PLAN PREPARATION

BOOK II

Prepared by the Road Design Division
and the Traffic Services Division
of the Texas Highway Department
for the Instructors School

Austin, Texas December 1952

FOREWORD

The discharge of our responsibilities and completion of our assigned tasks as employees of the Highway Department can best be accomplished by working together as a team. This volume is dedicated to a better understanding of our common problems.

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SIMPLIFIED USE OF GEOMETRIC DESIGN STANDARDS

With the changing traffic conditions brought about by the increased traffic volumes on our highways in the urban as well as rural areas and by the increased speed of vehicles, the necessity for constructing highways with different capacities has been made more evident. During the early period of highway construction, practically all highways were built to the same design, but these changing conditions have now made necessary the adoption of design standards providing for the various conditions. One condition influencing design is the density of traffic to be expected on the highway. Increasing density of traffic not only fills the highway lanes, but decreases the average speed, and this in turn tends to increase the congestion. As the traffic becomes more dense the requirements for curvature, grade and width of traffic lane used on the medium traffic highway are retained, and additional requirements become necessary in the form of additional lanes, median strips, protected left turn lanes, channelized intersections, grade separations and controlled access to and from the facility.

The Geometric Design Standards dated January, 1952 furnish our design criteria and supersede previous issues. The design criteria indicated in the Geometric Design Standards should not only be applied during plan preparation but as a basis for cost estimation for use in program formulation. So often design criteria are either forgotten or disregarded in preparation of programs. In many cases this results in excessive overruns or underruns in cost. In the event of excessive overruns there is usually a delay in obtaining additional finances and in a few cases projects have been deferred for a subsequent program. Large underruns are less troublesome but the individual district may lose the amount of the underrun for use on other worthy projects in the area.

The purpose of establishing design standards is to incorporate design features in each project which will result in the maximum degree of safety and utility of the ultimate facility.

The three primary features to be considered in designing a highway are:

1. Traffic density or volume
2. Character of traffic
3. Assumed design speed

The highway under consideration must first be classified. Reference to the Design Manual will show that highways are grouped into classes. Class "E" provides for traffic volumes under 400 V.P.D. while Class AA covers those highways with volumes in excess of 6000 V.P.D. Past and often times sad experience proves that it is not good planning to design a highway, of fifteen to twenty years life expectancy, on the basis of the latest traffic count map or even on the basis of someone's guess of future volumes of traffic. A classification map has been included in this text on which the traffic counts on the primary system have been projected to the year 1965. The basis for the preparation of this map has been previously covered in this text and for this treatise the map will be taken at face value. It should be pointed out here however, that administrative approval should be secured before planning for a four lane highway.

From the classification map may be obtained the traffic volume of the section of highway under consideration and by referring to the Geometric Design Standard book it can be placed in a "Class."

We now have the section of highway in a "Class" in relation to traffic density and further reference to the Design Manual will permit the selection of the following design features (1) The design speed (2) Number and minimum width of traffic lanes (3) The width of shoulders and the side slope ratio (4) Horizontal curvature (5) Grades (6) Non-passing sight distance (7) Passing sight distance and (8) Right-of-way width.

DESIGN SPEED

In the case of the degree of horizontal curvature, the Design Manual indicates a "desirable" and a "maximum." Similarly, in considering the design speed and passing sight distance, the Design Manual specifies a "desirable" and a "minimum." These extremes of maximum and minimum design features are indicated for use in those cases where it is not economically feasible to attain the design criteria indicated as "desirable," and should be used only in those cases. Comprehensive application of the proper design features during the preparation of estimates for program submission should reduce to a minimum the times when desirable design criteria are compromised in favor of minimum and often times unsafe and undesirable features.

TRAFFIC LANES

In an attempt to keep highway design abreast of the automotive industry as regards increased speeds the minimum lane widths of all "Classes" of highways above Class "D" have been increased to twelve feet. In the case of Class "D" and "E" highways the Design Manual indicates a minimum traffic lane width of eleven and nine feet respectively. Although, prior to the selection of a traffic lane width for the two lowest class highways a study should be made in regard to the speed and character of traffic using the facility. It is a recognized fact that as the density decreases the average speed of traffic increases so that it is possible that the same lane width requirements for medium and high traffic density highways may also be required on the light traffic density highway.

SHOULDERS AND SIDE SLOPES

A feature so often overlooked by the designers is the shoulder width requirement in respect to the ratio of the side slope. In several cases the design criteria as indicated in the Design Manual permit one width of shoulder when the side slopes are six to one or flatter and require two feet additional width if the side slope is steeper than six to one. This alternate shoulder width was not included in order to permit or encourage the frequent widening and narrowing of shoulders as the slopes varied from flat to steep. It was accepted for the purpose of assuring a minimum effective shoulder width that had been previously selected for that particular class of highway. For any particular project the general rule should be that the shoulder width be determined from the usual side slope. This is not intended to preclude the necessity of widening the shoulder at high fills adjacent to bridges. In connection with shoulder width determination the designer should not overlook the requirement for guard posts on high fills and the corresponding additional crown width required to accommodate them.

HORIZONTAL CURVATURE

In determining the maximum degree of horizontal curvature to be used on a particular section of highway, the principal factor to be taken into consideration is the speed of traffic. The ever increasing speed being built into the modern cars by their manufacturers is the greatest headache and challenge to the highway designer. We can appreciate the fact that speedlimits in Texas have not been pushed up accordingly but we cannot be assured by this fact because of the flagrant violation of these laws. We must be realistic and design our highways for the actual speeds we are experiencing. For this reason we should maintain the horizontal curvature indicated in the Design Manual as desirable except in those cases where it is not economically justifiable. In determining the economies of introducing a horizontal curve sharper than the desirable, consideration should be given to the possibility of the route becoming obsolete and having to be abandoned at a relatively early date due to curvature or the necessity of a major and costly realignment and exorbitantly high right-of-way costs due to ribbon development.

GRADES

The grades of a highway must be designed to meet the requirements of many principles. These are given in tabular form below and the first principle is considered to be the provision of an adequate facility for the flow of traffic. In controlling traffic flow, one of the first restrictions is the maximum grade on the highway. The Design Manual sets out the grade considered to be the maximum for each classification of highway and these maximums should not be exceeded except in very special conditions.

Grade Design Principles

1. Facility for Traffic Flow
2. Construction Economy
3. Safety
4. Sightliness
5. Drainage
6. Curvature and grade
7. Field check of designed grade
8. Adjustment of grade to provide adequate non-passing and passing sight distance

The restriction to the uniform flow of traffic offered by the maximum percent of grade depends on the length of that maximum grade and on the frequency at which such maximum grade occurs. In designing the grade the length of each maximum percent of grade and the total length of all the steeper grades must be considered. This statement can be clarified by saying that in a series of plus grades we should introduce flat or minus grades in order to allow the heavily loaded trucks an opportunity to accelerate to cruising speed. This subject will be covered more fully in the treatise on climbing lanes.

The second principle of the design of grades is to establish that design which will provide for economy of construction. The first method of obtaining economy is to design a grade which will require the minimum amount of cut and the minimum amount of fill. There are very distinct restrictions which will prevent the achieving of maximum economy by this method a few of which are (1) Required maximum grade (2) Required Grade to meet drainage structures (3) Necessity for safety to be provided by adequate passing and non-passing sight distance and the elimination of blind spots (4) Necessity of keeping grade above high water elevations both where the location crosses an overflow area and where it parallels a stream and (5) The requirement that the entire design must produce a pleasing appearance and a highway which will not be expensive to maintain.

The primary safety features of a grade line are met by obtaining adequate passing and non-passing sight distances. One feature that may be overlooked even after obtaining adequate passing and non-passing sight distance is the existence of blind spots in the grade line. A blind spot is defined as a dip in grade in which a car might be concealed and the driver of an approaching car can see over the car in the dip to the pavement beyond. This is usually occasioned by the designer's attempt to lay a contour or "grass roots" grade line. In every case after a grade line is laid and other design criteria are satisfied the designer should take an overall look at the grade line with the view of locating and eliminating any "blind spots."

The relation of horizontal curvature to vertical curvature must be carefully considered both in location and design to eliminate the construction of concealed curves; that is, curves which begin at a point on the grade not visible to the approaching driver at sufficient distance in advance to prevent the possibility of surprise due to encountering the curve without timely warning.

SIGHT DISTANCE

Passing and non-passing sight distance has been mentioned previously several times in this article. This is pertinent because it points to the importance of these two features in the safety and utility of the ultimate facility. Sight distance is the length of highway ahead visible to the driver. When not long enough to permit safe passing of overtaken vehicles it may be termed non-passing sight distance. The minimum non-passing sight distance should be long enough to permit a vehicle traveling at the assumed design speed of the highway to stop before reaching a stationary object in the same lane and is actually "Safe Stopping Distance." To put this in figures for use of the designer the non-passing sight distance is the longest distance in which a driver, whose eyes are assumed to be 4.5 feet above the pavement surface, can see the top of an object 4 inches high on the road. A convenient chart is included in the Design Manual for use in checking for non-passing sight distance. Sight distance at every point on a highway should be as long as possible but at no point should it be less than the minimum non-passing sight distance.

On two-lane two-way highways, which constitute the bulk of our highway system, fast-moving vehicles frequently overtake slow-moving vehicles. Passing must be accomplished on a lane that may be occupied by opposing traffic. If passing is to be accomplished with safety the driver of the passing vehicle must see enough of the highway clear of opposing traffic so that if vehicles appear after he has started to pass he will have sufficient time to pass and return to the right lane without cutting off the passed vehicle and before meeting opposing traffic. Highways with inadequate sight distance for safe passing are hazardous and inefficient. They are hazardous because they tend to encourage even the patient and careful drivers to take a chance, especially after remaining behind a slow-moving vehicle or train of vehicles for one hill or curve after another without encountering opposing traffic and realizing that passing could have been accomplished. By providing passing sight distance sufficient for safe passing at frequent intervals even the impatient drivers are prone to wait and take advantage of them. For this reason it is desirable that all primary highways have safe passing zones so spaced that the distance between the end and beginning of adjacent safe passing sections will be not more than one mile. This distance may be increased to two miles on the lighter traffic highways or more specifically those roads that fall in Class "D" or "E"."

The mechanics of checking a gradient for passing sight distance sections is a bit more complicated than that for checking for non-passing sight distance. A plan has been worked out for Texas highways which is suggested for use by the Districts. This is the method that will be used in reviewing plans in the Austin office. This method by necessity must be coordinated with the method employed by the Maintenance Division for marking barrier stripes on the highways at points of restricted sight distance. A barrier stripe is placed on the highway at every section on which the passing sight distance is less than 1000 feet. Passing sight distance as defined by the Design Manual is the longest distance in which a driver whose eyes are assumed to be 4.5 feet above the pavement surface can see the top of an object 4.5 feet high on the road. The time to check a grade line and correct for adequate sight distance is after the tentative gradient has been laid and the non-passing sight distance and other design criteria satisfied. The first step consists of checking each crest in the gradient for the length of passing sight distance. This can be done expeditiously by use of the passing sight distance chart included in this text. In the event there are no sections having a passing sight distance less than 1000 feet the task of providing adequate sight distance in accordance with the assumed design speed is quite simple. It consists of again going over the grade line and providing the proper number and spacing of safe passing zones as described above. In the event the first check indicates that there exists one or more sections having a passing sight distance of less than 1000 feet another step is introduced into the procedure. This will necessitate the use of a template so constructed that 1000 feet is provided on the horizontal scale with 4.5 feet legs on each end. By moving this template over the crests on which the chart indicates that less than 1000 feet of sight distance has been provided the designer may mark the beginning and end of the future barrier stripe on the profile. These are the points from which the adjacent safe passing zones must be computed because of the fact that a section of highway containing a barrier stripe is not available to the motorist for use in passing. After these points have been established on the profile, and that section bearing a barrier stripe eliminated from consideration, the procedure for laying out and spacing safe passing zones is the same as described above.

Strict adherence to the desirable minimum passing and non-passing sight distance requirements for two lane highways will delay the day when increased traffic and resultant accidents will require costly heavy betterment projects or provisions for divided roadway construction.

RIGHT OF WAY WIDTH

Today as never before more and more of our highways are becoming obsolete and having to be abandoned because of insufficient right of way to permit modernization, and the prohibitive cost of securing additional right of way on the old route due to ribbon development. This is not confined just to our larger urban areas but is general over the state adjacent to cities and very modest towns. Recent actions of the Highway Administration relative to Freeway designations which require sufficient right of way to accommodate frontage roads indicate their determination to reduce the number of our highways that will have to be abandoned due to insufficient right of way. The right of way widths indicated in the design manual are the absolute minimum to be employed on level terrain and in most cases will necessarily have to be increased to meet local conditions. It is always good practice to have the geometric design reasonably well developed prior to the preparation of right of way deeds but in the case of a freeway it is absolutely essential.

AUXILIARY CLIMBING LANES ON GRADES

There are two contributing factors to the inability of fast moving traffic to pass slow moving traffic on a two lane highway. They are high traffic density and inadequate safe passing zones. In most instances the cost of reducing grades on existing facilities in order to secure adequate passing sight distance is excessive and it becomes mandatory that an alternate method be substituted. This method can be the provision of climbing lanes at sections on which there exists inadequate passing sight distance and for which the cost of providing adequate passing sight distance by use of a grade revision would be prohibitive. The cost of a grade revision or climbing lanes on an existing facility is always higher than it would have been if either were provided during the initial construction operations. For this reason the designer should, in all cases, be sure to provide adequate safe passing zones or climbing lanes on all new construction.

The mechanics of checking the necessity for climbing lanes and of obtaining the length of climbing and acceleration lanes have been made very simple by the use of the chart submitted to the Districts with Road Design and Maintenance Informational Circular No. 1-52. A copy of this letter and attached chart is included herewith.

All of the special features discussed above may seem like an attempt to make highway design look complicated. Actually our objective is simple: it is to incorporate the maximum utility and safety in the ultimate facility at the least cost.

In connection with geometric design it is pertinent to call attention to Road Design Circular No. 10-45 dated September 1, 1945.

In addition to other instructions this circular canceled the requirement of submitting complete P. S. &E. in pencil to Austin for review and in lieu of this it contained the request that an outline of the proposed basic design be submitted to Austin and approved prior to plan development. The design outline can usually be ndicated on a sheet showing typical sections and should indicate all of the basic design information including right o way widths and the placing of the centerline of the typical section in respect to the centerline of the right of way.

This requirement is still in effect and should be adhered to in order to preclude the possibility of costly and often times embarrassing delays due to the late submission of completed plans in which some controversial basic design features are included. In order to assist in the coordination of design and to expedite the completion and processing of P. S. &E., the Road Design staff is available for consultation either in the Austin office or at the site at any stage of the plan development.

MEDIANS

As noted in the first of this treatise high traffic densities require several design features which are not necessary on the lighter traffic highways. One of these is the division of opposing traffic lanes by the use of medians. High densities makes it desirable to intorduce medians while the combination of high densities and a large volume of turning movements or cross traffic often times makes their use mandatory.

Medians in common use are divided into two classes namely the wide and narrow with the division point being generally accepted as eight feet. Wide medians may be raised or depressed but it is not good practice to depress a median of a width less than 20 and preferably 28'. Narrow medians should be raised and in most cases paved due to the difficulties of obtaining and maintaining adequate sod or planting on them. The width of a median to be used on a certain section of highway should be based on amount and type of traffic using the facility. For design purposes traffic is divided into three main classes (1) Highways used by passenger vehicles only on which other types are prohibited are designated as "P" type (2) Highways used by all types of traffic are designated as "M" type and (3) Highways on which the percentage of trucks is abnormally high are designated by the letter "T". On Texas highways "P" type traffic will seldom be encountered. The majority will fall in the "M" class with a surprisingly high percentage falling in the "T" class. Highway planning survey data indicates that the breakdown of traffic on Texas Highways will average 76 percent passenger vehicles and 24 percent trucks, combinations, pick-ups, panels and buses. A further breakdown indicates that there are 13 percent trucks, single and combinations and 6 percent truck combinations. With the exception of traffic density and number of turning movements the most important factor that will affect the width of a median is the percentage of truck combinations to the total traffic. Apparently no attempt has been made to set an arbitrary figure dividing "M" and "P" type traffic but it is safe to assume that any time the percent of truck combinations reaches 8 percent of the total traffic the designer should, on any divided roadway highway, provide a median of sufficient width to accommodate truck trailer combinations.

The desirable minimum width of a median to accommodate the three classes of traffic are 25 feet for "P" type, 32 feet for "M" type and 50 feet for "T" type traffic. There are too many cases when the designer is not allowed the privilege of fitting the median width to the type of traffic due to prior commitments on the width of right of way. It is hoped that the number of these cases will diminish in the near future. Comprehensive application of the proper width of median to the traffic density, turning movements and traffic type will delay the day when it will be necessary to provide traffic signals.

The width of opening in a median at intersections bears a direct relation to the width of median This will be discussed in more detail under the treatise on "Theory of Intersection Design."

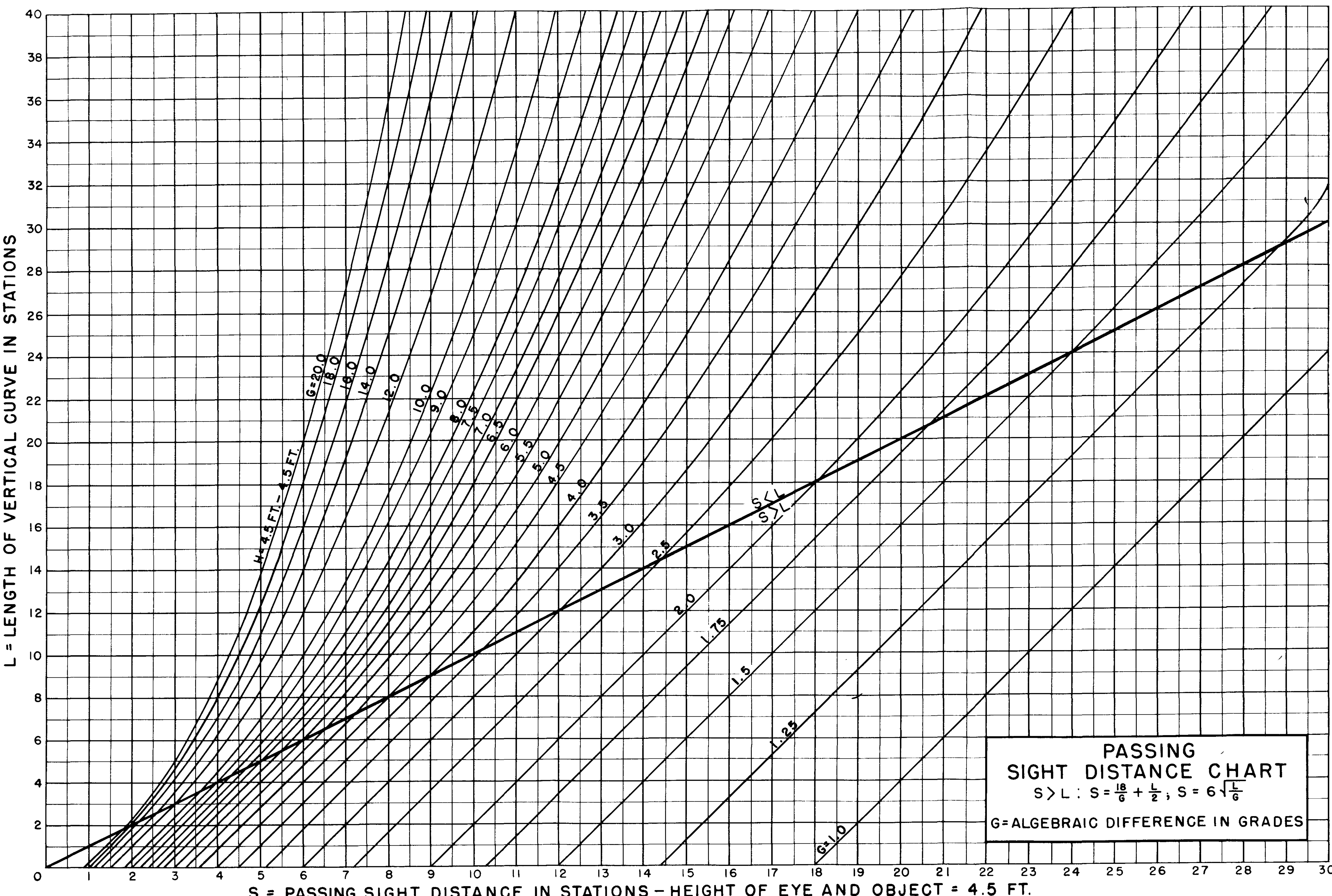
Left hand turn lanes or "shadow lanes" in medians are a necessity when high traffic densities exist with a corresponding high number of left turn movements at intersections at grade.

Narrow and intermediate width medians should be curbed. This bracket should include medians up to 20 feet wide. The height of the median curb is the most controversial issue regarding highway design.

A good rule to follow is to keep the curbs low with flat face slopes on the rural highway where speeds are high and the possibility of appreciable turning movements is low and to increase the height and decrease the batter in urban areas where the speeds are reduced and the tendency for turning movements is great. More specifically, the rural type curb should be not more than 4 inches high with a 1:1 batter and the urban type curb should not be more than 6 inches high with a vertical or nearly vertical face. The 6 inch curb will permit emergency type vehicles such as police cars, ambulances, fire trucks, and wreckers to cross the median yet will discourage unauthorized crossings. There is some justification of median curbs higher than 6 inches on expressways with no grade crossings and where full control of access exists. In this connection it should be remembered that a curb in excess of 6 inches in height is a barrier type curb and whenever it is used the adjacent traffic lane should be increased 2 feet.

A full treatise on medians and median curbs would take more space than is available for this text and it is hoped that the information given here will be considered only as a general guide and that the designer will refer to the following listed references for further study and research:

1. A. A. S. H. O., A Policy on Highway Types (Geometric)
2. A Preliminary Discussion on Arterial Highways in Urban Areas
3. Proposed Revision of Policies on Geometric Design of Rural Highways



PASSING
SIGHT DISTANCE CHART
S > L : S = 18/G + L/2 ; S = 6√(L/G)
G = ALGEBRAIC DIFFERENCE IN GRADES
L = LENGTH OF VERTICAL CURVE IN STATIONS
S = PASSING SIGHT DISTANCE IN STATIONS – HEIGHT OF EYE AND OBJECT = 4.5 FT.
H = 4.5 FT. – 4.5 FT.
S < L
S > L
G = 20.0
18.0
16.0
14.0
12.0
10.0
9.0
8.0
7.5
7.0
6.5
6.0
5.5
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2.5
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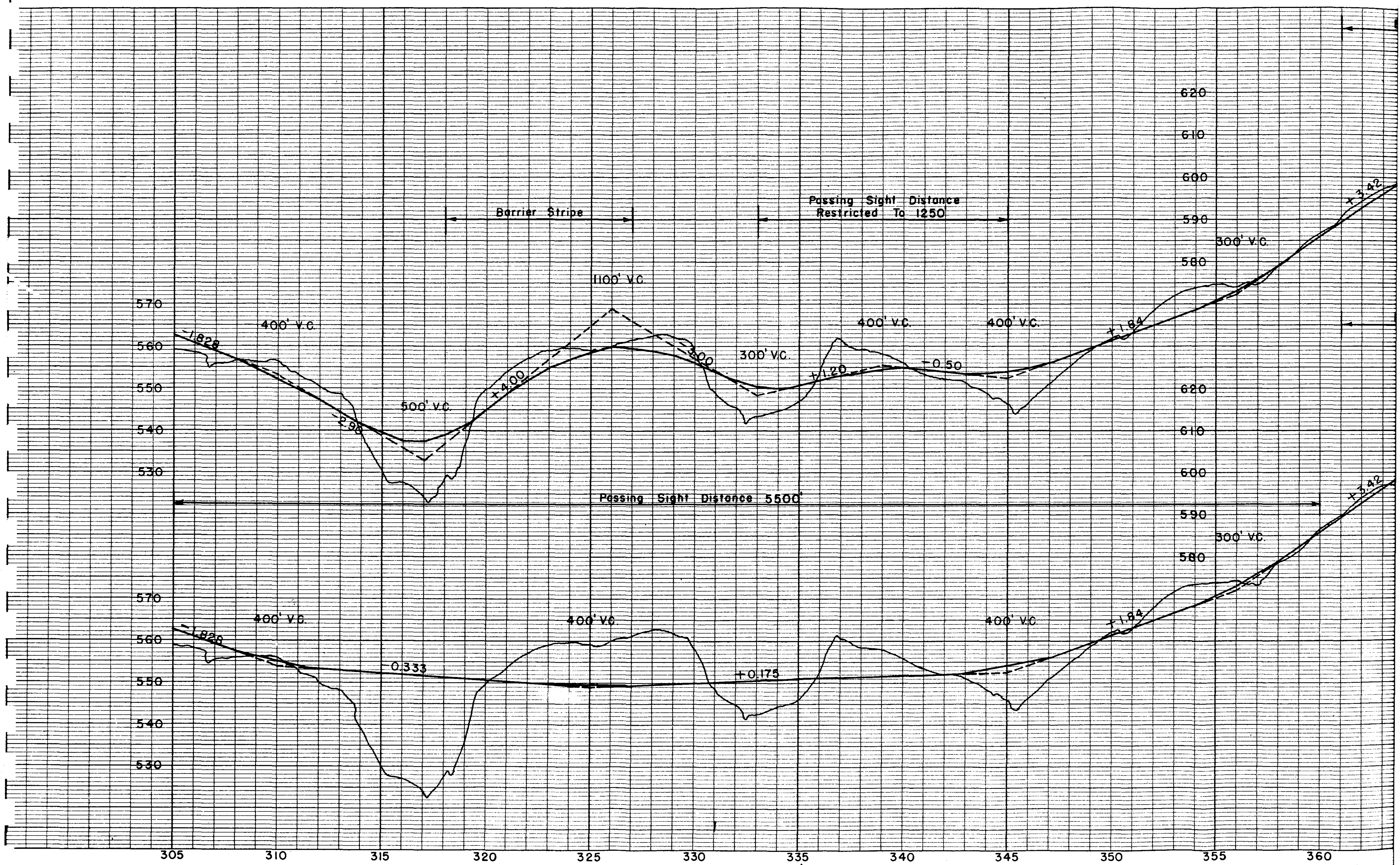
1.75
1.5
1.25
G = 1.0


Barrier Stripe
Passing Sight Distance Restricted To 1250'
1100' V.C.
400' V.C.
500' V.C.
300' V.C.
400' V.C.
400' V.C.
300' V.C.
-1.828
-2.96
+4.00
-3.00
+1.20
-0.50
+1.84
+3.42
Passing Sight Distance 5500'
400' V.C.
400' V.C.
400' V.C.
300' V.C.
-1.828
-0.333
+0.175
+1.84
+3.42
620
610
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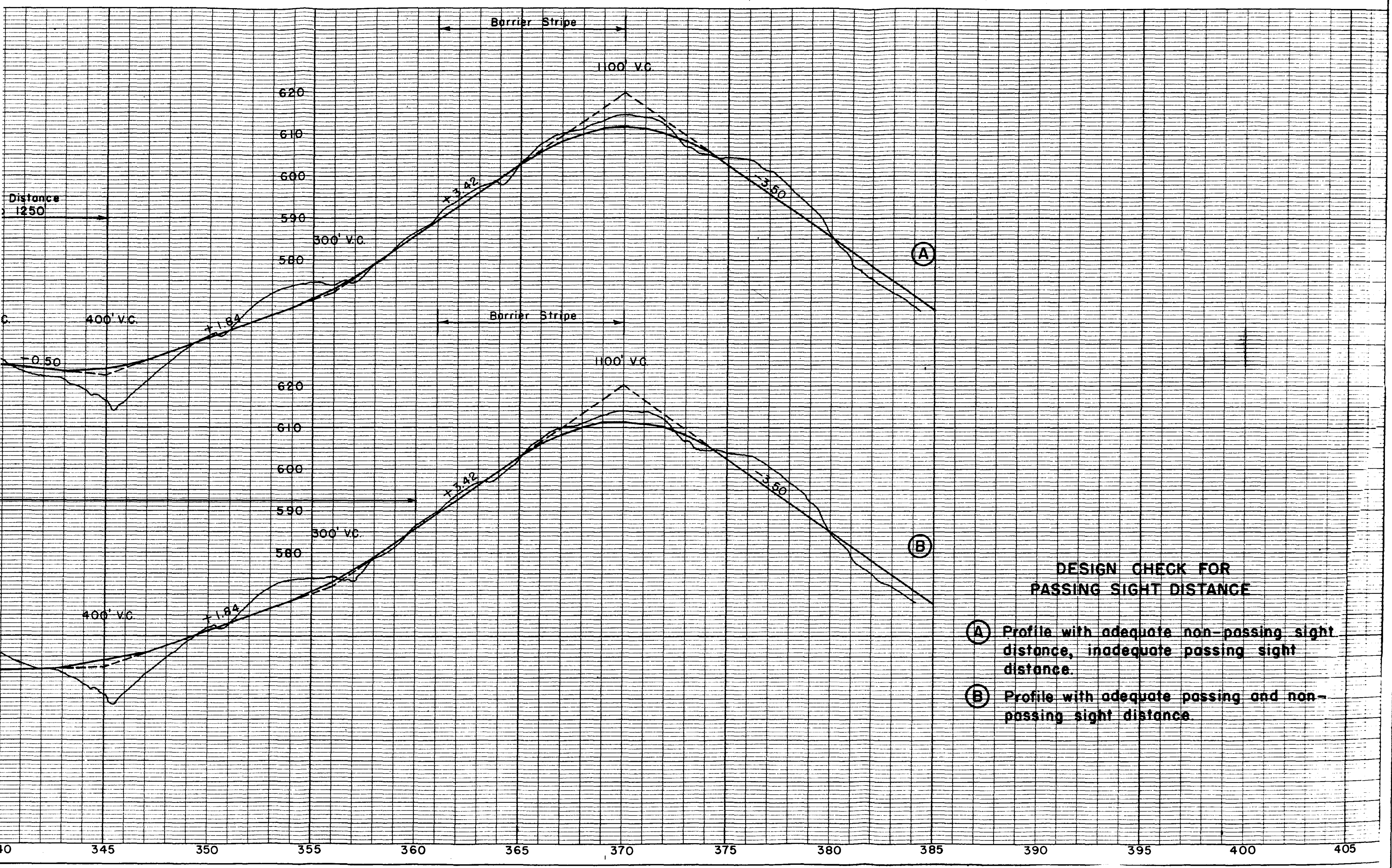


DESIGN CHECK FOR PASSING SIGHT DISTANCE

(A) Profile with adequate non-passing sight distance, inadequate passing sight distance.

(B) Profile with adequate passing and non-passing sight distance.

COMMISSION

E. H. THORNTON, JR., CHAIRMAN
FRED A. WEMPLE
ROBT. J. POTTS

TEXAS HIGHWAY DEPARTMENT

STATE HIGHWAY ENGINEER
D. C. GREER

Austin 14, Texas
August 5, 1952

IN REPLY REFER TO
FILE NO. D-8 & D-3

ROAD DESIGN AND MAINTENANCE INFORMATION CIRCULAR NO. 1-52

SUBJECT: Auxiliary Climbing Lanes on Steep Grades

TO: All District Engineers and Engineer-Managers

Gentlemen:

This supersedes and replaces Road Design Circular No. 5-46. Warrants and suggested design procedure have been brought up to date by incorporating into the attached chart results of recent road tests made in other States. Data acquired from truck distributors on the tractive ability of heavy trucks now being manufactured has also been used. Warrants for design in the various classes of highways have been determined from data furnished by D-10 from loadometer surveys.

It will be noted that an acceleration chart is presented as a companion to the deceleration chart. Profitable use can be made of this feature in terminating climbing lanes over hill crests.

Warrants, criteria and general conditions upon which the attached chart was based are believed to be normal. Special conditions will require special treatment. For example; the recommended transition distance of 525 feet between the normal lane and the full climbing lane provides for the truck to travel in a path conforming to a one degree horizontal reverse curve. If the use of the recommended transition distance involves lengthening a culvert, widening a rock cut or other expensive operation, the choice of a less convenient traffic path is indicated. Also, the recommended minimum design speed of thirty miles per hour for single lanes may be varied to meet economic conditions encountered on specific projects.

Climbing lane lengths may usually be determined from the chart with only small error, by disregarding the vertical curves and operating between points of intersection of grade tangents. However, if refinement is desired and particularly if the probable running speed of a loaded truck at a specific point on a vertical curve is required to be known, then the vertical curve should be broken into convenient chord lengths and auxiliary grades calculated.

The use of the climbing lane is strongly recommended wherever warranted whether on new construction or maintenance betterment. The geometric and structural design of the extra lane should provide a minimum width of 12 feet and a pavement depth equal to that of the normal two lane road.

Yours very truly,

D. C. Greer
State Highway Engineer

By: J. C. Dingwall
J. C. Dingwall
Engineer Road Design

And P. S. Bailey
P. S. Bailey
Maintenance Engineer

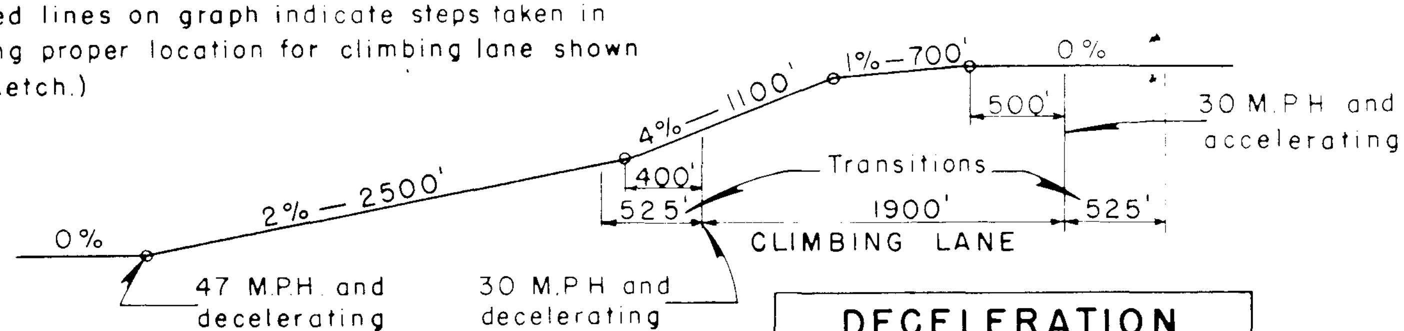
Attachment

SPEED-DISTANCE CURVES

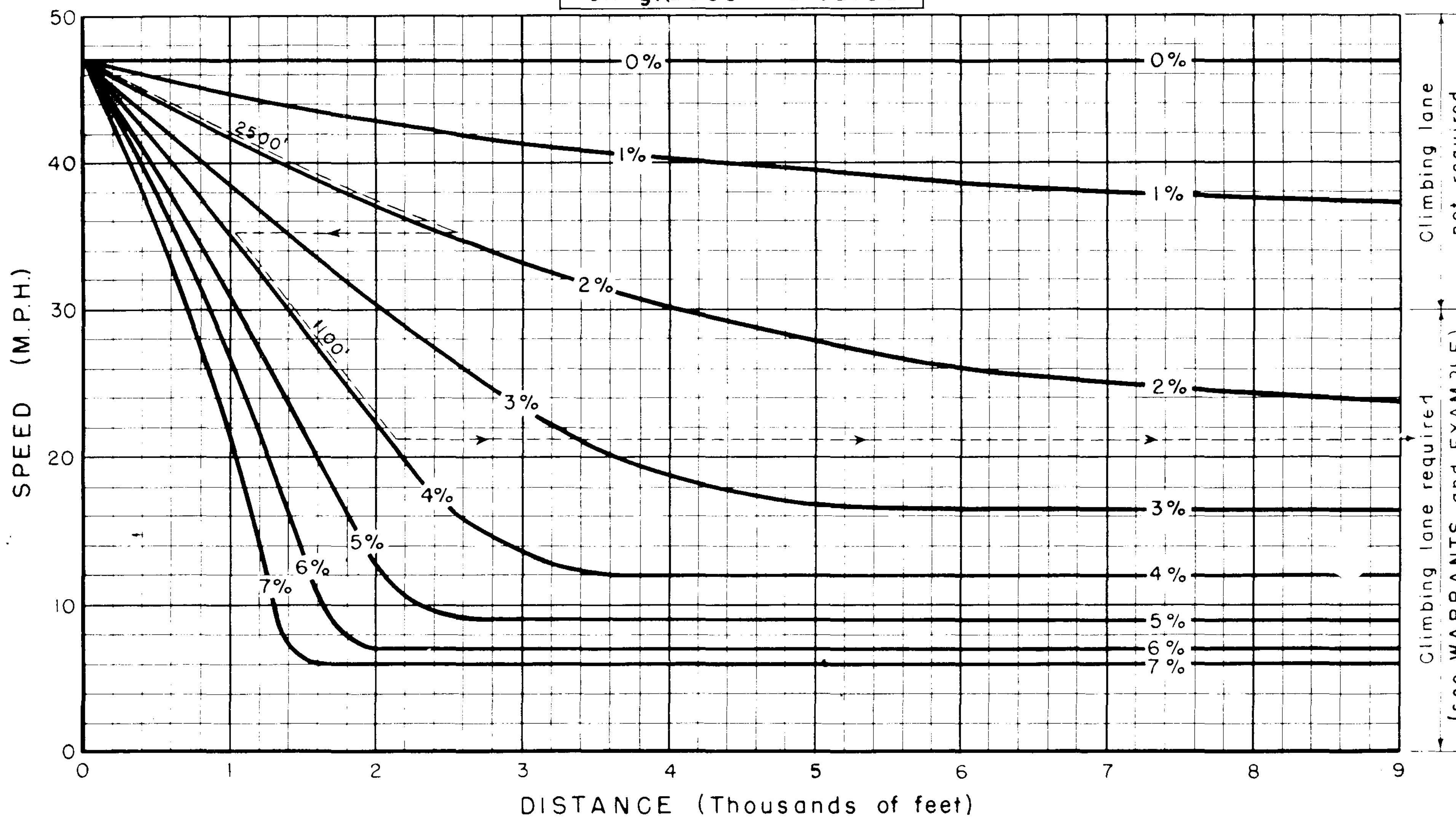
ESTIMATED FOR
A TYPICAL HEAVY TRUCK
OPERATING ON VARIOUS GRADES

EXAMPLE OF USE OF CURVES

(Dashed lines on graph indicate steps taken in finding proper location for climbing lane shown on sketch.)



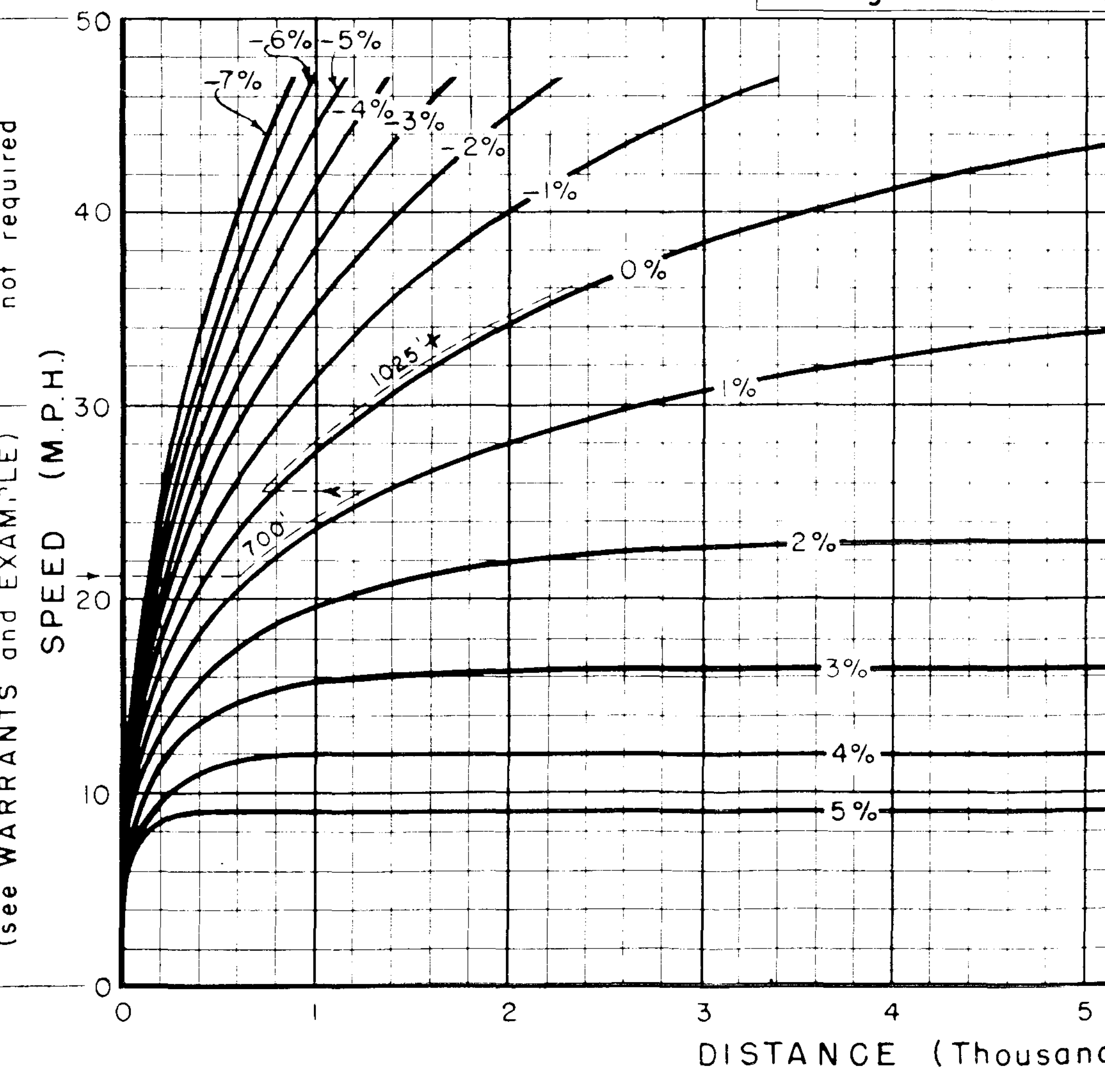
DECELERATION
on grades indicated



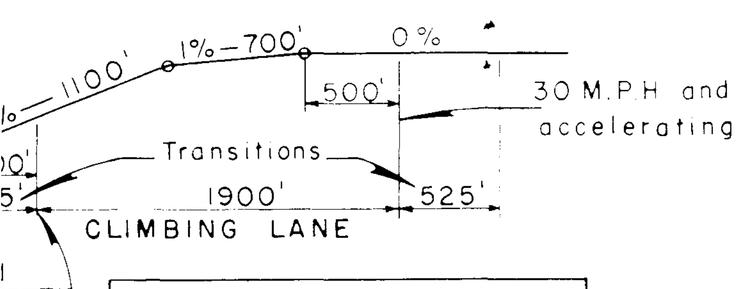
WARRANTS FOR

CLASS B HIGHWAYS — Provide cli
CLASS C HIGHWAYS — Desirable t
Minimum t
CLASS D HIGHWAYS — Make studi
shoulder to
(1) constr
(2) volum
CLASS E HIGHWAYS — Climbing la

ACCELERATION
on grades indica



SE OF CURVES



SPEED–DISTANCE CURVES

ESTIMATED FOR
A TYPICAL HEAVY TRUCK
OPERATING ON VARIOUS GRADES

WARRANTS FOR CLIMBING LANES

CLASS B HIGHWAYS — Provide climbing lane and parking shoulder.

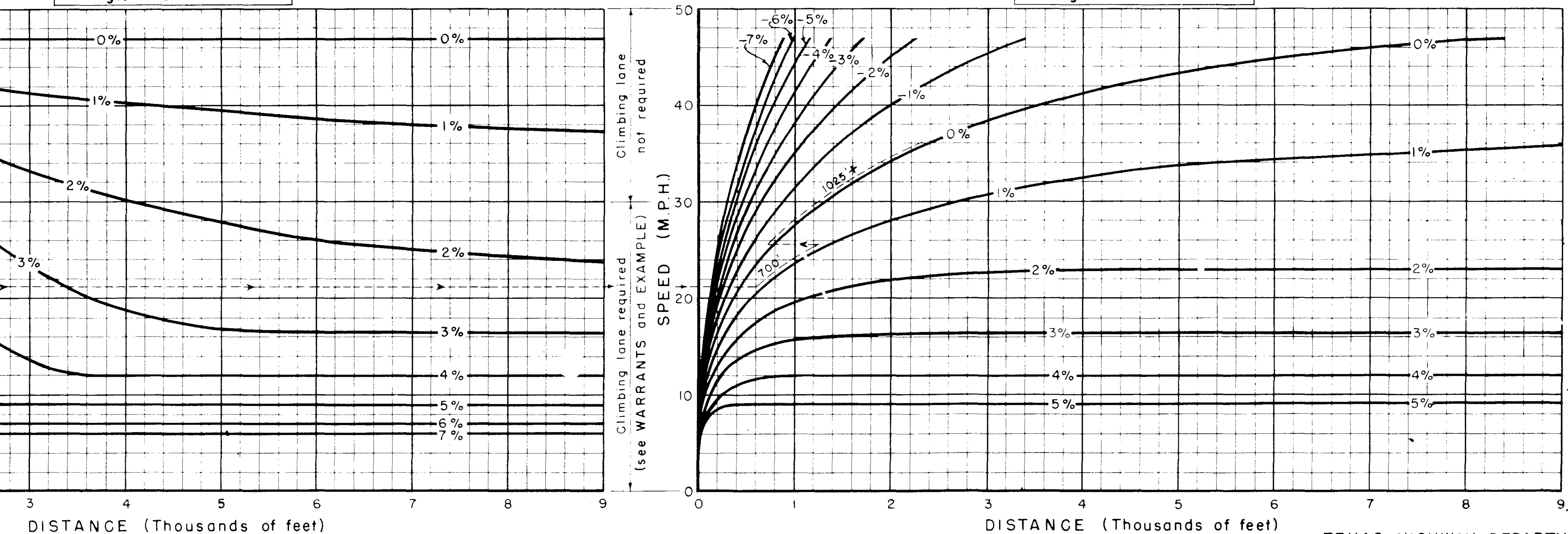
CLASS C HIGHWAYS — Desirable treatment: same as for CLASS B HIGHWAYS. Minimum treatment: convert shoulder to climbing lane.

CLASS D HIGHWAYS — Make studies to determine feasibility of converting shoulder to a climbing lane, taking into account:
(1) construction costs and,
(2) volume of heavy trucks.

CLASS E HIGHWAYS — Climbing lanes not considered necessary.

DECELERATION
on grades indicated

ACCELERATION
on grades indicated



TEXAS HIGHWAY DEPARTMENT
ROAD DESIGN DIVISION
AUGUST, 1952

SUPERELEVATION OF CURVES AND THE USE OF TRANSITION CURVES

The Texas Highway Department custom of superelevating, widening and transitioning curves is well known. How to superelevate, widen and transition curves is not so well understood. No rule or formula will fit all cases. Each case requires a decision by the designer after all of the facts have been evaluated.

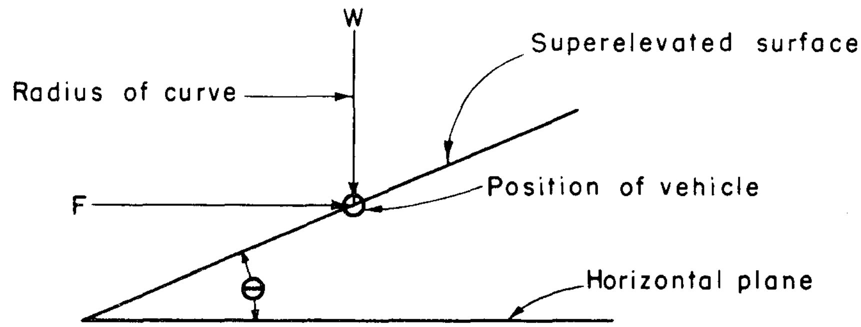
Our primary objective in curve design is to provide safety. Safety is attained when the transition is smooth with no objectionable side forces acting to surprise the driver or to force the vehicle out of its lane. Safety in this case is relative. A prudent Engineer will provide a much larger factor of safety for sixty miles per hour traffic than for twenty miles per hour traffic. The reasons are obvious.

The Texas Highway Department SWC - 39 under general notes gives the following formula: Maximum Safe Speed in miles per hour = $\sqrt{15R\ (e + 0.15)}$. This formula is nearly exact and may be used with confidence if the Engineer can be sure the friction factor is 0.15.

The friction factor of 0.15 is suitable for primary highways where high speeds are expected and when the surface is reasonably smooth. This is the use for which the formula is intended.

The derivation of the formula follows:

DERIVATION OF FORMULA FOR MAXIMUM SAFE SPEED



A moving vehicle on a curve is on the verge of sliding outward due to centrifugal force. The relation connecting speed, curvature, friction and superelevation is derived below.

Symbols:

R = radius of curve (ft.)
v = vehicle velocity (ft./sec.)
V = vehicle velocity (m.p.h.)
W = vehicle weight (lbs.)
θ = superelevation angle
e = $\tan\theta$
f = coefficient of kinetic friction between tire and road surface
g = acceleration of gravity (ft./sec.^{2})
F = centrifugal force (lbs.)
F_n and F_t are the normal and tangential forces exerted by the vehicle on the road surface

By definition, $f = \dfrac{F_t}{F_n}$ (1)

By resolution of the forces W and F,

$$F_t = F\cos\theta - W\sin\theta$$
$$F_n = F\sin\theta + W\cos\theta \qquad (2)$$

Since, by definition, $\tan \theta = e$, then

$$\sin \theta = \frac{e}{\sqrt{1 + e^2}}$$

$$\cos \theta = \frac{1}{\sqrt{1 + e^2}} \tag{3}$$

Then, from Equations (1), (2), and (3):

$$f = \frac{F - We}{Fe + W} \tag{4}$$

Transforming (4):

$$F = \left(\frac{e + f}{1 - ef}\right) W \tag{4a}$$

From theoretical mechanics:

$$F = \frac{W}{g} \bullet \frac{v^2}{R} \tag{5}$$

Equating the right members of Equations (4a) and (5), and solving for v:

$$v = \sqrt{\frac{gR\ (e + f)}{1 - ef}} \tag{6}$$

Since $v = 1.4667\ V$ and $g = 32.16$ (approx.),

$$V = 3.866 \sqrt{\frac{R(e + f)}{1 - ef}} \tag{7}$$

Since $\overline{3.867}^{2}$ is nearly 15 and, for most practical problems, $1 - ef$ is nearly 1.0, Equation (7) may be written in the following approximate form:

$$V = \sqrt{15\ R\ (e + f)} \quad \text{(Approx.)} \tag{8}$$

V is termed the safe speed for the curve with radius R, superelevation e and road surface kinetic friction coefficient, f.

The SWC - 39 contains two tables of superelevation. Table 1 is for primary highways. The superelevations shown will permit speeds of 70 miles per hour for all curves up to four degrees and a speed of 65 miles per hour for five degrees. Of course, the safe speeds on the flatter curves are greater than 70 miles per hour. All curves are to be superelevated but the rate of superelevation for curves of four degrees and over should be applied with caution. All values shown in table 1 are for high speeds on rural highways. Where sharper curves are used under special conditions such as at the entrance to a city, the probelm is a special one and Table 1 does not apply.

Table 2 was intended for feeder roads with lower design speed and traffic volumes. The superelevations of Table 2 will provide safety for speeds up to 60 miles per hour on curves up to five degrees. For curves between five degrees and eight degrees the safe speed is 50 miles per hour, between eight degrees and twelve degrees the safe speed is 40 miles per hour.

The following table illustrates the effect of various friction factors on high speed traffic. Calculations are based on the formula $V = \sqrt{15R\,(e + f)}$

$f = 0$	No force exerted on passenger or car
$f = 0.10$	Very comfortable, very safe
$f = 0.15$	Fairly comfortable, very safe
$f = 0.20$	Sway not bad, safe when pavement is smooth and dry.
$f = 0.25$	Uncomfortable, safe for skilled driver when the pavement is smooth and dry.

Degree of curve Degrees	Super-elevation ft. per ft.	Speed in M.P.H. f=0.00	f=0.10	f=0.15	f=0.20	f=0.25
1	.0	0	93	113	131	not recommended
1	.02	41	101	121	138	" "
1	.04	59	110	128	144	" "
3	.0	0	54	65	76	85
3	.02	24	59	70	79	88
3	.04	34	63	74	83	91
3	.06	41	68	77	86	94
3	.08	48	72	81	89	97
3	.10	54	76	85	93	100
6	.0	0	38	46	53	60
6	.06	29	48	55	61	67
6	.08	34	51	57	63	69
6	.10	38	53	60	65	71

The SWC-39 provides for widening pavements where the pavement width is 20 or 22 feet and permits widening if conditions warrant where the lane width is 12 feet. The latest geometric standards require 12 foot lane widths for class "C" highways (1000 - 1800 vpd) and above. A revision of the SWC-39 to recognize the latest design standards has been discussed but no decision has been made. Until a revision has been made the designer should carefully review lane widths, particularly where bridges are constructed on curves.

Shoulders should be superelevated at the same rate the pavement is superelevated. This of course will result in water from the shoulder flowing across the pavement. If this water deposits mud on the pavement or is likely to make the pavement slick, consideration should be given to providing surfaced shoulders.

It will be noted that the diagrams for methods of attaining superelevations show the superelevated section as extending from crown line to crown line. Any reduction of the superelevation rate on the outside shoulder of a curve would add to the difficulties of a driver forced off the pavement at a time when he most needs the assistance of superelevation. It might be argued that the inside shoulder if not superelevated would assist the driver back on the surface. It is probable however, that the quick change from superelevation to no superelevation would only add to the driver's difficulties. Consequently, the design is based on continuing the superelevation rate entirely across the crown width.

The curve standard illustrates two methods of attaining the superelevation required on the curve. The most usual method is that designated as "Revolved About Centerline" in which the calculations are made from the centerline grade, with the outer crown line of the roadbed rising uniformly from its normal position below the centerline to a position above the centerline grade equal to the superelevation rate times the distance from the centerline. As the outside crown line rises, the inside crown line must drop to a position below the centerline grade equal to the superelevation rate times the distance from the centerline.

Another method illustrated as "Revolved about the Inner Crown Line" requires the maintaining of the inner crown line grade and raising the outer crown line. This method is useful to avoid drainage problems.

To avoid a warped section of the pavement, that is, one in which the slope of the inside and outside halves of the pavement are different, the inside crown must drop on the same grade with reference to the centerline as that on which the outside crown line rose. The diagram for this method of attaining superelevation, by revolving about the centerline is given on the standard, and it may be seen that the point "C" at which the inner crown line begins to drop may easily be calculated.

Obviously it is necessary to have some form of transition from the highway tangent to the superelevated curve. Where the highway curve is properly designed for the speed anticipated on the highway, this necessity for design of the transition becomes more important. In the first place, there must be some length of roadway over which the superelevation is introduced, as it cannot be introduced suddenly. Second, the vehicle, on entering the curve, is acted upon by a centrifugal force which increases from zero on the tangent to a maximum as the vehicle enters into a path with a radius equal to that of the curve. Also, it is evident that this centrifugal force cannot be suddenly applied without causing dangerous effects.

The required minimum length of transition is determined as follows:

Symbols

Let v = velocity in ft. per second
V = velocity in miles per hour
L = length spiral in ft.
R = radius of circular curve in ft.

W = weight in lbs.
a = acceleration in ft./sec.^{2} toward the center of the curve
g = acceleration of gravity in ft./sec.^{2}

$$F = \frac{W}{g} \cdot \frac{v^2}{R}, \quad F = \frac{Wa}{g}; \text{ therefore } a = \frac{v^2}{R}$$

If a vehicle travels on a circular curve at a constant speed of v in feet per second it is accelerating toward the center at the rate of $\frac{v^2}{R}$. The total time required to traverse the transition curve is $\frac{L}{v}$. The average rate of the acceleration then is $\frac{v^2}{R} \div \frac{L}{v} = \frac{v^3}{RL}$.
The average rate of acceleration as determined by observation should not exceed 2. Therefore $\frac{v^3}{RL} = 2$, and substituting V for v, $L = 1.6 \frac{V^3}{R}$.

The spiral lengths shown in Table 1 and Table 2 of the SWC - 39 are preferred lengths and are based on an average acceleration rate of 2 ft./sec.^{2}/sec. toward the center of the curve, modified to restrict the outside crown line to a slope of one in two hundred and fifty with respect to the center line grade. The slope restriction metioned above will usually govern the length of curve as minimum values calculated from the formula are usually about one-half of the lengths shown in Table 1.

The preferred spiral lengths given on the standard are considered ample for 80 miles per hour for the flat curves and 70 miles per hour up to five degrees. If spiral lengths less than the preferred length shown in the Tables are used, the grade of the inner and outer edge of the pavement should be carefully checked with the centerline grade for appearance.

It is customary to show only circular curve data on the right of way map. Right of way is secured on the circular curve. Spiral curve data should preferably be indicated on the Plan-Profile sheets. If the spiral curve data is not indicated, then a note should be placed on the Typical Section Sheet as follows: All curves shall be superelevated, widened and spiralled in accordance with the attached SWC - 39 Table 1 or 2 as the case may be.

In order to avoid shifting the pavement center line too far from the right of way center line, the degree of circular curve may be increased slightly.

So far we have considered two lane rural highways. Four or more lane urban highways present a special problem. In such cases development along the highway will usually prevent maximum superelevation. A four lane highway with ten foot shoulders and a four foot median is 72 feet wide. A seven foot superelevation for such a highway is usually not practical. One possibility is to construct a wide median so that each roadway may be superelevated independently.

If the center lines of the two roadways are at the same elevation the vertical distance between the inside and outside crown lines of the two roadways is a maximum of (2 x 17 x 0.1) = 3.4 feet. This is less than half of the superelevation required for a four foot median and may be permissible.

Another possibility is a reduction of the design speed. Design speeds of fifty miles per hour are reasonable for some urban highways. Later we will discuss friction in more detail. At this time it is desired to point out that if the primary objective of safety is attained the friction factor may be increased to possibly 0.25 on urban section where the design speed is 50 miles per hour or less.

Since we have mentioned design speed it is well to review our definition of design speed in order that it will be fixed in our mind. "The assumed design speed of a highway is considered to be the maximum approximately uniform speed which probably will be adopted by the faster group of drivers but not, necessarily, by the small percentage of reckless ones."

To sum up our discussion of superelevating four or more lane highways, we can state that the SWC - 39 is applicable when the degree of curvature is not too large or when a wide median can be secured if the grade of the two roadways is approximately the same. If the median is narrow, either the degree of curvature or the design speed must be reduced, or conditions must permit the required superelevation. In special cases where the design speed is 50 miles per hour or less, the friction factor may be increased to 0.25.

The SWC - 39 is not suited for city streets and traffic interchanges. For this type of facility we refer to the AASHO policy on "Intersections at Grade" and previous Texas Highway Department practice.

The formula $V = \sqrt{15R\,(e + f)}$ reduces to $R = \dfrac{0.067V^2}{e + f}$ This latter formula is more convenient when dealing with intersections and city streets.

Many tests have been made by various agencies to determine values for friction. The friction factors shown below are in reasonable agreement with recommendations made by these various agencies and conform to Texas practice.

Superelevation practical for use on intersections and city streets is much less than the superelevation employed where the speed is not restricted. In some cases it will be necessary to use negative or adverse superelevation. Of course negative superelevation should be avoided when possible. It should be noted that "e" can be used in the above formulas as a negative quantity.

In the following table it is desired to emphasize the coefficient of friction is shown as the coefficient of friction at impending skid. A safety factor is applied, then a design coefficient of friction is calculated. This table is calculated from the formula $R = \dfrac{0.067V^2}{e + f}$.

MINIMUM SAFE RADII FOR CURVES AT INTERSECTIONS

Speed miles per hour	20	30	40	50
Coefficient of friction at impending skid	0.7	0.6	0.5	0.4
Safety factor used	1.3	1.4	1.5	1.6
Design coefficient of friction (f)	0.54	0.43	0.33	0.25
Assumed superelevation (4)	0.02	0.03	0.04	0.05
Total $(e + f)$	0.56	0.46	0.37	0.30
Calculated minimum safe radius	48	131	290	558

The maximum speed for which intersections should be designed has not been determined definitely. The average speed of travel through the intersection may be taken as seven-tenths of the assumed design speed of the highway. If no stops are required, the minimum design speed should be at least 20 miles per hour through the intersection.

In 1936 the Highway Research Board made 900 road tests to determine friction values. Their report stated that it could be assumed that a margin of safety against skidding exists when the first side pitch is felt by the passenger. On this basis they recommended a factor of 0.16 at 60 miles per hour. They reported a variation of 0.35 at ten miles per hour to 0.08 at eighty miles per hour. The report proposed that highways be superelevated to counteract three-fourths of the design speed.

We have secured a copy of the Bureau of Public Road's book "Transition Curves For Highways" for everyone attending this school. As you might expect, this volume does not exactly track the SWC - 39 or the recommendations we make for design of curves at intersections. It will, however, be a valuable reference book.

We wish to point out that superelevation recommended by Table 1 of "Transition Curves for Highways" (60 miles per hour speed) is practically the same as the superelevation recommended by the SWC - 39. However, the method used to calculate Table 1 in "Transition Curves for Highways" differs from the methods used to calculate Table 1 on the SWC - 39.

Table 1 of "Transition Curves for Highways" is calculated on the basis of counteracting all centrifugal force generated by a vehicle traveling three-fourths of the design speed by superelevation alone up to the practical maximum superelevation of 0.1 ft. per ft.

The formula used then becomes, superelevation = $\frac{0.067\,(3/4\ V)^2}{R}$ (This formula is not recommended).

While the results appear to be practically the same, we do not choose to change our definition of design speed. We also prefer to evaluate friction.

We recommend the formula for superelevation as follows:

$$e = \frac{0.067V^2}{R} - f$$

where e = superelevation in feet per foot
f = the coefficient of friction
V = velocity in miles per hour
R = radius in feet

Spiral curve lengths recommended in Transition Curves For Highways are almost half the length recommended by the SWC - 39. This is due to increasing the rate of slope of the outer edge of the pavement with respect to the center line to one in one hundred and fifty for 30 miles per hour, one hundred and seventy five for 40 miles per hour and two hundred for higher speeds.

You will recall the SWC - 39 uses less slope and besides uses the crown lines and not the pavement edge.

When "Transition Curves for Highways" is used as a reference, the designer should make sure he understands the methods used to calculate the Tables.

QUESTIONS

Q. What is the primary objective in curve design?

Q. What two elements are present when a curve is properly designed?

Q. Using SWC-39 calculate maximum safe speed for a one degree curve.

Q. Assuming a 36' crown width and a 5" normal crown slope calculate the distance AC for a two degree curve, superelevation to be secured by revolving about centerline.

Q. Define "Design Speed."

Q. What is the maximum design coefficient of friction you recommend for speeds of 20 miles per hour, 50 miles per hour?

Q. Describe the method used to calculate superelevation in "Transition Curves for Highways."

CALCULATION OF DEPTH OF FLEXIBLE PAVEMENT

GENERAL PROGRESS, 1901 - 1951

At the outset of this discussion let me state that although members of this Department, as well as many engineers in other states, have, from time to time, suggested certain mathematical formulas, or the graphs representing such formulas, for use in the calculation of the depth of protective cover required over the various types of natural soils, it is doubtful that any one of the proponents of these methods has firmly believed that the problem has been satisfactorily solved. In fact, it is probable that all the highway engineers who have seriously studied the problem have eventually realized that the mathematical theory capable of adequately representing the complex systems of strains and stresses which occur in a gravel or crushed-stone base under all the conditions of its use has not yet been invented.

Up to the present the only mathematical theories worthy of the name which have been devised for the calculation of stress and strain apply strictly to materials which are homogenous. While steel and other metals are usually uniform enough in their properties to be termed nearly homogenous, by no stretch of the imagination could a 12" gravel base containing 2" aggregate be termed homogenous. Nor can most of the other materials used in flexible pavements be called homogenous.

Therefore the application of mathematical theory to our problem is questionable from the outset.

In the face of this situation, what has been done in the way of research directed toward developing useable methods? We have turned to the publications of the Highway Research Board for an answer to the above question. While our survey of these publications may not have been entirely complete, we have managed to dig up some thirty-six different flexible base depth design methods which have arisen during the first half of this century.

Table 1, below, shows when these methods originated. Note that over twice as many new methods appeared in the last eleven years than during the first forty years of the twentieth century. This recent spurt of interest in the problem obviously is related to World War II and to the tremendous growth of traffic since 1941.

TABLE I

Time Interval		No. Methods Reported
1901 - 1910		1
1911 - 1920		1
1921 - 1930		1
1931 - 1940		8
1941 - 1951		25
	Total, 1901 - 1951	36

Each of these thirty six methods can be reduced to an algebraic formula (or to a graph representing such a formula) purporting to give the depth of protective cover required over any given subgrade. If this is done, and the methods compared, two prominent facts emerge:

(1) The majority of the writers did not agree on what variables belong in a depth of base formula;

(2) Even when two or more writers agreed on the names of the variables which should enter the depth of base formula they usually differed on

(a) Precisely how the variables should be measured and/or

(b) How the variables should be put together in a formula or a graph for depth of base.

TABLE 2 (a)

Variables Affecting Required Depth of Protective Cover Over Subgrade according to Thirty-six Methods Proposed During the period 1901 - 1951

Variable		No. of Methods Dependent on this Variable
Load		
1.	Weight	31
2.	Contact area dimensions	17
3.	Frequency	11
Cover		
1.	General type	2
2.	Angle of load distribution	1
3.	Shear strength in compression	1
4.	Tensile strength	1
5.	Stress-strain modulus	3
6.	Bearing value in place	4
7.	Density	1
Subgrade		
1.	Grading and Atterburg limits	5
2.	Shear strength in compression	8
3.	Stress-strain modulus	3
4.	Bearing value and bearing ratio	19
5.	Density	2
6.	Wear	1

TABLE 2 (b)

Combinations of Variables Used in Two or More Methods

Combination of Variables	No. of Methods Dependent On This Combination
Subgrade bearing value (or ratio)	2
Weight of load, Subgrade bearing value (or ratio)	2
Weight of load, Dimensions of loaded area, Subgrade bearing value (or ratio)	8
Weight of load, Dimensions of loaded area, Subgrade shear strength in compression	2

No two of the remaining twenty-two methods proposed the same combination of variables.

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Table 2 names the variables encountered in our survey of methods, and serves to illustrate the lack of uniformity in opinion among most of the writers on this subject. It should be explained that a "variable", as used in Table 2, includes only those quantities appearing in one or more base design formulas, or in the graphs representing such formulas, which normally must be assigned a numerical value by the user of the methods.

The differences of opinion among highway engineers as to the nature of that unique combination of variables which must be known in order to calculate the depth of flexible base would be of no significance if all, or even most of the proposed methods resulted in approximately

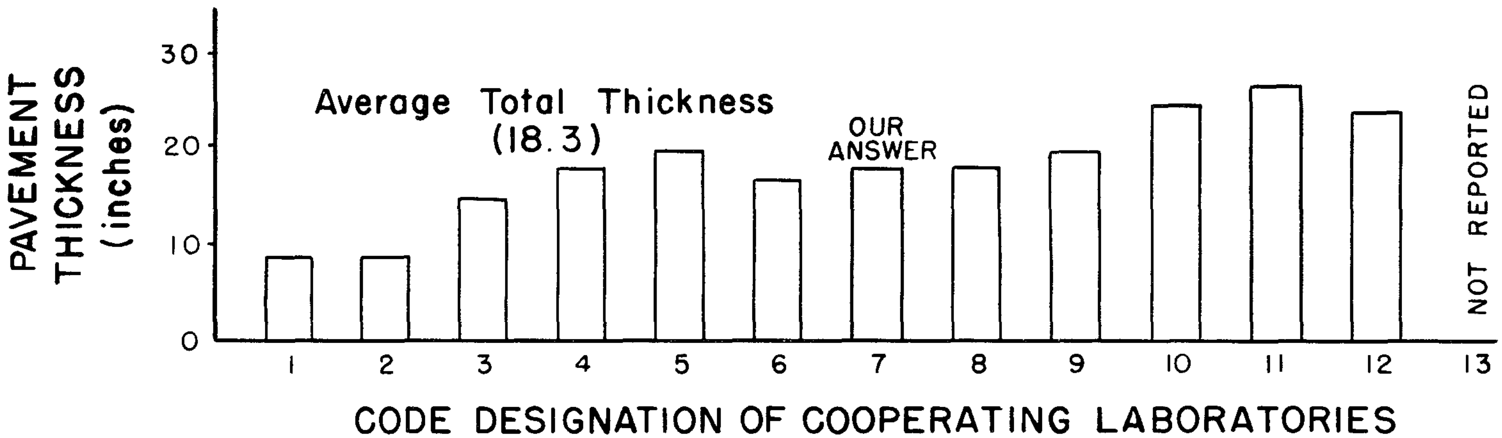


FIGURE I

(Twelve answers to the same problem, 1950.)

the same numerical value for depth in any given case. Perhaps in the expectation that numerical agreement would be found, a check among twelve American laboratories was made by a Highway Research Board Committee in 1950. Identical samples of flexible pavement and subgrade materials, together with detailed information as to traffic, were supplied to each of the twelve organizations. A request for depth designs netted twelve answers, all different, as may be seen in Figure 1. Many of these depths are not even approximately the same.

More recently a similar comparison made in connection with the WASHO Road Test at Malad, Idaho, resulted in similar discrepancies.

We conclude from these comparisons that the differences of opinion among highway engineers as to the variables which influence base depth design are important and must be resolved before numerical agreement on base depths can be reached. And until agreement is reached we must, in all honesty, remain in some doubt as to whether our own method is correct in all cases.

STRESS, AND THE MOHRS DIAGRAM

Of course, the principal object of this talk is to acquaint you in detail with just one of the foregoing methods, namely the particular procedure developed here since the war and now in use in several of the Districts of this Department. The method has already been described at length in Administrative Circular No. 43-50, so that this talk will merely furnish an exposition of some of the theory involved. Since the

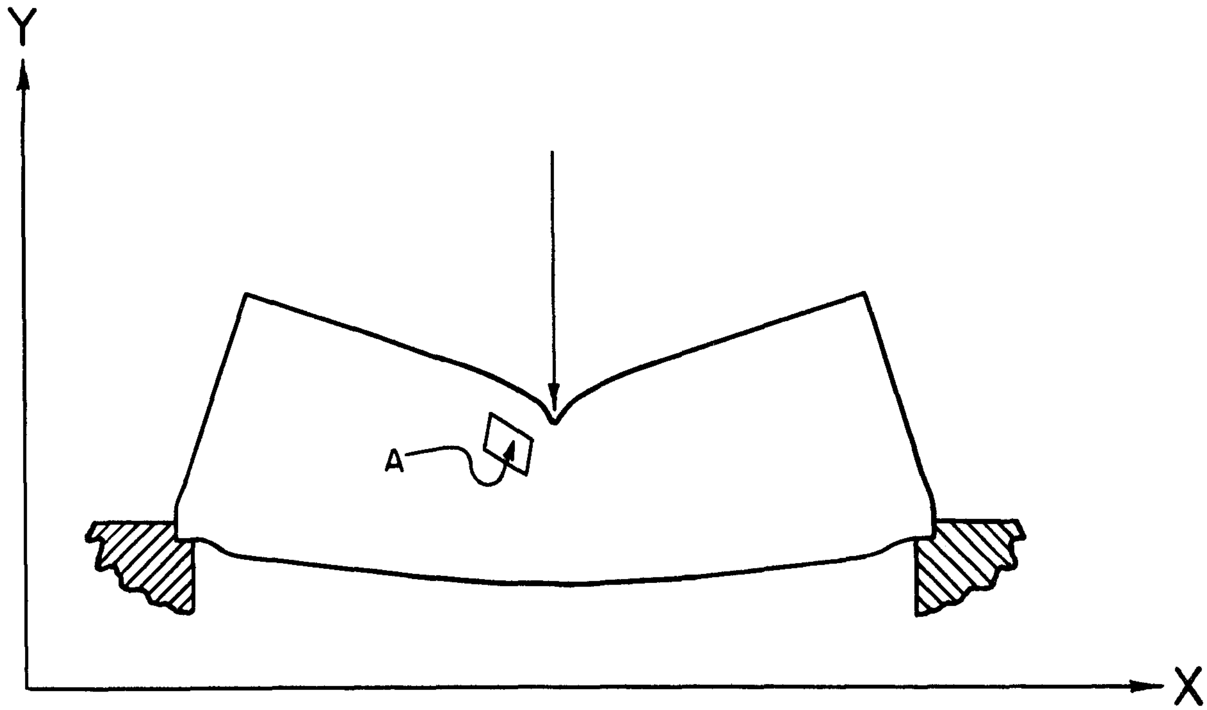


FIGURE 2

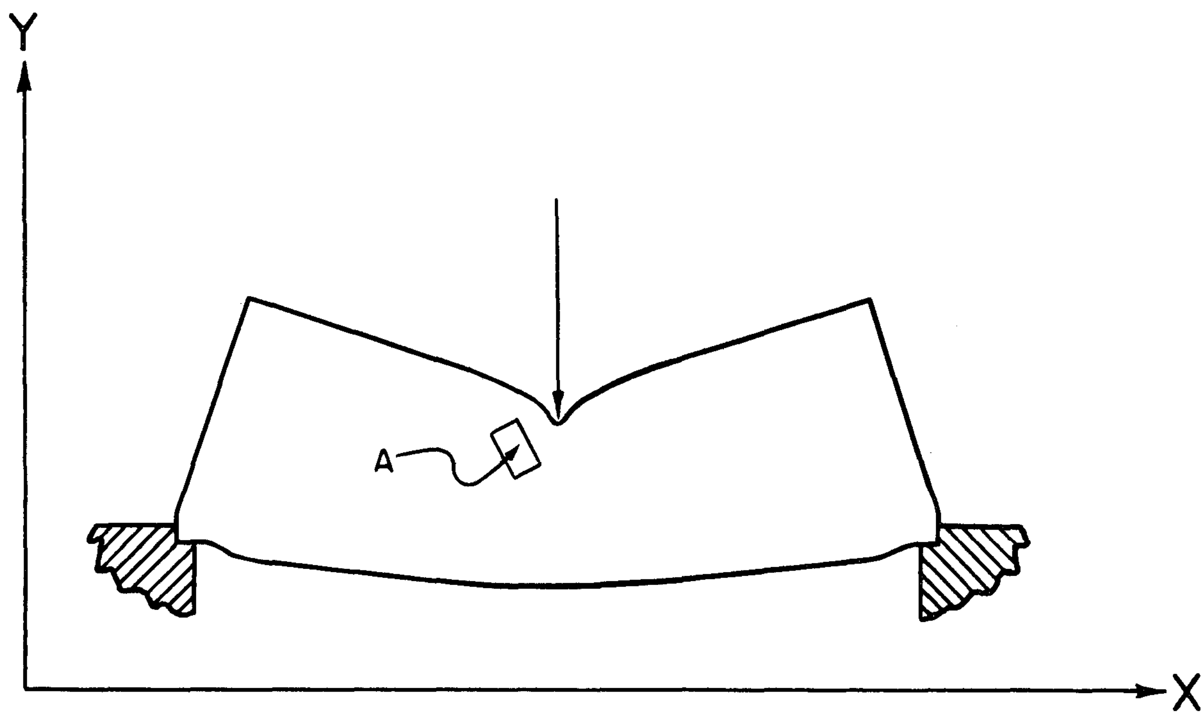


FIGURE 3

so-called "classification chart" (Figure 13), which is the heart of the method, is really a Mohrs' diagram of stress, it appears that any discussion of the theoretical concepts which led to the construction of the first classification chart of this kind must start with some explanation of exactly what is meant by the word, "stress", and then by the term, "Mohrs diagram."

Unfortunately, the word "stress" refers to a ratio, or a set of ratios, which cannot be measured directly, and therefore must be described in a round-about manner in terms of other associated phenomena which can be measured. Specifically, these other and measurable phenomena are the changes in shape which occur when a load is applied to an elastic body.

For example, Figure 2 illustrates the elastic deformations, greatly exaggerated, which might be caused by the application of a load to the center point of the upper edge of a beam consisting of a thin plate rigidly supported at the two lower corners.

Suppose that prior to the application of the load a small square had been inscribed at the point. A, with sides originally parallel and perpendicular to the axes of a rectangular coordinate system such as the X-Y axes indicated in Figure 2.

Upon application of the load, the square would have changed to a parallelogram, as indicated in Figure 2.

If, with the load removed, the square had been drawn at the same point but with its sides forming some angle, alpha, with the axes of the coordinate system, then the application of the load would have changed the square to a parallelogram with sides, or corner angles, or both somewhat different from the parallelogram of Figure 2.

In fact, if an infinite number of squares were drawn at the point, A, each with its sides forming a different angle, alpha, with the axes of the coordinate system, then, upon application of load, the corner angles and sides of each square would be changed by a different amount, and the corner angles of one (and only one) square would not change at all. This latter square, would become a rectangle upon application of load, as illustrated in Figure 3.

Suppose that we have at hand a small piece, a square, of the material of the beam available for testing in a machine capable of applying normal and tangential loads evenly along the edges of the test piece. By means of the machine we apply normal loads to the edges of this test piece in order to change the lengths of its sides, and tangential loads to change the angles at the corners, as illustrated in Figure 4 (a). We adjust these loads until, by a process of trial and error, we have caused the test piece to assume a shape geometrically similar to the parallelogram of Figure 2. We divide the numerical value of each of these loads by the area of the edge upon which it acts and record these force-to-area ratios. Incidentally, the tangential force-to-area ratio is the same for

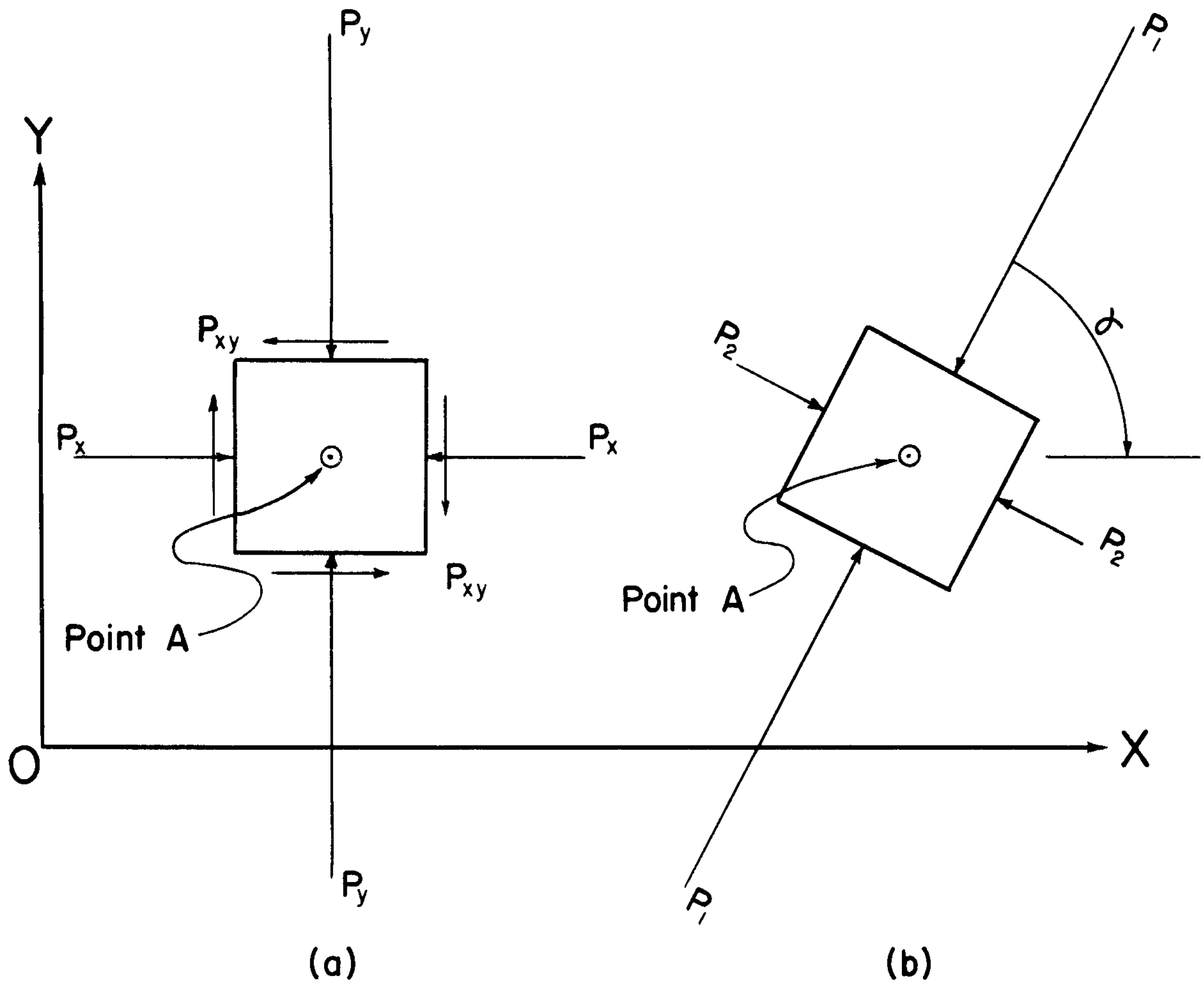


FIGURE 4: Stress at point A shown as vectors. Square at left represents the parallelogram of FIGURE 2 prior to deformation. Square at right represents the rectangle of FIGURE 3 prior to deformation.

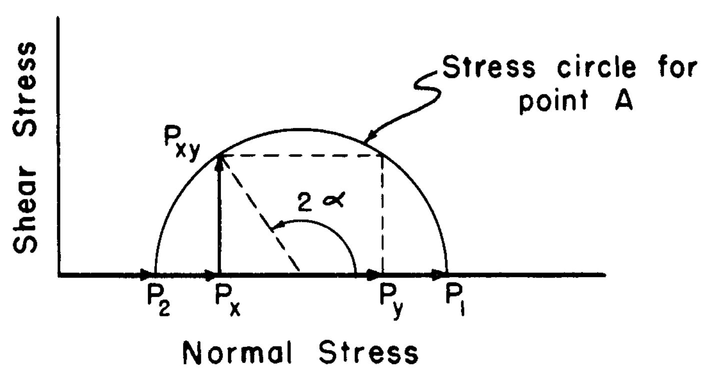


FIGURE 5: The vectors of FIGURE 4 arranged to form a Mohr's diagram of stress.

all foursides; otherwise, the test plate would rotate. And, of course, the normal forces applied to opposite sides are equal; else translation of the plate would occur.

We next (Figure 4(b)) apply only normal loads to the sides of the square plate, adjust them until the test piece assumes the shape of the rectangle of Figure 3, and record the corresponding values of the force-to-area ratios.

We are now finally ready to illustrate the meaning of "stress": The state of stress at the point, A, of the loaded beam (Figure 2 or 3) is equivalent to either the three force-to-area ratios, P_x, P_y, P_{xy} of Figure (4a), or the two force-to-area ratios P_1, and P_2 of Figure (4b), provided the size of the squares at the point, A, is reduced without limit. In fact, since the selection of the direction of the coordinate axes is arbitrary, there are an infinite number of sets of three load-to-area ratios, such as P_x, P_y and P_{xy}, any one of which may be selected to represent the stress at the point, A.

Conventionally, the force-to-area ratios shown in Figure 4 are known as "stress components." Those acting tangentially are "shear" components, the others, "normal" components. P_1 and P_2, which act on planes free from shear stress, are known as the "major principal stress" and the "minor principal stress," respectively.

Since the two stress systems, Figure 4 (a) and Figure 4 (b), exist simultaneously at the same point, they are obviously related mathematically. In fact, this relation may be derived from the simple consideration that after the load is applied to the beam, the square at A is in equilibrium. The resulting relationship may be represented graphically by the Mohrs diagram, Figure 5. Obviously the Mohrs diagram completely represents the stress at the point, A, since from it the numerical values of the stress components for any value of the angle, alpha, may be obtained, provided that the principal stresses are known. Conversely, if the stress components P_x, P_y, and P_{xy} are known, the principal stresses, P_1 and P_2, and the angle, alpha, may be found from the Mohrs diagram.

GRAPHICAL REPRESENTATION OF STRESS AT POINTS IN A HORIZONTAL PLANE BELOW A WHEEL LOAD

As has been indicated by the foregoing, the Mohrs diagram is a convenient means for graphically representing stress, provided the numerical values of either the stress components or the principal stresses are known. The calculation of these stresses from mathematical theory is open to question, as has been previously indicated; however, no other course was or is open to us, and the calculations have been made from the theory of elasticity, with some arbitrary modifications.

The general character of the applied load is indicated in Figure 6. Of the three types of possible loads, the third (Figure 6 (c)), caused by a moving vehicle with brakes applied, can be by far the most severe. A

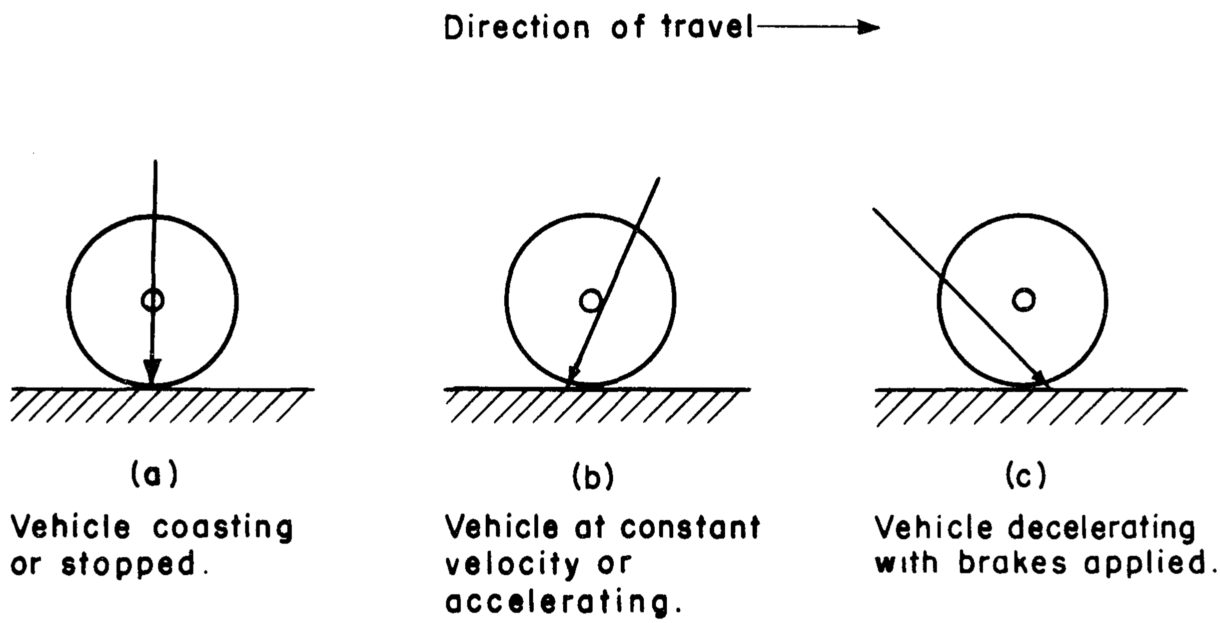


FIGURE 6: Kinds of loads

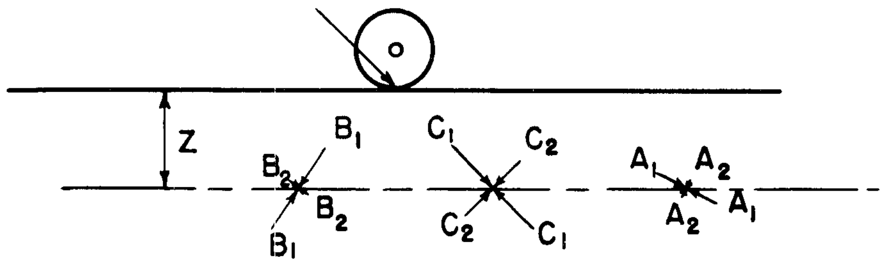


FIGURE 7: Principal stresses acting at three points in a horizontal plane under a wheel load.

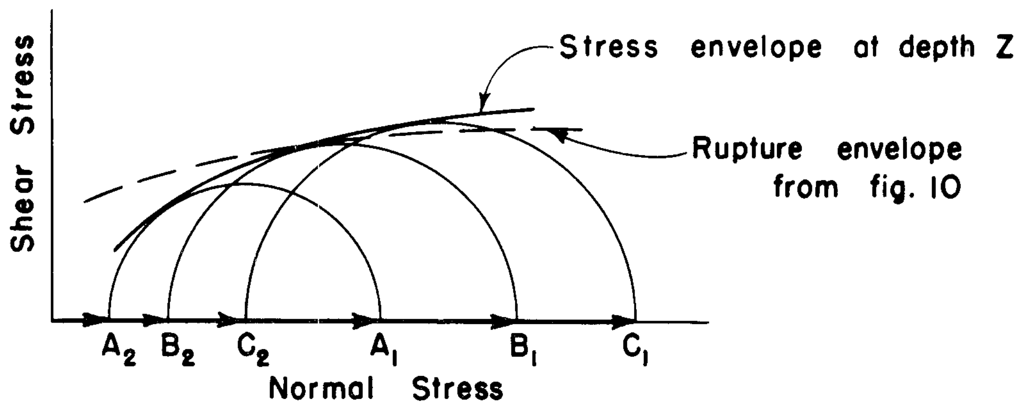


FIGURE 8: Mohr's diagram of stress on the horizontal plane of fig. 7 compared with strength from triaxial test.

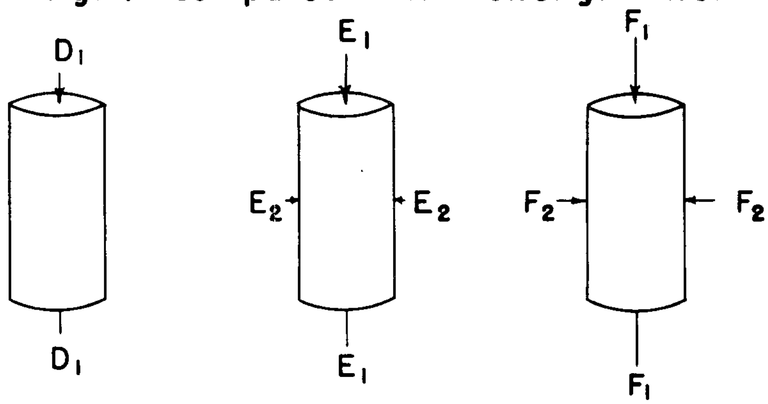


FIGURE 9: Principal stresses acting on three identical triaxial test specimens at instant of failure.

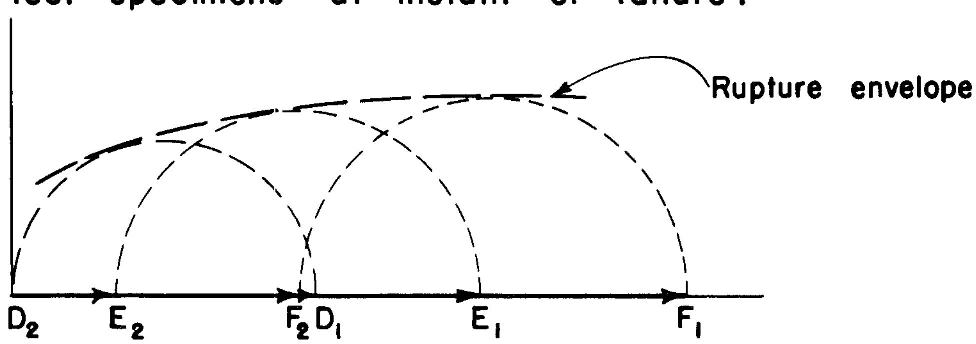


FIGURE 10: Mohr's diagram of stress for triaxial test specimens of fig. 9.

load of this third type was used in the computations. Arbitrary modifications were made in order to reduce the high tensile stresses which exist according to mathematical theory but which obviously cannot exist in fact. (Other modifications have been made from time to time as experience dictated.)

We have seen how the stress at a point can be represented on a Mohrs diagram. Suppose now that the principal stresses at each of the points A, B and C (Figure 7) on a horizontal plane at some depth, z, beneath a wheel load has been calculated from theory. We may plot these stresses on a Mohrs diagram in the manner shown in Figure 8, where each circle represents the stress at one of the points, A, B, or C. We may also draw a line tangent to these stress circles as a limiting stress line, or "stress envelope" which, for our purposes, will represent all the stresses acting on a horizontal plane at depth, z. How this line proves useful in design will become apparent in a moment.

Next let us consider the triaxial test specimens of Figure 9. Pressure is applied at top and bottom of each specimen, as well as to the sides. The pressure on the sides, applied by compressed air, is kept constant, while the loads on the end are increased to failure. Since no shear stress is applied to the surfaces of the specimens, the stress system is the same general type as the system illustrated in Figure 4 (b); therefore, we call the stress applied to the ends of the specimens the major principal stress while the smaller stress applied to the sides is called the minor principal stress. The corresponding stress circles appear in Figure 10. The line drawn tangent to the circles in Figure 10 is called the "rupture envelope" of the material from which the specimens illustrated in Figure 9 were made up.

Since a part of this "rupture envelope" lies below the "stress envelope" when plotted in Figure 8, it follows that the material represented by the rupture envelope will fail if placed at a depth, z, below the wheel load of Figure 7. We conclude that if the material used in the specimens of Figure 9 has been proposed as a part of a flexible pavement, then the thickness of protective cover required above that material is greater than the depth, z, of Figure 7.

STRESS ON A SERIES OF HORIZONTAL PLANES UNDER A WHEEL LOAD

Figure 8 showed how a single line (the stress envelope) on a Mohrs diagram could represent the stress acting on a horizontal plane at a given depth below a wheel load.

Figure 11 shows several such lines calculated for a load of 8,000 lbs., each line being labeled with the depth of the plane represented by that line. Superimposed on Figure 11 is a dashed line which we take to represent a material which has been proposed for use in a flexible pavement. Obviously the material represented by this rupture line requires a protective cover of approximately 11 inches, as indicated by the position of the line between the stress envelopes for 10 inches and 13 inches.

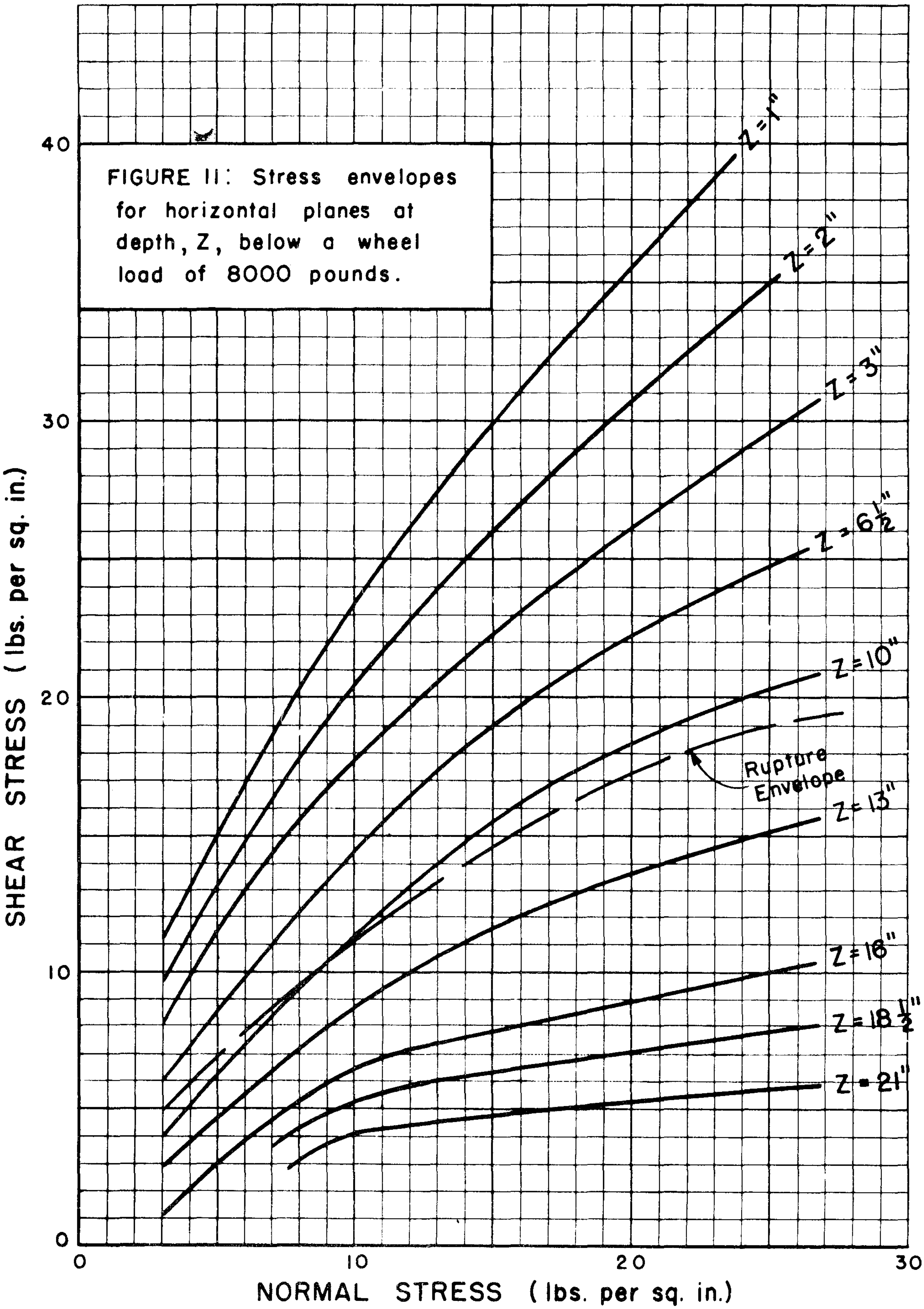


FIGURE 11: Stress envelopes for horizontal planes at depth, Z, below a wheel load of 8000 pounds.
SHEAR STRESS (lbs. per sq. in.)
NORMAL STRESS (lbs. per sq. in.)
0
10
20
30
40
Z=1"
Z=2"
Z=3"
Z=6½"
Z=10"
Rupture Envelope
Z=13"
Z=16"
Z=18½"
Z=21"

T.H.D. D-8 and D-9

EFFECT OF VARIATIONS IN LOAD ON REQUIRED DEPTH OF FLEXIBLE PAVEMENT

From Figure 12 we may state the following rule regarding variations of load:

If the stress envelope for the horizontal plane at a depth, z_1, beneath a wheel load, L_1, is known, then this stress envelope also applies to the horizontal plane at depth, z_2, under the load, L_2, providing

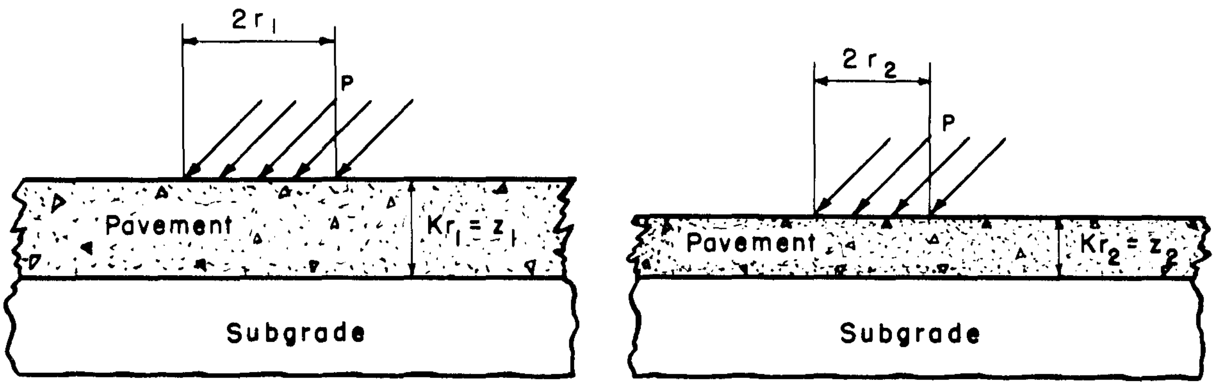
(a) Tire inflation pressures are the same for L_1 and L_2, and

(b) $z_2 = z_1 \sqrt{\frac{L_2}{L_1}}$

Thus, having calculated the stress envelopes of Figure 11 for planes at various depths, z_1, beneath the wheel load, $L_1 = 8,000$ lbs., it was a simple matter to calculate from the above equation the depths, z_2, corresponding to these same stress envelopes for any desired wheel load, L_2, and then, after assigning numbers to the stress lines for purposes of identification (Figure 13), to plot the curved lines appearing on the design chart (Figure 14).

DESIGN PROCEDURE

Figures 15 and 16 indicate the steps to be taken in solving a practical design problem. The dashed lines on the classification chart represent the rupture envelopes for the proposed materials. The class number assigned to each material is obtained by interpolating between



r_1, r_2 = radii of circular loaded areas.

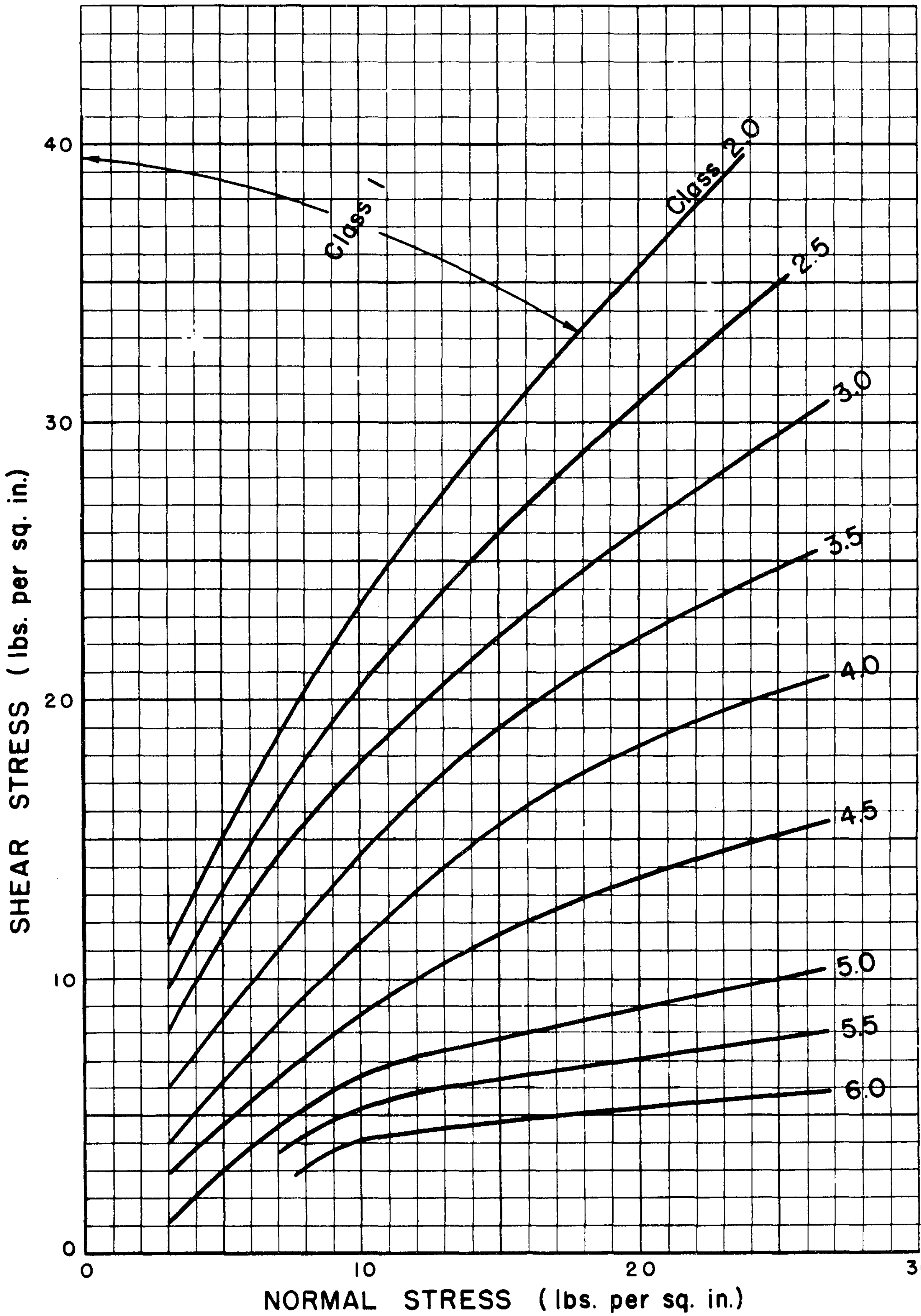
P = applied unit pressure (same for both loaded areas).

K = an arbitrary constant.

If corresponding layers contain identical, homogeneous materials, then the stress envelopes for the plane at the top of the subgrade are identical for both systems, and

$$\sqrt{\frac{L_1}{L_2}} = \frac{z_1}{z_2}.$$

FIGURE 12: Variation of pavement depth with load.



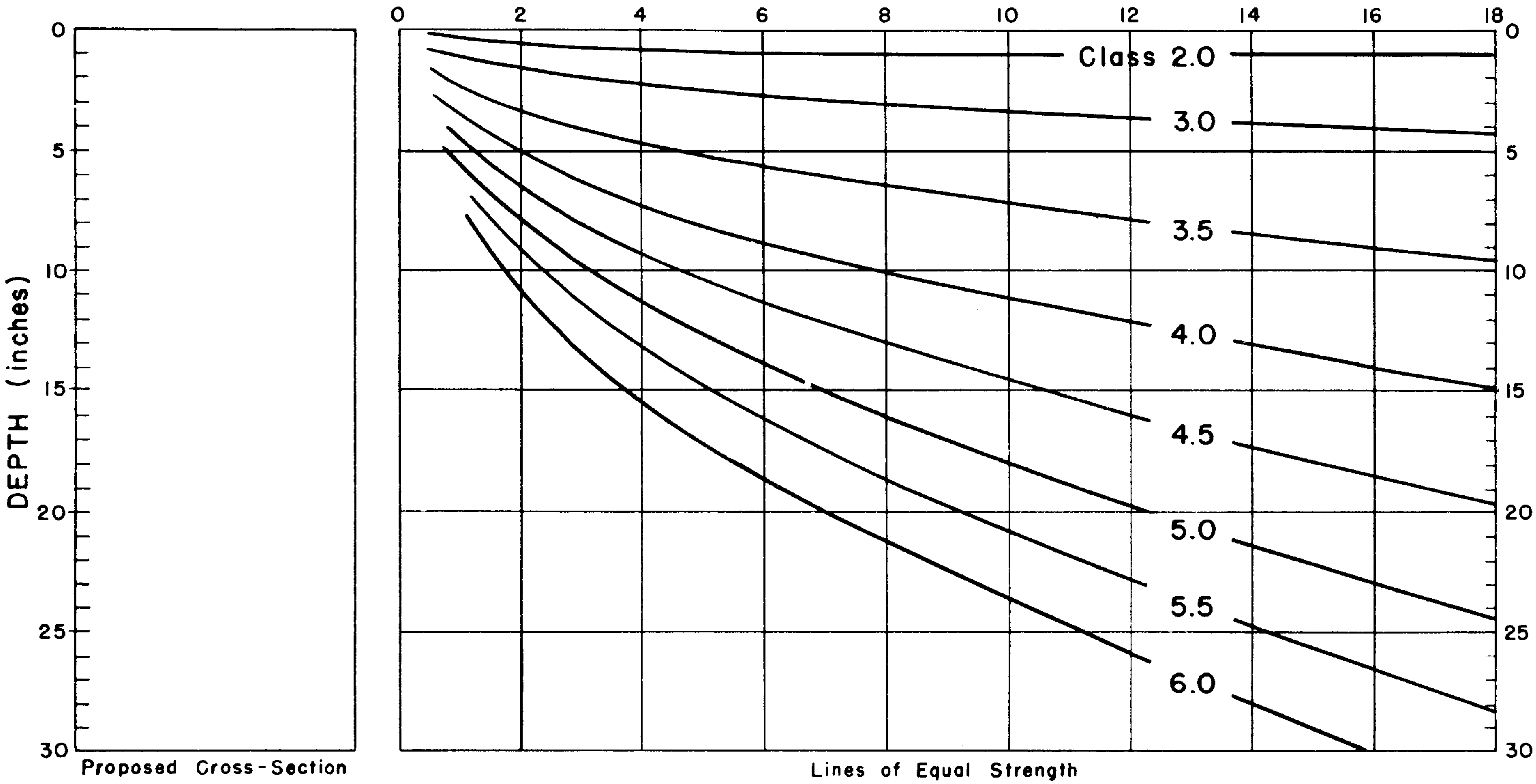
CLASSIFICATION CHART

(Design chart on reverse side.)

FIGURE 13

T.H.D. D-8 and D-9

Design
Wheel Load
_______ lbs.



FLEXIBLE PAVEMENT DESIGN CHART

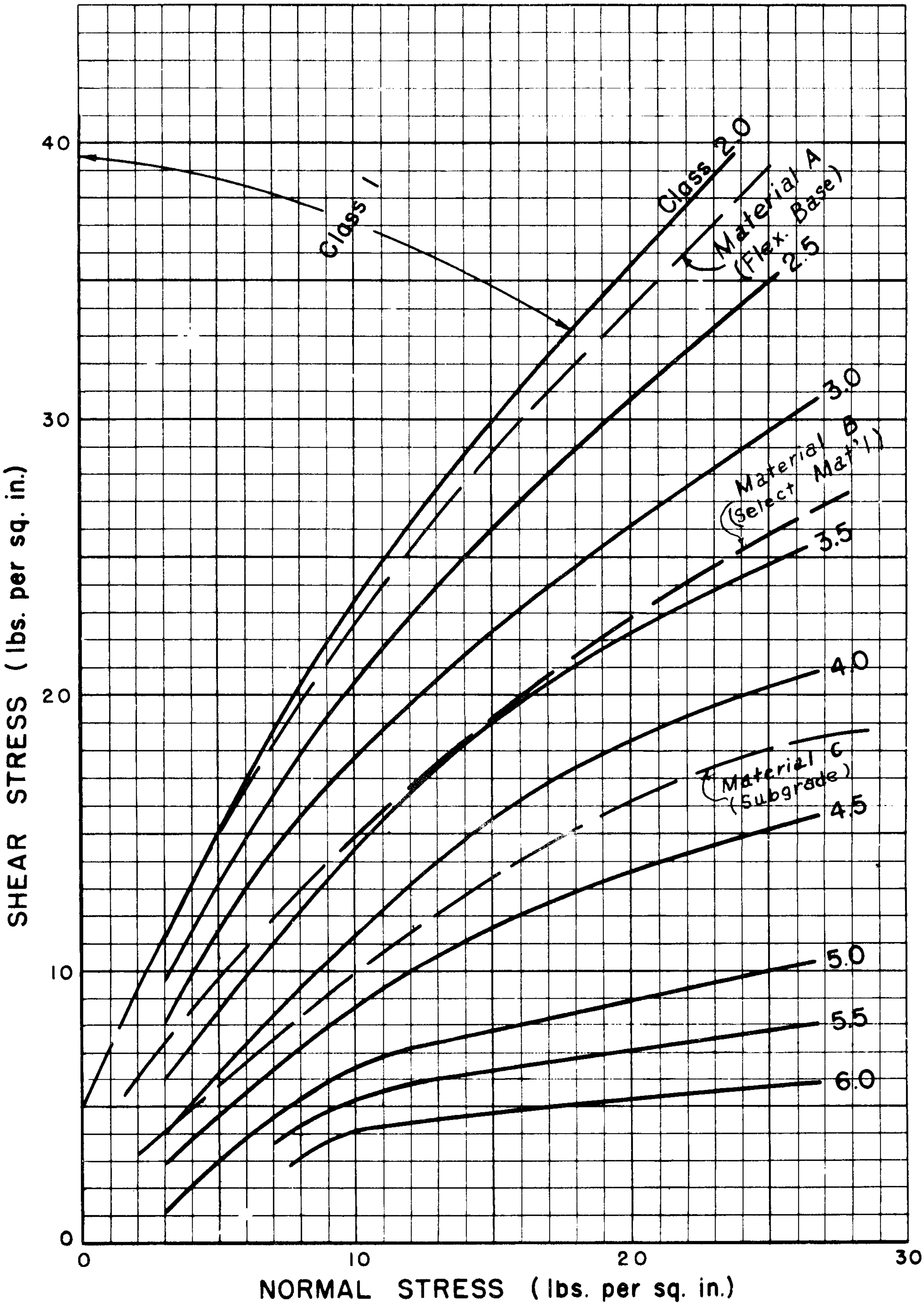
County___________ Highway_____ Control____ Section___ Job___ Project_______

This design applies from sta.______ to sta.______.

(Classification chart on reverse side.)

FIGURE 14

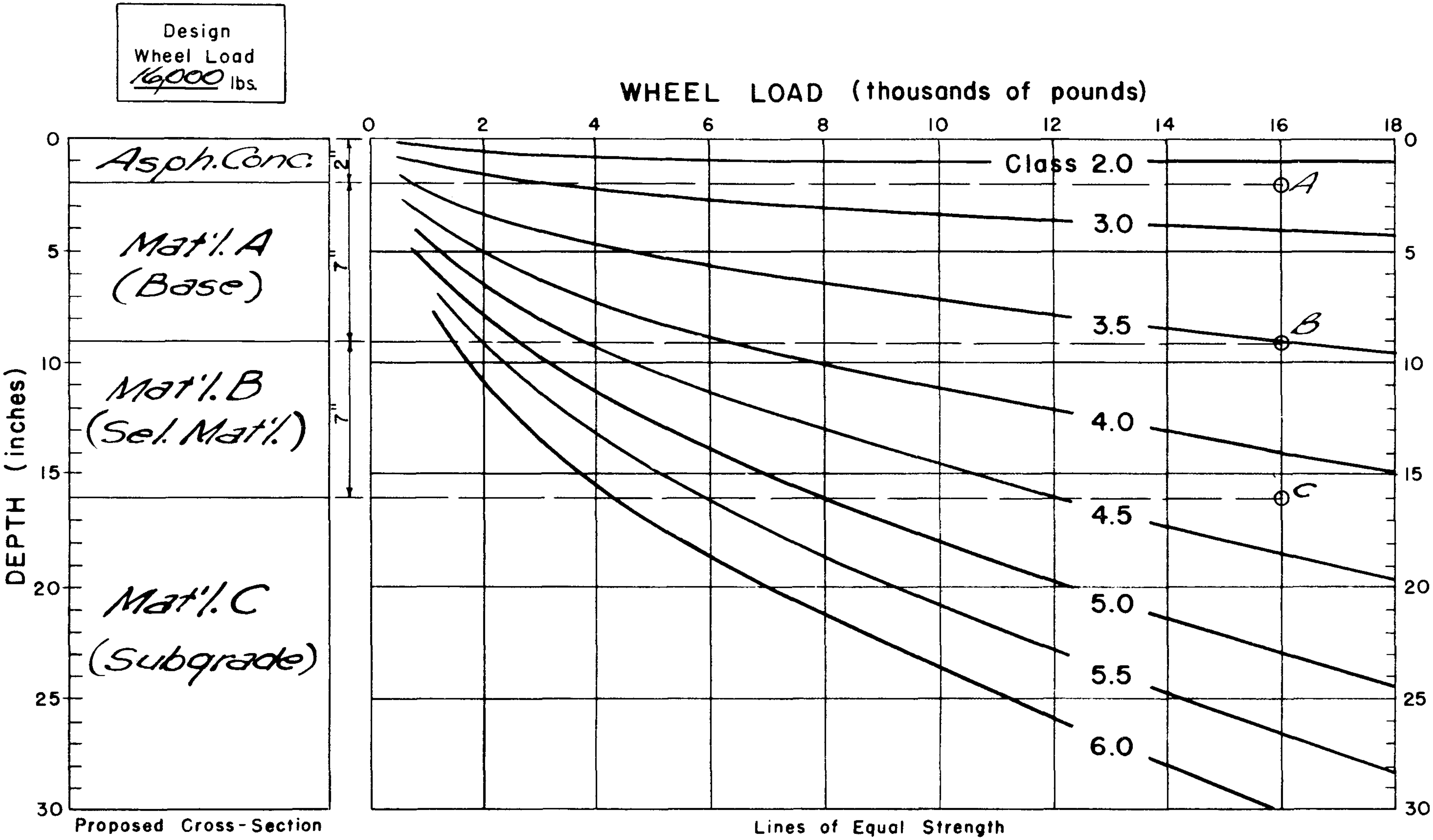
T.H.D. D-8 and D-9



CLASSIFICATION CHART

(Design chart on reverse side.)

FIGURE 15



FLEXIBLE PAVEMENT DESIGN CHART

County___________ Highway_____ Control____ Section___ Job___ Project_______

This design applies from sta.______ to sta.______.

(Classification chart on reverse side.)

FIGURE 16

T.H.D. D-8 and D-9

the class lines. The class numbers so obtained should be conservatively high.

The design wheel load may be taken from the Texas Highway Planning Survey's publication, "Average of Ten Heaviest Wheel Loads Per Average Day on State Highways and Farm to Market Roads, 1948." With regard to the use of the data contained in this publication we quote from its introduction: "It is suggested that the data presented on the accompanying maps could be used directly in the design of flexible base by those districts equipped with triaxal testing devices. A safety factor of 1.0 is suggested pending further investigation by the State and District Laboratories. If, however, a marked increase in wheel loads is expected to occur within the design life of the pavement the reported wheel loads should be increased accordingly." I believe the Planning Survey is in a position to furnish more up to date wheel load figures for specific projects if desired. Meanwhile late information indicates that the 1948 wheel loads should be increased by 40% to bring them up to date.

A design wheel load having been selected, the class number of each material is then plotted against the design wheel load on the design chart. Horizontal lines projected from each point to the box provided for showing the proposed cross section furnishes the required information.

CALCULATION OF DEPTH OF CONCRETE PAVEMENT

The problem of calculating the correct depth of a concrete pavement which is to be placed upon a given subgrade has been solved only approximately. However, efforts are still being made to find a more exact solution, and it is our purpose here to examine the progress which has been made and to outline briefly the method recommended for use in Texas.

By way of introduction let us go back twenty-five years to a meeting of the local Chapter of the Society of Civil Engineers in the City of Boston, Massachusetts. Here is what Dr. Karl Terzaghi, frequently referred to as the "father of soil mechanics," had to say at that meeting about the design of concrete pavement:*

"For the time being, there are two well developed methods of handling engineering problems: The method of theoretical analysis, used in bridge design and related fields of structural engineering, and the method of the model test, used in hydraulic engineering. The design of any structure whose integrity is directly dependent upon soil characteristics cannot now and very likely never will be accomplished by analytical methods . . . . The situation would seem to be quite hopeless were it not for the remarkable success resulting from the

*"Concrete Roads - A Problem in Foundation Engineering," Charles Terzaghi, Contributions to Soils Mechanics 1925 - 1940, Boston Society of Civil Engineers, 1940, p. 45-62.

application of scientific methods under similar conditions to another field of human endeavor. Strange as it may seem, this other field is modern medicine."

In drawing his analogy between road design and medicine Dr. Terzaghi went on to say, "There is not a single process in physiology so simple that it can be forced into the narrow frame work of mathematical calculation. In addition, there is no means of reproducing artifically the functions of the living organism. Hence, in medicine, as in road design, applied mechanics and model testing both fail to produce tangible results. In spite of this, the progress realized during the last century along the line of efficient treatment of diseases was tremendous . . . . . The pathology of the surgeon corresponds to the knowledge which should be gained by the results of a condition survey of the roads of the United States . . . . The results will merely consist of a systematic accumulation of facts, of an attempt to retrace the physical causes of the various types of failures, and of a rational study of the results of the different types of subgrade improvements. Yet that much, and no more, in the line of systematic experience and insight has caused the transformation of medieval quackery into modern medicine. If we succeed in improving our methods of subgrade treatment only half as well as the physicians have succeeded in their field, the hopes expressed at the outset of this paper would have to be termed conservative."

The condition survey, that is, the detailed examination of an existing concrete pavement with the object of collecting a large body of facts which may be analyzed statistically, has played an important part in the progress made since Terzaghi's speech in Boston twenty-five years ago. For example the causes and a fairly effective remedy for the troublesome phenomenon known as pumping have been discovered largely as the result of a series of such condition surveys made in several states in cooperation with the Portland Cement Association and the Highway Research Board. According to the analyses made from these condition surveys, three factors must be present simultaneously to produce pumping:

1. A soil that will go into suspension
2. Free water
3. Frequent passage of heavy wheel loads

As a result of these surveys and other researches we have come to think of a potentially "pumping subgrade" as being any material with more than about 45%, by weight, passing the 270 mesh sieve. Where such subgrades occur, we have recommended for new construction the placing of a thin blanket of granular material (less than 45% passing the 270 mesh sieve) over the soil. Recently published information from the Maryland Road Test, however, indicates that to be 100% effective, subgrade soils should have not more than about 10% finer than the 200 mesh sieve.

To help prevent the accumulation of free water under the slab which may lead to pumping the sealing of cracks and joints is undoubtedly helpful. And of course the lateral drainage provided by using full depth granular shoulders on crowned subgrades probably helps to prevent the accumulation of free water.

With regard to the "frequent passage of heavy wheel loads" mentioned above as a cause of pumping, it is well to bear in mind that the term "heavy wheel load" is relative, since a load which is considered heavy when applied to a six inch slab may be considered comparatively light when travelling over a nine inch slab. Thus, for the third cause of pumping mentioned above, "frequent passage of heavy wheel loads," we may substitute with equal validity the phrase, "thin slabs." We conclude, therefore that the building of thicker slabs may be listed as a remedy for pumping.

In spite of Dr. Terzaghi's twenty-five year old recommendation that we employ the statistical methods of the medical profession to solve all our problems in the design of concrete highways, we, being engineers instead of doctors, probably will never be satisfied until we have devised reliable analytical means for deciding the question of slab depth. Let us turn then to a consideration of the variables involved in the problem from the standpoint of available theory.

The weight of the load of course is a variable, as well as the dimensions of the loaded area. For factual data on the magnitude of the

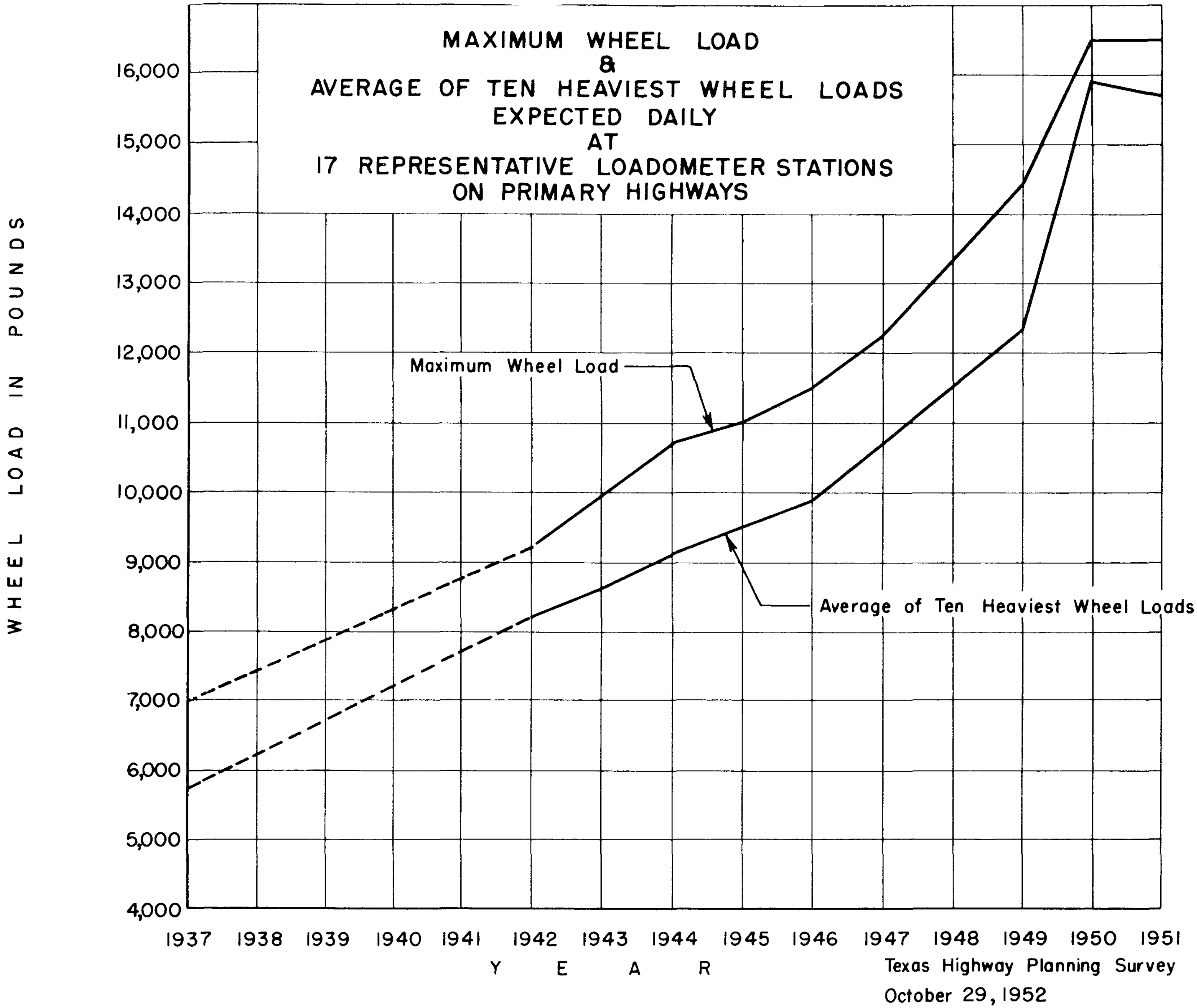

MAXIMUM WHEEL LOAD
&
AVERAGE OF TEN HEAVIEST WHEEL LOADS
EXPECTED DAILY
AT
17 REPRESENTATIVE LOADOMETER STATIONS
ON PRIMARY HIGHWAYS
Maximum Wheel Load
Average of Ten Heaviest Wheel Loads
WHEEL LOAD IN POUNDS
16,000
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
1937 1938 1939 1940 1941 1942 1943 1944 1945 1946 1947 1948 1949 1950 1951
YEAR
Texas Highway Planning Survey
October 29, 1952

FIG. 1

wheel loads on our highways we turn to the highway planning survey's publication, "Average of Ten Heaviest Wheel Loads per Average Day on State Highways and Farm to Market Roads, 1948." Figure 1 shows that the average of the ten heaviest daily wheel loads as recorded at 17 representative loadometer stations has increased about 37% since 1948. It is recommended, therefore, that wheel loads taken from the 1948 wheel load maps be multiplied by at least 1.4 to bring them up to date.

So much for the load. The variable characteristics of the concrete which must be considered are believed to be the following: Modulus of rupture, or tensile strength; Youngs modulus, or, as it is sometimes called, modulus of elasticity; and Poissons ratio.

It is customary to use the estimated 28-day modulus of rupture as the strength of the concrete. Generally speaking, the working stress will then be taken as one-half of this strength, because of the reasons outlined below.

Factual data with regard to the fatigue of concrete in flexure is presented in Figure 2, which shows a graph of safety factors versus number of stress repetitions to induce failure. This graph was originally published by the Portland Cement Association. It will be noted that a safety factor of 2.0 apparently insures the pavement against failure under unlimited repetitions of the design wheel load. In connection with the apparent significance of the value of 2.0 as a safety factor, we quote

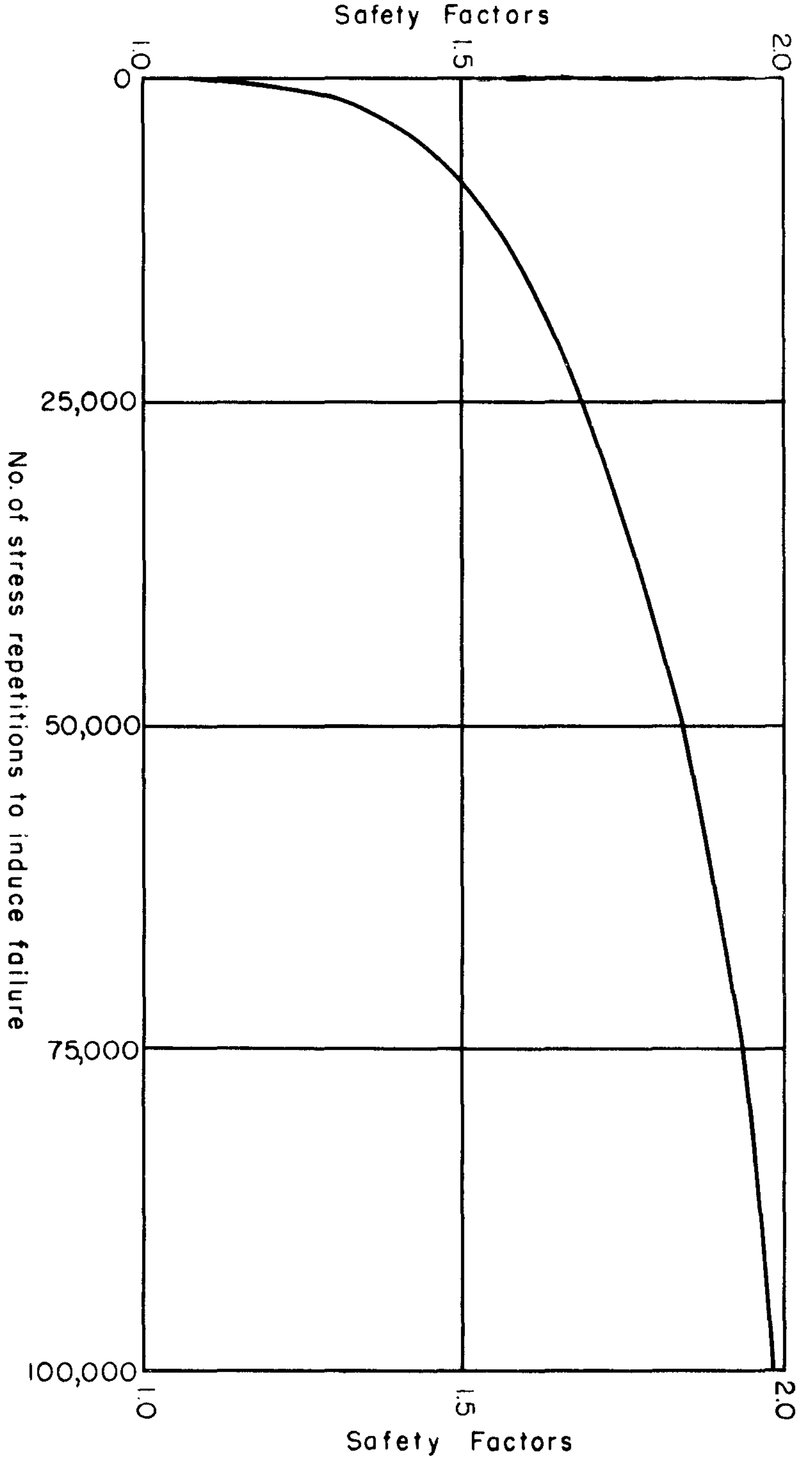


FIGURE 2: Fatigue curve for concrete

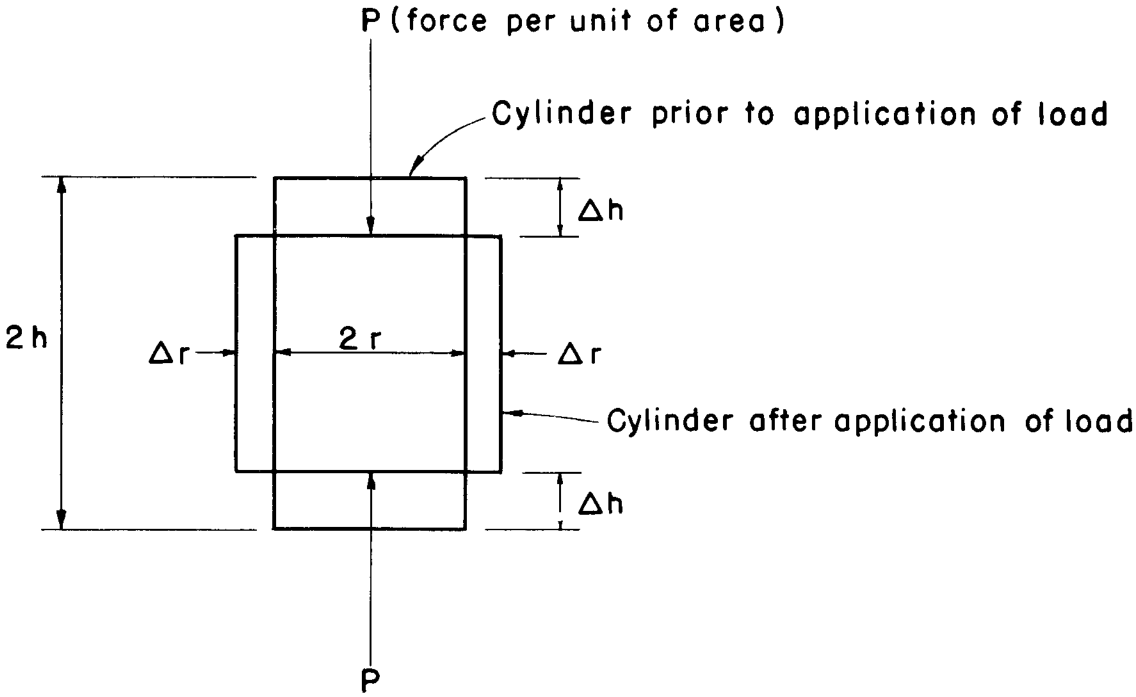
the following from the final report of the Maryland Road Test* on the subject of fatigue tests on beams cut from the test pavement:

"The data obtained from these tests (see table 39) substantiate the results of other earlier fatigue studies in that the beams failed after the application of a relatively few loads wherever such loads caused the transverse bending stress of the concrete to appreciably exceed one-half of the modulus of rupture but, on the other hand, failed only after the application of a very large number of loads whenever the transverse bending stress was approximately equal to one-half of the modulus of rupture of the concrete."

For design purposes the modulus of elasticity of ordinary gravel aggregate concrete is usually taken as four million pounds per square inch, while Poissons ratio is given a value of 0.15. These values were used in the stress charts which will be discussed later. However, special treatment must be given concrete made with shell aggregate, since tests have indicated that the Youngs modulus of this material is in the order of only about 1/4 of that of gravel concrete, a significant difference. The design procedure outlined herein therefore does not apply to shell concrete.

In the event you are not familiar with the nomenclature of the theory of elasticity, you may wish to refer to Figure 3, which illustrates the meaning of Youngs modulus and Poissons ratio.

*"Road Test One - MD," Special Report 4, Highway Research Board, 1952, Washington, D.C., p. 81.



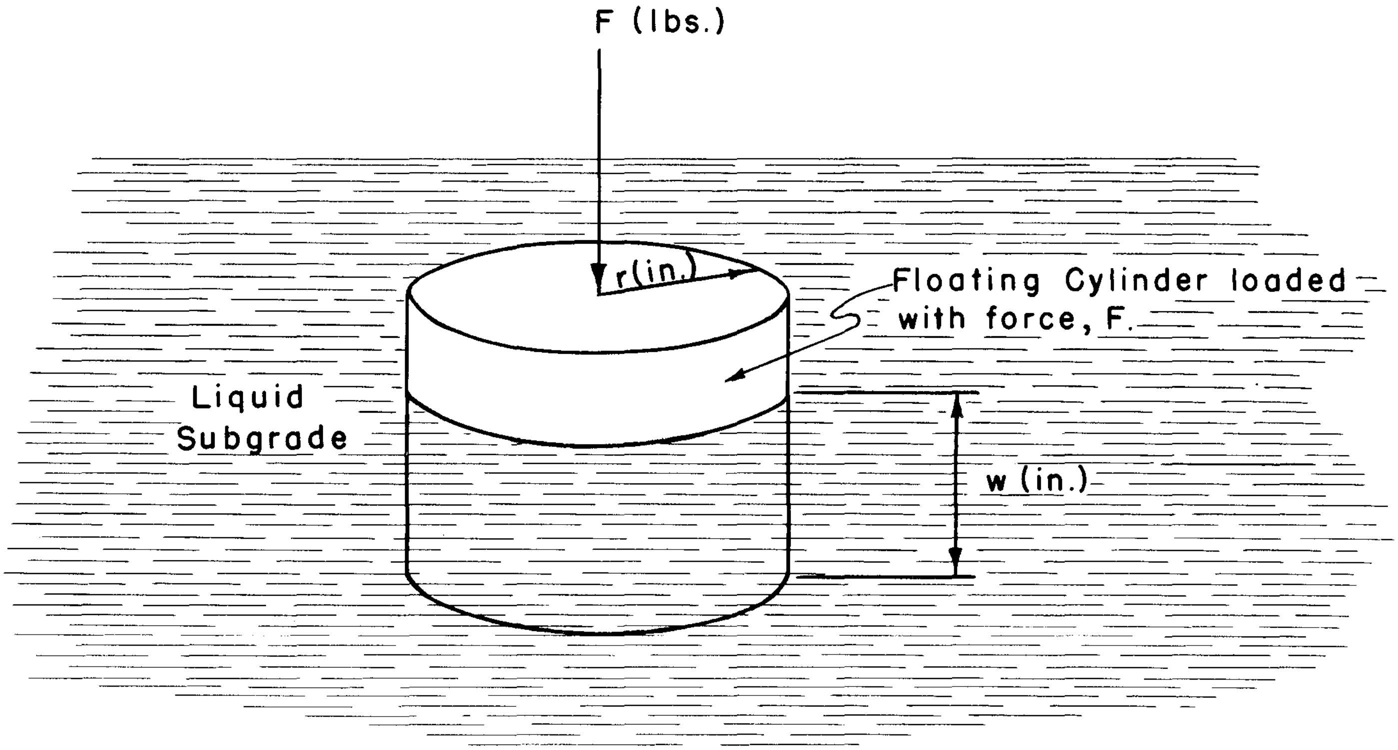
$$E = \frac{P}{\Delta h/h} \qquad \mu = \frac{\Delta r/r}{\Delta h/h}$$

FIG. 3: Youngs Modulus (E) and Poissons ratio (μ)

As was so accurately predicted by Dr. Terzaghi twenty-five years ago, that component of the concrete highway structure which makes the application of mathematical theory so difficult is the subgrade soil. Dr. Westergaard, whose solution from the theory of elasticity is the most widely known and used in the design of concrete pavement, lumped all the characteristics of the subgrade into one variable, his "coefficient of subgrade reaction," k. The value of k equals the load in pounds per square inch, on a loaded area of the subgrade, divided by the deflection in inches. However, upon examining the dimensions of this quantity more carefully, it becomes apparent that k can be described more precisely as the density of a liquid subgrade in pounds per cubic inch.* Figure 4 illustrates this idea. It is very important to bear in mind that the Westergaard theory is based on the assumption that the value of k for a given subgrade is a physical constant.

We have seen that k is defined as an applied pressure divided by a settlement; it is of interest and practical value to investigate the meaning of the pressure-settlement ratio when the subgrade is considered to be an elastic solid instead of a dense liquid. Assuming that the loaded area in this case is circular and that the load consists of a constant unit pressure, we find from the theory of elasticity that the pressure-settlement ratio is given by the quation below:

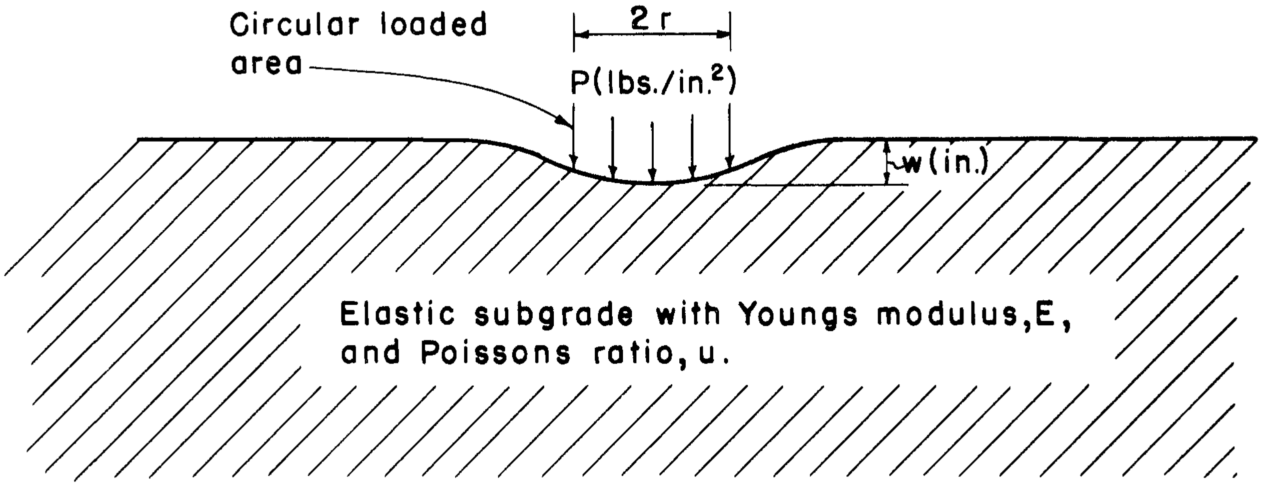
*Since k may range from 50 lbs./cu. in. to 750 lbs./cu. in., it is obvious that the concept of a liquid subgrade is entirely theoretical, although useful in describing the Westergaard theory.



$$k = \frac{\text{Applied pressure}}{\text{Settlement}} = \frac{F/\pi r^2}{w} = \frac{F}{\pi r^2 w}$$

$$= \frac{\text{Weight of displaced liquid}}{\text{Volume of displaced liquid}} = \text{Density of liquid (lbs./cu.in.)}$$

FIGURE 4: Physical meaning of Westergaard's constant pressure—settlement ratio, k.



$$\frac{P}{w} = \frac{E}{2(1-u^2)r}$$

FIGURE 5: The variable pressure – settlement ratio for a solid subgrade.

$$\frac{p}{w} = \frac{E}{2(1-u^2)r} \tag{1}$$

where the meanings of the symbols are given in Figure 5.

It is clear from the above equation that if the subgrade is considered to be an elastic solid, the pressure-settlement ratio is not a physical constant of the subgrade, but on the contrary varies inversely as the radius of the loaded circular area.

Many experiments made by loading circular plates and observing the settlement of the ground beneath them have invariably shown that the subgrade behaves more like an elastic solid than like a dense liquid. However, the mathematical theory of the elastic subgrade is not yet complete enough for practical application, and it appears likely that we will use Westergaards liquid subgrade, and his coefficient of subgrade reaction, k, for some time to come.

It is seen from the equation above that if the Youngs modulus for a subgrade material is known, say from a triaxial test, then the pressure-settlement ratio corresponding to any desired value for the radius of the loaded area may be calculated. Although it is incorrect, from the standpoint of theory, to refer to a pressure-settlement ratio so computed as Westergaard's coefficient of subgrade reaction, still its dimensions are the same as those of k, and experience here in Texas, mostly in the Houston-Beaumont area, has indicated that the pressure-settlement ratio obtained in this way may safely be used as the value for k.

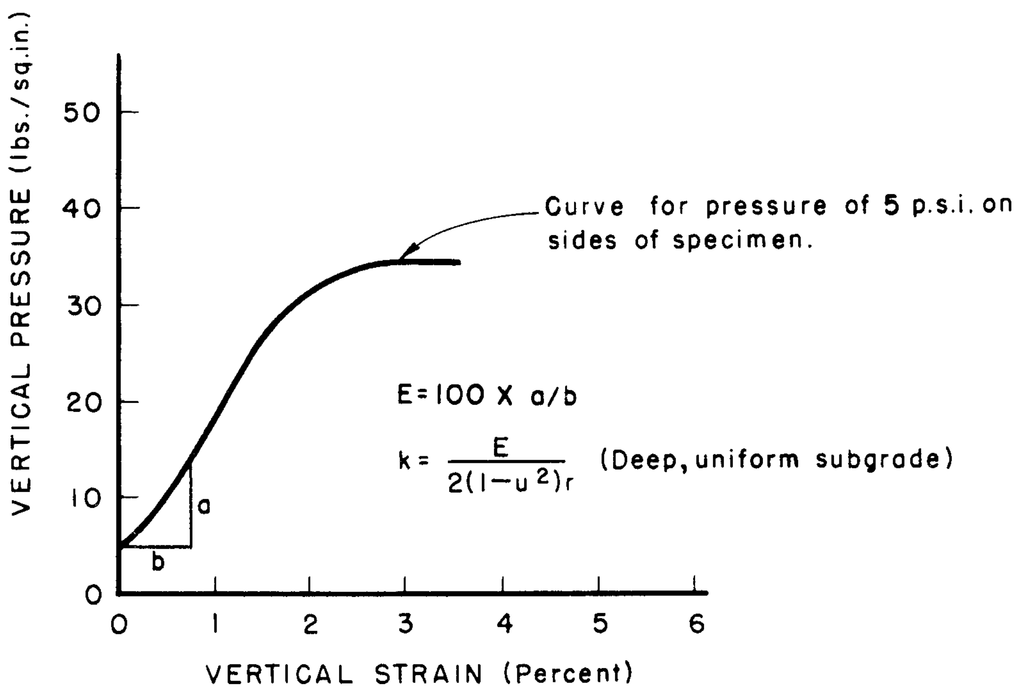


FIGURE 6: Value of k from triaxial test for a deep, uniform subgrade.

We recommend that the value of E for the subgrade be determined from the slope of the stress-strain curve near the origin when the lateral pressure is about five pounds per square inch, as shown in Figure 6. We also recommend that the value of Poissons ratio be set at 1/2, then, according to Equation (1), the value of k is given by

$$k = \frac{p}{w} = \frac{2E}{3r} \tag{2}$$

Graph No. 1 of Road Design Circular 4-48, dated April 1, 1948, recommended the following values for r:

For very firm materials, r = 18 inches, k = E/27.

For average materials, r = 24 inches, k = E/36.

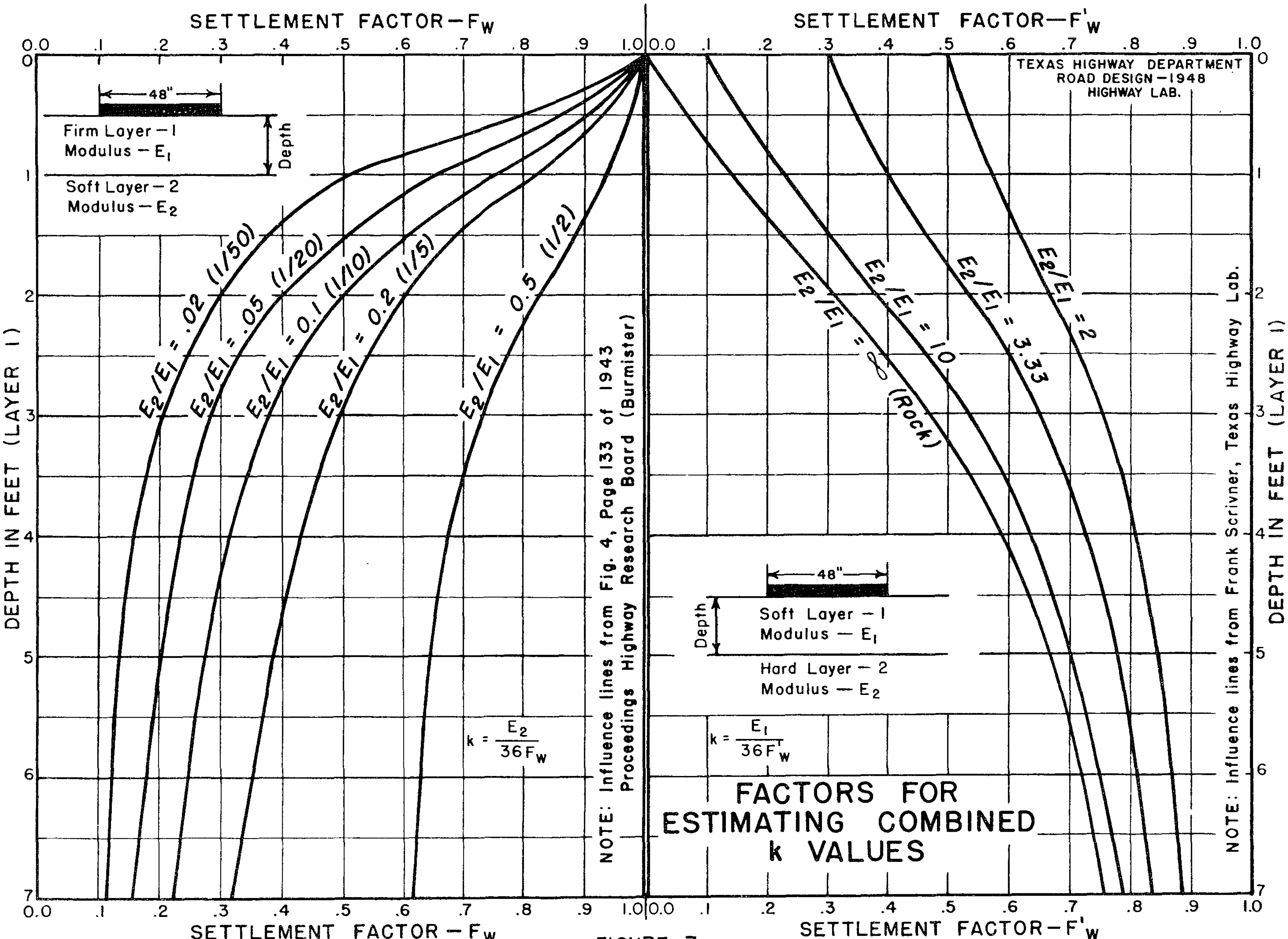
For extremely soft materials, r = 30 inches, k = E/45.

(My personal recommendation is that k = E/36 be used for all soils).

In defense of this juggling of theory in order to achieve a practical result, it may logically be contended that E plays the same role in the theory of the elastic subgrade as k in the theory of the liquid subgrade. As a matter of fact, a limited number of numerical comparisons indicates that the two theories give identical results for stress if E/k = a constant, the value of which is determined by trial and error.

As already indicated, the subgrade assumed in the Westergaard theory is a dense liquid, upon the surface of which the concrete is floating. Obviously, the behavior of this slab under load will be the same whether the depth of the liquid under the slab is only a few inches or many feet. But experience has shown that concrete slabs on soft materials underlain by harder materials at depths up to five or six feet generally perform better than slabs on soft layers where the hard layers occur only at great depths. Therefore, although it is not possible in the Westergaard theory to account for more than one layer of soil under the pavement, it became necessary, nevertheless, to find a method for altering the value of the subgrade modulus, k, in such a manner that it would reflect the presence of a hard layer within 5 or 6 feet of the surface of the ground. This was done by reference to the theory of the elastic subgrade, and the results of the computations from this theory are shown graphically in Figure 7. From the curves given in this figure the pressure-settlement ratio of a circular loaded area with a diameter of 48 inches may be computed, the subgrade being assumed to consist of either a soft over a hard layer or a hard over a soft layer. It will be noted that the size of the loaded area used in these computations is the same as the size recommended above for use in converting the value of E to the vahe of k for average materials.

In the absence of triaxial test results for the subgrade materials, Table 1 has been suggested by the Portland Cement Association as a means for estimating the value of k from ordinary soil tests. (Atterburg limits).



SETTLEMENT FACTOR — F_W
SETTLEMENT FACTOR — F'_W
0.0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0
TEXAS HIGHWAY DEPARTMENT
ROAD DESIGN — 1948
HIGHWAY LAB.
48"
Firm Layer — 1
Modulus — E_1
Depth
Soft Layer — 2
Modulus — E_2
$E_2/E_1 = .02$ (1/50)
$E_2/E_1 = .05$ (1/20)
$E_2/E_1 = 0.1$ (1/10)
$E_2/E_1 = 0.2$ (1/5)
$E_2/E_1 = 0.5$ (1/2)
$E_2/E_1 = \infty$ (Rock)
$E_2/E_1 = 10$
$E_2/E_1 = 3.33$
$E_2/E_1 = 2$
DEPTH IN FEET (LAYER 1)
0 1 2 3 4 5 6 7
NOTE: Influence lines from Fig. 4, Page 133 of 1943 Proceedings Highway Research Board (Burmister)
NOTE: Influence lines from Frank Scrivner, Texas Highway Lab.
Soft Layer — 1
Modulus — E_1
Hard Layer — 2
Modulus — E_2
$k = \frac{E_2}{36F_W}$
$k = \frac{E_1}{36F'_W}$
FACTORS FOR ESTIMATING COMBINED k VALUES

FIGURE 7

Table I—**Approximate Range of *k*-values for Soil Groups of the Highway Research Board Classifications* and of the Bureau of Public Roads Classifications**

Major divisions	Soil groups and typical description	Highway Research Board	Original Bureau of Public Roads symbol	Approximate range of *k*-values for each soil group
Gravelly and sandy soils	Well-graded gravel-sand-clay. Excellent binder.	A - 1 - a	A - 1	400-700 or greater
	Sand-clay mixtures. Excellent binder.	A - 1 - b	A - 1	250-575
	Gravel with fines, very silty gravel, poorly graded gravel-sand-clay, and sand-clay mixtures. Poor binder. Friable.	A - 2 - 4 A - 2 - 5	A - 2 friable	300-700 or greater
	Poorly graded clayey gravels, gravel-sand-clay, and sand-clay mixtures. Inferior binder. Plastic.	A - 2 - 6 A - 2 - 7	A - 2 plastic	175-325
	Well-graded gravel, gravel-sand mixtures, and sands. Little or no fines.	A - 1 - a	A - 3	325-700 or greater
	Poorly graded gravel, gravel-sand mixtures, and sands. Little or no fines.	A - 1 - b A - 3	A - 3	200-325
Fine-grained soils in which silt sizes predominate	Predominantly silt soils with moderate to small amounts of coarse material and small amounts of plastic clay.	A - 4	A - 4	100-300
	Poorly graded silty soils which contain mica and diatoms and which have elastic properties.	A - 5	A - 5	50-175**
Very fine-grained inorganic and organic soils in which the clay fraction governs	Clay soils with moderate to negligible amounts of coarse materials. Includes well-graded inorganic silt-clay, sand-silt-clay, and sand-clay soils.	A - 6 A - 7 - 6	A - 6	50-225
	Elastic clay soils with moderate to negligible amounts of coarse materials. Usually poorly graded or contains organic or other materials which make them elastic.	A - 7 - 5	A - 7	50-225

* As given in the Soil Committee Report, Highway Research Board Proceedings, 1945, Vol. 25, page 377, and adopted by the American Association of State Highway Officials.

** Some soils of volcanic origin may have *k*-values greater than those shown for this group.

As previously indicated two of the variables listed above, Youngs modulus and Poissons ratio of the concrete, are generally considered not to vary in gravel or crushed stone aggregate concrete. The design chart of Figure 8, which is recommended for use with gravel or crushed stone aggregate concrete, represents load-depth-k-stress relations for a concrete with a Youngs modulus of four million pounds per square inch and a Poissons ratio of 0.15. The use of this chart, which was published by the Portland Cement Association in 1951, is recommended over the similar design charts or graphs circulated with Road Design Circular No. 4-48. The method of using the chart is obvious.

The list of variables which we have considered in the theory of concrete slab depth design is summarized in Table 2. It may be of interest to compare this table with the corresponding list suggested over the past 50 years for the design of flexible pavement depth, and given in the lecture on that subject.

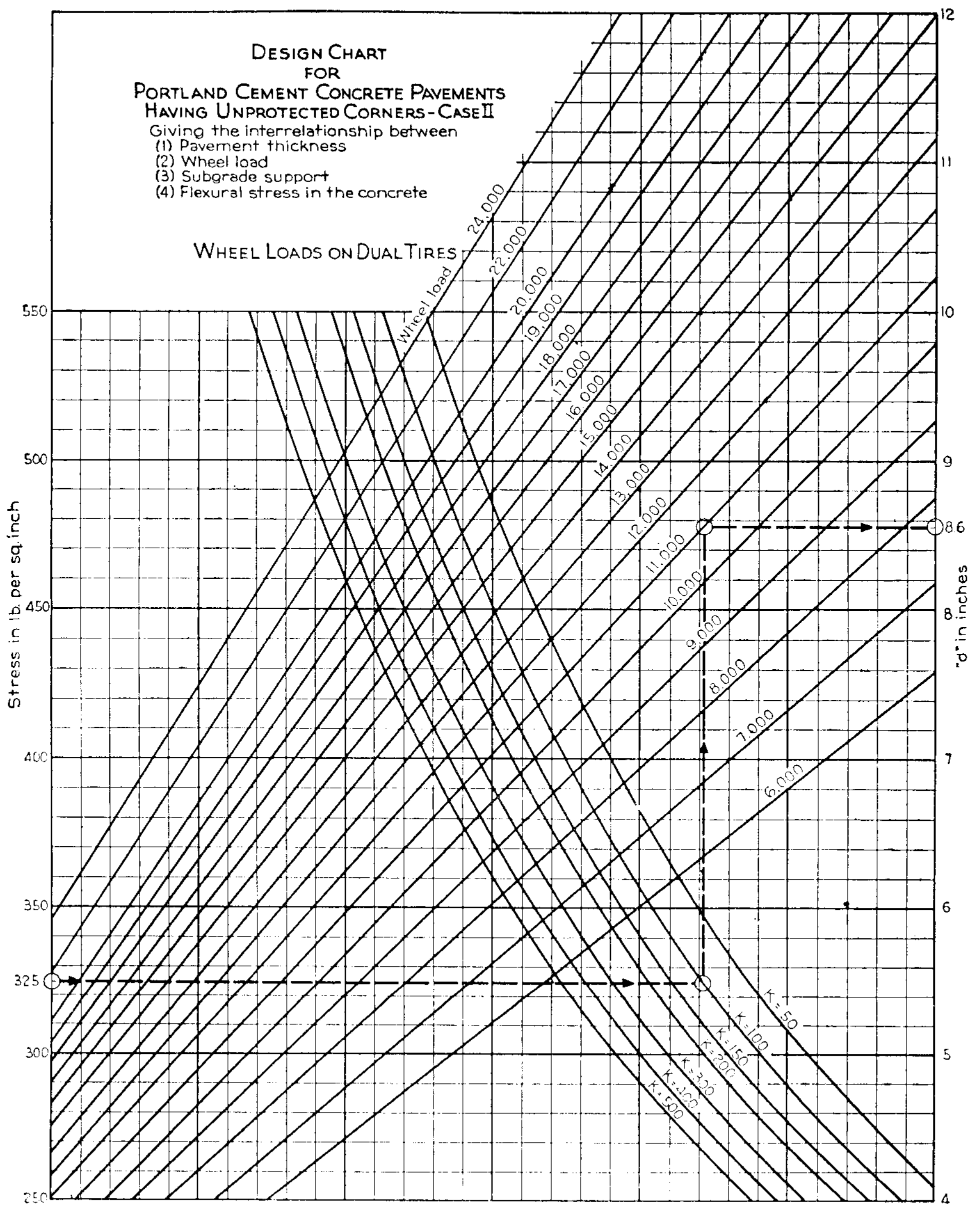

DESIGN CHART
FOR
PORTLAND CEMENT CONCRETE PAVEMENTS
HAVING UNPROTECTED CORNERS - CASE II
Giving the interrelationship between
(1) Pavement thickness
(2) Wheel load
(3) Subgrade support
(4) Flexural stress in the concrete
WHEEL LOADS ON DUAL TIRES
Wheel load
24,000
22,000
20,000
19,000
18,000
17,000
16,000
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
K=50
K=100
K=150
K=200
K=300
K=500
Stress in lb. per sq. inch
550
500
450
400
350
325
300
250
"d" in inches
12
11
10
9
8.6
8
7
6
5
4

FIGURE 8

TABLE 2

LIST OF VARIABLES CONSIDERED
IN THE THEORY OF CONCRETE PAVEMENT DEPTH DESIGN

Load -

1. Weight
2. Dimensions of loaded area

Concrete -

1. Tensile strength (modulus of rupture)
2. Youngs modulus
3. Poissons ratio

Subgrade -

1. Youngs or Westergaards modulus
2. Poissons ratio

Note: Only the first variable in each of the three groups is considered if the design chart of Figure 8 is used.

JOINTING AND REINFORCING OF CONCRETE PAVEMENT

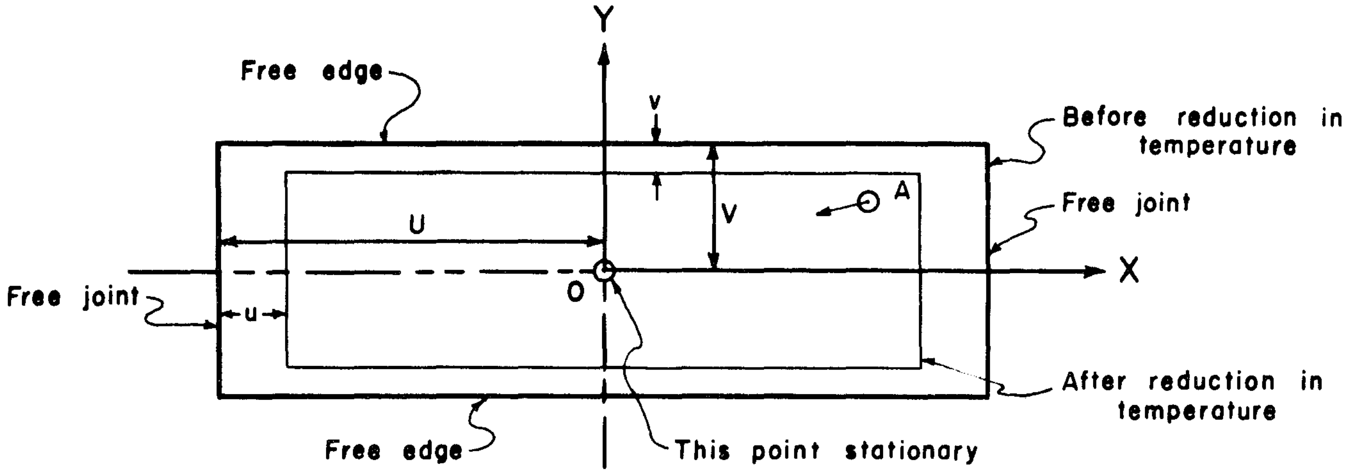
PART I - REINFORCING

DEFORMED BARS - GENERAL

The subject of the jointing and reinforcing of concrete pavement is largely concerned with the movements and stresses associated with the contraction of a concrete slab undergoing an overall reduction in its temperature. The importance of the contraction part of the volume change cycle rests mainly on the fact that concrete is relatively weak in tension, and tensile stresses invariably result from contraction.

In order to study the movements which occur during a temperature drop, we may consider first the simplest type of contraction - namely, the contraction of a concrete slab resting on a smooth, frictionless subgrade and subjected to a uniform reduction in temperature. (By "uniform reduction," we mean that at any instant the temperature is the same at every point in the slab).

Figure 1 illustrates this ideal case, which, of course, never occurs in nature. We assume that the center point, O, of the slab is fixed to the subgrade. Under these conditions every point in the slab (for example, point A) moves directly toward the point, O; all strains, such as u/U and v/V are equal at any instant, and the slab deforms without stress.



$$\frac{u}{U} = \frac{v}{V}$$

FIGURE 1: Plan of concrete slab undergoing a uniform reduction in temperature on a smooth, frictionless subgrade. Every point moves toward the point O.

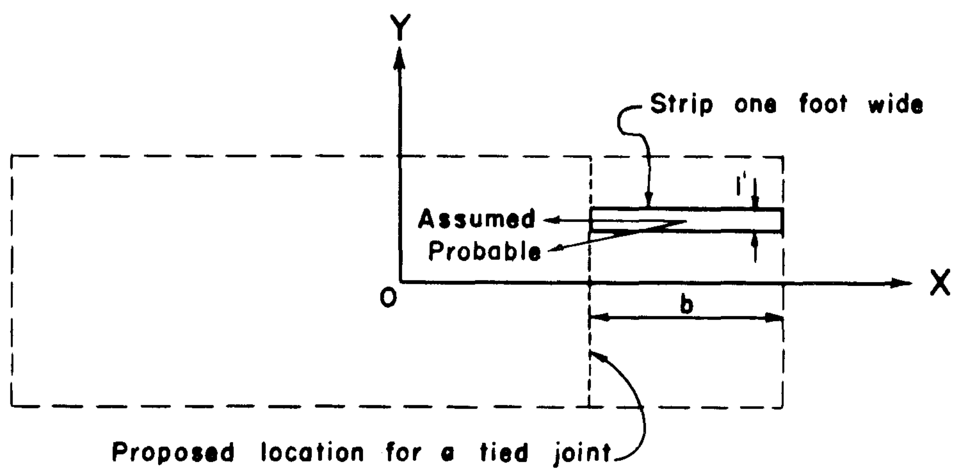


FIGURE 2: Arrows show probable and assumed direction of movement of a unit strip of a contracting slab on a rough subgrade.

Let us now consider the case represented in Figure 2, that is, a slab on a rough subgrade, undergoing the same kind of temperature change described above. Every point in the slab tends to move toward the point, O, as before, but every point in contact with the subgrade encounters a resistance to this movement. As a result the movement of every point is less than was the case for the geometrically similar point of Figure 1, and internal stresses within the slab are set up.

In order to estimate the magnitude of these stresses, the so-called "subgrade friction theory" is frequently employed by highway engineers. In this theory, we assume that every point in the slab moves parallel to the longitudinal center line toward the central transverse cross-section of the slab, and that the under surface of the slab slides over the subgrade.

TIE-BARS AND REINFORCING BARS

Now let it be supposed that a transverse joint of the tied type - we call it a "warping joint" - has been proposed for the location shown in Figure 2 at a distance, b feet, from the nearest free joint. We next draw a strip of length, b, and width of one foot, as shown. One of the two arrows in the figure indicates the probable direction of movement of the centroid of this strip; the other arrow shows the direction in which we assume it moves in the subgrade friction theory.

Figure 3 shows the forces acting on this strip on the assumption that the concrete block is perfectly rigid and is on the verge of being

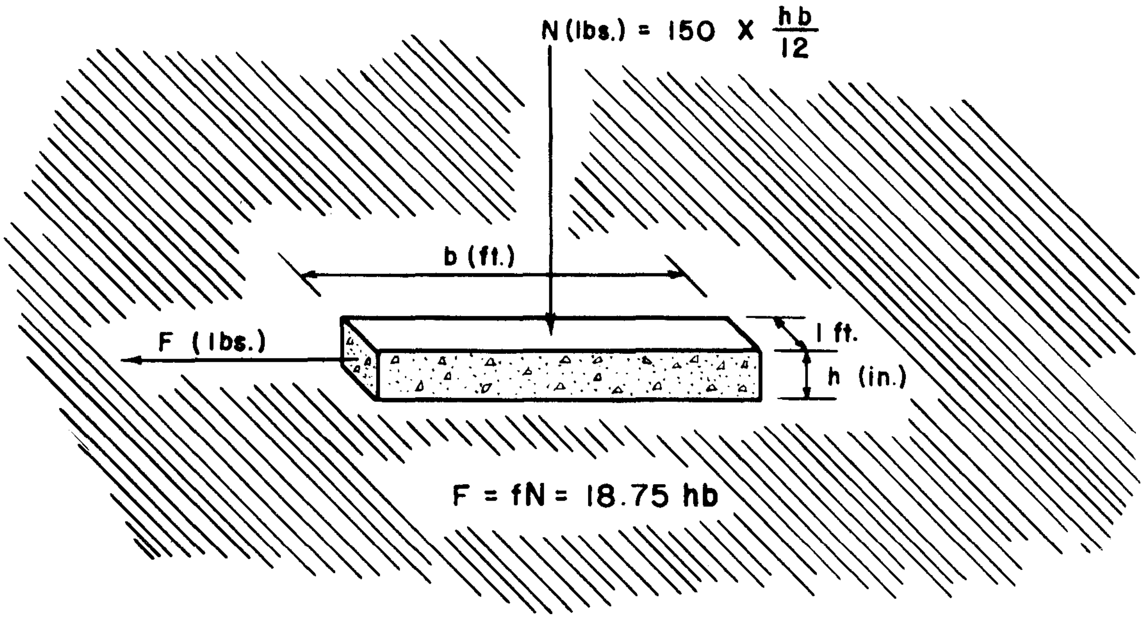
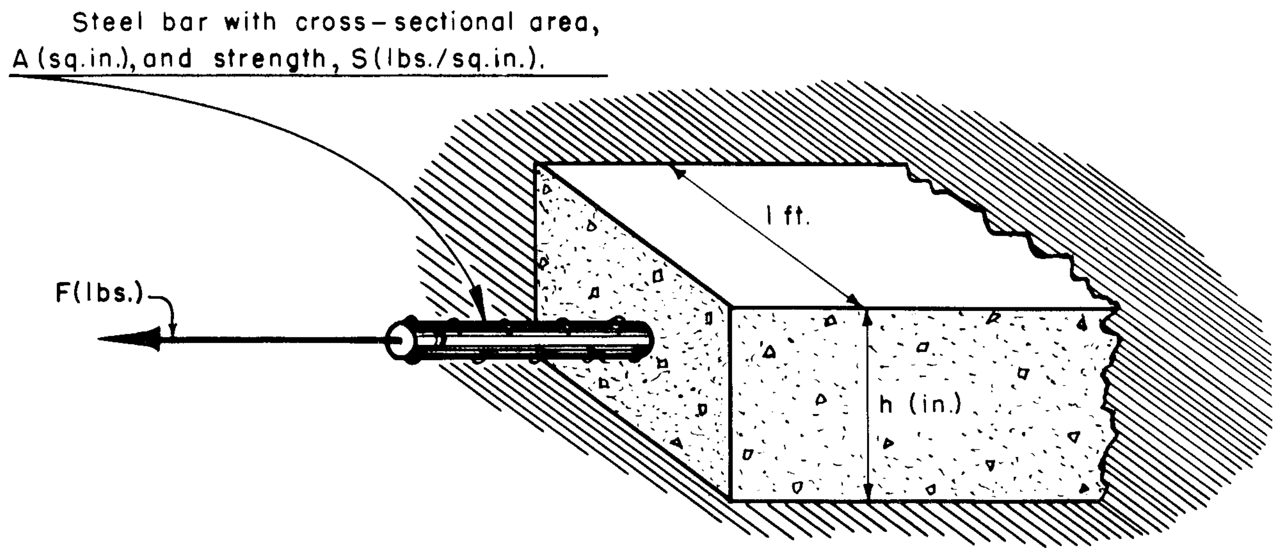


FIGURE 3: Enlarged view of the strip of FIGURE 2. Density of concrete = 150 lbs. per cu. ft., friction coefficient, f = 1.5.



$$F = SA = 18.75\ hb$$

$$A = 18.75\ \frac{hb}{S} = \text{area steel per ft. of joint.}$$

If d = diam. (in.) of bar selected for use, D = spacing (in.) = $\frac{3\pi d^2}{A} = \frac{d^2 S}{2hb}$.

FIGURE 4: Derivation of formula for spacing. The sketch represents left end of strip of Figure 3.

dragged along the subgrade toward the left. A value of 1.5 for the coefficient of sliding friction and 150 lbs. per cubic foot for the density of concrete are commonly used values.

The condition of equilibrium of the block of Figure 3 leads to the following equation:

$$F = 18.75\ hb \tag{1}$$

Assuming now, as illustrated in Figure 4, that a single bar of steel reinforcing is embedded in the block and that the force, F, acts on this bar, we find the area, A, of the cross-section of the bar in terms of its strength, S, as

$$A = 18.75\ \frac{hb}{S} \tag{2}$$

If the bar with area A, at a spacing of 12 inches is not suitable, then a bar of diameter, d inches, at a spacing of D inches, may be substituted, provided

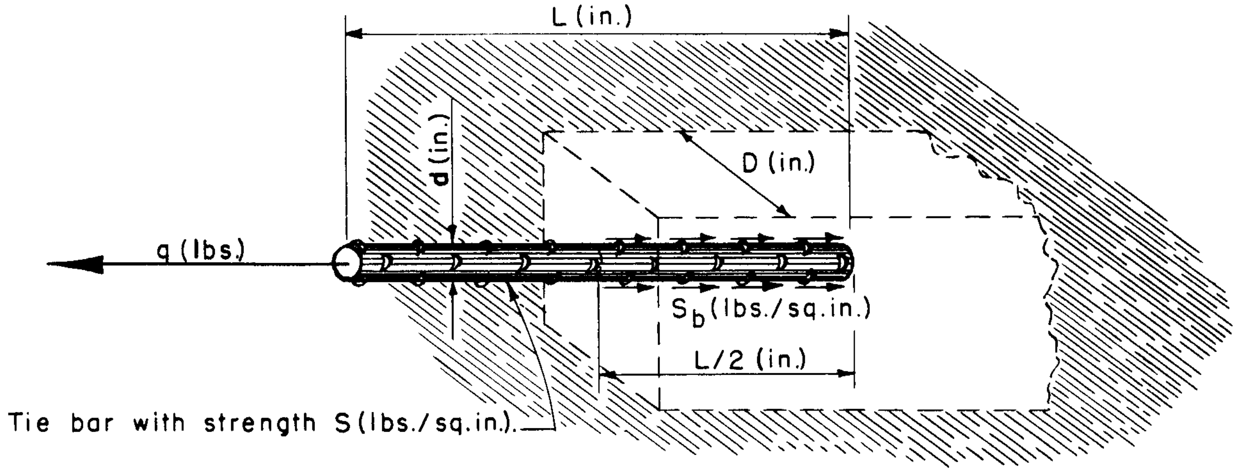
$$D(\text{in.}) = \frac{d^2S}{2hb} \qquad \text{(approx.)} \tag{3}$$

Equation (3) follows directly from Equation (2).

Having selected the bar of diameter, d, the next step is the determination of its length. Figure 5 shows the forces involved. From the condition of equilibrium we find the following:

$$L = \frac{dS}{2S_b} \tag{4}$$

The recommended value of the bond working stress, S_b, is 350 lbs. per square inch. As a result, Equation (4) becomes



$$q = \frac{\pi d^2}{4} S = \frac{\pi d L}{2} S_b$$

$$L = \frac{dS}{2S_b} = \frac{dS}{700}$$

FIGURE 5: Length of tie bar for a bond stress, S_b = 350 lbs./sq.in.

$$L(\text{in.}) = \frac{dS}{700} \quad (5)$$

where S is the working stress for the steel.

It will be noted that the dimensionless ratio, L/D, represents the length of bar required per unit length of joint. By dividing Equation (5) by Equation (3) we find

$$\frac{L}{D} = \frac{hb}{350d} \quad (6)$$

From Equation (6) we may compute the weight of steel required per foot of joint, as given below:

$$\text{Lbs. of steel tie bars/ft. of joint} = .0076\ hbd \quad (7)$$

It is of interest to note that Equation (7) is independent of the strength of the steel; also, it can be seen that the smallest practical diameter tie bar should be used, since the cost varies directly with the diameter, d. It should be remembered, however, that small bars rust through sooner than large ones.

We have discussed Equation (3) as being applicable to tie bars. The formula may also be used in designing reinforcing steel - that is, bars which extend longitudinally from one free joint to the next, or transversely from one free edge to the other free edge, with the purpose of minimizing the opening of cracks. The methods of measuring the distance, b, are shown in Figure 6.

The numerical values for spacing (D) and bar lengths (L) calculated from Equations (3) and (5) frequently must be altered because of

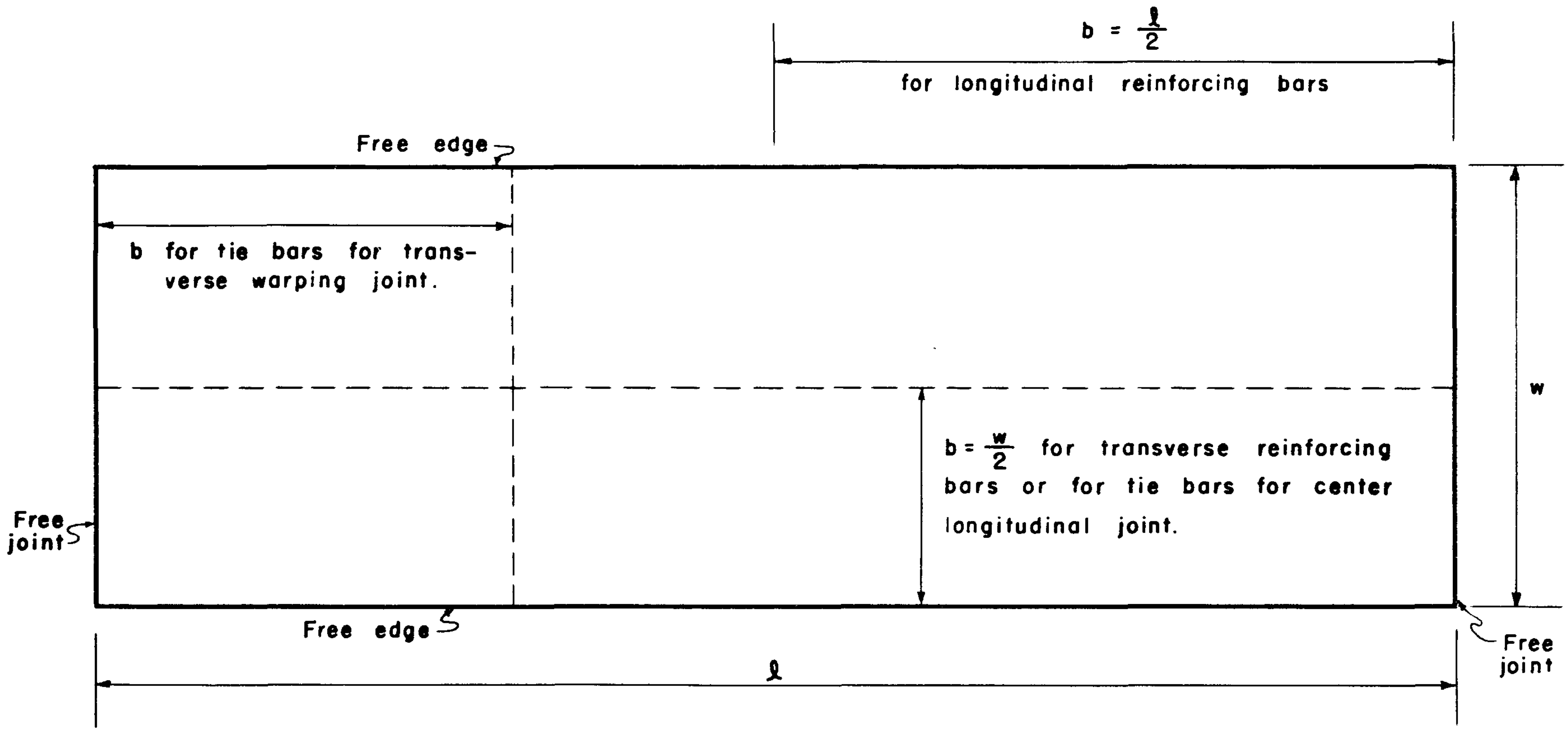


FIGURE 6: Methods of measuring b for use in spacing formula of FIGURE 4.

practical considerations. If either or both of the values actually used for L and D do not agree with their theoretical values, then Equation (7) cannot be used for the calculation of the pounds of steel bars per foot of joint. In this event, Equation (8), below, should be substituted for Equation (7):

$$\text{Lbs. of steel tie bars/ft. of joint} = \frac{LW}{D} \tag{8}$$

Where L = actual length (in.) of bar to be used
D = actual spacing (in.) to be used
W = weight (lbs./ft. of bar)

DOWELS

Smooth dowels or other load transfer devices are usually provided at the transverse free joints in concrete pavement. These devices are designed to prevent faulting of slab ends and serve, to a limited extent at least, to reduce the stress in the slab ends by transferring a part of the wheel load across the joint to the adjacent slab.

There is very little agreement among highway engineers as to how the spacing of dowels should be computed, but the spacing usually varies between about 12" and 18". Dowel sizes for highways vary from 3/4" to 1 1/4" in diameter, while lengths range from about 10" to about 24". We recommend 1" x 20" dowels on 12" centers for contraction joints and 1 1/4" x 20" dowels on 12" centers for expansion joints.

PART II - JOINTING

EXPANSION JOINTS

There has been a growing trend in recent years toward the elimination of expansion joints in new construction. Briefly, the reasons given are as follows:

(a) The high compressive strength of concrete makes crushing due to temperature increase alone improbable.

(b) The cause of blow-ups in many cases has been traced to a physical growth of the concrete not related to temperature change, such growth usually being attributed to chemical changes taking place in certain cement-aggregate combinations; such blow-ups usually cannot be prevented by expansion joints.

(c) The behavior of pavements without expansion joints has been generally good.

(d) A pavement without provision for expansion is in compression for at least a part of each year, and compression adds to the bearing power of the pavement.

(e) The contraction joints in a pavement without provision for expansion generally open less with less opportunity for entrance of water and debris.

(f) Expansion joints are more expensive than contraction joints.

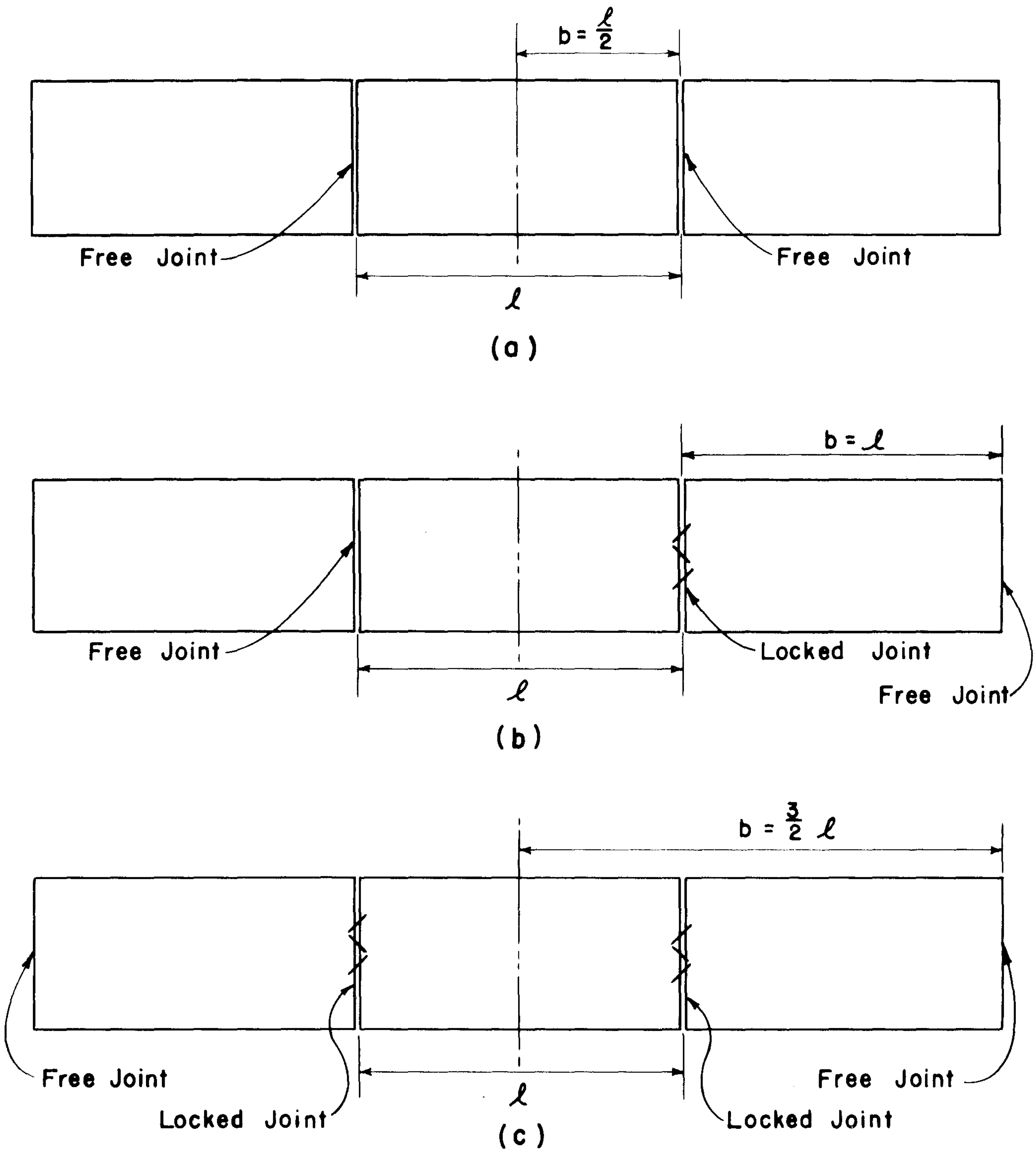


FIGURE 7: Values of b for use in Equation (9) for stress, Px, in concrete.

We recommend a minimum of expansion joints except at bridge ends or other special locations.

CONTRACTION JOINTS

Contraction joints, as the name implies, are designed primarily to relieve tensile stresses set up during contraction accompanying an overall reduction in temperature. The magnitude of these stresses are sometimes estimated from the subgrade friction theory, as follows:

Referring to Figure 4, we have written the expression for the total force, F, transferred across the joint as

$$F(\text{lbs.}) = 18.75\ hb \qquad (1)$$

Dividing Equation (1) by the area, 12h (sq. in.), of the section of concrete, we obtain the horizontal normal stress, P_x, as follows:

$$P_x\ (\text{lbs./sq. in.}) = 1.56b \qquad (9)$$

Figure 7 (a) shows how b is measured when it is desired to calculate the stress caused by an overall reduction in temperature. Figures 7(b) and 7(c) indicate the effect of locked joints on this stress.

It is well to remember that the stress, P_x, adds directly to the stress produced by wheel loads. Therefore, according to Equation (9), the spacing of contraction joints has an important effect on the probable behavior of the pavement. Obviously, b should be held to a minimum.

TIED JOINTS - WARPING AND LONGITUDINAL CENTER JOINTS

When the atmosphere undergoes a change in temperature a concrete pavement also changes in temperature, but generally the bottom of the slab lags behind the top. Thus, usually a temperature differential exists between top and bottom of the slab. The result is a warping of the slab upward or downward, which is resisted by the weight of the slab and any vehicle loads which may be present upon it.

Another common cause of warping is the volume change occurring in the soil under the free edges of the slab as a result of fluctuations in moisture content.

A third, but probably less important cause of warping, is a change in the moisture differential between top and bottom of the slab.

Studies from the theory of elasticity have indicated that warping stresses may, in many cases, be larger than stresses caused by overall temperature reduction or even by wheel loads and have shown that some relief from warping stresses should be provided at intervals of 15 to 20 feet along the length of the slab. And experience has shown that if these stresses are not relieved, transverse cracks often occur at intervals of 15 to 20 feet.

Experience has also shown that the pavement should be provided with a tied joint at the center line in order to relieve stresses probably occurring as a result of volume fluctuations in the soil under the pavement edges as well as because of temperature and moisture differentials between top and bottom of the slab.

Warping stresses frequently are added directly to load and overall temperature reduction stresses. Therefore the spacing of warping joints, like that of contraction joints, has an important bearing on the behavior of concrete pavement. Obviously, transverse joints capable of relieving warping stresses should be spaced at intervals not greater than 15 to 20 feet.

PART III - GENERAL

APPLICATIONS OF THEORY

In the development of the subgrade friction theory, we assigned a numerical value of 1.5 to the coefficient of friction, f (Figure 3).

Actually, that portion of the concrete slab in the neighborhood of point O, Figure 2, probably never slides on the subgrade, and for that part of the pavement, f is meaningless.

For portions of the slab more remote from the center, where sliding might be expected to take place as a result of large changes in tempature, the stress, P_x, in the slab may be quite different from the value computed from Equation (9), because of the variation of f with the type of soil, as will now be shown.

If the underside of the slab is tightly bonded to the subgrade, then sliding cannot take place until the bond is broken. If the cohesion, C (lbs./sq. in.) and the angle of internal friction, ϕ, of the subgrade soil are known, then the shear stress, T (lbs./sq.in.), acting on the under surface of the slab at the instant the bond is broken may be estimated from Coulomb's equation,

$$T = C + n \tan \phi \qquad (10)$$

where n (lbs./sq.in.) represents the vertical pressure exerted by the slab upon the subgrade by virtue of its weight.

Referring to Figure 3, and in view of Equation (10), we may write

$$F = fN = 144bT = 144\, b\, (C + n \tan \phi) \qquad (11)$$

or

$$f = \frac{144b\, (C + n \tan \phi)}{N} \qquad (12)$$

From Equation (12) we see that f is indeed a variable, since it depends on the values of C and ϕ of the subgrade soil.

From Equation (11) we find a new expression for the stress, P_x, replacing Equation (9), as follows:

$$P_x = \frac{F}{12h} = 12\, (C/h + .0868 \tan \phi)\, b \qquad (13)$$

where, as in Figure 3, we take the density of concrete as 150 lbs./cu. ft. (.0868 lbs./cu.in.).

In order to investigate further the effect of variations in the subgrade upon the stress, P_x, resulting from an overall reduction in temperature, let us first suppose the subgrade to be a Class 1 material with the following characteristics:

$C = 16$ lbs./sq. in

$\phi = 45^{\circ}$

For a 10" slab ($h = 10$) we find from Equation (13),

$P_x = 20.2\ b$

instead of 1.56 b, as given by Equation (9) for $f = 1.5$.

Now suppose the subgrade is a Class 5 material with the following strength values:

$C = 4.5$ lbs./sq.in.

$\phi = 13^{\circ}$

The stress in the 10" slab is, according to Equation (13),

$P_x = 5.6b$

Finally, from Equation (13) we find that the stress is as follows, if the subgrade is a Class 4 material with no cohesion and $\phi = 53^{\circ}$:

$P_x = 1.4\ b$

We note that the stress due to overall temperature reduction in a 10" slab apparently could vary from $P_x = 1.4\ b$ to $P_x = 20.2\ b$, as a result of changes in the shear strength of the subgrade.

CONCLUSIONS

The purpose of reinforcing steel is to minimize the opening of cracks, not to prevent them.

Formulas from the subgrade friction theory should be used with great caution, especially when applied to the spacing of contraction joints. The best guide is experience.

Experience indicates that warping stresses should be relieved by warping, contraction or expansion joints at intervals of 15 feet or less in plain concrete.

Expansion joints are expensive and believed generally to be unnecessary.

Contraction joints can relieve warping stresses, but warping joints cannot relieve contraction stresses (stresses due to an overall reduction in slab temperature).

Contraction joints should:

(1) Open with negligible resistance and be closely spaced.

(2) Resist the entrance of water and prevent roughness due to "faulting."

(3) Perform these functions for the life of the pavement with a minimum of maintenance.

(4) Be designed to permit rapid, and preferably, mechanized installation.

P. S. & E. SUBMISSIONS

The following comments are to supplement or emphasize the importance of certain features discussed in the "General Instructions For Preparing the Project Data Sheet" and other instructions contained in the Manual for P. S. & E. Submissions.

The Project Data Sheet should be carefully checked before submitting plans in order to avoid overlooking any of the supporting papers listed on that form. If for any reason, there will be a delay in submitting any of the supporting papers such as option agreements or Municipal Construction Agreements, information as to the status of such papers should be noted on this form with advice on this form or in the letter of transmittal as to when submission will be made.

LETTER OF TRANSMITTAL.

It is necessary that complete information as to reasons for overruns be presented by the Austin office through required channels for approval. When information in this regard is not furnished by the districts, it is difficult to present convincing reasons for the additional cost as information in this office as to factors causing the over-run is generally very limited.

PLANS ESTIMATE

The Plans Estimate should be as realistic as possible, and in its preparation study should be given to recent unit bid prices for like work in the vicinity of the project.

When materials are to be furnished by the state or miscellaneous day labor work is to be performed by state forces, the estimated cost of such materials and work should be itemized in the estimate. Borrow and material sources bought by the state are usually secured some time in advance of completion of P. S. & E. and the Plans Estimates frequently do not include allowances for the cost of these sources. These cost items should always be itemized in the Plans Estimate in order that funds therefor will be appropriated at the same time the appropriation for the contract work is made.

GOVERNING SPECIFICATIONS AND SPECIAL PROVISIONS

Frequently Item 540, Structure for Field Office and Laboratory, is not included in the list of Governing Specifications and Special Provisions, and when this item is omitted it is assumed by the Austin office that the district will furnish portable buildings for this purpose or that such buildings are not considered necessary for the particular work to performed; however, in instances when this omission is brought to the attention of the engineer, it is usually found that a building of some kind is desired and that inclusion of Item 540 with an indication as to the type of building desired was overlooked in preparing the list of governing specifications. If a field office or laboratory is not desired, a note on the list of specifications so stating will remove any doubt on the part of the Austin office as the District's intentions.

There have been misunderstandings as to the proper way to permit use of Item 531, Membrane Curing, and Item 532, Central Mixing Plants and Transit Mixers for Concrete Pavement." When it is desired to permit these methods of curing and mixing of concrete, Items 531 and/or 532 should be shown in parenthesis on the List of Governing Specifications and Special Provisions after the item or items on which they will apply. As an example, if both of these items will be permitted in concrete pavement construction, Item 320 should be shown on this list in this manner:

Item 320 Concrete Pavement (Water Cement Ratio) (531) (532)

SPECIAL SPECIFICATIONS AND SPECIAL PROVISIONS

It is desired to maintain as much uniformity in design and construction policies as possible throughout the state. It is therefore urged that unless a real reason exists, the standard specifications be used without modification. Particular attention is directed to the need for maintaining uniformity in the methods of measurement and payment.

It is realized there will be conditions where an economical advantage to the state will result by modifying the standard specifications.

Also, there will be new developments which will make parts of the specifications obsolete, and flaws in the specifications no doubt will develop. Under these conditions, there will be no objection to modification of the specifications.

MATERIAL TEST DATA

Test reports on representative samples of base materials from proposed local sources should accompany P. S. & E. submissions except in cases where samples of the material have been submitted to the Materials and Tests Laboratory in Austin for analysis.

Also, since soil conditions determine to a large extent the depth of pavement and bases, test reports on sub-grade soils which are representative between certain station limits are of value to the Austin office in checking base depths, particularily on projects with varying soil conditions where the base depth is adjusted between certain station limits to conform with subgrade soils.

OPTION FOR PURCHASE OF MATERIAL

The names of all parties (owners) signing option agreements should be shown under "Name" in the Special Provision "Local Material Sources."

Any special requirements of option agreements such as fencing the pit area or haul roads, watchmen, or cattle guards should be outlined in the Special Provision "Local Material Sources."

Before submitting option agreements to the Austin office, they should be checked to see that all required signatures have been obtained, including witness signatures, that the agreement date has been inserted, and that all blanks on the title page of the option have been properly filled.

MUNICIPAL CONSTRUCTION AGREEMENT AND MUNICIPAL ORDINANCE

This subject will be discussed in a separate paper.

WAGE RATE STATEMENT AND RECOMMENDATION

The form for this purpose (Stencil 12-51-2337) should accompany every P. S. & E. submission. If any changes in the minimum wage rates established by the State Highway Commission are proposed, copies of payrolls substantiating such changes should be forwarded to the Austin office for use in presenting the proposed changes through the channels required for approval.

STATUS OF RIGHT-OF-WAY

At the time of submission of P. S. & E. to the Austin office, there are usually right-of-way matters of some kind which have not been cleared up, and the letting of the project will be contingent upon the adjustment of such matters. It is important that the Austin office be advised as to progress being made in acquiring right-of-way and removal of encroachments and that notification be given as soon as possible after all right-of-way matters have been cleared. This information is necessary in order that letting schedules may be properly balanced, that Notices to Contractors and legal advertisements may be released at the proper time, and to assure no delay in the award of contract or issuance of Work Order.

PROCEDURE FOR ACQUIRING BORROW & MATERIAL SOURCES AT STATE'S EXPENSE

This subject will be discussed in the paper "Right-of-Way Procedures and the Acquisition of Material Sources."

RECOMMENDED LETTING DATE

A Departmental policy requires that proposals and blue printed plans be available for examination by bidders for a period of thirty days before the letting date. In order to allow time for review, for adjustment of any questions that may develop during review, and for processing of plans, specifications, and estimates, the district's submissions should reach the Austin office at least 45 days before the desired letting. As the Austin office personnel and facilities for review and processing of P. S. & E. are limited, additional time should be allowed if possible. On complicated Federal projects, this time should be increased to 60 days if at all possible.

MEMBRANE CURING OF CONCRETE STRUCTURES

Membrane curing of concrete in structures as a general practice is not recommended by the Bridge Division and no provision is made either in Item 531, "Membrane Curing", or Item 402, "Concrete Structures", for this method of curing on structures. Occasionally membrane curing on structural concrete may be desirable in which cases Item 531, Section 531.1 should be revised to include structures or portions of structures to be so cured or a special provision to Item 402, Section 402.21, included in the list of governing specifications.

ESTIMATE FOR RAILROAD FORCE ACCOUNT WORK

The estimate for railroad grade separation structures should include the cost of force account work to be done by the railroad company.

COMMON ERRORS IN P. S. & E. SUBMISSIONS AND SUGGESTED SHORT CUTS IN PLAN PREPARATION (ROADWAY FEATURES)

GENERAL

Several types of plans are in use by the Texas Highway Department, namely full scale plans, half scale or minor project plans, and special plans. Before selecting the type of plans to be used, careful study should be made of the type and character of work to be performed, and the detail which will be necessary to present the work in a clear and concise manner. There have been instances where designers have gone to such extremes in showing details and notes that the results have been confusing, causing conflicting provisions in some cases when later corrections are necessary. On the other hand, "Streamlining" has been carried to the other extreme, resulting in inadequate information for contract purposes. Simplicity, good arrangement, and neatness are prime factors in plan preparation and will do much to "sell" the plans.

(1) FULL SCALE PLANS:

The greater part of the projects assigned to the Road Design and Bridge Divisions for review, approval and processing are major construction projects on the more heavily travelled highways of the State. Use of full scale plans is essential on such projects as it is not practical to show the required details on the half scale plans without sacrificing clarity.

(2) MINOR PROJECT OR HALF SCALE PLANS:

Use of half scale plans should be limited to the less complicated projects such as seal coat or surface treatment projects, maintenance and minor rehabilitation projects, and grading and structure projects where the work to be performed is similar to that involved on the usual Farm to Market Road project. In some instances, a combination of half scale and full size plans has been used. This complicates sheet numbering, and the processing and filing of plans. For these reasons, it is urgent that all plan sheets be the same size.

(3) SPECIAL PLANS:

On seal coat and resurfacing contracts, it is often found desirable to combine a number of projects throughout the district in one contract. Projects of this type have involved lengths of more than four hundred miles and a large number of projects. Preparation of separate plans for each project would require considerable work and time. In order to speed preparation of plans and at the same time present the work to be done in a more clear and compact form, some districts have resorted to a simplified procedure which we believe is commendable. A map of the entire district has been reproduced on the regular full size Title Sheet and the sections of highways on which work is to be done have been shown by heavy lines with arrows indicating the beginning and ending of each control, section, and job number. Sheet indexes, signature blanks, shipping points, and other information usually included on the title sheet should be shown. On a second full size sheet, tables are inserted showing station and descriptive limits, equations, length in feet and miles, and crown and surface widths for each project. The Estimate Summary should of course show separate quantities for each project and total contract quantities. This sheet should also include the usual tables regarding rates of distribution, basis of estimate, and other information generally shown on the Estimate Quantity sheet for projects of this type.

Where the work to be performed is to be handled under the supervision of more than one resident engineer, additional copies of the plans and specifications can be furnished by the Austin office. The Austin office will also make reproductions of district maps on title sheets for the districts who desire to use this method.

(4) PLANS FOR DAY LABOR PROJECTS:

Day labor projects assigned to the Bridge and Road Design Divisions are generally limited to "Construction Projects;" that is, the work to be performed involves design features of the normal construction project such as base depth, drainage, etc., and review of P. S. & E. by these divisions is similar to that for contract projects. Plans are required for work of this character before work order can be issued as it is not considered practical to review and pass upon the design by the sketches and estimates which are permitted on D-14 and D-3 projects. (Administrative Order 34-52 dated September 29, 1952, applies only to Maintenance and Land Service Road Projects.) The plans of course can be "streamlined" and much simpler in detail than plans for like contract work. Minor project plans may be used if sufficient information for an understanding of the essential design features is shown.

Before a work order clearance can be issued, it is necessary that statements be furnished by the districts that all required right-of-way has been secured, that it will not be necessary to purchase or lease additional equipment (if purchase or lease of equipment is necessary, full particulars should be furnished), and that all conditions of authorizing Minutes have been complied with.

Administrative Order 7-52 dated March 28, 1952, outlines the procedure required on day labor projects for hiring and leasing equipment, and for receiving bids by the Districts on work involving less than $25,000 cost.

TITLE SHEET

One of the main purposes of the title sheet is to establish the location of the work in such manner that it can be easily located by anyone not familiar with the locality. The description in the heading should be such as to permit ready identification on road maps. If practical, the scale selected should be such as to include the nearest town or other well known landmarks, but should not be so small as to conceal the location or prohibit the showing of other essential information on the layout. A small scale layout with north point in the upper right hand corner of this sheet can be used if considered desirable for proper identification of project location.

CHECK LIST

(1) Calculate and show project lengths in accordance with instructions given in the discussion on "Controls and Sections."

(2) Omit job numbers unless assigned by the Austin office by special request during preparation of plans. When there is doubt as to the limits of Federal projects and/or state control and section numbers (particularily on complicated intersection projects), a sketch showing the limits of the work should be submitted to the Austin office with request for advice as to correct project and control-section limits.

(3) Plot alignment from left to right in the same order as station numbers shown on plan-profile sheets and show north point clearly.

(4) Include enough information in the description of work to identify the type of work to be done. Example: Grading, Structures, Flexible Base, and One Course Surface Treatment. (Identify type of surfacing)

(5) On layout, show station numbers at points where alignment crosses city limit lines. Show city names, whether or not incorporated, and 1950 U. S. Census.

(6) Secure approval signature of authorized city official if any part of the work is within the limits of cities. This simplifies handling of the Municipal Construction Agreement.

(7) Accurately plot all railroads, other highways, and important county roads within the limits of the layout.

(8) Plot correct position of all streams involving structures of bridge classification (over 20' clear span).

(9) In signature spaces, change "Assistant State Highway Engineer" to "Chief Engineer of Planning."

(10) Under Bureau signature spaces show the heading "Department of Commerce, Bureau of Public Roads" with signature spaces for "District Engineer" and "Division Engineer."

(11) On Federal projects, tie in stationing with previous Federal project. This is a Bureau requirement.

(12) Indication of plan-profile sheets on title sheet layout desirable but not required.

(13) Desirable to indicate local material sources, borrow sources, and haul roads on title sheet if this information is not clearly shown on pit layout sheets or plan-profile sheets.

(14) Show detours, barricades, and signs, and indicate maintenance responsibility for detours unless a "Detour Layout" sheet is included in the plans.

(15) Federal route numbers need not be shown on this sheet.

(16) If the plan-profile horizontal and vertical scales used are different from those shown in the title sheet heading, make proper corrections.

(17) Miscellaneous Features; Show exceptions both on layout and in

table; Railroad Delivery Points; Highway Classification and Design Speed in upper right hand corner; include all applicable standard plan sheets and special design sheets in "Index of Sheets."

(18) Standard Specification Notes now in use:

"Specifications adopted by the State Highway Department of Texas January 2, 1951, and approved by the U. S. Bureau of Public Roads July 25, 1951, and specification items listed and dated as follows shall govern on this project:

(Federal Projects) Required Contract Provisions for Federal Aid Projects Approved August 5, 1948.

(State Projects) Special Labor Provisions for Texas Highway Projects Adopted by the State Highway Department of Texas August 11, 1948."

DETOUR LAYOUT

The handling of traffic during construction presents difficulties in varying degrees on practically every project. The problem may be minor in some cases, involving only occasional crossings of existing roads, and in such instances indication of the desired barricades and signs on the title sheet and use of simple special provisions for "Detours, Barricades, Sequence of Work, Etc." should be sufficient. Where it is necessary to carry traffic through heavy construction work, a real problem is present. The importance of this feature is sometimes not given enough consideration in the preparation of plans, resulting in severe criticism of the Department by the public.

A "Detour Layout" sheet has been found useful where difficult traffic problems are involved. On this sheet, roadway sections may be shown indicating the sequence of widening or reconstruction operations, thus avoiding complicating the regular typical sections. Also typical sections and alignment of temporary detours to be constructed by the contractor can be shown with an indication as to the roadway width and drainage structure requirements. A summary of quantities should also be shown.

Where a substantial amount of detour construction is to be performed, it is recommended that direct payment for such work be made under regular specification items in order that contractor's may have a definite bidding basis. Some districts prefer to receive a lump sum bid for "Detours", and there is no objection to this procedure if the amount of work to be required is clearly indicated.

Where widening of existing pavements is undertaken, provisions should be made in the Special Provision "Detours, Warning Signs, Sequence of Work, etc." for limiting construction operations to one side at a time; for use of flares and flags along the pavement edges during excavation, backfilling, and curing operations; and for the limiting of excavation to a reasonable distance ahead of base course or pavement operations.

Attention is directed to the standard flagging provisions outlined in Construction and Maintenance Order 4-51 dated September 4, 1951 and to the sprinkling requirements for detour facilities outlined in Administrative Order 24-52 dated August 5, 1952. These requirements should be included in the Detour special provision.

TYPICAL SECTIONS

On some projects, a large number of typical sections are included in plans, some of them involving only minor slope variations. Also, the typical sections have been complicated by attempts to show the sequence to be followed in widening and reconstruction operations under traffic. As a general rule, it is suggested that the typical sections be general in scope with enough latitude in slopes to cover various topographical conditions. Any desired sequence of construction should be shown on a separate sheet.

Half sections may be shown if desired to indicate special conditions. It is not necessary to show a typical section for curves unless variations from the sections shown on Standard SWC-39 are involved.

The following typical sections should be adequate for the normal construction project:

(1) Existing Section.

(2) Regular Section.

(3) Cut Section.

(4) Side-Hill Section.

(5) Fill Section.

(6) Street sections where involved.

Check List of data to be shown on typical sections:

(1) Depths of sub-base, base or concrete pavement. Approximate depths should be shown for bases and sub-bases.

(2) Shoulder, surface, and crown widths and slopes.

(3) Number of courses for flexible bases, foundation courses, etc.

(4) The location of guard fence or guard fence posts with reference to center line.

(5) Standard notes in regard to superelevation, widening, and spiraling of curves. The table to be used for superelevation should be indicated.

(6) Type of surfacing. If asphaltic concrete pavement is to be used, the number of pounds per course, and aggregate type should be indicated.

(7) Dykes or ditches and dykes on side hill sections.

(8) Typical Sections should be numbered, and the approximate stations for each section should be shown. The sum of stations for the various sections should equal the project roadway length in stations.

(9) Salvage or disposition of old base should be indicated.

(10) Type and limits of transverse sodding.

(11) On grading plans, indicate by pencil sketch the contemplated dimensions of future surfacing and shoulders. This will not be considered as a commitment but as information indicating that final pavement and shoulder widths complying with the Standards of Design for the highway classification involved will be met.

(12) Approximate quantity of Flexible Base, Foundation Course, or Roadbed Treatment per station.

(13) Show relation of Plan-Profile grade to finished grade.

ESTIMATE AND QUANTITY SHEET

The Estimate Summary should show separate quantities for each job number involved and total quantities. In addition, on Federal projects it is necessary to show separate quantities for rural and municipal portions where the population is over 1,000. This separation is not required for state projects. Earthwork and surfacing quantities on fill type structures of bridge length should not be included in the summary of large structures. Miscellaneous items may be omitted from the summary of grading.

Where cities or counties are to pay part of the cost, the city or county items and quantities should be clearly shown. If there is any doubt as to the eligibility of construction of curb and gutter and storm sewers at state expense under the State's policy in this regard, full particulars and recommendations should be forwarded to the Austin office for a decision before any commitments are made and before completion of plans. This policy governs regardless of whether the work is financed under a Federal program or under a state program. For this policy refer to Minute 20,264 of October 6, 1943 with amendments under Minute 28,703 of June 29, 1950, Administrative Orders 55-46 dated October 6, 1943, 45-50 dated July 12, 1950 and 49-50 July 20, 1950.

Minor modifications of specifications should be grouped on this sheet under the heading "General Notes." Where the modifications are of importance, they should be covered by special provisions.

It is the general practice to show asphalt quantities to the nearest 100 gallons. Decimal point quantities should be limited to items having a high unit cost such as concrete for structures.

Alternate bids for asphaltic concrete pavements should be provided for when considered advisable for competition and when design requirements permit.

<u>Check List:</u>

(1) Basis of Estimate for rolling, sprinkling, blading, asphalt, aggregate, fertilizer, scraper work, etc. Allowances should be made for rolling asphalt surface treatment in order to conform with the provisions of the standard specifications.

(2) Limits of floating slabs and curb and gutter at bridge ends should be shown.

(3) Where the "Controlled Density Method" for embankment construction is to be used, a note so stating should be included in the General Notes on this sheet.

(4) Day labor work should be indicated separately from contract work.

(5) Nomenclature of pay items in the Estimate Summary should conform exactly with that shown in the specifications.

(6) Summaries for large structures, small structures, grading, re-

moving old concrete of various types, removing old structures, removing and replacing guard fence or guard fence posts, sodding, new guard fence or guard fence posts, etc.

(7) Where direct payment is to be made for blading embankment, this should be clearly indicated on the Estimate & Quantity Sheet.

(8) Check transfer of Quantities to Estimate Summary.

PLAN-PROFILE SHEETS

The entire length of the project should be studied to determine proper division of project length into the 26 stations of each sheet. By this study, it should be possible to avoid dividing any of the major features such as large bridges, highway intersections, or railroad grade separations into two sheets.

A profile of the natural ground or of existing road for at least ten stations beyond each end of the project should be shown as this information is needed for an understanding of sight and passing distances and for other purposes. Physical features which have an effect on the work should be shown.

Property lines should be shown, but it is not necessary to show property owner names.

Mass diagrams may be shown on plan-profile sheets in pencil, or can be shown in pencil on separate sheets if space on the plan-profile sheets is limited.

On some projects, sprinkling, rolling, blading, sodding, and quantities for other miscellaneous items have been shown on each plan-profile sheet. It is recommended that quantities for such items not be shown on these sheets because of the increased plan work and difficulty in making corrections after inking.

Question has been raised as to the necessity for the cross-section data for which space is provided in the upper right hand corner of the standard plan-profile sheet. This procedure was resorted to a number of years ago in order to reduce the bulk of grading plans by omission of detailed cross-sections. It is desired to continue showing this information except for curb and gutter street sections and on projects such as expressways were the cross-sections are too complicated to depict in this manner. With the broad limitations allowed by the typical sections, this data is necessary for understanding and agreement as to the cross-sections that will be constructed for particular slope, cut and fill conditions and is believed useful both for review and construction purposes. With this information, submission of detailed cross-sections to the Austin office will not be necessary unless specifically requested for a particular project.

Check List:

(1) Right-of-way widths at beginning and end of each plan-profile sheet and at all points where width changes.

(2) Gradients should be shown to three decimal places, grade elevations to two decimal places, and natural ground to one decimal place.

(3) North point and bearings for each tangent on each sheet.

(4) Usual notes in regard to removal of right-of-way encroachments, adjustment of utilities, and bench marks on the first plan-profile sheet.

(5) Indicate quantity of select material reserved and where used for each station.

(6) Typical sections for channels and channel excavation calculations.

HAUL DIAGRAM

The practices of the districts vary considerably in plan details for haul on base material. In addition to the usual haul diagram with calculations for haul into each quarter mile, some districts show pit layouts, boring data, soil constants for representative samples, a small scale sketch showing the location of the pit with reference to the project, and the location of haul roads. Others have shown only the regular haul diagram, and submitted test reports on representative samples. In exceptional instances, the plans have shown only the total haul quantity with no information as to the dead haul or haul roads, or location of pits except that shown in the option agreements.

It is of course necessary to secure as complete information as practical on the quality and quantity of base materials from local sources, as underestimating either may prove very costly. The complete information furnished by some districts is commendable and should be continued if desired; however, as a means of reducing plan work, pit layouts, test boring data, and test results may be omitted from the plans if desired. When this is done, it is assumed by the Austin office that the quality and quantity of available material has been definitely established.

Sufficient information should be shown on the plans to determine pit locations, dead haul, and the accuracy of haul calculations. In lieu of the regular haul diagrams, tables showing pit names, dead haul, points of entry, station limits, average quarters, and haul quantity for each source will be acceptable. Copies of test reports on representative samples should accompany P. S. & E. Submissions.

ROADWAY DETAIL SHEETS

Sheets under this heading should include layouts for intersections and transitions for changes in pavement and crown widths, and other roadway features for which special details are necessary such as retards, sidewalks, curb and gutter, etc. Sufficient details should be shown for construction and a summary of quantities should be given.

Where special layouts for concrete pavement of uniform or irregular widths are involved, cross-sections and joint arrangement should be shown.

Provisions for private entrances should conform with the policy outlined in Minute 20,846 dated October 23, 1944.

STANDARDS FOR ROADWAY ITEMS

(1) Concrete Pavement Details and Joint Details. (CPD-52-1, CPJ-52-1, and Special Contraction Design)

These standards are modified at frequent intervals. For this reason, it is recommended that when pavement of this type is to be included in plans the Austin office be requested to send reproduced tracings of the latest standards. When expansion joints are to be used, the spacing desired should be indicated in the space provided on Standard CPD-52-1.

(2) SWC-39. Superelevation and Widening of Curves.

The table to be used for superelevation should be indicated on the Typical Cross Section sheets. If modification of superelevation is desired, the changes should be shown by notes or in table form on the Typical Cross Sections.

(3) Bridge Approach Slabs and Curbs.

Where the adjoining pavement is flexible type, BASA-40 or BASA-60 should be used. Where the adjoining pavement is concrete pavement, BASC-40 or BASC-60 should be used.

When the adjoining pavement is of flexible type and it is not desired to use floating slabs, BCF-41 should be used for curb and gutter only.

If the bridges are of crown width, curb and gutter should be omitted.

When floating slabs are to be provided at bridges of crown width and the adjoining pavement is of flexible type, a special design should be used.

(4) BW 52 (1) and (2)

The barricades and signs to be used should be indicated on the Title Sheet or Detour Layout of the plans.

(5) M-47. Right-of-way and Project Markers.

This sheet should be listed in the Index of Sheets on all Federal Projects where Federal markers of approved design at the required locations have not been previously placed and on all projects involving an item of Right-of-Way Markers. It is necessary that the type of right-of-way markers desired, (Type I or Type II) be shown in the bid items of the Estimate Summary.

(6) GF-52. Steel Plate Guard Fence.

The bid item should read "Steel Plate Guard Fence" (Type 5 or 6)

(7) MXS-52. Metal Series Railroad Crossing Signs.

Administrative Circular 4-46 dated January 18, 1946 outlines the policy in regard to this item. This type of protective device is required at all railroad grade crossings on state highways except where conditions justify flasher type signals or other automatic types.

This item is frequently omitted from plans through oversight. It will be of assistance to the Austin office in review of P. S. & E. if the type of existing crossing protection device is indicated on plans.

COMMISSION

E. H. THORNTON, JR., CHAIRMAN
FRED A. WEMPLE
ROBT. J. POTTS

STATE HIGHWAY ENGINEER
D. C. GREER

TEXAS HIGHWAY DEPARTMENT

Austin 14, Texas
November 19, 1952

IN REPLY REFER TO
FILE NO. DCG

ADMINISTRATIVE CIRCULAR NO. 42-52

SUBJECT: ASPHALTIC CONCRETE PAVEMENT

TO: ALL DISTRICT ENGINEERS AND ENGINEER MANAGERS

Gentlemen:

In the past few months our procedure and practices for the taking of bids on pre-mixed asphaltic concrete pavements have been under study by a special Committee appointed to make the investigation. This Committee has made a diligent study of the matter and the following policy has been approved to take effect with the opening of bids on any project appearing in the January, 1953 letting.

1. The "optional method" of taking bids for asphaltic concrete pavement will be discontinued.

2. The present practice of allowing a "weight differential" will be discontinued.

3. The specifications on asphaltic concrete pavements permitting the use of water or volatiles will be revised for measurement and payment to exclude the weight of water and volatiles in quantities on which payment will be made.

4. One or more alternate types will be used unless design requirements and job conditions dictate the use of one type only.

A Special Provision to our standard specification item will be required by Number 3 above and will be prepared in the Austin office. Under Number 4, the use of only one type of pre-mixed asphaltic pavement is a matter for decision between the District Engineer and D-8 or D-14. The type to be used as the base bid will be at the discretion of the District Engineer.

Your usual support and adherence to the above policy is requested.

Sincerely,

D C Greer

D. C. Greer
State Highway Engineer

COMMISSION

E. H. THORNTON, JR., CHAIRMAN
FRED A. WEMPLE
ROBT. J. POTTS

TEXAS HIGHWAY DEPARTMENT

Austin 14, Texas
August 5, 1952

STATE HIGHWAY ENGINEER
D. C. GREER

IN REPLY REFER TO
FILE NO. DCG

ADMINISTRATIVE ORDER NO. 24-52

SUBJECT: Maintenance of Detours

TO: All District Engineers

During construction of asphaltic surfaces traffic is usually routed through the project along shoulders or in ditches. This frequently creates a cloud of dust which is both a nuisance and hazard to the traveling public as well as to the construction forces. In order to eliminate this condition you are hereby directed to conform to the following instructions.

1. PROJECTS ON WHICH NO PROVISION HAS BEEN MADE FOR MAINTENANCE OF DUSTLESS DETOURS. In all cases where dust is created by traffic through construction projects to the extent that it will result in a hazardous or undesirable condition, sprinkling or other methods will be utilized to eliminate this situation. This work may be performed by the contractor by supplemental agreement or on force account basis. If a satisfactory agreement cannot be reached with the contractor under either of these methods, the work may be performed with state maintenance forces and charged to regular maintenance.

2. FUTURE PROJECTS. All future P. S. & E. should contain provisions for controlling dust on detours where traffic is routed off the pavement but within the right of way. This will normally be made the responsibility of the contractor as an appropriate bid item, usually "Sprinkling" for jobs let to contract.

This practice should apply on pradtically all construction projects involving resurfacing with asphaltic concrete where the traffic is routed through the project. On seal coat and similar projects the construction progresses at such rapid rate that it may not be practical or necessary to sprinkle the detours, however, this will be left to the judgment of the District Engineer.

You are instructed to begin operating under the above policy immediately.

Sincerely yours,

D. C. Greer
State Highway Engineer

COMMISSION

E. H. THORNTON, JR., CHAIRMAN
FRED A. WEMPLE
ROBT. J. POTTS

TEXAS HIGHWAY DEPARTMENT

Austin 14, Texas
March 28, 1952

STATE HIGHWAY ENGINEER
D. C. GREER

IN REPLY REFER TO
FILE NO. D-18

ADMINISTRATIVE ORDER NO. 7-52

SUBJECT: Day Labor Construction and Small Contract Projects

TO ALL DISTRICT ENGINEERS

Gentlemen:

It has come to our attention that there is a need for clarification of procedure to be used in hiring, leasing, receiving bids and awarding minor contracts, as pertains to our day labor work and to small contract projects. Various methods are being used throughout the State and in general are satisfactory, but, in order that a uniform policy may be followed, definite governing methods are provided herein.

The work to be performed, under the procedure outlined below, is to be generally limited to those items which our own forces are not adequately equipped or trained to handle and which are not suitable or large enough for standard contract methods and to emergency conditions. Careful consideration should be given to all requests for force account road and bridge projects in order that only work which can be performed with your own forces will be selected.

The procedure to be used in hiring, leasing, receiving bids and awarding minor contracts, for emergency handling, and for work not common to our ordinary operations, is as outlined below:

I. HIRING, LEASING, AND FORCE ACCOUNT

a. Hiring of equipment such as mowers, trucks, etc., on an hourly, yard-quarter or mileage basis, should continue to be handled as in the past which generally consists of executing Form 339 at local prevailing rates and making payment through your S & L Payroll.

b. When performing emergency work on a force account basis, where labor and equipment use are normally hired by Extra Work Order and materials are purchased on Emergency Purchase Order or Emergency Requisition, bids should be secured if time permits.

c. Leasing of equipment on a time (hourly, monthly, etc.) basis should continue to be handled according to instructions from the Equipment and Procurement Division.

d. Leasing or hiring of equipment, or equipment and labor, on a work unit pay basis, except as provided in Paragraph "a" above, should be discontinued and handled only as set out in III and IV below.

 4-52-895

II. WORK NOT COMMON TO OUR OPERATIONS

a. Work involving furnishing and installing plumbing in section warehouses, furnishing and installing electrical wiring, traffic light installation, or other work of a nature not common to our operations, not to exceed $1,000.00, should continue to be handled on an Emergency Purchase Order as in the past. Bid tabulations, on local bids in excess of $1,000.00, should be sent to the Division charged with the responsibility of the construction project involved, for Contract Award by the Commission, as outlined under Paragraph IV below.

III. LABOR AND EQUIPMENT ON WORK UNIT BASIS

a. Work involving only equipment and labor; such as, heat, haul, and apply asphalt; load, haul, and spread aggregate; process, load, and haul flexible base; or similar items of work should be resorted to only in the event of emergency conditions which would prevent the work being handled by State forces and equipment or through regular or minor contract procedure. When an emergency condition exists, which would make it advisable to have work performed in this manner, the following steps should be taken:

1. Bids
Bid data should be sent to all known potential bidders with a copy to the appropriate Division in the Austin Office. Labor provisions should be included in the bid proposals.

2. Submission for Approval

Send a tabulation of bids, <u>explanation of the emergency</u>, statement of the time and date the bids were publicly opened and read, and recommendation of approval or rejection to the appropriate Division in the Austin Office. A statement that established labor provisions of the project on which the work is proposed will apply, or Stencil 12-51-2337, "Statement of Investigation...", must be included.

3. Work Order

When approval has been secured, execute Emergency Purchase Order showing bid tabulation and authorize the low bidder to proceed with the work. Payment is to be made on Form 132, Monthly Statement, on M & S Payroll. Show, on Emergency Purchase Order, date authorized and file number of authorizing Division.

IV. BIDS RECEIVED IN THE DISTRICT FOR CONTRACTS LESS THAN $25,000.00

a. Work involving equipment and labor only, or equipment, labor, and material, under $25,000.00, may be handled by receiving bids in the District Office, as outlined in this Section, when such procedure will afford an advantage to the State by expediting

IV. a. (Continued)

the project or using services of small local contractors which will result in a savings.

1. Authority to Receive Bids

   Submit P.S.&E. to the appropriate Division with request for authority to take local bids.

2. P.S.&E.

   Prepare a proposal (Form 419-A) containing the standard proposal sheet (Form 234B), specification index, General Provisions, Special Specifications, Plans (if required), and Labor Provisions. If change in existing Labor Provisions is needed, clearance must be secured before taking bids. Requirements of Financial Statement and Experience Questionnaire on Form 419-A and Specification General Requirements Item 2.11 should be deleted.

3. Bids

   Proposals should be made available to known local bidders, and copies sent to Texas Contractor and Associated General Contractors, and to fulfill legal requirements you must advertise in two successive issues of any newspaper in the county in which the work is to be done, and if that county has no newspaper, the advertisement should be placed in a newspaper of a county nearest its County Seat.

4. Bidder's Check

   At the option of the District Engineer, bidders' checks may be required. If required, it is suggested that after bids are opened, all checks be returned except that of the low bidder unless there is some question of award and the check of the low bidder should be held by the District until advised that the contract instruments and performance bond have been properly signed. This information is generally included in the letter authorizing work order.

5. Submission for Approval

   Send tabulation of bids with statement of the time and date the bids were publicly opened and read, and recommendation of award or rejection to the appropriate Division in the Austin Office. Include statement on labor provisions by executing Stencil 12-51-2337, "Statement of Investigations...". Also include four copies of the complete proposal for use in executing the contract. Submission should reach the Austin Office at least ten days before the Commission meeting in which the contract award will be made.

IV. a. (Continued)

6. Work Order

After the Commission awards the contract, the Austin office will handle preparation and signing of the contract and receipt of contractor's performance bond. When that is completed, the District will be authorized to issue the Work Order.

A copy of the bidding law is attached for your information and guidance.

Labor Provisions are required for work performed under all local contracts. Generally the required investigation will result in adoption of the established approved rates and the execution of Form 12-51-2337, "Statement of Investigation...," submitted with tabulation of bids, etc., will fulfill the requirements. If a change in rates is necessary, the change must receive Commission approval prior to advertisement for bids.

The above outlined procedure will be effective April 15, 1952.

Sincerely yours

DCGreer

D. C. Greer
State Highway Engineer

 4-52-895

Art. 6674h. Competitive Bids

All contracts proposed to be made by the State Highway Department for the improvement of any highway constituting a part of the State Highway System or for materials to be used in the construction or maintenance thereof shall be submitted to competitive bids. Notice of the time when and place where such contracts will be let and bids opened shall be published in some newspaper published in the county where the improvement is to be done once a week for at least two weeks prior to the time set for the letting said contract and in two other newspapers that the Department may designate. Provided, however, that on contracts involving less than Twenty-Five Thousand ($25,000.00) Dollars such advertising may be limited to two successive issues of any newspaper published in the county in which the work is to be done, and if there is no newspaper in the county in which the work is to be done then said advertising shall be for publication in some newspaper in some county nearest the county seat of the county in which the work is to be done. Provided, further, that any person, firm or corporation may make application to have the name of said applicant placed upon a mailing list to receive notices of lettings of any contracts provided for herein; and notices of said lettings shall be mailed by the Highway Commission of the State Of Texas to all persons, firms or corporations on said mailing list. The Highway Commission shall have the right to require all applicants to deposit with the commission a sum of not exceeding Fifteen ($15.00) Dollars per year to cover costs of mailing notices. (As Amended Acts 1933, 43rd Leg., 1st C.S., p. 286, ch. 103 §1.)

Art. 6674i. Opening and Rejecting Bids

The State Highway Department shall have the right to reject any and all such bids. All such bids shall be sealed, and filed with the State Highway Engineer at Austin, Texas, and shall be opened at a public hearing of the State Highway Commission. All bidders may attend and all bids to be opened in their presence. Copies of all such bids shall be filed with the county in which the work is to be performed. Provided however, on contracts involving less than Twenty-Five Thousand ($25,000.00) Dollars bids may be in the discretion of the Highway Commission be received at a public hearing by the Division Engineer at the Division Headquarters. All bids so received by the Division Engineer shall be tabulated and forwarded to the State Highway Commission, shall have the right to accept or reject same, and if accepted, award the contract to the lowest bidder. It shall be the duty of the Highway Commission to prescribe rules and regulations on all bidders on bids received by Division Engineers, but the rules and regulations required by the State Highway Commission for bids received at Austin by said Commission shall not apply to bidders submitting bids to Division Engineers. (As Amended Acts 1933, 43rd Leg., 1st C.S., p. 286, ch. 103, § 2.)

COMMISSION

E. H. THORNTON, JR., CHAIRMAN
FRED A. WEMPLE
ROBT. J. POTTS

STATE HIGHWAY ENGINEER
D. C. GREER

TEXAS HIGHWAY DEPARTMENT
Austin 14, Texas
September 4, 1951

IN REPLY REFER TO
FILE NO. D-18

CONSTRUCTION AND MAINTENANCE CIRCULAR NO. 4-51

SUBJECT: Instruction Pamphlet For Flagmen

TO ALL DISTRICT ENGINEERS

Gentlemen:

It is our belief that of all our traffic control practices the most non-uniform and confusing are the signals used by flagmen in attempting to control and route traffic through and around highway construction and maintenance operations.

This is a condition that should be corrected and we are of the opinion that it can be greatly improved by the development of uniform flagging procedure. To assist in this, the Traffic Services Division has prepared a small pamphlet entitled, "Instruction To Flagmen." The methods outlined in this pamphlet are not new to the maintenance personnel as they have been a requirement in the Maintenance Manual for a number of years.

One copy of the pamphlet is attached for your information. Under separate cover we are forwarding an additional supply to each District and wish to request the following distribution:

That they be placed in the hands of individual employees of the Highway Department with instruction that the methods outlined be followed.

That they be placed in the hands of the contractors with suggestion that the methods outlined be used by flagmen on their highway construction work.

We believe that standarization of flagging signals, location of flagmen, etc., will result in reduction of accidents, less work stoppage, lower construction and maintenance cost, and provide a more orderly control of traffic. It is therefore expected that you will give your usual excellent cooperation by distributing the pamphlets, promoting the uniform flagging methods and placing them in operation in your District.

Sincerely yours,

D. C. Greer
State Highway Engineer

COMMISSION

E. H. THORNTON, JR., CHAIRMAN
FRED A. WEMPLE
ROBT. J. POTTS

TEXAS HIGHWAY DEPARTMENT

STATE HIGHWAY ENGINEER
D. C. GREER

Austin 26, Texas
January 18, 1946

IN REPLY REFER TO
FILE NO. DCG

ADMINISTRATIVE CIRCULAR NO. 4-46

SUBJECT: Grade Crossing Protection Farm to Market Roads

TO ALL CHIEF ENGINEERS OF RAILWAYS

Gentlemen:

Circular Letter 97-45 dated December 4, 1945 established the policy of the Highway Department with respect to highway construction at highway-railway crossings to be financed with funds under the Highway Act of 1944.

Funds are also provided under the Highway Act of 1944 for construction of Secondary Highways variously called "Farm to Market Roads," "County Laterals" and "Land Service Roads." The preponderance of the roads to be constructed under this section of the Act are appreciably beneath the standard of highways and will be designed accordingly.

Whereas on highways our policy is to provide as a minimum type of protection, reflectorized cross-buck signs and reflectorized advance warning signs and to pay for the installations, on these secondary roads where traffic is local and light and where light or slow traffic railroads are crossed the minimum protection will be cross-buck signs paid for and installed by the Railroads of the type your line customarily installs at County Road crossings. The State will provide advance warning signs. In those instances where higher type protection is desired by the State, it will be paid for and installed by the State as in the case of Highway crossings.

Sincerely yours,

D. C. Greer
State Highway Engineer

Minute No. 20846
Oct. 23, 1944

Policy on Construction of Side Road Approaches to Private Property

WHEREAS, in the past there has been no definite Commission policy relative to the construction and maintenance of side road approaches to private property and to public throughfares; and

WHEREAS, it is apparent that such a policy is desirable due to the varied practices now in operation in the Districts;

NOW, THEREFORE, BE IT ORDERED that the following general Commission Policy relative to the construction and maintenance of side road approaches to private property and to public thoroughfares be established for guidance until such time as necessary modifications and additions may become apparent.

1. The maintenance of all existing side road approaches to private property shall be the responsibility of the property owner.

2. Upon request from a property owner to the District Engineer the Department will construct an approach to private property, provided the owner will furnish all necessary materials for the construction of a bridge, culvert, or dip of adequate size, or opening, to assure proper drainage.

3. Any existing side road structures used as approaches to private property which are destroyed or removed during the construction or reconstruction of a section of highway will be replaced or reconstructed by the Department to a design equal to or better than the original structures. The maintenance of these side road approaches shall be the responsibility of the property owners.

4. Should existing side road approaches to private property be in need of repair, the Department will render no assistance unless the entire installation is to be removed in which case the Department will make the installations after the materials have been furnished by the property owners.

5. The maintenance, construction and/or reconstruction of all side road approaches from all public thoroughfares intersecting or joining highways under State maintenance shall be the responsibility of the Department. This shall include all approaches from county or city maintained roads and streets, approaches to schools, churches, cemeteries and other places or buildings of like character, such as fair grounds, public golf courses, etc.

DEVELOPMENT OF FREEWAY PROJECTS THROUGH AUSTIN OFFICE DIVISIONS

Freeway projects developed through Austin office divisions are characterized by the need for more coordination by the various agencies and by the concurrences required from each. All or some of the following agencies may be concerned in the development of a freeway: The District, The City Council, The City Engineer, The City Plan Engineer, The City Traffic Engineer, The Commissioners Court, The County Engineer, The Road Design Division, The Bridge Division, The Highway Planning Survey, The Bureau of Public Roads and sometimes Navigation Districts, Drainage Districts, The Corps of Engineers and railroads.

Coordination can be achieved if the desire to cooperate exists. Some of the methods used to achieve coordination are conferences, visits and concurrences. Of these, concurrences is the chief method of showing and obtaining coordination.

Freeway projects also differ from ordinary road projects in that more planning is required and the sequence of development is not the same. For instance, on the usual road project right of way deeds can be one of the first tasks. On freeway projects, traffic studies, layouts and agreements must be completed before preparation of right of way deeds can be started.

FINANCED PROJECTS ON DESIGNATED FREEWAYS

Financed freeway projects have been authorized by Commission action. These authorized projects are easier to develop than projects that are not financed because a definite objective has been provided by the Highway Commission. When a freeway project has been financed, the local officials should be notified and arrangements made to coordinate the work.

DESIGNATED FREEWAYS, NO WORK AUTHORIZED

When a freeway is designated and no work is authorized, the Engineer must deduce an objective within his capabilities. This presents a more difficult problem than a financed project and requires a thorough analysis. Some guidance is provided by Road Design Information Circular 4-52.

For your convenience we have included as an addendum the Road Design Information Circular that explains this type of project and brings out the purpose of the Commission Minute, which is to permit long range planning for the acquisition of right of way and construction. This circular also suggests that the services of the Department should be offered and local officials notified that it will be necessary for municipalities to make a freeway declaration.

PROJECTS BEING DEVELOPED TO FIT AN ULTIMATE FREEWAY

Occasionally projects on the route of a future freeway are authorized before the freeway is designated. Here again the Engineer must deduce an objective. A decision to pattern the development to fit an ultimate freeway should be concurred in by the Austin office. Sound planning dictates that this type project be developed to fit the future freeway. The project should be designed for the traffic volume expected in the reasonable future, but right of way should be secured for the ultimate development.

In developing these projects, frontage roads and interchanges may be omitted in the first stage, or the frontage roads may be developed first. The mechanics of development are the same as for freeway projects. Right of way should be secured on the controlled access pattern.

ROUTE

Routes are included in this discussion for sequence only. Routes have already been discussed.

LOCATION

Precautions should be taken to avoid disclosing the location of a freeway to other than responsible local officials before the location has been fixed by agreement between the political subdivision, the District office and the Austin office. Employees working on locations should know that serious embarrassment could result from a premature disclosure of the location.

Location work on freeways, at least in the first stage, will be characterized by the increased use of aerial photographs. Photographs must be up to date and should cover the entire limits to be studied. If there is doubt about limits economy will be served by securing the large coverage. Photographs that have proposed locations projected on them should be carefully protected to avoid the possibility of prematurely exposing the proposed location.

When making a location, arrange the intersections with existing roads to avoid complicated interchanges. If too many roads are brought together at one point, interchange becomes difficult if not impossible without signalization.

During the location stage, investigate existing railroad crossings in the vicinity of the proposed freeway-railroad crossing. If these crossings can be closed, benefits may possibly be assessed against the railroad. In general, overpasses will provide better traffic interchanges than underpasses since additional local traffic may also be routed beneath the overpass structure.

Traffic studies to determine the location of interchanges should be completed if possible before the location has been finally fixed. The location of traffic interchanges corresponds to the location of control points on ordinary highway location. A freeway might be thought of as a connection between interchanges.

PROJECT LAYOUT MAP

A project layout map should be prepared and submitted to the Austin office as early as possible. Ordinarily a profile is not required but may be included in whole or part if necessary to adequately portray the project. Typical sections, traffic diagrams for each interchange and the location of exit and entrance ramps deserve careful study at this stage and should be presented with the layout map. If stage construction is proposed, a colored print may be used to indicate the various stages. In some case it may be desirable to request approval only of right of way widths and the authority to release deeds to political sub-divisions.

NEGOTIATIONS WITH POLITICAL SUB-DIVISIONS

After the layout map has been approved by the Austin office, negotiations should be started with local officials to secure their concurrence in the location and project layout. The municipal agreement for municipal projects should be discussed with local officials, prepared in the District office and submitted to the Austin office for administrative authority to formally present the agreement to the city for signature. Exhibit "A" of the agreement is a layout of the project to be constructed. This layout should be made as flexible as possible to allow freedom in the design of the project. The layout should be diagrammatic and to scale, but few dimensions should be indicated. The general arrangement of the geometrics including the usual right of way widths should be shown by typical sections on the project layout map. Details such as pavement type or depth, fill slope and pavement width should be omitted to permit flexibility in the project development.

The practical necessity for a project layout map will become evident during negotiations with local officials.

BRIDGE AND INTERCHANGE LAYOUTS

After the project layout has been approved by all concerned, preliminary layout studies may be started for interchanges and structures. These layouts should preferably be prepared on a scale of 1" = 10'. This is the scale of the bridge layouts in the final plans and is satisfactory for interchange layouts. Preliminary layouts may be in pencil if blue prints can be made from the pencil drawings.

Preliminary layouts of interchanges and bridges are submitted to D-5 and D-8 for concurrence. Interchange layouts should have estimated traffic volumes indicated by traffic diagrams or other method. Typical sections to show the geometrics but not necessarily the pavement type and depth are also shown on interchange layouts. Contours of the paved surfaces are not required on detail plans but should be shown on preliminary layouts where warped surfaces are to be used.

In addition to the requirements of the Bridge Division, concurrence from The Road Design Division is required on bridge layouts to include but not limited to the following: design speed, curvature, grades, width of traffic lanes, number of traffic lanes, height and slope of fill, medians and right of way width.

PREPARATION AND SUBMISSION OF RIGHT OF WAY DEEDS TO POLITICAL SUB-DIVISIONS

Preferably right of way deeds should not be written until agreement has been reached with the local political sub-division. In the case of municipalities right of way deeds may be written after the municipal agreement has been executed by the State. It also may be desirable to delay preparation of deeds until the municipality has made a freeway declaration.

If the project is programmed right of way deeds may be submitted to local officials of municipalities after the municipal agreement has been executed by the State, and to County officials after County officials have approved the project layout map. If the project is not programmed, special authority to release deeds should be requested.

The following clauses have been approved for inclusion in right of way deeds:

> "This conveyance is made for the purpose of a freeway and adjacent outer frontage roads and the grantor hereby releases and relinquishes to the grantee any and all abutter's rights, including access rights, appurtenant to grantor's remaining property, in and to said freeway, provided, however that such remaining property shall abut and have access to said frontage road."

As applicable, the following clause may be used:

> "The construction of said frontage road may be delayed for an indefinite period of time. Until said frontage road is constructed, said remaining property shall have access to the nearest roadway of said freeway, provided, however, that all rights of access to said freeway shall cease and terminate when said frontage road is constructed and said remaining property shall then abut on and have access to said frontage road."

DIVISION OF COST BETWEEN THE DEPARTMENT AND LOCAL POLITICAL SUB-DIVISION

In the past some embarrassment has occurred when policies on division of cost have been interpreted by field forces. Interpretation of policy should be referred to the Austin office before commitments are made to local officials.

PAVEMENT DESIGN

The large traffic volumes carried by freeways make future repairs and betterments difficult. For this reason pavements should be designed for the heaviest wheel loads expected plus an adequate safety factor.

Recommended pavement depths with supporting test data should be submitted to the Road Design Division for concurrence.

A non-pumping subgrade is required for concrete pavements.

DIVISION OF PROJECT FOR CONTRACTING

The decision to divide the project into separate parts for contracting is made by the District Engineer and concurred in by the Austin Office Divisions. Before a decision is made the project should be analyzed from the standpoint of the contractor who will build the project and from the standpoint of the Highway Department which will prepare the plans and bear most of the burden of handling traffic during construction.

Let us first consider those matters the contractor will be interested in. They are size, complexity, time allowed for completion, type of work and the competition from other contractors. From experience the Engineer can balance the foregoing factors to provide the contractor a desirable project and still preserve competition.

After the analysis of the project has been made from the standpoint of the contractor and a tentative plan for division adopted, then this plan should be examined from the standpoint of the Highway Department. Some of the items to be considered are the capabilities of the engineering organization, traffic requirements and maintenance problems, the time schedule for completion of the project and finance when two year programs are involved.

The decision to divide a project into separate parts for contracting should be made as early as possible to permit proper plan development and to allow time for negotiations and consummation of agreements.

QUESTIONS

Q. What is the purpose of a Commission Order that states, "It is the intent of the Highway Commission to develop a certain route?"

Q. When should the location of a freeway be made public?

Q. When should traffic studies to determine the location of interchanges be initiated?

Q. Why is a project location map necessary on freeway projects?

Q. How is controlled access secured?

Q. When should the decision to divide a freeway project into separate parts be made?

Q. How can the necessary coordination of various interested agencies be effected?

Q. How do freeway projects differ from ordinary road projects?

COMMISSION

E. H. THORNTON, JR., CHAIRMAN
FRED A. WEMPLE
ROBT. J. POTTS

STATE HIGHWAY ENGINEER
D. C. GREER

TEXAS HIGHWAY DEPARTMENT
Austin 14, Texas
August 13, 1952

IN REPLY REFER TO
FILE NO. D-8

ROAD DESIGN INFORMATION CIRCULAR NO. 4-52

SUBJECT: Acquisition of Right of Ways for Freeways

TO: All District Engineers and Engineer-Managers

Gentlemen:

During the past year a number of Commission Orders of the following general type have been passed:

> "In ________________ Counties, it is the intent of the Highway Commission that the route of Highway __________ be developed by stages to ultimate standards for a Freeway in accordance with the provisions of House Bill 451, 52nd Legislature, and the State Highway Engineer is directed to coordinate planning, right of way acquisitions, and construction for the ultimate accomplishment of this objective."

The principal purpose of this kind of Minute is to permit long range planning in both the acquisition of right of ways and construction. In order that the counties and cities which are affected may most efficiently accomplish their parts of the dual responsibility, the following action is recommended:

> Inform the counties and cities that in line with Department policy, no right of ways are requested of a local agency until we have funds for the construction. However, in a long range plan such as this, it will most likely be highly advantageous to the local governing units to protect themselves by a gradual right of way acquisition especially in those places where improvements are contemplated. which would, if constructed, have to be removed in the future at great expense. The services of the Department should be offered in furnishing right of way deeds for the acquisition of such property. Incorporated cities desiring to acquire right of ways on a long range plan should be advised that it is necessary for them to concur in the Freeway designation.

0-51

Wherever possible the existing road should be incorporated into the Freeway either as a part of the divided highway or as one of the ultimate frontage roads. Relocations, when contemplated, will warrant economic studies which place proper emphasis upon:

1. Comparative costs of developing and operating the existing and relocated routes as regards right of way, property damage, construction and maintenance.

2. System balances in an area designed to provide an adequate transportation network with minimum highway mileage. The local highways and streets will naturally have to be integrated into the overall system.

In all cases preliminary design features and right of way widths should receive prior concurrence from the Road Design Division before the deeds are released.

Yours very truly

D. C. Greer
State Highway Engineer

By: J. C. Dingwall
J. C. Dingwall
Engineer Road Design

0-51

AESTHETIC FEATURES OF HIGHWAY DESIGN

There are many viewpoints from which aesthetics may be considered relative to a particular subject. Primary purpose of highways is to provide a means of communication, but in recent years we find that they are being used by the public for recreation as well. When we consider them as dual-purpose highways, we must provide for utility, safety, comfort, and convenience of the traveling public.

Everyone can think of numerous sections of good highways, but when we think of a beautiful highway we eliminate a major portion of these, the primary reason being that it does not fit in or appear to be a part of the landscape. This may be the result of one or more reasons, such as cross-section design, profile grade, erosion control, preservation of vegetative growth, or location. Beauty is achieved through the rational development of the best design practices and is not something foreign, added to or plastered onto the highway. Unless the best design practices are used in the original construction, the highway will not be the most economical to maintain, and rarely ever is it possible to obtain comparable beauty.

When a highway has been well-located, not only is it utilitarian but it is a safe one. Adequate and economical drainage is provided through use of good cross-section design which creates spaciousness and gives the motorist a feeling of safety. These and other design features that provide for safety will not relieve the monotony incurred from the lines formed by the pavement, ditches, and edge of right of way converging in the distance. In divided lane highways this can be offset to a large degree by using a variable width median which will permit more variation in design. The greatest single factor in removing this monotonous condition is the judicious use of trees and vegetation.

When a highway has been designed not to conflict with the dictates of nature, a vegetative cover can be established, which is nature's way of preventing erosion and making things harmonious. This is economical construction and maintenance. The ratio of slope, location, soil, and rainfall should be considered in selecting the kind of vegetative cover. No doubt, many of you think when erosion control is mentioned that we refer to some particular type of Bermuda Grass sodding; this is just one method. In many cases, that is the ideal method; but also, in many instances it is the most expensive, and often it is not any more effective. It has been found that when construction and maintenance operations work in harmony with nature, a major portion of erosion control is accomplished for us.

Besides being an essential in providing beauty, along with the vegetative cover, trees are used to increase the safety, comfort, and utility for the motorist. The use of blooming shrubs and flowers is considered to be a refinement and not an essential. Transplanting of trees and shrubs is costly and many years are required for them to reach maturity or a size sufficient to serve their intended purpose. This necessitates the preservation of native growth in the initial highway construction. In so doing, we provide a complete facility at the conclusion of construction which permits us to render the maximum service to the public.

Too many trees on the right of way can be very monotonous, and generally, when this condition exists, the effectiveness of those that would increase the safety and beauty of the highway is reduced. Properly located trees will assist in determining alignment and also serve as a warning of some dangerous condition. When motorists drive long distances, an occasional group of trees, or even a single large tree, on a straight road which would otherwise be monotonous, can be an important safety factor. By judicious selective thinning, we can present a series and a variety of views that will make a road interesting to drive, which provides for the comfort of the motorist. Proper preservation of trees, along with adequate vegetative cover on a highway, increases its utility, safety, and comfort for the motorist, as well as providing the best possible appearance at the most economical construction and maintenance cost.

In roadside development work, we depend upon our wild-flowers for the color which is considered to be a refinement. This program generates a great amount of travel to see these splashes of color as evidenced by the complimentary letters. Preservation and distribution of our native wild flowers is accomplished through our maintenance operations.

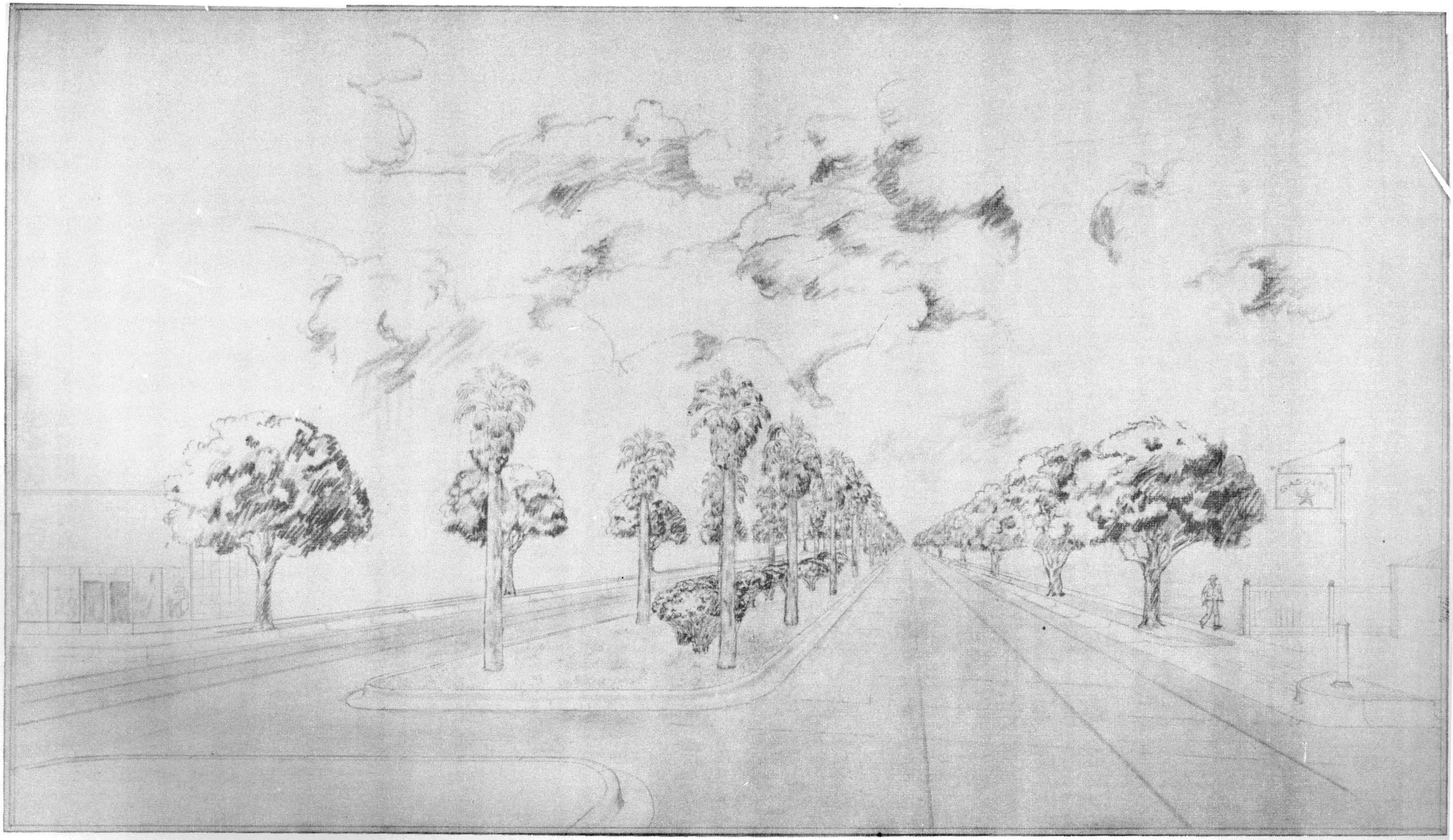
Probably the most popular facility for all types of highway users is our roadside parks, as evidenced by their use and comments from the public. Primary purpose of this facility is to serve the public when making long drives by offering them a place to stop in safety away from the travelway to relax and refresh themselves in pleasant surroundings. The numerous other reasons given for them are considered to be secondary. The site and park development should be simple, utilitarian, and in keeping with the landscape, but meet the traveler's needs.

A system of parks developed on our main highways will give the greatest amount of service to a maximum number of motorists. These sites should be a minimum of 3 to 5 miles from a city and spaced from 20 to 30 miles apart in the heavily populated eastern areas, with a 30-to-45-mile spacing in the western part of the state. Preferable sites are those that contain one acre or less, and when developed, have from two to five picnic units. This is the most economical sized parks to construct and maintain. The Landscape Adviser will be of valuable assistance in securing and developing these park sites to obtain the best results.

When requested, the Landscape Adviser will consult or assist you with erosion control, preservation of native trees, parks, or any other roadside development problem.

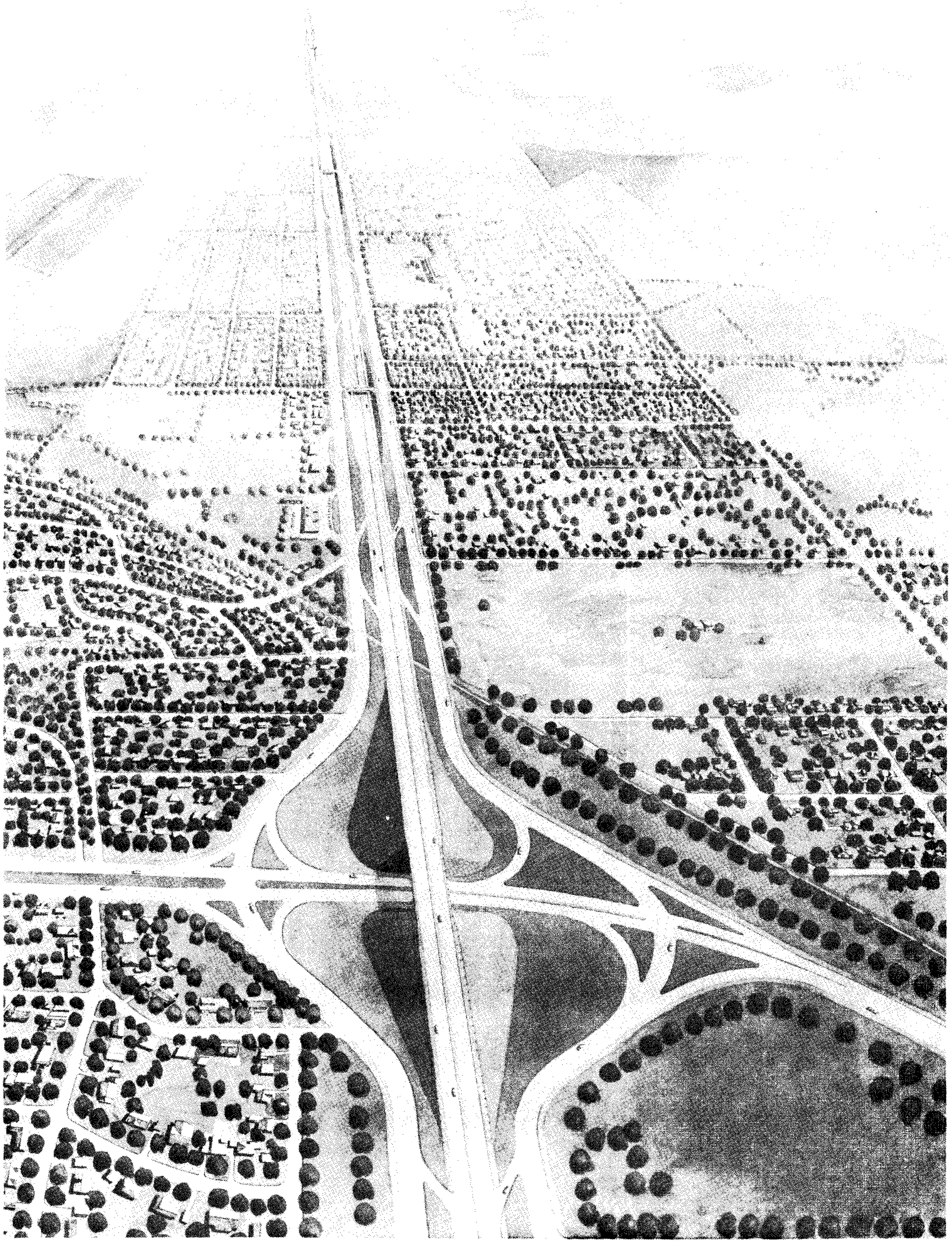
Another service that Traffic Services Division has rendered is the preparation of perspective drawings and illustrations to be used as a means of promoting a project which would probably be difficult to convince some organization or the public of its merits. The perspectives of the proposed widening of Broadway in Galveston and a view of the Austin Expressway are examples of this work. A picture will often sell an important project when no amount of talking can.

From this review, you will see that rational development of good design practices provides the basis and when supplemented with proper maintenance, we have a highway that has utility, safety, comfort, and convenience that is economical to construct and maintain. Proper consideration in design and sound construction methods will create beautiful highways at no additional cost, as beauty is a by-product of a job well done.



SKETCH OF PROPOSED IMPROVEMENT ON BROADWAY
GALVESTON, TEXAS

This sketch was prepared in color by the Traffic Services Division in cooperation with District 12 and the Road Design Division to illustrate a proposed improvement. Large colored reproductions were used for public information and a small reproduction was incorporated in a report.



SKETCH OF PROPOSED TRAFFIC INTERCHANGE
AUSTIN, TEXAS

INTERSECTION DESIGN

We are always striving to improve our highways so as to enable them to carry the maximum traffic volumes with a minimum of accidents and congestion.

The adopted design often varies widely from the ideal, in the "interests" of economy. Actually, it is often true that a safer design, which also has much more traffic capacity than that selected, could have been built for little or no increase in cost. We should carefully plan for capacity and safety and only adopt less than the ideal design with the thought that the higher type design can be attained in the future when the needed additional money may then be available. We rarely overdesign in areas where sufficient traffic volumes are present.

The intersection is a focal point for the diseases of accidents and congestion which have infected our highways because the capacity of the intersection is less in almost every case than the capacity of the entering roadways. It was found on a highway in Michigan that the intersection accident rate was 5.3 times as great as the non-intersection accident rate. It is fortunate, although we have not made full use of the fact due to lack of adequate funds, that highways and intersections which are designed for high traffic capacities also are safer than traffic facilities designed for lesser capacities.

The more common types of intersections at grade are: Branch, "Y", "T", and Crossing although Rotary, Cloverleaf or Direct Interchanges or their combinations may be used on the higher type facilities to reduce crossing or turning conflicts and provide greater capacity and safety.

In the proper design or re-design of an intersection many factors must be considered. A few of these are: (1) Number of intersecting roads, (2) Angles of intersection, (3) Traffic volumes (vehicular and pedestrian) and turning movements, (4) Sight distances, (5) Roadside development and access, (6) Right-of-way, (7) Desirable or actual operating speeds of traffic, (8) Traffic control, and (9) Accident experience.

Where a minor road intersects a major one at a flat angle, for example, the minor road should be relocated, whenever possible, so that it will intersect as nearly at right angles as possible. Where relocation is not feasible, often channelization may be used to accomplish the same result. Where a minor road intersects and crosses a major road at a flat angle each leg of the minor road should be turned so as to intersect the major road at or near a right angle with the two intersections offset by three or four hundred feet. This offset is based on the distance needed to weave with traffic on the main road and also to provide adequate turning radii.

For traffic which is turning at slow speeds minimum radii provided for turns may be 50 feet (this will take care of large trucks). If 50 foot radii are provided, both for the right turning traffic leaving the main road as well as for the right turning traffic from the minor road, the large flare at the entrance to the intersecting road will encourage traffic making left turns from the major and the minor road to cut the corners (See Figures 1 and 2). If the major road is divided, of course, this will not occur (See Figure 3). Where the traffic volume on the side road is quite low, the major road is undivided and does not have considerably more than 1,000 vehicles per day, the paved turning radii in the throat of the minor road may be reduced to, say, 30 feet. In fact, except in cases where the traffic is very heavy on the major road it is believed that the long paved radii are hazardous as well as expensive. In the event that maintenance becomes excessive in the turning area, need for longer paved radii will have been demonstrated and then can be provided.

For the same reason that long radii may be dangerous under some conditions the addition of acceleration and/or deceleration lanes can cause "corner cutting" (See Figure 4). On heavily traveled undivided roads the traffic pressure itself will tend to prevent the dangerous movements. Acceleration and deceleration lanes cannot be justified on low volume roads. Deceleration lanes can be justified at lower volumes than is the case for acceleration lanes.

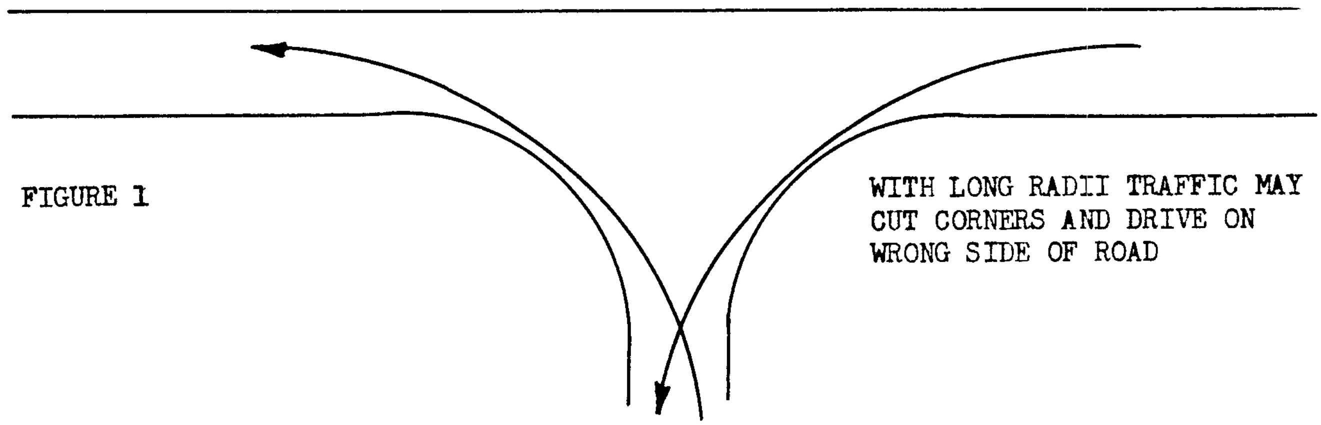


FIGURE 1

WITH LONG RADII TRAFFIC MAY CUT CORNERS AND DRIVE ON WRONG SIDE OF ROAD

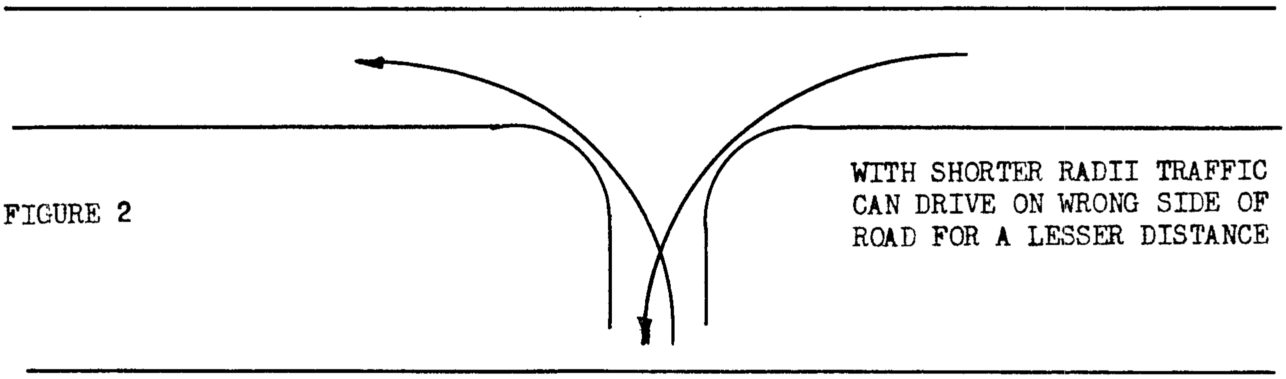


FIGURE 2

WITH SHORTER RADII TRAFFIC CAN DRIVE ON WRONG SIDE OF ROAD FOR A LESSER DISTANCE

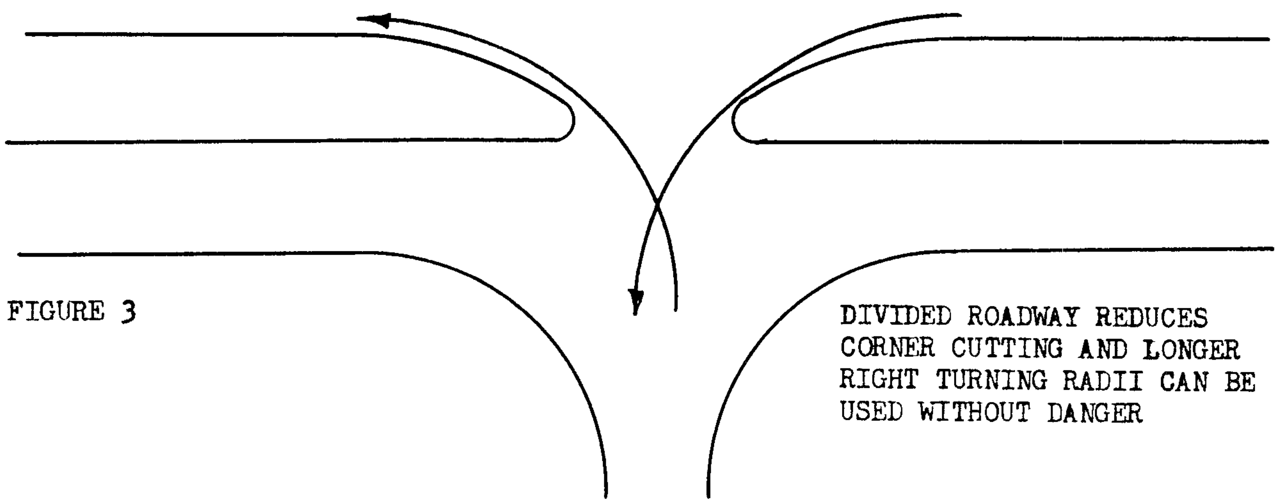


FIGURE 3

DIVIDED ROADWAY REDUCES CORNER CUTTING AND LONGER RIGHT TURNING RADII CAN BE USED WITHOUT DANGER

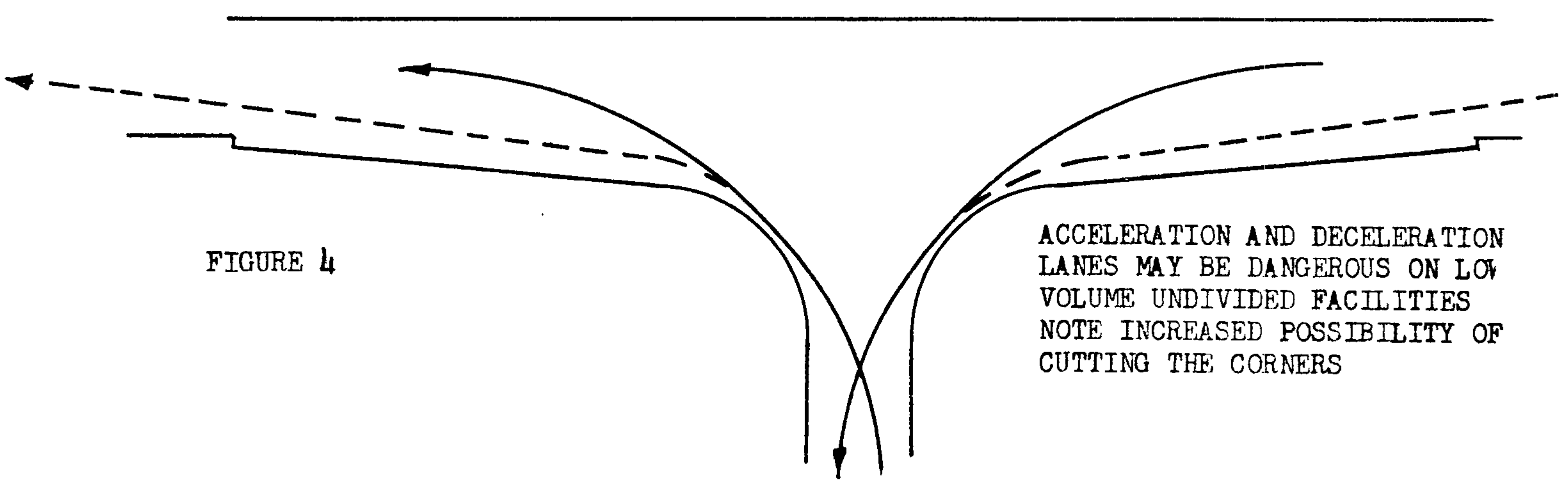


FIGURE 4

ACCELERATION AND DECELERATION LANES MAY BE DANGEROUS ON LOW VOLUME UNDIVIDED FACILITIES NOTE INCREASED POSSIBILITY OF CUTTING THE CORNERS

The lengths of deceleration and acceleration lanes to be used are debatable questions. Undoubtedly the length of the acceleration lane is dependent on the traffic volumes and the speed of movement. The length of the deceleration lane is far less dependent than the acceleration lane on traffic volumes although the speed of operation is still an important factor. For a turning speed of 20 m.p.h. and a design speed of 60 m.p.h. the A.A.S.H.O. policy calls for an acceleration lane 750 feet long. This length is obviously longer than we can afford to build except in special cases. Accelerating traffic will not use the major portion of an accelerating lane unless it is forced to do so by sufficiently heavy traffic. Shorter acceleration lanes can often be built and later extended when and if observation shows the need for such extension.

Division of highways through the use of medial islands provides many benefits to safe and efficient intersection operation. The medial island gives all of the benefits of a channelized intersection with little or no additional expense. The medial island should be 20 feet or more in width wherever possible. The 20 foot minimum is based on providing a sheltered waiting space for vehicles that must cross on the intersecting roadway.

Where it is impractical to provide a median as wide as 20 feet, the next minimum width to consider would be 14 feet. With this width waiting spaces for left turns can be provided. Narrower medians than 14 feet should be used only where wider medians cannot be secured and there is a need for the separation of opposing traffic. Although narrow medians can control access to some extent they may and often do substitute rear-end collisions for left turning accidents.

Caution should be used in the use of narrow medians in intermediate areas (i.e., having both urban and rural characteristics) where roadside development causes many turning movements onto and off of the highway and where relatively high highway speeds obtain.

Right turning lanes may and should be provided where sufficient right-of-way can be secured or is available particularly on those approaches to an intersection which have the heavier traffic. Even though the right turning traffic may in itself be small, right turning lanes can be justified where the straight through and/or left turning traffic is heavy since straight through traffic will not be thus inconvenienced. Right turning lanes may be separated by islands from the other traffic where sufficient right-of-way is available. This type of design allows right turning traffic to be removed from conflict with other movements, allows higher turning speeds, and furnishes a place on the island for traffic control devices (i.e., signs and signals).

Islands can be used to control merging movements by narrowing the traffic lane so as to control speeds and to reduce merging traffic to one lane. If merging traffic is allowed to enter the highway in more than one lane the other traffic movements can be unduly interfered with or even stopped. Of course, if the merging movement is replaced by traffic signal control then as many lanes may be allowed for movement as are available on the roadway.

Curb and gutter section should be used in many cases to prevent motorists from "cutting the corner" across the shoulder. Curb and gutter in such cases will render the traffic control more effective and will reduce maintenance of the shoulder section considerably.

An intersection in Garland, Texas on a highway route is shown in Figures 5, 6 & 7. The collision diagram for a year before and after the channelization and the traffic diagram are shown. The reduction in accidents is gratifying, congestion has been relieved, and the reaction of the motoring public has been favorable.

Data on the geometrics of intersection design have been reviewed briefly in the preceding portion of this paper.

The bibliography lists some sources for more detailed information. A general acquaintance with the literature should be acquired and copies of the books listed should be available for reference.

In deciding on a design for a specific intersection the following steps are often found to be helpful:

1. Make a layout of the proposed intersectional area to a large scale, say, 1" = 30'-0". This layout should show as much of the culture as practical. If the contour information is known it should also be shown.

TEXAS HIGHWAY DEPARTMENT

Division of
Traffic Services

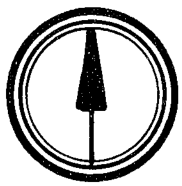
COLLISION DIAGRAM

GRAPHIC SUMMARY SHEET

Traffic Engineering
Sub-Division

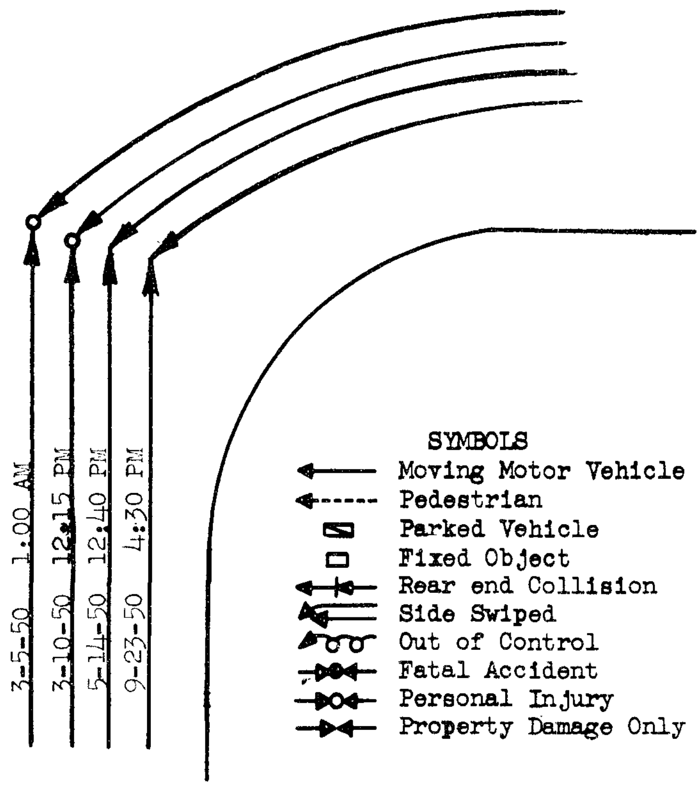
LEGEND

D - Dry Road
W - Wet Road
S - Snow on Road
I - Ice on Road
C - Clear Weather
R - Raining
SN - Snowing



Indicate North

Highway or Street



SYMBOLS

- Moving Motor Vehicle
- Pedestrian
- Parked Vehicle
- Fixed Object
- Rear end Collision
- Side Swiped
- Out of Control
- Fatal Accident
- Personal Injury
- Property Damage Only

Dist. No. 18

Control________ **Sec.**______

Intersection U. S. 67

and North Star Road

Dallas **County**

Date:______________ **Period** Year of 1950

Remarks:____________________

ONE YEAR BEFORE CHANNELIZATION

FIGURE 5

TEXAS HIGHWAY DEPARTMENT

Division of
Traffic Services

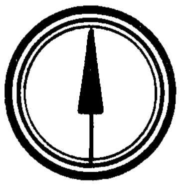
COLLISION DIAGRAM

Traffic Engineering
Sub-Division

GRAPHIC SUMMARY SHEET

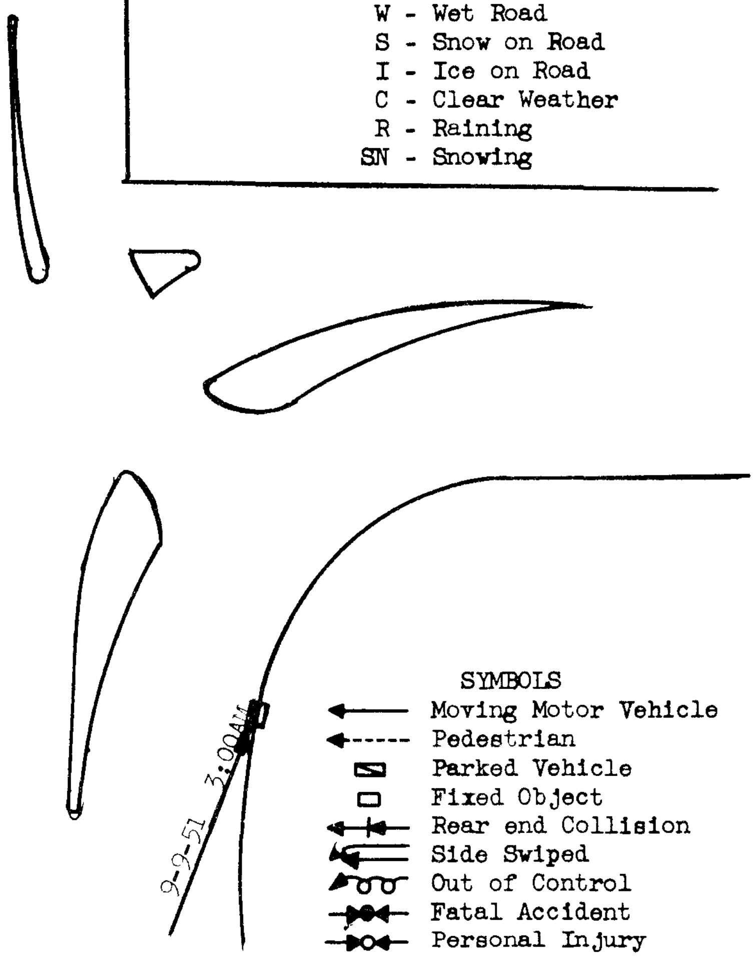
LEGEND

D - Dry Road
W - Wet Road
S - Snow on Road
I - Ice on Road
C - Clear Weather
R - Raining
SN - Snowing



Indicate North

Highway or Street



SYMBOLS
Moving Motor Vehicle
Pedestrian
Parked Vehicle
Fixed Object
Rear end Collision
Side Swiped
Out of Control
Fatal Accident
Personal Injury
Property Damage Only

Dist. No. 18

Control________ Sec._____

Intersection U. S. 67

and North Star Road

Dallas County

Date: ____________ Period Year of 1951

Remarks: Ran into sewer inlet.

ONE YEAR AFTER CHANNELIZATION

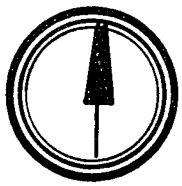
FIGURE 6

TEXAS HIGHWAY DEPARTMENT

Division of
Traffic Services

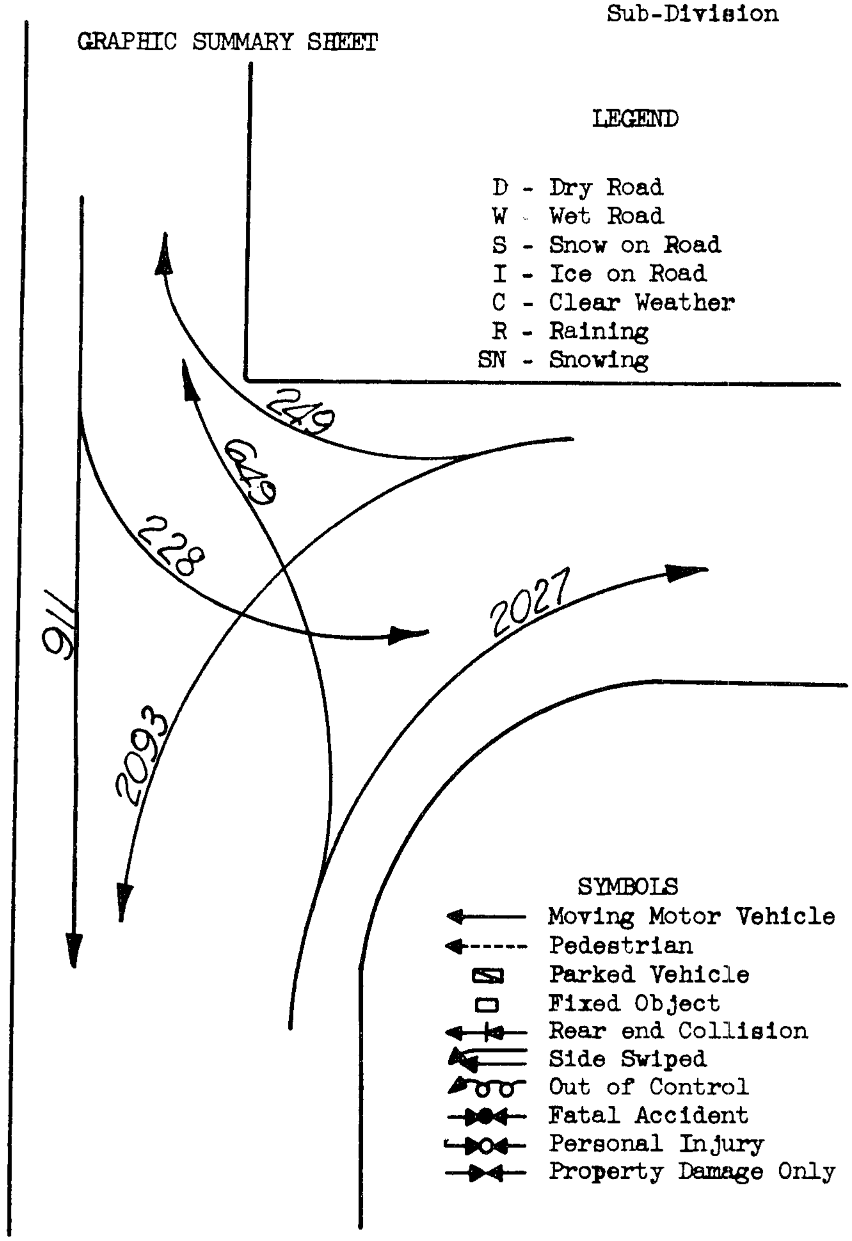
Traffic Engineering
Sub-Division

GRAPHIC SUMMARY SHEET



Indicate North

Highway or Street



Dist. No 18

Control________ Sec._____

Intersection U.S. 67

and North Star Road

Dallas County

Date: March 16, 1950 Period 6:45 A.M. - 4:00 P.M.

Remarks:

FIGURE 7

2. Make a traffic volume and turning movement count. Show the traffic movements on the layout diagrammatically.

3. Make a freehand sketch showing areas which are more or less unused in the intersection area.

4. The minor traffic movements then can be sketched in allowing more deviation from a direct routing than ordinarily would be prescribed for the major movements. It must be recognized that this is only a general rule, and where a design uses weaving sections, considerable circuity in route for even major movements may be required. In general, an effort should be made to see that where and when crossing conflicts at grade (which should be made at or near right angles) become heavy enough to cause congestion and/or hazard, separation of grades and/or a conversion to weaving movements should be considered. The use of bridges and/or weaving sections presupposes, of course, that sufficient right-of-way and financing are or can be made available. Wherever possible intersections should be planned with an eye to the future so that as a facility becomes obsolete further refinements may be added.

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