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Department of Design
Highway Research Board

REVIEW OF EXISTING THEORIES AND METHODS OF PAVEMENT DESIGN

PREFACE

The information contained in this report was collected as a part of the activity of Highway Research Board Committee DB-6, Theory of Pavement Design, in 1968 and 1969. The individual write ups were contributed by individual members of the committees indicated. The group was collated and edited by a subcommittee made up of Aleksandar S. Vesic, William H. Perloff, and Carl L. Monismith.

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INTRODUCTION

Over the past thirty years there have been many efforts by individuals and organizations to establish design procedures for thickness of pavements which would be based on some rational criteria. Some of these methods are widely used, a few have even become firmly established within certain design organizations. All too often, however, only procedures are readily available, while the background information remains scattered in the professional reports and journals.

Several years ago, at one of the first meetings of the HRB Committee D-B6 (Theory of Pavement Design), the committee members decided to prepare and exchange synopses of existing theories and methods of pavement design. These synopses were presented and discussed at a mid-year meeting of the Committee at the University of Illinois-Chicago Circle in October of 1966. Following this meeting a subcommittee consisting of Carl L. Monismith, William H. Perloff and Aleksandar S. Vesic as chairman was established with the task of revising the statements prepared by different committee members and putting them in a single condensed form. The present Special Report contains these statements, grouped under the four headings entitled: elasticity methods, ultimate strength method, semi-empirical and statistical methods, empirical and environmental methods.

Elasticity methods, according to this classification consider the behavior of pavements under working conditions, when deflections, by assumption, remain proportional to applied loads. Their principal design criterion consists of limiting stresses or strains as determined by a calculation based on Theory of Elasticity to certain values established by observation to be "safe". The methods of this group presented in this report include:

a) Kansas Highway Department method
b) Portland Cement Association method
c) U. S. Corps of Engineers (CBR) method
d) Shell method
e) Texas Highway Department method.

Ultimate strength methods are concerned with pavement behavior at failure. Their basic design criterion is that the pavement must possess an adequate safety factor against assumed shear failure of the pavement system. This group included two methods presented in this report:

a) Early English method
b) Yield-line method

Semi-empirical and statistical methods are based on assembled (and in some cases statistically processed) information of conditions under which pavements of certain composition and strength have experienced performance failure. They include no theoretical considerations of pavement mechanics, yet the thicknesses are determined on the basis of properties of pavement materials as determined by an empirical "strength" test. The methods belonging to this group include:

a) The original CBR-method
b) State of California method
c) Canadian Department of Transport (McLeod) method
d) AASHO interim guides for flexible pavements
e) Asphalt Institute method
f) AASHO interim guide for rigid pavements.

Finally, the empirical and environmental methods relate the pavement thickness to some particular soil and environmental conditions. No mechanical tests, other than those needed for soil classification, are used for determining of supporting characteristics of the pavement subgrade. From this group only two methods are presented in this survey:

a) Michigan Highway Department method
b) Canadian Good Roads Association method.

The reviews are accompanied by short, selected bibliographies, including principal relevant references published before 1969. It is hoped that the publication of this material will be of some use to pavement designers as well as to research workers active in this field.

ELASTICITY METHODS

A) KANSAS METHOD FOR STRUCTURAL DESIGN OF FLEXIBLE PAVEMENTS

History: This method was developed by the Kansas Highway Commission in the early 1940's following theoretical expressions presented by Palmer and Barber (1940) and Hogentogler (1940). The method is undergoing continuous re-evaluation.

Principal Design Criterion: The surface deflection of the pavement is the criterion for determining the adequacy of the structural design.

Assumptions:

1. The pavement system (including base and Sub-base) is infinite in lateral extent, incompressible, and experiences no vertical deformation.

2. The subgrade is an incompressible, homogeneous, isotropic, linear elastic half-space. All pavement deflection results from elastic strains in the subgrade.

3. The effect of the relative stiffness of pavement and subgrade materials on the distribution of stresses and deformations within the subgrade can be accounted for by replacing the pavement with an "equivalent" thickness of subgrade material (viz. Figure 1) which is continuous with the subgrade material itself.

4. The secant modulus determined from the relation between principal stress difference and axial strain in the triaxial compression test, at stress levels corresponding to those computed to exist beneath the pavement due to vehicle loading, is equal to the modulus of deformation for the in-situ conditions.

5. The saturated condition is the most critical state for the subgrade, base and sub-base materials, and the required pavement thickness will be a maximum for this case. The significance of this effect depends on the average annual rainfall, irrespective of its time-distribution or the type of subgrade soil. This effect can be accounted for by modifying the assumed applied wheel loading by an empirical rainfall factor.

6. The applied surface load is considered to be a single static load uniformly distributed over a circular area. Dual wheel effects are determined by superposition of individual wheel loads. Pavement deflections computed on this basis will apply to moving vehicular loadings.

7. The proportion of heavy wheel loads to light wheel loads is approximately constant, irrespective of traffic volume. The effect of loading frequency on design can be accounted for by modifying the assumed applied wheel loading by a coefficient which depends solely upon the traffic volume.

Determination of Material Properties: The material parameters required are the "moduli of deformation" of the subgrade and pavement components. These moduli are determined from the results of triaxial compression tests conducted on saturated specimens of these materials. (The asphaltic concrete specimens are not saturated.) In the case of the subgrade soil, undisturbed specimens saturated prior to testing, are used. Drainage of water into or out of the specimen is permitted during the test, which is conducted at an axial displacement rate of from 0.005 to 0.01 inches per minute depending on the specimen size and type. Prior to compression testing, specimens are permitted to come to equilibrium under a confining pressure of 20 pounds per square inch. This pressure is maintained constant during the compression test. Results are shown as a plot of principal stress difference versus axial strain. The "modulus of deformation" is determined as the secant modulus at the stress level corresponding to the computed principal stress difference at the top of the subgrade.

Experience: The Kansas Highway Commission appears to be satisfied with the results of applying the method. In November, 1966, Mr. V. R. Weathers, Engineer of Materials of the Kansas Highway Research and Materials Laboratory, stated that: "...Each year a small number of projects are chosen at random for a check of the original estimate by sampling the finished grade and recalculating the design requirements.

"The results obtained may be altered by assigning different values to the various factors in the formula; however, the system as used in Kansas has been substantiated periodically by correlation studies of pavements in service. After each study the coefficients are adjusted in accordance with service records."

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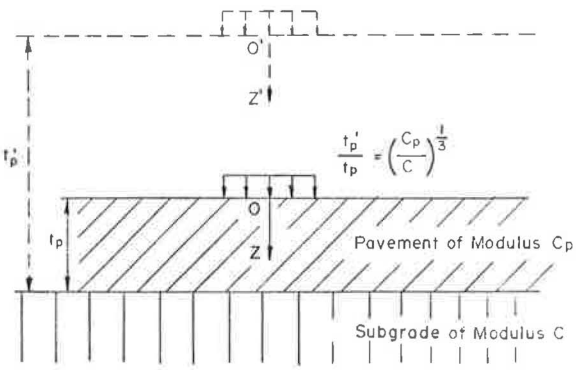

Figure 1. Equivalent thickness concept. This corresponds to a transformation of coordinates, displacing the origin from O to O', but keeping the interface unchanged.

(Contributed by William H. Perloff)

B) PORTLAND CEMENT ASSOCIATION PROCEDURE
FOR THICKNESS DESIGN OF CONCRETE PAVEMENTS

History: This method is an extension of earlier approaches using the Westergaard analysis.

Principal Design Criterion: The principal design criterion is the resistance to flexural fatigue failure of the concrete slab due to axle load repetitions.

Assumptions:

1. Load stresses are determined from stress charts based on an analysis of Pickett and Ray's Influence Chart No. 6. Influence Chart No. 6 is for the moment at the edge of a semi-infinite slab due to loads placed in the vicinity of the edge; subgrade assumed to be a dense liquid (theory of plates carried on a liquid).

2. Values for Poisson's ratio and modulus of concrete are assumed at 0.15 and 4,000,000 psi respectively.

3. The flexural strength of the concrete during the design life is assumed constant at a value equal to the modulus of rupture determined at concrete ages ranging from 28 to 90 days.

4. Results of flexural fatigue research are assumed to be applicable to pavement design. The relationship between stress and the allowable number of stress repetitions is based on this research. In addition, the Minor hypothesis is employed, i.e. fatigue resistance not consumed by repetitions of one load is available for repetitions of other loads.

Determination of Material Properties:

1. The modulus of rupture of the concrete is determined by third-point loading tests conducted at 28 or 90 days.

2. Westergaard's modulus of subgrade (subgrade-subbase) reaction, k, is determined by field plate loading tests or by correlation to laboratory strength tests or soil classification.

Experience: The design procedure is an extension of a methodology that has been used for more than 30 years: Westergaard's delineation of thin plate theory, Pickett-Ray influence charts, fatigue research and traffic analysis. In addition, the procedure was developed to reflect the experience gained from the performance of both experimental projects and in-service pavements. As a result, the thicknesses determined by this method are known to be conservative for the design conditions.

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(Contributed by G. K. Ray)

C) U.S. CORPS OF ENGINEERS CBR-METHOD FOR DESIGN OF FLEXIBLE PAVEMENTS

History: Following study of available design methods, prior to the outset of World War II, the CBR method, then in use in California, was adopted as best suited to the military requirement for reliable designs using a test, which can be conducted with reasonably mobile testing equipment. Extensive subsequent development has produced methods for reliably designing airfield or highway pavements for any given load, tire pressure, number and spacing of wheels, load applications, and on any strength subgrade. Further developments have extended the method to permit designs for the same broad range of parameters for expedient airfields using either unsurfaced areas or any of various types of prefabricated landing-mat surfacings.

Principal Design Criterion: Overlying thickness required relates directly to strength of each layer, as indicated by the CBR-value and to the loading to be sustained. Loading includes load magnitude, repetitions, tire pressure, and number and spacing of tires.

Assumptions:

1. Surface loading is distributed through the pavement system according to predictions of the theory of a homogeneous-isotropic elastic solid. (Boussinesq solution).

2. The strength required of any layer in a pavement structure, to sustain the loading delivered to it from above, is directly reflected by its CBR-value.

3. Thickness required is a direct function of the log of the load repetitions.

Determination of Material Properties:

1. The CBR is determined as indicated in Military Standard 621 CE (quite similar to ASTM D-1883). Results are required for a range of moisture contents from below to above optimum; for three compaction efforts: standard effort, an intermediate effort, and modified effort; and for both the unsoaked and soaked specimen conditions. The design CBR is selected from the pattern of test results based on expected prototype conditions. In-situ CBR tests are also used as pertinent.

2. Base and subbase qualities are further controlled through plasticity (LL and PI) and gradation requirements.

Experiences:

1. The method has been successfully used on airfields throughout the world.

2. Expedient pavements (landing mat, membrane, and unsurfaced) designed using extensions to the CBR method for flexible pavements are currently being extensively used successfully in Southeast Asia and elsewhere.

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(Contributed by Richard G. Ahlvin)

D) SHELL METHOD OF THICKNESS DESIGN FOR FLEXIBLE PAVEMENTS

History: This method was developed by engineers of the Shell Oil Company during the 1950's and early 1960's.

Principal Design Criterion:

1. The horizontal (radial) tensile strain on the underside of the asphalt-bound layer must be sufficiently small to prevent cracking in the asphalt layer.

2. The vertical compressive strain in the surface of the subgrade must be maintained sufficiently small to prevent permanent deformation of the top of the subgrade.

Assumptions:

1. The pavement structure can be represented as a three-layer elastic system with no relative displacement between layers at their boundaries.

2. Subgrade strains can be determined by considering a 9,000 lb. wheel load applied uniformly over a single circular area with a six-inch radius.

3. Tensile strains in the asphalt layer are determined using a circular area with a radius of 4.2 inches subjected to a uniform contact pressure of 80 psi.

Determination of Material Properties: The only experimental determination of material properties is the CBR of the subgrade soil. This has been previously correlated to the subgrade modulus and the modulus of the aggregate base. The elastic stiffness of the asphaltic concrete is assumed at an average value.

Experience: Comparisons between thicknesses developed by this procedure and results from both sections of the AASHO Road Test still in good condition after two successive spring periods with a PSI of 2.5 or greater after 1 million load applications support the results of this design method.

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(Contributed by Carl L. Monismith)

E) TEXAS HIGHWAY DEPARTMENT METHOD OF THICKNESS DESIGN FOR FLEXIBLE PAVEMENTS

History: This method grew out of previous application of triaxial testing to highway design in Texas, and the 1962 AASHO Design guides.

Principal Design Criterion: The surface deflection of the pavement is the criterion for determining the adequacy of the structural design.

Assumptions:

1. The components of the pavement system are assumed to be homogeneous, isotropic, and linearly elastic.

2. The appropriate elastic properties can be defined by the results of triaxial compression tests.

3. The effect of environment can be taken into account by testing the pavement components in their assumed worst condition.

Two methods are currently in use for applying the results of triaxial compression tests to pavement design. The assumptions concerning the effect of traffic on pavement thickness are different in these two methods:

4a. Traffic can be evaluated in terms of the average of the 10 heaviest loads.

4b. The concept of an equivalent 18 kip wheel load as described in "AASHO INTERIM GUIDE FOR THE DESIGN OF FLEXIBLE PAVEMENT STRUCTURES" is used.

Determination of Material Properties: Compaction curves yielding the optimum moisture content and the maximum density for specific compactive efforts related to the individual material, are determined. Stress-deformation properties of pavement component specimens, which have been permitted to absorb water, are tested using triaxial compression tests.

Experience: During the past 15 years, experience with the Texas Triaxial method has been very good. This may be due as much to the experience with the basic method and with materials evaluation in the area however, as to the method itself.

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(Contributed by W. Ronald Hudson)

ULTIMATE STRENGTH METHODS

A) EARLY ENGLISH METHOD OF PAVEMENT DESIGN

History: Developed in England during World War II, primarily in connection with airfield construction on soft to firm saturated clays. Later extended to all pavements and all types of subgrade soils. During the 1950's gradually abandoned in favor of the CBR-method.

Principal Design Criterion: Vertical stress σ_z acting on the subgrade soil should not exceed a limit, established as a fraction of the bearing capacity q_o of that soil.

Assumptions:

1. Wheel load is assumed to be static and uniformly distributed over a circular area. (Rectangular area can also be assumed as an alternative.)

2. Vertical stress distribution in the pavement system is assumed to follow the Boussinesq pattern. (Simplified distribution along a truncated pyramid, Fig. 1a, can be assumed as an alternative.)

3. The shear strength of the pavement layers is neglected - it is assumed that the pavement offers no resistance to punching of the loaded area downward.

4. The bearing capacity of the subgrade soil is computed according to the well known equation:

$$q_o = cN_c + qN_q + 1/2\delta \; BN_\delta$$

where the bearing capacity factors N_c, N_q, N_δ are introduced after Terzaghi. (alternatively, Prandtl and Frohlich factors have been used for saturated clays.)

Determination of Material Properties: Strength characteristics c, ϕ of the subgrade soil are determined, in principle, by triaxial tests. Alternatively, unconfined compression tests have been used for saturated clays.

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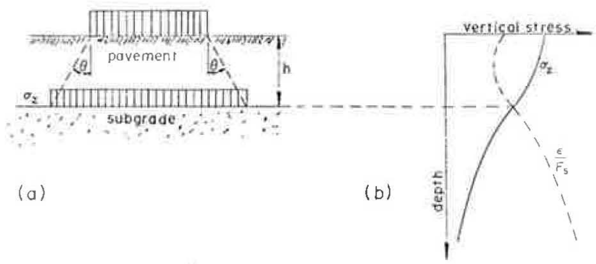

Figure 1. Vertical stress distribution.

(Contributed by Aleksandar S. Vesic)

B) YIELD-LINE METHOD OF PAVEMENT DESIGN

History: This method originated in Sweden in the 1950's primarily in connection with design of structurally reinforced airfield concrete pavements. Used also for plain concrete highway and airfield pavements. Basic premises of the method have been verified experimentally on full-scale pavements. However, a number of design details still need to be developed.

Principal Design Criterion: Bending moments, along a critical failure line (yield line) in the slab (Fig.1) should not exceed the ultimate negative bending moment m_{ult} of the slab section. The latter is defined as the bending moment at which a continuous circumferential crack of radius r_o can be observed around the loaded area.

Assumptions:

1. Wheel load is assumed to be static and uniformly distributed over a circular area.

2. Contact pressure distribution between the slab and subgrade at failure is assumed to be the same as that under working loads.

3. Moments m_r along radial cracks are assumed to be equal to ultimate positive bending moments of the slab section. The vertical shear v_o along the yield line is then determined from equilibrium conditions to be:

$$v = \frac{m_r + m_o}{r_o}$$

Determination of Material Properties:

1. Steel and concrete strengths are determined by usual testing methods for these materials.

2. The flexural rigidity of the slab is determined on the basis of a secant modulus corresponding to slab deformation at the yield point.

3. The deformation properties of the subgrade are determined either by a deformation modulus E or by a coefficient of subgrade reaction k. Both parameters are, in principle, determined from plate load tests.

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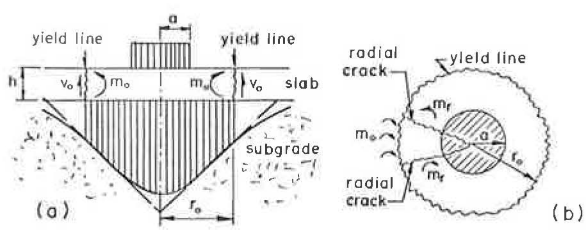

Figure 1. Yield Line Concept

(Contributed by Aleksandar S. Vesic)

SEMI-EMPIRICAL AND STATISTICAL METHODS

A) CBR METHOD OF THICKNESS DESIGN FOR FLEXIBLE PAVEMENTS

History: The California Bearing Ratio (CBR) test and design method were developed by O. J. Porter prior to 1930, while Porter was Materials Engineer for the California Highway Department. The test procedure and design method have been modified somewhat by various agencies, which employ the method. Despite this, the basic philosophies involved and the method in general remain as originally established by Porter.

Principal Design Criterion:

1. Materials within a pavement structure must be protected (or insulated) from surface loadings by overlying layers whose thickness can be empirically related to the strength of the material as indicated by the CBR test. Porter, originally, and many others since have established experience relations between thickness required and CBR.

2. Extensions and modifications to permit treatment of traffic volume, minimum ultimate subgrade strengths, etc., vary greatly between organizations currently using the CBR method.

Assumptions:

1. Surface loading is distributed to the lower layers in a pavement structure as a function of thickness alone.

2. The strength required of any layer in a pavement structure to sustain the loading delivered to it from above is directly reflected by its CBR value.

Determination of Material Properties: The CBR is generally determined as indicated in ASTM D-1883. No other material properties are required by the basic, unmodified CBR method.

Experience:

1. The CBR method of flexible pavement design is currently used by a number of state highway departments.

2. This method has been extended for use in airfield design by the U. S. Corps of Engineers and has been used satisfactorily for over 25 years for design and evaluation of military airfields throughout the world.

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(Contributed by Richard G. Ahlvin)

B) THE STATE OF CALIFORNIA METHOD FOR THICKNESS DESIGN OF ASPHALTIC CONCRETE PAVEMENTS

History: This method was developed by Hveem in the 1940's and has been modified on the basis of data from road tests as well as from in-service highways in California.

Principal Design Criterion: Pavement thickness in this empirical method is determined by the requirement that permanent deformation in each layer of the pavement system be prevented. The thickness desired to accomplish this is considered to be a function of the traffic, tensile properties of the paving materials, and the shear strength characteristics of the paving materials as measured by the stabilometer tests.

Assumptions:

This method is largely empirical, and therefore is based on the general assumption that the relationships developed apply under all conditions in which they will be used. In addition the following assumptions are made:

1. The effect of traffic repetitions and vehicle weight can be expressed by a "Traffic Index" which is presumed to be a measure of the number of repetitions of a 5000 pound equivalent wheel load during the design life.

2. The stabilometer tests can provide an appropriate measure of the strength characteristics of the paving materials for use in design.

3. There is an equivalency between various thicknesses of different materials in the pavement system. This equivalency is a function of the tensile properties of the material, and can be described in terms of an empirically-determined "gravel equivalent factor" which represents the thickness of a given material equivalent to a unit thickness of gravel subbase.

Determination of Material Properties: The material properties used to select a pavement thickness by this method are:

1. "R"-Value as measured by the stabilometer. Normally a particular material is prepared at a series of water contents and dry densities.

2. The exudation pressure. This is the pressure required to force water from a sample of the appropriate material which has been compacted in a mold by kneading methods.

3. Tensile strength of paving components as measured by the cohesiometer test.

4. Expansion pressure of subgrade materials.

Experience: This procedure has been used successfully by the California Division of Highways in a number of modified forms since the early 1940's. It is also used by a number of other Western states.

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(Contributed by Carl L. Monismith)

C) CANADIAN DEPARTMENT OF TRANSPORT METHOD FOR THICKNESS DESIGN OF FLEXIBLE PAVEMENTS

History: This empirical method is based on conclusions drawn from evaluation by N. W. McLeod of the performance of Canadian airport pavements.

Principal Design Criterion: The surface deflection of a pavement under repeated load is the criterion for determining the adequacy of the structural design.

Assumptions:

1. The load carrying capacity of a given pavement can be determined from the results of a repeated plate loading test, conducted at the surface of the pavement. The contact area of the plate must be the same as the contact area of the tire considered to apply pressure to the pavement.

2. The effect of one pavement material, i.e. asphaltic concrete or granular base course, relative to that of another material in the pavement system is proportional to the ratio of their thicknesses. Thus the concept of equivalency of a thickness of one material to a different thickness of another material is assumed.

3. The pavement deflection arises from the deflection of the subgrade under load. This load carrying capacity of the subgrade can be measured by a repeated plate loading test.

Determination of Material Properties:

1. The subgrade strength is determined by repetitive static plate tests according to ASTM Designation: D 1195. It is expressed in terms of the load carried at the surface of the subgrade by a 30-in. diameter rigid plate at 0.5-in. deflection after 10 repetitions of loading. Since load testing is normally conducted in summer, the bearing value obtained thus are reduced to allow, in part, for the reduction in bearing capacity in the spring.

   If no test of any kind can be obtained, the load carrying capacity of the subgrade may be estimated on the basis of soil classification, moisture, drainage conditions, etc.

2. Standard densely graded, hot mix asphaltic concrete mixture made up of two layers of different gradation is used for the wearing course. The mixture is designed according to the Marshall Method (ASTM Designation: D 1559). The penetration grade of the bitumen in the mixture is based on the freezing index of the location and the particular use of the mixture.

3. Standard soil-aggregate materials are used for the base course and the subbase. The quality of these materials is controlled by Specification requirements.

Experience: According to Dr. G. Y. Sebastyan, Chief, Engineering Design Division of the Construction Engineering and Architectural Branch of the Canadian Department of Transport, the following problems have been encountered in using the method:

1. The correlation determines the overall pavement thickness requirement and the design does not provide for the stability of the various pavement structural components.

2. For a given subgrade strength and applied load the total pavement thickness determined by this method will be mainly related to the value "K" or the size of plate or contact area used in the design, which give rise to some inconsistency. This was one of the reasons why the Department standardized on a 30-in. diameter plate in pavement design and evaluation work.

3. The original study indicated a constant "K" value for given diameter plate. As "K" is an inverse measure of pavement strength increase per inch thickness, its value, within certain limits should be a function of the type of the material incorporated into the pavement structure.

4. "K" should also be a function of the thickness of the various pavement components. This matter has been investigated by Dr. McLeod and indirectly by Dr. Sebastyan.

5. The correlation between the pavement secant modulus of deformation and pavement performance is based on subjective knowledge and experience.

6. The design equation gives some difference in results if the contact area of the applied load is converted to an equivalent 30-in. plate on the pavement surface and then compared with a subgrade strength value determined on a 30-in. diameter plate and alternatively, if the subgrade strength is given on an equivalent plate size basis and compared with the actual contact area on the surface.

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(Contributed by Eugene Y. Huang)

D) AASHO INTERIM GUIDE FOR THE DESIGN OF FLEXIBLE PAVEMENTS

History: This method was developed from results of the AASHO Road Test by the AASHO Operating Committee on Design and released for study and trial use in 1961.

Principal Design Criterion: The adequacy of the structural design is measured by the change in the Present Serviceability Index (PSI) of the pavement. The PSI is defined as the momentary ability of a pavement to serve traffic. The change in PSI is a function of maximum axle load, number of axles, number of load repetitions, seasonal effects, thickness of pavement components and the subgrade soil support.

Assumptions:

1. The significant relationships found between the number of repetitions of specified axle loads, the thicknesses of surface, base and subbase, and the basement soil used on the Road Test are valid for all soil types. This assumption permits the establishment of a soil support scale.

2. Each axle load applied to a pavement structure in a mixed traffic stream has the same relationship to pavement performance as was found in the Road Test for pavements carrying axle loads of a fixed magnitude. This assumption leads to the development of equivalence factors and the expression of traffic loadings in terms of a common denominator.

3. An environmental factor may be introduced into the design analysis on the basis of a summation of the seasonal weighting factors used to weight the axle load applications on the Road Test.

4. The arbitrary soil support value scale (scale values 1 to 10, 3 being the AASHO Road Test soil) can be correlated to certain CBR and R-value test procedures.

Determination of Material Properties: Materials are generally specified by type or classified by routine AASHO test procedures (grading, etc.)

The structural number,1SN, expresses an empirical relationship between the thickness of a component layer in a pavement structure and the type of material used in constructing the layer. The relationship is expressed by the general equation

$$SN = a_1D_1 + a_2D_2 + a_3D_3.$$

The Road Test established coefficients for certain types of surface course, base course and subbase materials. Coefficients for other materials and mixtures were established by rationalization and a study of comparative cohesion, stability and bearing values obtained in the laboratory. A table of coefficients, thus determined, is given, although further experience and research will be required to establish fully the validity of the estimated factors.

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(Contributed by James F. Shook)

E) ASPHALT INSTITUTE METHOD FOR THICKNESS DESIGN OF ASPHALT PAVEMENTS

History: This method was developed from the statistical analysis of data from the AASHO Road Test. Information from the WASHO Road Test, from British Test Roads, older editions of the Asphalt Institute manual, and state highway and other existing design procedures was incorporated. The present version was published in 1963.

Principal Design Criterion: The adequacy of the structural design is measured by the change in the Present Serviceability Index (PSI) of the pavement. The PSI is defined as the momentary ability of the pavement to serve traffic. The change in PSI is a function of the number and rate of all axle and wheel loads, strength of the subgrade soil in its critical moisture condition and strength, or relative strengths of the surface, base and subbase courses.

Assumptions:

1. The number of applications of various wheel loads can be expressed in terms of an equivalent number of 18,000 pound single-axle load applications. This assumption leads to the development of equivalence factors and the expression of traffic loadings in terms of a common denominator.

2. The effect of one pavement material, i.e., asphaltic concrete or granular base course, relative to that of another material in the pavement system is proportional to the ratio of their thicknesses. Thus the concept of equivalency of a thickness of one material to a different thickness of another material is assumed.

3. The relationships found between the equivalent pavement thickness, the equivalent number of 18 kip axle loads and the soil support value for the AASHO Road Test data are valid for all soil types.

4. The soil support value can be measured by either the California Bearing Ratio (CBR) or the Stabilometer R-value.

Determination of Material Properties: The soil support value is determined by either the California Bearing Ratio test or the Stabilometer test. No determination of properties of the other pavement components is made. However it is assumed that all such components exhibit at least the minimum quality specified in terms of gradation, CBR, Marshall stability and other standard tests normally used in highway work.

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(Contributed by James F. Shook)

F) AASHO INTERIM GUIDE FOR THE DESIGN OF RIGID PAVEMENTS

History: This method was developed from results of the AASHO Road Test by the AASHO operating committee on design and released for study and trial use in 1961.

Principal Design Criterion: The adequacy of the structural design is measured by the change in the Present Serviceability Index (PSI) of the pavement. The PSI is defined as the momentary ability of a pavement to serve traffic. The change in PSI is considered to depend upon the maximum tensile stress in the concrete relative to the tensile strength. This stress is a function of maximum axle load, number of axles, number of load repetitions, seasonal effects, thickness, stiffness, and strength of the concrete, and the subgrade soil support.

Assumptions:

1. The significant relationships found between the number of repetitions of specified axle loads, rigid pavement thickness, characteristics of the pavement and subgrade on the AASHO Road Test are valid for all soil types.

2. Each axle load applied to a pavement structure in a mixed traffic stream has the same relationship to pavement performance as was found in the AASHO road test for pavements carrying axle loads of a fixed magnitude. This assumption leads to the development of equivalence factors and the expression of traffic loadings in terms of a common denominator.

3. An environmental factor may be introduced into the design analysis on the basis of a summation of the seasonal weighting factors used to weight the axle load applications on the AASHO road test.

4. The capacity of the subgrade to support traffic loadings can be measured by the modulus of subgrade reaction.

5. The maximum tensile stress in the concrete can be predicted from the Spangler equation of corner load stresses.

Determination of Material Properties: The material parameters required are the modulus of rupture of the concrete and the modulus of subgrade reaction of the subgrade. The modulus of rupture of the concrete is determined from a compression test on 28-day old concrete using the test procedure specified in AASHO Designation T-97. The modulus of subgrade reaction is determined from a plate loading test conducted in accordance with ASTM Designation D 1196-57, using a 30-inch diameter plate. This modulus may also be estimated in such cases as this is warranted by experience.

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(Contributed by James F. Shook)

EMPIRICAL AND ENVIRONMENTAL METHODS

A) MICHIGAN METHOD OF THICKNESS DESIGN FOR FLEXIBLE PAVEMENTS

History: This method has been used in Michigan since the early 1930's.

Principal Design Criterion: The method is based on experience, and therefore the design criterion is that the pavement section shall be similar to one which has been successful under similar traffic and subgrade conditions.

Assumptions:

The method is empirical and no assumptions are required.

Determination of Material Properties:

In general, no determination of material properties is made other than that available on agricultural soil survey maps.

Experience:

The experience of the Michigan State Highway Department with this method has been excellent according to McLaughlin and Stokstad (1946). The key to the success is annual condition surveys which continually update the information concerning the relationship between soil type, traffic and pavement section.

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(Contributed by Eugene Y. Huang)

B) CANADIAN GOOD ROADS ASSOCIATION METHOD FOR STRUCTURAL DESIGN OF FLEXIBLE AND RIGID PAVEMENTS

History: This method was developed by the Canadian Good Roads Association based upon observation of the performance of many existing pavements.

Principal Design Criterion: This empirical method considers that deflection of the road surface under load must not exceed a value which is a function of the particular area in which the pavement is constructed.

Assumptions:

The basic assumption of this method is that the experience of a given pavement in one area can be extrapolated to the experience of a new pavement in that area which is constructed on a similar subgrade soil.

Determination of Material Properties:

No individual material properties are determined.

Experience:

The method has been used successfully in Canada

(Contributed by W. J. Kenis)

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