SECTION 500.00 – PAVEMENT DESIGN

SECTION 510.00 – THICKNESS DESIGN FOR FLEXIBLE PAVEMENT

The design procedure described herein is based on methods developed by the California Department of Transportation (Caltrans), which have been modified to accommodate Idaho conditions. Minimum design standards are based on recommendations of Caltrans, AASHTO, The Asphalt Institute, and local experience.

510.01 Summary of Design Factors.

1. Traffic - Expressed in terms of Traffic Index (TI) for the design period (generally 20 years) and determined as follows: State Highway Routes (On-System) - use the estimate of accumulated 8000 kg (18 kip) Equivalent Single Axle Loads (ESALs) to compute the Traffic Index directly by formula; Off-System Routes - use the estimate of current and future ADT and commercial volume percentage to compute the commercial ADT (CADT). Then use the commercial classification (truck density) and Traffic Index Chart to determine the Traffic Index graphically.

2. Structural Quality of the Subgrade Soil - Expressed in terms of Resistance Value (R-value) as measured by the Hveem Stabilometer and expansion pressure as determined by the expansion pressure test.

3. Climate - Express in terms of the Climatic Factor (F) is used to adjust the roadway structure thickness (ballast depth) to account for the detrimental effects of climate on the ability of the structural cross section to support traffic loading.

4. Stiffness - Expressed in terms of the Substitution Ratio (G_f) is used to adjust the thickness of the individual pavement layers in consideration of the cohesive strength of the binder materials, relative stiffness of unbound layers and drainage capability.

5. Economics - Design the structural cross section necessary to accommodate the estimated traffic loading for the design period, using various combinations of base and surfacing materials, that will result in the lowest overall life cycle cost.

Report all test data necessary to each method of design on the Soils Evaluation for Flexible Pavement, Form ITD-808 (Figures 510.01-1 and 510.01-2), for each profile and borrow soil sample.

ITD-808 2-87

SOILS EVALUATION FOR FLEXIBLE PAVEMENT

PROJECT NUMBER	IR-84-3(13)173	TRAFFIC DATA	1987	2007			
		ACCUM. ESALS	1,285,000	18,551,000	[AVE. CADT / 2]	=	—
LOCATION	US-93 - SH50	ADT (TOTAL)	6420	10,330	TRUCK DENSITY		Heavy
COUNTY	Jerome	% COMMERCIAL	30.7	36.4	CLIMATIC FACTOR		1.00
WORK AUTHORIZATION	I854170	COMMERCIAL ADT (CADT)	1970	3760	TRAFFIC INDEX		12.6 by ESALS

IDENT. NUMBER	LABORATORY NUMBER	STATION	DEPTH, MM	UNIFIED SOIL CLASSIF.	L.L.	P.I.	4.75 mm	2.0 mm	0.425 mm	0.075 mm	kg/m³	OPT. MOIST.	'R' VALUE	EXPANSION PRESSURE kPa	RECOMMENDED THICK., mm 'R'	RECOMMENDED THICK., mm EXP.	BLANKET
3-P	87-A0064	—	0.0-305	ML	22	2	95	94	91	66	1685	16.5	54	9.38	549	488	N
4-P	87-A0190	Jr-4	0.0-305	ML	22	4	100	93	84	64	1862	13.2	35	7.65	792	396	N

500-2

- * Wt./C.F. Taken from 'R' value determination.
- ** Wt./C.F. Corrected for 3/4-inch material.
- *** Wt./C.F. Taken from T-74 curve on material at field gradation.

Note: The recommended thicknesses are expressed in terms of untreated aggregate base corrected for climatic factor.

Date mailed April 1, 1987

_______________, P.E.
MATERIALS SUP[illegible]OR

FIGURE 510.01-1

ITD-808

SOILS EVALUATION F R FLEXIBLE PAVEMENT

PROJECT NUMBER	HES-4755(7)	TRAFFIC DATA	1987	2007		
		ACCUM. ESALS	—	—	[AVE. CADT / 2]	= 33
LOCATION	Waha Road	ADT (TOTAL)	220	300	TRUCK DENSITY	Heavy
COUNTY	Nez Perce	% COMMERCIAL	25	25	CLIMATIC FACTOR	1.00
WORK AUTHORIZATION	T852160	COMMERCIAL ADT (CADT)	55	75	TRAFFIC INDEX	8.0 by CADT

IDENT. NUMBER	LABORATORY NUMBER	STATION	DEPTH, MM	UNIFIED SOIL CLASSIF.	L.L.	P.I.	4.75 mm	2.0 mm	0.425 mm	0.075 mm	Kg/m³	OPT. MOIST.	'R' VALUE	EXPANSION PRESSURE kPa	RECOMMENDED THICK., mm 'R'	RECOMMENDED THICK., mm EXP.	BLANKET
1-P	87-A0291	—	0-610	CL	41	23	77	76	72	60	—	—	13	0	671	—	N

- * Wt./C.F. Taken from 'R' value determination.
- ** Wt./C.F. Corrected for 3/4-inch material.
- *** Wt./C.F. Taken from T-74 curve on material at field gradation.

Note: The recommended thicknesses are expressed in terms of untreated aggregate base corrected for climatic factor.

Date mailed April 1, 1987

______________________, P.E.
MATERIALS SUPERVISOR

FIGURE 510.01-2

510.02 Traffic Evaluation. The magnitude of the axle load and the number of load repetitions are major factors in the performance of a flexible pavement structure. Since axle load data are not available for all roadways throughout the state, the data available are combined to give a figure applicable to all routes. Thus, corrections are necessary only for traffic volume and classifications.

Classify commercial vehicles into “Heavy,” “Medium,” and “Light” categories according to the percentages of two-axle and five-axle vehicles within the commercial volume. From this, the 8000 kg (18 kip) Equivalent Single Axle Loads (ESALs) can be estimated for the design period, which in turn are used to calculate the Traffic Index.

	% of Commercial Volume (CADT)	
Classification	Two Axle	Five Axle
Heavy	30 - 50	25 - 40
Medium	50 - 70	10 - 25
Light	70 - 100	0 - 10

If the two-axle classification differs from the five-axle, use the higher classification for design. Interstate highways are always classified as “Heavy.”

Lane distribution of commercial vehicle traffic should be as follows:

Lanes Per Direction	% CADT in Design Lane
1	100
2	70 - 100
3	60 - 80
4	50 - 75

Different methods of traffic analysis are required for on-system and off-system routes due to the availability of load data. Common to both analysis techniques is the Traffic Index, which is a direct input into the thickness design equation. The Traffic Index for both methods is based on the anticipated traffic loading for a 20-year design period and determined as follows.

510.02.01 On-System Route Traffic Index. Figure 510.02.01-1 shows the projected, cumulative ESALs for a particular asphalt pavement. When requesting these data from Headquarters Traffic Survey Unit, submit Form ITD-1151, Traffic Data Request. Two ESAL projections will be returned. One will account for truck ESAL growth on flexible pavements, the other will represent rigid pavement ESAL counts. Flexible pavement ESALs will be lower than rigid pavement ESALs.

PROJECTED COMMERCIAL AND 18,000 EQUIVALENT SINGLE AXLE LOADINGS (ESALS)

3
9:27 TUESDAY, JULY 11, 1989

ROUTE NUMBER : I 90 SEGMENT CODE : 001660 BEGINNING MILEPOINT : 20.930 ENDING MILEPOINT : 21.850
TRUCK DENSITY = 3 : HEAVY LAST YEAR WITH DATA : 1988 CUMULATING ESALS UP TO 2010 STARTING TO CUMULATE IN 1988

YEAR	PASSENGER CAR ADT	PICKUP ADT	COMMERCIAL ADT	ESALS FOR BOTH LANES YEAR VALUE	ESALS FOR BOTH LANES CUMULATIVE	FLEXIBLE PAVEMENT ESAL (IN THOUSANDS) DIRECTION OF TRAVEL YEAR VALUE	DIRECTION OF TRAVEL CUMULATIVE	INSIDE LANE 20 % YEAR VALUE	INSIDE LANE 20 % CUMULATIVE	OUTSIDE LANE 80 % YEAR VALUE	OUTSIDE LANE 80 % CUMULATIVE
1988	6,810	2,680	1,510	594	594	297	297	59	59	237	237
1989	6,980	2,750	1,590	641	1,234	320	617	64	123	256	494
1990	7,150	2,810	1,660	683	1,917	342	959	68	192	273	767
1991	7,320	2,880	1,740	733	2,650	367	1,325	73	265	293	1,060
1992	7,490	2,950	1,810	778	3,429	389	1,714	78	343	311	1,371
1993	7,660	3,020	1,890	824	4,253	412	2,126	82	425	330	1,701
1994	7,830	3,080	1,960	879	5,131	439	2,566	88	513	351	2,053
1995	8,000	3,150	2,040	927	6,059	464	3,029	93	606	371	2,423
1996	8,170	3,220	2,110	977	7,036	488	3,518	98	704	391	2,814
1997	8,340	3,280	2,190	1,036	8,071	518	4,036	104	807	414	3,229
1998	8,510	3,350	2,270	1,088	9,159	544	4,580	109	916	435	3,664
1999	8,680	3,420	2,340	1,150	10,309	575	5,155	115	1,031	460	4,124
2000	8,850	3,480	2,420	1,204	11,513	602	5,757	120	1,151	482	4,605
2001	9,020	3,550	2,490	1,260	12,774	630	6,387	126	1,277	504	5,109
2002	9,190	3,620	2,570	1,326	14,100	663	7,050	133	1,410	531	5,640
2003	9,360	3,690	2,640	1,385	15,435	692	7,742	138	1,548	554	6,194
2004	9,530	3,750	2,720	1,454	16,939	727	8,469	145	1,694	592	6,775
2005	9,700	3,820	2,790	1,515	18,453	757	9,227	151	1,845	606	7,381
2006	9,870	3,890	2,870	1,576	20,030	788	10,015	158	2,003	631	8,012
2007	10,040	3,950	2,940	1,650	21,680	825	10,840	165	2,168	660	8,672
2008	10,220	4,020	3,020	1,714	23,394	857	11,697	171	2,339	686	9,358
2009	10,390	4,090	3,100	1,791	25,185	896	12,593	179	2,519	716	10,074
2010	10,560	4,150	3,170	1,858	27,043	929	13,522	186	2,704	743	10,817

FIGURE 510.02.01-1

PROJECTED COMMERCIAL AND 18,000 EQUIVALENT SINGLE AXLE LOADINGS (ESALS)

2
9:27 TUESDAY, JULY 11, 1989

ROUTE NUMBER : I 90 SEGMENT CODE : 001660 BEGINNING MILEPOINT : 20.930 ENDING MILEPOINT : 21.850
TRUCK DENSITY = 3 : HEAVY LAST YEAR WITH DATA : 1988 CUMULATING ESALS UP TO 2010 STARTING TO CUMULATE IN 1988

				RIGID PAVEMENT ESAL (IN THOUSANDS)							
				ESALS FOR BOTH LANES		DIRECTION OF TRAVEL		INSIDE LANE 20 %		OUTSIDE LANE 80 %	
YEAR	PASSENGER CAR ADT	PICKUP ADT	COMMERCIAL ADT	YEAR VALUE	CUMULATIVE	YEAR VALUE	CUMULATIVE	YEAR VALUE	CUMULATIVE	YEAR VALUE	CUMULATIVE
1988	6,810	2,680	1,510	902	902	451	451	90	90	361	361
1989	6,980	2,750	1,590	970	1,873	485	936	97	187	388	749
1990	7,150	2,310	1,660	1,041	2,914	520	1,457	104	291	416	1,165
1991	7,320	2,880	1,740	1,113	4,027	557	2,013	111	403	445	1,611
1992	7,490	2,950	1,810	1,182	5,209	591	2,604	118	521	473	2,083
1993	7,660	3,020	1,890	1,258	6,467	629	3,233	126	647	503	2,587
1994	7,830	3,080	1,960	1,337	7,804	669	3,902	134	780	535	3,122
1995	8,000	3,150	2,040	1,418	9,222	709	4,611	142	922	567	3,689
1996	8,170	3,220	2,110	1,494	10,716	747	5,358	149	1,072	598	4,286
1997	8,340	3,280	2,190	1,579	12,295	790	6,148	158	1,230	632	4,918
1998	8,510	3,350	2,270	1,667	13,962	833	6,981	167	1,396	667	5,585
1999	8,680	3,420	2,340	1,756	15,718	878	7,859	176	1,572	703	6,287
2000	8,850	3,480	2,420	1,848	17,566	924	8,783	185	1,757	739	7,027
2001	9,020	3,550	2,490	1,933	19,500	967	9,750	193	1,950	773	7,800
2002	9,190	3,620	2,570	2,029	21,529	1,015	10,764	203	2,153	812	8,611
2003	9,360	3,690	2,640	2,127	23,656	1,064	11,828	213	2,366	851	9,462
2004	9,530	3,750	2,720	2,228	25,884	1,114	12,942	223	2,588	891	10,353
2005	9,700	3,820	2,790	2,330	28,214	1,165	14,107	233	2,821	932	11,286
2006	9,870	3,890	2,870	2,425	30,639	1,212	15,319	242	3,064	970	12,255
2007	10,040	3,950	2,940	2,531	33,170	1,266	16,585	253	3,317	1,013	13,268
2008	10,220	4,020	3,020	2,640	35,811	1,320	17,905	264	3,581	1,056	14,324
2009	10,390	4,090	3,100	2,752	38,562	1,376	19,281	275	3,856	1,101	15,425
2010	10,560	4,150	3,170	2,865	41,427	1,432	20,713	286	4,143	1,146	16,571

FIGURE 510.02.01-2

To calculate the design Traffic Index for a 20-year design, begin by subtracting the design year's cumulative ESALs (furthest right column) from the same column 20 years later. Shorter term analysis will require the design year's ESALs be subtracted from the corresponding design period, cumulative ESALs. ESALs shown are in thousands. Use the following equation to compute the design Traffic Index.

$TI = 9.0\ (ESALs/10^6)^{0.119}$

EXAMPLE:

Refer to the flexible pavement ESAL table (Figure 510.02.01-1). The TI would be calculated in the following manner: the ESALs accumulated by 1989 are 494,000. A 20-year design (year 2009) shows cumulative ESALs of 10,074,000. The 20-year ESAL loading on this segment is the difference between the two numbers, or 9,580,000 ESALs. Calculate the TI with 9,580,000 ESALs.

$TI = 9.0\ (9{,}580{,}000/10^6)^{0.119} = 11.78$

Round the TI to 11.8 for use in the design thickness equation (see Section 510.03).

510.02.02 Off System Routes. Use the estimate of current and future traffic volumes (ADT) and commercial volume percentage to compute the commercial ADT (CADT), then use the commercial classification (truck density) and TI chart (Figure 510.02.02-1) to determine the TI graphically. Round the result to the nearest half unit. Commercial vehicles are defined as having at least one dual-wheeled axle and at least 4550 kg (10, 000 lb) GVW.

510.03 Design by R-Value. The Resistance Value (R-value) is a test value, which measures the ability of a soil to resist lateral flow due to vertically applied load. Conduct this test using the Hveem Stabilometer in accordance with Idaho T-8, wherein the soil is tested at an applied load of 1,135 kg (2,500 lbs.). Plot the R-values obtained by testing at three or more moisture conditions as shown in Figure 510.03-1.

The intersection of this curve with 1135 kg (2,500 lbs.) ordinate gives the design R-value.

Use the following formula to compute flexible pavement thickness.

GE (in millimeters) = 0.975 (TI) (100-R) (CF)

GE (in meters) = 0.001 (TI) (100-R) (CF)

GE (in feet) = 0.0032 (TI) (100 R) (CF)

Where:	GE	=	Equivalent thickness of gravel
	TI	=	Traffic index (510.02)
	R	=	Resistance value
	CF	=	Climatic Factor (510.05)

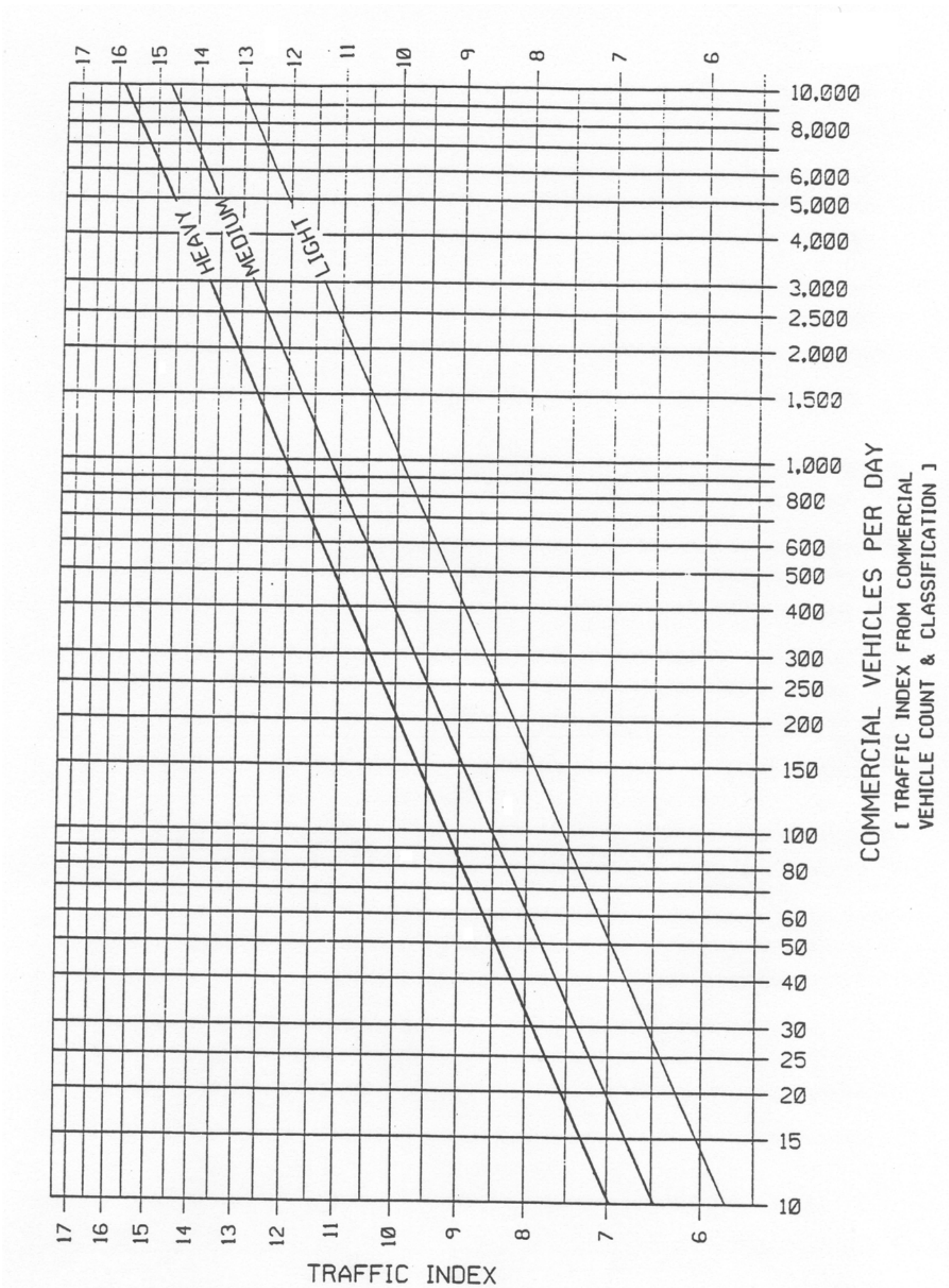


FIGURE 510.02.02-1

ITD-803 1-88

REPORT OF TESTS ON SOIL

LAB. NO. ______
JOB ORDER NO. ______

PROJECT NO. *SAMPLE* SOURCE NO. ______
IDENT. NO. *AB/XXXXXXX-A-PE/3-P* COUNTY *Somewhere*
SUBMITTED BY *Able Body* DATE SAMPLED *6-6-88* DATE RECEIVED *6-8-88*
STATION *625+00* TEST HOLE *3* LAYER NO. ______ DEPTH *0.0-1.0'*
DESCRIPTION OF SOIL *Silt*

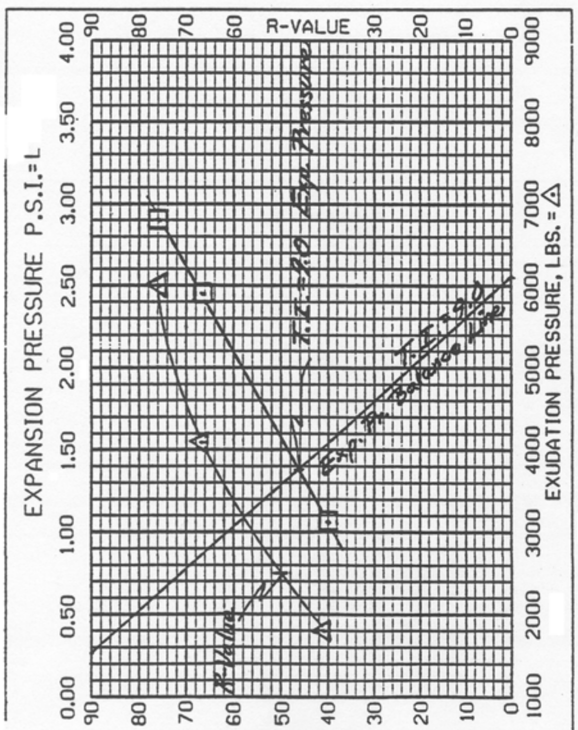
MECHANICAL ANAL. % PASS	
3" SQ.	100
2" SQ.	98
1" SQ.	97
3/4" SQ.	96
1/2" SQ.	96
NO. 4	95
NO. 10	94
NO. 20	93
NO. 30	92
NO. 40	91
NO. 50	89
NO. 100	78
NO. 200	66

SOIL CONSTANTS	
LIQUID LIMIT	22
PLASTIC LIMIT	20
PLASTICITY INDEX	2
SPECIFIC GRAVITY (+3/4")	
SPECIFIC GRAVITY (-NO.4)	
SAND EQUIVALENT	
"R" VALUE	50
EXP. PRESSURE, PSI	1.38
UNIFIED CLASSIFICATION	ML
TRAFFIC INDEX	9.0

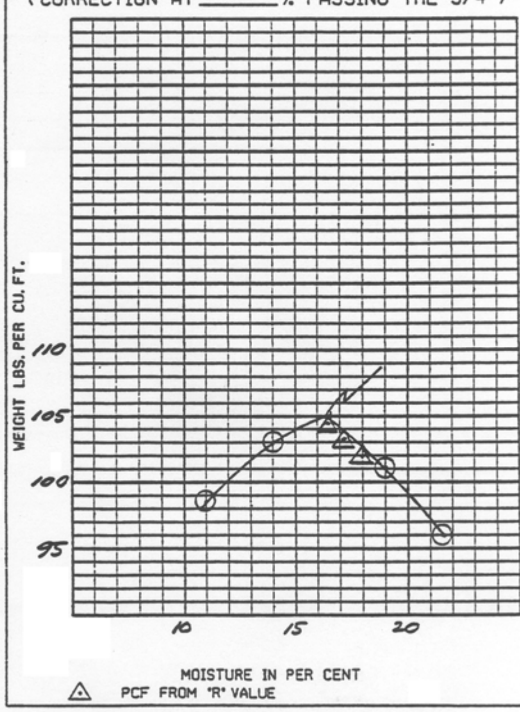
PIPE DATA

PH- ______ RESISTIVITY ______ OHM. CM.

REMARKS



MOISTURE DENSITY CURVE
AASHTO DESIGNATION T 99, METHOD *A*
MAX. DRY WT. *105.0* #/CU. FT. OPT. MOIST. *16.3* %
CORRECTED MAX. DRY WT.= ______ LB./CU. FT.
(CORRECTION AT ______ % PASSING THE 3/4")



THIS REPORT COVERS ONLY MATERIAL AS REPRESENTED BY THIS SAMPLE AND DOES NOT NECESSARILY COVER ALL SOIL FROM THIS LAYER OR SOURCE.

DATE MAILED *1 Jul 88* ______ , P.E.
MATERIALS SUPERVISOR

4/94W

FIGURE 510.03-1

Design each layer in the pavement structure based on the R-value of the layer below. Round the result to the next higher 15 mm (0.05 foot). For convenience, Figure 510.03-2 can be used to solve this equation graphically. (Note: Correct for regional (climatic) factor before rounding.)

Some moisture sensitive soils will exhibit severe reductions in R-value with small increases in moulding moisture content. For these soils, it may be advisable to use lower exudation pressures to estimate design R-value. Subgrade improvement and/or use of separation geotextiles may be necessary.

510.04 Design by Expansion Pressure. Given the expansion pressure data from Idaho T-8, plot a curve as shown in Figure 510.03-1.

Obtain the design expansion pressure where this curve intersects the diagonal balance line, using Figure 510.04-1. The balance line represents the condition at which the ballast requirement from R-value, at the governing TI, is equal to that from expansion pressure. The overlying material must provide sufficient to prevent any volume change in the subgrade soil caused by expansion. For design purposes, the unit weight of this material is assumed to be 2100 kg/m^3 (130 pcf) for most granular materials, with the exception of some volcanic aggregates. The thickness in meters (feet) necessary to confine soil with expansive properties is computed with the following formula:

$$\text{B (meters)} = \frac{\text{Expansion pressure (kPa)} \times 102}{\text{Unit weight of aggregate (kg/m}^3\text{)}}$$

$$\text{B (feet)} = \frac{\text{Expansion pressure (kPa)} \times 144}{\text{Unit weight of aggregate (lb/ft}^3\text{)}}$$

For convenience, Figure 510.08-1 can be used to solve this equation graphically.

510.05 Design Adjustments for Climatic Factor. The Climatic Factor (CF) is used to adjust the required pavement structure thickness to compensate for the detrimental effects of severe climate on the ability of the pavement to carry traffic.

Apply the climatic factor (CF) as shown in 510.03

Where: CF = 1.00 for Region 1
CF = 1.05 for Region 2
CF = 1.10 for Region 3
CF = 1.15 for Region 4

The various regions were defined through a study of precipitation records during the periods when the 30-year mean temperature remained below 0°C (32°F) and from the experience of the District Maintenance Engineers. Figure 510.08-1 illustrates the climatic regions to be used.

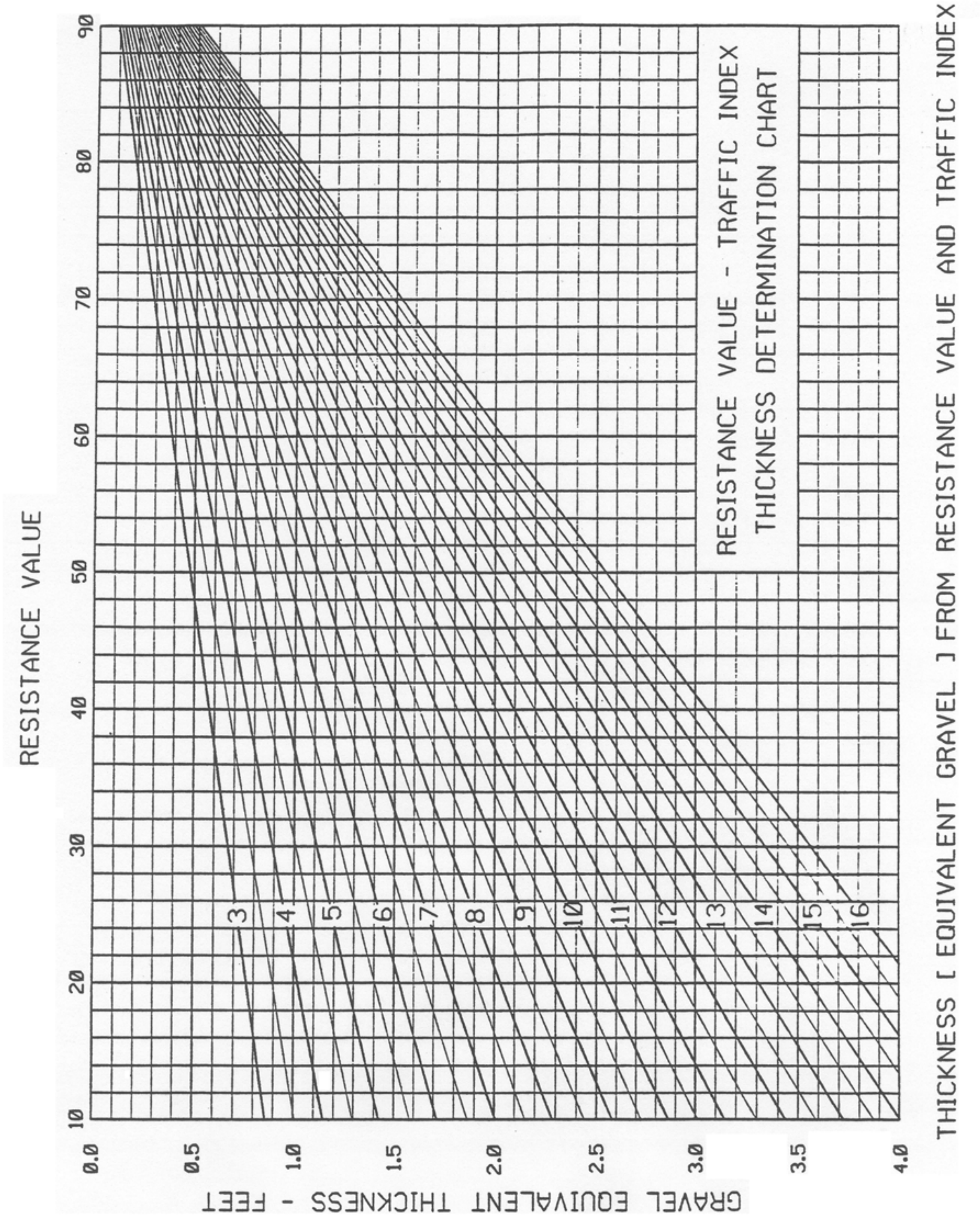


FIGURE 510.03-2

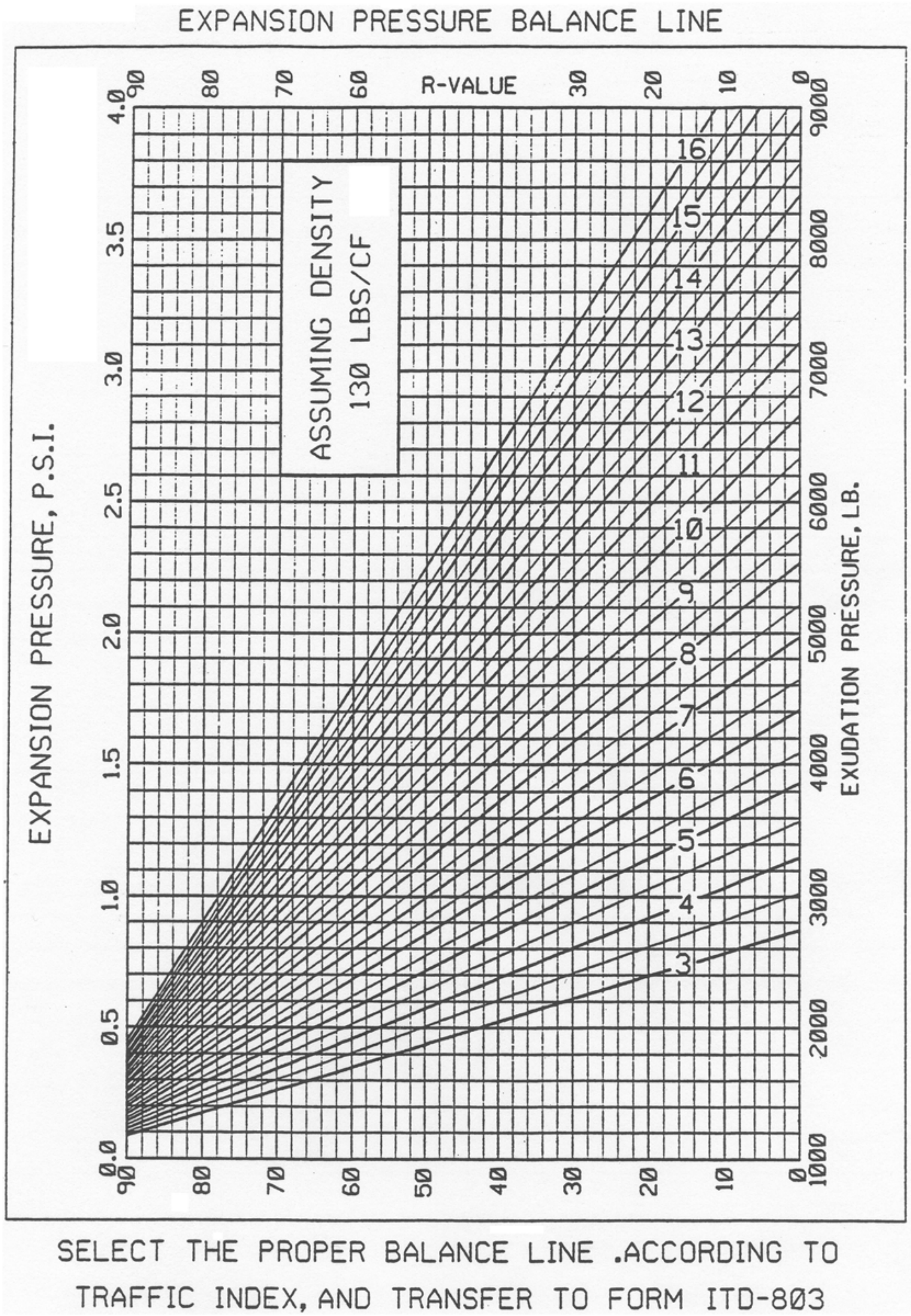


FIGURE 510.04-1

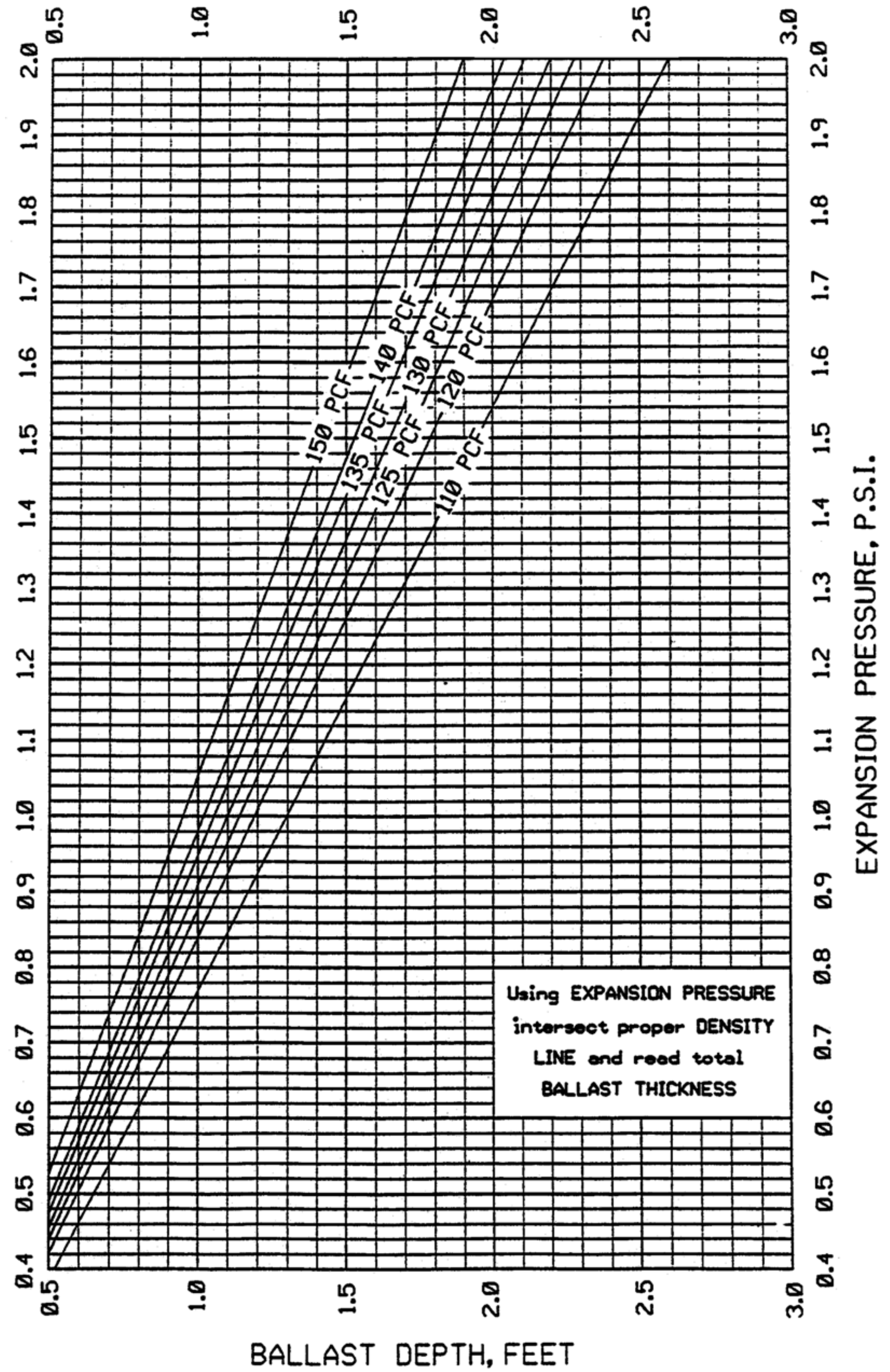


FIGURE 510.04-2

510.06 Design Adjustments for Material Cohesion, Stability and Drainage. The cohesion of compacted asphalt treated mixtures gives additional strength to the pavement structure. In consideration of this cohesive strength, it is then reasonable to adjust the total pavement thickness determined from R-value design after adjustment for climatic effects. Likewise, the stability and drainage capacity of unbound mixtures affects the strength of the pavement structure. Adjust the total pavement thickness in accordance with the relative strength of the unbound materials.

Obtain the adjustment in pavement thickness by use of Substitution Ratios (G_f) as follows:

Layer Thickness = Design Thickness / G_f

SUBSTITUTION RATIOS (G_f)
FOR COMMON PAVEMENT AND BASE MATERIALS

Traffic Index	Plant Mix Pavement	Road Mix Pavement and ATB	(ATPB) Asphalt Treated Permeable Base	Untreated Aggregate Base*	Granular Subbase **
14.5-16.5	1.4	1.10	1.2	1.0	0.85
12.7-14.4	1.5	1.20	1.2	1.0	0.85
10.0-12.6	1.6	1.30	1.2	1.0	0.85
8.1-9.9	1.8	1.45	1.2	1.0	0.85
6.7-8.0	2.0	1.60	1.2	1.0	0.85
5.6-6.6	2.2	1.75	1.2	1.0	0.85
0.0-5.5	2.4	1.90	1.2	1.0	0.85

*Open graded shot rock base material has been assigned an equivalency value of 1.2:1. For untreated aggregate base with an R-value less than 75, but greater than 70, reduce the substitution ratio to 0.90:1.

**For Subbase with an R-value of less than 60 reduce the substitution ratio to that of granular borrow, (0.75:1).

Granular borrow is material designated as improved subgrade and should have an R-value greater than the natural subgrade to be improved. Granular borrow may include cinder aggregate and selected granular excavation if quality is satisfactory.

510.07 Minimum Thickness of Pavement Elements. In any design procedure, it is also necessary to consider construction and maintenance operations in order to avoid the possibility of producing an impractical design. Based on these considerations, it is generally impractical to place surface, base, or subbase layers less than some minimum thickness. For purposes of this design procedure, the following are considered to be minimum practical thicknesses that are to be applied to each pavement layer:

Surface	45 mm (0.15 foot)
Base	100mm (0.35 foot) (ATB, ATPB, UTB)
Subbase	100mm (0.35 foot) ((If used) or a minimum of 2 times the maximum particle size.)

The minimum thickness of asphalt pavement placed upon asphalt treated permeable base (ATPB) shall be 75 mm (0.25 foot), regardless of Traffic Index.

The minimum lift thickness of asphalt pavement constructed with coarse graded aggregate should be at least 3 times the nominal maximum aggregate size.

The minimum thickness of open graded shot rock base (rock cap) shall be 180 mm (0.6 foot).

Establish the minimum thicknesses with the following stipulations:

- Design Traffic Index shall not be less than 6.0 for routes on the state highway system.
- Where traffic including construction traffic will run on exposed base prior to placing the surface, the gravel equivalent of the base and subbase shall support a Traffic Index of at least 7.0 on Interstate and NHS routes.
- Design thicknesses shall not be less than 150 mm (0.50 foot) actual depth for off-system routes, nor less than 250 mm (0.80 foot) actual depth for on-system routes.
- Treat base course aggregates with an R-value less than 80 to a depth that will satisfy the ballast requirements of the underlying base and/or subbase courses, keeping in mind the minimum thicknesses stated above.
- In lieu of treating base course aggregates, increase the surface course thickness to satisfy the ballast requirements of the underlying base and/or subbase course, if more economical to do so.
- Design base course thickness for the actual subbase R-value where possible.
- The overall thickness design must satisfy the ballast requirements of the subgrade soil.
- Granular borrow, placed as improved subgrade, must be thick enough to protect the native subgrade.
- Structural elements of a flexible pavement are illustrated in Figure 510.07-1.

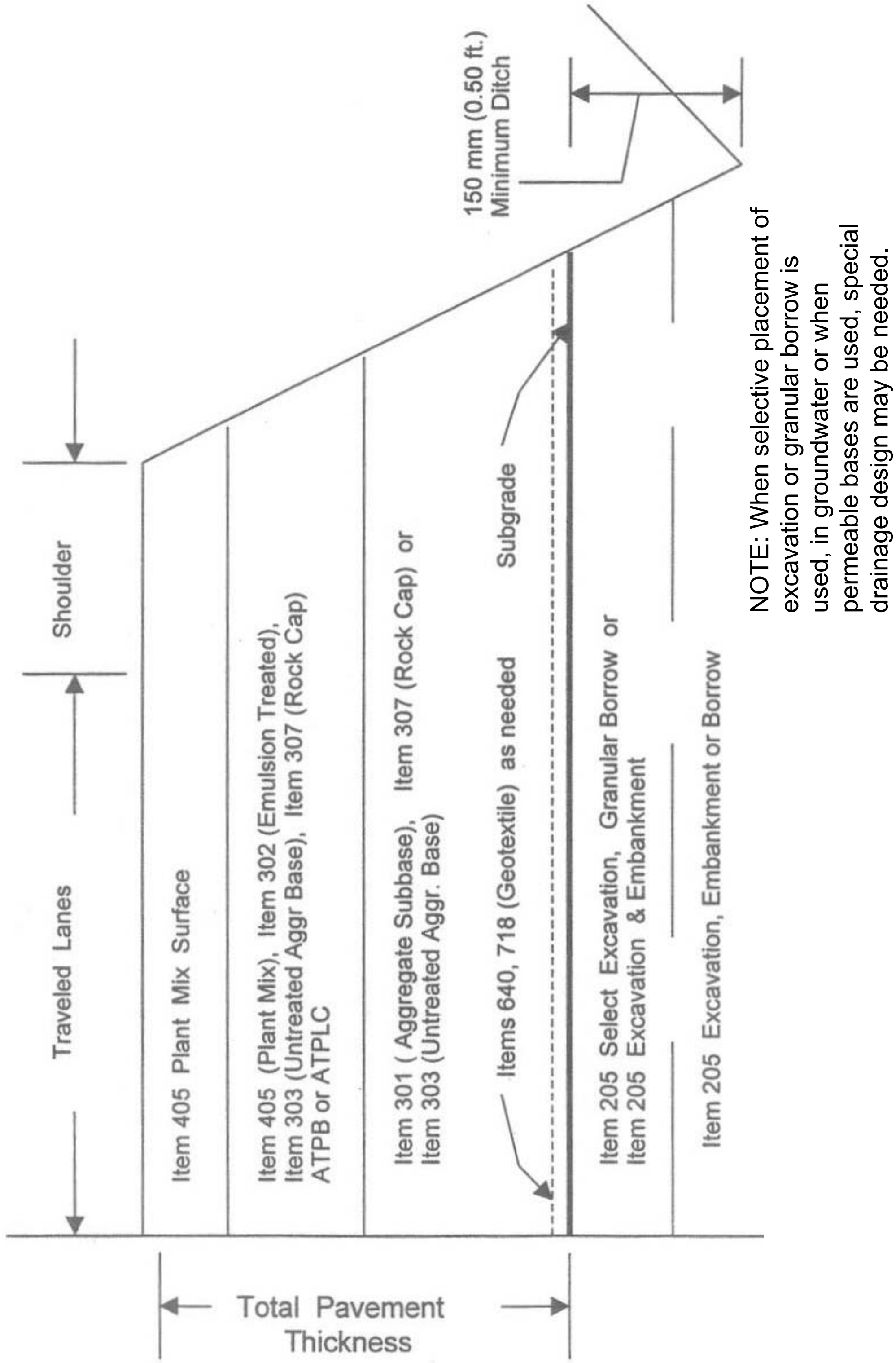


FIGURE 510.07-1. STRUCTURAL ELEMENTS OF FLEXIBLE PAVEMENTS

510.08 Reduced Design Period Thickness Design for Flexible Pavement. It is the policy of the Department to build projects with completed pavements. However, there are circumstances where a reduced design period will permit increased benefits to the public or provide a higher type pavement. Prior approval will be required to use a design period less than 20 years.

In many cases, a reduced design period cannot be effectively provided, i.e., in sections with curb and gutter or where several bridges are included within the project boundaries. Large traffic volumes may also pose difficulties. Make a detailed economic analysis before a reduced design period is selected.

For projects where a reduced design period is feasible and desirable, design the pavement structural cross section according to the following criteria:

- Step 1: Determine the pavement structural cross section required for a 20-year design, as if a reduced design period was not to be considered.
- Step 2: Determine the Traffic Index for a reduced design period by using the design traffic loading for at least the first 8 years of the 20-year design period used in Step 1 above (use ESALs for on-system routes, CADT for off-system routes).
- Step 3: Determine the surface course thickness for a reduced design period using the Traffic Index computed in Step 2 above. Complete the pavement structural cross section for the reduced design period by using the base and subbase thicknesses computed in Step 1 above.
- Step 4: The addition of the desired future wearing surface to the pavement structural cross section determined in Step 3 above fulfills the requirements for the 20-year design.
- Step 5: The pavement structural cross section for a reduced design period shall not be less than the minimum standards specified in Section 510.07.
- Step 6: In all cases, fulfill expansion pressure thickness requirements during a reduced design period.

510.09 Design Examples. The following examples are offered to illustrate the design method described previously.

510.09.01 Example. Assume a four-lane interstate highway with the following design data.

	1987		2007
Accumulated ESALs (design lane)	545,000		21,392,000
R-value		30	
Subgrade expansion pressure in kPa (psi)		4.13 (0.60)	
Unit weight base and surface in kg/m^3 (pcf)		2,080 (130)	
Climatic region		2	

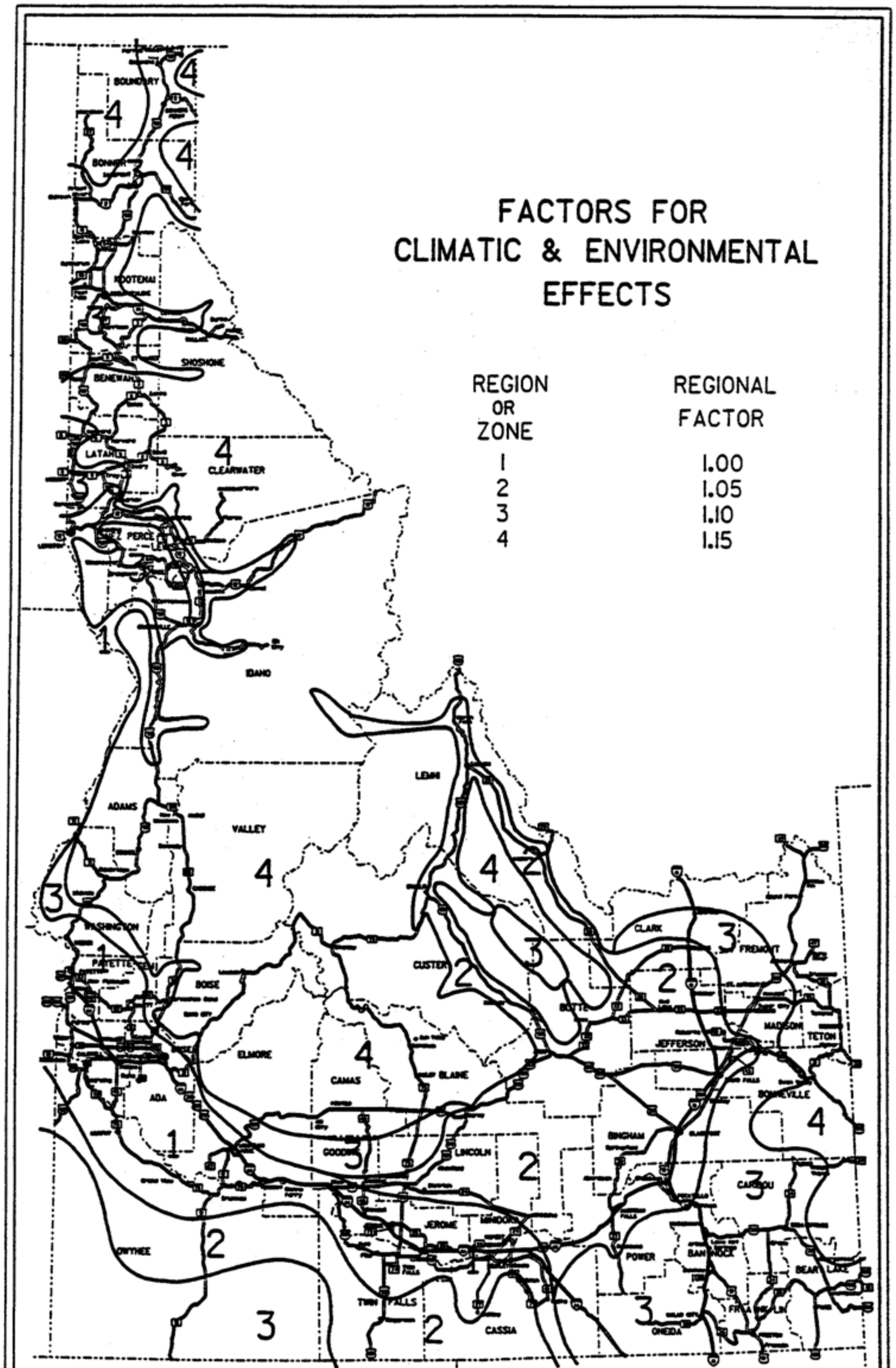
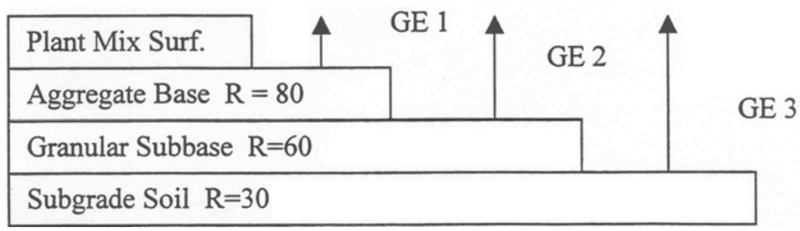


FIGURE 510.08-1

Assume that the available crushed aggregate base material has an R-value of 80+, and that a granular subbase source is also available with an R-value of 60.

Begin by making a sketch of the pavement cross section to be designed.



Calculate the design ESALs.

ESALs = 21,392,000 - 545,000 = 20,847,000

$TI = 9.0(20{,}847{,}000/10^6)^{0.119}$
TI = 12.92, use 12.9

Calculate the ballast requirement for the plant mix surface, including climatic adjustment.

GE = 0.975(TI)(100 - R)(CF)
GE = 0.975(12.9)(100 – 80)(1.05) = 265 mm

GE = 0.0032(TI)(100 – R)(CF)

GE = 0.0032(12.9)(100 – 80)(1.05) = 0.87 ft.

Calculate the layer thickness by applying the substitution ratio for plant mix pavement.

T = 265 / 1.5 = 177 mm, use 180 mm
GE 1 (actual) = 180 × 1.5 = 270 mm

T = 0.87 / 1.5 = 0.58 ft., use 0.60 ft.

GE 1 (actual) = 0.60 × 1.5 = 0.90 ft.

Calculate the ballast requirement for the crushed aggregate base course.

GE = 0.975(12.9)(100 - 60)(1.05) = 528 mm

GE = 0.0032 (12.9)(100 – 60)(1.05) = 1.73 ft.

Calculate the layer thickness by applying the substitution ratio for aggregate base.

T = (528 mm - 270 mm) / 1.00 = 258 mm, use 270 mm
GE 2 (actual) = (270 mm × 1.00) + 270 mm = 540 mm

T = (1.73 ft. – 0.90 ft.) / 1.00 = 0.83 ft., use 0.85 ft.
GE 2 (actual) = (0.85 ft. × 1.00) + 0.90 ft. = 1.75 ft.

Calculate the ballast requirement for the granular subbase.

GE = 0.975 (12.9)(100 - 30)(1.05) = 925 mm

GE = 0.0032 (12,9(100 – 30)(1.05) = 3.03 ft.

Calculate the layer thickness by applying the substitution ratio for granular subbase.

T = (925 mm - 540 mm) / 0.85 = 453 mm, use 465 mm
GE 3 (actual) = (465 mm × 0.85) + 540 mm = 935 mm

T = (3.03 ft. – 1.73 ft.) / 0.85 = 1.53 ft., use 1.55 ft.
GE 3 (actual) = (1.55 ft. × 0.85) + 1.75 ft. = 3.06 ft.

Check the actual pavement thickness provided by R-value design against the actual thickness requirement by expansion pressure.

T (actual) = 180 mm + 270 mm + 465 mm = 915 mm
B = (4.13 kPa × 102,000) / 2080 kg/m^3 = 202 < 915 mm, OK

T (actual) = 0.60 ft. + .85 ft. + 1.55 ft. = 3.00 ft.
B = (0.60 psi × 144) / 130 pcf = 0.66 ft. < 3.00 ft., OK

The typical section is then composed of:

180 mm (0.60 foot) plant mix pavement
270 mm (0.85 foot) crushed aggregate base
465 mm (1.55 feet) granular subbase

The section provides an actual total thickness of 915 mm (2.95 feet) and a gravel equivalent total thickness of 935 mm (3.06 feet)

NOTE: The conversion from English to metric units is not exact, hence the calculated thicknesses may not be the same.

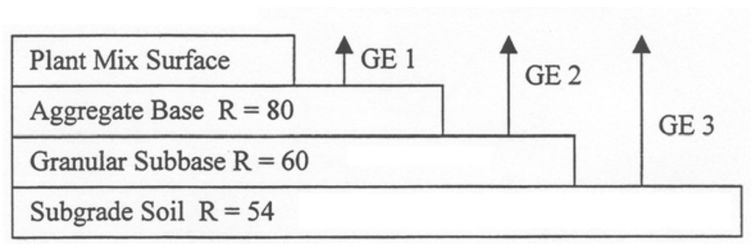
NOTE: For convenience, R-value ballast requirements can be determined graphically using Figure 510.03-2 and expansion pressure requirements using Figure 510.04-2.

510.09.02 Example. Assume a four-lane interstate highway with the following design data:

	1987		2007
Accumulated ESALs (design lane)	30,000		1,070,000
R-value		54	
Subgrade expansion pressure in kPa (psi)		9.38(1.36)	
Unit weight base and surface in kg/m^3 (pcf)		2,080 (130)	
Climatic region		1	

Assume that the available crushed aggregate base material has an R-value of 80+, and that a granular subbase source is also available with an R-value of 60.

Begin by making a sketch of the pavement cross section to be designed.



Calculate the design ESALs.

ESALs = 1,070,000 - 30,000 = 1,040,000

Calculate the Traffic Index.

$TI = 9.0\ (1{,}040{,}000/10^6)^{0.119}$
TI = 9.04, use 9.0

Calculate the ballast requirement for the plant mix surface, including climatic adjustment.

GE = 0.975 (9.0)(100 - 80)(1.00) = 176 mm

GE = 0.0032 (9.0)(100 – 80)(1.00) = 0.58 ft.

Calculate the layer thickness by applying the substitution ratio for plant mix pavement.

T = 176 mm / 1.8 = 98 mm, use 105 mm
GE 1 (actual) = 105 mm × 1.8 = 189 mm

T = 0.58 ft. / 1.8 = 0.32 ft., use 0.35 ft.
GE 1 (actual) = 0.35 ft. × 1.8 = 0.63 ft.

Calculate the ballast requirement for the plant mix and crushed aggregate base course, assuming granular subbase is not used.

GE = 0.975 (9.0)(100 - 54)(1.00) = 404 mm

GE = 0.0032 (9.0)(100 – 54)(1.00) = 1.32 ft.

Calculate the layer thickness for aggregate base by applying the substitution ratio for aggregate base and subtracting the gravel equivalent for plant mix.

T = (404 mm) - (189 mm) / 1.00 = 215 mm, use 225 mm
GE 2 (actual) = (225 mm × 1.00) + 189 mm = 414 mm

T = (1.32 ft.) – (0.63 ft.) / 1.00 = 0.69 ft., use 0.70 ft.
GE 2 (actual) = (0.70 ft. × 1.00) + 0.63 ft. = 1.33 ft.

check the actual pavement thickness provided by R-value design against the actual thickness requirement by expansion pressure.

T (actual) = 105 mm + 225 mm = 330 mm
B = (9.38 kPa × 102,000) / 2082 kg/m^3 = 460 > 330 mm, add subbase

T (actual) = 0.35 ft. + 0.70 ft. = 1.05 ft.
B = (1.36 psi × 144) / 130 pcf = 1.51 > 1.05 ft., add subbase

In this case, expansion pressure governs and additional material is needed. Since the granular subbase has an R-value different than that of the subgrade soil, recalculate the ballast requirement for the aggregate base layer to include a layer of granular subbase.

GE = 0.975 (9.0)(100 - 60)(1.00) = 351 mm

GE = 0.0032 (9.0)(100 – 60)(1.00) = 1.15 ft.

Recalculate the layer thickness by applying the substitution ratio for aggregate base.

T = (351 mm - 189 mm) / 1.00 = 162 mm, use 165 mm
GE 3 (actual) = (165 mm × 1.00) + 189 mm = 354 mm

T = (1.15 ft. – 0.63 ft. / 1.00 = 0.52 ft., use 0.55 ft.
GE 3(actual) = (0.55 ft. × 1.00) + 0.63 ft. = 1.18 ft.

Recalculate the depth of granular subbase necessary to fulfill the ballast requirement from expansion pressure.

T = 460 - (105 mm + 165 mm) = 190 mm, use 195 mm
GE 3 (actual) = (195 mm × 0.85) + 354 mm = 520 mm

T = 1.15 ft. – (0.35 ft. + 0.55 ft.) = 0.61 ft., use 0.65 ft.

Check the ballast provided against the ballast required by the subgrade soil.

GE = 0.975 (9.0)(100 - 54)(1.00) = 404 mm
GE (provided) = 520 mm > 404 mm, OK

GE = 0.0032 (9.0)(100 – 54)(1.00) = 1.32 ft.
GE (provided) = 1.73 ft. > 1.32 ft., OK

The typical section is then composed of:

105 mm (0.35 foot) plant mix pavement
165 mm (0.55 foot) crushed aggregate base
195 mm (0.65 foot) granular subbase

The section provides an actual total thickness of 465 mm (1.55 feet) and a gravel equivalent total thickness of 520 mm (1.73 feet).

510.09.03 Example. Assume a ramp on the interstate project shown in example 510.09.02 above. This example (510.09.03) is presented to illustrate the necessity to establish a new expansion pressure balance line when the traffic changes for a given soil. It will also show the alternate method of determining Traffic Index.

	1987		2007
Total ADT	83		250
% Commercial volume		12	
Commercial class ‘n		Medium	
Subgrade R-value		54	
Subgrade expansion pressure in kPa (psi)		9.38 (1.36)	

Unit Weight base in surface in kg/m^3 (pcf)		2,082 (130)	
Climatic region		1	

Traffic on the ramp is one-way. Calculate the design ADT.

ADT = (83 + 250) / 2 = 167

Compute the commercial volume.

CADT = 167 × 0.12 = 20

Use Figure 510.02.02-1 with the CADT and commercial classification shown above to determine that the Traffic Index is 7.0.

Using Figure 510.03-2, a Traffic Index of 7.0, and R-value of 54, the total unadjusted thickness (gravel equivalent) is 314 mm (1.03 feet).

Determine the expansion pressure balance line from Figure 510.04-1 with the use of the test report (Figure 510.03-1). Select the expansion pressure value for the changed traffic conditions at the intersection of the expansion pressure curve and the expansion pressure balance line (Figure 510.09.03-1). This gives an expansion pressure of the subgrade soil equal to 7.86 kPa (1.14 psi).

Using Figure 510.04-2 with the 7.86 kPa (1.14 psi) expansion pressure and 2082 kg/m^2 (130 pcf) for weight of base and pavement materials results in a required thickness of 384 mm (1.26 feet).

The climatic factor for Region 1 is 1.00 (Figure 510.08-1), resulting in no increase for climate.

It should be noted at this point, that if a comparison is made with example 510.09.02 above, the change in Traffic Index from 9.0 to 7.0 has decreased the required thickness for the ramps from 402 mm (1.32 feet) to 314 mm (1.03 feet) gravel equivalent by R-value and from 460 mm (1.51 feet) to 384 mm (1.26 feet) actual thickness by expansion pressure.

Calculate the ballast requirement for the plant mix surface, including climatic adjustment.

GE = 0.975 (7.0)(100 - 80)(1.00) = 137 mm

GE = 0.0032 (7.0)(100 – 80)(1.00) = 0.45 ft.

Calculate the layer thickness by applying the substitution ratio for plant mix pavement.

T = 137 mm / 2.0 = 70 mm, use 75 mm
GE 1 (actual) = 75 mm × 2.0 = 152 mm

T = 0.45 ft. / 2.0 = 0.23 ft., use 0.25 ft.
GE 1 (actual) = 0.25 ft. × 2.0 = 0.50 ft.

ITD-803 1-88

REPORT OF TESTS ON SOIL

LAB. NO. ____
JOB ORDER NO. ____

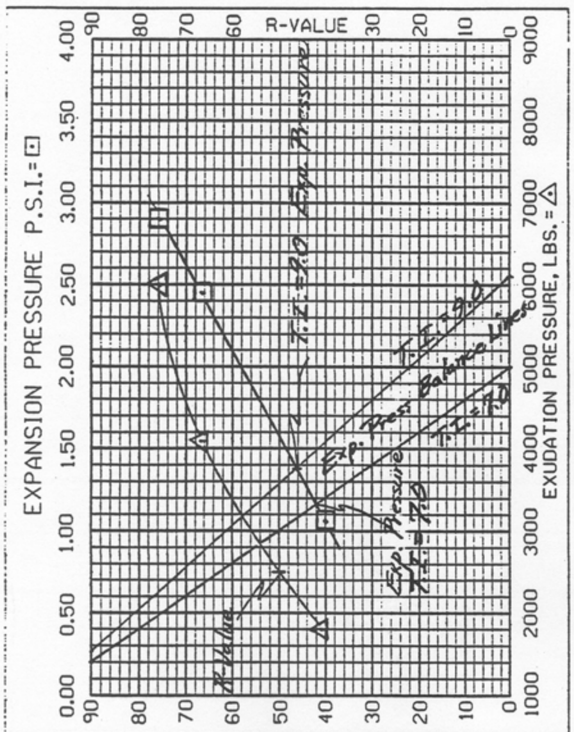
PROJECT NO. SAMPLE SOURCE NO. ____
IDENT. NO. AB/XXXXXXX-A-FE/S-P COUNTY Somewhere
SUBMITTED BY Able Body DATE SAMPLED 6-6-88 DATE RECEIVED 6-8-88
STATION 625+00 TEST HOLE 3 LAYER NO. ____ DEPTH 0.0-1.0'
DESCRIPTION OF SOIL Silt

MECHANICAL ANAL. % PASS		SOIL CONSTANTS	
3" SQ.	100	LIQUID LIMIT	22
2" SQ.	98	PLASTIC LIMIT	20
1" SQ.	97	PLASTICITY INDEX	2
3/4" SQ.	96	SPECIFIC GRAVITY (+3/4")	
1/2" SQ.	96	SPECIFIC GRAVITY (-NO.4)	
NO. 4	95	SAND EQUIVALENT	
NO. 10	94	"R" VALUE	50
NO. 20	93	EXP. PRESSURE, PSI	1.15
NO. 30	92	UNIFIED CLASSIFICATION	ML
NO. 40	91	TRAFFIC INDEX	7.0
NO. 50	89		
NO. 100	78		
NO. 200	66		

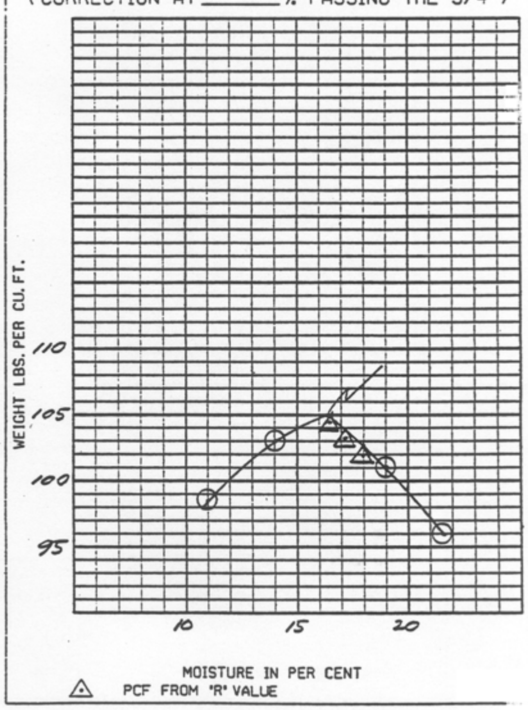
PIPE DATA

PH- ____ RESISTIVITY ____ OHM. CM.

REMARKS



MOISTURE DENSITY CURVE
AASHTO DESIGNATION T 99, METHOD A
MAX. DRY WT. 105.0 #/CU. FT. OPT. MOIST. 16.3 %
CORRECTED MAX. DRY WT.= ____ LB./CU. FT.
(CORRECTION AT ____ % PASSING THE 3/4")



THIS REPORT COVERS ONLY MATERIAL AS REPRESENTED BY THIS SAMPLE AND DOES NOT NECESSARILY COVER ALL SOIL FROM THIS LAYER OR SOURCE.

DATE MAILED 1 Jul 88 ____________, P.E.
4/94W MATERIALS SUPERVISOR

FIGURE 510.09.03-1

Calculate the ballast requirement for the crushed aggregate base course.

GE = 0.975 (7.0)(100 - 54)(1.00) = 314 mm

GE = 0.0032 (7.0)(100 – 54)(1.00) = 1.03 ft.

Calculate the layer thickness by applying the substitution ratio for aggregate base.

T = (314 mm - 150 mm) / 1.00 = 164 mm, use 165 mm
GE 2 (actual) = (165 mm × 1.00) + 150 mm = 315 mm

T = (1.03 ft. – 0.50 ft.) / 1.00 = 0.53 ft. use 0.55 ft.
GE 2 (actual) = (0.55 ft. × 1.00) = 0.50 ft. = 1.05 ft.

Check the actual pavement thickness provided by R-value design against the actual thickness requirement by expansion pressure.

T (actual) = 75 mm + 165 mm = 240 mm
B = (801 kPa × 144) / 2082 kg/m^3 = 384 mm > 240 mm, add subbase

T (actual) = 0.25 ft. + 0.55 ft. = 0.80 ft.
B = (1.14 psi × 144) / 130 pcf = 1.26 ft. > 0.80 ft., add subbase

In this case, expansion pressure governs and additional material is needed. Since the granular subbase has an R-value different than that of the subgrade soil, recalculate the ballast requirement for the aggregate base layer to include a layer of granular subbase.

GE = 0.975 (7.0)(100 - 60)(1.00) = 273 mm

GE = 0.0032(7.0)(100 - 60)(1.00) = 0.90 ft.

Recalculate the layer thickness by applying the substitution ratio for aggregate base.

T = (273 mm - 152 mm) / 1.00 = 122 mm, use 120 mm
GE 2 (actual) = (120 mm × 1.00) + 152 mm = 272 mm

T = (0.90 ft. – 0.50 ft.) / 1.00 = 0.40 ft., use 0.40 ft.

Recalculate the depth of granular subbase necessary to fulfill the ballast requirement from expansion pressure.

T = 384 - (75 mm + 120 mm) = 189 mm, use 195 mm
GE 3 (actual) = (195 mm × 0.85) + 272 mm = 437 mm

T = 1.26 –(0.25 ft + 0.4 0 ft.) = 0.61 ft., use 0.65 ft.
GE 3 (actual) = (0.65 ft. × 0.85) + 0.90 ft. = 1.45 ft.

Check the ballast provided against the ballast required by the subgrade soil.

GE = 0.975 (7.0)(100 - 54)(1.00) = 314 mm
GE (provided) = 437 mm > 314 mm, OK

GE = 0.0032 (7.0)(100 – 54)(1.00) = 1.03 ft.
GE (provided) = 1.45 ft. > 1.03 ft., OK

The typical section is then composed of:

75 mm (0.25 foot) plant mix pavement
120 mm (0.40 foot) crushed aggregate base
195 mm (0.65 foot) granular subbase

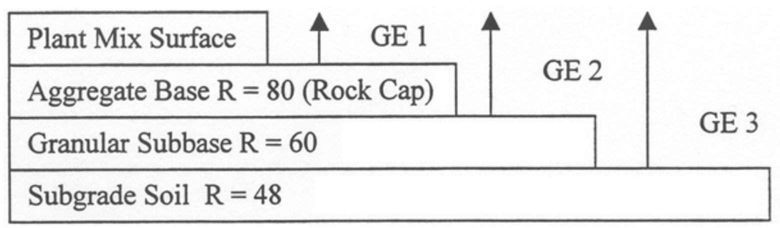
This section provides an actual total thickness of 390 mm (1.30 feet) and a gravel equivalent total thickness of 437 mm (1.45 feet).

510.09.04 Example. Assume an Interstate or major NHS Highway with the following design data: This is a major route, carrying in excess of 1000 trucks per day. To achieve pavement drainage, Open-graded Shot Rock Base (Rock Cap) is selected for base.

	1995		2015
Accumulated ESALs (Design Lane)	400,000		16,500,000
Subgrade R-value		48	
Subgrade Expansion Pressure: kPa (psi)		2.75 (0.4)	
Unit Weight - Surfacing: kg/m^3 (pcf)		2,360 (147)	
Unit Weight - Rock Cap: kg/m^3 (pcf)		1,760 (110)	
Unit Weight - Rock Cap: kg/m^3 (pcf)		2,080 (130)	
Climatic Region		3	

Assume Rock Cap has an R-value of at least 80, and that a source of granular subbase is available with an R-value of at least 60.

Begin by making a sketch of the pavement cross section to be designed.



1. A plantmix binder/leveling course is placed an average of 45mm (0.15 feet) thick over the rock cap before placing plantmix surface. This binder course is given no structural value. An overrun of 5 to 10% in plant mix binder should be expected due to penetration into the rock cap.

2. If aggregate base is used to level the surface of the rock cap, an overrun of up to 40% may occur depending on the gradation of the rock cap. Unless filter criteria is satisfied, this option is not recommended, since infiltration of the aggregate base may continue after paving. In certain conditions, where traffic must be routed over the Rock Cap before the plant mix binder can be placed, an aggregate base binder becomes necessary.

Calculate Traffic Index:

$TI = 9.0\ (13{,}550{,}000/10^{6})^{0.119}$
TI = 12.27 Use 12.3

Calculate the ballast requirement for the plant mix surface, including climatic adjustment.

$GE = 0.975(TI)(100\text{-}R_B)(CF)$
GE = .0975(12.3)(20)(1.10) = 264mm

$GE = 0.0032\ (TI)(100 - R_B)(CF)$
GE = 0.0032 (12.3)(20)(1.10) = 0.87 ft.

Calculate the layer thickness by applying the substitution ration for plant mix pavement.

T = 264 mm / 1.6 = 165mm, use 165
GE 1 (actual) = 165 mm × 1.6 = 264 mm

T = 0.87 ft / 1.6 = 0.54 ft., use 0.55 ft.
GE 1 (actual) = 0.55 ft. × 1.6 = 0.88 ft.

Calculate the ballast requirement over subgrade.

GE = .0975(12.3)(100-48)(1.10) = 686mm

GE = 0.0032 (12.9)(100 – 48)(1.10) = 2.25 ft.

Calculate the layer thickness by applying the substitution ration for Rock Cap and subtract out the plantmix surfacing.

T = (686 mm – 264 mm)/1.2 = 352mm, Use 360mm
GE 2 (actual) = (360 mm × 1.2) + 264 mm = 696mm

T = (2.25 ft. – 0.88 ft./ 1.2 = 1.14 ft., use 1.2 ft.
GE 2 (actual) = (1.20 ft. × 1.2) + 0.88ft. = 2.32 ft.

NOTE: A subbase layer may be placed beneath the rock cap in some instances provided the filter criteria in Section 511 is satisfied or a geotextile is placed over the subbase.

Check the actual pavement thickness provided by R-value design against actual thickness required by expansion pressure.

T (actual) = 165mm + 360mm = 525mm
B = (2.75 kPa × 102)/2080 = 135mm < 525mm, OK

T (actual) = 1.20 ft. + 0.55 ft. = 1.75 ft.
B = (0.4 psi × 144) / 130 = 0.44 ft. < 1.75 ft., OK

The above calculations were based on an averaged unit weight of 2,080 kg/m^3 (130 pcf). Where pavement components have different unit weights, a weighted average may be used to calculate the equivalent thickness, or make the comparison based on vertical pressure.

Compute weighted average unit weight:

(165 mm × 2360) + (360 mm × 1760)/(165+360) = 1956 kg/m^3 (122 pcf)

Recalculate thickness required by expansion pressure.

T (actual) = 525 mm
B = (2.75 kPa × 102)/1956 = 143 mm (a 6% increase)

Calculate subgrade pressure exerted by pavement section.

P = (2360 kg/m^3 × 165 mm/1000) + (1760 kg/m^3 × 360 mm/1000) = 1023 kg/m^2

P = 1023 kg/m^2 × 0.00978 = 9.95 kPa > 2.75 kPa OK

510.10 References.

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