社会開発調査部報告書

No. 202

REPUBLIC OF THE PHILIPPINES
DEPARTMENT OF PUBLIC WORKS & HIGHWAYS

Feasibility Study on The Rural Road Network Development Project

FINAL REPORT (Volume 30)

MANUAL FOR DESIGN AND CONSTRUCTION OF LOW-CLASS PAVEMENT

OCTOBER, 1990

JAPAN INTERNATIONAL COOPERATION AGENCY

S S F
90-112(30/30)

REPUBLIC OF THE PHILIPPINES
Feasibility Study on the Rural Road Network Development Project
FINAL REPORT (Volume 30)
MANUAL FOR DESIGN AND CONSTRUCTION OF LOW-CLASS PAVEMENT

REPUBLIC OF THE PHILIPPINES
DEPARTMENT OF PUBLIC WORKS & HIGHWAYS

Feasibility Study
on
The Rural Road Network Development Project

FINAL REPORT (Volume 30)

MANUAL FOR DESIGN AND CONSTRUCTION
OF
LOW-CLASS PAVEMENT

OCTOBER, 1990

JAPAN INTERNATIONAL COOPERATION AGENCY

MANUAL FOR DESIGN AND CONSTRUCTION OF LOW-CLASS PAVEMENT

TABLE OF CONTENTS

PAGE

PART I

G E N E R A L

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The Feasibility Study on the Rural Road Network Development Project was carried out with the following objectives:

- To conduct the feasibility study on rural road projects, establishing basic technical and administrative procedures and methods for the functional development of road network in the rural areas, and recommending a system and investment program for the implementation of rural road projects; and

- To investigate performance of low-class pavements and recommend structural design for the economical implementation of the above projects.

The Study consisted of two (2) parts; Part-A Feasibility Study on the Rural Road Network, and Part-B Study on Low-Class Pavements.

Major activities in the Part-B were as follows:

- Investigation on general use of low-class pavements,
- Surface condition survey and evaluation,
- Analysis on pavement distress, 1)
- Planning and design of experimental pavement,
- Construction of experimental pavement,
- Planning of follow-up survey of experimental pavement, and
- Recommendation on design and construction of low-class pavement.

This Manual was prepared on the basis the of results of the above investigations. This manual, therefore, may not be complete for the following reasons:

- It is based on the limited investigations as mentioned above.

- Since the experimental pavement has just constructed, the follow-up survey results have not been reflected yet.

This Manual intends to be used as a material for engineering discussion among those who are concerned with road planning, design and construction.

1.2 LIMITATION OF THE MANUAL

As mentioned above, the Study was confined to low-class pavements to be used for rural road projects. This Manual therefore, has the following limitations.

1) Road Class and Traffic Carried

Arterial roads carrying heavy traffic such as national primary roads are not covered in this Manual. The coverage of this Manual is limited to the roads with not more than 200,000 annual 18-kip equivalent single axle load (ESAL) applications in the initial year. The relationship between number of 18-kip ESAL applications and AADT depends very much on axle load distribution. In the average condition in the rural roads in the Philippines, 200,000 annual 18-kip ESAL applications are equivalent to AADT 3,500.

Note 1)The experimental pavement is outlined as follows :

- Location : Province of Cavite
- Type : 18 models on five (5) sections

  Section-1 = Gravel, SBST, DBST, BMP
  Section-2 = Gravel, SBST, DBST, BMP
  Section-3 = DBST, BMP, AC(4cm), AC(5cm)
  Section-4 = DBST, BMP, AC(4cm), AC(5cm)
  Section-5 = AC(5cm), PCC(18cm)

- Length : 200m per model, totaling 3,600m

2) Pavement Type

Pavement types discussed in this Manual are as follows:

- Gravel surfacing
- Single bituminous surface treatment (SBST)
- Double bituminous surface treatment (DBST)
- Bituminous penetration macadam pavement (BMP)
- Asphalt concrete pavement (AC) of 5cm or less in thickness
- Portland cement concrete pavement (PCC) of 23cm or less in thickness

AC and PCC pavements with thicker surface course are not covered in this Manual.

3) Rehabilitation and Maintenance

Discussions are mainly focused on new construction and reconstruction of low-class pavements. Rehabilitaion, repair and preventive works and maintenance operations are, therefore, not discussed in this Manual although future rehabilitation and maintenance are taken into consideration in the life cycle costs analysis.

4) Construction Cost

Recommendations on selection of pavement type and design performance period are mainly based on life cycle costs analysis wherein the costs are at 1990 price level. Therefore, cost related data in this Manual may have to be updated for future use.

As for high-class pavements not covered by this Manual which are used for arterial roads carrying heavy traffic, available is the "Guide for Pavement Rehabilitation Design" prepared on the occasion of conducting the "Feasibility Study of the Road Improvement Project on the Pan-Philippine Highway", which covers pavement reconstruction design as well as rehabilitation design.

1.3 ORGANIZATION OF THE MANUAL

This Manual is divided in three parts.

Part I provides basic information on low-class pavements. Chapter 1 gives background, limitation and organization of the manual. Chapter 2 presents general description on types of low-class pavement and pavement structure as well as current use in the Philippines.

Part II provides a detailed method for pavement design. Chapter 3 presents the general information on design principles covering pavement performance concept, life cycle costs analysis and performance period. Chapter 4 and 5 provide the basic engineering information for pavement design dealing with traffic loading and material properties, respectively. Chapter 6 presents structural design procedures covering gravel-surfaced roads, flexible pavements and rigid pavements. Chapter 7 and 8 provide the information on weak subgrade improvement design and drainage design, respectively. Chapter 9 discusses the method for evaluation of present serviceability and identification of the section needing rehabilitation/ reconstruction. Chapter 10 shows the standard design of individual pavement types and recommendation on the selection of pavement type.

Part III provides engineering information concerning construction. Chapter 11 to 18 deal with construction methods of subgrade, subbase course, base course, gravel surfacing, bituminous surface treatment, bituminous penetration macadam pavement, hot-mix asphalt concrete surface course and portland cement concrete pavement, respectively. Chapter 19 discusses the method for quality control and inspection.

CHAPTER 2

TYPE OF LOW-CLASS PAVEMENTS AND PAVEMENT STRUCTURE

2.1 PAVEMENT TYPES IN THE PHILIPPINES

1) Existing Pavement Types

Of a total of 158,000 kms. of public roads in the Philippines, 86% are gravel/earth roads and only 6% are paved with PCC and 8% with bituminous surfaces as shown in Table 2.1-1. About 24% of national roads are paved with PCC, 22% with bituminous surfaces and the rest are still gravel/earth surfaces. About 89% of provincial roads are still gravel/earth surfaces and only 2.5% are paved with PCC and 8.9% with bituminous surfaces. Most of barangay roads (99%) are gravel/earth roads. In general, majority of rural roads are still gravel/earth roads.

TABLE 2.1-1 ROAD LENGTH IN 1987 BY TYPE OF PAVEMENT IN THE PHILIPPINES

	PCC	Bituminous	Gravel	Earth	Total
National Road	6,179.7 (23.6%)	5,829.3 (22.3%)	13,400.3 (51.3%)	734.4 (2.8%)	26,143.7 (100%)
Provincial Road	714.1 (2.5%)	2,584.4 (8.9%)	20,477.9 (70.6%)	5,215.0 (18.0%)	28,991.4 (100%)
City Road	649.4 (16.3%)	2,006.0 (50.3%)	1,164.5 (29.3%)	164.7 (4.1%)	3,984.6 (100%)
Municipal Road	1,676.4 (13.0%)	1,574.5 (12.3%)	6,383.0 (49.6%)	3,224.8 (25.1%)	12,858.7 (100%)
Barangay Road	229.1 (0.3%)	557.7 (0.7%)	84,828.9 (99.0%)	- (-)	85,685.7 (100%)
Total	9,518.7 (6.0%)	12,551.9 (8.0%)	126,254.6 (80.1%)	9,338.9 (5.9%)	157,664.1 (100%)

Source: 1988 DPWH Infrastructure Atlas

There is no statistical data on what types of bituminous surfaces were used. However, the DPWH road inventory of national roads suggests the types of bituminous surfaces as follows (see Figure 2.1-1 and Table 2.1-2):

Thickness of Bituminous Surface from Road Inventory (cm)	Percentage (%)	Assumed Type of Bituminous Surface
0.5 - 2.0	13.6	SBST or DBST
2.1 - 4.0	13.4	DBST or thin AC
4.5 - 4.5	38.8	AC (one layer)
6.1 - 8.5	17.7	AC (one or two layers)
9.0 - 10.0	16.5	AC (two layers)

It could be said that aspahlt concrete surface of about 5 cm is most commonly used among bituminous surfaces, followed by asphalt concrete surface of 6-10 cm thickness and single or double bituminous surface treatment has still low share.

Thickness of Bit. Surfaces (cm)	Assumed Type of Pavement
0.5 - 2.0	SBST or DBST
2.1 - 4.0	DBST or thin AC
4.5 - 4.5	AC (1-layer)
6.1 - 8.5	AC (1or2-layers)
9.0 - 10.0	AC (2-layers)

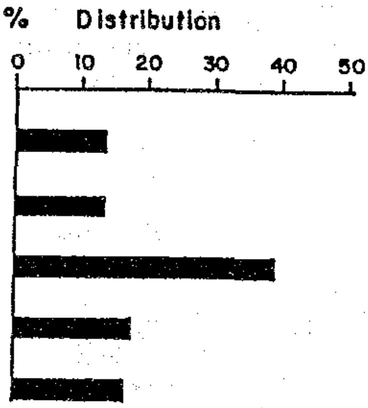


FIGURE 2.1-1 BITUMINOUS PAVEMENT THICKNESS DISTRIBUTION

2) Pavement Types Suggested by DPWH/DLG Design Guidelines

DPWH Design Guidelines (1984) and DLG Interim Design Guidelines (1981) suggests pavement types for the respective ranges of traffic volume as shown in Table 2.1-3.

TABLE 2.1-2 THICKNESS OF BITUMINOUS SURFACING ON NATIONAL ROADS

As Of January 1980 - June 1989

THICKNESS (CM) / REGION	LENGTH (KM)									
	0.5-1.0	1.2-2.0	2.1-2.54	2.7-4.0	4.5-5.0	5.1-6.0	6.1-7.5	8.0-8.5	9.0-10.0	(0.5-10.0 TOTAL)
R - I					126.876	54.422	130.677		205.473	517.448
C A R			2.640	1.332	170.642				81.737	256.351
R - II			0.300		11.712		15.681	9.378	32.101	69.172
R - III	.961	12.415		123.847	143.216	3.710	6.914		89.093	380.156
N C R		0.550			209.363	9.994	33.938	5.400	26.398	285.643
R - IV A	16.995		12.548	14.754	512.983	74.757	29.672	9.240	85.363	756.312
R - IV B		121.124			188.348		0.300	1.140	5.794	316.706
R - V		96.207	92.252		73.771	10.027	2.933		40.704	315.894
R - VI		0.244	56.886	128.927	199.816	81.923	92.127	88.584	125.460	773.967
R - VII	1.505	238.713		0.752	68.884	134.067	10.472		40.180	494.573
R - VIII					18.719	3.890			4.116	26.725
R - IX		135.511	112.826		25.467	0.477	6.774			281.055
R - X	0.982	39.109	53.943	34.449	101.734	38.636		3.584	34.413	306.850
R - XI				18.577	34.061				22.29	74.932
R - XII					1.800	0.809			8.87	11.476
T O T A L	20.443	643.873	331.395	322.638	1,887.394	412.712	329.488	117.326	801.99	4,867.262
%	0.4	13.2	6.8	6.6	38.8	8.5	6.8	2.4	16.5	100.0
Cumulative %	0.4	13.6	20.4	27.0	65.8	74.3	81.1	83.5	100.0	

<u>SOURCE :</u> 1989 DPWH ROAD INVENTORY

TABLE 2.1-3 PAVEMENT TYPES AND TRAFFIC VOLUME

Guidelines	Range of Traffice Volume (AADT in Opening Year)				
	Under 50	50 - 400	400 - 1,000	1,000 - 2,000	More than 2,000
DPWH Design Guidelines	.Gravel (natural or crushed) .Bit. Preservative Treat. .SBST .DBST .Bit. Macadam Pavement		.Bit. Macadam Pavement .Dense or Open Graded Plant Mix Surface Course .Bit. Concrete Surface Course	.Bit. Concrete Surface Course .PCC Pavement	.Bit. Concrete Surface Course .PCC Pavement
DLG Interim Design Guidelines	.Natural Gravel	.Crushed Gravel	.Surface Treatment		

3) Pavement Types in DPWH Standard Specifications

Pavement types of which specifications are described in the 1988 and Specifications, are listed in Table 2.1-4.

TABLE 2.1-4 Pavement Types in DPWH Standard Specifications

	1988 Standard Specifications	1972 Standard Specifications
Pavement Type	.Aggregate Surface Course .Bituminous Surface Treatment .Bituminous Penetration Macadam Pavement .Bituminous Road Mix Surface Course .Bituminous Plant-Mix Surface Course, Cold-Laid .Bituminous Concrete Surface Course, Hot-Laid .Portland Cement Concrete Pavement	.Aggregated Surface Course .Bituminous Surface Treatment .Bituminous Macadam Pavement (Hot-Asphalt Type and Emulsified Asphalt (Type) .Dense Graded Plant-Mix Surface Course .Open-graded Plant-Mix Surface Course .Bituminous Concrete Surface Course .Bituminous Preservative Treatment .Portland Cement Concrete Pavement .Rock Asphalt Bound Surface Course

4) Pavement Types in the Philippines and Low-class Pavement

Based on the discussion in 1), 2) and 3) above, pavement types which are commonly adopted or suggested by the Design Guidelines, can be summarized to be the following six (6) types:

a) Gravel Surface
b) Single Bituminous Surface Treatment (SBST)
c) Double Bituminous Surface Treatment (DBST)
d) Bituminous Macadam Pavement (BMP)
e) Asphalt (or Bituminous) Concrete Pavement (AC)
f) Portland Cement Concrete Pavement (PCC)

As suggested by the DPWH Design Guidelines, pavement types a) to d) are generally applied to low traffic roads of which AADT in opening year is less than 400 vehicles per day, thus considered low-class pavement. AC pavement is suggested for roads with AADT of more than 400 vehicles per day and thin AC pavement of about 5 cm is most comnmonly used among bituminous surfaces, therefore, AC pavement of 5 cm or less in thickness is considered as low-class pavement in this maual . PCC pavement is suggested for roads with AADT of more than 2,000 vehicles per day, however, this type of pavement is commonly used for much lesser traffic roads in the country due mainly to availability of materials, equipment requirement, durability of the pavement and lesser maintenance requirement. PCC pavement of which thickness is 20 cm or less is considered low-class pavement in this manual.

2.1.1 General Description of Low-Class Pavement

General description of low-class pavement is summarized in Table 2.1-2.

1) Gravel Surfacing (GR)

Used for low-volume traffic roads.

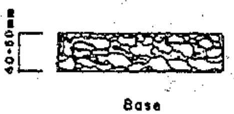
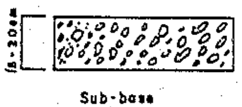
On a prepared sub-base, a course of selected quality of sandy gravel or crushed rock/gravel is laid and compacted. Finished thickness is usually 12 to 20 cm depends on the road bed bearing capacity and traffic condition.

2) Single Bituminous Surface Treatment (SBST)

Used for low-volume traffic roads.

A single layer of liquid asphalt is sprayed and immediately after uniform size of stone chippings are spread and rolled. Finished thickness is usually 6 to 10 mm. Not durable under wet climatic condition.

TABLE 2.2-1 GENERAL DESCRIPTION OF LOW-CLASS PAVEMENTS

Surface Course (Illustration)	Pavement Structure (Examples)	Traffic Volume	Descriptions	Materials / Equipment	Remarks
Gravel Surfacing 	GR Surface 12-20cm Sub-base (10cm) Subgrade	Low	• On a prepared sub-base, a course of selected sandy gravel or crushed rock/ gravel is laid and compacted • Finished thickness: usually 12-20cm	• Material Well graded sandy gravel and/or crushed gravel/rock with light silt • Equipment Road grader, Rollers	A good gravel surfaced road is only attained by continous maintenance operation
Single Bituminous Surface Treatment 	SBST Surface 6mm Base 10-15cm Sub-base (12cm) Subgrade	Low	• A single layer of liquid asphalt is sprayed and immediately uniform size stone chippings are spread and rolled • Not so durable under wet climatic condition • Finished thickness: usually 6-10mm.	• Material Cut-back/Emulsified asphalt stone chipping 5-10/10-15mm • Equipment Asphalt distributor or Asphalt sprayer, Chip spreader, Broomer, Rollers	Production/preparation of uniform chippings, Well equiped asphalt distributor or asphalt sprayer, Uniform spraying of asphaltic binder, are necessary.
Double Bituminous Surface Treatment 	DBST Surface Base 10-15cm Sub-base (15cm) Subgrade	Low to Medium	• Two course surface treatments are placed. The size of second treatment chippings is about the one-half of the first one. • Finished thickness: 12-16mm about the nominal size of the first course • Durable under certain climatic condition.	• Material Cut back/Emulsified asphalt Stone chipping 5-10/10-15/20mm • Equipment Asphalt distributor or Asphalt sprayer, Chip spreader, Broomer, Rollers	
Bituminous Penetration Macadam 	BMP Surface 40 mm Base 10-15cm Sub-base (15cm) Subgrade	Low to Medium	• First, base stone course is placed. Then liquid asphalt is sprayed and penetrates into base stone course and key stones are spread and rolled. Asphalt sprayed and cover stones spread. rolled. Seal coat is followed. • Finished thickness: usually 30-60mm depend on the first base stone course thickness. • Durable under certain climatic condition	• Material Straight/Cut-back/Emulsified asphalt Crushed stone 5-10/10-20/20-30mm • Equipment Asphalt distributor or Asphalt sprayer (Chip spreader), Broomer, Rollers	
Asphalt Concrete 	HAC Surface 50 mm Base 10-15cm Sub-base (15cm) Subgrade	Medium to Heavy	• Smooth and durable surface is attained for all seasons. • Surface thickness; 40mm or 50mm	• Material Crushed stone 5-10/10-20mm, sand, Mineral filler • Equipment Straight asphalt, asphalt paver, Rollers	Stationary asphalt mixing plant is necessary.
Portland Cement Concrete 	PCC Surface 18 cm Sub-base (15cm) Subgrade	Medium to Heavy	• Stable pavement is attained. • Surface thickness: 15-20cm	• Material Portland cement Gravel 5-25/25-40mm, Sand, Water • Equipment Concrete mixer, Vibrator, Forms	

3) Double Bituminous Surface Treatment (DBST)

Used for low to medium traffic roads.

Two courses of surface treatments are placed over the other. The size of chipps used for the second treatment is about one-half of the first one.

Finished thickness is 12 to 16 mm which is about the nominal size of the first one. With seal coat, this treatment is durable under proper climatic condition. This type of pavement has been mainly applied to ADB/ IBRD funded provincial road improvement projects. Since this pavement construction requires well equipped asphalt distributor, chip spreader, and trained skill for uniform rate of asphaltic binder spraying and uniform chip spreading, DBST has seldom been used for locally funded projects.

4) Bituminous Penetration Macadam Pavement (BMP)

Used for medium volume traffic roads.

After first base stone layer is placed, liquid asphalt is sprayed and penetrates into base stone layer, then key stones are spread and rolled. Asphalt and cover stones are sprayed, spread and rolled. Seal coat is followed.

Finished thickness is usually 30 to 60 mm depending on the first base layer stone size and thickness. Durable under proper climatic condition and traffic volume.

This pavement had been used widely, however, has been seldom used for new construction in recent years. Because it requires complicated construction process such as spreading and rolling of cover stones with different size in three to four layers and spraying of asphalt in each layer as well as trained skills for these works.

BMP is sometimes used for repair or minor rehabilitation of existing bituminous pavements.

5) Asphalt Concrete Pavement (AC)

Used for medium to heavy traffic roads.

Hot mix consists of asphalt crushed stone, sand and mineral filler is placed and rolled. Finished thickness is usually 4 to 5 cm. The structure is one layer of AC with granular base. Smooth and durable surface is attained for all season. Stationally asphalt mixing plant is necessary for the production of asphalt concrete mixture.

6) Portland Cement Concrete Pavement (PCC)

Used for medium to heavy volume traffic roads.

Portland cement concrete is placed and cured for 2 weeks, and open to traffic. Slab thickness of PCC for low to medium traffic roads is usually 15 to 20 cm. The structure of PCC slab with sandy gravel subbase is the standard. Stable pavement is attained for all seasons. Where plenty of good quality of gravels and sands are available, PCC pavement is generally economical and used widely.

2.2 PAVEMENT STRUCTURE

Pavement is constructed on a subgrade in layers generally designated subbase, base and surface courses.

Roadway shoulders are usually constructed on both sides of the pavement, adjacent to the traffic lanes.

1) Subgrade

The designated subgrade refers to the soil under the pavement, within a depth of approximately 1.0 m below the subbase bottom.

It also includes: a) the fill materials which is either completely or partially replaces the natural soil which has been found to be unsuitable for road construction; b) the stabilized soil treated with Portland Cement admixture; and c) the fill materials used in a transition section between cut and fill. The level of the finished subgrade surface is referred to as the subgrade level.

The bearing capacity of the subgrade is a basic factor to determine the thickness of the pavement, and is commonly evaluated by means of the CBR test.

2) Base and Subbase Courses

The base and subbase courses play an important role in distributing the traffic load safely over the subgrade. They must, therefore, be built of sufficiently strong and durable materials in sufficient thickness and must be properly compacted. Pursuit of sound balance between economy and physical performance of the pavement is a major objective in designing the base and subbase courses. Generally, the subbase is made up of economic materials with relatively small bearing capacity while the base course is usually made up of strong and high quality materials.

3) Surface Course

The surface course is the uppermost structural component of the pavement. It is required to be resistant to the wearing and shearing stress inflicted by traffic loads, to provide an even, non-skidding and comfortable riding surface, and also to prevent water penetrating into the pavement.

The surface course is constructed with the following types:

(1) Aggregate surface:

Either sandy gravel or crushed aggregates

(2) Asphalt surface:

Either asphalt surface treatment or asphalt penetration macadam or hot mix asphalt concrete

(3) Cement concrete surface:

Portland cement concrete

4) Shoulder

Compared with the carriageway, a simpler structure is acceptable for shoulder construction. However, the base and subbase structure of the carriageway should be extended beyond the edge of the traffic lane for a width at least 25 cm.

PART II

D E S I G N

CHAPTER 3

DESIGN PRINCIPLES

The main concepts on pavement design adopted in this Manual are serviceability and performance concepts recommended by AASHTO in the following guide.

- AASHTO Guide for Design of Pavement Structures

  American Association of State Highway and Transportation Officials, 1986. (hereinafter called AASHTO Guide 1986)

The major changes from AASHTO Interim Guide for Design of Pavement Structures 1972 include the following considerations.

- Reliability
- Soil Support Value
- Layer Coefficient (Flexible Pavements)
- Drainage
- Environment
- Tied Shoulder and Widened Lanes
- Subbase Erosion
- Life Cycle Costs
- Rehabilitation
- Pavement Management
- Load Equivalency Values
- Traffic
- Low-Volume Road
- Mechanistic-Empirical Procedure

3.1 PAVEMENT PERFORMANCE CONCEPT

Current concepts of pavement performance include some consideration of functional performance, structural performance and safety. This Guide is primarily concerned with functional and structural performance.

The structural performance of a pavement relates to its physical condition: e.g., occurrence of cracking, faulting, raveling, or other conditions which would adversely affect the load carrying capability of the pavement structure or would require maintenance.

The functional performance of a pavement is briefly discussed hereunder.

(1) Serviceability-Performance Concept

The functional performance of a pavement concerns how well the pavement serves the user. In this context, riding comfort or ride quality is the dominant characteristic. In order to quantify riding comfort, the "serviceability-performance" concept was developed by the AASHO Road Test staff in 1957.

The serviceability-performance concept is based on five fundamental assumptions, summarized as follows:

- Highways are for the comfort and convenience of the travelling public (User).

- Comfort, or riding quality, is a matter of subjective response or the opinion of the User.

- Serviceability can be expressed by the mean of the ratings given by all highway Users and is termed the serviceability rating.

- There are physical characteristics of a pavement which can be measured objectively and which can be related to subjective evaluations. This procedure produces an objective serviceability index.

- Performance can be represented by the serviceability history of a pavement.

(2) Present Serviceability Index

The serviceability of a pavement is expressed in terms of the present serviceability index (PSI). The PSI is obtained from measurements of roughness and distress, e.g., cracking, patching and rut depth (flexible), at a particular time during the service life of the pavement. Roughness is the dominant factor in estimating the PSI of pavement.

(3) Initial and Terminal Serviceability Index

The scale for PSI ranges from 0 to 5, with a value of 5 representing the highest index of serviceability. For design it is necessary to select both an initial and terminal serviceability index.

The initial serviceability index (P_i) is an estimate by the user of what the PSI will be immediately after construction. Values of P_i, established for AASHO Road Test conditions were 4.2 for flexible pavements and 4.5 for rigid pavements. Because of the variation of construction methods and standards, it is recommended that more reliable levels be established by each agency based on its own conditions.

The terminal serviceability index (P_t) is the lowest acceptable level before resurfacing or reconstruction becomes necessary for the particular class of highway. An index of 2.5 or 3.0 is often suggested for use in the design of major highways, and 2.0 for highways with a lower classification. For relatively minor highways, where economic considerations dictate the initial expenditures be kept low, a p_t of 1.5 may be used.

For aggregate-surfaced roads, the overall design serviceability loss is estimated to be 3.0. Thus, if the initial serviceability of an aggregate-surfaced road was 3.5, the corresponding terminal serviceability inherent in the design solution is 0.5.

(4) Reliability

In AASHTO Guide 1986, the new concept of reliability was introduced in pavement structural design. 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 environmental conditions for the design period.

Basically, it is a means of incorporating some degrees of certainty into the design process to ensure that the design alternatives will last the analysis period. The reliability design factor accounts for chance variations in both traffic prediction (w_{18}) and the performance prediction (W_{18}), and therefore provides a predetermined level of assurance (R) that pavement sections will survive the period for which they were designed.

AASHTO suggests levels of reliability as shown in Table 3.1-1.

TABLE 3.1-1 SUGGESTED LEVELS OF RELIABILITY FOR VARIOUS FUNCTIONAL CLASSIFICATIONS

Functional Classification	Recommended Level of Reliability Urban	Rural
Interstate and other freeways	85 - 99.9	71 - 99.9
Principal Arterials	80 - 99	75 - 95
Collectors	80 - 95	75 - 95
Local	50 - 80	50 - 80

Note: Results based on a survey of the AASHTO Pavement Design Task Force

3.2 LIFE CYCLE COST ANALYSIS

When a pavement project is planned and assured economically feasible, it is required to achieve the maximum economy within that project. It involves a detailed economic evaluation of the possible alternatives within the project to optimize the project investment. It is essential in economic evaluation that all costs occuring during the life of the facility (Life cycle cost) be included.

Life cycle cost analysis was coined to emphasize the need for a complete cost analysis to determine the most economic pavement type. Life cycle costs refer to all costs and all benefits which are involved in the provision of a pavement during its complete life cycle. The costs include construction costs and maintenance costs, while the benefits are in general composed of savings in traffic cost and savings in maintenance cost. Based on this analysis, the most economical alternative of pavement type can be decided.

An economic evaluation should consider many possible alternatives within the constraints of time and resources. It involves the selection of most economical pavement types, most economical performance period of initial pavement structures and planned stage construction (planned rehabilitation).

Figure 3.2-1 graphically demonstrate an example of the outputs of life cycle cost analysis of gravel road, double bituminous surface treatment and bituminous macadam pavement in case of 1st year ESAL of 1500 and CBR of 8.

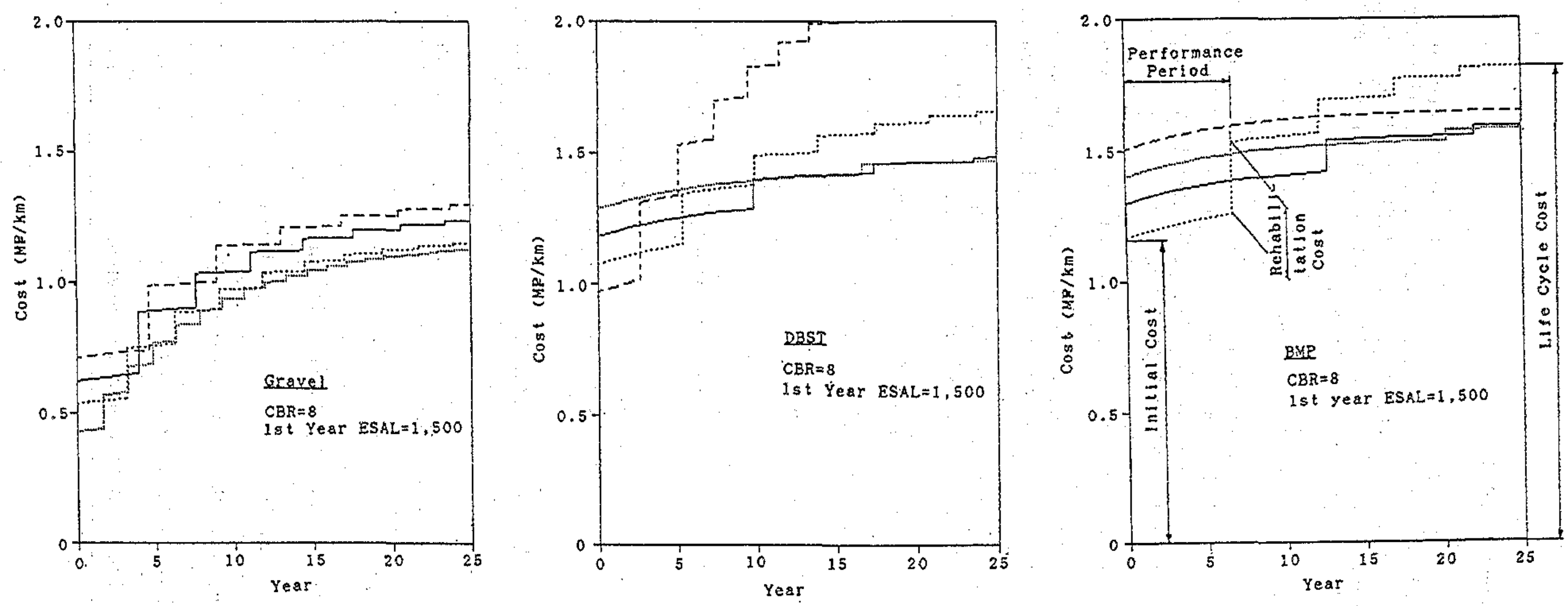


FIGURE 3.2-1 LIFE CYCLE COST

3.3 PERFORMANCE PERIOD

Analysis on most economical performance period of initial pavement structures was made with the life cost analysis method by an electric computer, selecting most economic pavement structures among alternatives of each proposed pavement type under the following conditions.

- Proposed pavement structures (See Chapter 9)
  - Gravel surfaced roads : 5 types
  - Single bituminous surface treatment: 5 types
  - Double bituminous surface treatment: 5 types
  - Bituminous macadam pavement : 5 types
  - Asphalt cement pavement : 5 types
  - Portland cement concrete pavement : 5 types
- Rehabilitation works after initial pavement structures reached to the corresponding terminal serviceability
  - Gravel surface roads : Re-surfacing with gravel
  - Other 5 pavement structures: Overlay with asphalt
- Traffic loading classes (1st Year ESAL)
  - 10 classes (1300 ~ 200,000)
- Strength of Subgrade
  - 7 cases (3 ~ 20)

Figure 3.3-1 summarizes the outputs of analysis in case of CBR 8.

Based on the analysis, the performance period of initial pavement structures are recommended as summarized in Table 3.3-1.

TABLE 3.3-1 RECOMMENDED PERFORMANCE PERIOD OF INITIAL PAVEMENT STRUCTURES

Pavement Type	Performance Period (Years)
Gravel Road	3 - 4
Single Bituminous Surface Treatment	3 - 5
Double Bituminous Surface Treatment	5 - 8
Bituminous Macadam Pavement	8 - 10
Asphalt Cement Pavement	10 - 15
Portland Cement Concrete Pavement	15 - 20

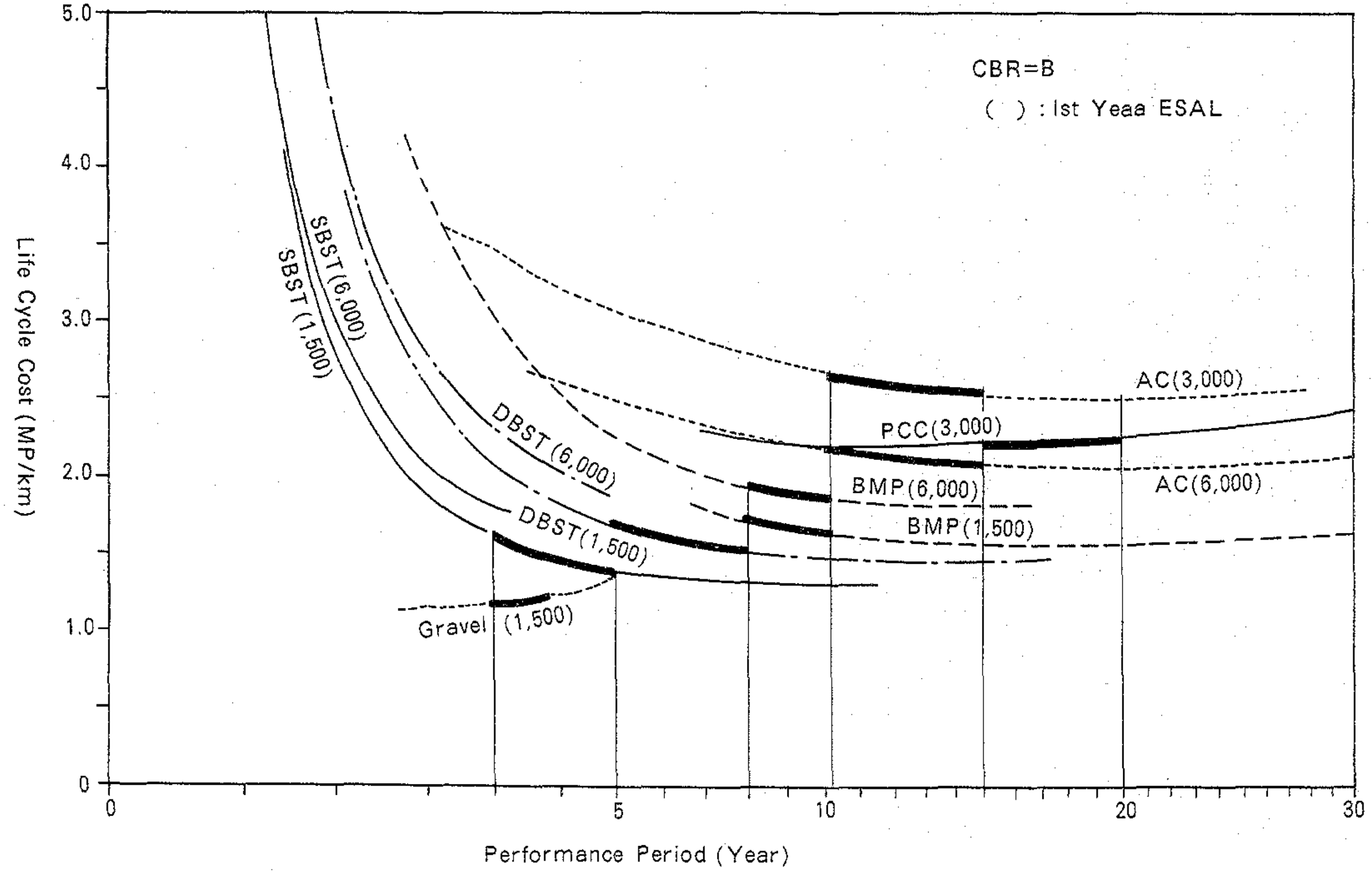


FIGURE 3.3-1 PERFORMANCE PERIOD

CHAPTER 4

TRAFFIC LOADING

4.1 EQUIVALENT SINGLE AXLE LOAD

In the pavement structural design, appropriate traffic input factors should be determined. The primary concern are the number and weights of axle loads expected to be applied to the pavement during a given period of time. Since the axle loads from the light cars contribute very little to structural deterioration of the pavement, it is widely accepted that only heavy trucks and buses are considered for the purpose of designing pavement thickness.

The result of the AASHTO Road Test has shown that damaging effect on pavement performance of the passage of an axle load of any mass can be represented by a number of 18-kip equivalent single axle loads or ESAL. This concept has been applied to the design equation of AASHTO Guide. The load equivalency factors derived from the AASHO Road Test are available in the same Guide. Table 4.1-1 shows the factors for structural number (SN) 3.0. Pt of 2.0 for single and tandem axles.

TABLE 4.1-1 AXLE LOAD EQUIVALENCY FACTOR
SN = 3.0, Pt = 2.0

Axle Load			Axle Load Equivalent Factor	
Kips	Tons	KN	Single	Tandem
2	0.907	8.889	.0002	.0000
4	1.814	17.778	.002	.0003
6	2.721	26.667	.011	.001
8	3.628	35.556	.036	.003
10	4.535	44.444	.090	.008
12	5.442	53.333	.189	.016
14	6.349	62.222	.354	.029
16	7.256	71.111	.613	.050
18	8.163	80.000	1.00	.081
20	9.070	88.889	1.56	.124
22	9.977	97.778	2.35	.183
24	10.884	106.667	3.43	.260
26	11.791	115.556	4.88	.360
28	12.698	124.444	6.78	.487
30	13.605	133.333	9.2	.646
32	14.512	142.222	12.4	.843
34	15.420	151.111	16.3	1.08
36	16.327	160.000	21.2	1.38
38	17.234	168.889	27.1	1.73
40	18.141	177.778	34.3	2.15
42	19.048	186.667	43.0	2.64
44	19.955	195.556	53.4	3.23
46	20.862	204.444	65.6	3.92
48	21.769	213.333	80.0	4.72
50	22.676	222.222	97.0	5.64
52	23.583	231.111		6.71
54	24.490	240.000		7.93
56	25.397	248.889		9.3
58	26.304	257.778		10.9
60	27.211	266.667		12.7
62	28.118	275.556		14.7
64	29.025	284.444		17.0
66	29.932	293.333		19.6
68	30.839	302.222		22.4
70	31.746	311.111		25.6
72	32.653	320.000		29.1
74	33.560	328.889		33.0
76	34.467	337.778		37.3
78	35.374	346.667		42.0
80	36.281	355.556		47.2
82	37.188	364.444		52.9
84	38.095	373.333		59.2
86	39.002	382.222		66.0
88	39.909	391.111		73.4
90	40.816	400.000		81.5

4.2 TRAFFIC LOADING CLASSES

Estimating the initial and future volumes and loading for pavement structural design requires substantial study and analysis for each number of heavy trucks and buses, traffic growth, axle loads and axle configurations.

For the purpose of simplicity and convenience, traffic loadings are classified into 10 classes using the number of ESAL application at the initial year, as shown in Table 4.2-1.

TABLE 4.2-1 STANDARD TRAFFIC LOADING CLASS FOR RURAL ROADS

Traffic Loading Class			No. of ESAL 1st Year	Assumed 1/ AADT
Light Loading Traffic	R1	R1-1	0 - 1,300	0 - 100
		R1-2	1,300 - 3,000	100 - 200
	R2	R1-1	3,000 - 8,000	200 - 400
		R1-2	8,000 - 14,000	400 - 600
	R3	R3-1	14,000 - 21,000	600 - 800
		R3-2	21,000 - 30,000	800 - 1,000
Heavy Loading Traffic	A	A -1	30,000 - 60,000	1,000 - 1,500
		A -2	60,000 - 100,000	1,500 - 2,000
	B	B -1	100,000 - 150,000	3,000 - 3,000
		B -2	150,000 - 200,000	3,000 - 4,000

Note: 1/ Assumed only for rural roads.
It cannot be applied for major principle highways where traffic compositions and road factors may be different.

4.3 ESTIMATION OF ESAL FOR RURAL ROADS

Generally, informations on traffic volumes by types of vehicles are obtained from the agencies concerned. Aside from these informations, data on axle load distribution pattern by type of axle and by types of vehicles are required for the estimation of the number of ESAL's application. However, data on these traffic loadings are hardly obtained. In such cases, the following assumption may be adopted in estimation of ESAL for rural roads.

The discussion in this section was made based on data obtained through the Pilot Study for the Rural Road Network Development Project (Phases I and II) and some data including axle load distribution are reported in Appendix I.

(1) Vehicle Composition

The vehicle compositions of rural roads in the studies of 15 provinces were analyzed and graphically showed in Figure 4.3-1 and summarized in Table 4.3-1.

TABLE 4.3-1 AVERAGE VEHICLE COMPOSITION IN RURAL ROADS

A A D T		Vehicle Composition (%)				
		Car	Jeepney	Bus	Truck	Total
	1,000	40	41	6	13	100
Rural	2,000	42	34	7	17	100
Roads	3,000	44	32	6	18	100
	4,000	48	30	6	16	100
PPH1/	8,000	48	18	10	24	100

Note: 1/ The average composition in Pan-Philippine Highway assumed in Feasibility Study of the Road Improvement Project in the Pan-Philippine Highway, for comparison only.

(2) Load Factors

The loadometer survey was conducted in Cavite Province to measure number and weights of axle loads of buses and trucks. Refer to Appendix I.

Based on the analysis of survey results, load factors of buses and trucks are estimated as shown in Table 4.3-2.

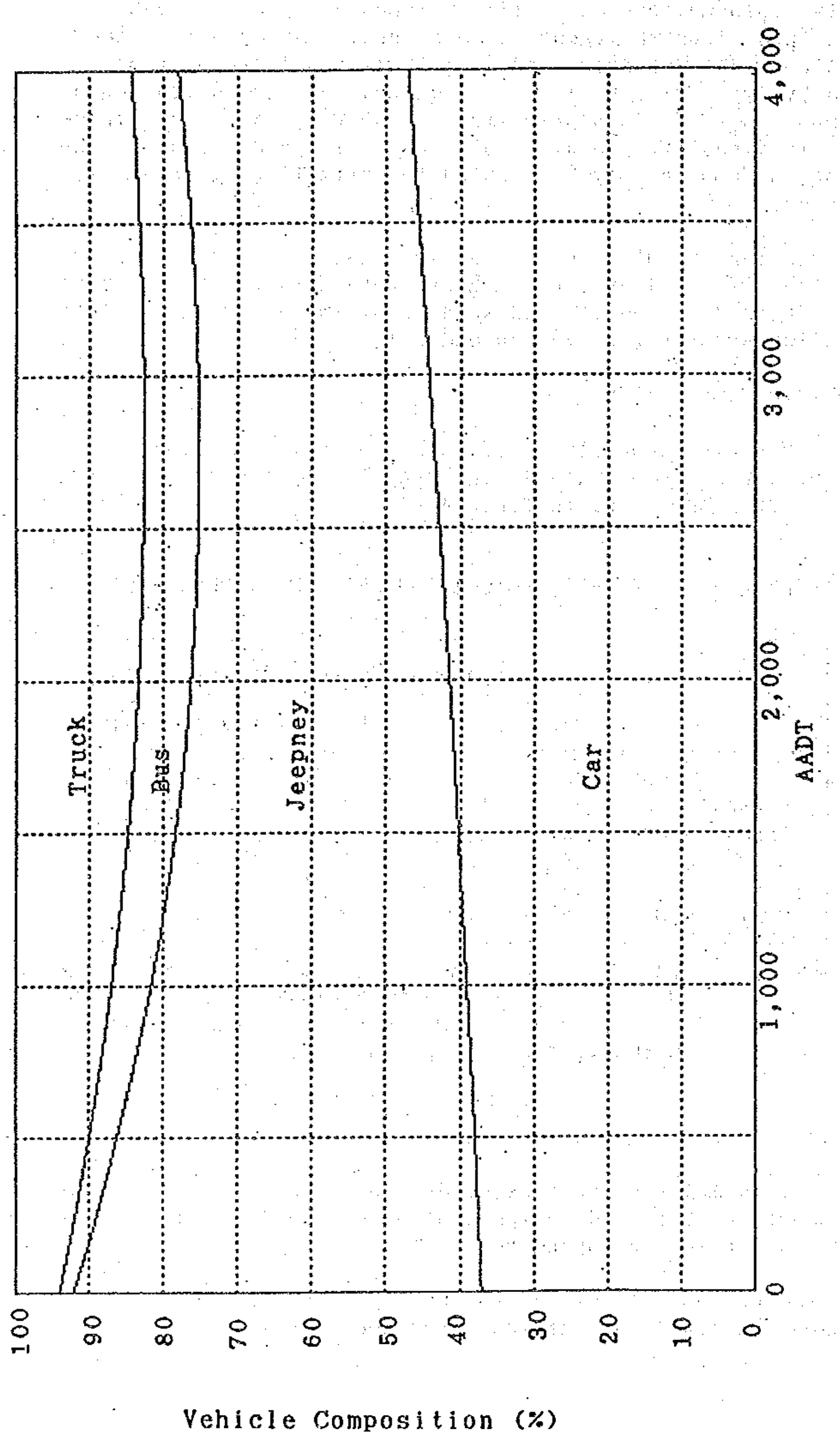


FIGURE 4.3-1 AVERAGE COMPOSITION IN RURAL ROAD

TABLE 4.3-2 AVERAGE LOAD FACTORS OF BUS AND TRUCKS

	AADT	Bus	Truck 1/
Rural Roads	1,000	0.7	1.0
	2,000		1.25
	3,000		1.50
	4,000		1.75
PPH 2/	8,000	1.0	8 (Manila Bound, North Section) 3 (Cagayan Bound, North Section)

Note: 1/ Estimated based on the following equation.
L.F. = 0.75 + 0.25/1000 x AADT

2/ The average load factors in Pan-Philippine Highway assumed in Feasibility Study of the Road Improvement Project on the Pan-Philippine Highway, for comparison only.

(3) Relationship between AADT and ESAL

The proportional relationship between AADT and ESAL was analyzed based on average vehicle compositions and average load factors in rural roads.

Table 4.3-3 summarizes the analysis outputs and Figure 4.3-2 graphically shows the relationship between AADT and ESAL in rural roads.

When AADT is known, ESAL is necessary for pavement structural design of low-volume roads in rural areas which may be roughly estimated based on this curve relationship.

TABLE 4.3-3 RELATIONSHIP BETWEEN AADT AND ESAL

ESAL 1st Year	AADT Rural Roads	AADT P.P.H. 1/
1,300	100	6
3,000	200	15
8,000	400	40
14,000	600	70
21,000	800	100
30,000	1,000	140
60,000	1,500	280
100,000	2,000	480
150,000	2,700	710
200,000	3,500	940

NOTE: 1/ AADT assumed for Pan-Philippine Highway based on traffic composition and load factor in the Highway, for comparison only.

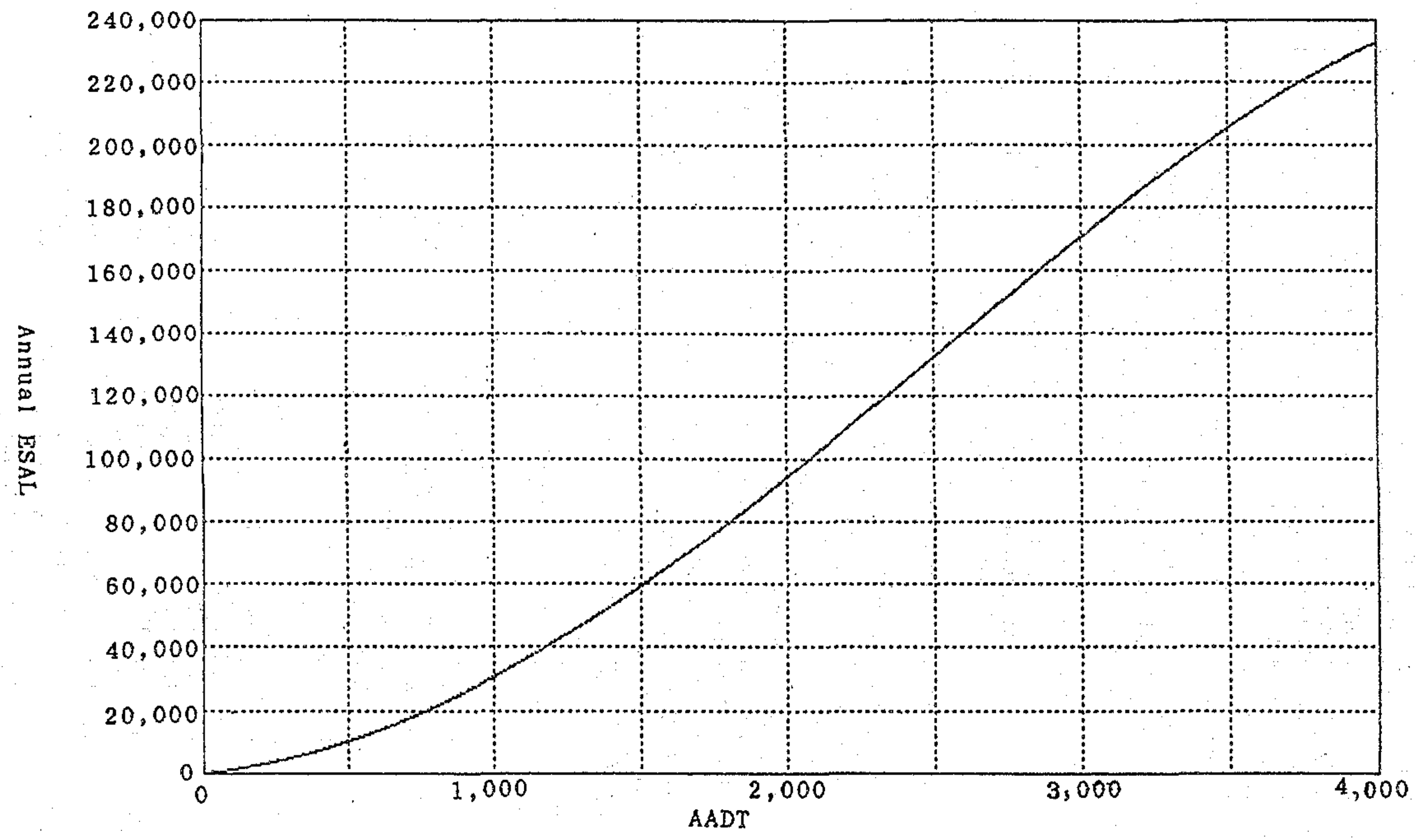


FIGURE 4.3-2 AVERAGE RELATIONSHIP BETWEEN AADT AND ESAL

CHAPTER 5

MATERIAL PROPERTIES

5.1 SUBGRADE

5.1.1 Specification Requirements

Standard Specification 1988 requires that all materials below subgrade level to a depth 150 mm or to such greater depth as may be specified shall meet the requirements of selected borrow for tapping, as shown in Table 5.1-1.

TABLE 5.1-1 MATERIAL REQUIREMENTS OF SUBGRADE

1. Grading

Standard Sieve Size	Grading
75 mm (3 in.)	100
0.075 mm (No. 200)	0-15

2. Index

Liquid Limit (L.L.)	≤ 30
Plasticity Index (P.I.)	≤ 6

5.1.2 Design Value

Several methods are proposed to estimate strength of subgrade for pavement design.

(1) AASHTO Guide 1986 Method

<u>Resilient Modulus of Roadbed (M_R)</u>

The definite material property used to characterize roadbed soil for pavement design in the Guide is the resilient modulus (M_R). The procedure for determination of M_R is given in AASHTO Test Method T274.

The resilient modulus is a measure of the elastic property of soil recognizing certain nonlinear characteristics. The resilient modulus can be used directly for the design of flexible pavements but must be converted to a modulus of subgrade reaction (k-value) for the design of rigid or composite pavements.

The following correlations between M_R, CBR and R-value are suggested.

M_R (psi) = 1500 x CBR

(Reasonable for fine-grained soil with a soaked CBR of 10 or less)

M_R = 1000 + 555 (R-value)

(Used for fine-grained soil with R value of 20 or less)

Effective Roadbed Soil Resilient Modulus (Flexible Pavement)

The seasonal resilient modulus values may be determined by correlations with soil properties, i.e., clay content, moisture, PI, etc.

An effective roadbed soil resilient modulus (M_R, Psi) is then established which is equivalent to the combined effect of all the seasonal modulus value. In establishing M_R, the relative damage values corresponding to each seasonal modulus are proposed.

Effective Modulus of Subgrade Reaction (Rigid Pavement)

Since an effective modulus of subgrade reaction (k-value, Psi) is dependent upon several factors besides roadbed soil resilient modulus, the following factors are proposed to be taken into consideration.

- Types and thickness of subbase
- Seasonal roadbed soil resilient modulus (M_R)
- Subbase elastic (resilient) modulus (E_{SB})
- Composite modulus of subgrade reaction for each season (K)
- Adjustment by rigid foundation
- Relative damage by thickness of Concrete Slab (Ur)
- Potential loss of support (LS)

(2) PCA Method

Portland Cement Association suggest the following in Thickness Design for Concrete Highway and Street.

Since the plate-loading is time consuming and expensive, the k value is usually estimated by correlation to simpler tests such as the California Bearing Ratio (CBR) or R-value tests. The result is valid because exact determination of the k value is not required; normal variations from an estimated value will not appreciably affect pavement thickness requirements. The relationships shown in Figure 5.1-1 are satisfactory for design purposes.

(3) Corps of Engineers Method

Corps of Engineers suggests unit dry weight, field CBR and subgrade modulus in accordance with the Unified Classification System of Soils originally developed by Casagrande. See Table 5.1-2.

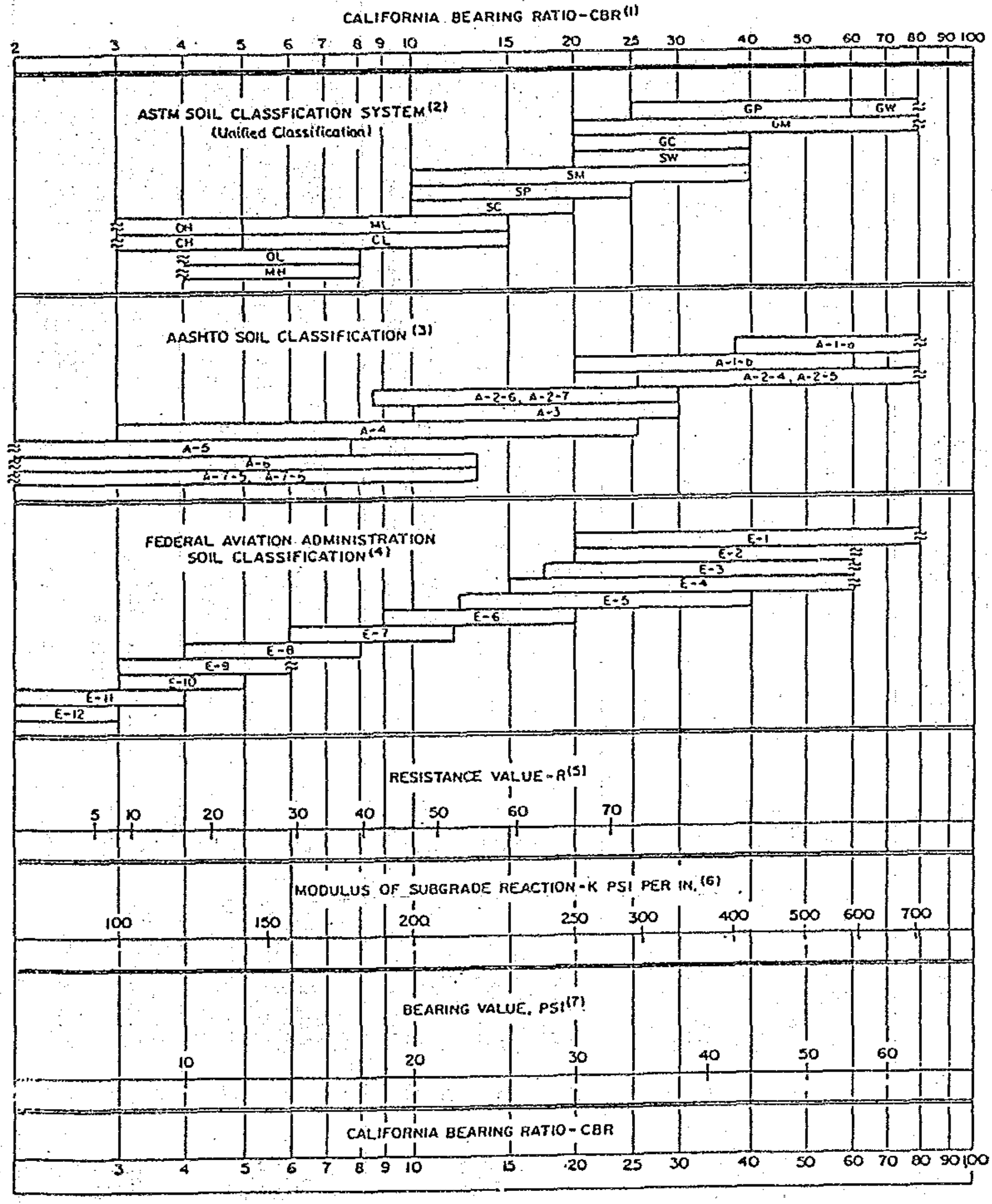


FIGURE 5.1-1 APPROXIMATE INTERRELATIONSHIPS OF SOIL CLASSIFICATIONS AND BEARING VALUES

TABLE 5.1-2 CHARACTERISTICS PERTINENT TO ROAD AND RUNNING FOUNDATIONS

Major Divisions (1)	(2)	Letter (3)	Name (4)	Value as Foundation When Not Subject to Frost Action (5)	Value at Base Directly under Wearing Surface (6)	Potential Frost Action (7)	Compressibility and Expansion (8)	Drainage Characteristics (9)	Compaction Equipment (10)	Unit Dry Weight (pcf) (11)	Field CBR (12)	Subgrade Modulus k (pci) (13)
Coarse-grained soils	Gravel and gravelly soils	GW	Gravel or sandy gravel, well graded	Excellent	Good	None to Very Slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment, steel-wheeled roller	125-140	60-80	300 or more
		GP	Gravel or sandy gravel, poorly graded	Good to Excellent	Poor to Fair	None to Very Slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment, steel-wheeled roller	120-130	35-60	300 or more
		GU	Gravel or sandy gravel, uniformly graded	Good	Poor	None to Very Slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment	115-125	25-50	300 or more
		GM	Silty gravel or silty sandy gravel	Good to Excellent	Fair to Good	Slight to Medium	Very Slight	Fair to Poor	Rubber-tired equipment, sheepsfoot roller, close control of moisture	130-145	40-80	300 or more
		GC	Clayey gravel or clayey sandy gravel	Good	Poor	Slight to Medium	Slight	Poor to practically impervious	Rubber-tired equipment, sheepsfoot roller	120-140	20-40	200-300
	Sand and sandy soils	SW	Sand or gravelly sand, well graded	Good	Poor	None to Very Slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment	110-130	20-40	200-300
		SP	Sand or gravelly sand, poorly graded	Fair to Good	Poor to not suitable	None to Very Slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment	105-120	15-25	200-300
		SU	Sand or gravelly sand, uniformly graded	Fair to Good	Not Suitable	None to Very Slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment	100-115	10-20	200-300
		SM	Silty sand or silty gravelly sand	Good	Poor	Slight to High	Very slight	Fair to Poor	Rubber-tired equipment, sheepsfoot roller, close control of moisture	120-135	20-40	200-300
		SC	Clayey sand or clayey gravelly sand	Fair to Good	Not Suitable	Slight to High	Slight to Medium	Poor to practically impervious	Rubber-tired equipment, sheepsfoot roller	105-130	10-20	200-300
Fine Grained Soils	Low compressibility LL < 50	ML	Silts, sandy silts, gravelly silts, or diatomaceous soils	Fair to Poor	Not Suitable	Medium to Very High	Slight to Medium	Fair to Poor	Rubber-tired equipment, sheepsfoot roller, close control of moisture.	100-125	5-15	100-200
		CL	Lean clays, sandy clays, or gravelly clays	Fair to Poor	Not Suitable	Medium to High	Medium	Practically impervious	Rubber-tired equipment, sheepsfoot roller	100-125	5-15	100-200
		OL	Organic silt or lean organic clays	Poor	Not Suitable	Medium to High	Medium to High	Poor	Rubber-tired equipment, sheepsfoot roller	90-105	4-8	100-200
	High compressibility LL > 50	MH	Micaceous clays or diatomaceous soils	Poor	Not Suitable	Medium to Very High	High	Fair to Poor	Rubber-tired equipment, sheepsfoot roller	80-100	4-8	100-200
		CH	Fat clays	Poor to Very Poor	Not Suitable	Medium	High	Practically impervious	Rubber-tired equipment, sheepsfoot roller	90-110	3-5	50-100
		OH	Fat organic clays	Poor to Very Poor	Not Suitable	Medium	High	Practically impervious	Rubber-tired equipment, sheepsfoot roller	80-105	3-5	50-100
Peat and other fibrous organic soils		Pt	Peat, humus, and other	Not Suitable	Not Suitable	Slight	Very High	Fair to Poor	Compaction not practical			

* From Corps of Engineers

(4) Recommendation

As PCA mentioned, CBR may be valid, especially rigid pavement design. However, it is recommended, particularly for flexible pavement that resilient modulus of several types of subgrade should be investigated beforehand so that the result can be commonly used in this country.

In this Manual, effective modulus of subgrade reaction (k-value) and effective roadbed soil resilient modulus (M_R) are estimated, taking into account the effect of subbase, as shown in Table 5.1-3.

TABLE 5.1-3 STRENGTH OF ROADBED/SUBGRADE

CBR of Subgrade	k (psi) of Subgrade	M_R (psi) of Subgrade	k (psi)
2	50	2,500	80
3	100	4,000	130
4	120	5,000	170
6	160	6,000	210
8	180	7,000	230
10	200	8,000	250
15	230	12,000	280
20	250	15,000	300

Note: K = estimated based on the suggestion by Portland Cement Association.

5.2 AGGREGATE SUBBASE COURSE

5.2.1 Specification Requirements

Standard Specification 1988 requires that aggregate for subbase shall consist of sand, durable particles or fragments of crushed stone, crushed slag or crushed a natural gravel and filter of natural or crushed sand or other finely divided mineral matters.

The subbase material shall conform to material requirements as shown in Table 5.2-1.

TABLE 5.2-1 MATERIAL REQUIREMENTS

1. Grading

Standard Seive Size	Mass Percent Passing
50 mm (2")	100
25 mm (1")	55 - 85
9.5 mm (3/8")	40 - 75
0.075 mm (No. 200)	0 - 12

Note: 0.075 mm (No. 200) passing fraction ≤ 2/3 of 0.425 (No. 40) passing fraction

2. Index

   L.L. (fraction passing 0.425 mm) ≤ 35
   P.I. (fraction passing 0.425 mm) ≤ 12

3. Los Angeles Abrasion Test

   Mass percent of wear ≤ 50

4. CBR

   Soaked CBR (19 mm passing) ≥ 25%

5.2.2 Design Value

In flexible pavement design, AASHTO employed the structural layer coefficients (A-values). A- value for this coefficient is assigned to each layer material in the pavement structures in order to convert actual layer thickness into structural number (SN).

AASHTO suggests structural layer coefficient , A3, for granular subbase material as shown in Table 5.2-2.

TABLE 5.2-2 STRUCTURAL COEFFICIENT FOR GRANULAR SUBBASE

CBR	Modulus (psi)	Coefficient, A3
40	17,000	0.12
30	15,000	0.11
20	13,000	0.095
10	11,000	0.08

In this Manual, A3 of 0.095 was recommended taking into consideration the material requirements and tropical condition in the country.

5.3 AGGREGATE BASE COURSE

5.3.1 Specification Requirements

Standard Specification 1988 calls that aggregate for base course shall consists of hard, durable particles or fragments of crushed or natural gravel and filter of natural or crushed sand or other finely divided mineral matter.

The base course material shall conform to material requirements as shown in Table 5.3-1.

TABLE 5.3-1 MATERIAL REQUIREMENTS

1. Grading		Mass Percent Passing	
Standard Sieve Size		Grading A	Grading B
80	(2")	100	
37.5	(1 1/2")	-	100
25.0	(1")	60 - 85	-
19.0	(3/4")	-	60 - 85
12.5	(1/2")	35 - 65	-
4.75	(No. 4)	20 - 50	35 - 55
0.425	(No. 40)	5 - 20	8 - 25
0.075	(No. 200)	0.12	2 - 14

Note: 0.075 mm (No. 200) passing fraction $\leq$ 2/3 of 0.425 mm (No. 40) passing fraction.

2. Index
   L.L. (fraction passing 0.425 mm) $\leq$ 25
   P.I. (fraction passing 0.425 mm) $\leq$ 6

3. Los Angeles Abrasion Test
   Mass percent of wear $\leq$ 50

4. CBR
   Soaked CBR (19 mm passing) $\geq$ 80%

5.3.2 Design Value

Structural layer coefficient, A2, for granular base layer in flexible pavement structural design may be estimated based on values shown in Table 5.3-2 as recommended by AASHTO.

TABLE 5.3-2 STRUCTURAL COEFFICIENT FOR GRANULAR BASE

CBR	Modulus (psi)	Coefficient, A2
100	30,000	0.14
66	27,000	0.125
40	22,000	0.105
20	15,000	0.07

In this Manual, a structural layer coefficient of 0.105 was suggested based on material requirements, construction performance and length of rainy seasons.

5.4 *CRUSHED AGGREGATE BASE COURSE*

5.4.1 Specification Requirements

Standard Specification 1988 requires that crushed aggregate shall consist of hard, durable particles or fragments of stones or gravel crushed to the size and of the quality requirements of this item.

The crushed aggregate base course shall conform to material requirements as shown in Table 5.4-1.

TABLE 5.4-1 MATERIAL REQUIREMENTS OF BASE

1. Grading		Mass Percent Passing	
Standard Sieve Size		Grading A	Grading B
37.5	(1 1/2")	100	
25	(1")	-	100
19	(3/4")	60 - 85	-
12.5	(1/2")	-	60 - 90
4.75	(No. 4)	30 - 55	35 - 65
0.425	(No. 40)	8 - 25	10 - 30
0.075	(No. 200)	2 - 14	5 - 15

Note: 0.075 mm (No. 200) passing fraction $\leq$ 2/3 of 0.425 mm (No. 40) passing fraction.

2. Index
   L.L. (fraction passing 0.425 mm) $\leq$ 25
   P.I. (fraction passing 0.425 mm) $\leq$ 6

3. Los Angeles Abrasion Test
   Mass percent of wear $\leq$ 45

4. CBR
   Soaked CBR (19 mm passing) $\geq$ 80%

5.4.2 Design Volume

The same volume as aggregate base course or a little higher volume, 0.125 for mechanically stabilized crushed stone, may be used.

5.5 AGGREGATE SURFACE COURSE

5.5.1 Specification Requirements

Standard Specification 1988 requires that the aggregate for surface course shall consist of hard, durable particles or fragments of stone or gravel and sand or other fine material particles.

The aggregate shall conform to the material requirements shown in Table 5.5-1.

TABLE 5.5-1 MATERIAL REQUIREMENTS

1. Grading	Mass Percent Passing			
Standard Sieve Size	Grading A	Grading B	Grading C	Grading D
25 (1")	100	100	100	100
9.5 (3/8")	50 - 85	60 - 100	-	-
4.75 (No. 4)	35 - 65	50 - 85	55 - 100	70 - 100
2.00 (No. 10)	25 - 50	40 - 70	40 - 100	55 - 100
0.425 (No. 40)	15 - 30	25 - 45	20 - 50	30 - 70
0.075 (No. 200)	5 - 20	5 - 20	6 - 20	8 - 25

Note: 0.075 mm (No. 200) passing through fraction $\leq$ 2/3

2. Index

L.L. (fraction passing 0.425 mm) $\leq$ 35
P.I. (fraction passing 0.425 mm) = 4 to 9

3. Los Angeles Abrasion Test

Mass percent of wear $\leq$ 45

5.5.2 Design Value

Structural layer coefficient for aggregate surface course may be considered the same for aggregate base course.

5.6 BITUMINOUS SURFACE TREATMENT

5.6.1 Specification Requirements

Bituminous surface treatment shall consist of either a single application of bituminous material followed by a single spreading of aggregate (single surface treatment) or two application of bituminous material each followed by a spreading of aggregate (double surface treatment).

Standard Specification 1988 cells for the approximate amounts of materials per square meter and sequence of operations for single and double surface treatment as shown in Table 5.6-1.

TABLE 5.6-1 QUANTITY OF MATERIALS AND SEQUENCE OF OPERATIONS (CUT-BACK ASPHALT OR ASPHALT CEMENT)

Aggregate Grading and Sequence of Operations	Single S.T.	Double S.T.
First Course:		
Apply bituminous material, L/m2	1.36	1.36
Spread Aggregate:		
Grading A, kg/m2	13.60	27.20
Grading B, kg/m2		
Second Course:		
Apply bituminous material, L/m		1.582
Spread Aggregate:		
Grading B, kg/m2		10.88
Totals:		
Bituminous Material, L/m2	1.36	2.94
Aggregate, kg/m2	13.60	38.00

5.6.2 Design Value

The structural layer coefficient for bituminous surface treatment is difficult to estimate since a coefficient is determined based on its elastic (resilient) modulus (E).

In this Manual, however, the layer coefficient was presummed to be 0.3 based on structure coefficient of dense-graded asphalt concrete as recommended by AASHTO. Refer to Section 5.8.

5.7 BITUMINOUS PENETRATION MACADAM PAVEMENT

5.7.1 Specification Requirement

Bituminous penetration macadam pavement shall consist of placing one or more courses of graded aggregate and one or more application of bituminous material.

Standard Specification 1988 calls for the amount of materials per square meter and sequence of operations as shown in Table 5.7-1.

TABLE 5.7-1 QUANTITY OF MATERIALS AND SEQUENCE OF OPERATIONS

Type of Aggregate and Sequence of Operations	Type of Bituminous Material: Asphalt Cement or Rapid Curing (RC)	Type of Bituminous Material: Emulsified Asphalt
First Layer:		
Spread Aggregates		
Coarse Aggregate, kg/m2	90	90
Choker Aggregate, kg/m2	-	10
Apply bituminous material, L/m2	4.0	5.5
Second Layer:		
Spread Aggregate		
Key Aggregate, kg/m2	13	10
Apply bituminous material, L/m2	1.8	3.5
Third Layer:		
Spread Aggregate		
Key Aggregate, kg/m2	11	8
Apply bituminous material, L/m2	1.4	2
Fourth Layer:		
Spread Aggregate		
Cover Aggregate, kg/m2	8	8
Total Quantities		
Bituminous Material, L/m2	7.2	11
Aggregate, kg/m2	122	126

5.7.2 Design Value

The structural layer coefficient of 0.30 adopted for bituminous surface treatment was also recommended for the bituminous penetration macadam.

5.8 BITUMINOUS CONCRETE SURFACE COURSE

5.8.1 Specification Requirements

Bituminous concrete surface course composes of aggregate, mineral filter and bituminous material mixed in a central plant during construction and laid hot on the prepared base.

Bituminous material shall be either Medium Curing (MC) Cut-Back Asphalt or Asphalt Cement. It shall conform to the requirements shown in Table 5.8-1.

TABLE 5.8-1 REQUIREMENTS FOR ASPHALT CEMENT
ASSHTO M 20

	Penetration Grade									
	40 - 50		60 - 70		85 - 100		120 - 150		200 - 300	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Penetration at 25C (77F) 100 g. 5 sec.	40	50	60	70	85	100	120	150	200	300
Flash point, Cleveland Open Cup	450	....	450	....	450	....	425	....	350	....
Ductibility at 25C (77F) 5 cm. per min. cm.	100	....	100	....	100	....	100	....	....	....
Solubility in trichlorethylene percent	99	....	99	....	99	....	99	....	99	....
Thin-film oven test, 1/8 in. (3.2 mm), 163C (325F) 5 hour										
Loss on heating, percent	....	0.8	....	0.8	....	1.0	....	1.3	....	1.5
Penetration, of residue, percent of original........	58	....	54	....	50	....	46	....	40	....
Ductility of residue at 25C (77F) 5 cm. per min. cm.	....	....	50	....	75	....	100	....	100	....
Spot test (when and as specified (see Note 1) with):										
Standard naphtha solvent	Negative for all grades									
Naphtha-xylene solvent, percent xylene	Negative for all grades									
Heptane-xylene solvent, percent xylene	Negative for all grades									

Note: The use of the spot test is optional. When it is specified, the Engineer shall indicate whether the standard naphtha solvent, the naphtha-xylene solvent, or the heptane-xylene solvent will be used in determining compliance with the requirement, and also, in the case of the xylene solvents, the percentage of xylene to be used.

5.8.2 Design Value

The structural layer coefficient of dense-graded asphalt concrete in structural design of flexible pavement is recommended as shown in Table 5.8-2.

TABLE 5.8-2 STRUCTURAL COEFFICIENT OF DENSE-GRADED ASPHALT CONCRETE

Elastic Modulus (Psi)	Structural Layer Coefficient, a1
400,000	0.42
350,000	0.39
300,000	0.38
200,000	0.30
110,000	0.20

In this Manual, the coefficient of 0.39 (Elastic Modulus 350,000 psi) was adopted taking into consideration the construction performance and drainage condition.

5.9 PORTLAND CEMENT CONCRETE PAVEMENT

5.9.1 Specification Requirements

Standard Specification 1988 calls for the applicable requirements by hydraulic cement, type 1 portland cement for portland cement concrete pavement.

Fine aggregate shall be consists of natural sand, stone screenings or other inert materials with similar characteristics and be well-graded from course to fine. It shall not contain more than three (3) mass percent of material passing the 0.075 mm (No. 200 Sieve) by washing nor more than one (1) percent each of clay lumps or shale.

Coarse aggregate consists of crushed stone, gravel, blast, furnace slag or other inert materials of similar characteristics and be well-graded. It shall contain not more than one (1) mass percent of material passing the 0.075 mm (No. 200) sieve, not more than 0.25 mass percent of clay lumps, for more than 3.5 mass percent of soft fragments.

Proportioning and other requirements of concrete shall be shown in Table 5.9-1.

TABLE 5.9-1 MATERIAL REQUIREMENTS OF PORTLAND CEMENT CONCRETE

Items	Requirements
Cement Content	9.0 bag/m^3 (standard)
Consistency (Slump)	4.0 ~ 7.5 cm (not vibrated) 1.0 ~ 4.0 cm (vibrated)
Flexural Strength	39 kg/cm2 (550 psi) (minimum by third-point method, 14 days) 46 kg/cm2 (650 psi) (minimum by middle-point method, 14 days)
Compressive Strength	245 kg/cm2 (3500 psi, 14 days)

5.9.2 Design Value

The modulus of rupture (flexural strength) of portland cement concrete required by the design procedure for rigid pavement is the mean value determined after 28 days using third-point loading (AASHTO T97, ASTM C78) and estimated as follows:

S'c (mean) = Sc + Z (SDs)

S'c = estimated mean value for PCC Modulus of Rupture (psi); 580 psi in the Study

Sc = construction specification of concrete modulus of rupture (psi)

SDs = estimated standard deviation of concrete modulus of rupture (psi)

Z = standard normal variate

In this Manual, the modulus of rupture of 580 psi (40 kg/cm2) is adopted in accordance with the specification requirement of 550 psi (39 kg/cm2) at 14 days in the country. The modulus of elasticity of PCC is estimated to be 3.28 x 10^6 psi.

CHAPTER 6

STRUCTURAL DESIGN

6.1 GRAVEL-SURFACED ROADS

6.1.1 Design Criteria and Variables

(1) Traffic

The 18-kip equivalent single axle load (ESAL) design approach was used because the primary basis for all rational pavement performance prediction method is cummulative heavy axle load applications.

(2) Resilient Modulus of Roadbed Soil

The basis for treating the effects of seasonal moisture changes on the roadbed soil resilient modulus, M_R, is the same for aggregate-surfaced road design as it for flexible or rigid pavement design.

(3) Elastic Modulus

The elastic modulus of aggregate base layer (E_{BS}, psi) and aggregate subbase layer (E_{SB}, psi) are the basis for materials characterization, which are the same for flexible pavement structural design.

(4) Design Serviceability Loss

No date on design serviceability loss in gravel-surfaced road are available. The overall design serviceability loss, Δ PSI, of 3.0 was adopted as recommended of AASHTO.

If the initial serviceability of an aggregate-surface road was 3.5, the corresponding terminal serviceability inherent in the design solution is 0.5.

(5) Allowable Rutting in Surface Layer

Rutting is considered only as a performance criteria for aggregate-surfaced roads. The allowable rut depth, RD, is dependent on the average daily traffic. Typically, allowable rut depth range from 1.0 to 2.0 inches for aggregate-surfaced roads.

(6) Aggregate Loss of Surface Layer

For aggregate-surfaced roads, an additional concern is the aggregate loss due to traffic and erosion. When aggregate loss occurs, the pavement structure becomes thinner and the load-carrying capacity is reduced. This reduction of the pavement structure thickness increases the rate of surface deterioration.

To treat aggregate loss in the procedure, it is necessary to estimate (1) the total thickness of aggregate that will be lost during the design period, and (2) the minimum thickness of aggregate that is required to keep a maintainable working surface for the pavement structure.

The following are example of equation to predict the rate of aggregate loss.

$$GL = 0.12 + 0.1223\ (LT)$$

where:

GL = total aggregate loss in inches,
LT = number of loaded trucks in thousands.

A second equation, which was developed from a recent study in Brazil on typical rural section, can be employed by the user to determine the input for gravel loss.

$$GL = (B/25.4)/\ (0.0045LADT + 3380.6/R + 0467G)$$

where

GL = aggregate loss, in inches, during the period of time being considered,

B = number of bladings during the period of time being considered,

LADT = average daily traffic in design lane (for one-lane road use total traffic in both directions),

R = average radius of curves, in feet,

G = absolute value of grade, in percent.

Another equation, developed through a British study done in Kenya, is more applicable to areas where there is very little truck activity and thus the facility is primarily used by cars. Since this equation (below) is for annual gravel loss, the total gravel loss (GL) would be estimated by multiplying by the number of years in the performance period.

$$AGL = [T2/T2+50]\ f(4.2+.092T+.0889R2+1.88VC)$$

where:

AGL = annual aggregate loss, in inches,

T = annual traffic volume in both directions, in thousands of vehicles,

R = annual rainfall, in inches,

VC = average percentage gradient of the road,

f = .037 for lateritic gravels,

= .043 for quartzitic gravels,

= .028 for volcanic gravels

= .059 for coral gravels

6.1.2 Gravel Surfaced Road Design

For design of aggregate-surfaced roads, the procedure are recommended by AASHTO with the computation chart and the design nomographs.

Step 1: Select for levels of aggregate base thickness, D_{BS}, which should bound the probable solution. For this, four separate tables, identical to Table 7.1-1, should be prepared. Enter each of the four trial base thickness, D_{BS}, in the upper left-hand corner of each of the four table (D_{BS} = 8 inches is used in the example).

Step 2: Enter the design serviceability loss as well as the allowable rutting in the appropriate boxes of each of the four tables.

Step 3: Enter the appropriate seasonal resilient (elastic) moduli of the roadbed (M_R) and the aggregate base material, E_{BS} (psi), in Columns 2 and 3, respectively, of Table 6.1-1. The base modulus of the roadbed soil during a given season. A constant value of 22,000 psi was used in the example, however, 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 4: Enter the seasonal 18-kip ESAL traffic in Column 4 of Table 6.1-1. 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.

Step 5: Within each of the four tables, estimate the allowable 18-kip ESAL traffic for each of the two seasons using the serviceability-based nomograph in Figure 6.1-1, and enter in Column 5.

Step 6: Within each of the four tables, estimate the allowable 18-kip ESAL traffic for each of the two seasons using the rutting-based nomograph in Figure 6.1-2 and enter in Column 7.

Step 7: 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 6.1-1 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 8: Compute the total damage for both the serviceability and rutting criteria by adding the seasonal damages. When this is accomplished for all four tables (corresponding to the four trial base thicknesses), a graph of total damage versus base layer thickness should be prepared. The average base layer thickness D_{BS}, required is determined by interpolating in this graph for a total damage equal to 1.0. Figure 6.1-3 provides an example in which the design is controlled by the serviceability criteria: D_{BS} is equal to 9.5 inches.

Step 9: 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, then the design thickness is determined using the following equation:

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

where

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

If, for example, the total estimated gravel loss was 2 inches and the average base thickness required was 9.5 inches, the design thickness of the aggregate base layer would be

$$D_{BS} = 9.5 + (0.5 \times 2) = 10.5 \text{ inches}$$

Step 10: 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 6.1-4. Select the final base thickness desired, $D_{BS}6$ (6 inches is used in the example). Draw a line to the estimated modulus of the subbase material, E_{SB} (8000 psi is used in the example). Go across and through the scale corresponding to the reduction in base thickness, $D_{BSi} - D_{BSf}$ (10.5 minus 6 equal to 4.5 inches is used in the example). Then, for the known modulus of the base material, E_{BS} (22,000 psi in the example), determine the required subbase thickness, D_{SB} (9 inches).

TABLE 6.1-1 EXAMPLE APPLICATION OF CHART FOR COMPUTING TOTAL PAVEMENT DAMAGE (FOR BOTH SERVICEABILITY AND RUTTING CRITERIA BASED ON A TRIAL AGGREGATE BASE THICKNESS)

Trial Base Thickness, D_{BS} (Inches) 8				Serviceability Criteria PSI = 3.0		Rutting Criteria RD (inches) = 2.5	
(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}	(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
Rainy Season	1,500	22,000	4,500	3,800	1.18	4,500	1.00
Dry Season	4,900	22,000	4,500	11,000	0.41	15,000	0.30
		Total Traffic =	9,000	Total Damage =	1.59	Total Damage =	1.30

Example:

D_{BS} = 8 inches
E_{BS} = 22,000 psi
M_R = 4,900 psi
ΔPSI = 3.0
Solution: $W_{18_{PSI}}$ = 11,000 (18-kip ESAL)

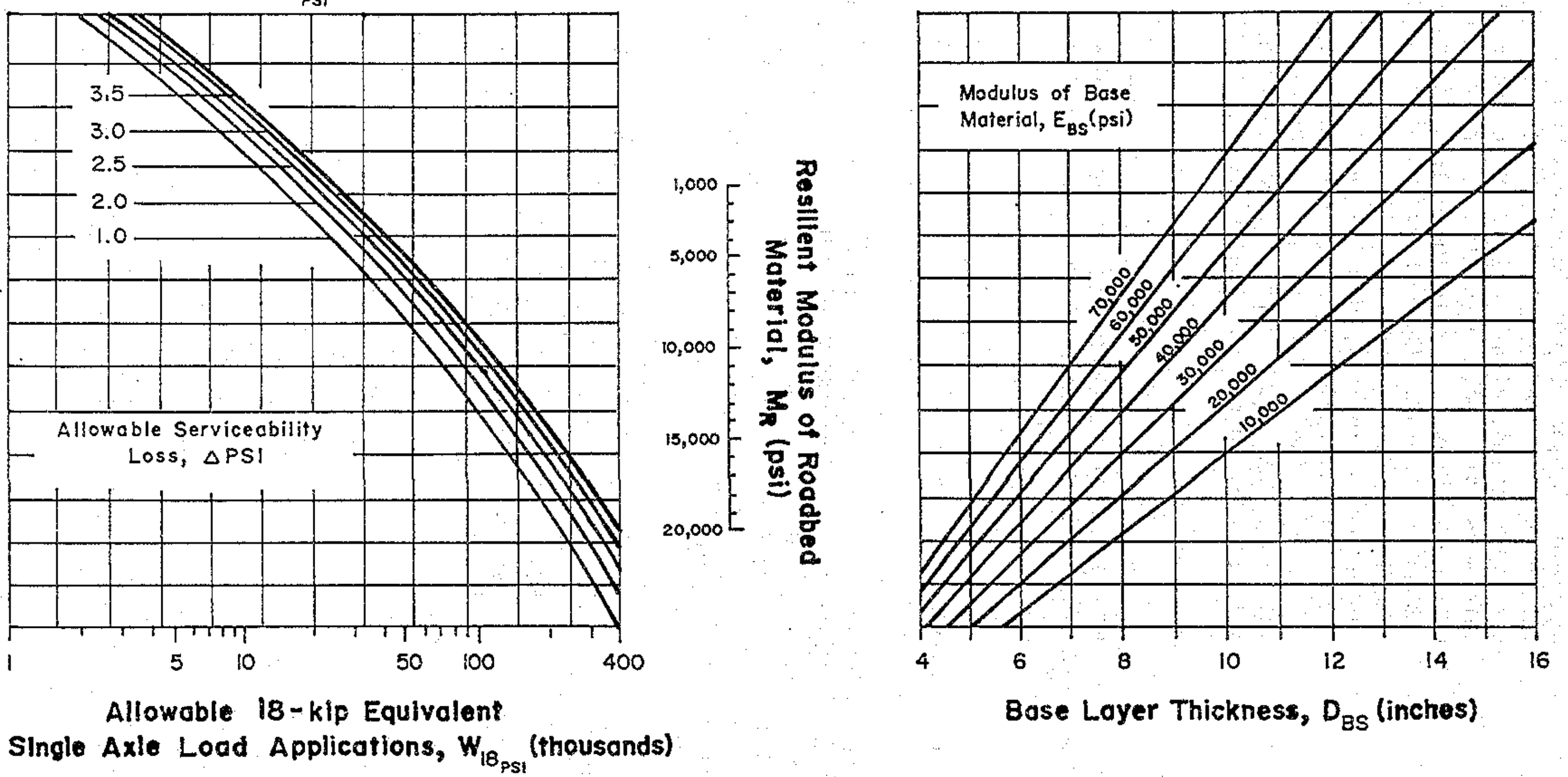


FIGURE 6.1-1 DESIGN CHART FOR AGGREGATE-SURFACED ROADS CONSIDERING ALLOWABLE SERVICEABILITY LOSS

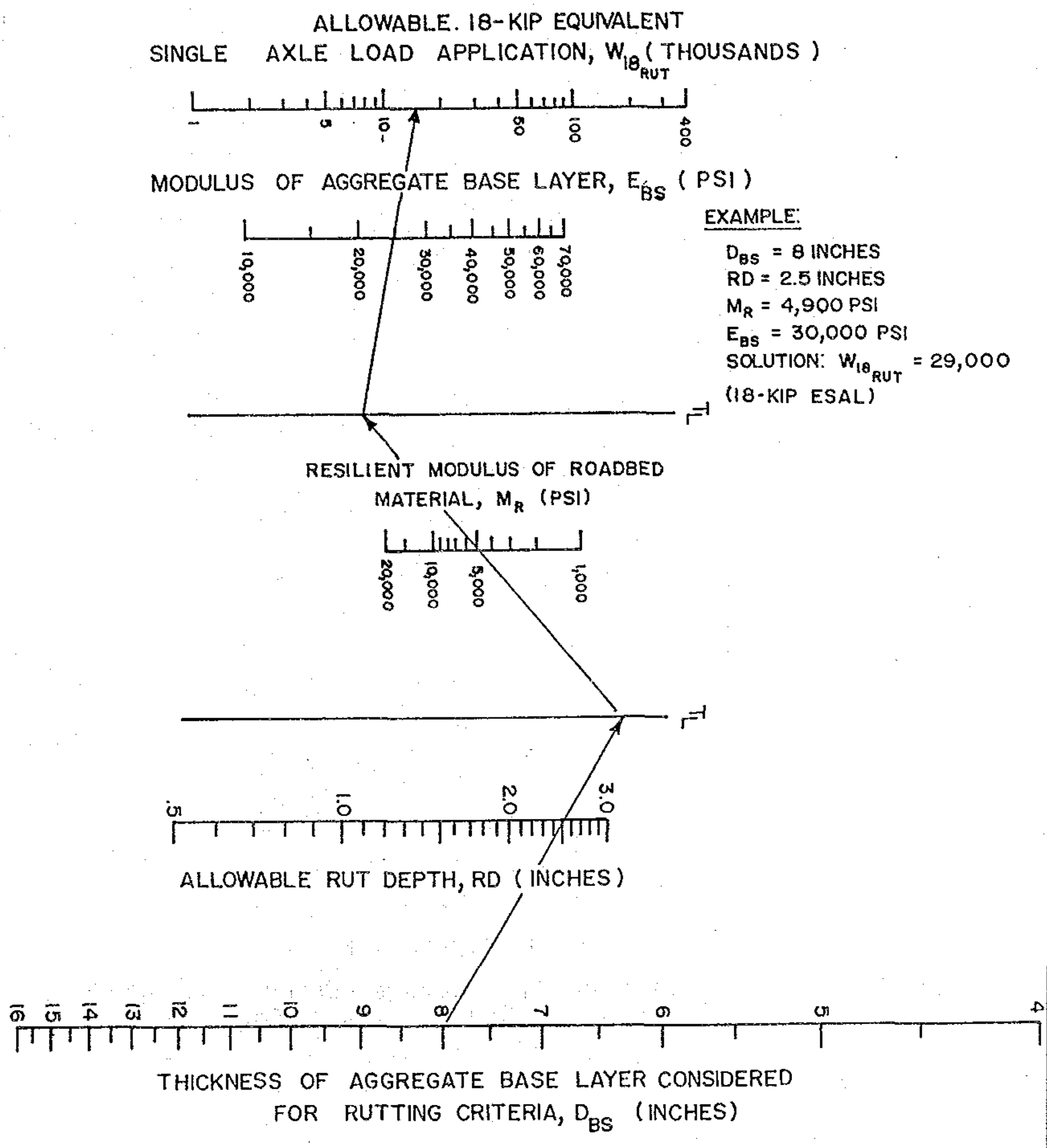


FIGURE 6.1-2 DESIGN CHART FOR AGGREGATE-SURFACE ROADS CONSIDERING ALLOWABLE RUTTING

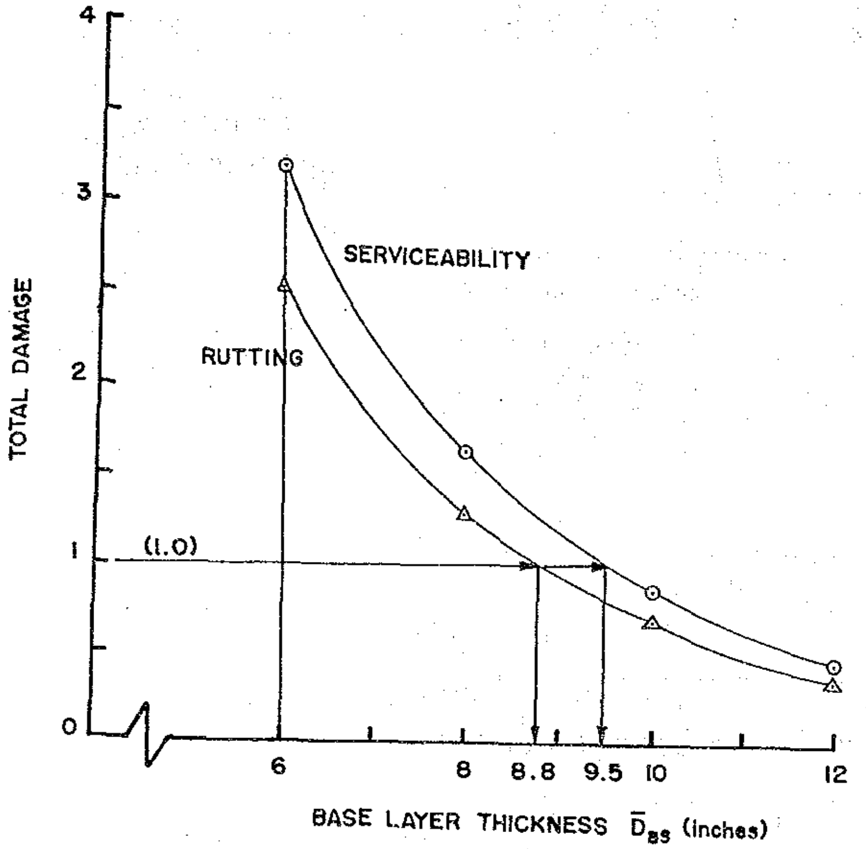


FIGURE 6.1-3 EXAMPLE GROWTH OF TOTAL DAMAGE VERSUS BASE LAYER THICKNESS FOR BOTH SERVICEABILITY AND RUTTING CRITERIA.

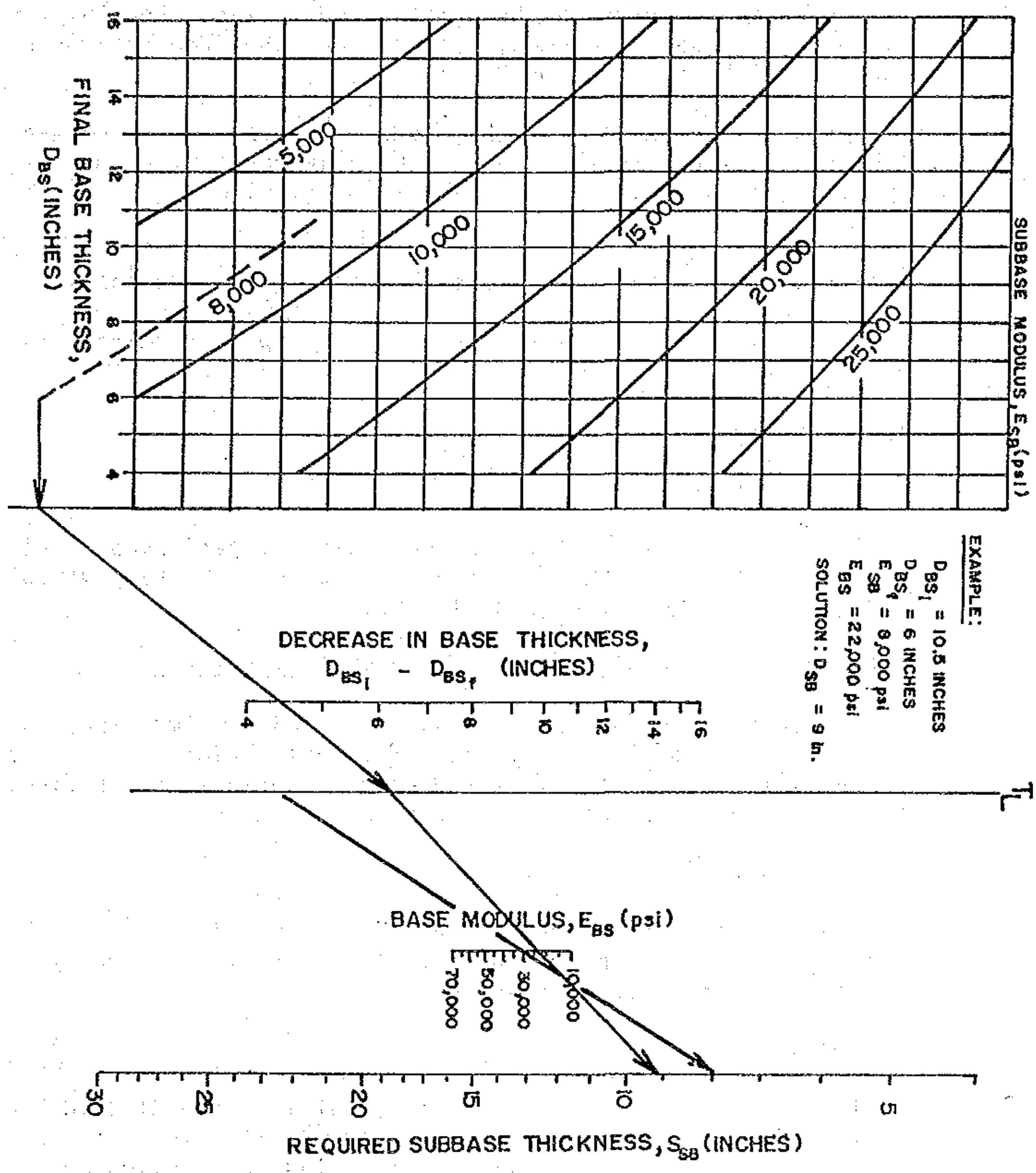


FIGURE 6.1-4 CHART TO CONVERT A PORTION OF THE AGGREGATE BASE LAYER THICKNESS TO AN EQUIVALENT THICKNESS OF SUBBASE.

6.2 LOW-CLASS FLEXIBLE PAVEMENTS

The low-volume road design method of flexible pavement is basically same as those for highway pavement design.

Refer to Guide for Pavement Rehabilitation Design, Feasibility Study of the Road Improvement Project on the Pan-Philippine Highway, Final Report, Volume VI.

For surface treatment or chip seal pavement structures (bituminous surface treatment and bituminous penetration macadam pavement), the procedures for flexible pavement design may be used.

6.2.1 Design Criteria and Variables (Flexible and Rigid Pavements)

Table 6.2-1 identifies all possible design inputs required for pavement design.

6.2.1.1 Design Variables

(1) Time Constraints

Time constraints involves the selection of performance and analysis period inputs which affect (or constrain) pavement design from the dimensions of time.

<u>Performance Period of Initial Pavement Structures</u>

Performance period refers to the period of time that an initial pavement structures will last before it needs rehabilitation. The most economical performance periods for type of pavements are discussed in Chapter 3.

<u>Analysis Period</u>

Analysis period means the period of time for which the analysis is to be conducted. In general, an analysis period of 25 years is adopted.

(2) Traffic

The design analysis is based on cummulative expected 18-kip equivalent single axle loads (ESAL) during the analysis period (W_{18}). The traffic loading classes applicable in this country is proposed in Chapter 4.

(3) Reliability

Reliability concept is introduced in AASHTO Guide 1986 to account for chance variations in both traffic prediction and performance prediction as mentioned in Chapter 2.

TABLE 6.2-1 DESIGN REQUIREMENTS

Category	Description
1. Design Variables	
1.1 Time Constraints	
• Performance Period	Life of Initial Pavement Structure
• Analysis Period	Planned Stage Construction: 25 years
1.2 Traffic	W_{18} = 18 kip Equivalent Single Axle Load (ESAL) Application Traffic Loading Classes: 10 classes (A to J)
1.3 Reliability	Z_R = 1.645 for 95% reliability R) not considered S_o = 03 ~ 0.4 for standard error
1.4 Environmental Impact	
• Roadbed Swelling	$\triangle PSI_{SW}$ = Loss of PSI: not considered
2. Performance Criteria	
2.1 Serviceability	$PSI_{SW} = P_o - P_t = \triangle PSI_W \quad \triangle PSI_{SW}$ ($\triangle PSI_{SW}$: not considered)
3. Material Properties for Structural Design	
3.1 Effective Roadbed Soil Resilient Modules (Flexible)	MR (pci): estimated based on CBR, 8 cases (2 20)
3.2 Effective Modulus of Subgrade Reaction (Rigid)	K-Value (pci): estimated based on CBR, 8 cases (2 20)
3.3 Pavement Layer Materials Characterization	E_{SB} = Modulus of Subbase : 8,000 psi E_{BS} = Modulus of Base : 22,000 psi $E_{BT/MP}$ Modulus of Bituminous Surface 200,000 psi E_{AC} = Modulus of Asphalt Concrete: 350,000 psi
3.4 PCC Modulus of Rupture (Rigid) Flexural Strength	E_C = Modulus of PCC : 3.28×10^6 psi S'_C = Estimated Mean Value for PCC Modulus of Rupture : 580 psi
3.5 Layer Coefficient (Flexible)	Asphalt Concrete Layer Coefficient : 0.39 Bituminous Surface (BST/BMP) : 0.30 Bitumen Stabilized : 0.2 Mechanically Stabilized (Crushed Stone) : 0.125 Crusher Run (Crushed Gravel) : 0.105 Subbase : 0.095
4. Pavement Structural Characteristics	
4.1 Drainage	Flexible m = Layer Coefficient Modifying Factor: 0.9 Rigid Cd = Drainage Coefficient: 0.9
4.2 Load Transfer (Rigid)	
• Jointed Pavement	
• Tied shoulder or Widened Outside Lane	J = Load Transfer Coefficient: 4
4.3 Loss of Support (Rigid)	LS = Loss of Support 1.0 ~ 3.0 for unbounded granular materials 2.0 ~ 3.0 for fine granular or natural subgrade materials 0 ~ 1.0 for cement Treated Granular Base
5. Reinforcement Variables (Rigid)	
5.1 Slab Length	Depending on local conditions, subbase type, course aggregate, etc.
5.2 Working Stress	
5.3 Friction Factors	

(4) Environmental Impacts

In this Manual, serviceability loss due to roadbed swelling (PSI_{SW}) is not accounted for, because the effects of seasonal temperature and moisture changes on material properties are not analyzed.

6.2.1.2 Performance Criteria

The primary measure of serviceability is the Present Serviceability Index (PSI) which ranges from 0 (impassible road) to 5 (perfect road). The original or initial serviceability (P_0) observed at the AASHO Road Test were:

Po = 4.5 for Rigid Pavement
= 4.2 for Asphalt Pavement
= 3.0 for Gravel-Surfaced Road

AASHTO Guide for 1986 suggests the lowest allowable PSI or terminal serviceability Index (Pt).

Pt = 2.5 for major highway
= 2.0 for highway with lesser traffic/lower classification
= 1.5 for relatively minor highway where economic consideration dictates that initial expenditures be kept low
= 0.5 for gravel-surfaced road

6.2.1.3 Material Properties for Structural Design

(1) Effective Roadbed Soil Resilient Modulus, (Flexible Pavement)

To determine effective roadbed soil resilient modulus (M_R) exclusively for the design of flexible pavements based on serviceability criteria, laboratory resilient modulus test (AASHTO T274) should be performed on representative samples in stress and moisture conditions. Seasonal resilient modulus should also be determined based on conditions of primary moisture seasons, dry and wet seasons.

In this Manual, effective roadbed soil resilient modulus (M_R) are estimated only based on soil classification and CBR Test results because of absence of available data, as shown in Table 6.2-2.

(2) Effective Modulus of Subgrade Reaction (Rigid Pavement)

An effective modulus of subgrade reaction (k-value) should be developed for rigid pavement design, accounting for seasonal modulus value, effects of subbase characteristics, effects of rigid foundation, relative damage or slab thickness due to 18 kip ESAL, loss of support etc.

In this Manual, effective modulus of subgrade reaction (k-value) are estimated, taking into account the effect of subbase, as shown in Table 6.2-2.

The detailed discussions on estimation of k-value are presented in Chapter 5.

TABLE 6.2-2 STRENGTH OF ROADBED/SUBGRADE

CBR of Subgrade	k (psi) of Subgrade	MR (psi) of Subgrade	k (psi)
2	50	2,500	80
3	100	4,000	130
4	120	5,000	170
6	160	6,000	210
8	180	7,000	230
10	200	8,000	250
15	230	12,000	280
20	250	15,000	300

Note: K = estimated based on the suggestion by Portland Cement Association.

(3) Pavement Layer Materials Characteristics

In this Manual, modulus of pavement layer materials are estimated following the suggestion by AASHTO Guide, 1986 as follows:

. Moduli for Subbase, E_{SB}: 8,000 psi

. Moduli for Base, E_{BS}: 22,000 psi

. Moduli for Bituminous Surface Treatment, (BST/BMP): 200,000 psi

. Moduli for Asphalt Concrete, E_{AC}: 350,000 psi

. Moduli for Portland Cement Concrete, E_c: 3.28 x 10^6 psi

$$E_c = 57,000\ ('c)^{0.5}$$

where:

E_c = PCC elastic modulus (psi)

'c = PCC compressive strength (psi)

(4) PCC Modulus of Rupture (Rigid Pavement)

The modulus of rupture (flexural strength) of portland cement concrete required by the design procedure is the mean value determined after 28 days using third-point loading (AASHTO T97, ASTM C78) and estimated as follows:

S'_c (mean) = Sc + Z (SDs)

S'c = estimated mean value for PCC Modulus of Rupture (psi); 580 psi in the Study

Sc = construction specification of concrete modulus of rupture (psi)

SDs = estimated standard deviation of concrete modulus of rupture (psi)

Z = standard normal variation

In this Manual, the modulus of rupture of 580 psi (40 kg/cm^2) is adopted in accordance with the specification requirement of 525 psi (36.8 kg/cm^2) at 14 days in the country.

(5) Structural Layer Coefficients (Flexible Pavement)

A value for layer coefficient is assigned to each layer material in the pavement structure in order to convert actual layer thickness into structural number (SN).

In this Manual, the structural layer coefficients (Ai values are assumed as follows.

TABLE 6.2-3 STRUCTURAL LAYER COEFFICIENTS, Ai

Layer Material	Layer Coefficient
Asphalt Concrete Surface Course	0.39
Bituminous Surface Treatment (BST/BMP)	0.30
Bitumen Stabilized	1.2
Mechanically Stabilized (Crushed Stone)	0.125 (CBR 40, R value 70)
Crusher Run (Crushed Gravel)	0.105 (CBR 25, R value 60)
Subbase	0.095 (CBR 8, value 40)

6.2.1.4 Pavement Structural Characteristics

(1) Drainage

The effects of certain levels of drainage on predicted pavement performance are important consideration in pavement design.

Table 6.2-4 presents the general definitions corresponding to different drainage levels from pavement structure.

TABLE 6.2-4 DRAINAGE LEVELS

Quality of Drainage	Water Removed Within
Excellent	2 hours
Good	1 day
Fair	1 week
Poor	1 month
Very Poor	(water will not drain)

In accordance with drainage level, AASHTO recommends m_1, values for modifying structural coefficients of base and subbase materials for flexible pavements and value of drainage coefficients Cd for rigid pavements.

In this Manual, m_1 of 0.9 and Cd of 0.9 are used.

(2) Load Transfer (Rigid Pavement)

The load transfer coefficient, J, is a factor used in rigid pavement design to account for the ability of a concrete pavement structure to transfer (distribute) load across discontinuities, such as joints or cracks.

In this Manual, load transfer coefficient of 4 is used considering from effect of plain joint.

(3) Loss of Support

This factor, LS, is included in the design of rigid pavements to account for the potential loss of support arising from subbase erosion and/or differential vertical soil movements. It is treated in the actual design procedure by diminishing the effective or composite k-value based on the size of the void that may develop beneath the slab.

6.2.1.5 Reinforcement Variables

Reinforcement variables are not discussed in this Manual.

6.2.2 Flexible Pavement Design

(1) Basic Design Equation

The basic design equation based on serviceability-performance concept for flexible pavement in AASHTO Guide 1986 is as follows:

<u>Basic Design Equation for Flexible Pavements:</u>

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

where:

W_{18} = predicted number of 18-kip equivalent single axle load application

Z_R = standard normal deviation

S_0 = combined standard error of the traffic prediction and performance prediction

PSI = *difference between the initial design* serviceability index, P_i, and the design terminal serviceability index P_t, and

M_R = resilient modulus (psi)

SN = structural number

The design nomograph to solve the equation is prepared in AASHTO Guide 1986 as shown in Figure 6.2-1.

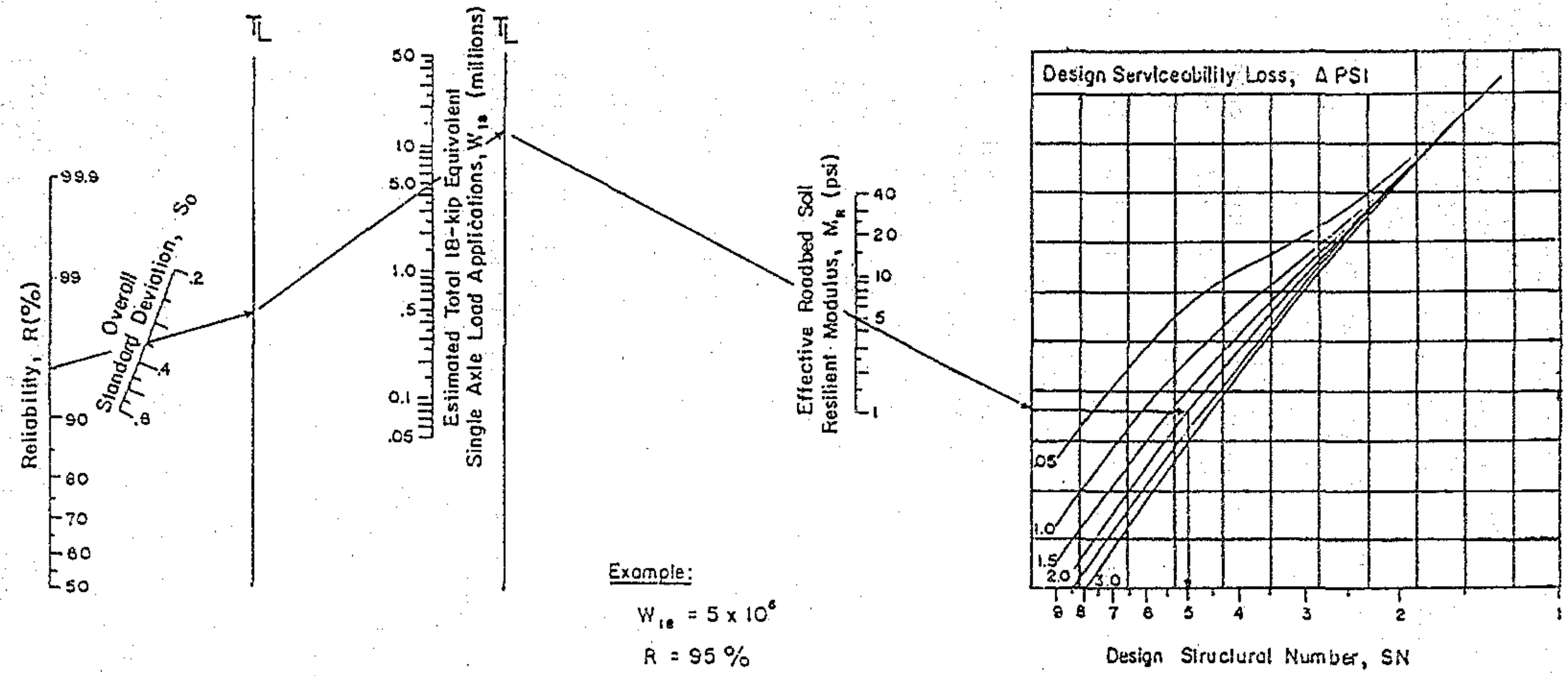
In this Study, a computer program was developed to analyze the equation. The outputs of basic design equation by electric computer are summarized in Chapter 10.

(2) Selection of Layer Thickness

The *design is based on identifying a flexible pavement* Structural Number (SN) to withstand the projected level of axle load traffic for the analysis period.

NOMOGRAPH SOLVES:

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



Example:

$W_{18} = 5 \times 10^6$

$R = 95\%$

S_0 0.35

$M_R = 5000$ psi

$\Delta PSI = 1.9$

Solution: SN = 5.0

Figure 6.2-1 DESIGN CHART FOR FLEXIBLE PAVEMENTS BASED ON USING MEAN VALUES FOR EACH INPUT

Once the design Structural Number (SN) for an initial pavement structure is determined, it is necessary to identify a set of pavement layer thickness. The following equation provides the basis for converting SN into actual thicknesses of surfacing, base and subbase;

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3$$

where:

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

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

m_2, m_3 = drainage coefficients for base and subbase layers, respectively.

Since it is generally impractical and uneconomical to place surface, base or subbase courses less than the minimum thickness, the value shown in Table 6.2-5 are provided as minimum practical thicknesses for each pavement course.

TABLE 6.2-5 FLEXIBLE PAVEMENT

Unit = Inches

Traffic, ESAL's	Asphalt Concrete	Aggregate Base
Less than 50,000	1.0 (or surface treatment)	4
50,001 - 150,000	2.0	4
150,001 - 500,000	2.5	4
500,001 - 2,000,000	3.0	6
2,000,001 - 7,000,000	3.5	6
Greater than 7,000,000	4.0	6

6.3 LOW-CLASS RIGID PAVEMENT

The structural design of rigid pavements prepared for highway pavement design are also applicable for design of low-class rigid pavements.

Refer to Guide for Pavement Rehabilitation Design, Feasibility Study of the Road Improvement Project of the Pan-Philippine Highway, Final Report, Volume VI.

6.3.1 Design Criteria and Variables

Refer to Chapter 6.2.1.

6.3.2 Rigid Pavement Design

This section describes the design for portland cement concrete pavements, including plain jointed (JCP), jointed reinforced (JRCP), and continuously reinforced (CRCP).

Rigid pavement design, rigid pavement reinforcement design and prestressed concrete pavement are not discussed in this Manual but available in ASSHTO Guide 1986.

(1) Basic Design Equation

The AASHTO design procedure is based on AASHO Road Test pavement performance algorithm. The basic design equation based on seriveability-performance concept for rigid pavement in AASHTO Guide 1986 is as follows:

Figure 6.3-1 presents the nomograpgh used for determining the slab thickness required for estimation total 18-kip Equivalent Single Axle Load Application and effective modulus of subgrade developed by AASHTO Guide 1986.

In this Study, a computer program to solve this equation was developed. The output of basic structural design by an electric computer are summarized in Chapter 10.

<u>Basic Design Equation for Rigid Pavements</u>

$$\log_{10}(W_{18}) = Z_R \times S_o + 7.35 \times \log_{10}(D+1) - 0.06 + \left[\frac{\mathrm{Log}_{10} \dfrac{\Delta PSI}{4.5-1.5}}{1 + \dfrac{1.624 \times 10^7}{(D+1)^{8.6}}}\right]$$

$$+ (4.22 - 0.32 \times p_t) \log_{10} \left[\frac{S_c \times C_d \times (D^{0.75} - 1.132)}{2.1563 \times J \left[D^{0.75} - \dfrac{18.42}{(E_c/k)^{0.25}}\right]}\right]$$

where:

W_{18} = predicted number of 18-kip equivalent single axle load application,

Z_R = standard normal deviation,

S_0 = combined standard error of the traffic prediction and performance prediction,

D = thickness (inches) of pavement slab,

PSI = difference between the initial design serviceability index, P_i, and the terminal design serviceability index, P_t,

S_c = modulus of rupture (psi) for portland cement concrete used in a specific project,

J = load transfer coefficient used to adjust for load transfer characteristics of a specific design,

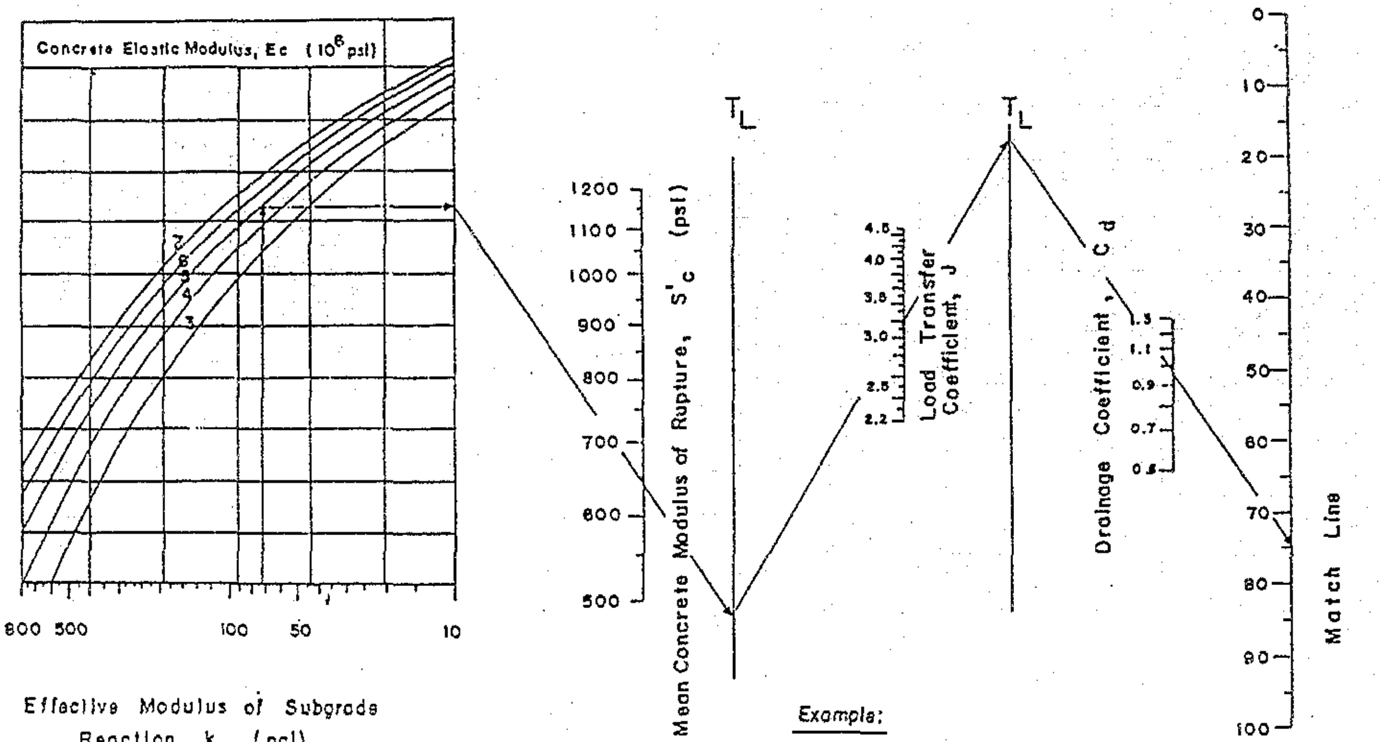
C_d = drainage coefficient,

E_c = modulus of elasticity (psi) for portland cement concrete, and

k = modulus of subgrade reaction (psi)

NOMOGRAPH SOLVES:

$$\log_{10} W_{18} = Z_R * S_O + 7.35 * \log_{10}(D+1) - 0.06 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.5 - 1.5}\right]}{1 + \frac{1.624 * 10^7}{(D+1)^{8.46}}} + (4.22 - 0.32 p_t) * \log_{10}\left[\frac{S_c' * C_d \left[D^{0.75} - 1.132\right]}{215.63 * J \left[D^{0.75} - \frac{18.42}{(E_c/k)^{0.25}}\right]}\right]$$



Example:

$k = 72$ pci

$E_c = 5 \times 10^6$ psi

$S_c' = 650$ psi

$J = 3.2$

$C_d = 1.0$

$S_o = 0.29$

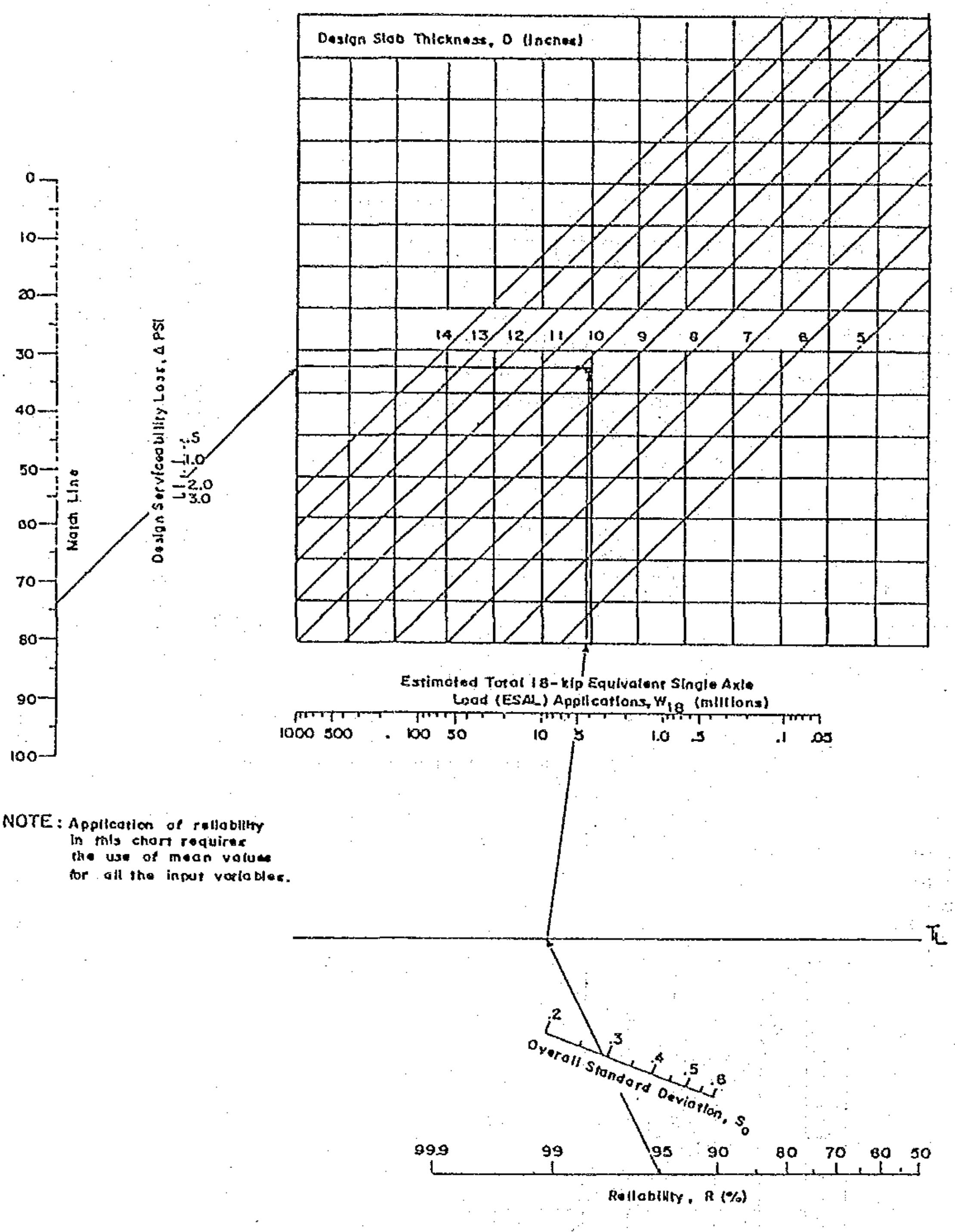
$R = 95\%$ ($Z_R = -1.645$)

$\Delta PSI = 4.2 - 2.5 = 1.7$

$W_{18} = 5.1 \times 10^6$ (18 kip ESAL)

Solution: D=10.0 inches (nearest half-inch, from segment 2)

FIGURE 6.3-1(1) DESIGN CHART FOR RIGID PAVEMENT BASED ON USING MEAN VALUES FOR EACH INPUT VARIABLE (SEGMENT 1)



NOTE: Application of reliability in this chart requires the use of mean values for all the input variables.

FIGURE 6.3-1(2) DESIGN CHART FOR RIGID PAVEMENT BASED ON USING MEAN VALUES FOR EACH INPUT VARIABLE (SEGMENT 2)

CHAPTER 7

WEAK SUBGRADE IMPROVEMENT DESIGN

The definition of weak subgrade is not clearly termed, but the Japan Road Association defines it as subgrade with CBR values less than 2, particularly for asphalt pavement design.

In general, weak subgrades includes soft soil composed largely of silt or clay, soil with void ratio such as organic deposits or peats and loose sand. All of them have high water contents.

Common methods widely adopted for treatment of such weak subgrades are embankment, soil replacement, soil stabilization and sandwich methods. Embankment method is advisable for new construction of roads. The latter three methods are discussed in this Chapter.

In concrete pavement design, the provision of filter layer is recommended where CBR values are equal or higher than 2 but less than 3. Where CBR values are less than 2, the application of methods mentioned above are recommended.

7.1 FILTER LAYER

As mentioned above, filter layer is recommended to be provided where CBR values are equal or higher than 2 but less than 3.

The filter layer of 15 cm to 30 cm thick is effective to prevent weak subgrades from piping and migrating into subbases. Materials used as filter layer are sand containing small volume of silt in general, but crusher-run for some cases.

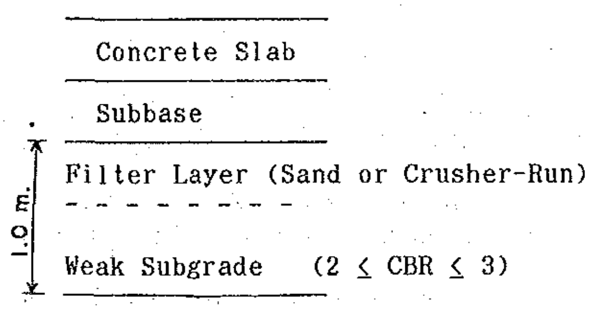


FIGURE 7.1-1 FILTER-LAYER

7.2 SOIL REPLACEMENT METHOD

Soil replacement method is to replace the weak subgrade soil with higher quality material to attain the desired value of CBR which should be greater than 3.

The depth of excavation for replacement should be determined to obtain the required average CBR. The average CBR can be calculated using the following formula with the assumption that *the CBR value of the bottom, 20 cm layer of the improved soil is* still assumed to be the same as that of the original soil

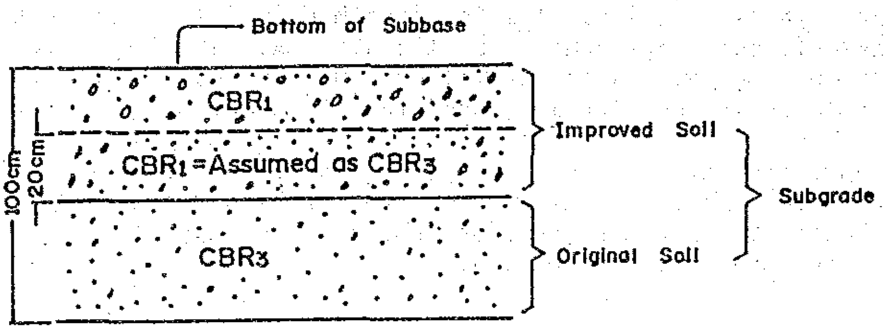


FIGURE 7.2-1 AVERAGE CBR

$$\text{Average CBR} = \left[\sum_{r=1}^{n} \frac{hi \,.\, CBRi^{1/3}}{100} \right]^3$$

Where:

hi: Thickness of i layer (cm)
Ehi = 100 cm
CBRi: CBR value of i layer

In applying this construction method, attention should be paid to the following points:

. That excavation should be carried out to the designated depth with great care taken not to disturb the soil below.

. That the refilled soil should be thoroughly compacted.

7.3 SOIL STABILIZATION METHOD

Soil stabilization is a construction method in which an admixture such as cement or lime is mixed into the surface layer of a weak subgrade to improve its bearing strength.

(1) Selection of Admixtures

Generally, cement is used as a treatment agent for sandy soil, and lime for silty and clayey soils. Lime used for such purpose includes calcined and hydrated types.

When applied to soils of high water content, calcined lime yields better effect.

The general guidance in selection of admixtures is summarized in Table 7.3-1.

TABLE 7.3-1 CHARACTERISTICS AND STABILIZATION EFFECT OF ROADBED SOIL

SOIL CLASSIFICATION			APPLICABILITY TO SUBGRADE X Unadvisable △ Sometimes unadvisable				STABILIZATION EFFECT ◎ Always effective o Mostly effective △ Sometimes effective			REMARKS
							STABILIZER			
			STRENGTH (CBR)	TRAFFICA-BILITY	PI	SURFACE STABILITY	CEMENT	SLACKED LIME	QUICK LIME	
Coarse-Grained Soils	Gravel	Pure gravel	(△)	—	—	—	(△)	(◎)	—	— Caution should be paid to mudstone and tuff against change into clay by slacking. — Material with less than 25% fine-grained contents is applicable without stabilization even if PI is found high.
		Silty gravel or silty sandy gravel	(△)	—	—	—	(△)	(◎)	—	
		Gravelly soils	X	△	X	—	(◎)	(◎)	—	
	Sand	Pure sand	—	—	—	(△)	(O)	(△)	—	— Sand with less than 15% fine-grained contents is rarely necessary to be stabilized although sometimes the surface is a little unstable.
		Silty sand	(△)	(△)	—	(△)	(O)	(△)	—	
		Sandy soils	X	X	X	(△)	(◎)	(◎)	—	
Fine Grained Soils		Silts	X	X	X	—	—	◎	O	— In Japan Highway Public Corporation, disturbed fine-graded soils are not applied to subgrade unless being stabilized.
		Clays	X	X	X	—	—	◎	O	
		Lean organic clays	Not Applicable							
		Volcanic clays	X	X	X	—	—	(O)	◎	
		Fat organic clays	Not Applicable							

( ) Shows that some material is exceptional

(2) Mix Design

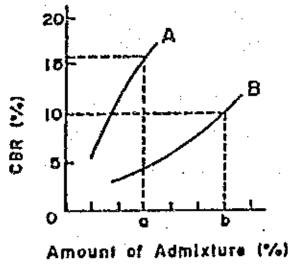
Mix design for soil stabilization is conducted in the following process.

1) Alternative mixes are produced by adding the required amount of cement or lime to the sampled subgrade soil in the natural state of water content, with the amount of admixture varied in 2% intervals, centering at its presumed optimal proportion against the dry weight of the treated soil. Test specimens of the mixes are prepared in accordance with the standard specification of JIS A 1211 using a CBR test mold, and compacting the specimen in 3 equal layers, each undergoing 67 blows.

   NOTE: Where quick-lime is used, the soil-lime mix should be covered after initial mixing, and permitted to hydrate for over 3 hours, and then remix and compact.

2) Immediately after compaction, surface of the specimens are throughly coated with paraffin wax and cured at 20°C for 3 days in the case of soil-cement mix and 6 days in the case of soil-lime, and then immersed in water for 4 days.

3) After water immersion curing, a CBR test is conducted on the sample specimens, and a graph as shown in Figure 7.3-1, of the relation between the amount of admixture and the CBR value is drawn based on the test data. From this graph, the amount of admixture required to achieve the desired CBR value in the improved soil is found.



A: For weak subgrade soil
B: For high water content soil such as that found in reclaimed area

FIGURE 7.3-1 RELATION BETWEEN AMOUNT OF ADMIXTURE AND CBR VALUE

Average CBR can be calculated adopting the formula mentioned for Soil Replacement Method.

However, CBR_2 is the average of CBR_1 and CBR_3.

(3) Execution

In executing road mix admixture treatment of a subgrade soil, it is essential that the treated soil and the admixture be uniformly mixed, and the soil-mix layer be properly compacted. The generally required procedure is as follows:

1) Prior to the mixing operation, the soil surface should be levelled. Where ponding occurs or where the ground water table is high, drainage facilities such as trenches should be provided.

2) In applying the admixture, the required amount per unit area should be calculated beforehand, and the admixture should be spread in uniform thickness.

3) Immediately after spreading, the mixing operation should be throughly performed to the required depth. Where irregularity is found in the resultant soil-mix, the mixing operation should be performed again.

NOTE: Where quick-lime is applied, the soil-mix after the initial mixing operation should be permitted to hydrate before resuming the mixing operation.

4) After mixing operation, the soil surface should be levelled and shaped by mechanical means, such as a small size bulldozer, and then throughly compacted by means of either a tire roller, a vibratory roller, or other similar equipment.

5) Subsequent to compaction, the subgrade surface should be finished and cured.

6) During curing period, attention should be paid to the drainage performance and the prevention of heavy vehicles from travelling on the subgrade surface.

7.4 SANDWICH METHOD

This method is mainly applied for asphalt concrete pavement. In this method, the weak subgrade is improved by first placing a sand layer, and then cast a layer of lean concrete or cement stabilized soil upon it. This method is advisable for the cases that deep excavation of heavy traffic road is required for soil replacement method or high ground water table is anticipated so that the improved soil may not be able to be compacted satisfactorily.

The first work in this method is to improve the weak subgrade by placing a 15 cm layer of sand. The sand layer is briefly rolled and levelled after being spread. And then, a 15 to 20 cm thick sandwich slab is constructed. The Sandwich slab is either the lean-mixed concrete or cement stabilized soil. The cement content of a lean concrete sandwich is about 220 kg/cm^3, and for cement stabilized soil, it is determined based on test mixture to attain a target unconfined compressive strength of 30 to 50 kg/cm2.

Figure 7.4-1 shows the example of sandwich method.

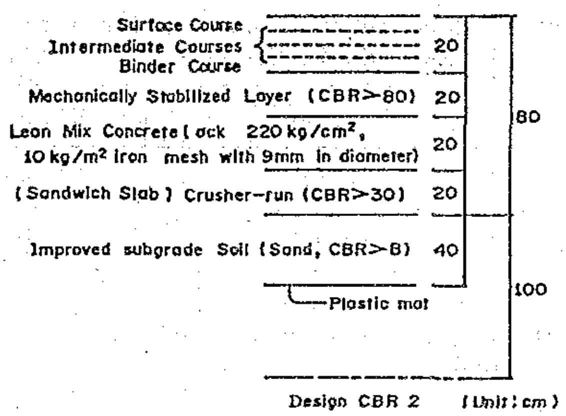


FIGURE 7.4-1 EXAMPLE OF PAVEMENT DESIGN APPLYING SANDWICH METHOD FOR SUBGRADE CONSTRUCTION

CHAPTER 8

DRAINAGE DESIGN

8.1 SURFACE DRAINAGE DESIGN

8.1.1 Design Year of Rainfall Intensity

The factor influencing the design of drainage facilities is run-off due to rainfall, characteristics of which shall therefore be carefully examined. Similarly, other factors to be considered are the importance of the road and the anticipated degree of damage when actual run-off exceeds expected design discharge. Therefore, the design year of rainfall probability shall be determined giving considerations to topographic characteristics aside from the factors mentioned above. Table 8.1-1 presents the recommended design year of rainfall probability.

TABLE 8.1-1 DESIGN YEAR OF RAINFALL PROBABILITY

Required Level of Drainage	Design Year of Rainfall Probability	
	Road Surface and Small Scale Slope	Important Drainage Facility
High	3 years	more than 10 years
Average	2 years	7 years
Low	1 year	5 years

Required level of drainage may be decided in accordance with the importance of the road.

8.1.2 Calculation of Run-Off

Run-off is calculated by the following Rationale Formula.

$$Q = \frac{1}{3.6 \times 10^6} \cdot C \cdot I \cdot A$$

where:

Q = Run-off (m^3/sec)
C = Coefficient of run-off
I = Rainfall Intensity within time of concentration (mm/hr.)
A = Catchment Area (m2)

Coefficient of Run-Off

The coefficient of run-off varies on the condition of ground surface, slope soil, duration of rainfall, etc. The standard value of coefficient of run-off shown in Table 8.1-2 may be used for the calculation of run-off.

The "C" value in the Rationale Formula reflects this variation in the terrain.

Rainfall Intensity

The value of rainfall intensity (mm/hr.) is found from the Rainfall Intensity Curve. Time of concentration for the different surface characteristics of the catchment is shown in Figure 8.1-1(1) to 8.1-1(4).

The catchment should be divided into separate areas, a_1, to a_n, where the corresponding value of I will be constant, hence:

$$Q = I \times (c_1 a_1 + c_2 a_2 + a_3 a_3 + \dots\dots\dots)$$

where:

a_1 to a_n are the number of each sub-areas

c_1 to c_n are the corresponding coefficients of run-off

Time of Concentration

$$t = t_1 + t_2$$

where:

t = Time of Concentration

Travel time in minutes of water from the farthest point to the point where run-off is to be calculated.

t_1 = Inlet time from slope to water course (Refer to Figure 7-2)

t_2 = Travel time from water course to the point where run-off is to be calculated

$$t_2 = \frac{l}{60 \cdot V}$$

l = Horizontal length of water course (m)

V = Average velocity of water course (m/sec)

Catchment Area

The catchment area to be considered may be determined by one of the following methods:

(a) Direct field survey using conventional survey instruments;
(b) Use of topographical maps together with field surveys to check details, e.g., artificial barriers such as terraces, ponds, etc;
(c) Aerial photography.

TABLE 8.1-2 COEFFICIENT OF RUN-OFF

Kind of Ground Surface			Coefficient of Run-Off
Surface of road	Pavement		0.70 to 0.95
	Gravel Road		0.30 to 0.70
Shoulder, slope, etc.	Fine-grained soil		0.40 to 0.65
	Coarse-grained soil		0.10 to 0.30
	Hard rock		0.70 to 0.85
	Soft rock		0.50 to 0.75
Lawns on sandy soil	Gradient	0 to 2%	0.05 to 0.10
		2 to 7%	0.10 to 0.15
		More than 7%	0.15 to 0.20
Lawns on cohesive soil	Gradient	0 to 2%	0.13 to 0.17
		2 to 7%	0.18 to 0.22
		More than 7%	0.25 to 0.35
Ridge			0.75 to 0.95
Intermediate area			0.20 to 0.40
Park with lawns and many trees and forest			0.10 to 0.25
Mountain with gentle slope			0.30
Mountain with steep slope			0.50
Paddy field, water surface			0.70 to 0.80
Field			0.10 to 0.30

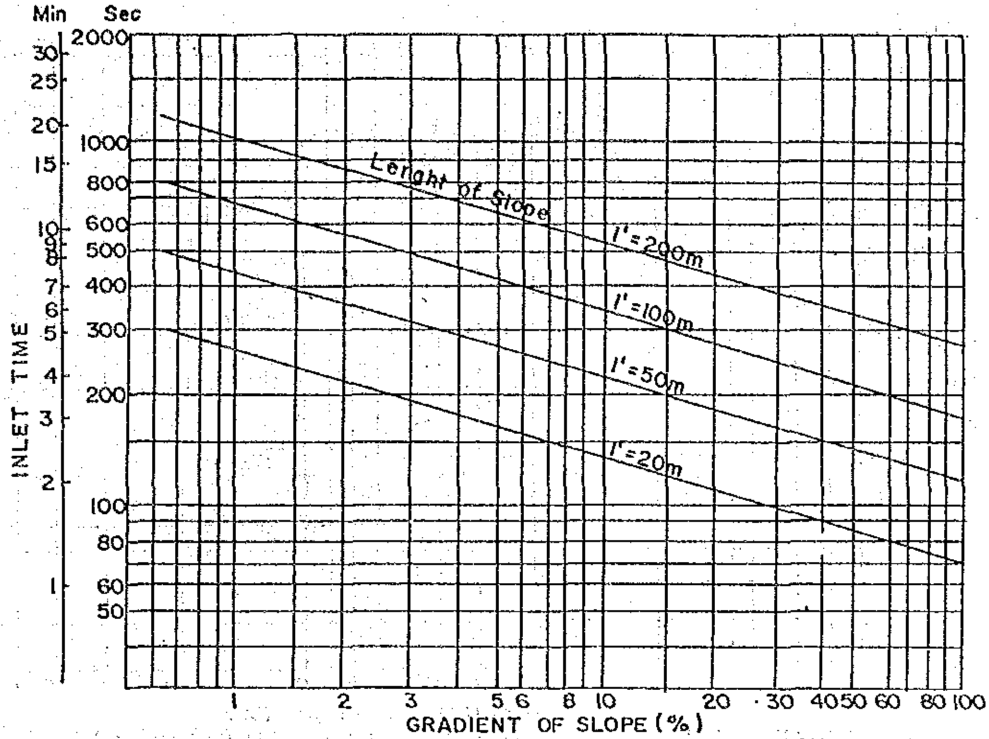


FIGURE 8.1-1(1) INLET TIME (SMOOTH SURFACE, COEFFICIENT OF ROUGHNESS) n = 0.02

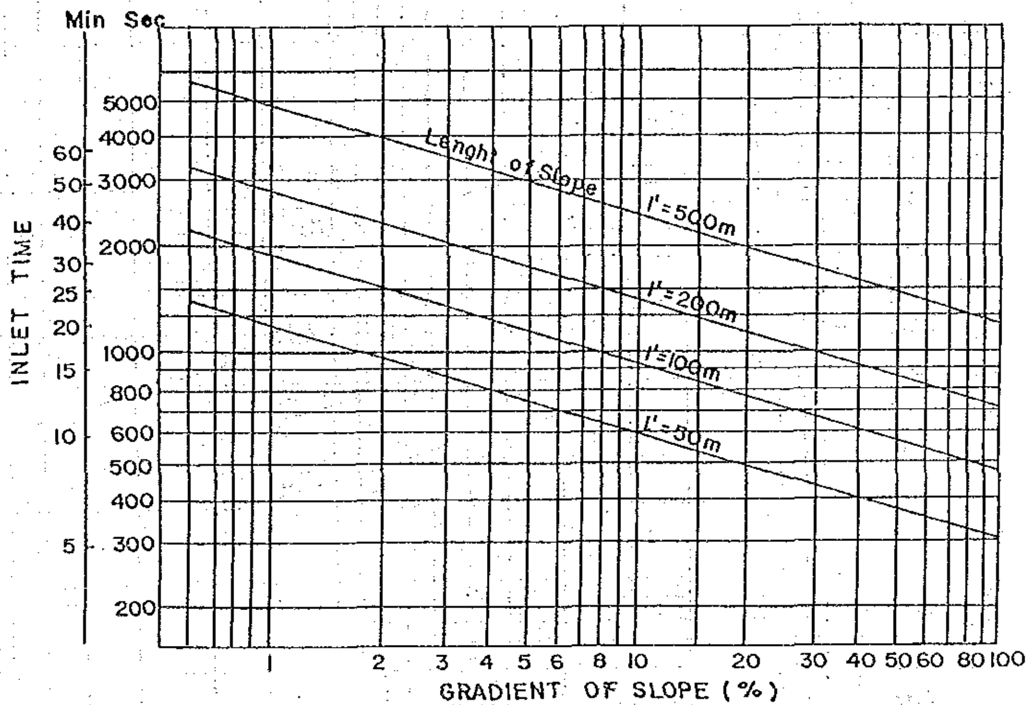


FIGURE 8.1-1(2) INLET TIME (BARE AREA WITH NO STONE n = 0.1)

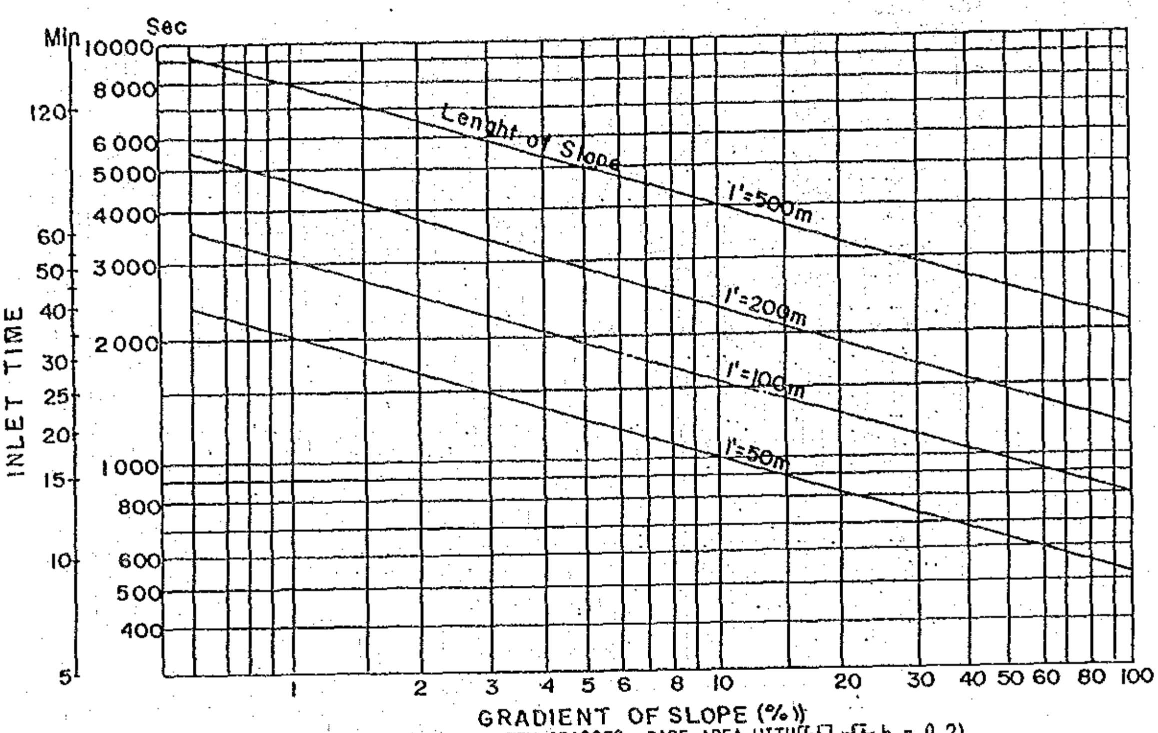


FIGURE 8.1-1(3) INLET TIME (AREA WITH FEW GRASSES, BARE AREA WITH h = 0.2)

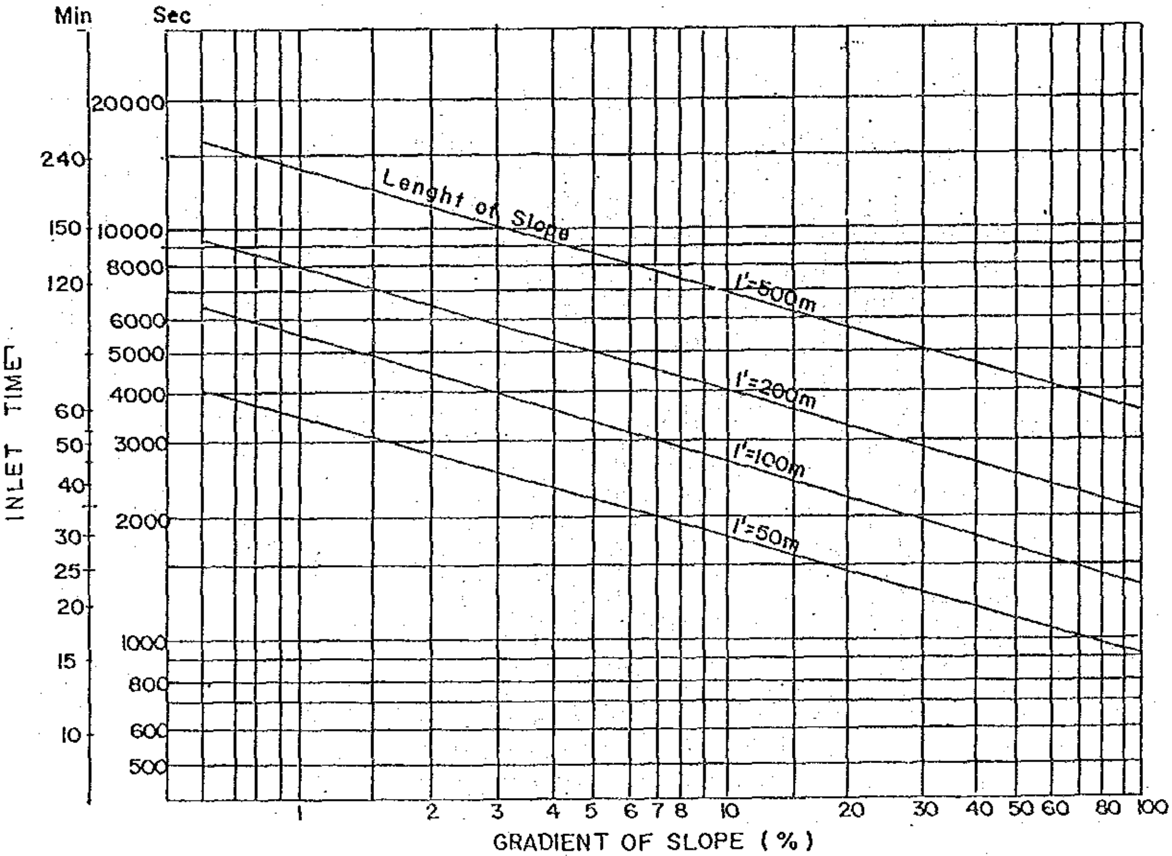


FIGURE 8.1-1(4) INLET TIME (ORDINARY GRASSLAND n = 0.4)

8.1.3 Running Water Velocity

The running water velocity is calculated using Manning's Formula.

$$V = \frac{1}{n} \cdot R^{2/3} \cdot i^{1/2}$$

where:

n = Coefficient of roughness
i = Hydraulic gradient
R = Hydraulic radius $\frac{(A)}{P}$
A = Area of running water
P = Wetted perimeter

Travel time of water flows in water course to the point under consideration may be calculated using the estimated velocity.

Required cross-sectional area of water course (side ditch) is calculated using the following formula.

$$Q = A \cdot V$$

where:

Q = Discharge of side ditch
A = Cross-sectional area of side ditch
V = Mean velocity of stream

Coefficient of Roughness

Table 8.1-3 shows the coefficient of roughness generally adopted for different types of drainage.

TABLE 8.1-3 COEFFICIENT OF ROUGHNESS

Type of Drainage		n (Coefficient of Roughness)
Earth and Gravel	Earth	0.02 ~ 0.025
	Sand and Gravel	0.025 ~ 0.04
	Rock	0.025 ~ 0.035
Cast-in-Place	Cement Mortar	0.01 ~ 0.013
	Concrete	0.013 ~ 0.018
	Stone Pitching	0.015 ~ 0.03
Fabricated	Concrete Pipe	0.012 ~ 0.016

8.1.4 Side Ditch Design

Side ditch are designed to cope with the maximum amount of run-off from the slope and adjacent areas.

The following types of ditch are generally used:

- Gravel Ditch
- Stone-Pitching Ditch
- Stone Masonry Ditch
- Cast-in-Place Concrete Ditch
- Precast Concrete Ditch

A description of each type is described below.

(1) Gravel Ditch

Gravel ditch may be used where the discharge is less and there is enough space available. See Figure 8.1-2.

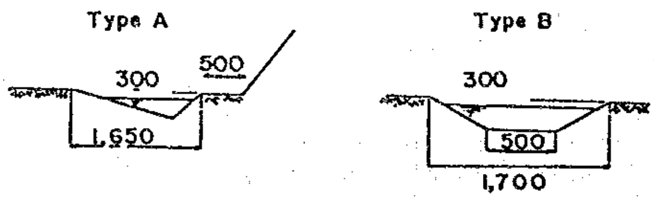


FIGURE 8.1-2 GRAVEL DITCH

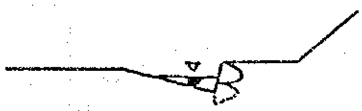
(2) Stone-Pitching Ditch

The bottom of the ditch is protected with boulder stones. This type is adoptable when the velocity of water is a little faster. See Figure 8.1-3.

FIGURE 8.1-3 STONE PITCHING DITCH

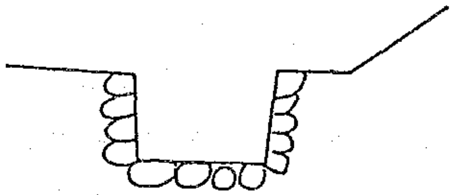
(3) Stone Masonry Ditch

The ditch is covered with boulders at one or both sides, sometimes even the bottom. See Figure 8.1-4.



a) one side

b) both side



c) all side

FIGURE 8.1-4 SEVERAL TYPES OF STONE MASONRY DITCH

The following stone masonry ditches may be recommended for mountainous and rolling areas, as shown in Figure 8.1-5.

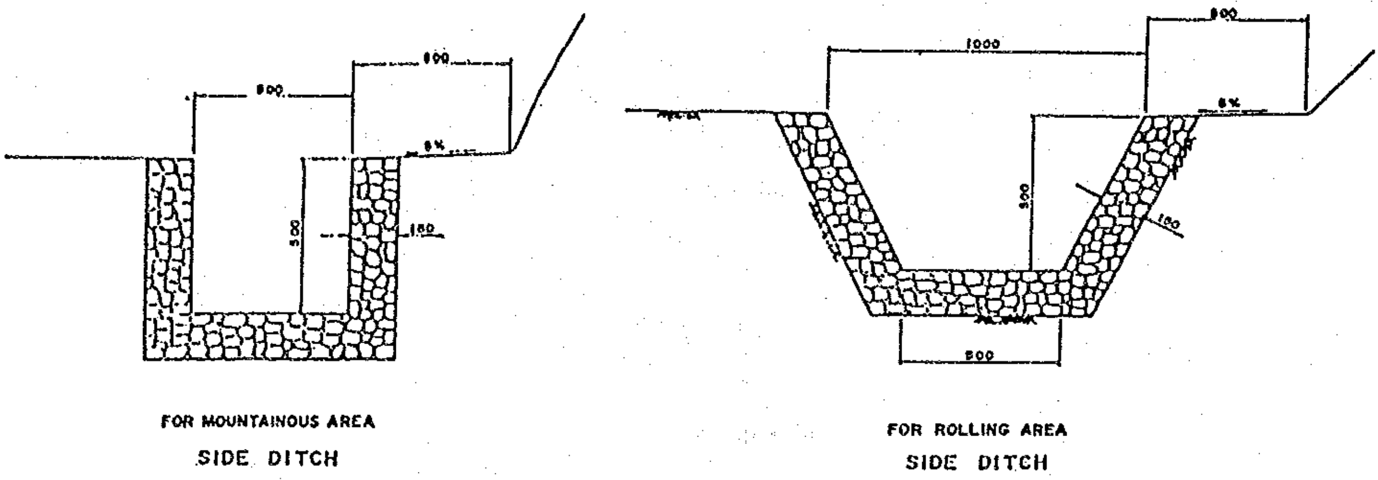


FIGURE 8.1-5 RECOMMENDED STONE MASONRY DITCH

(4) Cast-in-Place Concrete Ditch

Where the discharge is quite big and the velocity of water is fast, concrete ditch is recommended. Cast-in-place reinforced concrete ditch is often used, with or without cover. See typical example in Figure 8.1-6.

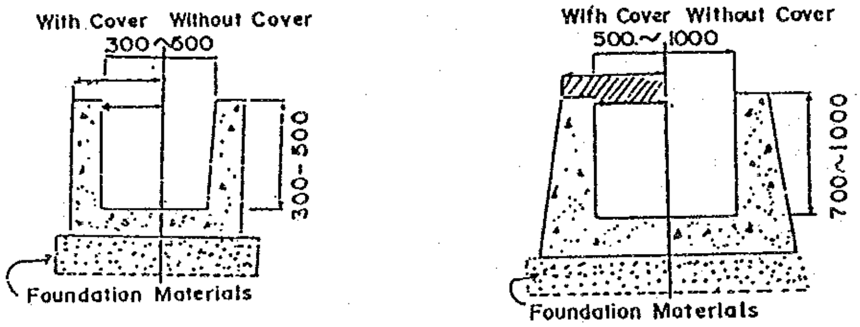


FIGURE 8.1-6 CAST-IN-PLACE CONCRETE DITCH

8.2 SUBSURFACE DRAINAGE DESIGN

8.2.1 General

Methods for Treating Water in Pavement

Drainage of water from pavement has always been an important consideration in road design. Methods for treating water in pavements generally consist of three methods as summarized in Table 8.2-1. To obtain adequate pavement drainage, the provision of three types of drainage systems 1) surface drainage, 2) groundwater (subsurface) drainage, and 3) structural drainage should be considered. In this Chapter, however, discussed is only subsurface drainage system.

TABLE 8.2-1 METHODS FOR TREATING WATER IN PAVEMENT

Method 1	Preventing water from entering the pavements . Surface Drainage . Paved Shoulder . High Embankment (for groundwater) . Maintenance (Sealing of joints and cracks)
Method 2	Providing drainage to remove excess water quickly . Subsurface Drainage . Selected Base and Subbase Materials
Method 3	Building the pavement strong enough to resist the combined effect of load and water . Increased Structural Number (Flexible Pavement) . Increased Thickness of Concrete Slab (Rigid Pavement)

8.2.2 Pavement Subsurface Drainage Design

Design process of pavement subsurface drainage system are illustrated in Figure 8.2-1.

(1) Design Criteria

Two general types of pavement subsurface drainage criteria have been proposed:

1) Time Criterion (Criterion 1)

The time for certain percentage of drainage of the base or subbase beginning with the completely flooded condition should be less than a certain value.

The time required for 50 percent drainage of free water from the base course should not be more than 10 days. It is, however, considered that this criteria is not sufficient for highway pavement with frequent repetition of loads.

2) Inflow-Outflow Criterion (Criterion 2 and 3)

The base or subbase should be capable of draining the water at a rate equal to or more than the inflow rate without becoming completely saturated or flooded.

The following two design infiltration rate have been proposed.

1) Cedergren et al, (Criterion 2)

$$\text{Design infiltration} = \frac{\text{1 hr. duration}}{\text{1 yr. frequency} \times s}$$

$s = 0.5 - 0.67$ (PCC pavement)
$s = 0.33 - 0.65$ (AC pavement)

2) Rigeway (Criterion 3)

For rigid pavements

$$Q = q\left(N + 1 + \frac{W}{S}\right)$$

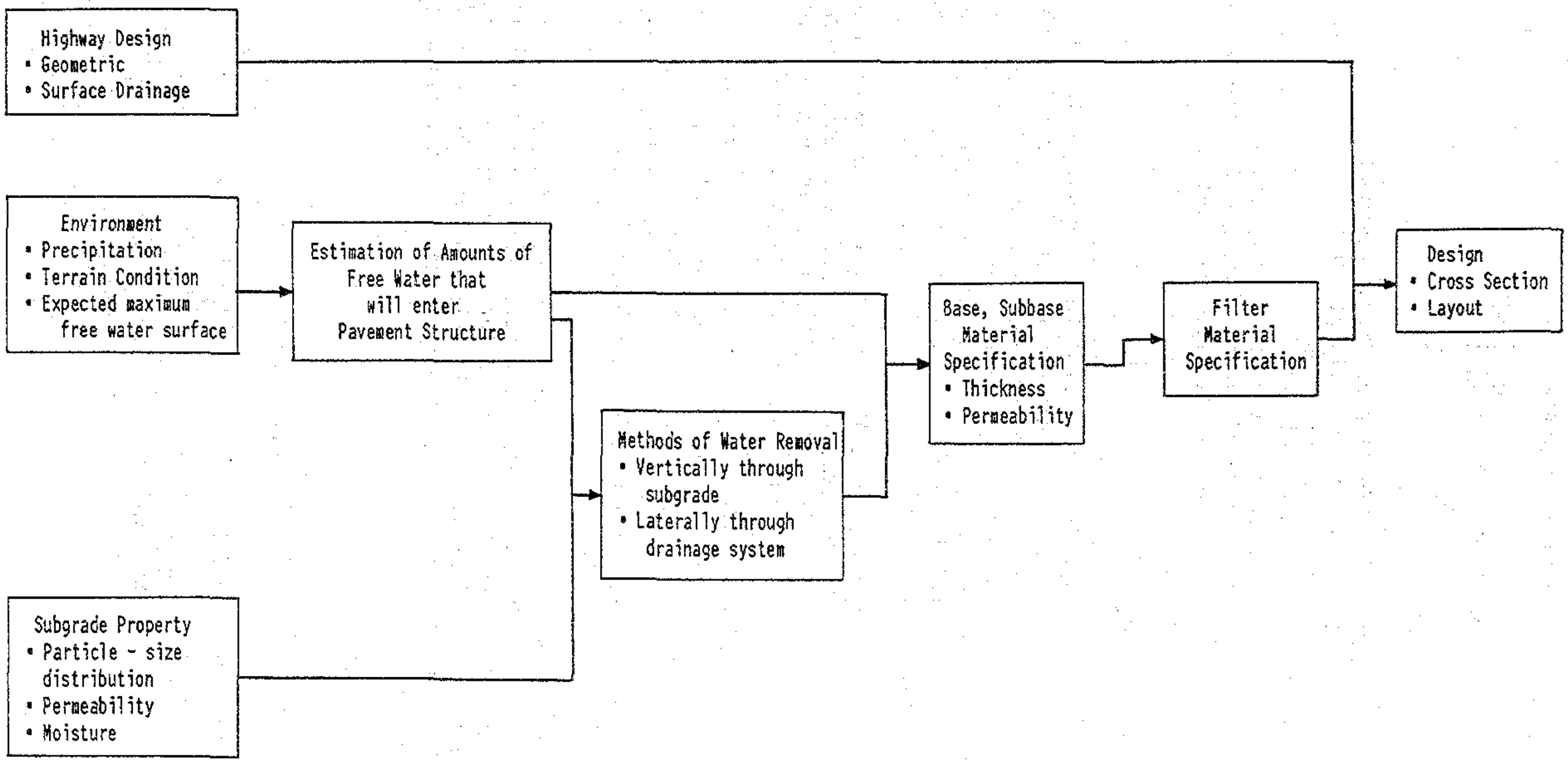


FIGURE 8.2-1 DESIGN PROCESS OF PAVEMENT SUBSURFACE DRAINAGE SYSTEM

For Flexible Pavements

$$Q = q \left[N + 1 + \frac{W}{40} \right]$$

where:

Q	=	ft^3/hr/linear ft. of pavement
q	=	0.1 ft2/hr./ft. of crack
N	=	Number of lanes
W	=	Lane width (ft.)
S	=	Transverse joint spacing (ft.)
40	=	Estimated mean spacing of transverse cracks in flexible pavement (ft.)

(2) Removal of Water

The infiltrating free water must be removed from the base and subbase materials. This can be done by draining the free water vertically through the subgrade or laterally through a drainage layer to a system of drainage pipes that carry the water away from the pavement structures. In many cases the actual drainage will be a combination of the two methods.

Where the maximum free water surface and/or permeabilities are less than the 1-hr duration/1-yr. frequency storm, vertical flow is indeed possible and a drainage system designed to provide lateral flow will not be required.

Where the estimated vertical flow is not sufficient to remove water from the base and subbase at rate equal to or more than the estimated inflow rate, lateral drainage is needed. The quantity and rate of lateral drainage needed can be computed using the estimated inflow minus the estimated vertical flow.

The system of lateral drains used as drainage layer, usually but not necessary the base, carries the infiltrated water to collector drains. After the criteria for the amount of infiltrated water is selected for the section, the required thickness permeability can be determined as follows:

Criterion 1

$$K = \frac{Ne\ L2}{2\ t50\ (H + L\ tan)}$$

Criterion 2 and 3

$$K = \frac{q.L}{H\ (SL + H/2)}$$

where:

K	=	Permeability (ft/day)
Ne	=	Effective porosity or yield (80% of absolute porosity)
L	=	Length of drainage path (ft)
t 50	=	Time for 50 percent drainage (days)
H	=	Thickness of drainage layer (ft)
L tan	=	Angle of slope drainage layer
q	=	Quantity of inflow (ft^3/day/ft. of pavement)
S	=	Slope of drainage path

Tables 8.2-2 and 8.2-3 show permeability of various graded aggregates.

TABLE 8.2-2 PERMEABILITY OF GRADED AGGREGATES

	Sample Number					
Percent Passing	1	2	3	4	5	6
3/4 inch sieve	100	100	100	100	100	100
1/2 inch sieve	85	84	83	81.5	79.5	75
3/8 inch sieve	77.5	76	74	72.5	69.5	63
No. 4 sieve	58.5	56	52.5	49	43.5	32
No. 8 sieve	42.5	39	34	29.5	22	5.8
No. 10 sieve	39	35	30	25	17	0
No. 20 sieve	26.5	22	15.5	9.8	0	0
No. 40 sieve	18.5	13.3	6.3	0	0	0
No. 60 sieve	13.0	7.5	0	0	0	0
No. 140 sieve	6.0	0	0	0	0	0
No. 200 sieve	0	0	0	0	0	0
Dry density (pcf)	121	117	115	111	104	101
Coefficient of permeability (ft. per day)	10	100	320	1,000	2,600	3,000

TABLE 8.2-3 EFFECTS OF PERCENTAGE PASSING 200 MESH SIEVE ON COEFFICIENT OF PERMEABILITY OF DENSE GRADED AGGREGATE, FEET PER DAY

	Percent Passing No. 200 Sieve			
Types of Lines	0	5	10	15
Silica or Limestone	1.0	0.07	0.08	0.03
S i l t	1.0	0.08	0.001	0.0002
C l a y	1.0	0.01	0.0005	0.00009

(3) Filter

The drainage layer and the collector system must be prevented from clogging if the system is to remain functioning for a long period of time. This is accomplished by means of a filter between the drain and the adjacent material.

The filter material, which is made from selected aggregates or fabrics must meet the three general requirements:

1) It must prevent finer material, usually the subgrade soil, from piping or migrating into the drainage layer and clogging it.

   The filter material must be coarse enough so that it does not pipe or migrate into the drainage layer, and it must be fine enough so that the subgrade material will not migrate into the filter. The following criterion will accomplish this:

   $$\frac{\text{D15 size of the coarse layer}}{\text{D85 size of the fine material}} \leqq 5\ \mu\text{m}$$

   where:

   D15 = 15 percent of the particle, by weight are smaller than the size.

2) It must be permeable enough to carry water without any significant resistance.

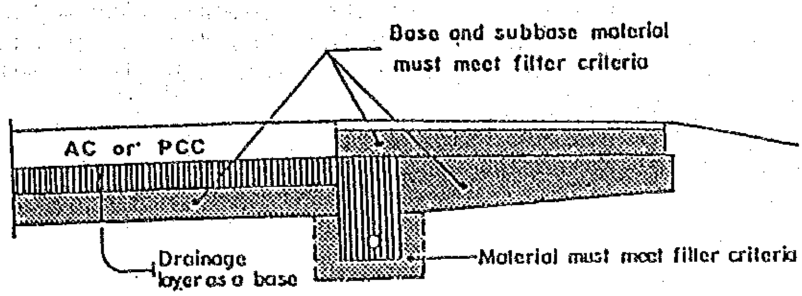
   The filter should be so coarse as possible.

   D15 size of the filter $\geqq$ 0.074 u m.

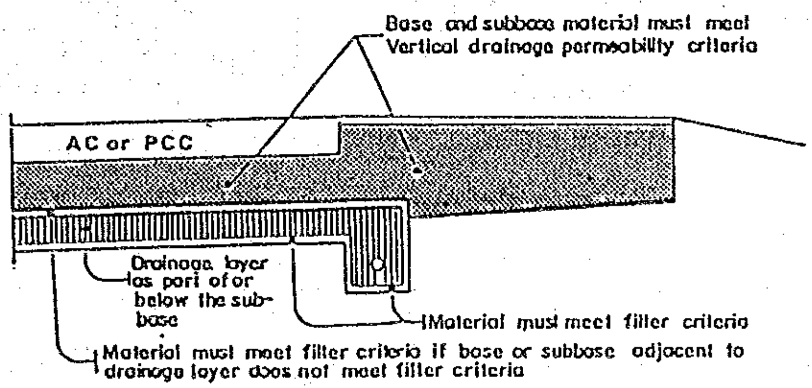
3) It must be strong enough to carry the loads applied and, for aggregate filters, to distribute live loads to the subgrade.

   Location of material that must meet filter criterion is shown in Figure 8.2-2.

A. Base is used as the drainage layer



B. Drainage layer is part of or below the subbase



Note: Filter fabrics may be used in lieu of material, soil or aggregate, depending on economic consideration.

FIGURE 8.2-2 EXAMPLE OF DRAINAGE LAYER IN PAVEMENT STRUCTURE

8.2.3 Typical Subdrainage Systems

The lateral drainage layer must include some method of removing the free water from the edge of the pavement. One method is to carry the drainage layer through the shoulder to the edge of the embankment or to the side ditches, although this method has several draw backs.

Typical cross sections of subdrainage systems are shown in Figure 8.2-3

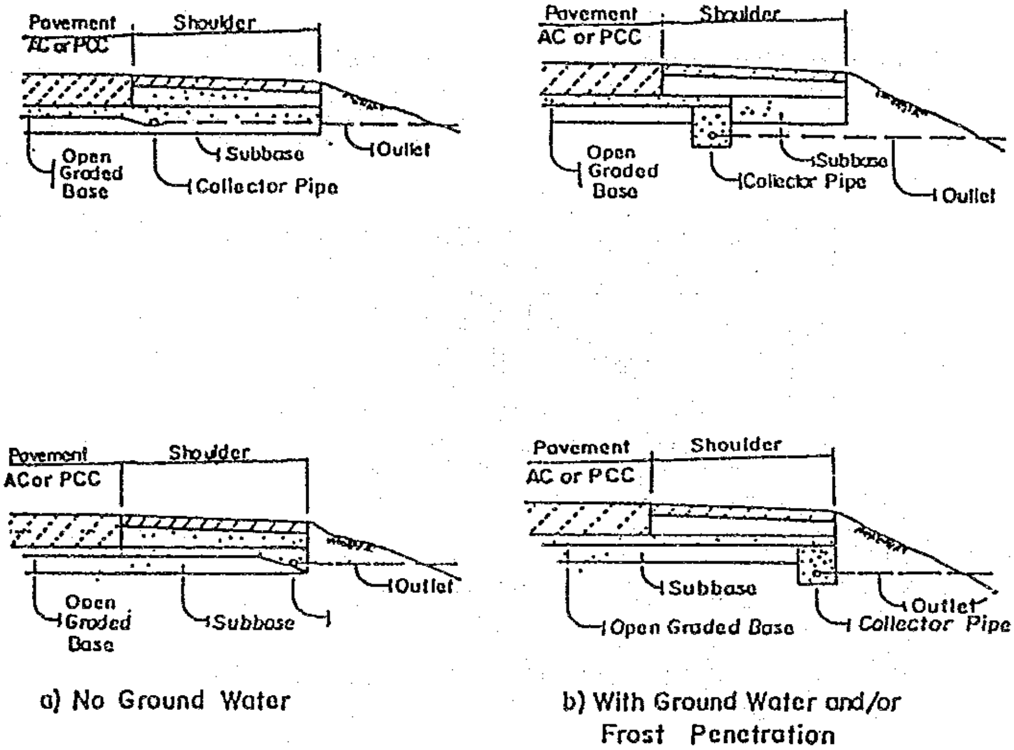


FIGURE 8.2-3 TYPICAL CROSS SECTIONS OF SUBGRADE SYSTEMS

In most cases, system of longitudinal collectors, with some traverse collectors at critical points, is required to remove the free water from the drainage layer. The collection system consists of a set of perforated or slotted pipes that are utilized to remove water from the pavement drainage layers and to convey it to suitable outlets outside the roadway limits.

CHAPTER 9

EVALUATION OF PRESENT SERVICEABILITY AND IDENTIFICATION OF REHABILITATION SECTION

The pavement condition survey is conducted to evaluate the present surface condition of pavements and identify the road sections where the pavement rehabilitation is required. The evaluation indices adopted in this Manual are :

- Present Serviceability Index (PSI)
- Rehabilitation Requirement Index (RRI)

9.1 SURFACE CONDITION SURVEY

To determined the evaluation indices, measurements of physical characteristics of pavement are necessary, which are :

- Surface deformation = roughness
- Surfaces deterioration = cracks
  patching
  pothole

Other deficiencies such as rutting, faulting, pumping, etc. are not incorporated in the evaluation indices.

9.1.1 Roughness Measurement

Roughness of a road surface can be surveyed by the Bump Integrator equipped to a light truck or passengers vehicles (see Figure 9.1-1).

The bump integrator is a device which produces an electric impulse for a particular amount of movement of an axle relative to the frame of the test vehicles. The pulses are counted and expressed as a total amount of movement per length of road. The survey engineer with a long experience is desired for the roughness survey. The test vehicle should de driven at about 30 kph. The intensity of the integrator should be recorded at every 100 m or 200 m with the odometer reading. The survey should be conducted at least three (3) times for each direction.

Figure 9.1-2 shows the roughness survey sheet.

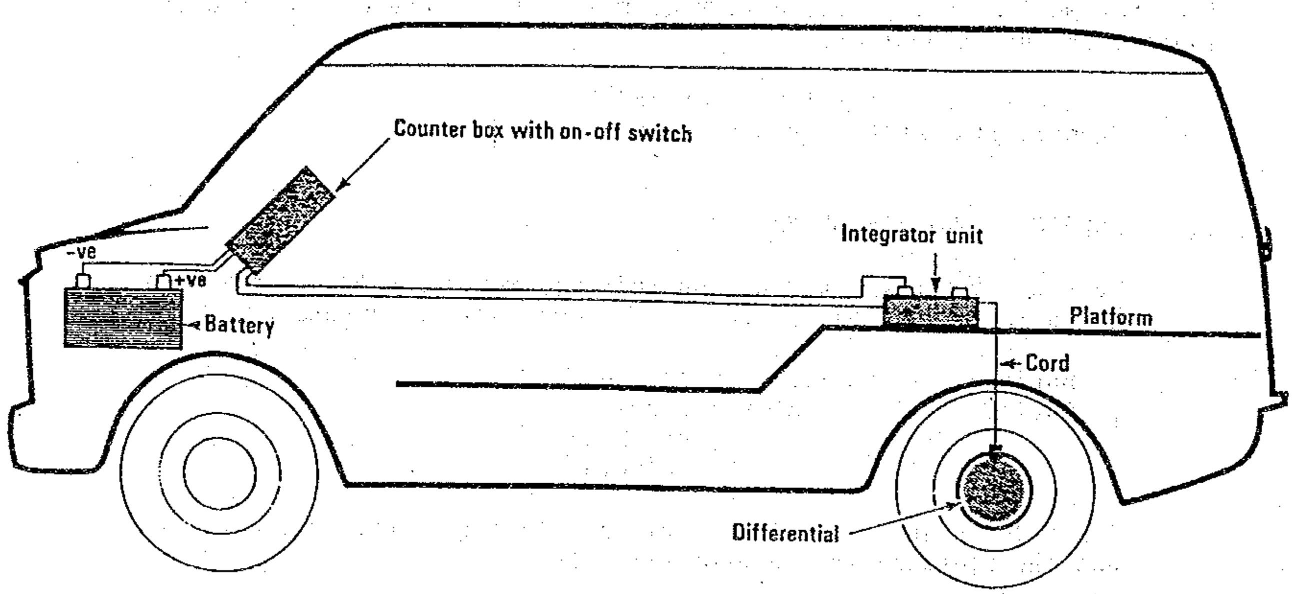


FIGURE 9.1-1 BUMP INTEGRATOR

ROAD NAME ____________________ RUN NO. ______

FROM ______ TO ______ DRIVER ______ RECORDER ______

SPEEDOMETER AT START ______ AT END ______ FACTOR ______ ACT. DIST. ______ DATE ______

TACHOMETER AT START ______ AT END ______ FACTOR ______ ST. TIME ______

ODOMETER AT START ______ AT END ______ FACTOR ______ FIN.TIME ______

ODOMETER	INTEGRATOR		PAVEMENT		STRUC. JCT.	REMARKS
	INTENSITY	DIFF.	TYPE	COND.		

FIGURE 9.1-2 ROUGHNESS SURVEY SHEET

9.1.2 Surface Deterioration Survey

1) Crack

<u>Classification of Cracks</u>

Flexible Pavement (SBST/DBST/BMP/AC)

Class 1 : fine disconnected hairline cracks.

Class 2 : cracking which has progressed to the stage where cracks have connected together to form a grid-type pattern.

Class 3 : cracking in which the bituminous surfacing segments have become loose.

Rigid Pavement (PCC)

Class 1 : Fine cracks not visible under dry surface condition to a man with good vision standing at a distance of 15 ft.

Class 2 : Cracks that can be seen at a distance of 15 ft. but exhibited only minor spalling such that the opening at the surface is less than 1/4 inch.

Class 3 : Any crack spalled at the surface to a width of 1/4 inch or more for at least one-half its length.

Class 4 : Any check which has been sealed.

<u>Method of Survey</u>

Flexible Pavement

Only class 2 and class 3 crackings are considered in the evaluation indices. The area of class 2 and class 3 crackings can be estamated in terms of percent of pavement surface, only from visual observation. At the early stage of the survey, the surveyors should be trained by actual measurement of individual cracking area. The area surveyed should be recorded every 100 m. of road.

Rigid Pavement

Only class 3 and class 4 cracks are considered in the evaluation indices. The length of class 3 and class 4 cracks can be estimated for each slab by observing its proportion is a longitudinal or transversal length of a slab. At the early stage of the survey, the surveyors should trained by measuring the actual length of individual cracks. The number of slabs by crack level should be recorded every 100 m of road.

2) Patching

The area of pavement surface patched with bituminous material is surveyed in square meter for every 100 m of road.

3) Pothole

The area of pothole is surveyed in square meter for every 100 m of road.

4) Survey sheet

Figures 9.1-3 and 9.1-4 show the surface deterioration survey sheets for flexible pavement and rigid pavement, respectively.

Road Name ____________

From ________ to ________

Date: ________

Surveyor: ________

KM	Town / City	General Information					Cracking		Patching	Pothole	Remarks
		T	L	S	D	CY	Class 2 (%)	Class 3 (%)	(m²)	(m²)	
+000		1 2 3	1 2 3 4 5	1 2 3	1 2 3						
+100		1 2 3	1 2 3 4 5	1 2 3	1 2 3						
+200		1 2 3	1 2 3 4 5	1 2 3	1 2 3						
+300		1 2 3	1 2 3 4 5	1 2 3	1 2 3						
+400		1 2 3	1 2 3 4 5	1 2 3	1 2 3						
+500		1 2 3	1 2 3 4 5	1 2 3	1 2 3						
+600		1 2 3	1 2 3 4 5	1 2 3	1 2 3						
+700		1 2 3	1 2 3 4 5	1 2 3	1 2 3						
+800		1 2 3	1 2 3 4 5	1 2 3	1 2 3						
+900		1 2 3	1 2 3 4 5	1 2 3	1 2 3						

Topography (T)
1. Flat (F)
2. Rolling (R)
3. Mountainous (M)

Land Use (L)
1. Rice Field (R)
2. Plowed Field (P)
3. Coconut Field (C)
4. Forest (F)
5. Wasteland (W)

Section Type (S)
1. Cut (C)
2. Embankment (E)
3. Cut/ Embankment (C/E)

Drainage Condition (D)
1. Good (G)
2. Fair (F)
3. Bad (B)

CY

Construction Year

Cracking

Class 2 = Cracks which have connected together to form a grid-type pattern.

Class 3 = Cracking in which bituminous surfacing segments have become loose.

Figure 9.1-3 Surface Deterioration Survey Sheet for Flexible Pavement

Road Name ______________ Date: ______________

From ________ to ________ Surveyor: ______________

K M	Town / City	General Information					Class 3 and Class 4 Cracks (Number of Slabs)									Patching	Remarks
		T	L	S	D	CY	Type	Crack Length per 100 m of a lane (m)									
								0	50	100	150	200	250	300		m^2	
+000		1 2 3	1 2 3 4 5	1 2 3	1 2 3		1 2 3 4										
+100		1 2 3	1 2 3 4 5	1 2 3	1 2 3		1 2 3 4										
+200		1 2 3	1 2 3 4 5	1 2 3	1 2 3		1 2 3 4										
+300		1 2 3	1 2 3 4 5	1 2 3	1 2 3		1 2 3 4										
+400		1 2 3	1 2 3 4 5	1 2 3	1 2 3		1 2 3 4										
+500		1 2 3	1 2 3 4 5	1 2 3	1 2 3		1 2 3 4										
+600		1 2 3	1 2 3 4 5	1 2 3	1 2 3		1 2 3 4										
+700		1 2 3	1 2 3 4 5	1 2 3	1 2 3		1 2 3 4										
+800		1 2 3	1 2 3 4 5	1 2 3	1 2 3		1 2 3 4										
+900		1 2 3	1 2 3 4 5	1 2 3	1 2 3		1 2 3 4										

Topography (T)
1. Flat (F)
2. Rolling (R)
3. Mountainous (M)

Land Use (L)
1. Rice Field (R)
2. Plowed Field (P)
3. Coconut Field (C)
4. Forest (F)
5. Wasteland (W)

Section Type (S)
1. Cut (C)
2. Embankment (E)
3. Cut/ Embankment (C/E)

Drainage Condition (D)
1. Good (G)
2. Fair (F)
3. Bad (B)

CY

Construction Year

Types of Cracking
1. Longitudinal Cracking (L)
2. Transverse Cracking (T)
3. Corner Cracking (C)
4. Block / Random Cracking (A)

Figure 9.1-4 Surface Deterioration Survey Sheet for Rigid Pavement

9.2 EVALUATION OF SURFACE CONDITION

9.2.1 Present Serviceability Index (PSI)

The present serviceability is a subjectve assessment by the road users using their own guideline and judgement. It is understood that the basis of judgement may be swayed by the tolerableness of road users, national characters as well as economic conditions of the country since comfort or riding quality is a matter of subjective response or the opinion of the users. Each country, therefore, may have their own rating.

In order to ascertain the basis in the Philippines, the present serviceability rating on surface condition were conducted under the Feasibility Study of the Road Improvement Project on the Pan-Philippine Highway, for rigid pavement in arterial roads; and the Feasibility Study on the Rural Road Network Development Project, for gravel surfacing and flexible pavement in rural roads. Each member of the rating panel composed of road users and drivers were asked, to rate the serviceability/comfort using their own judgement.

Based on the correlation analysis between the present serviceability ratings and physical measurements, the equations to determine the present serviceability index (PSI) were derived as follows :

Gravel Surfacing

$$PSI = 7.49 - 2.06 \log R$$

where:

PSI = present serviceability index

R = roughness, in cm/km

R is the value converted from the reading of the counter of the bump integrator, as follows:

$$R(cm/km) = \frac{\text{Counter Reading (inches)} \times 2.54(cm/inch)}{\text{Interval of Reading (km)}}$$

Flexible Pavement

$$\text{SBST/DBST} = \text{PSI} = 7.76 - 1.99 \log R - 0.11 \sqrt{P}$$
$$\text{BMP} = \text{PSI} = 9.80 - 2.46 \log R - 0.25 \sqrt{P}$$
$$\text{AC} = \text{PSI} = 7.32 - 1.68 \log R - 0.14 \sqrt{P}$$

where:

PSI, R = same definitions as in PSI for gravel surfacing

P = patching plus pothole, in %

P is converted from the surveyed area of patching and pothole, as follows :

$$P = \frac{\text{Patching plus Pothole(m}^2\text{ Per 100 m of road)}}{\text{Width of lane (m)}}$$

Rigid Pavement

$$\text{PSI} = 7.75 - 2.0 \log R - 0.06 \sqrt{C + P}$$

where:

PSI, R = same definitions as in PSI for gravel surfacing

C = total of class 3 and class 4 cracks, in m^2 per 1,000 m^2 of pavement surface

P = patching, in m^2 per 1,000 m^2 of pavement surface

C and P are converted from the survey data as follows :

$$C = \frac{\text{crack length(m per 100 m of road)}}{\text{width of lane (m)}} \times 10$$

$$P = \frac{\text{patching (m}^2\text{ per 100 m of road)}}{\text{width of lane (m)}} \times 10$$

9.2.2 Rehabilitation Requirement Index (RRI)

Since the present serviceability index is a subjective assessment by the road users using their own guideline and judgement , the index does not necessarily identify the sections where the rehabilitation works are needed, when judged from the engineering point of view.

The road user is not directly interested in the amount of cracking or deformation present in the pavements over which he drives. He is primarily interested in the ability of the road to provide a comfortable and safe ride. Riding quality is not, however, necessarily related to the structural condition of the pavement.

In order to asses the structural capacity, the survey team composed of only the experienced engineers conducted the occular survey on the pavement condition, paying their attentions to the pavement deficiencies such as cracking and pothole.

The index derived from this rating is called Rehabilitation Requirement Index (RRI), the formulas of which was established by the Feasibility Studies as follows :

Flexible Pavement

$$\text{SBST/DBST} = RRI = 6.22 - 1.29 \log R - 0.51\sqrt{P}$$
$$\text{BMP} = RRI = 5.80 - 0.89 \log R - 0.42\sqrt{P}$$
$$\text{AC} = RRI = 6.04 - 1.12 \log R - 0.39\sqrt{P}$$

where:

RRI = rehabilitation requirement index

R,P = same definitions as in PSI formulas for flexible pavement

Rigid Pavement

$$RRI = 7.53 - 1.5 \log R - 0.11\sqrt{C + P}$$

where:

RRI = rehabilitation requirement index

R,C,P = same definitions as in PSI formula for rigid pavement

9.2.3 Characteristics of Evaluation Indices

Average relationship between roughness and deterioration measurements was obtained by the least squares regression analysis for each type of pavement. Figures 9.2-1, 9.2-2, and 9.2-3 show such relationship for DBST/BMP, AC, and PCC, respectively, together with PSI/RRI contour lines. Figures 9.2-2 and 9.2-3 include AASHO Road Test (data) for reference.

Note : In AASHO Road Test, roughness was measured by the longitudinal profilometer, while in this Study, the bump integrator was used. Although no relationship between two measurements in both studies have been authorized, the AASHO logitudinal profilometer measurements were converted into roughness by the bump integrator based only upon very loose relation between multi-wheeled profilometer and bump integrator measurements shown in the "Design and Performance of Road Pavements, TRRL, 1977". This conversion was made to plot them on the same scale for the comparative purpose.

The following characteristics of PSI/RRI are found from these figures :

(1) The dominant factor in determining PSI of DBST and AC is roughness, while for BMP and PCC, both roughness and surface deterioration are related to PSI.

(2) The dominant factor in determining RRI is surface deterioration for all types of pavement, except for AC where both roughness and surface deterioration are related to RRI.

(3) PSI is higher than RRI in all types of pavement except in PCC. It might be interpreted as follows:

- The lowest acceptable levels as a rural road for road users might not be so high.
- Earlier rahabilitation might be necessary even when surface condition is still acceptable to road users.

(4) In case of PCC in which the ratings were made on arterial road, PSI is a little lower than RRI. It might be an expression of user's desire for higher level as arterial road.

(5) Comparing with the AASHTO's PSI on and around the line of average relationship between roughness and surface deteriorations, RRI is close to the AASHTO's PSI except in the range of very low RRI.

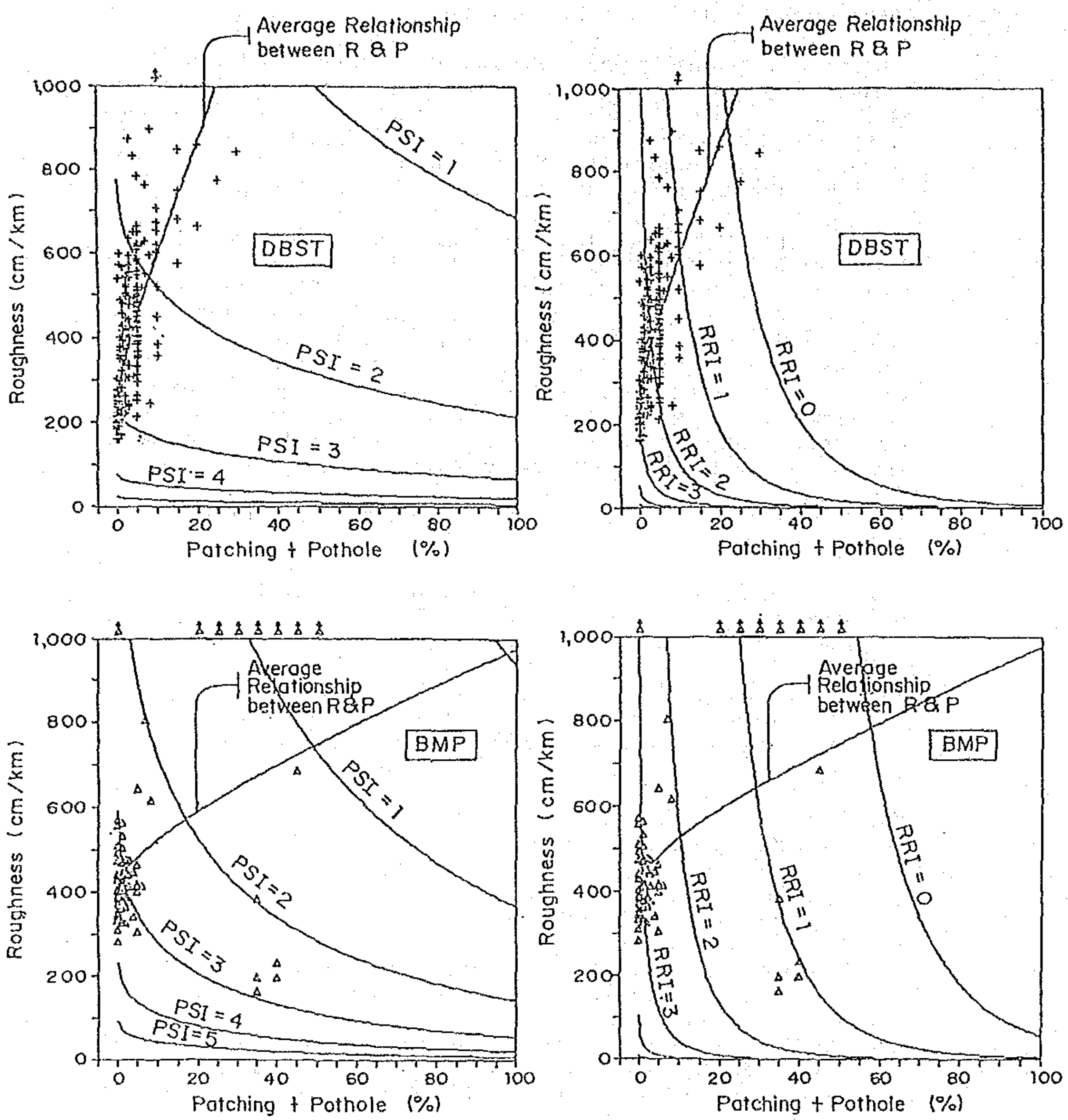


FIGURE 9.2-1 AVERAGE RELATIONSHIP BETWEEN ROUGHNESS (R) AND PATCHING PLUS POTHOLE (P) IN DBST AND BMP

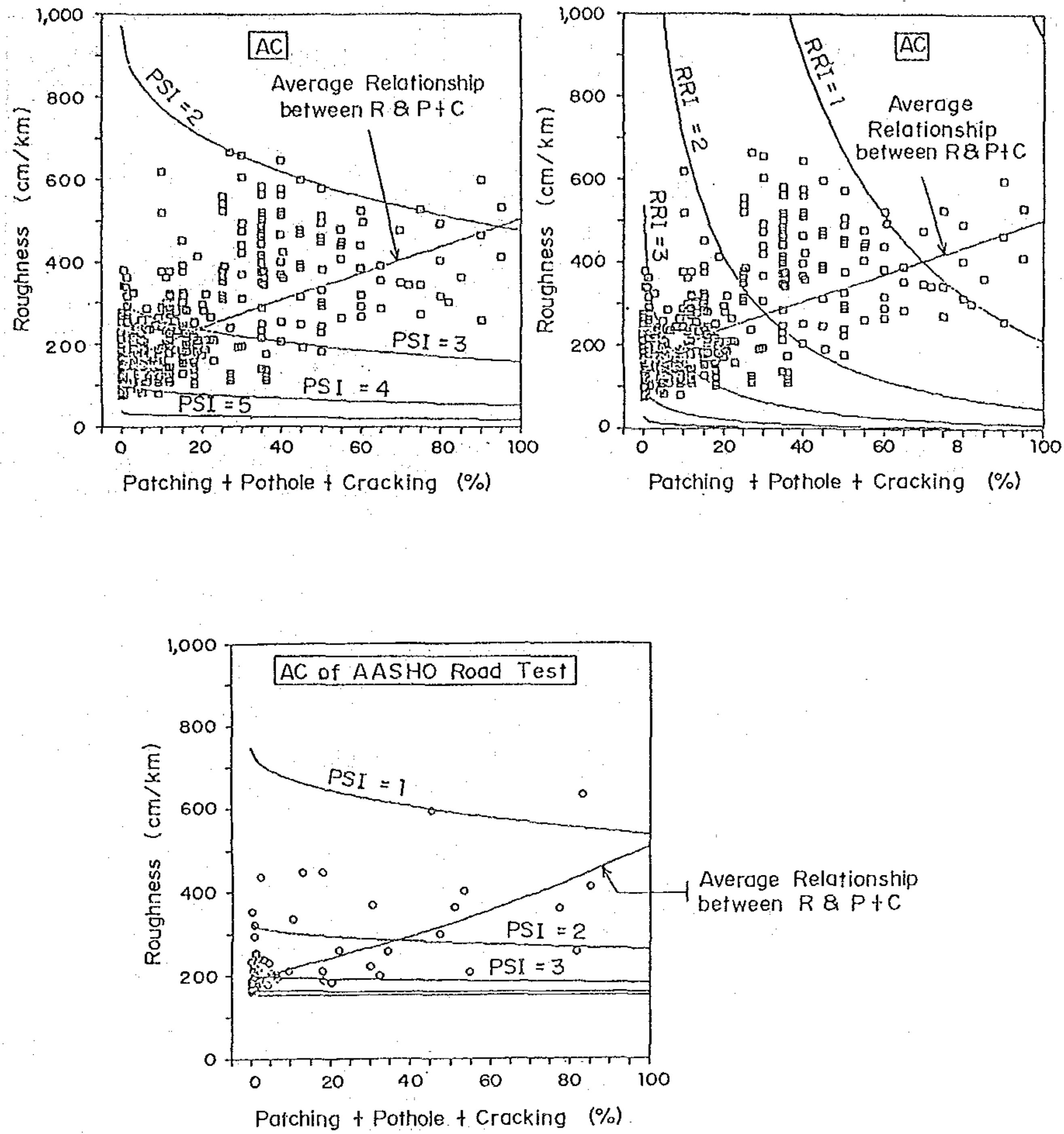


FIGURE 9.2-2 AVERAGE RELATIONSHIP BETWEEN ROUGHNESS (R) AND PATCHING PLUS CRACKING (P + C) IN AC

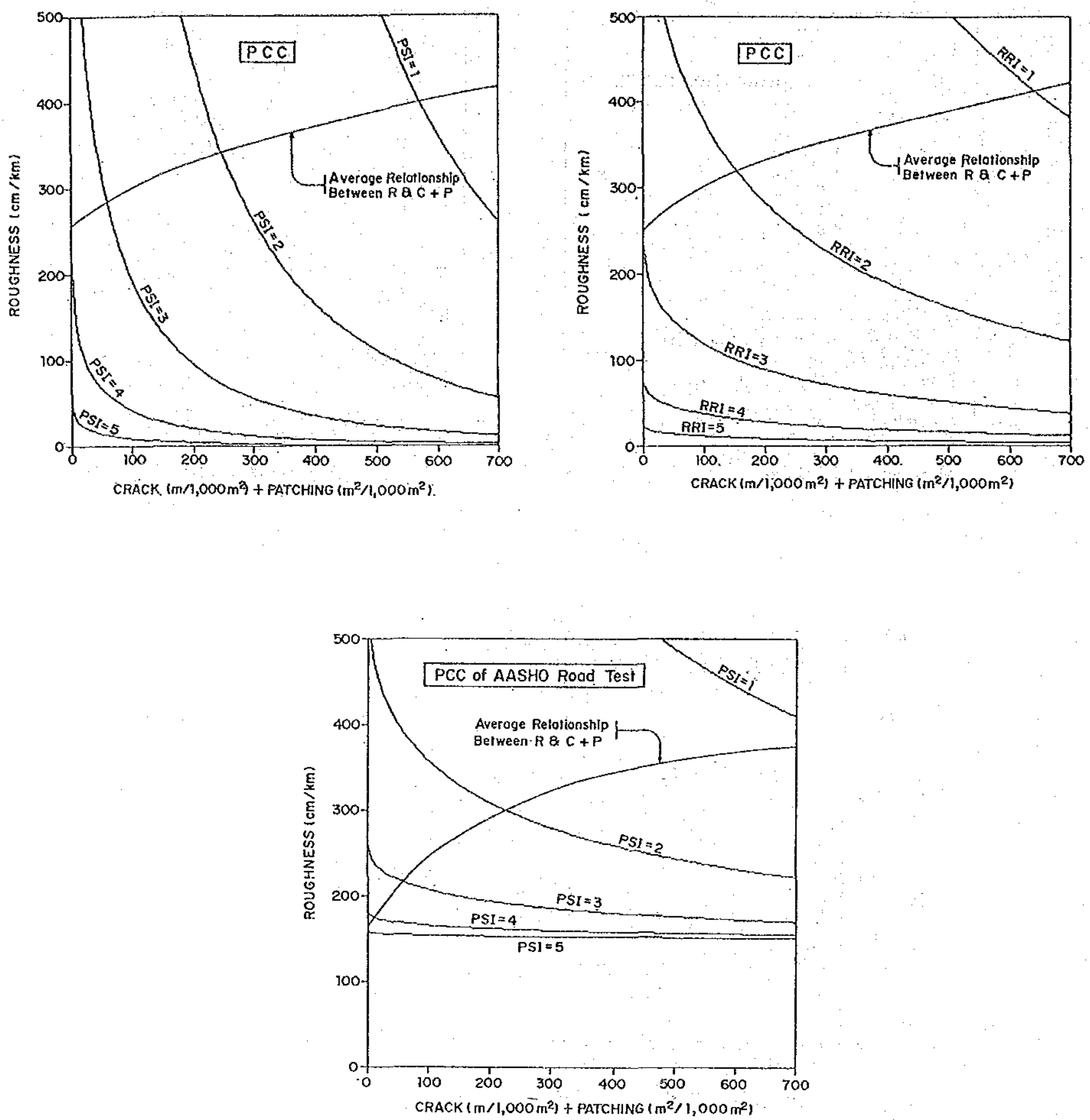


FIGURE 9.2-3 AVERAGE RELATIONSHIP BETWEEN ROUGHNESS (R) AND CRACK (C) PLUS PATCHING (P) IN PCC

9.3 IDENTIFICATION OF REHABILITATION SECTION

9.3.1 Serviceability Requirement for Pavement Rehabilitation

Since highways are defined as facilities for the comfort and convenience of the travelling public, the serviceability (riding quality) should be given precedence over other consideration when the pavement rehabilitation is proposed. It should however, be within the technical justification and the possible financial arrangements.

AASHTO Guide 1986

AASHTO Guide 1986 suggests the following guidelines. The primary measure of serviceability is the Present Serviceability Index (PSI) which ranges fom 0 (impassible road) to 5 (perfect road). The terminal serviceability index (P_t) is the lowest acceptable level before resurfacing or reconstruction becomes necessary, which is suggested as follows :

Design of Major Highways : P_t = 2.5 or higher

Design of Highways with a lower classification : P_t = 2.0

Design of Minor Highways : P_t = 1.5 (due to economic consideration)

Acceptability opinions in the AASHTO Road Test were as follows :

Present Serviceability Rating	Percent of People Stating Acceptable
3.0	88
2.5	45
2.0	15

Survey in the Feasibility Study

Each member of the rating panel was asked to indicate wether the pavement being rated is acceptable or not. The relationship between acceptability opinions and PSI is graphically shown in Figure 9.3-1.

The results are summarized as shown in Table 9.3-1

TABLE 9.3-1 ACCEPTABILITY OPINIONS

PSI	Percent of People Starting Acceptable
3.0	90
2.5	80
2.0	60
1.8	50
1.5	30

Acceptable percentage for every level of PSI is higher than that in AASHO Road Test. It might be due to difference in class of road surveyed as well as in national characters.

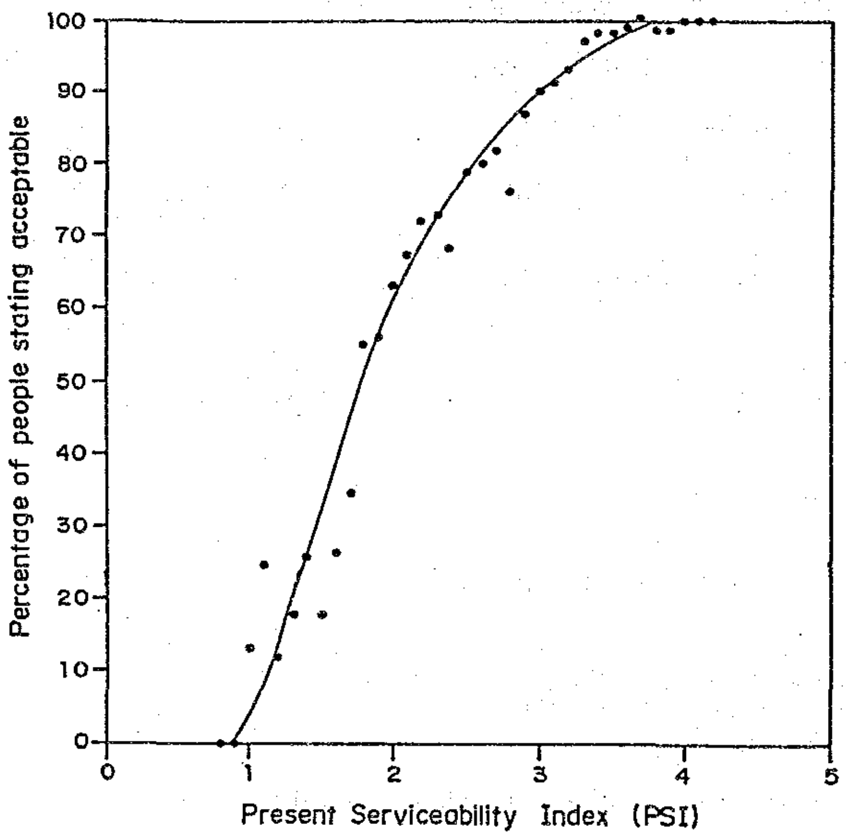


FIGURE 9.3-1 ACCEPTABILITY VS. PSI

9.3.2 Recommended Criteria for Evaluation of Rehabilitation Necessity

Taking into consideration the results of the acceptability survey and relationship between PSI and RRI as described in Section 9.2.3, following criteria are recommended for the rural road network development project :

Highway Class	Pavement Type	Ist Year ESAL	Criteria
Major Highway	PCC/AC	More than 30,000	RRI = 2.5
Highway with a lower classification	PCC/AC	30,000 or less	RRI = 2.0
Minor Highway	SBST/DBST BMP	14,000 or less	RRI = 1.5

Since RRI is close to the AASHTO's PSI as mentioned in Chapter 9 Section 9.2.1 basic design equations in the AASHTO Guide for Design of Pavement Structures are applicable by replacing the serviceability with RRI.

CHAPTER 10

STANDARD DESIGN OF LOW-CLASS PAVEMENTS

10.1 SELECTED PAVEMENT TYPES FOR STANDARD DESIGN

The structural design of low-class pavements was analyzed for the selected pavement types widely adopted in the country. The selected pavement types for design analysis are summarized in Table 10.1-1 and the conceptional cross sections are shown in Figure 10.1-1 and 10.1-2. The detailed cross sections are attached to Appendix II.

10.2 DESIGN CRITERIA AND ASSUMPTIONS

The design criteria assured for standard design of pavement structures are summarized in Table 10.2-1.

10.2.1 Design Variables

(1) Analysis Period

The analysis period means the period of time for which the analysis is to be conducted. In general, an analysis period of 25 years is adopted.

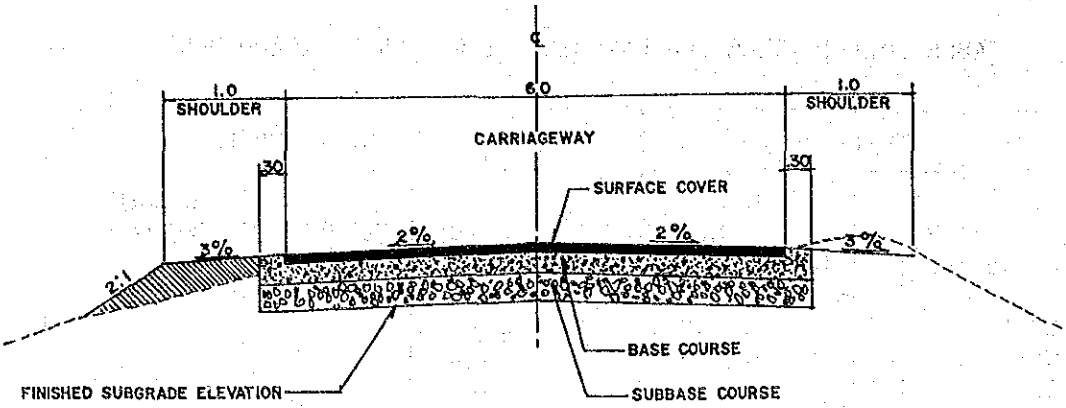
(2) Performance Period

The performance period refers to the period of time that an initial pavement structures will last before it needs rehabilitation. The most economical performance periods for each pavement type are discussed in Chapter 3.

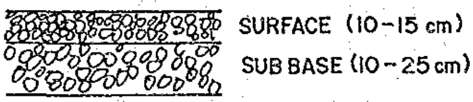
TABLE 10.1-1 SELECTED PAVEMENT TYPES FOR STANDARD DESIGN

Type No.	Thickness (cm) Surface	Base	Subbase	SN	Cost (MP/km) Construction	Rehabilitation	Annual Maintenance
GR-1	10	-	10		1.078		
GR-2	15	-	10		1.186		
GR-3	15	-	15		1.274	Tx0.0275	0.004150
GR-4	15	-	20		1.363		+ 0.000045
GR-5	15	-	25		1.454		x AADT
SBST-1	0.5	10	10	0.77	1.308		
SBST-2	0.5	15	10	0.95	1.435		
SBST-3	0.5	15	15	1.12	1.538	0.275	0.021
SBST-4	0.5	15	20	1.29	1.643		+ 0.0000075
SBST-5	0.5	15	25	1.46	1.750		x AADT
DBST-1	1.5	10	10	0.89	1.491		
DBST-2	1.5	15	10	1.07	1.618		
DBST-3	1.5	15	15	1.24	1.722	0.45	0.021
DBST-4	1.5	15	20	1.41	1.827		+ 0.000007
DBST-5	1.5	15	25	1.58	1.934		x AADT
BMP-1	5	10	10	1.30	1.815		
BMP-2	5	15	10	1.49	1.945		
BMP-3	5	15	15	1.65	2.049	0.75	0.021
BMP-4	5	15	20	1.82	2.156		+ 0.0000075
BMP-5	5	15	25	1.99	2.265		x AADT
AC-1	5	10	10	1.48	2.129		
AC-2	5	15	15	1.83	2.359		
AC-3	5	20	20	2.19	2.602	1.07	0.0183
AC-4	5	25	25	2.54	2.854		
AC-5	5	30	30	2.89	3.113		
PCC-1	13	-	20		2.260		
PCC-2	15	-	20		2.443		
PCC-3	18	-	20		2.706	1.07	0.0166
PCC-4	20	-	20		2.902		
PCC-5	23	-	20		3.167		

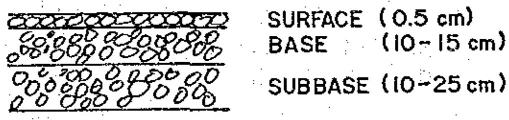
NOTE: T = thickness of surface



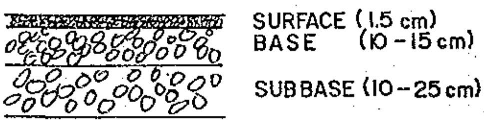
TYPICAL ROADWAY SECTION



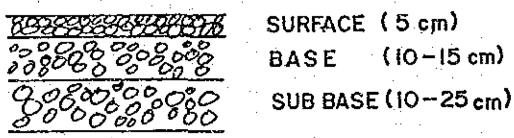
GRAVEL-SURFACED ROAD
(GR)



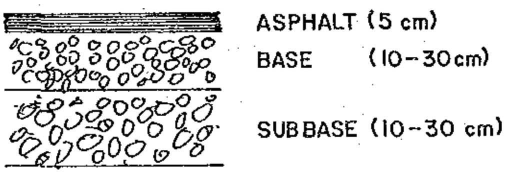
SINGLE BITUMINOUS
SURFACE TREATMENT
(SBST)



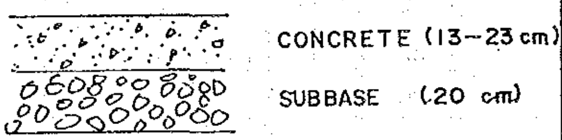
DOUBLE BITUMINOUS
SURFACE TREATMENT
(DBST)



BITUMINOUS PENETRATION
MACADAM PAVEMENT
(BMP)



ASPHALT
CONCRETE PAVEMENT
(AC)



PORTLAND CEMENT
CONCRETE PAVEMENT
(PC)

FIG. 10.1-1 CROSS SECTIONS OF SELECTED PAVEMENTS

GRAVEL

	Crushed Aggregate Surface Course	Aggregate Subbase Course	Total
GR-1	100	100	200
GR-2	150	100	350
GR-3	150	150	300
GR-4	150	200	350
GR-5	150	250	400

SBST

	SBST	Crushed Aggregate Base Course	Aggregate Subbase Course	Total
SBST-1 (SN= 0.77)	5	100	100	205
SBST-2 (SN = 0.95)	5	150	100	255
SBST-3 (SN=1.12)	5	150	150	305
SBST-4 (SN=1.29)	5	150	200	355
SBST-5 (SN=1.46)	5	150	250	405

DBST

	DBST	Crushed Aggregate Base Course	Aggregate Subbase Course	Total
DBST-1 (SN = 0.89)	15	100	100	215
DBST-2 (SN=1.07)	15	150	100	265
DBST-3 (SN=1.24)	15	150	150	315
DBST-4 (SN=1.41)	15	150	200	365
DBST-5 (SN=1.58)	15	150	250	415

BMP

	BMP	Crushed Aggregate Base Course	Aggregate Subbase Course	Total
BMP-1 (SN=1.30)	50	100	100	250
BMP-2 (SN=1.49)	50	150	100	300
BMP-3 (SN=1.65)	50	150	150	350
BMP-4 (SN=1.82)	50	150	200	400
BMP-5 (SN=1.99)	50	150	250	450

AC

	AC	Crushed Aggregate Base Course	Aggregate Subbase Course	Total
AC-1 (SN=1.48)	50	100	100	250
AC-2 (SN=1.83)	50	150	150	350
AC-3 (SN=2.19)	50	200	200	450
AC-4 (SN=2.54)	50	250	250	550
AC-5 (SN=2.89)	50	300	300	650

PCC

	Portland Cement Concrete Pavement	Aggregate Subbase Course	Total
PCC-1	130	200	330
PCC-2	150	200	350
PCC-3	180	200	380
PCC-4	200	200	400
PCC-5	230	200	430

Fig 10 1-2 STANDARD PAVEMENT STRUCTURE

TABLE 10.2-1 DESIGN CRITERIA AND ASSUMPTIONS

	GR	SBST	DBST	BMP	AC	PCC	Reference
1. Design Variables							
Analysis Period (years)	25	25	25	25	25	25	
Performance Period (years)	3-4	3-5	5-8	8-10	10-15	15-20	Table 2.3-1
Traffic (classes)	10	10	10	10	10	10	Table 4.2-1
Reliability (%)	50	50	50	50	50	50	Table 3.2-1
2. Performance Criteria							
Initial Service-ability (Po)	3.5	4.2	4.2	4.2	4.2	4.5	Section 3.1
Terminal Service-ability (Pt)	0.5	1.5	1.5	1.5	2.0/2.5	2.0/2.5	
3. Material Property							
3.1 Elastic Modulus							
Subgrade	CBR = 3, 4, 6, 8, 10, 15 and 20 (See Table 5.1-3)						
Subbase (PSi)	8,000	8,000	8,000	8,000	8,000	8,000	Table 5.2-2
Base (PSi)	22,000	22,000	22,000	22,000	22,000	-	Table 5.3-2
SBST/DBST/BMP (PSi)	-	200,000	200,000	200,000	-	-	Table 5.8-2
AC (PSi)	-	-	-	-	350,000	-	Table 5.6-2
PCC (PSi)	-	-	-	-	-	3.28×10^6	Section 5.9
3.2 Modulus of Rupture, PCC (PSi)	-	-	-	-	-	580	Section 5.9
3.3 Structural Layer Coefficient							
Subbase	0.095	0.095	0.095	0.095	0.0954	0.095	
Base	0.105	0.105	0.105	0.105	0.105	-	
SBST/DBST/BMP	-	0.30	0.30	0.30	-	-	
AC	-	-	-	-	0.39	-	
PCC	-	-	-	-	-	-	
4. Structural Characteristics							
Drainage	-	m = 0.9	m = 0.9	m = 0.9	m = 0.9	Cd = 0.9	
Load Transfer	-	-	-	-	-	J = 4	
5. Rehabilitation Works	Re-gravel	Re-construction of Surface	Re-construction of Surface	Re-construction of Surface	5 cm. AC Overlay	5 cm. AC Overlay	