APPENDIX 2

TABLE 1

Class	min. r.o.w.	design capacity A.D.T.	design speed	grade min.	grade max.	allowed surface
Expressway	150	20-50,000	60	0.5	6	pave.
Principle Arterial	120	12-28,000	60	0.5	6	pave.
Minor Arterial	100	5-10,000 two lane 10-18,000 four lane	50	0.5	6	pave.
Major Collector	80	2-5,000	45	0.5	8	pave.
Minor Collector	60	1250-2500	40	0.5	8	pave.
Local Access	60	500-1250	30	0.5	10	pave.
Local Minor Residential	60	0-500	30	0.5	10	pave. gravel *
Local Industrial	70	0-1250	30	0.5	8	pave.
Local Commercial	70	0-1250	30	0.5	6	pave.

* subject to the restrictions and conditions listed in Article 6

TRIAL BASE THICKNESS, D_{BS} (INCHES) ________				SERVICEABILITY CRITERIA PSI = ________		RUTTING CRITERIA RD (INCHES) ________	
(1) SEASON (ROADBED MOISTURE CONDITION)	(2) ROADBED RESILIENT MODULUS M_R (psi)	(3) BASE ELASTIC MODULUS E_{BS} (psi)	(4) PROJECTED 18 - KIP ESAL TRAFFIC W_{18}	(5) ALLOWABLE 18 - KIP ESAL TRAFFIC $(W_{18})_{PSI}$	(6) SEASONAL DAMAGE $W_{18}/(W_{18})_{PSI}$	(7) ALLOWABLE 18 -KIP ESAL TRAFFIC $(W_{18})_{RUT}$	(8) SEASONAL DAMAGE $W_{18}/(W_{18})_{RUT}$
WINTER (FROZEN)							
SPRING/THAW (SATURATED)							
SPRING/FALL (WET)							
SUMMER (DRY)							
		TOTAL TRAFFIC =		TOTAL DAMAGE =		TOTAL DAMAGE =	

TABLE 2

APPENDIX 3 - PAVEMENT DESIGN EXAMPLES

ASPHALT PAVEMENT

As an example to illustrate the procedure and requirements of Article 6, assume the following:

o Minor collector functional classification

o HVEEM test R value of 20

o Projected traffic volume equivalent to the minimum 18K EDLA value of 30 for a minor collector

From the equations in 6.2 c:

$S_1 = [(20-5)/11.29] + 3 = 4.33$

$M_R = 10^{(S_1 + 18.72)/6.24} = 4898$ (use 5000)

Convert EDLA to ESAL (20 year design period)

30 x 20 x 365 = 219,000

From 6.3 c , the reliability factor for a minor collector is 80

From Figure 17 in Appendix 1:

Modulus for base course with structural coefficient of 0.12 is approximately 26,000.

Modulus for subbase course with structural coefficient of 0.10 is approximately 21,000.

From the nomograph in Figure 16 of Appendix 1 (reproduced to illustrate example as Figure A3 - 1, this Appendix) read the following structural numbers for layered design per Figure 15:

$SN_1 = 1.45$

$SN_2 = 1.65$

$SN_3 = 2.7$

Per the procedure described in 6.5 and illustrated in Figure 15:

$D^*_1 \geq SN_1/a_1 = 1.45/0.44 = 3.3$; use 3.5

$SN^*_1 = a_1 D^*_1 \geq SN_1 = (3.5)(0.44) = 1.54$

$D^*_2 \geq SN_2 - SN^*_1/a_2 m_2 = (1.65-1.54)/0.12 = 1$; use 6 inch min.

$SN^*_1 + SN^*_2 \geq SN_2 = (0.12)(6) + (3.5)(0.44) = 2.26$; > 1.65 ok

$D^*_3 \geq SN_3 - (SN^*_1 + SN^*_2)/a_3 m_3 = (2.7 - 2.26)/0.10 = 4.4$; use 5

total = $SN^*_1 + SN^*_2 + SN^*_3 = 1.54+0.72+0.50 = 2.76 > 2.7$ ok

Therefore use the following layer thickness:

Depth of HBP (D^*_1) - 3.5 inches

Depth of Class 6 base course (D^*_2) - 6 inches

Depth of Class 2 subbase course (D^*_3) - 5 inches

The above would be the minimum allowed values.

If a full depth asphalt design were proposed for this example (and APPROVED by the Public Works Director) the required depth would be :

$D_{fda} = SN_3/a_1 = 2.7/0.44 = 6.14$; use 6.5 inches

GRAVEL ROAD DESIGN

The primary design requirements for aggregate surfaced roads include:

- o Predicted future traffic for the design period (see Article 2)
- o The lengths of the seasons (see Article 6.6.1e)
- o Seasonal resilient moduli of the roadbed soil (see Article 6.6.1f)
- o Elastic modulus, E_{BS}(psi), of aggregate base layer (from HVEEM or other testing. M_R value)
- o Elastic modulus, E_{BS}(psi), of aggregate subbase layer (from HVEEM or other testing. M_R value)
- o Design serviceability loss, ΔPSI (Article 6.6.1c)
- o Allowable rutting, RD(inches), in surface layer (Article 6.6.1a), and
- o Aggregate loss, GL(inches), of surface layer (Article 6.6.1b)

These design requirements are used in conjunction with the computational chart in Table 2 in Appendix 2 and the design nomographs for serviceability (Figure 18, Appendix 1) and rutting (Figure 19, Appendix 1). The following steps outline the procedure:

Step 1: Select four levels of aggregate base thickness, D_{BS}, which should bound the probable solution. Prepare four separate tables, one for each trial thickness, identical to Table 2. On each of the four tables enter the trial base thickness, D_{BS}; design serviceability loss, Δ PSI; and the allowable rutting, RD in the appropriate boxes.

Step 2: Enter the appropriate seasonal resilient (elastic) moduli of the roadbed (M_R) and the aggregate base material, E_{BS}, in columns 2 and 3, respectively, of Table 2. The base modulus values may be proportional to the resilient modulus of the roadbed soil during a given season. However, a constant value of 30,000 psi was used in the example which follows since a portion of the aggregate base material will be converted into an equivalent thickness of subbase material (which will provide some shield against the environmental moisture effects).

Step 3: Enter the seasonal 18-kip ESAL traffic in column 4 of Table 2. Assuming that truck traffic is distributed evenly throughout the year, the lengths of the seasons should be used to proportion the total projected 18-kip ESAL traffic to each season. If the road is load-zoned (restricted) during certain critical periods, the total traffic may be distributed only among those seasons when truck traffic is allowed. Total traffic of 36,500 18-kip ESAL applications (the minimum 5 EDLA and a 20 year design period) and a seasonal pattern corresponding to U. S. Climatic Region VI was used in the example.

Step 4: Within each of the four tables estimate the allowable 18-kip ESAL traffic for each of the four seasons using the serviceability-based nomograph (Figure 18) and enter the result in column 5. If the resilient modulus of the roadbed soil (during the frozen season) is such that the allowable traffic exceeds the upper limit of the nomograph, assume a practical value of 500,000 18-kip ESAL.

Step 5: Within each of the four tables estimate the allowable 18-kip ESAL traffic for each of the four seasons using the rutting-based nomograph (Figure 19) and enter the result in column 7. Again, if the resilient modulus of the roadbed soil is such that the allowable traffic exceeds the upper limit of the nomograph, assume a practical value of 500,000 18-kip ESAL.

Step 6: Compute the seasonal damage values in each of the four tables for the serviceability criteria by dividing the projected seasonal traffic (column 4) by the allowable traffic in that season (column 5). Enter these seasonal damage values in column 6 of Table 2 corresponding to serviceability criteria. Next, follow these same instructions for rutting criteria, i.e., divide column 4 by column 7 and enter in column 8.

Step 7: Compute the total damage for both the serviceability and rutting criteria by adding the seasonal damages. When this is accomplished for all four tables, a graph of total damage versus base layer thickness should be prepared. The average base layer thickness, $\underline{D}_{BS}$, required is determined by interpolating in this graph for a total damage equal to 1.0. Figure A3-5 provides an example in which the design is controlled by the serviceability criteria.

Step 8: The base layer thickness determined in the last step should be used for design if the effects of aggregate loss are negligible. If, however, aggregate loss is significant, the design thickness is determined using the following equation:

$$D_{BS} = \underline{D}_{BS} + (0.5 \times GL)$$

where GL = total estimated aggregate (gravel) loss (in inches) over the performance period.

Step 9: The final step of the design chart procedure for aggregate surfaced roads is to convert a portion of the aggregate base layer thickness to an equivalent thickness of subbase material. This is accomplished with the aid of Figure 20. Select the final base thickness desired, D_{BS_f} (6 inches is used in the example). Draw a line to the estimated modulus of the subbase material, E_{BS}. Go across and through the scale corresponding to the reduction in base thickness, $D_{BS_i} - D_{BS_f}$. Then for the known modulus of the base material, E_{BS}, determine the required subbase thickness, D_{SB}.

As an example to illustrate the described procedure and the requirements of Article 6, assume the following:

- o HVEEM R value of 20 for the roadbed soil.
- o The minimum required EDLA of 5, over a 20 year design period for a total traffic of 36,500 18-kip ESAL.

Assume 6, 8, 10, and 12 inches of base thickness for preparation of the four tables. Per Article 6.6.1, the design serviceability loss is 3, and the allowable rutting is 2.

Proportion the total projected 18-kip ESAL traffic into the seasonal traffic values for column 4 according to the lengths of season specified in 6.6.1e.

The results of proceeding according to steps 4, 5, and 6 above are shown in the example tables, Tables A3-1 through A3-4.

Figure A3-5 shows the graph of total damage versus base layer thickness for this example. The serviceability criteria require a larger thickness of base than the rutting criteria. Use the higher value (11.6 inches) for design.

Gravel loss is specified for design purposes in 6.6.1b as 2 inches, therefore the required thickness, D_{BS}, is:

$$D_{BS} = \underline{D}_{BS} + (0.5 \text{ x } GL) = 11.6 + (0.5 \text{ x } 2) = 12.6 \text{ inches.}$$

Use Figure 20 (reproduced showing the example as Figure A3- 4) to determine the amount of subbase material required to reduce the base thickness by 6 inches.

TABLE 2a - EXAMPLE ASSUMING 6 INCHES BASE COURSE

TRIAL BASE THICKNESS, D_{BS} (INCHES) 6				SERVICEABILITY CRITERIA PSI = 3		RUTTING CRITERIA RD (INCHES) 2	
(1) SEASON (ROADBED MOISTURE CONDITION)	(2) ROADBED RESILIENT MODULUS M_R (psi)	(3) BASE ELASTIC MODULUS E_{BS} (psi)	(4) PROJECTED 18 - KIP ESAL TRAFFIC W_{18}	(5) ALLOWABLE 18 - KIP ESAL TRAFFIC $(W_{18})_{PSI}$	(6) SEASONAL DAMAGE $W_{18}/(W_{18})_{PSI}$	(7) ALLOWABLE 18 -KIP ESAL TRAFFIC $(W_{18})_{RUT}$	(8) SEASONAL DAMAGE $W_{18}/(W_{18})_{RUT}$
WINTER (FROZEN)	20,000	30,000	9,125	32,000	0.29	350,000	0.03
SPRING/THAW (SATURATED)	1,500	30,000	4,563	2,200	2.07	3,500	1.30
SPRING/FALL (WET)	3,300	30,000	9,125	5,000	1.83	4,500	2.03
SUMMER (DRY)	4,900	30,000	13,687	7,000	1.96	7,500	1.82
		TOTAL TRAFFIC =	36,500	TOTAL DAMAGE =	6.15	TOTAL DAMAGE =	5.18

TABLE 2b - EXAMPLE ASSUMING 8 INCHES BASE COURSE

TRIAL BASE THICKNESS, D_{BS} (INCHES) 8				SERVICEABILITY CRITERIA PSI = 3		RUTTING CRITERIA RD (INCHES) 2	
(1) SEASON (ROADBED MOISTURE CONDITION)	(2) ROADBED RESILIENT MODULUS M_R (psi)	(3) BASE ELASTIC MODULUS E_{BS} (psi)	(4) PROJECTED 18 - KIP ESAL TRAFFIC W_{18}	(5) ALLOWABLE 18 - KIP ESAL TRAFFIC $(W_{18})_{PSI}$	(6) SEASONAL DAMAGE $W_{18}/(W_{18})_{PSI}$	(7) ALLOWABLE 18 -KIP ESAL TRAFFIC $(W_{18})_{RUT}$	(8) SEASONAL DAMAGE $W_{18}/(W_{18})_{RUT}$
WINTER (FROZEN)	20,000	30,000	9,125	70,000	0.13	400,000	0.02
SPRING/THAW (SATURATED)	1,500	30,000	4,563	4,200	1.09	7,000	0.65
SPRING/FALL (WET)	3,300	30,000	9,125	12,000	0.76	11,000	0.83
SUMMER (DRY)	4,900	30,000	13,687	13,500	1.01	16,000	0.86
		TOTAL TRAFFIC =	36,500	TOTAL DAMAGE =	2.99	TOTAL DAMAGE =	2.36

TABLE 2c - EXAMPLE ASSUMING 10 INCHES BASE COURSE

TRIAL BASE THICKNESS, D_{BS} (INCHES) 10				SERVICEABILITY CRITERIA PSI = 3		RUTTING CRITERIA RD (INCHES) 2	
(1) SEASON (ROADBED MOISTURE CONDITION)	(2) ROADBED RESILIENT MODULUS M_R (psi)	(3) BASE ELASTIC MODULUS E_{BS} (psi)	(4) PROJECTED 18 - KIP ESAL TRAFFIC W_{18}	(5) ALLOWABLE 18 - KIP ESAL TRAFFIC $(W_{18})_{PSI}$	(6) SEASONAL DAMAGE $W_{18}/(W_{18})_{PSI}$	(7) ALLOWABLE 18 -KIP ESAL TRAFFIC $(W_{18})_{RUT}$	(8) SEASONAL DAMAGE $W_{18}/(W_{18})_{RUT}$
WINTER (FROZEN)	20,000	30,000	9,125	120,000	0.08	400,000	0.02
SPRING/THAW (SATURATED)	1,500	30,000	4,563	8,000	0.57	11,000	0.41
SPRING/FALL (WET)	3,300	30,000	9,125	20,000	0.46	21,000	0.43
SUMMER (DRY)	4,900	30,000	13,687	28,000	0.49	28,000	0.49
		TOTAL TRAFFIC =	36,500	TOTAL DAMAGE =	1.60	TOTAL DAMAGE =	1.35

TABLE 2d - EXAMPLE ASSUMING 12 INCHES BASE COURSE

TRIAL BASE THICKNESS, D_{BS} (INCHES) 12				SERVICEABILITY CRITERIA PSI = 3		RUTTING CRITERIA RD (INCHES) 2	
(1) SEASON (ROADBED MOISTURE CONDITION)	(2) ROADBED RESILIENT MODULUS M_R (psi)	(3) BASE ELASTIC MODULUS E_{BS} (psi)	(4) PROJECTED 18 - KIP ESAL TRAFFIC W_{18}	(5) ALLOWABLE 18 - KIP ESAL TRAFFIC $(W_{18})_{PSI}$	(6) SEASONAL DAMAGE $W_{18}/(W_{18})_{PSI}$	(7) ALLOWABLE 18 -KIP ESAL TRAFFIC $(W_{18})_{RUT}$	(8) SEASONAL DAMAGE $W_{18}/(W_{18})_{RUT}$
WINTER (FROZEN)	20,000	30,000	9,125	200,000	0.05	400,000	0.02
SPRING/THAW (SATURATED)	1,500	30,000	4,563	18,000	0.25	22,000	0.21
SPRING/FALL (WET)	3,300	30,000	9,125	30,000	0.30	31,000	0.29
SUMMER (DRY)	4,900	30,000	13,687	40,000	0.34	45,000	0.30
		TOTAL TRAFFIC =	36,500	TOTAL DAMAGE =	0.94	TOTAL DAMAGE =	0.82

NOMOGRAPH SOLVES:

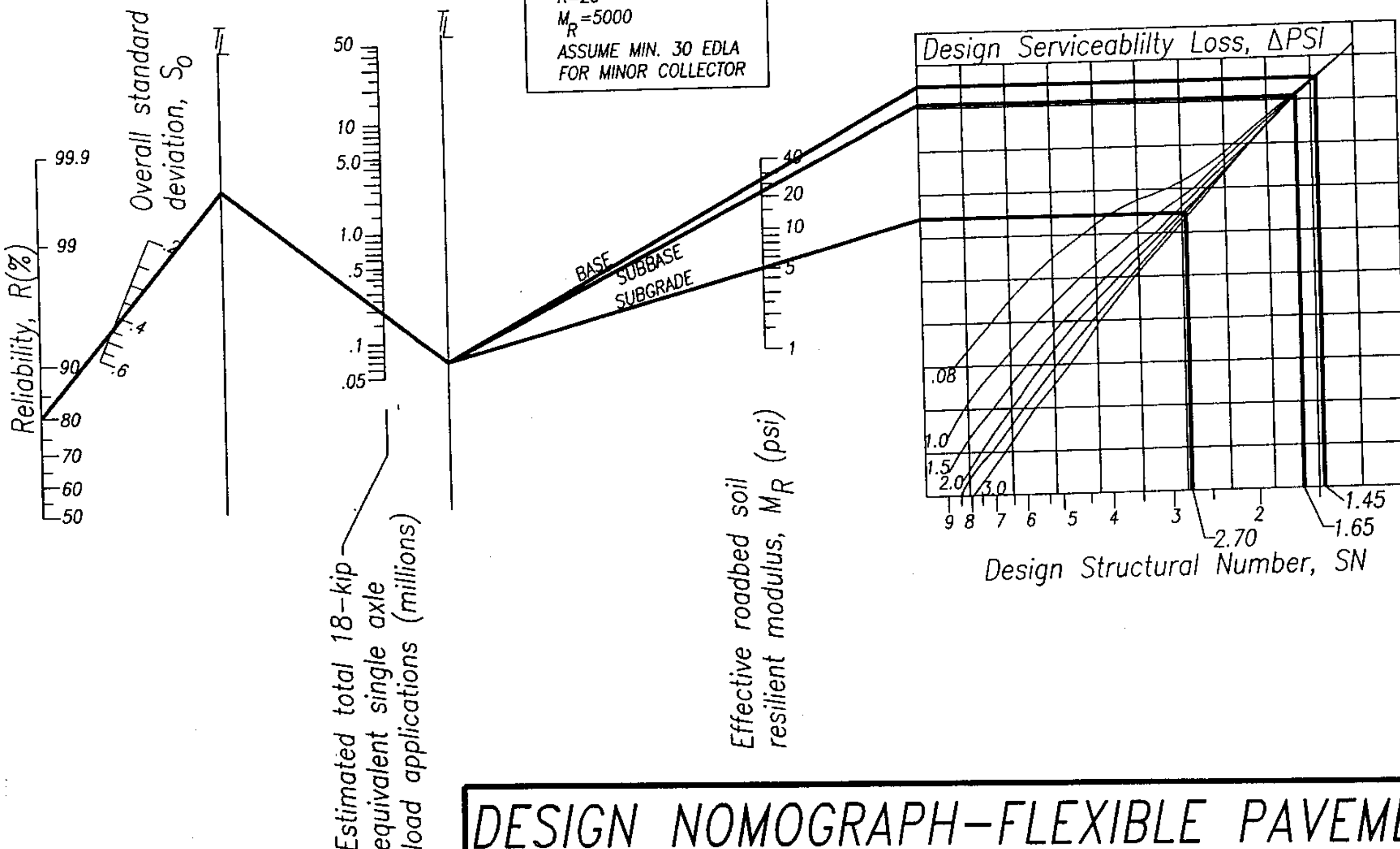
$$\log_{10} 18^{K}ESAL = Z_R^{*} S_0 + 9.36^{*}\log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32^{*}\log_{10} M_R - 8.07$$

VALUES USED

R=20

M_R=5000

ASSUME MIN. 30 EDLA FOR MINOR COLLECTOR



DESIGN NOMOGRAPH–FLEXIBLE PAVEMENTS

PUEBLO COUNTY PUBLIC WORKS

APPROVED: 4–23–98
REVISED: ______
REVISED: ______

FIGURE NO. A3–1

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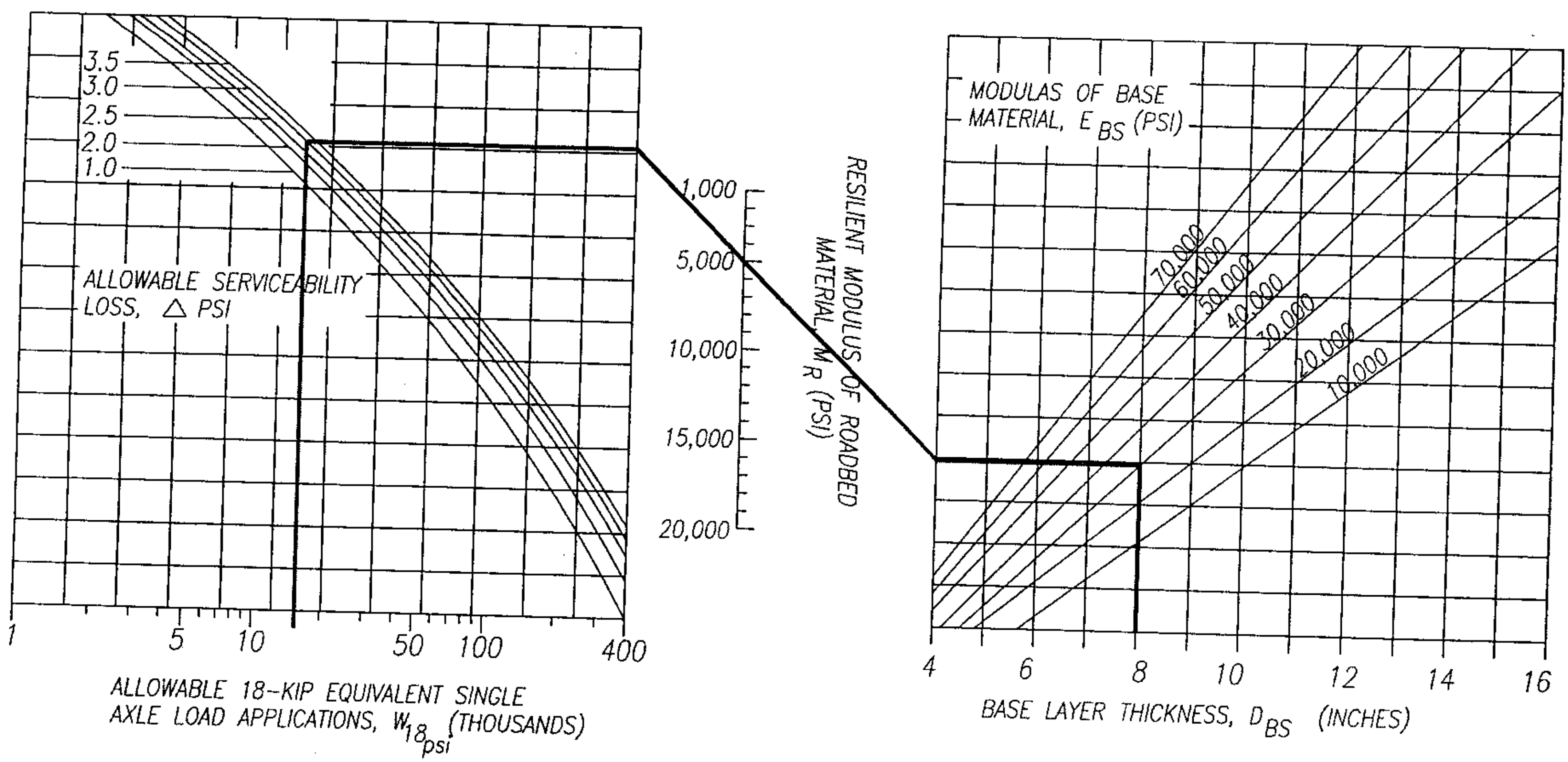
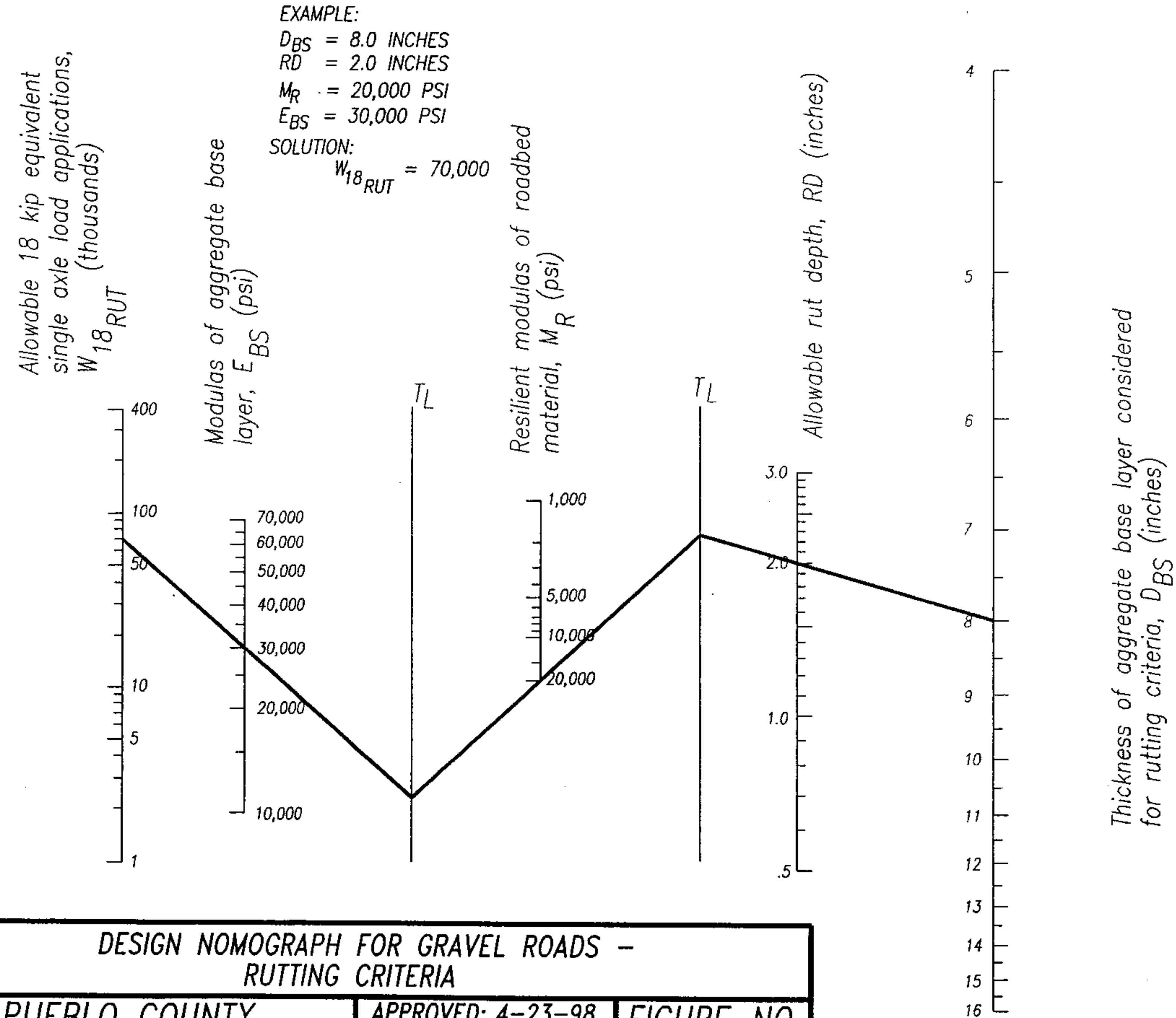


EXAMPLE:
D_{BS} = 8.0 INCHES
E_{BS} = 30,000 PSI
M_R = 5,000 PSI
ΔPSI = 3.0
SOLUTION $W_{18_{PSI}}$ = 18,000

DESIGN NOMOGRAPH FOR GRAVEL ROADS – SERVICEABILITY CRITERIA		
PUEBLO COUNTY PUBLIC WORKS	APPROVED: 4-23-98 REVISED: ____ REVISED: ____	FIGURE NO. A3-2

C:\ROADSTND\NOMOROD1.DWG



DESIGN NOMOGRAPH FOR GRAVEL ROADS – RUTTING CRITERIA

PUEBLO COUNTY PUBLIC WORKS

APPROVED: 4-23-98
REVISED: ______
REVISED: ______

FIGURE NO. A3-3

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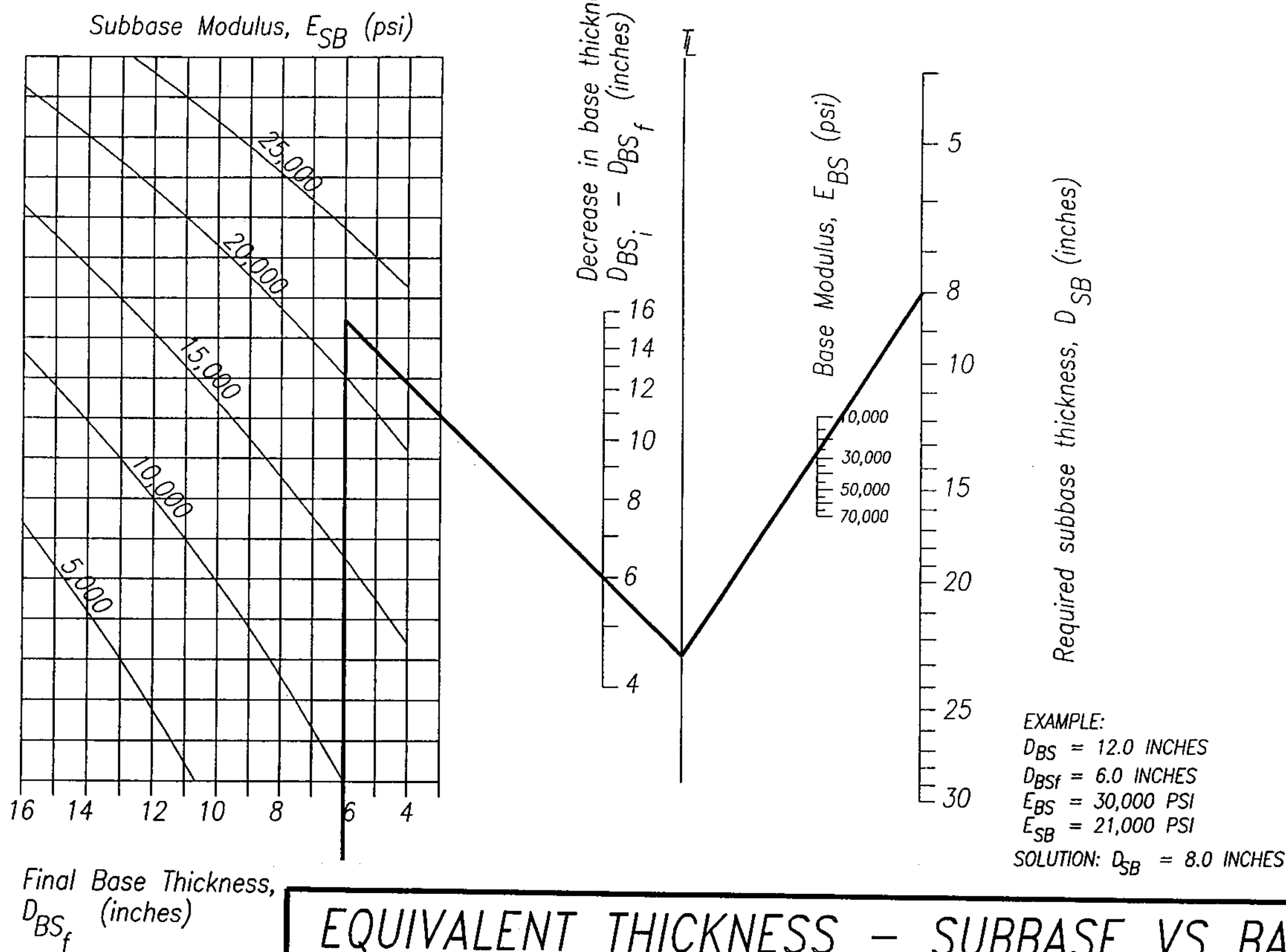


EXAMPLE:
D_{BS} = 12.0 INCHES
D_{BSf} = 6.0 INCHES
E_{BS} = 30,000 PSI
E_{SB} = 21,000 PSI
SOLUTION: D_{SB} = 8.0 INCHES

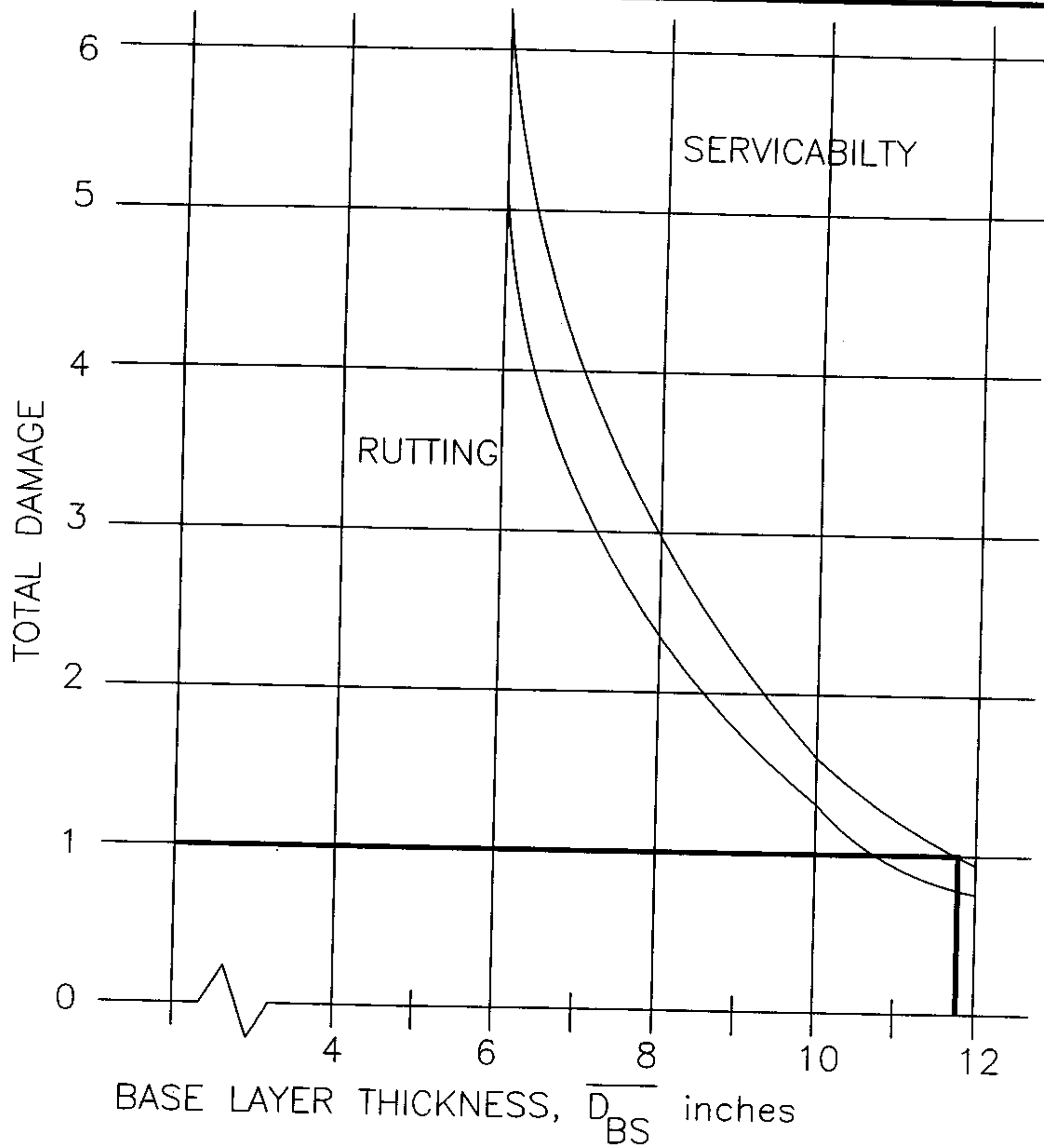
EQUIVALENT THICKNESS – SUBBASE VS BASE

PUEBLO COUNTY
PUBLIC WORKS

APPROVED: 4-23-98
REVISED:
REVISED:

FIGURE NO.
A3-4

C:\ROADSTND\SUBBASE1.DWG



$D_{BS} = \overline{D_{BS}} + (0.5 \times GL)$ GL=2

$\overline{D_{BS}} = 11.75$

EXAMPLE:

$D_{BS} = \overline{11.75} + (0.5 \times 2) = 12.75$ inches

TOTAL DAMAGE VS LAYER THICKNESS GRAPH

PUEBLO COUNTY PUBLIC WORKS	APPROVED: 4-23-98 REVISED: REVISED:	FIGURE NO. A3-5

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