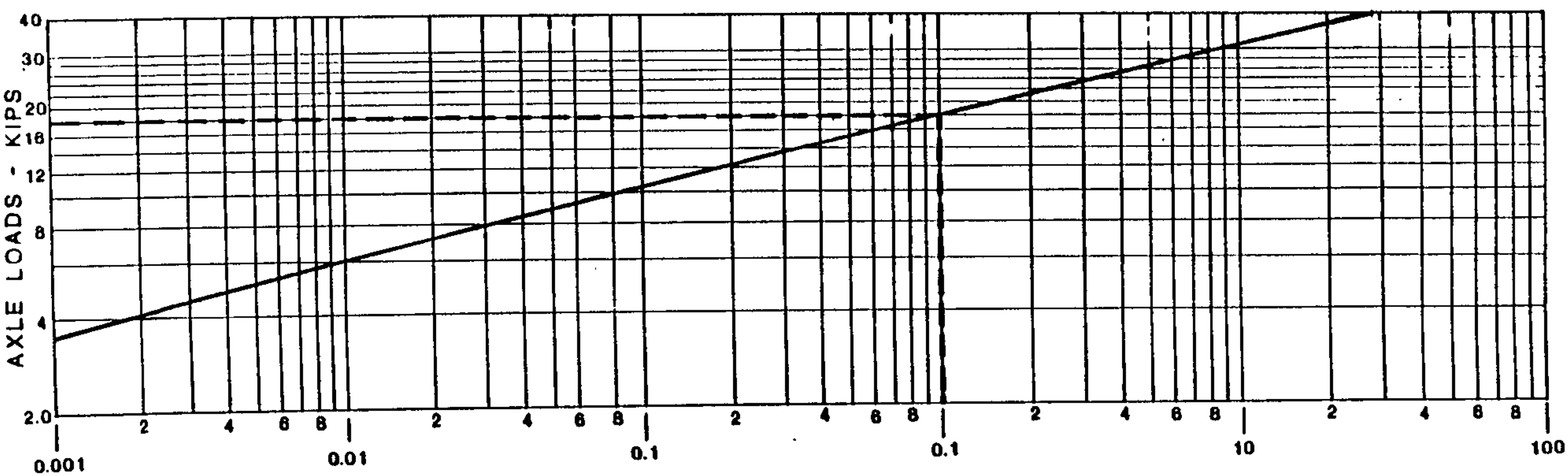
Where a road has unique traffic loadings, consideration should be given to calculating EAL constants for the particular road. This may result in savings in design of the structural section or justify a heavier section for especially heavy loadings.

The State Highway constants should be used where the 10-year TI is equal to or greater than 8.

FIGURE A-1

CONVERSION CHART

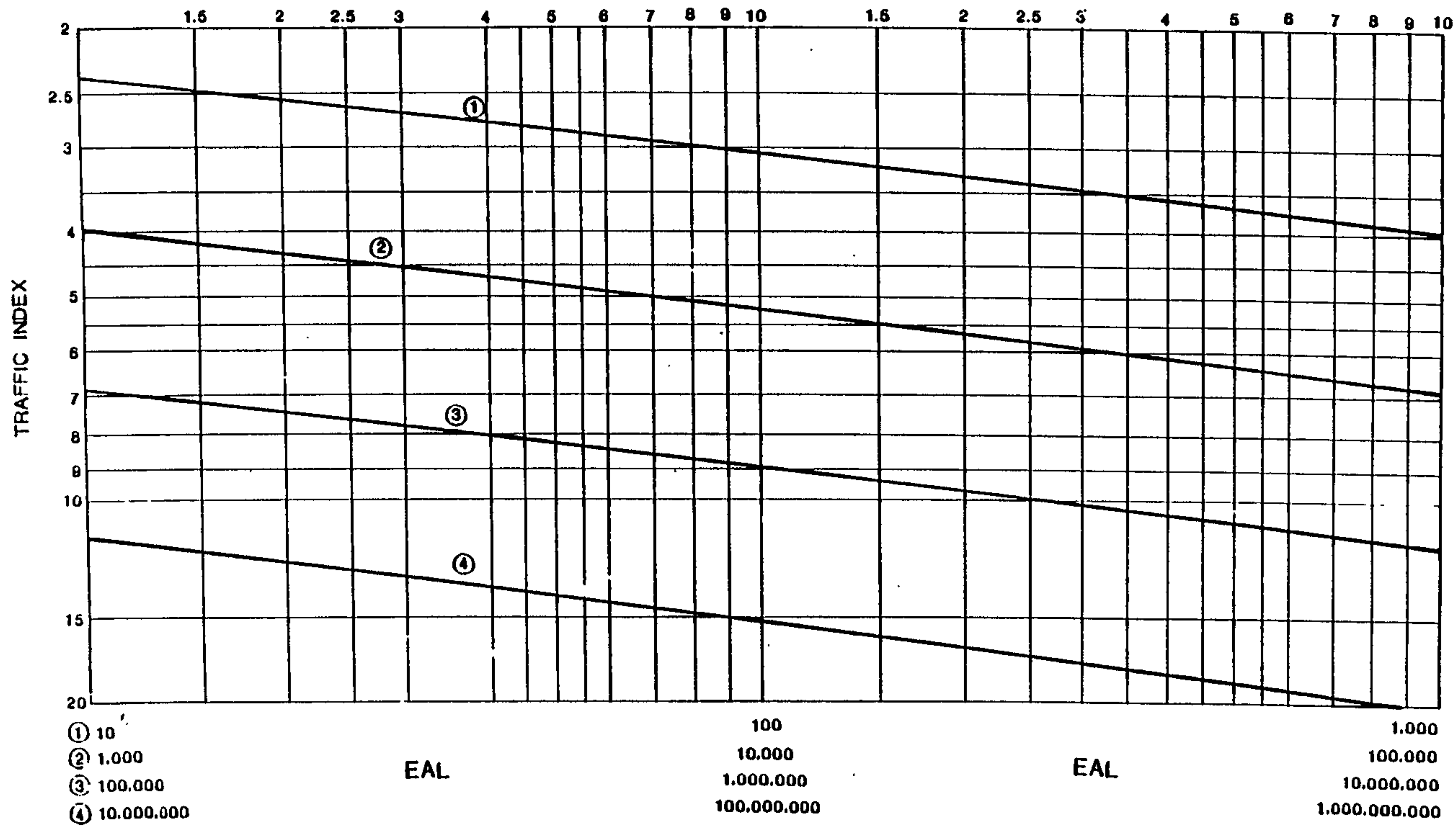
AVERAGE AXLE LOAD TO EQUIVALENT 18,000 LB. AXLE LOADS



SOLUTION OF : $EAL = (\frac{A}{18})^{4.2}$

FIGURE A-2

CONVERSION CHART
EAL TO TI



SOLUTION OF $TI = 9.0 \left(\frac{EAL}{10^6}\right)^{0.119}$

APPENDIX B

TEST METHOD FOR CALIFORNIA BEARING RATIO

APPARATUS REQUIRED

A cylindrical mold six inches (6") in diameter and eight inches (8") high. The mold is to be fitted with a detachable base plate, a piston or plunger five inches (5") high and of slightly less diameter than the inside diameter of the mold for compacting the specimen, and a round penetration postion with an end area of three (3) square inches.

A perforated plate with an adjustable stem and a ten (10) pound weight.

A testing machine, calibrated hydraulic press or other static loading apparatus of at least 60,000 pounds capacity.

A scale or balance of twenty (20) kilograms capacity sensitive to one (1.0) gram.

A dial or other suitable gauge for measuring the penetration of the three inch (3") area piston.

A dial or gauge mounted in a tripod for measuring the specimen during the soaking period.

A suitable water tank or vat for immersing the specimen during the soaking period.

A twelve and one-half (12-1/2) pound round surcharge weight for confining the top of the specimen during penetration.

A suitable drying oven with forced ventilation.

Miscellaneous equipment including a depth gauge graduated in hundredths of an inch, mixing bowl, spoons, spatulas, graduates, brushes, etc.

PREPARATION OF SAMPLE

A representative sample of sufficient size for the tests (usually 20 to 40 pounds) shall be accurately quartered. The sample to be tested shall be separated into sizes by screening on 3/4", 3/8" and No. 4 sieves, and the percentage passing each sieve determined, if a grading analysis has not been made. Particles retained on the 3/4" sieve shall not be used in the material to be tested. This procedure will result in three sizes of material for the test, namely 3/4" to 3/8", 3/8" to No. 4, and passing the No. 4. The three sizes should be kept separate.

The tests, insofar as possible, shall be made on a representative sample of the material proposed for use in the work.

STATIC LOAD COMPACTION TEST PROCEDURE

A test sample of approximately four thousand (4,000) grams or such amount which will result in a compacted specimen four to six inches (4" to 6") high, having the same gradation as the minus 3/4" fraction of the original sample, shall be weighed to an accuracy of five (5) grams and placed in the mixing bowl. In the event the maximum dry weight per cubic foot and the optimum moisture content have not been previously determined, three to six identical samples shall be prepared.

Samples need not be completely dried out, but should contain less than the moisture content for the test. If not completely dry, the moisture content should be determined so that the actual dry weight of material used and its actual moisture content will be available before adding additional water.

The sample shall be mixed with the amount of water (optimum moisture content) producing the maximum dry weight per cubic foot obtainable under the static load compaction test herein specified. If the optimum moisture content has not been previously determined, the additional samples referred to above shall be moistened and compacted at varying moisture contents so that a range well on each side of optimum is covered and the optimum moisture content determined.

After thoroughly mixing the material with water, it shall be lightly tamped into the tared mold and then compacted to its maximum density under a load of two thousand (2,000) pounds per square inch. In applying the load between one thousand (1,000) pounds and two thousand (2,000) pounds, the head of the testing machine or hydraulic press shall be operated at a rate of approximately five hundredths of an inch (0.05") per minute. The static load of two thousand (2,000) pounds shall be maintained on the specimen for one (1) minute and then gradually released during a period of twenty (20) seconds.

The mold shall then be removed from the testing machine or hydraulic press and the height of the compacted specimen measured, with a depth gauge, to the nearest hundredth of an inch. The dry weight per cubic foot of the specimen shall be calculated from the height and diameter of the specimen and its dry weight.

BEARING RATIO TEST PROCEDURE (RELATIVE BEARING VALUE)

A seven inch (7") diameter filter paper shall then be placed on top of the mold containing the above-described compacted specimen, and the base plate removed from the bottom and fastened to the mold over the filter paper. The mold shall then be turned over and the specimen recompacted under a load of two thousand (2,000) pounds per square inch, applied as specified for the "Static Load Compaction Test" on preceding page.

After being soaked as hereinafter provided under "Expansion Test", the specimen shall be tested for penetration in the following manner:

The specimen shall be placed in the testing machine and tested by penetrating with the small piston (end area of three square inches). Before starting the penetration test, the surcharge weight shall first be placed on the top of the specimen. The piston shall then be set on the center of the compacted specimen and firmly seated by applying an initial load of ten (10) pounds, after which the dial shall be set at zero to measure the penetration of the piston. During the penetration test, the head of the testing machine shall be operated at a rate of five hundredths inch (0.05") per minute and the total load and the load in pounds per square inch shall be recorded at penetrations of 0.1 inch, 0.2 inch, 0.3 inch, 0.4 inch and 0.5 inch.

The bearing ratio (relative bearing value) shall be computed in percentage of the following standard loads for each one-tenth inch (1/10") increment of penetration:

Penetration Inches	Standard Load pounds per square inch
0.1	1,000
0.2	1,500
0.3	1,900
0.4	2,300
0.5	2,600

Unless otherwise specified, the bearing ratio of a material shall be considered as the bearing ratio at 0.1" penetration.

EXPANSION TEST PROCEDURE

The height of the recompacted specimen described under "Bearing Ratio Test Procedure" shall be recorded to check the height and the dry weight per cubic foot of the specimen as originally compacted as well as for use in determining the expansion percentage.

A six-inch (6") diameter filter paper shall then be placed on the recompacted specimen, followed by the perforated plate and then the ten (10) pound weight. The gauge and tripod assembly shall next be set on the mold and the stem on the perforated plate adjusted and locked to a zero gauge reading. After removing the gauge, the mold assembly shall be placed in the tank and water poured in the top of the mold. The water level in the tank and in the mold shall, at all times, be kept between one inch (1") above and two inches (2") below the top of the mold.

The specimen shall be soaked for four days or if the material becomes fully saturated and all expansion ceases before this time, a shorter soaking period will be permitted. The expansion shall be measured each day with the gauge and tripod assembly and recorded to the nearest one-thousandth of an inch. The percentage of expansion shall be calculated on the basis of the height of the recompacted specimen before soaking.

After the soaking period, the specimen shall be removed from the tank, the ten (10) pound weight removed, and with the perforated plate held firmly in place, the mold shall be tipped up to allow the free water to drain off for a period of one (1) minute. Care must be taken to prevent disturbing the surface of the sample and to avoid vibration which will cause saturated material, particularly sands and silts, to become "quick". The ten (10) pound weight, perforated plate and filter paper shall then be removed, after which the specimen, contained in the mold, shall be weighed to determine the moisture content of the material after the soaking period.

After weighing, the soaked specimen shall be tested for penetration as above described under "Bearing Ratio Test".

MOISTURE CONTENT PROCEDURE

After the penetration test has been completed on the soaked specimen as above specified, a sample shall be taken from the top of the specimen to a depth of one inch (1"), weighed and dried to constant weight at 100 to 104 degrees centigrade.

This moisture content shall be recorded together with the moisture content for maximum compaction and that of the total specimen after soaking.

Design Procedure:

The first requirement of the design is to convert the known CBR values to equivalent R-values by means of the nomograph delineated in Figure B-1. The nomograph is not applicable for a material possessing all three of the following characteristics: (1) Less than 75% passing a #4 sieve, (2) more than 8% passing the #200 sieve, and (3) a product of the plasticity index and percent passing the #200 sieve is greater than 72. The R-values for materials possessing all three of the preceding characteristics should be determined in accordance with the R-value test procedures as outlined in Test Method No. Calif. 301F.

After the equivalent R-values for the various structural section components have been determined, the structural section design method should follow the procedures previously outlined in the text.

Example: Conversion of CBR to an equivalent R-value:

Given: Material characteristics
Subgrade CBR = 4 Swell = 4%
Percent passing #200 sieve = 67
Percent passing #4 sieve = 100
Plastic Index = 10

a. Check subgrade material characteristics against the limitations specified for acceptable use on Nomograph (Figure B-1).

Limitation 1 - Less than 75% passing #4 sieve
Sample has 100% passing #4 sieve

Limitation 2 - More than 8% passing #200 sieve
Sample has 67% passing #200 sieve

Limitation 3 - Product of the Plastic Index and percent passing #200 sieve greater than 72.
Sample = 10 x 67 = 670, which is greater than 72.

The material does not meet Limitation #1, therefore, the Nomograph is applicable since the criteria for rejection of the Nomograph requires conformance to all three Limitations.

b. Nomograph Procedure.

Refer to the Nomograph (Figure B-1) for the following example procedure. The corresponding steps (1, 2, 3, 4, and 5) and the straight edge projections denoted by dashed lines are indicated on the Nomograph.

(1) Locate CBR value of 4 on Scale A.

(2) Locate on Scale B the numerical value determined from the formula:

$$\frac{\text{\% pass \#200 sieve}}{\text{\% pass \#4 sieve}} \times 100 = \frac{67}{100} \times 100 = 67$$

(3) By means of a straight-edge project a line through points located on Scales A and B to Scale C the Turning Scale.

(4) Locate on Scale D the CBR expansion value determined from the CBR test which in our example is 4%.

(5) By means of a straight edge project a line through the points located on Scales C and D to Scale E.

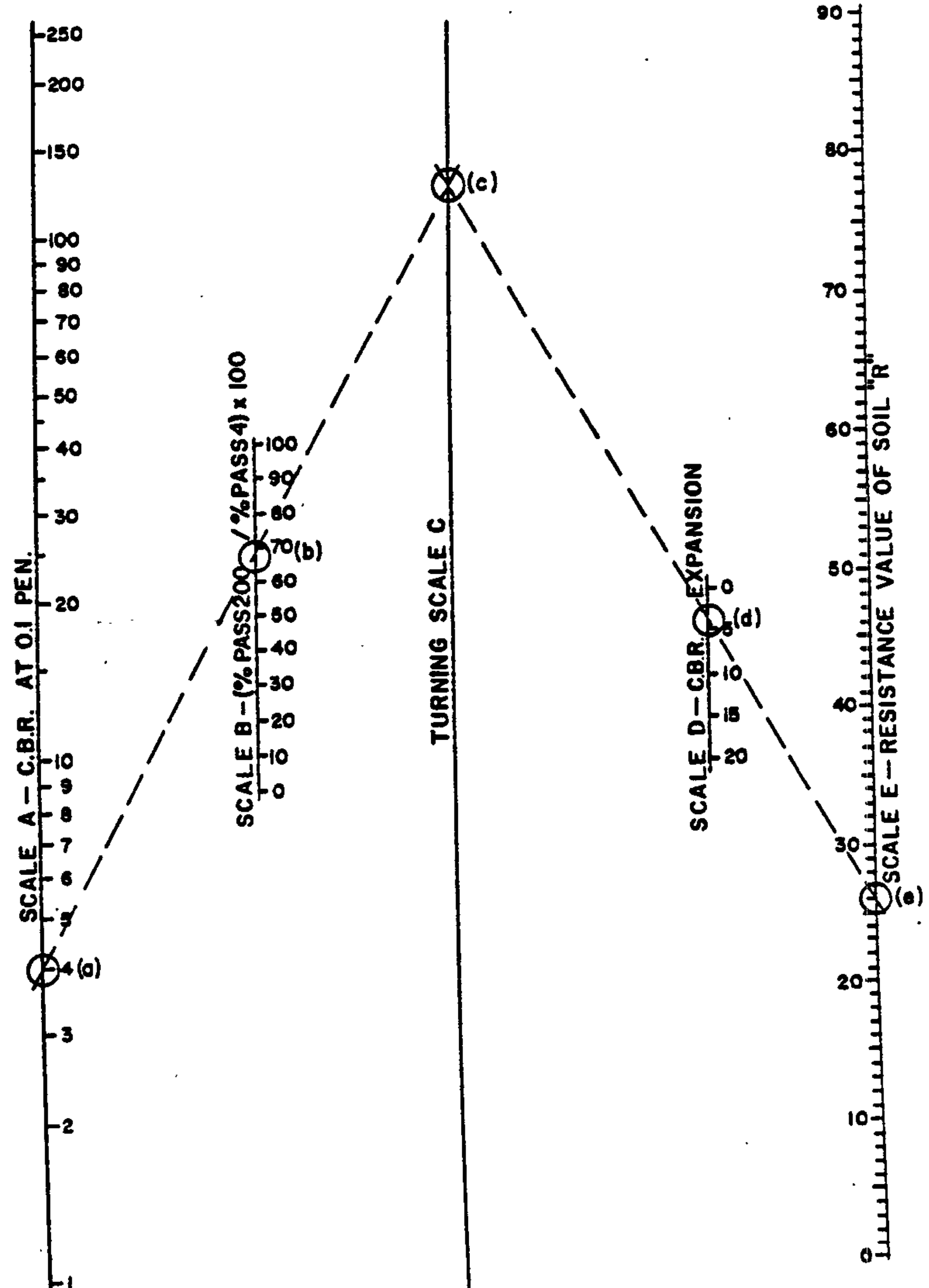
(6) Read the equivalent R-value (Resistance Value) on Scale E which for our example is 26 (for subgrade).

(7) Repeat steps 1 through 6 to determine equivalent R-values from CBR values for other structural section components.

(Base, subbase)

(8) After the determination of the R-values for the base, subbase and subgrade materials, the structural design method should follow the procedures previously outlined in the text.

Figure B-1



RESISTANCE VALUE OF SOIL "R" ESTIMATED FROM C.B.R. DATA

This chart not applicable for any material possessing all three of the following characteristics: (1) Less than 75% passing #4 sieve, (2) more than 8% passing #200 sieve and (3) a product of the plasticity index and percent passing #200 sieve greater than 72.

13051 3-73 DPW REPRO SACTO.
13051 6-73 500 DPW REPRO SACTO, CA.