CITY OF TUCSON, ARIZONA
DEPARTMENT OF TRANSPORTATION

ENGINEERING DIVISION
ACTIVE PRACTICES GUIDELINES

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SUBJECT: DESIGN OF FLEXIBLE PAVEMENT

A. PURPOSE

1. To simplify and condense the 1986 AASHTO guide and reduce its scope to match local conditions. This guideline should be utilized as a supplement to the 1986 AASHTO guide.

2. To establish a uniform procedure for the determination of total thickness of the pavement structure as well as the thickness of the individual structural components.

B. GENERAL

1. The main differences between the 1986 version of the AASHTO guide and the previous versions are the consideration of the reliability concept, the use of the elastic (resilient) modulus, the consideration of drainage conditions, the use of nondestructive testing, and the use of life-cycle cost analysis. Both soil support values and regional factors have been deleted from the new guide.

2. This guide is not a substitute for the AASHTO guide, but it highlights important sections in the guide and provides guidelines and typical design values that can simplify the pavement design process on a routine basis. If more details are needed, the AASHTO guide should be consulted.

C. PROCEDURE

1. RELIABILITY:

The reliability of a pavement design-performance process is the probability that a pavement section designed using the process will perform satisfactorily over the traffic and the environmental conditions for the design period.

1.01 Criteria for Selection of Reliability Level:

The selection of an appropriate level of reliability (R) for the design of a particular facility depends primarily upon the projected level of usage and the consequences (risk) associated with constructing an initially thinner pavement structure. If a facility is heavily trafficked, it may be undesirable to have to close or even restrict its usage at future dates because of the higher levels of distress, maintenance, and rehabilitation associated with an inadequate initial thickness. On the other hand, a thin initial pavement (along with the heavier maintenance and rehabilitation levels) may be acceptable, if the projected level of usage is such that fewer conflicts can be expected.

In general, larger reliability values increase the required pavement thickness and its associated initial cost, and decrease the future distress-related costs (maintenance, rehabilitation, user delay, etc.). The total overall cost is the sum of the initial cost and the distress-related costs. The optimum reliability is the level that minimizes the total overall cost. It should be noted that this optimum reliability varies from one project to another, depending on the level of usage and the risk of failure. Table 1 presents recommended levels of reliability for various functional classifications.

In order to reduce the amount of risk in pavement performance, the City of Tucson recommends the use of reliability levels of 95% for principal arterials, 90% for collectors, and 80% for residential streets.

1.02 Criteria for Selection of Overall Standard Deviation:

The selection of the overall standard deviation (S_0) is dependent on the variability of various factors associated with the performance prediction model such as future traffic, soil modulus, etc. Obviously, the larger the variability of various performance factors, the larger the overall standard deviation (S_0) and the larger the required pavement thickness. According to AASHTO, an approximate range of S_0 is 0.40 - 0.50 for flexible pavements. The City of Tucson recommends a standard deviation of 0.4 based on historical experience.

TABLE 1

Suggested Levels of Reliability for Various Functional Classifications (AASHTO, Table II, 2.2)

Functional Classification	Recommended Level of Reliability (AASHTO)		
	Urban	Rural	C.O.T. Std.
Interstate & Other Freeways	85 - 99.9	80 - 99.9	
Principal Arterials	80 - 99	75 - 95	95
Collectors	80 - 95	75 - 95	90
Local	50 - 80	50 - 80	80

2. TRAFFIC ANALYSIS:

The design procedure is based on the cumulative expected 18-kip equivalent single axle load (ESAL) during the design (performance) period in the design lane. In order to convert mixed traffic into 18-kip ESAL units, the AASHTO equivalency factors can be used. Note that the load equivalency factors have been extended in the new guide to include heavier loads, more axles, and terminal serviceability levels up to 3.0 (see AASHTO, Appendix D). If the cumulative two-directional 18-kip ESAL expected on the road is known, the designer must factor the design traffic by directions and then by lanes in order to calculate the axle repetitions in the design lane. The following equation may be used to determine the traffic (W_{18}) in the design lane:

W_{18} = Directional distribution factor X lane distribution factor X cumulative two-directional 18-kip ESAL.

The directional distribution factor is generally 0.5 and it may vary from 0.3 to 0.7 if there are significantly "loaded" and "unloaded" directions (for City streets, 0.5 is to be used). On the other hand, Table 2 may be used as a guide for the lane distribution factor.

A two-way traffic control count shall be taken on the road segment. From this traffic count, a base year ADT is prepared. Note that the base year is the year in which the roadway is open to traffic after construction. A traffic classification showing percentages of the different classes of vehicles is established. Classes of vehicles are shown in Figure 1. If the roadway is a new road with no existing counts, then the base year ADT will be 60% of PAG's 20 year projection.

The projected terminal year ADT's (typically 20-year ADT) are furnished by the City of Tucson, Traffic Engineering Division and are based on projections of the Pima Association of Governments (PAG).

The total 18-kip single axle loads are computed by using Table 3 and Table 4. Column 5 of Table 4 gives the factors to be used to convert the different classes of vehicles to 18-kip single axle loads.

If no classification percentages exist for a new street, then the following will be the assumed values: Car=67%, Bus=2%, LT(2P)=25%, MT=4%, TS=2%, and other truck percentage will be zero. (See Page 6)

TABLE 2

PAVEMENT DESIGN

Number of Traffic Lanes (Total of Both Directions)	Percent of Vehicles in Design Lane
2	50
4	45
6 or more	40

FIGURE 1
ILLUSTRATION OF COMMERCIAL VEHICLE TYPES

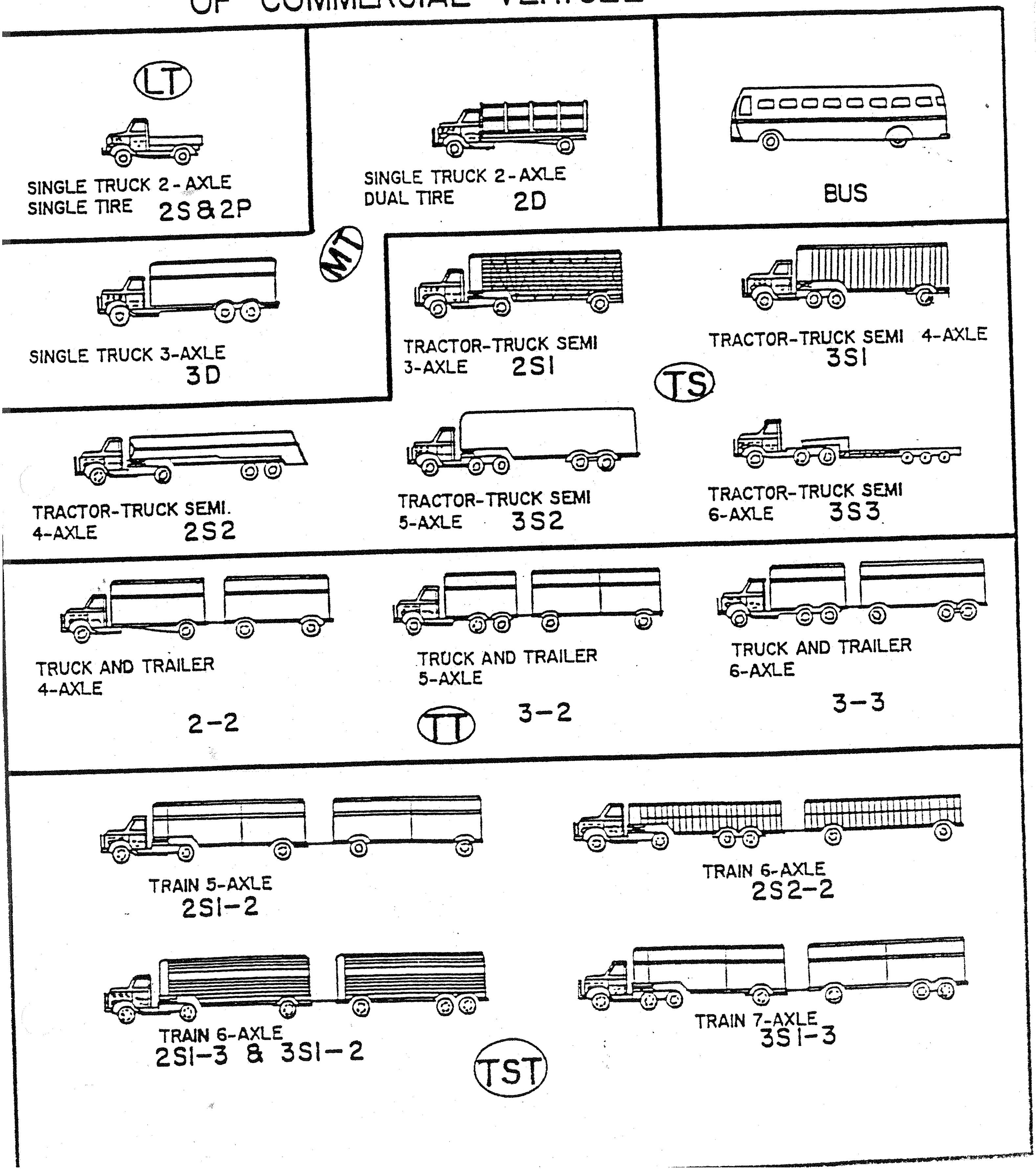


TABLE 3

PAVEMENT DESIGN -- EQUIVALENT 18 KIP SINGLE AXLE LOADINGS (ESAL)

Computed By ______________________ Date ____________

Project ______________________

Checked By ______________________ Date ____________

Location ______________________

Job No. ______________________

	A	B	C	D	E	F	G	H	I
Pavement Design Period	ADT: Base Year (Two-Way)	ADT: Terminal Yr.	% Vehicles in Design Lane (Table 2)	Base Year ADT in Design Lane (C x A)	Terminal Year ADT in Design Lane (B x C)	Mean ADT in Design Lane, over Design Period (D + E) ÷ (2)	Adjustment Factor (F ÷ D)	Base Year Daily ESAL (Col. 6, Table 4)	Total ESAL over Design Period [(H) x (G) x (365) (# Yrs. in Design Period)]

TABLE 4

18 KIP EQUIVALENT SINGLE AXLE LOADINGS (ESAL)

Project ______________________ Computed By ______________________ Date ______________

Location ______________________ Checked By ______________________ Date ______________

Job No. ______________________

1 Vehicle Class	2 Vehicle Type	3 % Classification	4 Base Year ADT in Design Lane	5 Equivalent* Factors	6 Base Year Daily ESAL
			Col. 3xD (Table 3) / 100		(Col. 4) x (Col. 5)
	CAR			0.0008	
LT	2P			0.010	
	2S			0.010	
MT	2D			0.400	
	3D			0.400	
TS	2S1			1.869	
	2S2			l.869	
	3S2			1.869	
TT	2-2			2.125	
	3-2			2.125	
	3-3			2.125	
TST	2S1-2			2.988	
	3S1-2			2.988	
	BUS			4.28**	
TOTALS					
		Should Equal 100%	(Should Match Col. D of Table 3)		(Enter this Total in Col.H Table 3)

* Subject to future revision based on availability of updated data from ADOT.

** Obtained from the Gross Vehicle Weight of a Sun Tran bus of 38,000 lbs.

3. EFFECTIVE ROADBED SOIL RESILIENT MODULUS

The basis for material characterization in the 1986 AASHTO guide is the elastic or resilient modulus. The roadbed soil resilient modulus can be either measured in the lab using AASHTO T 274 test procedure on representative samples, or backcalculated from nondestructive deflection measurements. Nondestructive deflection measurements can be performed using the Dynaflect, while backcalculation can be performed using a backcalculation computer program.

For design purposes, the resilient modulus value used should be determined using the following Arizona Department of Transportation (ADOT) developed relationship:

$$M_R = \frac{1815 + 225\ (R_{mean}) + 2.4\ (R_{mean})^2}{0.6\ (\text{Seasonal Variation Factor})^{0.6}}$$

which is modified for C.O.T. to:

$$M_R = 2200 + 273\ (R_{mean}) + 2.91\ (R_{mean})^2$$

Where mean R-Value is obtained from laboratory tests in accordance with the latest ADOT Engineering Manual.

At intervals of approximately 500 feet or as designated by the engineer, test pits to two (2) feet below subgrade should be taken (as close as possible to new centerline but off existing pavement). Take test samples and prepare descriptive log of materials encountered. The consultant shall submit a geotechnical report as outlined in ADOT Manual.

4. SERVICEABILITY

The serviceability of a pavement is defined as its ability to serve the type of traffic (automobiles and trucks) which uses the facility. The primary measure of serviceability is the present serviceability index (PSI), which ranges from 0 (impassable road) to 5 (perfect road). The terminal serviceability index is the lowest allowable PSI that can be tolerated before rehabilitation. A terminal serviceability index of 2.5 or higher is suggested for main roads and 2.0 for secondary roads. The design serviceability loss ΔPSI is the difference between the initial PSI and the terminal PSI. Therefore, the ΔPSI for C.O.T. arterials and collectors is 2.0 and for residential is 3.0.

5. STRUCTURAL LAYER COEFFICIENTS

A value of the structural layer coefficient (a_i) is assigned to each layer material in the pavement structure in order to convert actual layer thicknesses into structural number (SN). The elastic (resilient) modulus has been recommended as the parameter to be used in assigning layer coefficients to both stabilized and unstabilized materials.

Research and field studies indicate many factors influence the layer coefficients; thus, previous experience might be used to assign the layer coefficients. For example, the layer coefficient may vary with thickness, underlying support, position in the pavement structure, etc.

The structural coefficients recommended by the City of Tucson are as follows:

PAVEMENT COMPONENT	STRUCTURAL COEFFICIENT	RANGE
Plant-Mixed Asphalt Concrete and Recycled A.C.	0.44	
Cement-Treated Base	0.27	0.15 - 0.29
Cement or Lime Treated Subgrade	0.23	
Aggregate Base	0.14	0.08 - 0.14
Select Material (sandy gravel subbase)	0.11	0.05 - 0.12

6. STRUCTURAL NUMBER AND DRAINAGE CONDITIONS

The structural number (SN) is an index number that may be converted to thickness of various flexible pavement layers through the use of structural layer coefficients (a_i). The layer coefficients of the base and subbase should be modified depending on the expected level of drainage of the pavement section.

For a typical pavement consisting of surface, base and subbase, three structural numbers can be identified as follows:

$$SN_1 = a_1D_1$$

$$SN_2 = a_1D_1 + a_2D_2m_2$$

$$SN_3 = a_1D_1 + a_2D_2m_2 + a_3D_3m_3$$

Where:

SN_1, SN_2, SN_3 = Structural numbers above base, subbase and subgrade respectively.

a_1, a_2, a_3 = Structural layer coefficients of surface, base and subbase, respectively.

D_1, D_2, D_3 = Layer thicknesses (in.) of surface, base and subbase, respectively.

m_2, m_3 = Drainage coefficients of base and subbase, respectively.

Recommended drainage coefficients are shown in Table 5.

In Tucson, the typical time when pavement is exposed to moisture levels approaching saturation is less than 1%. Also, the quality of drainage varies from "Good" to "Fair". Therefore the m_2 and m_3 values vary from 1.15 to 1.35 as shown in Table 5 (for Tucson, use 1.25).

Table 6 gives the minimum recommended structural numbers to be used for different classes of roads.

TABLE 5

Recommended m_i Values for Modifying Structural Layer Coefficients of Untreated Base and Sub-base Materials in Flexible Pavement. (AASHTO TABLE II, 2.4)

Quality of Drainage	Percent of Time Pavement Structure is Exposed to Moisture Levels Approaching Saturation			
	Less Than 1%	1 - 5%	5 - 25%	Greater Than 25%
Excellent	1.40 - 1.35	1.35 - 1.30	1.30 - 1.20	1.20
Good	1.35 - 1.25	1.25 - 1.15	1.15 - 1.00	1.00
Fair	1.25 - 1.15	1.15 - 1.05	1.00 - 0.80	0.80
Poor	1.15 - 1.05	1.05 - 0.80	0.80 - 0.60	0.60
Very Poor	1.05 - 0.95	0.95 - 0.75	0.75 - 0.40	0.40

TABLE 6

MINIMUM STRUCTURAL NUMBERS FOR FLEXIBLE PAVEMENT DESIGN

TYPE OF ROADWAY	EXAMPLE OF EQUIVALENT PAVEMENT SECTION	S.N. (Min.)
Interstate Highway Travelways, Ramps, Acceleration Lanes, Deceleration Lanes, Distress Lanes, Shoulders, & Rest Areas.	5" A.C./9" A.B.C.	3.46
Arterials	5" A.C./6" A.B.C.	3.04
Primary Highways		2.45
Secondary Highways		2.25
City Collectors		2.00
Interstate Highway Cross-Roads, Frontage Roads, and Access Roads		1.75
Temporary Detours and Connections (Paved)		1.65
Residential Streets	2" A.C./4" A.B.C.	1.44
Unpaved Temporary Connections, Detours, and Graded Roads (6" minimum gravel surface)		.60

7. DESIGN OF NEW PAVEMENTS

Figure 2 presents the nomograph recommended for determining the design structural number (SN) required for specific conditions, including:

a. the reliability, R, which assumes all input is at average value;

b. the overall standard deviation, S_O;

c. the estimated future traffic, W_{18}, for the design period;

d. the effective resilient modulus of roadbed material, M_R, and;

e. the design serviceability loss, ΔPSI.

The nomograph is used from left to right as shown by arrows. The nomograph is used to obtain the required SN_1, SN_2, and SN_3 above the base, subbase and subgrade, respectively.

Once the design structural numbers (SN_1, SN_2, and SN_3) for an initial pavement structure is determined, it is necessary to identify a set of pavement layer thicknesses which, when combined, will provide the load-carrying capacity corresponding to the design structural numbers.

The SN equations do not have a unique solution; i.e., there are many combinations of layer thicknesses that are satisfactory solutions. The thickness of the flexible pavement layers should be rounded up to the nearest 1/2 inch. When selecting appropriate values for the layer thicknesses, it is necessary to consider their cost effectiveness along with the construction and maintenance constraints in order to avoid the possibility of producing an impractical design.

FIGURE 2

NOMOGRAPH SOLVES:

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

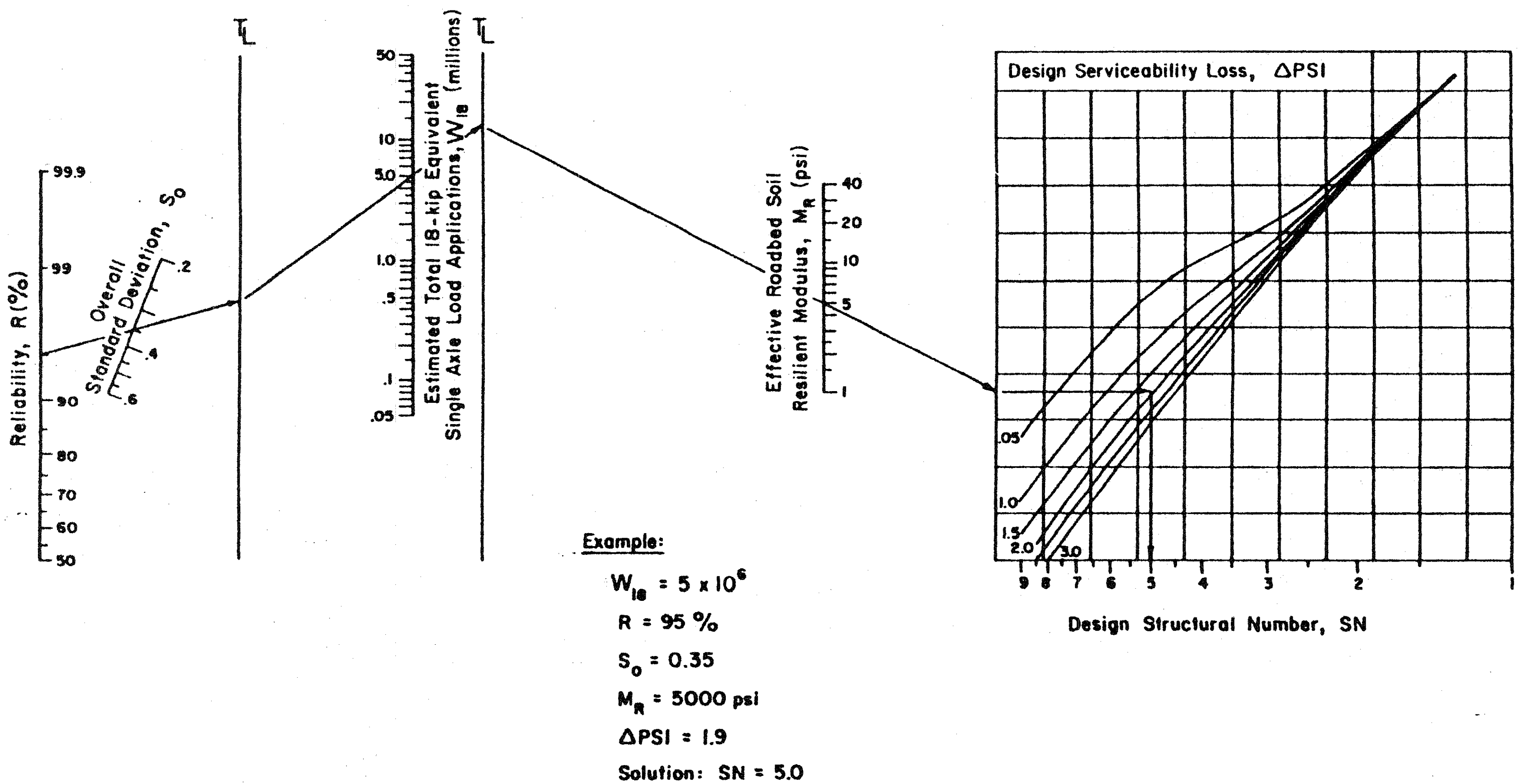


Figure 3.1. Design chart for flexible pavements based on using mean values for each input.

(AASHTO Fig. II, 3.1)

For a cost-effective view, if the ratio of costs for layer 1 to layer 2 is less than the corresponding ratio of layer coefficients times the drainage coefficient, then the optimum economical design is one where the minimum base thickness is used. Also, since it is generally impractical and uneconomical to place surface, base, or subbase courses of less than some minimum thickness and considering the specific climatic conditions and stop-and-go traffic in the City streets, the following are provided as minimum practical thicknesses for various pavement courses.

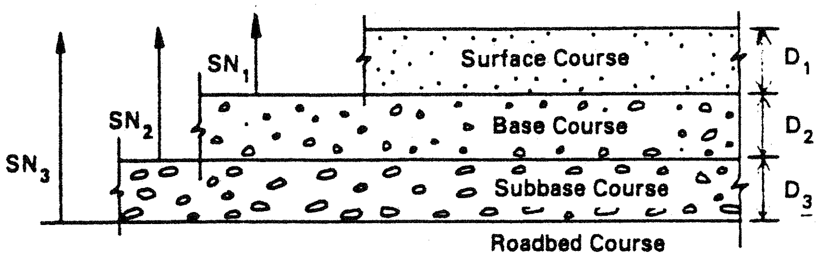
PAVEMENT COMPONENT	MINIMUM THICKNESS (INCHES)
Major Streets: (Arterials)	
Asphaltic Concrete	5
Cement-Treated Base	6
Aggregate Base	4
Select Material	4
All Other Streets: (Collector and Residential)	
Asphaltic Concrete	2
Cement-Treated Base	6
Aggregate Base	4

NOTE: In a CTB Design, 5" Minimum Aggregate Base Thickness is Required.

In all cases, the required structural number above each layer has to be satisfied. Figure 3 shows the procedure for determining the minimum thicknesses of each layer.

Table 7 is used to show all combinations of layer thicknesses that are satisfactory solutions.

FIGURE 3



$$D^*_1 \geq \frac{SN_1}{a_1}$$

$$SN^*_1 = a_1 D^*_1 \geq SN_1$$

$$D^*_2 \geq \frac{SN_2 - SN^*_1}{a_2 m_2}$$

$$SN^*_1 + SN^*_2 \geq SN_2$$

$$D^*_3 \geq \frac{SN_3 - (SN^*_1 + SN^*_2)}{a_3 m_3}$$

1) a, D, m and SN are as defined in the text and are minimum required values.

2) An asterisk with D or SN indicates that it represents the value actually used, which must be equal to or greater than the required value.

Figure 3.2. Procedure for determining thicknesses of layers using a layered analysis approach.

(AASHTO Fig. II, 3.2)

TABLE 7

PAVEMENT STRUCTURE DESIGN ANALYSIS

Project ______________________ Computed By ______________________ Date ______________

Job No. ______________________ Checked By ______________________ Date ______________

PAVEMENT COMPONENT COSTS

Aggregate Base: ______________________ Coeff. = ______ /inch

Soil Cement: ______________________ Coeff. = ______ /inch

Asphaltic Concrete: ______________________ Coeff. = ______ /inch

SUBGRADE

Design / SN	Surface Course		Base Course		Sub-Base Courses				Total Struc. Number	Total Cost
	Coeff x Thick	Cost	Coeff x Thick	Cost	Coeff x Thick	Cost	Coeff x Thick	Cost		