Colorado's Flexible Pavement Design Method

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●THE opportunity to report to the Highway Research Board on the evolution of our design method is one that is appreciated by the engineering staff of the Colorado Department of Highways. Actually, the method was originally reported to the 1947 Annual Meeting of the Highway Research Board and was subsequently published in the Proceedings of that year. Any who are interested in a detail review of the method under discussion have access to that publication.

Briefly, to lead-in to the following discussion, the Colorado design method evaluates (a) the capabilities of the normal basement soils, to sustain loads, when they are in different degrees of saturation; (b) the anticipated traffic volumes for a period 20 years hence; and (c) the damage to the pavement structure that is probable from the frost potential of the soils over which the pavement is to be placed. With these fundamentals determined on an empirical evaluation, a thickness is determined from a series of five curves. The curves used are shown in Figure 1. Actually, Curve A relates to very light volumes of traffic combined with low moisture and frost potential and Curve E is at the extreme of the heavy volumes combined with high moisture and frost potential.

The only difference between the present design chart and the original is in the elimination of a group index value which was shown on the bottom of the chart. At the time of the original preparation, we attempted to correlate Group Index and California Bearing Ratio. This proved to be groundless as a generalization, hence the elimination of the Group Index value from the chart.

In addition to the elimination of the group index value from the design chart, we have made another major change for the soils of the A-1 and A-3 classifications. Their evaluation, which was originally obtained by CBR method, is now determined by the stabilometer equipment developed by Hveem. This change was made because we feel that more consistent values are developed for granular materials by the stabilometer than by a direct sheer test.

Another fundamental change is also tied to the use of stabilometer values. After the total thickness of the pavement structure has been determined from the design chart (Figure 1), it is assumed to be the "gravel equivalent" of the California design chart shown as Figure 2. This "gravel equivalent" is then used in combination with the California design chart to develop the balance of the pavement structure. As a side note, it should be explained that our acceptance of the Hveem stabilometer for evaluating granular materials was considered for a long time before adoption. In prior years, we had assumed that granular materials of the same sieve analysis and having similar Atterberg limits were actually equal materials and could be used from a design standpoint as having identical characteristics. Field performance did not substantiate this assumption. Literally, the assumption would actually mean that crushed materials and rounded water-washed materials would have the same amount of stability. In addition, it presumed that the minus 200-mesh material was always identical and that in combination with the granular materials it would produce identical surfacing materials. Actually, we have long known that the minus 200-mesh material can vary widely in its capabilities for altering the performance of soil-aggregate mixtures. This is easily explained by the fact that the minus 200-mesh material can be anything from a rock flour or a lime stone dust to a highly expansive clay. The actual potential that these widely separated materials have to alter the performance characteristic of a mixture, of which they are a part, is widely recognized.

Now to discuss the merits of the design method on the basis of our experience. Simply stated, it is so far superior to what we were doing previous to 1947 that all of the engineering personnel of the department have accepted it without question and only disagree on some of the minor details regarding application. Each of us feels that a method which gives a definite answer to the pavement thicknesses to be used for varying conditions is a necessity. One which provides uniformity of application and ease of handling in the field is highly desirable. We don't believe that anyone in the department would

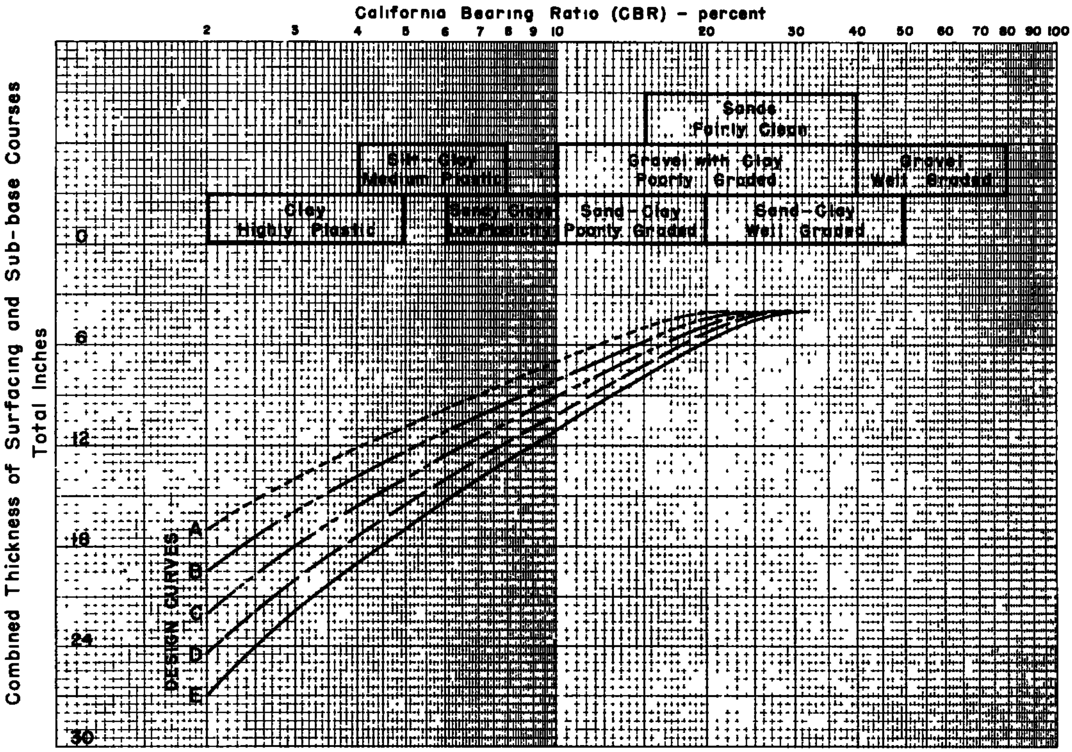

Figure 1. Design chart for thickness of surfacing and subbase courses.

go back to the method where variations of 10 to 12 inches in thickness for identical operating conditions would be possible. On the other hand, we do not want to leave the impression that every job planned under this design method has been a masterful success and that we have had no failures.

To have a look at the procedural angle, we will go to a description of the method of carrying out a typical project. At the time the ground survey, giving center line profiles and topography, has been plotted, a set of the preliminary plans are handed to the central laboratory as an automatic order to proceed to obtain the soil and material surveys. If heavy drilling equipment is necessary, the central laboratory is the only one with equipment to undertake the soil survey and they then proceed to schedule this work. The results of the work are submitted to the field district, in which the project is located, and to the Surveys and Plans Engineer who is responsible for design. If the profile is uniform and no deep holes are required, the soil survey information is often acquired by the field district. As a minimum, auger holes are driven at the beginning and ends of cuts and in the center of the mass. In uniform profiles, the soil samples are taken at intervals not to exceed 1,000 feet. Intermediate samples are lifted at anytime there appears to be a soil change. The depth of the borings are not less than 3 feet below the profile grade. This minimum has been established to insure that the soil samples extend far enough into the basement soil to provide necessary data for design.

Using the soils information from the central laboratory, which includes frost potential established from the soil samples; traffic data supplied by the Planning and Research Division, from their traffic surveys; and, frost penetrations from field surveys, an evaluation is made which automatically selects a design curve or curves for the project. The use of multiple curves can and does occur because of the difference in potential for soaking of the pavement structure, including the basement soil. The potential for soaking varies for the environment changes inherent on any job. As an example, through cuts on flat grades are always subject, in snow country, to continuous infiltration of surface moisture. High fills on steep grades, which drain very rapidly, provide very little opportunity for surface moisture infiltration. Obviously, the potential of the two conditions for soaking is essentially different. The design curves that would be used under the two conditions would thus be different.

Colorado predesignates pits from which the contractor is expected to obtain materials for use in construction of the pavement structure. The granular materials are selected from designated pits on the basis of Hveem criteria for subbase, base course and wearing course materials.

During construction, the basement soils are moved into a position called for in the design, and, if there is any apparent variation from the design presumptions, sand equivalent tests are run to find out if a change in thickness is desirable. Some correlation CBR's are run on the constructed foundations to assure that the design presumptions are being carried out. Such correlation data is obtained only when the district personnel feel that it is required, based on the other physical tests.

With 8 years of experience, certain performance data have become available and a very brief discussion of it will be attempted at this point. Our method of rating performance is related to our annual inventory of road conditions, published as a Rural Sufficiency Rating Study. Special evaluations are made in 22 different test areas where physical data on the basement soils and on construction materials are available. The sufficienty rating, used in combination with this information, is a fairly effective tool

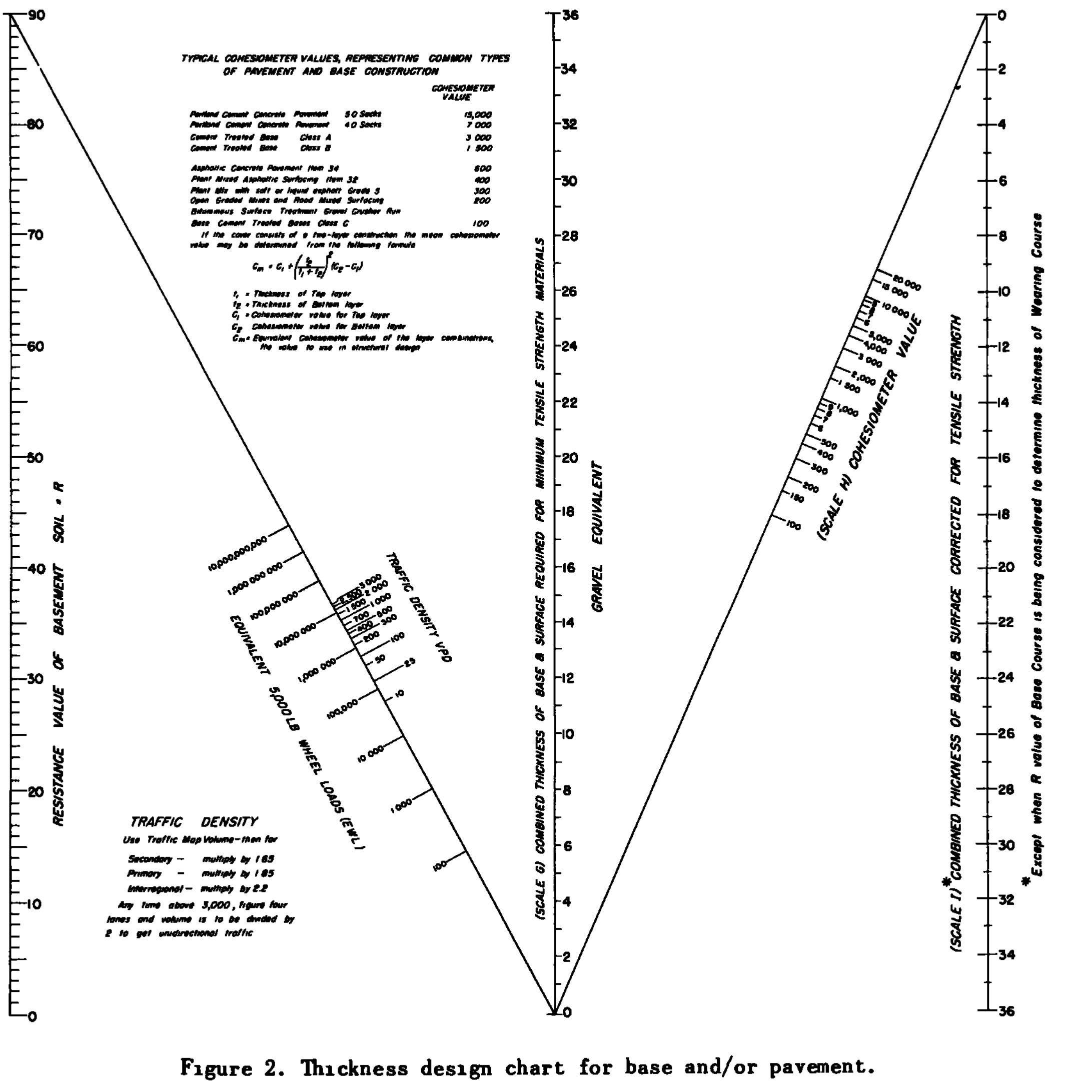

Figure 2. Thickness design chart for base and/or pavement.

TABLE 1

TABULATION OF DATA OF 11 SELECTED SITES BUILT USING THE DESIGN METHOD

Site No.	Project No.	Location	Year Built	Struct Sufficiency Rating[1] 1952	1954	Remarks
4	FI 44 (3)	Loveland Jct - Ft Collins Jct	1947	9-17-8	9-16-9	Generally good.
5	S 0024(1)	Sterling - West	1948	9-15-7	9-11-8	Foundation good, surface failing.
6	S 0009(1)	Sterling - East	1948	10-16-6	8-11-7	Foundation fair, surface failing.
9	F 193 (3)	Morrison - Conifer Jct	1948	8-13-8	4- 6-8	Unsatisfactory, sub-surface drainage failure.
10	F 292 (8)	Dowd - Wolcott	1948	10-19-9	9-16-8	Generally good.
11	F 019 (1)	Delta - West	1950	10-18-9	10-17-8	Generally good.
12	F 232A(1)	Grand Jct - Fruita	1948	10-17-9	10-17-9	Generally good, superior native material.
14	F 001-3(2)	Canon City - East	1949	10-19-9	10-19-9	Generally good.
16	S 0002 (3)	Springfield - Walsh	1948	9- 9-4	10-19-9	Foundation good, original surface treatment failed, new surface placed 1952.
22	F 006-1(1)	Adams City - North	1948	9-10-10	9-12-8	Foundation good, road mix surface failing under heavy truck traffic, no stability.
23	F 138-B & C	Muddy Pass - South	1948	10-20-10	8-16-9	Project at present is fair, original construction resurfaced in 1952.

[1]The sufficiency rating in Colorado awards a par of 40 points for structure. This is broken down to 10 points foundation, 20 points surface, and 10 points drainage. The figures given in the tabulation can be compared to these values.

to determine the adequacy of the design method. Shown in table form are the ratings for a number of projects designed and constructed under this method beginning in 1947. Ratings are shown terminating with those made in the spring and summer of 1955.

Table 1 indicates eleven projects that were built using the described design method. An examination of the table indicates two projects with unsatisfactory performance records. The first project at Site 9 and located between Morrison and Conifer, Colorado, failed because sub-surface drainage problems were not properly cared for at the time of construction. At Site 23, located near Muddy Pass, the failure has been adjudged to have been caused by an inferior foundation material.

The pit used on this project contained aggregate which was coated with a plastic material which had a definitely adverse effect when seasonal moisture permeated the foundation courses. This is one of the types of materials which cannot be properly evaluated by a simple sieve analysis in combination with Atterburg limits. The amount of material passing the No. 200 mesh is not sufficiently large to adversely affect the Atterburg limit test. When the same material is subjected to a stabilometer test its true potential is demonstrated. The change in the design method previously described will eliminate to a great extent the potential for this kind of failure occurring in the future.

All of the remaining nine sites built with the design method have good service records to date. There have been some demonstrated difficulties which have to do with wearing-course problems. As an example, in one place, a surface treatment was employed which did not have sufficient durability to withstand the type of traffic that uses the highway. In the other three cases, a road mix wearing-course was subjected to the type of beating that requires the stability of an asphaltic concrete. In none of the discussed cases was there any indication that the thickness determined by the design method was inadequate nor was there any deformation to indicate lack of stability in the foundation courses.

Reducing the tabular values to a description of the success or failure of the method, we find that 82 percent of the projects employing the method have been adjudged to have good performance and thus are classified as being successful. Unsatisfactory performance was exhibited in the remaining 18 percent and in the unsatisfactory areas, we believe that we now know the things that caused us to fail.

Table 2 shows the information on eleven sites of approximately the same era of construction as are represented by the other projects reported constructed under the principles of the design method. Eight of the eleven sites reported and that were not designed according to the described design method have either been reconditioned at the present time or, according to our own rating, should be rebuilt. The three successful areas are in the opinion of the writer located where the natural foundation soils are of a quality comparable to materials which would have been imported had a formal design method been used. Generally, the foundation soils on these three sites are of a sandy material which only needs to be confined in order to give it good bearing characteristic. Examining the good and bad performances on the eleven comparative sites, we find that the ratings would indicate that 27 percent of the projects have a satisfactory service record and 73 percent have an unsatisfactory record.

It is not to be judged that from this report that we have only built eleven sites to a

TABLE 2

A TABULATION OF DATA OF 11 SELECTED SITES BUILT JUST PRIOR TO THE ADOPTION OF THE FORMAL DESIGN METHOD

Site No.	Project No.	Location	Year Built	Struct Sufficiency Rating[1] 1952	1954	Remarks
1	FAP 150-D(3)	Elk Springs - Massadona	1947	6- 9-7	9-17-8	Original condition became untenable in 1952 and the project was rebuilt in 1953.
2	F 005-2(2)	Steamboat Springs - West	1949	7-11-8	8-16-8	Generally unsatisfactory. Extensive maintenance in 1954 and 1955, providing suitable sufficiency rating in 1955.
3	FAP 151-C(3)	Granby - Tabernash	1946	6- 8-8	10-20-10	The unsatisfactory condition which occurred in 1952 has been picked up by a construction project in 1955.
7	S 0111(1)	Holyoke - South	1948	8-13-3	7-11-6	Unsatisfactory, proposed for reconstruction.
8	F 040(3)	Brush - East	1947	10-17-7	9-16-7	Generally good.
15	F 006(7)	Lamar - South	1948	10-18-7	10-17-9	Present condition generally good. Extensive maintenance in 1949 for stabilization.
17	FI 002(15)	Trinidad -North	1948	10-18-7	10-18-8	Generally good.
18	S 0013(3)	Hooper - Moffat	1947	10-18-8	9-16-8	Generally good.
19	S 0122(2)	Del Norte - Northeast	1948	7-10-7	9-16-8	1952 condition required reconstruction in 1955.
20	F 298(11)	Pagosa Springs - East	1947	6- 3-7	7-13-8	1952 condition required extensive maint. in 1954. Present condition is only fair.
21	F 067(6)	Denver - West U. S. 6	1949	10-15-10	9-15-8	The 1952 condition had worsened in 1954 to require reconstruction in that year.

[1]The sufficiency rating in Colorado awards a par of 40 points for structure. This is broken down to 10 points foundation, 20 points surface, and 10 points drainage. The figures given in the tabulation can be compared to these values.

TABLE 3

GEOMETRIC DESIGN STANDARDS FOR RURAL HIGHWAY CONSTRUCTION, COLORADO DEPARTMENT OF HIGHWAYS

24 Hr Annual Avg Traffic, Design Period[a]	Pavement Type[b]	No. of Lanes	Lane Width (L)	Shoulder Width	Roadbed Width (R)	Design Speed	Maximum Grade %	R O W Width		Access Control (Desirable)	Max Curve Degree	Bridge and Separations		
								Desirable	Minimum			Design Load	Clear Width[g] 60' Long and Over	Clear Width[g] Less Than 60' Long
Type A				c				d	e					
5,000 - 15,000	High	4	12'										2L + 6'	R - 2'
1. Plains				10' - 4'	76' + Med	70	5	250'	150'	Full	3	H-20 S-16	Each	Each
2 Rolling				8' - 4'	72' + Med	60	6	250'	150'	"	5	" '	2	2
3 Rolling				8' - 4'	72' + Med	50	6	250'	150'	"	8 30'	" "	Lanes	Lanes
4 Mountainous				4' - 4'	64' + Med	40	6	250'	150'	"	14	' "		
Type B														
1,600 - 5,000	High	2	12'										2L + 6'	R - 2'
1 Plains				10'	44'	70	5	200'	120'	Partial	3	H-20 S-16		
2 Rolling				8'	40'	60	6	200'	120'	"	5	" "		
3. Rolling				8'	40'	50	6	200'	120'	"	8 30'	" "		
4 Mountainous				4'	32'	40	6	200'	120'	"	14	" "		
Type C														
800 - 2,000	High Med	2	11'										2L + 6'	R - 2'
1 Plains				8'	38'	70	6	150'	120'	No	3	H-20 S-16		
2 Rolling				8'	38'	60	6	150'	120'	"	5	' "		
3 Rolling				4'	30'	50	6	150'	120'	"	8 30'	' "		
4 Mountainous				4'	30'	40	6	150'	120'	"	14	' "		
Type D									f			h		
400 - 1,000	Medium	2	11'										2L + 6'	2L 6"
1. Plains				8'	38'	60	6	120'	80'	No	5	H-20		
2 Rolling				4'	30'	50	6	120'	80'	"	8 30'	"		
3 Mountainous				4'	30'	40	6[f]	120'	80'	"	14	"		
Type E									f			h	i	i
100 - 600	Low Med	2	10'										24'	24'
1. Plains				4'	28'	50	6	100'	60'	No	8 30'	H-20		
2 Rolling				4'	28'	40	6	100'	60'	"	14	"		
3 Mountainous				4'	28'	30	7[f]	100'	60'	"	24	"		
Type F									f			h	i	i
0 - 200	Low	2	-										24'	24'
1 Plains				-	26'	-	6	80'	60'	No	24	H-20		
2 Rolling				-	26'	-	8[f]	80'	60'	"	24	"		
3 Mountainous				-	22'	-	8[f]	80'	60'	"	24	"		

[a] The ' Types ' indicated refer to details shown on Department Standard M-4-F covering typical cross-sections The traffic volumes shown are based on annual average traffic volumes per 24 hours Since all designs are now based on the 30th highest hour, the following reference table is given for the purposes of correlation

Annual Average 24 Hr Volume	Equivalent 30th ø Highest Hour Traffic per Lane		
	P*	M*	T*
5,000	500	400	300
1,600	160	130	100
800	80	65	50
400	40	35	25
100	10	8	6

ø Unless actual traffic counts give a different value, the 30th highest hour is assumed to be 16 percent of the 24 hr annual average traffic volume

* AASHO classification for different types of traffic and used herein as follows

P = Predominantly passenger traffic = 0 to 10 percent trucks having wheel loads 5,000 lb and over.
M = Mixed traffic = 10 to 20 percent trucks having wheel loads 5,000 lb and over
T = Predominantly truck traffic = 20 percent trucks having wheel loads 5,000 lb and over

[b] High = portland cement concrete, asphaltic concrete, or equal.
High Medium = plant mix mats (2"+)
Medium = plant mix or road mix mats (2"+).
Low Medium = surface treatments and light road mix mats (2"-)
Low = natural gravel, sand clay, gravel or crushed rock
When comparative estimates indicate that a higher surface type can be constructed for a cost approaching the cost of a lower surface type, the higher type shall be used.

[c] In the case of divided highways, the larger dimension is the outside shoulder, the smaller the inside shoulder, when used.

[d] Desirable width is 200 feet with full access control, and where service roads are constructed outside of the right-of-way.

[e] Only with full access control, and where service roads are constructed outside of the right-of-way.

[f] In unusual cases the minimums shown may be altered after approval by the Denver Headquarters.

[g] For the interstate system, bridges less than 80 ft long shall have curb-to-curb width equal to the roadbed width, including shoulders and bridges 80 ft and over, the curb-to-curb width shall be the paved width + 6'

[h] Where the character of traffic is predominantly passenger vehicles or other unusual conditions exist, this loading may be reduced on order of the chief engineer

[i] Minimum bridge width on federal aid primary system shall not be less than 26'

preconceived design standard. Actually, at the inception of the design method in 1947, 26 areas were picked for evaluation. About one-half of the sites were currently under construction with the new design method and the others were sites that had been recently built which carried comparable traffic volumes and which were located in environmental conditions similar to the new areas of construction that had been selected. Out of the 26 original sites, 22 are still available for examination and they have become the basis of information which has here been presented. The other 4 sites have either been transferred off the state system, or have been rebuilt for reasons other than structural failure.

Figure 1, which was previously used in exhibiting the design curve information, can be used to determine the over-all thickness of pavements on the various classifications of soils. The design curves indicate that for foundations which approximate surfacing values, a minimum of 4 in. of a pavement structure would be employed. Actually, the 4-in. thickness is nominal and has been established as the minimum that can be used with out present construction equipment to lay a uniform base and wearing course. At the other extreme, under the lightest type traffic and under adverse soil, frost and saturation conditions, a pavement of 17 in. would be employed. For the same conditions and under the heaviest traffic, the pavement structure would be a minimum of 10 in. thicker or would approximate 27 in. in total thickness. Moderate traffic would about split the difference and the pavement thickness would approximate 22 in. The author has always had a personal antipathy for the use of the terms, light traffic, medium traffic, and heavy traffic. It is believed that these generalized terms should not be used in the presumptions used in designing a pavement structure. A heavy duty road on a transcontinental route in the far reaches of the western United States might carry as little as 3,000 to 4,000 vehicles a day. This would be referred to as heavy traffic whereas the same volume in proximity to one of the big metropolitan centers of the east would be considered to be very light. Actually, the traffic volume must be considered, not only in numbers but should be related to wheel loads and repetitions of those loads by magnitude. The performance related to that type of criterion, which would have significance, does not attach itself to the generalized terms spoken of above.

In conjunction with the design method, we may use road mix bituminous pavements as light as 1½ in. for traffic volumes of less than 500 vehicles per day. For the volumes between 500 and 1,500, a hot mix of not less than 2 in. is most commonly used. Above that volume, 3 in. of hot mix is employed and is usually placed in two 1½-in. layers. Any of these basic thicknesses and types may be varied for unusual conditions such as abnormal volumes of heavy truck loads, non-availability of desired grades of aggregate or other similar conditions.

Resurfacing and reconstruction projects are handled in a manner identical to new construction, that is, the same soil survey and analysis of materials are made and the design proceeds in a perfectly normal manner as if the road were to be newly constructed. The criteria for the selection of surface types and the change from one traffic category to another are predetermined on the basis of a set of standards which are a part of the department's field and office manual. Shown as Table 3 are the design criteria which are employed by the department.

Discussion

RAYMOND C. HERNER, Chief, Airport Division, Technical Development and Evaluation Center, Civil Aeronautics Administration, Indianapolis — Livingston's paper is of real value because it describes the service records of roads which have been in use long enough to give some indication of their ultimate behavior. In a refreshingly frank manner he enumerates his failures as well as his successes but does pause long enough to indicate some plausible reasons - outside the realm of the designer - which may account for the failures. This is a point much too frequently overlooked. It is common practice to assign all failures to inadequate design, whereas they often are caused by poor construction practices or control.