DESIGN OF FLEXIBLE BASES

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SYNOPSIS

The method of design of flexible bases described in this paper is based upon the consideration of four items: (1) subgrade soil; (2) volume and character of traffic; (3) moisture conditions of subgrade; and (4) climatic conditions. All items are evaluated on a numerical basis, thus the method gives a standardized answer for any given set of conditions regardless of the personalities involved.

The subgrade is evaluated by the CBR test. A series of five CBR thickness relations were developed and the sum of the numerical values for the items enumerated above for a given set of conditions determines the design curve to be used.

The design curves and the method of numerical evaluation are considered to be subject to modification as experience is acquired from the use of the described method.

The Colorado State Highway Department has been faced with the same problem as all agencies charged with the responsibility of building and maintaining a large network of highways on a small income. This problem resolves itself into the basic form of building a highway that will adequately serve the involved traffic for the expected life of the road, with a minimum of maintenance. Any solution to the problem must be predicated on the construction of a base free of structural failure. While we recognize that such a solution is at this time far from accomplishment, we believe that with the use of available information we must at least make an attempt to reach the ultimate answer. Time and service records will reveal the amount of success which we achieve.

Beginning with the issuance of the Public Roads Administration classification procedure in 1931, which was later augmented with simplified recognition chart and recommended thicknesses of base materials, the Colorado Department has attempted to apply available information in the design of base courses. The basic chart used by the Department, prior to this year, was the one published in Public Roads of February 1942 (Table 1). This chart gave as recommended thicknesses of sub-base, base course, and surfacing a wide variance which might be used over any given soil. The underlying reason for the wide variance was the fact that other conditions than the soil itself must be recognized in the design. The statement most generally made in correction with the application of the chart was that "sound engineering judgment based on long experience must be used in the application of any table of recommended thicknesses." This statement, while most certainly true, has led to an avoidance of responsibility by recommendations which invariably landed in the upper range of thicknesses. Also, the most fundamental evil occurring was the complete lack of uniformity resulting from different individuals making recommendations which varied widely for the same range of conditions. In order to overcome as much as possible the variations resulting from individual differences of opinion, and in order to arrive at an economical design, we undertook the preparation of a design method which would give a standardized answer for any given set of conditions regardless of the individuals involved. The method we proposed would be based on a series of design curves, (Fig. 1) indicating varying thicknesses for varying conditions.

An examination of all available design methods and research documents developed the fact that there were four universally recognized factors which must be considered in arriving at a rational design. The four factors briefly tabulated are as follows:

1. The natural soil which would immediately underlie the roadway surface;
2. The volume and character of traffic which would be assumed to use the completed facility;
3. The moisture conditions which would exist in the completed facility;
4. The climatic conditions, other than

TABLE 1
SUMMARY OF SOIL CHARACTERISTICS AND CLASSIFICATION

Group	A-1	A-2		A-3	A-4	A-5	A-6	A-7	A-8
		Friable	Plastic						
General stability properties.	Highly stable at all times	Stable when dry; may ravel	Good stable material	Ideal support when confined	Satisfactory when dry; loss of stability when wet or by frost action	Difficult to compact; stability doubtful	Good stability when properly compacted	Good stability when properly compacted	Incapable of support
Physical constants									
Internal friction	High	High	High	High	Variable	Variable	Low	Low	Low
Cohesion	High	Low	High	None	Variable	Low	High	High	Low
Shrinkage	Not detrimental.	Not significant.	Detrimental when poorly graded	Not significant	Variable	Variable	Detrimental	Detrimental	Detrimental
Expansion	None	None	Some	Slight	Variable	High	High	Detrimental	Detrimental
Capillarity	None	None	Some	Slight	Detrimental	High	High	High	Detrimental
Elasticity	None	None	Some	None	Variable	Detrimental	None	High	Detrimental
Textural classification:									
General grading	Uniformly graded; coarse-fine excellent binder	Poor grading, poor binder	Poor grading; inferior binder	Coarse material only; no binder	Fine sand cohesionless silt and friable able clay	Micaceous and diatomaceous	Deflocculated cohesive clays	Drainable flocculated clays	Peat and muck
Approximate limits:									
Sand (percent)	70–85	55–80	55–80	75–100	55 (maximum)	55 (maximum)	55 (maximum)	55 (maximum)	55 (maximum)
Silt (percent)	10–20	0–45	0–45	[a]	High	Medium	Medium	Medium	Not significant
Clay (percent)	5–10	0–45	0–45	[a]	Low	Low	30 (minimum)	30 (minimum)	Not significant
Physical characteristics:									
Liquid limit	14–35[b]	35 (maximum)	35 (maximum)	NP[c]	20–40	35 (minimum)	35 (minimum)	35 (minimum)	35–400
Plasticity index	4–9[b]	NP–3[c]	3–15	NP[c]	0–15	0–60	18 (minimum)	12 (minimum)	0–60
Field moisture equivalent	Not essential	Not essential	Not essential	Not essential	30 (maximum)	30–120	50 (maximum)	30–100	30–400
Centrifuge moisture equivalent	15 (maximum)	12–25	25 (maximum)	12 (maximum)	Not essential	Not essential	Not essential	Not essential	Not essential
Shrinkage limit	14–20	15–25	25 (maximum)	Not essential	20–30	30–120	6–14	10–30	30–120
Shrinkage ratio	1.7–1 9	1.7–1.9	1.7–1.9	Not essential	1.5–1.7	0.7–1.5	1.7–2.0	1.7–2.0	0.3–1.4
Volume change	0–10	0–6	0–16	None	0–16	0–16	17 (minimum)	17 (minimum)	4–200
Lineal shrinkage	0–3	0–2	0–4	None	0–4	0–4	5 (minimum)	5 (minimum)	1–30
Compaction characteristics.									
Maximum dry weight, pounds per cubic foot	130 (minimum)	120–130	120–130	120–130	110–120	80–100	80–110	80–110	90 (maximum)
Optimum moisture, percentage of dry weight (approximate)	9	9–12	9–12	9–12	12–17	22–30	17–28	17–28	
Maximum field compaction required, percentage of maximum dry weight, pounds per cubic foot	90	90	90	90	95	100	100	100	Waste

Table 1 continued next page

TABLE 1—*Continued*

Group	A-1	A-2		A-3	A-4	A-5	A-6	A-7	A-8
		Friable	Plastic						
Rating for fills 50 feet or less in height	Excel-lent	Good	Good	Good	Good to poor	Poor to very poor	Fair to poor	Fair to poor	Unsatis-factory
Rating for fills more than 50 feet in height	Good	Good to fair	Good to fair	Good to fair	Fair to poor	Very poor	Very poor	Very poor	Unsatis-factory
Required total thickness for subbase, base and surfacing, inches	0–6	0–6	2–8	0–6	9–18	9–24	12–24	12–24	

[a] Percentage passing No. 200 sieve, 0 to 10
[b] When used as a base course for thin flexible surfaces the plasticity index and liquid limit should not exceed 6 and 25, respectively.
[c] NP—nonplastic

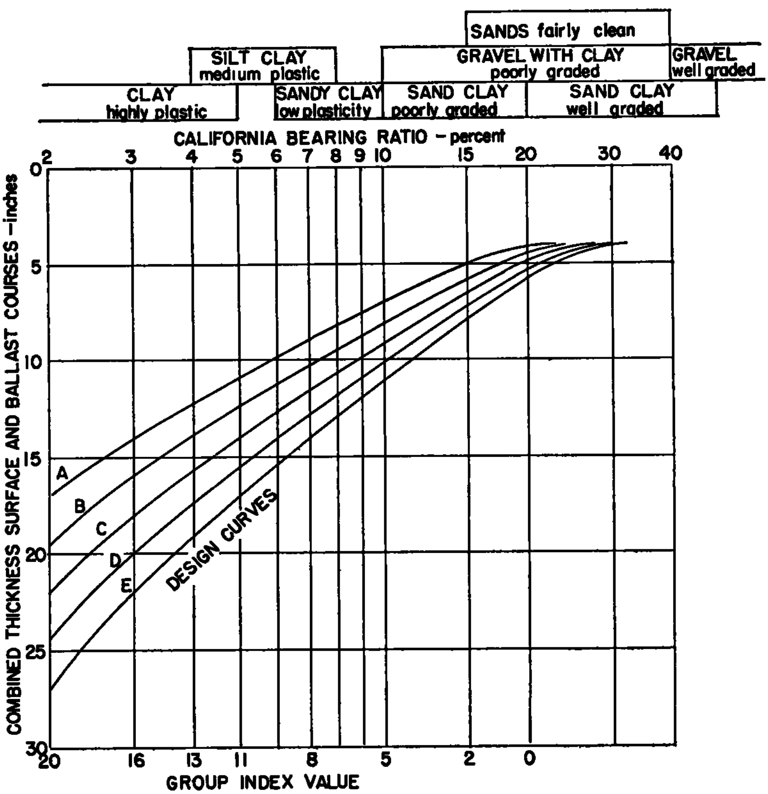

Figure 1. Colorado State Highway Department Design Chart—Note: This is a dual purpose chart to indicate required thicknesses using either CBR or GI values. The coincidence of the values on the chart does not mean that they are equal. When design is based on CBR, the GI values should be ignored and vice versa.

moisture, and specifically relating to the frost and its resultant detrimental effects.

In order to arrive at the most reasonable and reproducible method of handling the four factors involved in any solution of a design problem, we decided to evaluate all factors on a numerical basis. Obviously any evaluation of the variables on an adjective basis such as, "fair," "good," etc., will become involved in the personalities making the adjective evaluation. On the other hand, a numerical evaluation is more nearly reproducible regardless of the personalities involved. Fortunately for us, the research background for such an evaluation was available on two of the four factors. For the other two, we had our own experiences to use as a guide.

Soils—There were two generally recognized methods of evaluation which had a numerical evaluation base. First, the California bearing ratio, and second, the Group Index method.[1] In our design method, each is used in what we consider to be the applicable range; that is, the Group Index value may be used on any of the granular type soils, and the California bearing ratio on any soil, but of particular value in determining the supporting characteristic of those soil classes having a wide variation of bearing range within any soil group. This applies particularly to any of the silt clay combinations.

It is appropriate to note that we are attempting to correlate the California bearing ratio and Group Index values for the various soil groups on a localized basis for the different sections of the State. We are also engaged in an attempt to determine, by a compilation of our California bearing ratio values, the Atterburg limits and grain size limits which may be used to assign a preliminary bearing value for design purposes. This may lead into a blind alley, but at this time it does appear to have favorable potential.

Traffic—The California Division of Highways has developed the traffic volume-traffic character constants which were employed in our method.[2] We have assumed for practical application that the volume of commercial traffic is fixed at twenty-five percent of the total, and further that the distribution of the commercial traffic in wheel load categories is fixed. On this assumption we have translated all traffic to an annual average volume basis and have then prepared a normal curve to determine the numerical evaluation to be used. The traffic volume used is the expanded figure assumed for twenty years hence.

[1] *Proceedings*, Highway Research Board, Vol. 25 (1945).

[2] *California Highways and Public Works*, March 1942.

Moisture Conditions—We have been forced to attempt a numerical evaluation for which we have been unable to find any published precedent. We do believe that the effects of moisture are so widely divergent in different localities that it probably is best to make such an evaluation on a regional basis. For this reason we have not been averse to setting up such values based on the observed conditions within our own State. Briefly there are four general conditions which we recognize and which result in a wide variation of service behavior.

1. *Arid or High Table Land Not Subject to Standing Water.* This can be considered to be any ground which because of the natural soils, drainage, relation of grade line to ground, etc. is not subject to soaking by either rain or snow moisture.

2. *Ground Subject to Occasional Standing Water During Storms.* This can be considered to be any ground which is not normally subjected to soaking but which because of the slow escape of drainage water brought about by flat grades and/or impermeable soils is subject to occasional soaking.

3. *Ground Subject to Saturation Only During Periods When Frost Is Not Present.* This can be considered to be any irrigated ground which is saturated during the growing season but where the soil is free draining to the extent that the saturated areas dry out prior to the occurrence of ground frost.

4. *Ground Subject to Saturation During Periods When Frost Is Present.* This can be considered to be any irrigated ground over a poorly drained soil which retains moisture into the period of ground frost; also, any ground which has a water table which remains in the frost penetration area during periods of frost; and, areas subject to saturation from snow moisture over extended periods.

The assigned values used in the design method agree essentially with service records within the state.

Frost Conditions—We have been forced again to assign evaluation figures which are without precedent except from our observation of the conditions as they exist in our own State. We fully recognize that frost alone without moisture sources on which to feed is impotent.

Unfortunately for road builders, there always seems to be sufficient moisture which in combination with the adverse temperature makes plenty of trouble when the soils are of a frost susceptible type. Past research has provided an analysis which determines the frost susceptible soils.[3] Frost penetration and frost susceptibility have been combined in the evaluation for our design method and values assigned on the basis of observed service behavior.

volume of traffic. Our past experience has tended to prove that a California bearing ratio curve based on a 13,000-lb. wheel load provided a total thickness of base and surfacing adequate to handle our heaviest volumes of traffic and under the most severe conditions of moisture and frost. On the other hand, a California bearing ratio curve based on a wheel load of 5,000 lb. has provided sufficient thickness of base and surfacing to adequately handle low volumes of traffic in areas where the conditions of moisture and frost were least severe. The two aforementioned curves show a thickness of 4-in. for a soil having a CBR of 3, and a 5,000-lb. wheel load, and a thickness of 22 in. on the same soil with a 13,000-lb. wheel load. It was our judgment that the smallest increment of thickness which was practicable from a design standpoint would approximate 2 inches. This indicates that we should set up five curves within the limits of thickness stated above. This was done and the three intermediate curves were interpolated between the 5,000- and the 13,000-lb.

TABLE 2

Design Aid No. 12
April 14, 1947

Project Plans & Estimates
Project No. —

THICKNESS OF SURFACING & BALLAST COURSES

Sta.—— To Sta.—— Date——

Note: Use Check Marks to indicate proper condition

	Assigned Value	Used in Design
Frost Conditions:		
Penetration of 0" to 12" & Low Frost Potential	1	
Penetration of 0" to 12" & High Frost Potential	3	
Penetration of 13" to 24" & Low Frost Potential	2	
Penetration of 13" to 24" & High Frost Potential	5	
Penetration of 25" to 36" & Low Frost Potential	4	
Penetration of 25" to 36" & High Frost Potential	7	
Penetration of over 36" & Low Frost Potential	6	
Penetration of over 36" & High Frost Potential	10	
Moisture Conditions:		
Arid or high table land not subject to standing water	2	
Ground subject to occasional standing water during storms	4	
Ground subject to saturation *only* during periods when frost is not present	7	
Ground subject to saturation during periods when *frost is present*	10	
Traffic Conditions:		
Traffic of 0 to 50 vehicles per day	0	
Traffic of 51 to 100 vehicles per day	1	
Traffic of 101 to 200 vehicles per day	2	
Traffic of 201 to 300 vehicles per day	3	
Traffic of 301 to 400 vehicles per day	4	
Traffic of 401 to 700 vehicles per day	5	
Traffic of 701 to 1000 vehicles per day	6	
Traffic of 1001 to 1500 vehicles per day	8	
Traffic of over 1500 vehicles per day	10	

Total Assigned Value:

Sum of Assigned Values	*Design Curve to be Used*
From 0 to 8	Use Curve A
From 9 to 13	Use Curve B
From 14 to 18	Use Curve C
From 19 to 24	Use Curve D
25 and Over	Use Curve E

Laboratory Information.

CBR Value —— GI Value ——

Combined Thickness of Ballast and Surfacing —— In

Thickness of Surfacing Used —— In.

Required Thickness of Ballast —— In

Prepared By—— Checked By——

The tabular values used for the conditions of traffic, moisture and frost are shown in Table 2.

The assignment of values to the above listed variables was a necessary preliminary to the main objective of the design method. It is fundamental that a road built in an area of bad soil, severe moisture and frost, and carrying a heavy volume of traffic will need a heavier base than one built in an area of good soil, light moisture and frost carrying a light

[3] Highway Research Bulletin No. 4, Purdue University (1940).

wheel load curves. The five curves so selected were designated "A," "B," "C," "D," and "E" (See fig. 1).

The tabular values indicated in Table 2 are summarized and the total tabular value is used to determine the proper design curve. The proper curve when used in conjunction with the soil bearing value as represented by either the California bearing ratio or Group Index value, determines the total thickness of sub-base, base course, and surfacing to be used in the design of the project. In order to correlate the terminology used in the design method with that used in most texts, it should be noted that we use the term "ballast" in lieu of "sub-base."

The efficiency of this design method depends to a great extent on the degree of accuracy of the sources of information which determine the tabular values which in the final analysis result in the selection of the design curve to be used, and in this manner finally determine the thickness of base material to be used. For this reason it is necessary to acquire the basic information from that source which is best able to supply it in the most accurate and normal manner. Following this line of thought to its logical conclusion resulted in our designating the following persons or groups to supply the indicated information:

1. All soils information including a California bearing ratio or Group Index value and a grain size analysis to determine frost susceptibility is supplied by the Materials Engineer.

2. All traffic information both as to volume and character is supplied by the Planning Division of the Highway Department.

3. A description of the moisture conditions as they apply to the various sections of a project is supplied by the Engineer in charge of the preliminary survey.

4. Information relative to the frost conditions and penetration as they relate to sections of the project is supplied from the field by the Engineer in charge of the preliminary survey.

The information supplied by the designated sources is assembled in the design section, values tabulated and summarized, and the project designed in accordance with the findings. Finished plans indicate the design curve used on specific sections of any project as well as the thicknesses of the base course and surfacing materials. In addition, all plan profiles indicate the soil survey information obtained during survey stage and in addition indicate either a Group Index or California bearing ratio value on which the design is based. In this manner, the field construction forces are fully informed regarding the assumptions used in the design office. During the construction of the project, the grading operations are constantly observed, and any deviation of the soils from that shown on the design plans is cause for immediate recheck and if necessary redesign of the surfacing and base courses to care for the soil conditions as they exist in the constructed project.

This particular design method has been in use such a relatively short time that we are unable at this writing to determine just what success may result from its use. It has accomplished one tangible result, namely, uniformity in the manner of approach to the solution of our most troublesome design problem.