Modified C.B.R. Flexible-Pavement Design

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Approximately 1,450 miles of road have been constructed during the past 7 years following the modified California Bearing Ratio flexible-pavement design initiated in 1946. This method is reported in the 1947 PROCEEDINGS of the Highway Research Board as "Wyoming Method of Flexible-Pavement Design."

The modified C.B.R. controls (1) overall thickness of pavement, base, subbase, and that portion of the basement soil classed as selected embankment and (2) the thicknesses and quality of the selected embankment and subbase.

The base and pavement have had no test requirements for stability, other than the Wyoming stability test, so they have been designed both for thicknesses and quality by past experience plus gradation, liquid limit, plasticity index, and wear tests. A test procedure is now being put into practice to allow a better selection of base and pavement aggregates.

Included are tabulations of: (1) roadway and pavement widths, also surfacing widths, based on traffic and state highway system; (2) traffic variations within each state highway system; (3) several near typical highway projects showing number of soil samples taken, number of different designed thicknesses, etc., for both the preliminary and construction stages; and (4) the opinions of the various engineers of the Wyoming Highway Department as to the merits and weaknesses of the present design.

● DURING the past 7 years the modified C.B.R. flexible pavement design has been used in bringing to completion, including a bituminous pavement, approximately 350 miles of reconstruction and 1,100 miles of new construction on Wyoming's 4,800-mile state highway system. Many more miles are in various stages of construction, but not entirely completed.

The present design procedure was initiated in 1946, and reported in the 1947 PROCEEDINGS of the Highway Research Board as "Wyoming Method of Flexible Pavement Design." Briefly, this method includes: (1) compacting the C.B.R. specimen under static load at optimum moisture to the standard AASHO density; (2) soaking the specimen four days with a ten pound surcharge; and (3) using the bearing value determined on a design curve selected by an empirical evaluation of (a) annual precipitation, (b) depth of water table below profile grade, (c) frost action, (d) general existing conditions, and (e) traffic in order to determine the total overall thickness of pavement, base, subbase, and selected embankment.

The modified C.B.R. is used in determining the quality, also the thickness that may be used, of selected embankment and subbase materials. However, the base and pavement have had only the Wyoming stability test, gradation, liquid limit, plasticity index, wear test, and past experience used as the criteria for design thickness and quality of materials.

MODIFICATIONS OF METHOD

Modifications have been made from the original method when revision was justified, as follows:

1. The material originally called "imported fill" has been reclassified as "selected embankment."

2. Thicknesses of pavement and base are held uniform on any one job, and the thicknesses of subbase or selected embankment are used as the adjustable components. These have been modified to vary in uniform increments of 2 or 3 inches, instead of the ½-inch increments originally indicated. This reduces the number of sections necessary on a project, and simplifies the staking.

3. Selected material surfacing is now crushed to a 2-inch maximum in place of allowing up to 4-inch-maximum size in a 6-inch lift. This allows traffic a better riding surface on stage construction.

4. The original minimum center sections, (shown in Figure 1 of the original

TABLE 1

ROADWAY WIDTHS, PAVEMENT WIDTHS, AND SURFACING THICKNESSES, BASED ON TRAFFIC

	TRAFFIC - ESTIMATED EQUIVALENT 5000 POUND WHEEL LOADS FOR 20 YEARS IN ONE DIRECTION - IN MILLIONS													
	0-0.25	0.25-1	1-3	3-5	5-7	7-9	9-11	11-14	14-17	17-21	21-26	26-32	32-40	40-50
Width at bottom of base	26'	28'	30'	40'	40'	40'	40'	42'	42'	42'	42'	48'	48'	48'
Width of bituminous pavement	20'	22'	24'	28'	28'	28'	28'	25'	28'	28'	28'	28'	28'	28'
Minimum total thickness	4½"	5"	5½"	6"	6½"	7"	7½"	8"	8½"	9"	9½"	11"	11½"	12"
Minimum pavement thickness	1½"	1½"	1½"	2"	2"	2"	2"	2½"	2½"	2½"	2½"	2½"	2½"	2½"
Minimum base thickness	3"	3"	3"	4"	4"	4"	4"	4"	4"	4"	4"	5"	5"	5"
	FEDERAL AID SECONDARY			FEDERAL AID PRIMARY				FEDERAL AID INTERSTATE						
	STATE HIGHWAY SYSTEM													

paper) have been increased as indicated in Table 1. The 1½-inch pavement is road mix, the 2-inch pavement either road or plant mix, and the 2½-inch pavement is plant mix laid in two courses. This change was based upon (1) a large increase in equivalent 5,000-lb. wheel loads revising the 1951 to 1971 traffic on some roads up to over 40 million in one direction, whereas the 1946 to 1966 traffic had indicated a high of approximately 15 million, and (2) the conclusion that the original minimum thicknesses were inadequate. These data are shown in Table 2.

5. Occasionally, where conditions are unfavorable, it is the practice to increase total thicknesses above the minimum indicated by the design procedure. This practice is most often used in low areas with high water table, and may double the total minimum required thickness.

SERVICE

Generally the pavement and its substructure components are giving satisfactory service, but in a small percentage (less than 5 percent) of total constructed mileage the performance has not been satisfactory. Briefly, where investigations of failures have been made, poor service has been attributed to one or more of the following:

1. Preliminary soil survey; (a) samples not representative; (b) not recognizing, or properly evaluating, special problems; (c) omission of pertinent data from the preliminary soil profile; (d) soil survey delayed so that testing and design is not allowed adequate time for proper handling.

2. Testing and design; (a) improper processing of samples; (b) not recognizing, or properly evaluating, special problems; (c) not reviewing the tentative preliminary design in the field with the project engineer.

3. Construction practices: (a) pockets, or sections, of unstable basement soil "bridged over" in lieu of subexcavation and backfill; (b) drainage problems not recognized and corrected; (c) no field adjustments in thicknesses made as based on experience and field construction control tests; (d) construction samples not submitted in time to allow revised design of construction thicknesses by the central laboratory; (e) insufficient control of materials.

IMPROVED DESIGN FOR BASE AND PAVEMENT

Experience has proved that (1) some granular materials satisfactory for pavement and base materials would just pass modified C. B. R. requirement for subbase, yet these same materials may have given satisfactory service as base and pavement for a number of years, and (2) some granular materials having a relatively high C. B. R. had inherent characteristics that did not contribute to satisfactory bases and pavements.

The materials section of the Colorado Highway Department had tested a number of the questionable granular materials for the Wyoming Highway Department with Hveem Stabilometer testing equipment, and the resulting design thicknesses were much closer to those indicated by experience than the modified C. B. R. design had indicated. Furthermore, the equipment appeared to be sensitive to small changes in gradation or plasticity, thus it would enable one to evaluate increased stability, if desired, by improving gradation, and addition of binder or filler.

Similar stabilometer equipment has been installed in the Wyoming laboratory for future use on granular materials, including the pavement. It is not expected that this will solve all problems associated with granular materials, only that it will give a more practical evaluation of many materials than has been obtained previously.

DESIGN OF NEAR TYPICAL PROJECTS

Near average projects for secondary, primary and interstate highway systems are shown in Table 3, with a breakdown of soil samples, granular materials samples, tests, and design, on both preliminary and construction. These projects are referred to as "near average" for they include only the middle ranges of soils, and exclude any projects that (1) fall mostly in the A-1-b(0) and A-2-4(0) classifications with modified C. B. R. high enough that thicknesses are governed mostly by the minimum total thickness requirements indicated in Table 1 or (2) fall mostly in the A-6(10 to 16) and A-7-6 (12 to 20) classifications with modified C. B. R. mostly low enough, (3.0 percent or less) that maximum total thicknesses are required for the particular design curve being used, plus any other additional thicknesses allowed for thru cut sections, or low areas with a water table relatively close to profile grade.

The project engineer makes the preliminary soil and materials survey. The samples are tested, and preliminary design set up, by the central laboratory. This design is usually reviewed in the field with the project engineer and adjustments made. Later, during construction, it may be necessary to again make revisions based on construction samples plus other revised data. The projects shown in Table 3 are typical examples of the near-average projects in Wyoming, and study of the tabulation will give an understanding of variations occurring within different projects.

QUESTIONNAIRE ON DESIGN

Recently a questionnaire regarding design methods and practices was submitted to all assistant project engineers, project engineers, maintenance engineers, and district engineers; 32 of 39 engineers considered that they had sufficient experience to answer one or more sections of the questionnaire, and their answers to the main points are given in Table 4.

Thicknesses of Materials

The engineers listing overall thicknesses as being inadequate qualified their statements by pointing out a specific section of a project, or a particular project, and these references were to a very small percent of the total mileage constructed by each engineer. Approximately 25 percent of the engineers answering felt that the 1½-inch road-mix pavements were inadequate, with few unfavorable comments on the 2-inch pavements, and none on the 2½-inch pavements. The engineers reporting base thicknesses as inadequate were referring to the 1½-inch and 2-inch center-base thicknesses used in the past, or the 3-inch-minimum center thicknesses now being used on secondary roads.

TABLE 2

TRAFFIC VARIATION WITHIN EACH WYOMING HIGHWAY SYSTEM

System	U. S. ROUTES	SECTION	TRAFFIC 1941 Daily Total	1941 Daily Commercial	1951 Daily Total	1951 Daily Commercial	20 Year Factor 1951 to 1971	1971 Est. Daily Total	1971 Est. Daily Commercial	20 Year Estimate of Equivalent 5000 lb. Wheel Loads in One Direction 1951 to 1971
Federal Aid Interstate	30	Hanne-Sinclair	1096	147	2014	319	3.0	6042	957	40,525,435
	85 & 87	Cheyenne-South	1044	208	2750	451	3.0	8250	1353	27,780,428
	30	Rock Springs-Gr.River	1561	278	2517	412	2.7	6796	1112	28,266,299
	20	Evansville-Glenrock	1287	233	2698	350	3.0	8094	1050	25,620,263
	87	Kaycee-Buffalo	299	97	514	97	2.5	1285	243	3,109,976
	14	Moorcroft-Carlile	247	55	340	32	2.2	748	70	933,692
Federal Aid Primary	85	Newcastle-Mule Cr.Jct.	269	89	683	205	2.7	1844	554	13,908,143
	20	Moneta-Hiland	469	80	862	141	2.5	2155	353	6,713,212
	189	Big Piney-Daniel	295	92	190	32	2.2	418	70	788,499
Fed.Aid Secondary		Medicine Bow-Casper	----	---	56	10	*15.0	----	*150	*4,532,698
		Gillette-Broadus, Mont.	----	---	56	13	2.7	151	35	439,524
		Manderson-Hyattville	80	13	198	29	2.2	436	64	126,329

*Estimated upon completion of thru route.

TABLE 3

TABULATION OF SAMPLES, TESTS AND DESIGN THICKNESSES ON A NEAR AVERAGE PROJECT ON SECONDARY, PRIMARY AND INTERSTATE HIGHWAYS

PROJECT			PRELIMINARY											CONSTRUCTION				
			SAMPLES				TESTING	SURFACING DESIGN				SAMPLES			TESTS	DESIGN REVISED		
	Number also Estimated Equiv. 5000 lb. Wheel Loads in One Direction in 20 Years in Millions	LENGTH	Soil	Soil Comparisons in Field	Granular Materials	Predominate Soil Types	Modified C.B.R.	Pavement Thickness	Base Center Thickness	Subbase Thickness	Sel. Embankment Thickness	Soil Lab. & Field	Granular Mat'ls. Lab. & Field	Modified C.B.R.	Increased Thickness	Decreased Thickness	Total
		Miles	No.	No.	No.	Classification	No.	In.	In.	In.	In.	No.	No.	No.	Miles	Miles	Miles
INTERSTATE	I 221(6) 40.5	6.98	16	14	96[1]	A-2-4(0), A-4(2 to 8) A-6(8 to 9)	28	2½"[2]	5"[3]	0	4",& 10"	L.22 F.77	L. 32 F.140	0	2.22 2",& 3"	0.96 3",& 6"	3.18
								11½" Minimum Section									
			[1]An extensive granular materials survey was made on this project.														
			[2] 2½" plant mix will be contracted at some future date.														
			[3]Top 2" of 1" base was oil stabilized with 4½% of MC-3, as temporary pavement.														
PRIMARY	F 76(2) 3.6	4.88	28	0	17	A-2-4(0), A-4(3 to 8), A-6(6 to 11)	10	1½"[4]	3½"[4]	4"	0",3", & 9"	L.15 F.30	L.25 F.50	2[6]	0.20 2"	0.00	0.20
								9" Minimum Section[5]									
			[4]Designed & constructed prior to latest revision in thicknesses, see Figure 1.														
			[5]Each project has a minimum section set up on preliminary that governs construction.														
			[6]Most construction samples have C.B.R. referenced to, or estimated from, a similar preliminary.														
SECONDARY	S 84(1) 0.4	8.59	11	11	19	A-3(0), A-2-4(0), A-4(2)	8	1½"	3"	4",& 6"	0	L.18[7] F.39[8]	L.34[7] F.54[8]	4	4.69 2"[9]	0.00	4.69
								8½" Minimum Section									
			[7]Laboratory tests include weekly check tests, finals on the pavement and its substructure components, etc.														
			[8]Field tests include density tests, quality tests, etc., used in the field for control.														
			[9] 4.69 Miles of the 4" subbase was increased 2", to a total of 6", based on construction samples														

TABLE 4

ANSWERS TO QUESTIONNAIRE ON MODIFIED C. B. R. FLEXIBLE-PAVEMENT DESIGN

	QUESTION	Inadequate	Adequate	Excessive	Yes	No	Not Answering
THICKNESS	Total thicknesses of pavement, base, subbase & sel.mat'l.surf.have been	3	26				3
	Pavement thicknesses (as shown in Fig. 1) have been	7	21				4
	Base thicknesses (as shown in Fig. 1) usually have been	5	22				5
	Subbase thicknesses usually have been	6	6				20
	6" additional (used occasionally) thru cuts on C.B.R. of 3.0-% is	2	18				12
QUALITY	Has lack of proper quality in pavement sometimes contributed to failure				14	11	7
	Has lack of proper quality in bases sometimes contributed to failure				15	10	7
	Has lack of proper quality in subbases sometimes contributed to failure				15	6	11
	Should the quality of the bituminous pavements be improved				27	0	5
	Should the quality of the bases be improved				25	1	6
	Should the quality of the subbases be improved				23	1	8
MISCELLANEOUS	For a balance between safety and drainage, which of the following is your choice for finish pavement crown per lineal foot of width of pavement (1/8"				8		2
	(3/16"				16		
	(1/4"				6		
	Which do you prefer (An untreated shoulder				1		
	(A bituminous treated shoulder				16		
	(Extension of pavement to the shoulder line				4		
	(Pavement to the shoulder line & slope treatment				11		
	(Other				0		
	Do you prefer the ditch section to extend well below any granular pavement substructure components				23	1	8

Note: Seven of the thirty-nine engineers did not feel that they had sufficient experience to answer any portion of the questionnaire.

Quality of Materials

Nearly all of the engineers indicated their opinion that the quality of the pavements, bases and subbases should be improved, mostly by better gradation or addition of binders and fillers, yet only about 50 percent indicated that lack of quality in these materials had contributed to failures

Miscellaneous Design Considerations

The present pavement crown of $\frac{1}{8}$ inch per lineal foot of width was considered inadequate for proper drainage by approximately 75 percent of the engineers, with 50 percent preferring a $\frac{3}{16}$-inch pavement crown, and 20 percent favoring a $\frac{1}{4}$-inch crown.

In regard to pavement width and shoulder construction, approximately 45 percent favored extension of the pavement to the shoulder line, and approximately 35 percent favored a slope treatment beyond this point. Those not favoring extension of the pavement to the shoulder line wanted a bituminous treated shoulder similar to the double shot bituminous treatment being used.

The standard ditch section drops $1\frac{1}{2}$ feet below profile grade (carried at the bottom of the base at shoulder), and the practice of deepening this ditch, where necessary to keep it well below any granular materials placed, was approved by most of the engineers familiar with this practice.

SUMMARY

It is estimated that over 95 percent of the mileage constructed by the modified C. B. R. design during the last 7 years is at present giving satisfactory service. The fact that trouble often becomes evident in very short periods makes one hesitant on future predictions of service without accurate projected traffic data and test track studies.