8.1.6 Execution Plan

With regard to the construction of the experimental pavement, the following preparation and planning were carried out.

(1) Preparation of the Construction Documents

- Construction Drawings
- Bill of Quantities
- Specifications

The Specifications for the Construction of Experimental Pavement was prepared in accordance with Standard Specifications: Volume II Highways, Bridges and Airport, 1988, DPWH.

The Specifications include special provisions for quality control tests. The test items for quality control of the work are the same as that stipulated in the above Standard Specifications. In order to obtain quality control data as the original data for the follow-up survey on the constructed experimental pavement models, the frequency at which quality control tests are to be conducted for every 50 m on both lanes of each pavement model is specified.

(2) Construction Sections and Fund Source

Fund sources for each construction section are as shown below:

Construction Section	Fund Source
Sections No. 1, 2, 3 and 4	JICA
Section No. 5	DPWH

(3) Construction Schedule

It was assumed that three (3) construction teams and three (3) sets of equipment would be organized, one for each of the following sections:

- Sections 1 and 2
- Sections 3 and 4
- Section 5

Based on the above assumption, a total of 45 days was estimated as being needed to complete the experimental pavement construction. The construction schedule is given in Figure 8.1-5.

FIGURE 8.1-5 (1) EXPERIMENTAL PAVEMENT CONSTRUCTION SCHEDULE: SECTION No.1 ANDNo.2

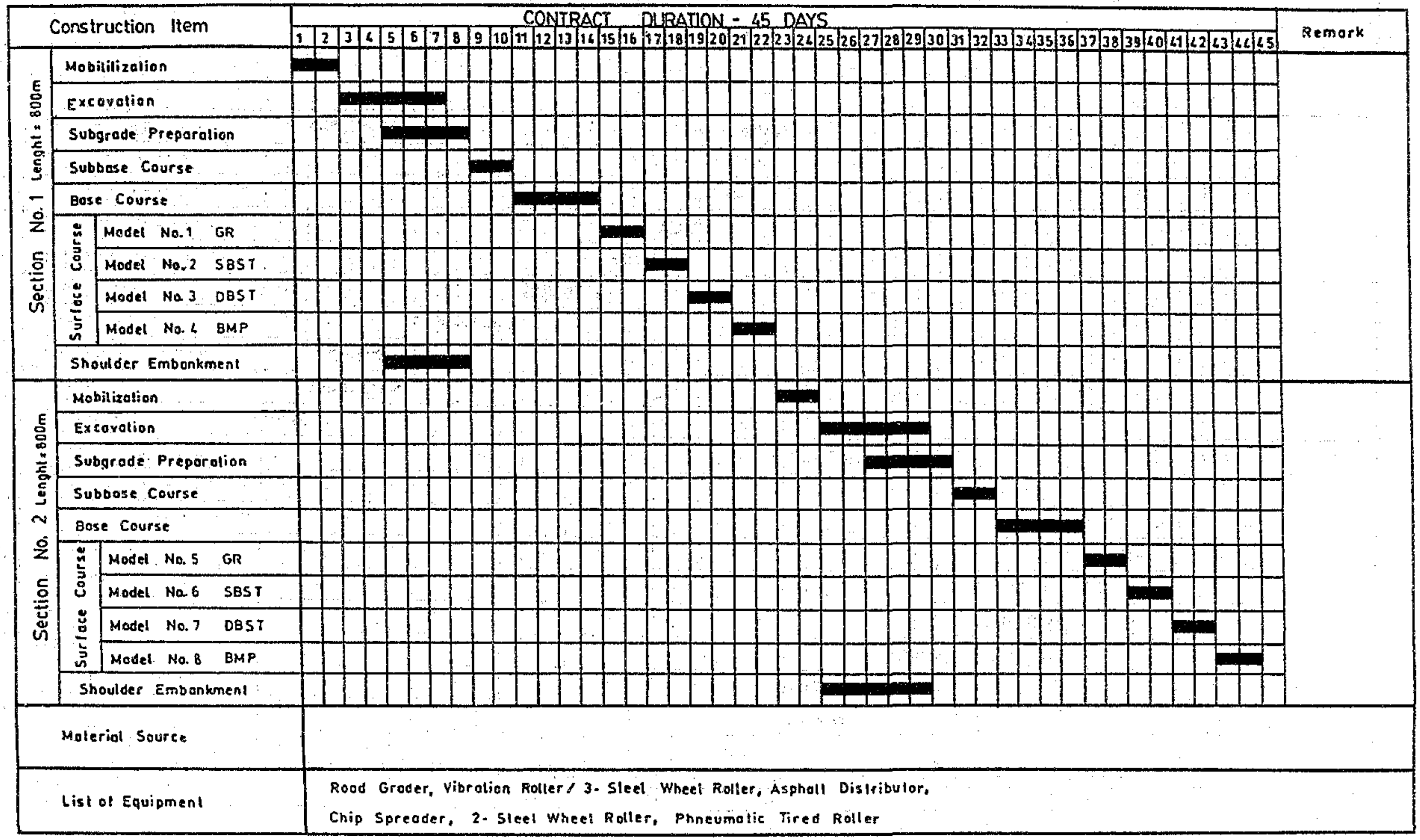


FIGURE 8.1-5 (2) EXPERIMENTAL PAVEMENT CONSTRUCTION SCHEDULE: SECTION No.3 AND No.4

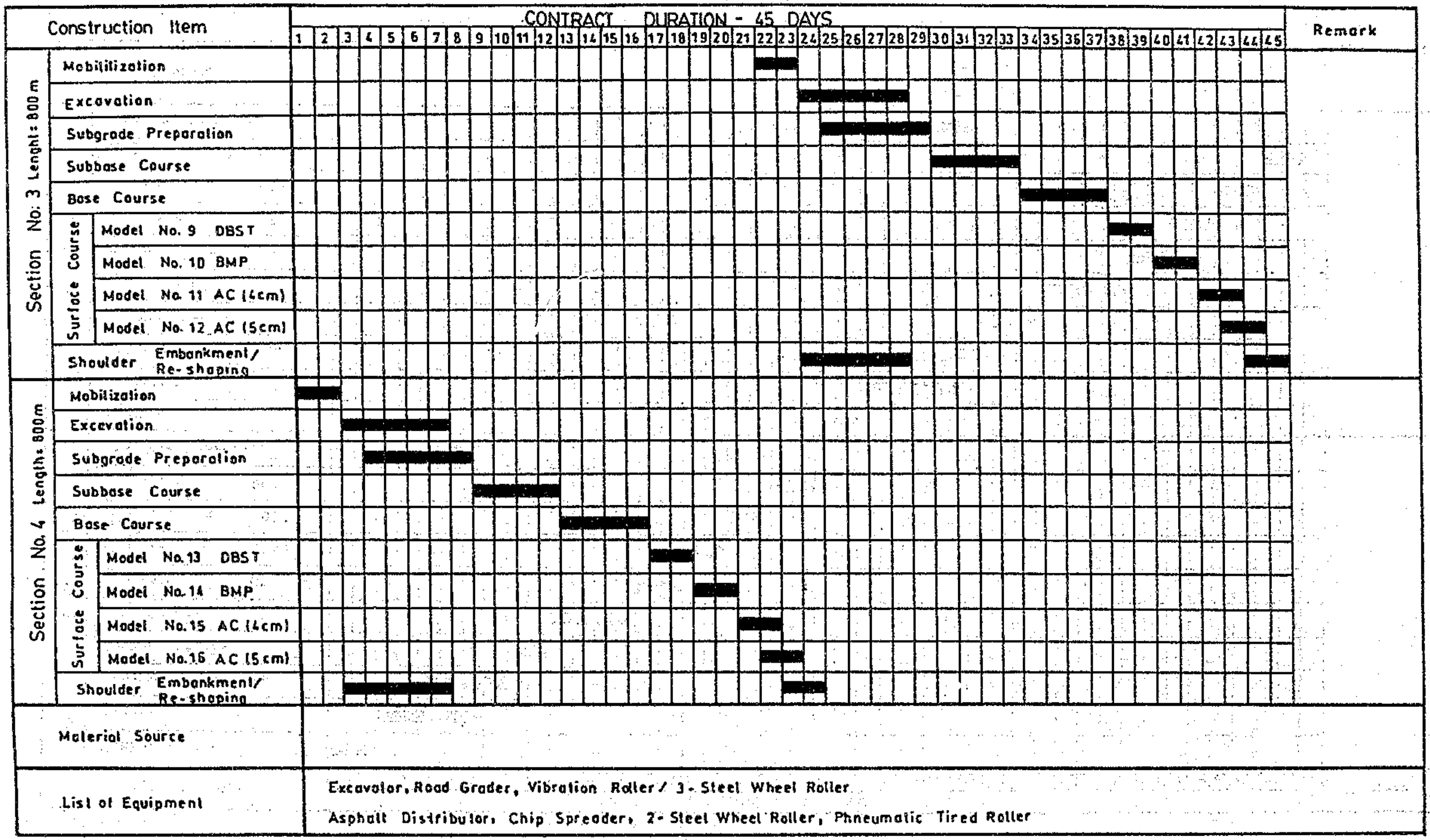
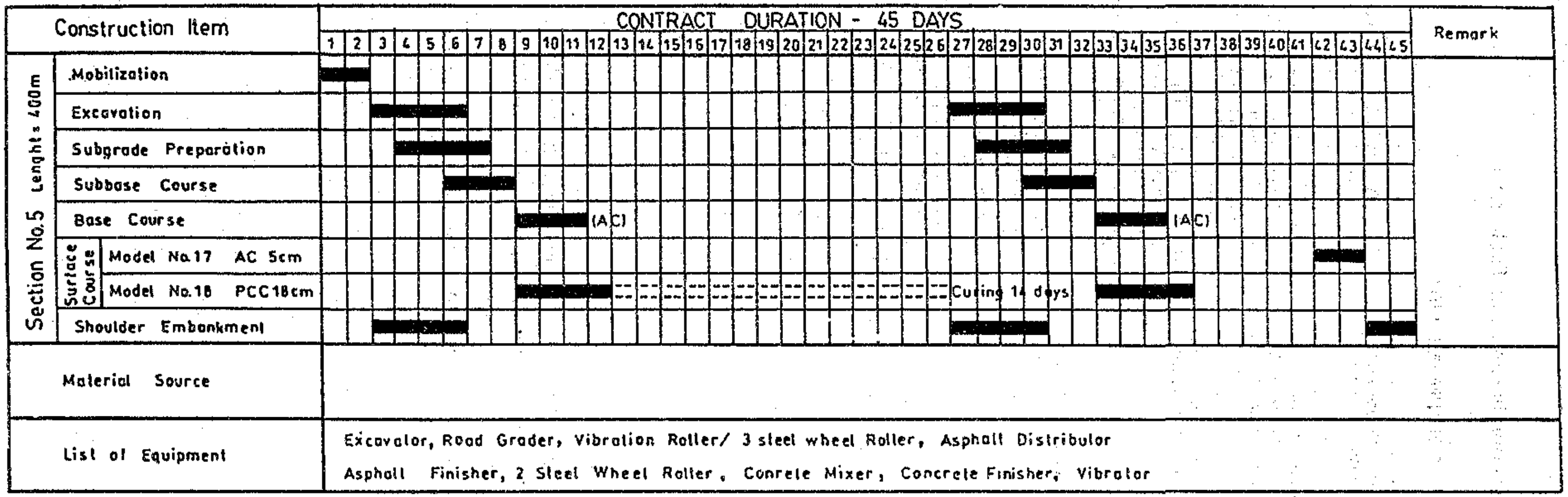


FIGURE 8.1-5 (3) EXPERIMENTAL PAVEMENT CONSTRUCTION SCHEDULE: SECTION No.5



(4) Construction Equipment

The equipment required for construction is shown in Table 8.1-17.

TABLE 8.1-17 EQUIPMENT LIST

Section	Earth Work and Subgrade Preparation	Base Subbase and GR Surface	Asphaltic Surface and Cement Concrete Surface
No. 1 and No. 2	. Backhoe Crawler . Wheel Loader . Road Grader	. Road Grader . Vibratory Roller/ Three Steel Wheel	(SBST, DBST, BMP) . Asphalt Distributor, Chip Spreader . Pneumatic Tired Roller, Tandem Roller
No. 3	Same as Above	Same as Above	(DBST, BMP, AC) . Asphalt Distributor, Chip Spreader . Pneumatic Tired Roller, Tandem Roller
No. 5	Same as Above	Same as Above	(AC) . Asphalt Distributor, Asphalt Finisher . Pneumatic Tired Roller, Tandem Roller (PCC) . Concrete Mixer . Concrete Finisher, Vibrator

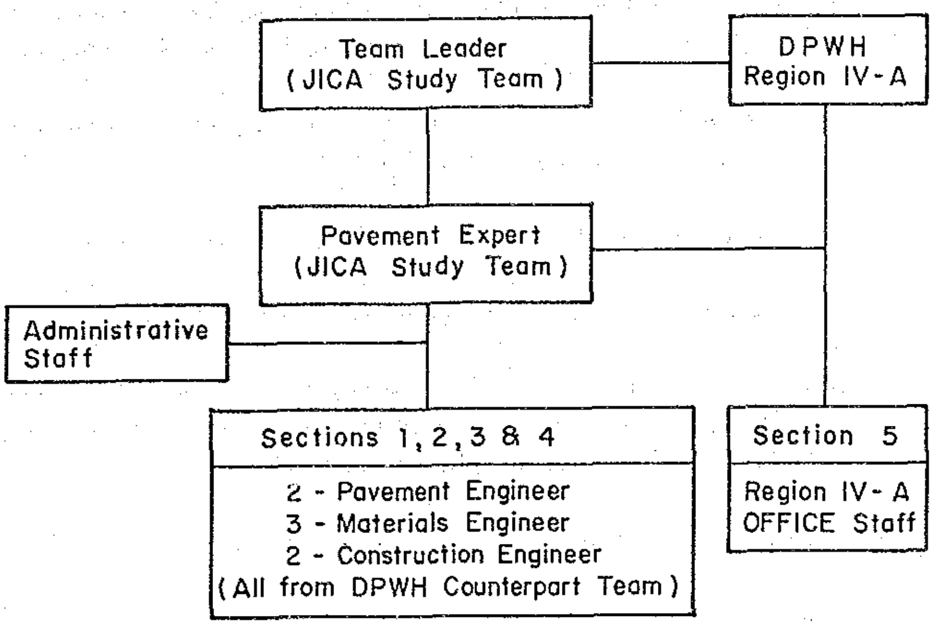
(5) Construction Cost

The total construction cost was estimated at 7.94 million pesos, the breakdown being 6.551 million pesos for Sections 1 to 4 and 1.389 million pesos for Section 5.

Unit price analysis, unit prices of construction items and estimated costs are given in Appendix 8-7.

(6) Organization of Construction Supervision

In order to carry out the experimental pavement construction in compliance with the object of the study and in close collaboration with the DPWH Counterpart Team, the organization of personnel for supervising the construction work was planned as illustrated below.



8.2 CONSTRUCTION

8.2.1 Considerations Made For Construction

The experimental pavement models are to be constructed in accordance with the existing specifications and at the general level of Filipino Contractors' capabilities, skills and performance, so that models will represent the quality of ordinarily constructed pavements in the Philippines. Based on this principle, construction of the experimental pavement models were carried out under the following conditions:

- The specifications adopted shall be the DPWH Standard Specifications, Volume II: Highways, Bridges and Airport (1988).

- The contractors shall be selected from Filipino Contractors.

- No special equipment nor materials shall be required.

- However, material testings shall be conducted more frequently than required by the 1988 DPWH Standard Specifications in order to provide enough data for analysis during and after the follow-up survey period.

8.2.2 Summary of Operation

(1) Contracts

The funding sources for the experimental pavement construction being two (2), construction involved the two (2) following contracts.

<u>Sections No. 1 through No. 4 (Number of models: 16)</u>

Funding : JICA

Contractor : Fischer Engineering and Maintenance Co., Inc. (FEMCO)

Contract Amount : P 6,551,005.38

Construction Supervision : JICA Study Team/DPWH Counterpart Team

Section No. 5 (Number of models: 2)

Funding : DPWH

Contractor : Atari Construction and Development Corporation

Contract Amount : ₱ 1,355,750.47

Construction Supervision : Region IV-A, DPWH (With JICA Study Team providing technical assistance)

Unit price of construction items and cost of each pavement model are presented in Appendix 8-7.

(2) **Progress of Construction**

The progress chart of construction is shown in Appendix 8-8. Construction of Sections No. 1 through No. 4 was started in April 27, 1990 and completed after seven (7) months while Section No. 5 was started in May 1, 1990 and completed after six (6) months.

Completion of construction was delayed due to the following reasons.

i) unfavorable weather conditions

Construction was scheduled so as to take advantage of the dry season. However, the rainy season started much earlier than expected.

ii) frequent breakdown of equipment

iii) poor accessibility to subbase material source after rain

iv) supply of aggregates from crushing plants was not steady affected by construction boom in Metro Manila area.

v) preparation of materials and equipment was not always appropriate.

vi) insufficient provision for drainage prior to the start of excavation, which affected subbase course construction of Sections No. 1 and No. 2.

To comply with the planned construction schedule, much improvement is required of the contractor in carrying out such preparatory work as material preparation, maintenance of equipment, preparation of a set of equipment and tools necessary for the activity, etc.

(3) Weather

This year's rainy season started in the middle of May and since then rainy weather greatly affected the progress of work. Unworkable days by month from June to August were 16 days to 20 days a month. The rainfall record at DPWH Region IV, Office of the District Engineer, Trece Martirez City, Cavite and number of unworkable days are listed in Table 8.2-1. Weather record is reported in Appendix 8-9.

TABLE 8.2-1 RAINFALL AND NUMBER OF UNWORKABLE DAYS BY MONTH

Month	Rainfall (mm)	Unworkable days	%	Remarks
May	180	13	42	
June	436	20	63	Typhoon Aking June 13-15 Typhoon Bising June 18-23 Typhoon Claring June 24-25
July	379	16	52	Typhoon Deling July 6-15 Typhoon Emang July 28
August	632	18	58	Typhoon Gading Aug. 15-20 Typhoon Heling Aug. 28 Typhoon Iling Aug. 28
September	314	16	53	Typhoon Loleng Sept. 6- 7

8.2.3 Materials

(1) Material Sources and Suppliers

Materials sources and supplies are presented in Table 8.2-2 (a) and 8.2-2 (b). Materials sources in Cavite Province being scarce, only materials for the subbase course were obtained from within the province. All other materials were procured in Metro Manila and Rizal Province.

TABLE 8.2-2 (A) MATERIAL SOURCES AND SUPPLIERS SECTION NO. 1 TO NO. 4

Material		Material Sources / Suppliers
Subbase Course	River-run Sandy Gravel	Mabato Quarry, Maragondon, Cavite (Section No. 1 & No. 2)
	River-run Sandy Gravel	Mamba Quarry, Maragondon Cavite (Section No. 3 & No. 4)
Base Course	Crushed Stone	Unirock Quarry, Antipolo, Rizal
Cover Aggregate for Type 2 Seal Coat	Manufactured Sand	Concrete Aggregate Corp. Angono, Rizal
Aggregate for Bituminous Surface Treatment and Bituminous Penetration Macadam	Crushed Stone 3/8" Crushed Stone 3/4" Crushed Stone 1-1/2" Crushed Sand	Concrete Aggregate Crop. Angono, Rizal
Aggregate for Asphalt Concrete	Crushed Stone 3/4" Crushed Stone 3/8" Crushed Sand Natural Sand	Golden Hills, Taytay, Rizal Golden Hills, Taytay, Rizal Golden Hills, Taytay, Rizal Bulacan
Bituminous Materials for Prime Coat, Seal Coat, Surface Treatment for SBST, DBST & BMP	Cationic Emulsified Asphalt (CSS-1h)	Rigid Sales Corporation
Bituminous Materials for Asphalt Concrete	Asphalt Cement 60/70	Petron Phil Corporation
Aggregate Surface Course	Crushed Stone	Unirock Quarry, Antipol, Rizal

TABLE 8.2-2 (B) MATERIAL SOURCES AND SUPPLIERS SECTION NO. 5

Material		Material Sources / Suppliers
Subbase Course	Blended Crushed Stone Natural Sand Soil Binder	 Angono Rizal Trece Martrez City, Cavite Cegeo, Antipolo, Rizal
Base Course	Crushed Stone	Antipolo, Rizal
Bituminous Material for Prime Coat	Emulsified Asphalt SS-1	Petron Phil Corporation
Bituminal Material Asphalt Cement	Asphalt Cement Pen. 60/60	Petron Phil Corporation
Aggregate for Asphalt Concrete	Crushed Stone 3/4" Crushed Stone 3/8" Sand Mineral Filler	Marocco, Antipolo, Rizal Marocco, Antipolo, Rizal Montelban, Rizal Guanzon, Quzon
Portland Cement	Type 1	Iland Cement, Antipolo, Rizal
Aggregate for Portland Cement Concrete	Crushed Aggregate Fine Aggregate	Marocco, Antipolo, Rizal Porac, Pampanga

(2) Material Laboratory Test Results

Laboratory tests for following materials are conducted. Results are presented in Appendix 8-10.

- Aggregates for subbase and base courses
- Aggregates for aggregate surface course
- Bituminous surface treatment and bituminous penetration macadam
- Asphalt binder for prime coat bituminous surface treatment and bituminous penetration macadam
- *Asphalt cement for hot mix asphalt concrete*
- Asphalt concrete mixture design
- Portland cement concrete mixture design

8.2.4 Construction Equipment

Main construction equipment used for this project are listed in Table 8.2-3 (a) and 8.2-3 (b).

TABLE 8.2-3 (A) LIST OF EQUIPMENT USED FOR THE PROJECT

Activity	Sections No. 1 & 2/Sections No. 3 & 4	
	Name of Equipment	Type
Excavation	1 - Bulldozer 1 - Wheel Loader 1 - Motor Grader 3 - Dump Trucks	Caterpillar D60A Caterpillar Payloader Mitsubishi LG 2H
Subgrader	1 - Motor Grader 1 - Roller 1 - Water Truck	Mitsubishi LG 2H Kawasaki, 12 tons
Subbase Course	1 - Motor Grader 1 - Roller 1 - Water Truck	Mitsubishi LG 2H Kawasaki, 20 tons
Base Course	1 - Motor Grader 1 - Vibratory Roller 1 - Water Truck	Mitsubishi LG 2H Kawasaki, 20 tons
Prime Coat	1 - Asphalt Distributor	Hanta (6,000 ltr. capa.)
Bituminous Macadam and Surface Treatment	1 - Aggregate Spreader 1 - Asphalt Distributor 1 - Pneumatic Roller 1 - Vibratory Roller 1 - Light Cargo Truck	Tail-Gate Type Hanta (6,000 ltr. capa.) Watanabe, 15 tons Ingersoll-Rand, 12 tons Isuzu, ELF
Asphalt Concrete Surface Course	1 - Asphalt Mixing Plant 1 - Asphalt Paver 1 - Pneumatic Roller 1 - Tandem Roller 7 - Dump Trucks	Nigata, 3,000 kg/batch Barber Greene Watanabe, 15 tons Watanabe, 8 tons

TABLE 8.2-3 (B) LIST OF EQUIPMENT USED FOR THE PROJECT

Activity	Section No. 5	
	Name of Equipment	Type
Excavation	1 - Bulldozer 1 - Motor Grader 1 - Wheel Loader	Caterpillar D7 Mitsubishi LG 2H Caterpillar
Subgrader	1 - Motor Grader 1 - Road Roller 1 - Water Truck	Mitsubishi LG 2H Kawasaki, 12 tons Isuzu
Subbase Course	1 - Motor Grader 1 - Road Roller	Mitsubishi LG 2H Watanabe, 15 tons
Base Course	1 - Motor Grader 1 - Vibratory Roller 1 - Water Truck	Mitsubishi LG 3 Ingersoll-Rand 12 tons Isuzu
Prime Coat	1 - Asphalt Distributor	Water Tank Type
Asphalt Concrete Surface Course	1 - Asphalt Mixing Plant 1 - Asphalt Paver 1 - Pneumatic Roller 1 - Tandem Roller	Barber Greene,2ton/Batch Nigata, NF 220 Asahi, 15 tons Watanabe, 15 tons
Portland Cement Concrete Surface Course	1 - Concrete Batching Plant	
	8 - Truck Mixer	5-Isuzu, 2-Hino 3-Fuso 5.5 cu.m. capa.
	1 - Water Truck	Isuzu
	1 - Concrete Vibrator	2ϕ Vibrate head 3 HP
	1 - Concrete Cutter	Kawasaki KF 100D 10 HP

8.2.5 Quality Control and Inspection

Quality control and inspection were carried out at every 50-meter interval on both lanes of each pavement model.

The test and inspection items are shown below:

Test Item	Inspection Item
a. Subbase and Base Course	
Grading of Aggregates	Thickness of Layer
Water Content	Level of Surface
Degree of Compaction	Surface Irregularity
PL, LL if necessary	Cross Fall

Test Item	Inspection Item
b. Prime Coat	
Binder Spraying Rate	
c. SBST, DBST, and BMP	
Aggregate Spreading Rate for each Layer Binder Spraying Rate for each Layer	Thickness of Layer Level of Surface Surface Irregularity Cross Fall
d. Asphalt Concrete Surface Course	
Laying Temperature Grading of Aggregate Asphalt Content Thickness Degree of Compaction	Thickness of Layer Level of Surface Surface Irregularity Cross Fall
e. Portland Cement Concrete Surface Course	
Grading of Coarse Aggregate and Fine Aggregate, and Water Current Ratio (Everyday before starting *mixing of concrete*) Slump Test (Every truck mixer before placing of concrete) Flexural Strength Test	Thickness of Layer Level of Surface Surface Irregularity Cross Fall

The results of quality control test are reported in Appendix 8-11.

8.2.6 Construction of Section No. 1 to 4 (16 Models)

(1) Excavation of Existing Road

Sections No. 1 and No. 2

The existing gravel roads were excavated to the designated subgrade elevation of the proposed roadway. This included the excavation of side slopes at cut sections and the side ditches for surface drainage. All excavated materials were stockpiled in nearby locations for possible utilization of suitable soils. Cobbles or boulders, and unsuitable materials were removed and disposed.

Sections No. 3 and No. 4

The existing DBST road was excavated by scarifying the existing asphalt surface, and then the existing base and subbase materials were removed up to the designated subgrade elevation. In some locations wherein muck excavation was carried out, saturated soils and organic matters were removed and disposed. Suitable materials were utilized for shoulder embankment.

(2) Subgrade Preparation

This was carried out after excavating to the desired elevation and shaping to the required crown slope. Compaction was performed for the full width of roadway by repeated moistening and compaction continued until approved by the Engineer.

(3) Subbase Course

Materials for the subbase were hauled from the provincial quarry, dumped and then laid over the construction site. For required thicknesses of 150mm or less, the materials were spread and compacted in one layer. For greater thicknesses, the subbase materials were spread and compacted in two or more approximately equal layers, with the maximum thickness of any one layer kept within 150mm. The moisture content was adjusted by watering when required, and then the materials were thoroughly compacted over the full width of the roadway. Field density tests were conducted following completion of the compaction.

The properties of material were as follows and meet the specification requirements.

Sections No. 1 and No. 2 Sandy Gravel Mabato Quarry, Cavite

Item	Test Result	DPWH Specification
Maximum Size	50 mm	50 mm
LL	29	<35
PI	5	<12
Soaked CBR (at max dry density)	50%	>25%

Sections No. 3 and No. 4 Sandy Gravel Mabato Quarry

Item	Test Result	DPWH Specification
Maximum Size	50 mm	50 mm
LL	NP	<35
PI	NP	<12
Soaked CBR (at max dry density)	53%	>25%

(4) Base Course

The crushed aggregates were hauled from the Unirock quarry, Antipolo, Rizal and stockpiled near the construction site. The materials were spread to the required width, thickness, and elevation, and then moistened and compacted to the required compaction degree. Field density tests conducted after compaction yield satisfactory results.

Item	Test Result	DPWH Specification
Maximum Size	37.5 mm	37.5 mm
LL	23	<25
PI	4	<12
Soaked CBR (at max dry density)	117%	>80%

(5) Aggregate Surface Course

The crushed stone aggregates were hauled from Unirock quarry, Antipolo, Rizal. Damped and spread to the required width, thickness, and elevation, then compacted at approximately optimum water contents. Continuous rolling has been conducted to the required compaction degree.
The properties of material were as follows and meet the specification requirements.

Item	Test Result	DPWH Specification
Maximum Size	25 mm	25 mm
LL	16	<35
PI	8	4 - 9

(6) Prime Coat

After cleaning the constructed base course surface thoroughly by manual blooming, cationic emulsified asphalt, CSS-1h, diluted with water at the ratio of 1:1, was sprayed on the surface at an application rate of 1.20 ltr/m^2, and then sufficiently cured. In some portions of Sections No. 3 and No. 4, coarse sand was spread immediately after the binder was sprayed to protect the primed base surface from passing vehicles.

CSS-1h binder penetrated well into the moist aggregate particles of base course surface and adequately set by breaking into its constituent parts of asphalt and water. The asphalt adhered firmly the aggregates of course surface and the water was removed by evaporation. Finally stable prime coat was formed and protected the finished base course surface from shearing force by moving wheel loads and erosion action by rain water.

(7) Bituminous Surface Treatment and Bituminous Penetration Macadam

For each surface treatment and penetration macadam construction, the asphalt binder was sprayed by an asphalt distributor and aggregate was spread by an aggregate spreader. To obtain the specific binder spraying rate, the required running speed of the distributor was carefully controlled by using the graph for asphalt distributor running speed and binder spraying relationship shown in Figure 8.2-1.

a) Single Bituminous Surface Treatment (SBST)

Finished Thickness : 5mm

Asphalt binder, Emulsified Asphalt CSS-1h, was uniformly sprayed on the primed base surface at the rate of 1.40ltr/m^2. Then aggregate of 10 - 5mm size crushed stone was spread at 14kg/m^2, and properly seated and compacted by rolling.

Finally, the surfacing was protected by seal coat from rain water. The sealing consists of spraying 1.0ltr/m^2 of CSS-1h binder, and spreading manufactured sand at 8kg/m^2, followed by repeatedly rolling the newly treated surface until thoroughly compacted. The aggregate spreading rate and the binder spraying rate were measured and checked by tray method at every 50m interval, and adjusted to obtain the required application rate.

b) Double Bituminous Surface Treatment (DBST)

Finished Thickness : 15 mm

The sequence operation spraying rate of asphalt binder, Emulsified Asphalt CSS-1h, and the spreading rate of aggregate are shown in Table 8.2-4. By tray test method, the spraying rate of binder and spreading rate of aggregate were tested. Correction was immediately applied for any deficiency or excess in application rate. Compaction was followed immediately after spreading aggregate for each layer.

c) Bituminous Penetration Macadam Pavement (BMP)

Finished Thickness : 50 mm

The sequence of operation and rates of spreading aggregates and spraying asphalt binder, Emulsified Asphalt CSS-1h, are shown in Table 8.2-5.

The aggregate spreading rates and the binder spraying rate were measured and checked by tray test method at every 50m interval, and controlled to obtain the required application rate. Correction was immediately applied for aggregate spread layer and binder sprayed surface if any deficiency found in application rate or insufficient work skilled portion. Composition followed immediately after spreading aggregate for each layer.

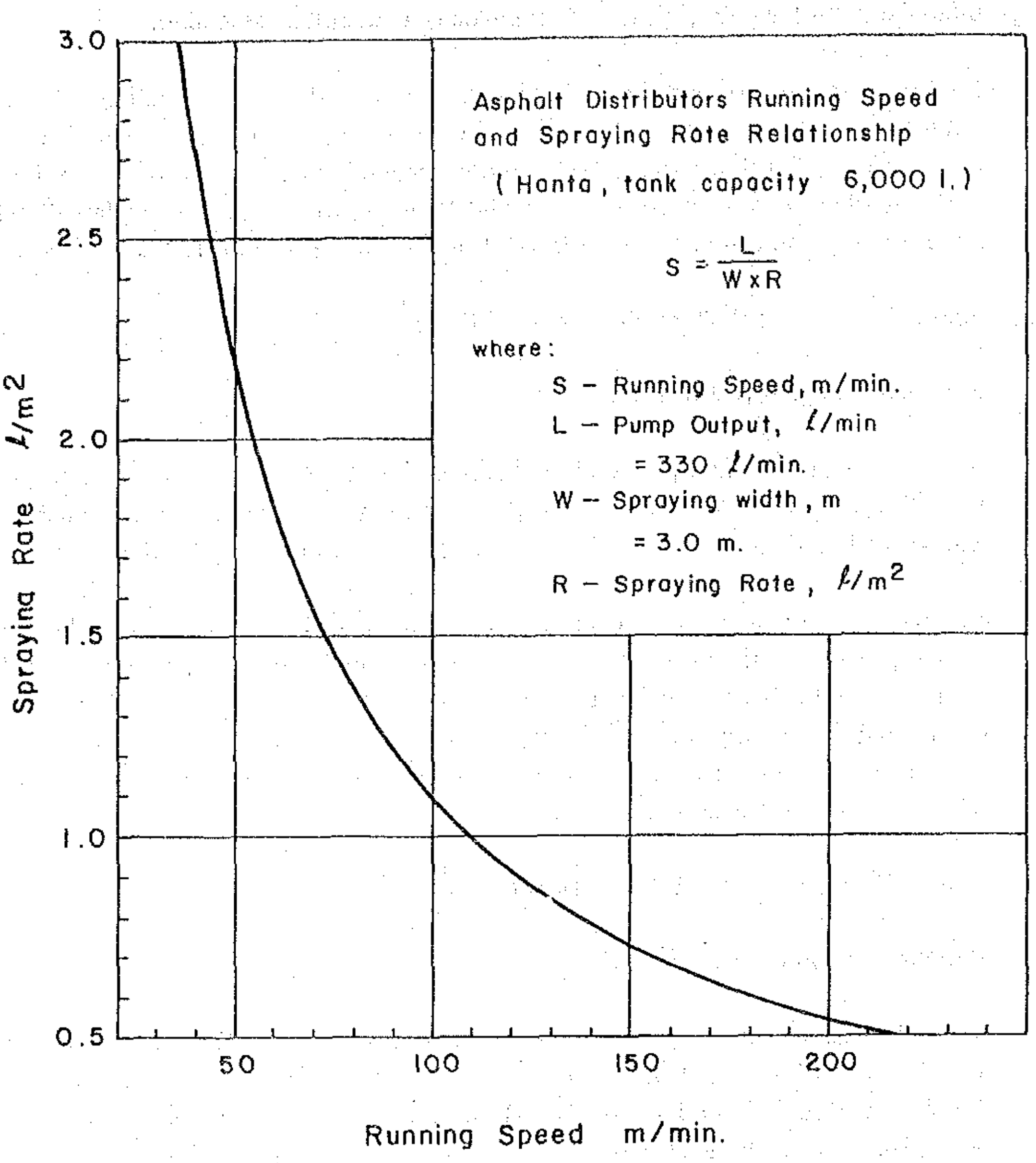


FIGURE 8.2-1 BINDER SPRAYING RATE AND RUNNING SPEED OF ASPHALT DISTRIBUTOR

TABLE 8.2-4 QUANTITIES OF MATERIALS AND SEQUENCE OF OPERATION FOR DOUBLE BITUMINOUS SURFACE TREATMENT (Emulsified Asphalt)

	Bituminous Binder	Aggregates		
		1st Layer 20-10 mm	2nd Layer 10-5 mm	Cover Layer Sand
	lit/m2	kg/m2		
First Layer				
Spray Binder	1.4			
Spread Aggregate		22		
Second Layer				
Spray Binder	1.2			
Spread Aggregate			12	
Seal Coat Layer				
Spray Binder	1.5			
Spread Aggregate				6
Total	4.1	40		

Remarks : These quantities don't include handling loss.

TABLE 8.2-5 QUANTITIES OF MATERIALS AND SEQUENCE OF OPERATION FOR BITUMINOUS PENETRATION MACADAM : 5 CM THICK (Emulsified Asphalt)

	Bituminous Binder	Aggregates			
		Base 40-20mm	Key 20-10mm	Choker 10-5mm	Cover Sand
	lit/m2	kg/m2			
First Layer					
Spread Aggregate		80			
Spray Binder	2.7				
Second Layer					
Spread Aggregate			13		
Spray Binder	1.8				
Third Layer					
Spread Aggregate				11	
Spray Binder	1.5				
Fourth Layer					
Spread Aggregate					6
Total	6.0	110			

Remarks : These quantities don't include handling loss.

(8) **Asphalt Concrete Surface Course (AC)**

Finished thickness : Model No. 11 and 15 40 mm
Model No. 12 and 16 50 mm

The hot-mixed asphalt mixture was produced in Socor asphalt batching plant in Carmona, Cavite. The mixing average temperature was 145 - 165℃, mixture was delivered to the site by dump trucks, spread by asphalt paver at a temperature of not less than 130℃ and thoroughly compacted by pneumatic tired roller and tandem roller to the required density.

The properties of the asphalt concrete were as follows and meet the specification requirements.

Type of Mix — Dense graded asphalt concrete
Aggregate maximum size 19 mm
(DPWH specification, Grading F)

Asphalt Grade — 60/70

Asphalt Content — 5.7%

Marshal Stability Test

Item		Test Result	DPWH Specification
Stability	lb	1,920	>1,200
Flow	0.01 in	11.8	8 – 16
Void	%	4.2	3 – 6
Void Filled	%	73	70 – 80

8.2.7 Construction of Section No. 5 (2 Models)

(1) **Excavation of Existing Road**

The existing asphalt concrete surface course were scarified and removed, then the debris were transported to a waste deposit. The existing base course and subbase course were excavated to the designated elevation of subgrade. All the excavated materials were transported and stock piled in nearby dumpsite for utilization on the shoulder embankment.

(2) **Subgrade Preparation**

The road bed was shaped to the desired elevation and cross section. The surfaces underlying the carriageway and shoulder were compacted and smoothed until it was accepted by engineer.

(3) Subbase

Materials for subbase were hauled from Trece Mritrez Quarry dumped and spread then compacted. Rolling, with watering and blading to close tolerances on the full width of the roadway continue until the rolled course was thoroughly consolidated. Field test for density of soil were conducted to determine the compaction degree. Further compaction and a retest of field density was conducted for the unsatisfied portion until it reached the required degree of compaction.

The properties of materials were as follows.

Blended aggregates of crushed stone, sand and soil.

Item	Test Result	DPWH Specification
Maximum Size	50 mm	50 mm
LL	32	<35
PI	12	<12

(4) Base Course

The crushed stone aggregates were hauled from Unirock quarry, Antipolo, Rizal, to the site and dumped then spread to the required width, thickness, and elevation, then moistened and compacted to the required compaction degree. Field density test followed after compaction has been finished.

The properties of material were as follows and meet the specification requirements.

Item	Test Result	DPWH Specification
Maximum Size	37.5 mm	37.5 mm
LL	23	<25
PI	4	4–9
Soaked CBR (at max dry density)	117	>25%

(5) Asphalt Concrete Surface Course (AC)

Finished Thickness : 50 mm

The hot-mix asphalt mixture was produced at an asphalt batching plant of Ready Con Asphalt in Mangahan, Pasig, Metro Manila. The mixing average temperature was 140 to 145℃, then mixture was delivered at the site by dump trucks, spread by asphalt paver at a temperature not less than 130℃ and thoroughly compacted to the required thickness and density.

(6) Portland Cement Concrete Surface (PCC)

Finished thickness : 180 mm

The concrete was produced at a batching plant, Exan Builder Corp. in Imus, Cavite. The materials were batched and mixed in truck mixers. At the beginning of a mixing run, the amount of moisture in the aggregates were determined and the aggregates batching weights and the required amount of mixing water were adjusted to the designed water - cement ratio. The concrete was batched at 5 cu.m. per truck mixer and delivered to the site.

The design of the concrete mixture is as follows.

Design Mix /m³/Mix		DPWH Specification
Portland Cement *	379 kg	Approximately 380 kg
Fine Aggregate	704 kg	–
Coarse Aggregate	1,194 kg	–
Water	176 kg	–
Total	2,453 kg	–
Water Content Ratio	0.46	–
Slump	3 in	1–1/2 – 3 in

* Portland Cement Type 1

The concrete was placed evenly across the width of the lane and consolidated with an internal vibratory equipment for full depth of the thickness of concrete slab. Initial hand finishing followed immediately after placement of concrete. Then, hand-operated flat follows to smooth and consolidate the surface. After the completion of the floating, the concrete surface was transversely finished with a long-handed wood float. At the time concrete had attained a hardness suitable for edging, all slab edges were carefully finished. Before the surface seen disappeared and concrete becomes non-plastic, the surface of the concrete were given a broom finish texture.

The hardened concrete were cured by outling the concreted surface with native soil which was kept wet by sprinkling water.

Transverse contraction joints were sawed with a diamond saw blades at 4.5 meter interval, 50 mm depth and 5 mm width, after the concrete has hardened. The joints were cleaned and sealed by bituminous sealant.

8.3 PLAN OF FOLLOW-UP SURVEY

8.3.1 Objectives Of Follow-up Survey

The follow-up survey has the following objectives:

i) To verify the performance period of selected types of pavement.

ii) To verify an appropriate timing for rehabilitation.

iii) To provide basic data for an appropriate structural design.

iv) To establish the selection criteria for pavement types and level of rehabilitation, using i), ii) and iii) as the basis.

The performance period is defined as the period that an initial pavement structure will last before it needs rehabilitation, and is equivalent to the time elapsed from the initial serviceability to terminal serviceability of the structure. As the follow-up survey will be conducted for five (5) years, the performance periods for most of the pavement models will be verified under different conditions of traffic load repetitions and subgrade bearing capabilities. For those models which do not reach terminal serviceability, the performance period will be estimated by analyzing relationships between serviceability and traffic repetitions.

Another important objective is to verify the timing of rehabilitation. As low-class pavements are usually designed with a performance period of 3 to 8 years, rehabilitation must be implemented in a timely manner. The level of rehabilitation will be recommended by analyzing data obtained by the follow-up survey.

The pavement design method recommended by the AASHTO Guide for Design of Pavement Structures requires the use of design variables, performance criteria, etc. as shown in Table 8.3-1. Data obtained by the follow-up survey will provide useful information for the designer.

Based on the findings of the follow-up survey and additional life cycle cost analysis, an appropriate pavement type and rehabilitation level will be established for different levels of traffic and subgrade conditions.

TABLE 8.3-1 DESIGN REQUIREMENTS

	Pavement Type: AC	Surface Treatment	PCC	Gravel	Data obtained by Follow-up Survey
DESIGN VARIABLES					
Time Constraints					
Performance Period	O	O	O	O	●
Analysis Period	O	O	O	O	—
Traffic	O	O	O	O	●
Reliability	O	O	O	—	—
Environmental Impact					
Roadbed Swelling	Δ	Δ	Δ	—	—
PERFORMANCE CRITERIA					
Serviceability	O	O	O	O	●
Allowable Rutting	—	—	—	O	●
Aggregate Loss	—	—	—	O	●
MATERIAL PROPERTIES STRUCTURAL DESIGN					
Effective Roadbed Soil Resilient Modulus	O	O	—	O	—
Effective Modulus & Subgrade Reaction	—	—	O	—	—
Pavement Layer Materials Characteristics	Δ	Δ	O	O	—
PCC Modulus of Rupture	—	—	O	—	—
Layer Coefficients	O	O	—	—	—
PAVEMENT STRUCTURAL CHARACTERISTICS					
Drainage	O	O	O	—	●
Load Transfer	—	—	O	—	—
Loss of Support	—	—	O	—	—

NOTES: O *Design input variable that must be determined*
Δ *Design variable that should be considered*
● *Data to be obtained by the follow-up survey*

8.3.2 Follow-up Survey Items

The follow-up survey items with regard to their frequencies and timing are listed in Table 8.3-2.

TABLE 8.3-2 FOLLOW-UP SURVEY ITEMS

Survey Items	Frequency	Timing
1. Inspection and Data Collection which includes meteorological data, road maintenance data, drainage condition data, and rehabilitation data.	Monthly	Second week of each month
2. Traffic Survey		
2.1 Traffic Count Survey	Quarterly	January, April, July and October
2.2 Loadometer Survey	Once a Year	October
3. Surface Condition Survey	Quarterly	January, April, July and October and October
3.1 Roughness Survey		
3.2 Cracking Survey		
3.3 Patching Survey		
3.4 Rutting Survey		
3.5 Pothole Survey		
3.6 Present Serviceability Rating (PSR)		
3.7 Rehabilitation Requirement Rating (RRR)		
4. Deflection Survey	Twice a Year	April and October
5. Gravel Loss Survey	Quarterly	January, April, July and October and October
6. Photo Taking	Quarterly	January, April, July and October and October

8.3.3 Survey Items and Their Intended Usage

Survey items, indices to be developed based on collected data, analyses to be undertaken and recommendations to be made which are the final outputs of the follow-up survey are summarized in Table 8.3-3.

8.3.4 Survey Method

Survey methods to be adopted for the survey items are discussed in detail in the Follow-up Survey Manual.

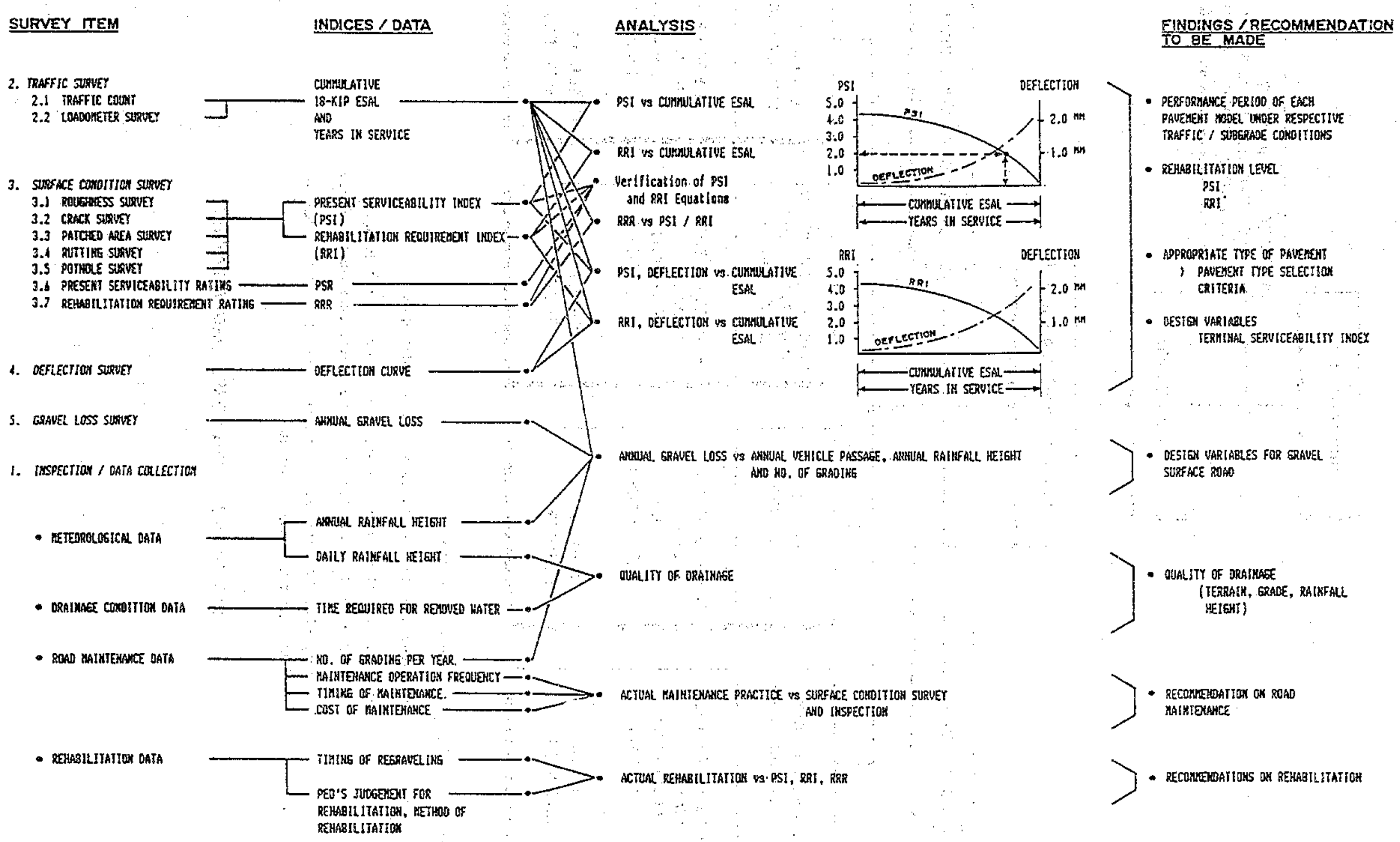
8.3.5 Proposed Organization

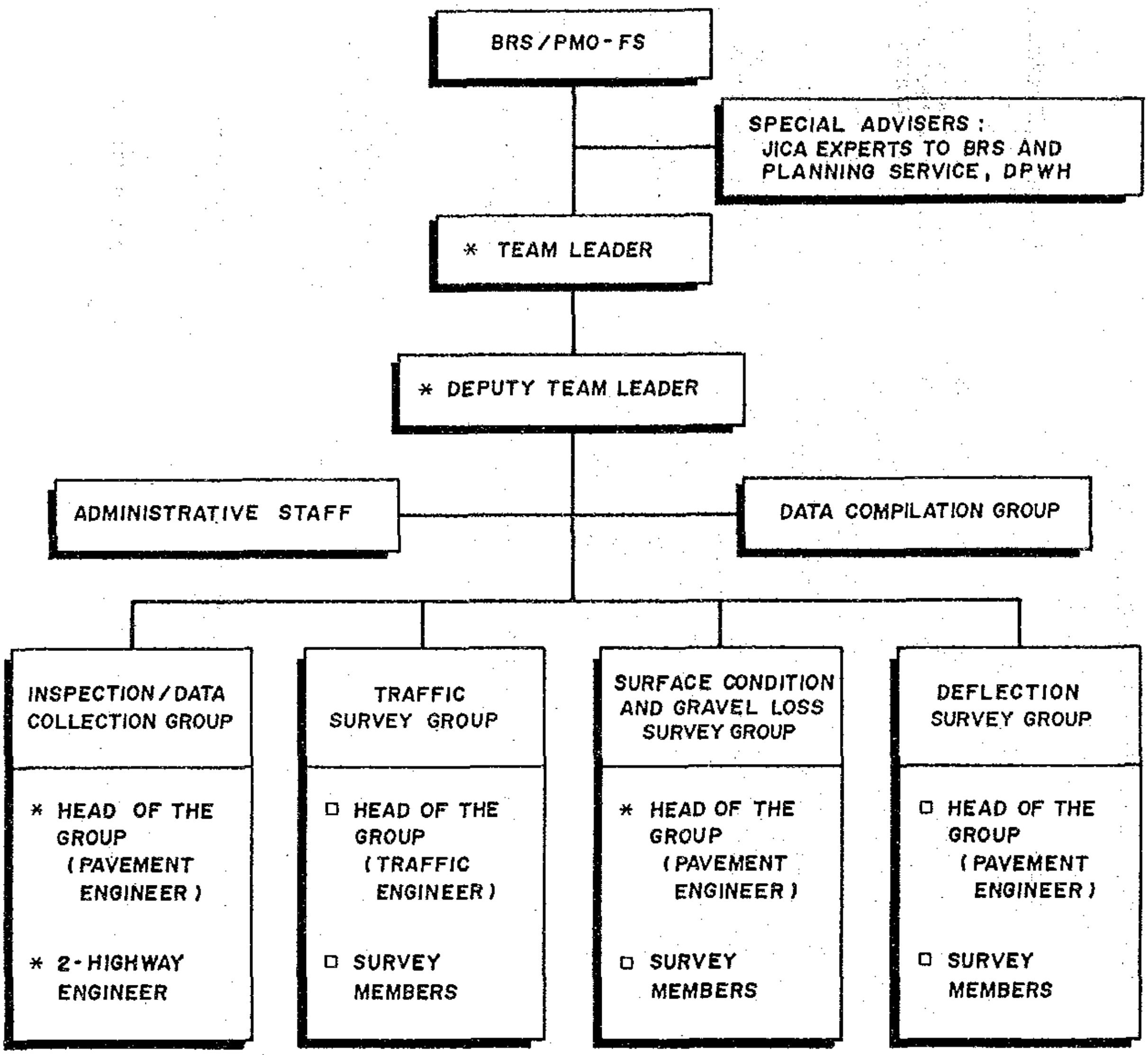
It is recommended that the Bureau of Research and Standards (BRS) and the Project Management Office - Feasibility Study (PMO-FS) jointly organize the Follow-up Survey Team. The proposed organization of the Follow-up Survey Team is shown in Figure 8.3-1.

8.3.6 Survey Schedule

The annual survey schedule is shown in Table 8.3-4.

TABLE 8.3-3 SURVEY ITEMS AND THEIR INTENDED USAGE





NOTE :

- * Permanently Assigned.
- □ Mobilized when the respective survey is undertaken.
- \- Head of Inspection / Data Collection Group can be concurrently assigned to Head of Surface Condition / Gravel Loss Survey Group.
- \- Existing PMO - FS organization can be utilized for Administrative Staff and Data Compilation Group

FIGURE 8.3-1 PROPOSED ORGANIZATION

TABLE 8.3-4 ANNUAL SURVEY SCHEDULE

Survey Items	MONTH											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1. Inspection and Data Collection	X	X	X	X	X	X	X	X	X	X	X	X
2. Traffic Survey												
2.1 Traffic Count Survey	X			X			X			X		
2.2 Loadometer Survey										X		
3. Surface Condition Survey	X			X			X			X		
4. Deflection Survey				X						X		
5, Gravel Loss Survey	X			X			X			X		
6. Photo Taking	X			X			X			X		

NOTE: Inspection in the months of January, April, July and October is not required, however, data collection shall be undertaken.

CHAPTER 9

STANDARD STRUCTURAL DESIGN OF LOW-CLASS PAVEMENTS

Assuming certain values of material properties and structural characteristics of pavements which are deemed as being representative of actual conditions in the country, standard structural design was made for use in rural road projects covering a wide range of traffic and subgrade conditions. This chapter summarizes the standard design, the details of which are presented in Volume 30: Manual for Design and Construction of Low-Class Pavements.

9.1 GENERAL PROCEDURE

The standard design was made in accordance with the following procedures (see Figure 9.1-1).

i) Preparation of Pavement Types for Standard Design

Various pavement types of different thicknesses were prepared for standard design.

ii) Design Criteria and Assumptions

The inputs required for pavement design were prepared and/or selected, including design variables, performance criteria, material properties, structural characteristics of pavements and future rehabilitation works.

To enable application of the standard design to roads under various traffic and subgrade conditions, 10 classes of traffic loading and 7 kinds of subgrade strength were taken into account in the analysis.

iii) Structural Analysis

Each pavement type was analyzed individually for all combinations of traffic loading class and subgrade strength.

iv) Selection of Appropriate Type

The appropriate type was selected individually for each combination of traffic loading class and subgrade strength.

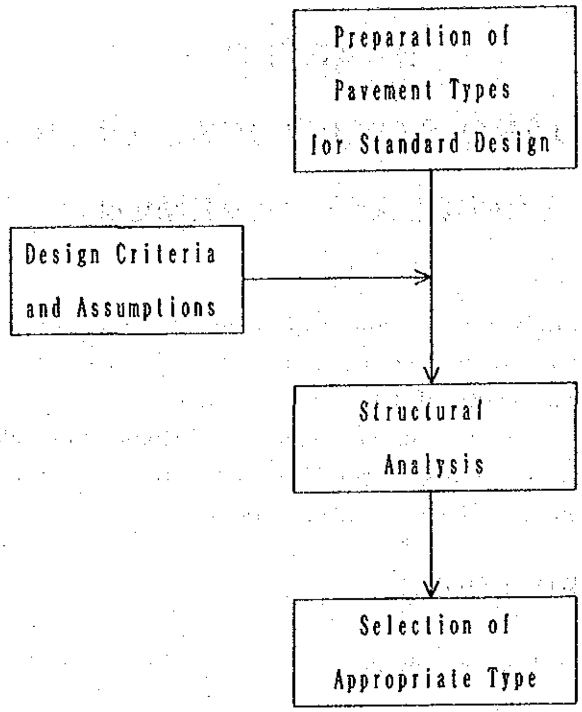


FIGURE 9.1-1 GENERAL PROCEDURE FOR STANDARD DESIGN

9.2 PREPARATION OF PAVEMENT TYPES FOR STANDARD DESIGN

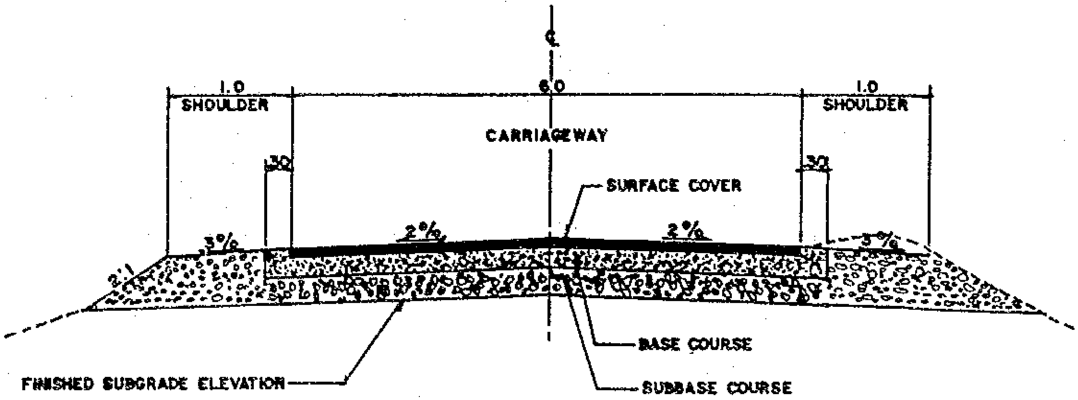
Five pavement types with different thicknesses were prepared for each of the following pavements:

- Gravel-surfaced road .... GR-1 to GR-5
- Single bituminous surface treatment .... SBST-1 to SBST-5
- Double bituminous surface treatment .... DBST-1 to DBST-5
- Bituminous penetration macadam pavement ... BMP-1 to BMP-5
- Asphalt concrete pavement .... AC-1 to AC-5
- Portland cement concrete pavement .... PCC-1 to PCC-5

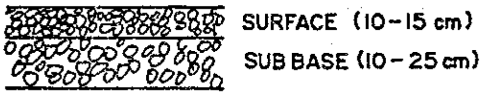
The pavement types are summarized in Table 9.2-1 while the conceptional cross sections are shown in Figures 9.2-1 and 9.2-2.

TABLE 9.2-1 PAVEMENT TYPES FOR STANDARD DESIGN

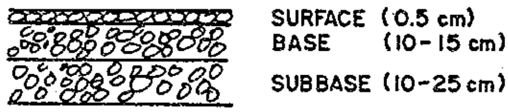
Type No.	Thickness (cm) Surface	Base	Sub-base	SN	Cost (MP/km) Cons-struc-tion	Rehabi-litation	Annual Maintenance
GR-1	10	-	10		1.078	TX0.0275	0.004150 +0.000045 AADT
GR-2	15	-	10		1.186		
GR-3	15	-	15		1.274		
GR-4	15	-	20		1.363		
GR-5	15	-	25		1.454		
SBST-1	0.5	10	10	0.77	1.308	0.275	0.021 +0.0000075 AADT
SBST-2	0.5	15	10	0.95	1.435		
SBST-3	0.5	15	15	1.12	1.538		
SBST-4	0.5	15	20	1.29	1.643		
SBST-5	0.5	15	25	1.46	1.750		
DBST-1	1.5	10	10	0.89	1.491	0.45	0.021 +0.0000075 AADT
DBST-2	1.5	15	10	1.07	1.618		
DBST-3	1.5	15	15	1.24	1.722		
DBST-4	1.5	15	20	1.41	1.827		
DBST-5	1.5	15	25	1.58	1.934		
BMP-1	5	10	10	1.30	1.815	0.75	0.021 +0.0000075 AADT
BMP-2	5	15	10	1.49	1.945		
BMP-3	5	15	15	1.65	2.049		
BMP-4	5	15	20	1.82	2.156		
BMP-5	5	15	25	1.99	2.265		
AC-1	5	10	10	1.48	2.129	1.07	0.0183
AC-2	5	15	15	1.83	2.359		
AC-3	5	20	20	2.19	2.602		
AC-4	5	25	25	2.54	2.854		
AC-5	5	30	30	2.89	3.113		
PCC-1	13	-	20		2.260	1.07	0.0166
PCC-2	15	-	20		2.443		
PCC-3	18	-	20		2.706		
PCC-4	20	-	20		2.902		
PCC-5	23	-	20		3.167		



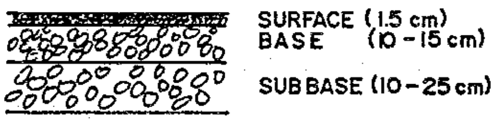
TYPICAL ROADWAY SECTION



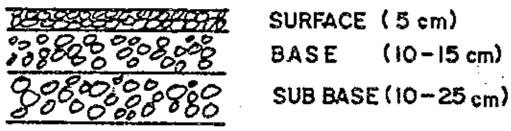
GRAVEL-SURFACED ROAD
(GR)



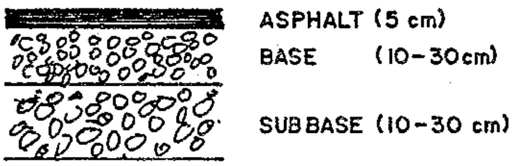
SINGLE BITUMINOUS
SURFACE TREATMENT
(SBST)



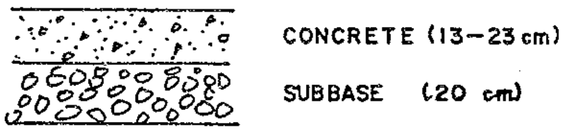
DOUBLE BITUMINOUS
SURFACE TREATMENT
(DBST)



BITUMINOUS PENETRATION
MACADAM PAVEMENT
(BMP)



ASPHALT
CONCRETE PAVEMENT
(AC)



PORTLAND CEMENT
CONCRETE PAVEMENT
(PC)

FIGURE 9.2-1 CROSS SECTIONS OF PAVEMENTS

GRAVEL

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

SBST

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

DBST

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

BMP

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

AC

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

PCC

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

FIGURE 9.2-2 PAVEMENT TYPES FOR STANDARD DESIGN

9.3 DESIGN CRITERIA AND ASSUMPTIONS

The design criteria and assumptions for the standard design are summarized in Table 9.3-1.

9.3.1 Design Variables

(1) Analysis Period

The analysis period refers to the period of time for which the analysis is to be conducted. In general, the analysis period is set to 25 years.

(2) Performance Period

The performance period refers to the period of time for which an initial pavement structure will last before it needs rehabilitation. The recommended performance period, obtained through life-cycle costs analysis for individual pavement types are as shown Table 9.3-2. (See Chapt. 3 of Volume 30.)

TABLE 9.3-2 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 Pavements	15 - 20

(3) Traffic

Design analysis is conducted based on the cumulative expected 18-kip equivalent single axle loads (ESAL) applied during the analysis period. For sake of simplicity and convenience, traffic loadings are classified into 10 classes using the number of ESAL applications for the initial year (Table 9.3-3).

TABLE 9.3-1 DESIGN CRITRIA AND ASSUMPTIONS

	G R	S B S T	D B S T	B M P	A C	P C C
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
Traffic (classes)	10	10	10	10	10	10
Reliability (%)	50	50	50	50	50	50
2. Performance Criteria						
Initial Serviceability (P_o)	3.5	4.2	4.2	4.2	4.2	4.5
Terminal Serviceability (P_t)	0.5	1.5	1.5	1.5	2.0/2.5	2.0/2.5
Allowable Rutting (inches)	2.5	-	-	-	-	-
Gravel Loss	(See 9.3.2 (3))	-	-	-	-	-
3. Material Property		(CBR = 3, 4, 6, 8, 10, 15 and 20)				
3.1 *Elastic Modulus Subgrade*						
Subbase (PSI)	8,000	8,000	8,000	8,000	8,000	8,000
Base (PSI)	22,000	22,000	22,000	22,000	22,000	-
SBST/DBST/BMP (PSI)	-	200,000	200,000	200,000	-	-
AC (PSI)	-	-	-	-	350,000	-
PCC (PSI)	-	-	-	-	-	3.28 x 10^6
3.2 Modulus of Rupture						
PCC (PSI)	-	-	-	-	-	580
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	Reconstruction of Surface	Reconstruction of Surface	Reconstruction of Surface	5 cm. AC Overlay	5 cm. AC Overlay

TABLE 9.3-3 TRAFFIC LOADING CLASSIFICATION FOR RURAL ROADS

Traffic Loading Class			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.
Not applicable to major highways where traffic composition and load factors may be different.

(4) **Reliability**

AASHTO Guide 1986 introduces the reliability concept to account for chance variations in both traffic prediction and performance prediction. A reliability of 50 percent is adopted in the standard the design, which is the lowest level suggested by the AASHTO Guide 1986.

9.3.2 Performance Criteria

(1) **Serviceability**

The primary measure of serviceability is the Present Serviceability Index (PSI) which ranges from 0 (impassable) to 5 (perfect road). The following assumptions are adopted in the standard design.

Gravel Road : Overall serviceability loss 3.0
(Po = 3.5, Pt = 0.5)

SBST/DBST/BMP : Po = 4.2, Pt = 1.5

AC : For Light Traffic Loading Classes
Po = 4.2, Pt = 2.0

For Heavy Traffic Loading Classes
Po = 4.2, Pt = 2.5

PCC : For Light Traffic Loading Classes
Po = 4.5, Pt = 2.0

For Heavy Traffic Loading Classes
Po = 4.5, Pt = 2.5

Where, Po = initial serviceability
Pt = terminal serviceability

(2) Allowable Rutting

Rutting is considered only as a performance criteria of gravel road. The allowable rut depth of 2.5 inches is adopted.

(3) Gravel Loss

Based on the Kenya Road Transport Cost Study, annual gravel loss is estimated by the following equation:

$$AGL = f\{T^2 /(T^2 +50)\}(4.2+0.092T+3.50R^2 +1.88VC)$$

where, AGL = annual gravel loss, in mm
T = annual traffic volume in both directions, in thousands of vehicles
R = annual rainfall, in m
VC = average percentage gradient of road
f = 0.94 for lateritic gravels
1.1 for quartzitic gravels
0.7 for volcanic gravels
1.5 for coral gravels

In the standard design, the following values are assumed:

R = 2.5, VC=3.0, and f=1.1

9.3.3 Material Properties

(1) Subgrade

The Effective modulus of subgrade reaction (K-value) and effective resilient modulus (M_R) of subgrade soil are estimated, taking into account the influence of the subbase, as shown in Table 9.3-4.

TABLE 9.3-4 STRENGTH OF ROADBED/SUBGRADE

CBR of Subgrade	K (pci) of Subgrade	Mr (psi) of Subgrade	K (pci)
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 the Portland Cement Association.

(2) Subbase Course

For flexible pavement design, AASHTO employs structural layer coefficients (a values). A value for this coefficient is assigned to each layer material in the pavement structure to convert the actual layer thickness into a structural number (SN).

AASHTO suggests structural layer coefficient, a_3 for granular subbase material as shown in Table 9.3-5.

TABLE 9.3-5 STRUCTURAL COEFFICIENT FOR GRANULAR SUBBASE

CBR	Modulus (psi)	Coefficient, a_3
40	17,000	0.12
30	15,000	0.11
20	13,000	0.095
10	11,000	0.08

In the standard design, a_3 of 0.095 was adopted taking into consideration the material requirements and tropical condition in the country.

(3) Base Course

The structural layer coefficient, a_2 for granular base layers in flexible pavement structural design may be estimated based on the values shown in Table 9.3-6 as recommended by AASHTO.

TABLE 9.3-6 STRUCTURAL COEFFICIENT FOR GRANULAR BASE

CBR	Modulus (psi)	Coefficient, a_2
100	30,000	0.14
66	27,000	0.125
40	22,000	0.105
20	15,000	0.07

A structural layer coefficient of 0.105 was assumed based on the material requirements, construction performance and length of rainy seasons.

(4) SBST/DBST/BMP

The structural layer coefficients for SBST/DBST/BMP are difficult to estimate since a coefficient is determined based on its elastic (resilient) modulus (E).

In the standard design, however, the layer coefficient was assumed to be 0.3 based on the structure coefficient for dense-graded asphalt concrete as recommended by AASHTO.

(5) Asphalt Concrete Surface Course

Table 9.3-7 shows the recommended structural layer coefficients for dense-graded asphalt concrete for use in the structural design of flexible pavements.

TABLE 9.3-7 STRUCTURAL COEFFICIENT OF DENSE-GRADED ASPHALT CONCRETE

Elastic Modulus (Psi)	Structural Layer Coefficient, a_1
400,000	0.42
350,000	0.39
300,000	0.38
200,000	0.30
110,000	0.20

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

(6) Portland Cement Concrete Pavement

The following formula is used for estimating the modulus of rupture (flexural strength) for portland cement concrete required in the design procedure for rigid pavements, which is the mean value determined after 28 days of third-point loading (AASHTO T97, ASTM C78) and estimated as follows:

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

where:

- S'c = estimated mean value for PCC Modulus of rupture (psi)
- Sc = construction specification of concrete modulus of rupture (psi)
- SDs = estimated standard deviation of concrete modulus of rupture (psi)
- Z = standard normal variate

In the standard design, a modulus of rupture of 580 psi (40 kg/cm²) is adopted to comply with the specification requirement of 550 psi (39 kg/cm²) at 14 days in the country. The modulus of elasticity for PCC is estimated as 3.28×10^6 psi.

9.3.4 Structural Characteristics

(1) Drainage

The effects of certain levels of drainage on predicted pavement performance constitutes an important factor in pavement design.

Table 9.3-8 shows the general definitions corresponding to different levels of drainage from the pavement structure.

TABLE 9.3-8 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 the drainage level, AASHTO recommends the use of m_i values for modifying the structural coefficients of base and subbase materials for flexible pavements and drainage coefficients Cd for rigid pavements.

The standard design adopts $m_i = 0.9$ and $Cd = 0.9$.

(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.

The standard design, adopts a load transfer coefficient of 4 in consideration of the effects of plain joints.

9.3.5 Rehabilitation Works

(1) Gravel-Surfaced Road

When the condition of the initial pavement structure reaches terminal serviceability (Pt = 0.5), or the rut depth reaches the allowable limit, rehabilitation work is required. For gravel-surfaced roads, re-graveling is proposed for gravel loss.

(2) **SBST, DBST and BMP**

For rehabilitation, reconstruction of the surface course is proposed to restore the structural strength of the pavements to the original strength.

(3) **Asphalt Concrete Pavement**

An asphalt concrete overlay of 5 cm was assumed. The structural strength of the pavement after overlay was estimated from the following formula.

$$SN_y = SN_{OL} + F_{RL} \cdot SN_{xeff}$$

where:

SN_y : total structural capacity required to support the overlay traffic

SN_{OL} : structural capacity of overlay

SN_{xeff} : effective structural capacity of existing pavement immediately prior to the application of overlay.

F_{RL} : remaining life factor which accounts for damages of existing pavement, 0.7.

(4) **Portland Cement Concrete Pavement**

For PCC pavements, an AC overlay of 5 cm was assumed. The structural strength of rigid pavements with flexible overlay is estimated based on the following formula.

$$SN_y = SN_{OL} + F_{RL} (A_{2x} \cdot D_o + SN_{xeff} - rp)$$

Where:

A_{2x} : Structural layer coefficient for existing cracked PCC pavement layer, 0.4

D_o : Thickness of Existing PCC layer

$SN_{xeff} - rp$: Effective (in situ) structural capacity of all remaining pavement layers above subgrade except for existing PCC layer.

9.4 STANDARD DESIGN

In accordance with the design methods provided by the AASHTO Guide 1986, structural analysis was carried out based on the design criteria and assumptions described in 9.3, the results of which are given in Appendix III of Volume 30.

Table 9.4-1 summarizes the outputs of analysis as the standard pavement design.

From this table, the economic pavement structures for each pavement type may be selected depending on traffic volume as converted into the number of 1st year ESAL and strength of subgrades as represented by CBR values.

TABLE 9.4-1 (1) STANDARD PAVEMENT DESIGN

GRAVEL

First Year ESAL	C B R							Performance Period (Year)
	3	4	6	8	10	15	20	
0 - 1,300	GR-3	GR-2	GR-2	GR-2	GR-2	GR-2	GR-1	3-4
1,300 - 3,000	GR-5	GR-5	GR-4	GR-3	GR-3	GR-2	GR-2	

SBST

First Year ESAL	C B R							Performance Period (Year)
	3	4	6	8	10	15	20	
0 - 3,000	-	SBST-5	SBST-5	SBST-4	SBST-4	SBST-3	SBST-2	3-5
3,000 - 8,000	-	-	-	SBST-5	SBST-5	SBST-4	SBST-3	
8,000 - 14,000	-	-	-	-	-	SBST-5	SBST-4	

DBST

First Year ESAL	C B R							Performance Period (Year)
	3	4	6	8	10	15	20	
0 - 3,000	-	DBST-5	DBST-5	DBST-4	DBST-4	DBST-3	DBST-2	5-8
3,000 - 8,000	-	-	-	DBST-5	DBST-5	DBST-4	DBST-3	
8,000 - 14,000	-	-	-	-	-	DBST-5	DBST-4	

BMP

First Year ESAL	C B R							Performance Period (Year)
	3	4	6	8	10	15	20	
0 - 3,000	BMP-5	BMP-4	BMP-3	BMP-3	BMP-2	BMP-1	BMP-1	8-10
3,000 - 8,000	-	BMP-5	BMP-5	BMP-4	BMP-3	BMP-2	BMP-1	
8,000 - 14,000	-	-	-	BMP-5	BMP-4	BMP-3	BMP-2	

TABLE 9.4-1 (2) STANDARD PAVEMENT DESIGN

AC

First Year ESAL	CBR							Performance Period (Year)
	3	4	6	8	10	15	20	
3,000 - 8,000	AC-4	AC-3	AC-3	AC-2	AC-2	AC-1	AC-1	10-15
8,000 - 14,000	AC-5	AC-4	AC-3	AC-3	AC-3	AC-2	AC-1	
14,000 - 21,000	AC-5	AC-4	AC-4	AC-3	AC-3	AC-2	AC-2	
21,000 - 30,000	-	AC-5	AC-4	AC-4	AC-3	AC-3	AC-2	
30,000 - 60,000	-	AC-5	AC-5	AC-5	AC-4	AC-3	AC-3	
60,000 - 100,000	-	-	-	AC-5	AC-5	AC-4	AC-3	
100,000 - 150,000	-	-	-	-	AC-5	AC-4	AC-4	
150,000 - 200,000	-	-	-	-	-	AC-5	AC-4	

PCC

First Year ESAL	CBR							Performance Period (Year)
	3	4	6	8	10	15	20	
8,000 - 14,000	PCC-2	PCC-2	PCC-1	PCC-1	PCC-1	PCC-1	PCC-1	15-20
14,000 - 21,000	PCC-2	PCC-2	PCC-2	PCC-2	PCC-2	PCC-2	PCC-2	
21,000 - 30,000	PCC-3	PCC-3	PCC-3	PCC-2	PCC-2	PCC-2	PCC-2	
30,000 - 60,000	PCC-4	PCC-4	PCC-3	PCC-3	PCC-3	PCC-3	PCC-3	
60,000 - 100,000	PCC-4	PCC-4	PCC-4	PCC-4	PCC-4	PCC-4	PCC-4	
100,000 - 150,000	PCC-5	PCC-5	PCC-5	PCC-5	PCC-5	PCC-5	PCC-5	
150,000 - 200,000	PCC-5	PCC-5	PCC-5	PCC-5	PCC-5	PCC-5	PCC-5	

9.5 RECOMMENDED PAVEMENT TYPES

A life-cycle cost analysis was conducted on the standard structure for each pavement type. Figures 9.5-1 and 9.5-2 graphically demonstrate the findings of analysis including the initial cost and life-cycle cost of standard pavement structures, for CBR values of 3, 8 and 20.

Figure 9.5-3 shows an example of recommended economical pavement types for CBR = 8, which may be considered to be the average subgrade strength. The recommendation may be summarized as follows:

Primary Major Road

. 1st year ESAL	0 – 1,300 (AADT 100)	:	Gravel
. 1st year ESAL	1,300 (AADT 100) – 8,000 (AADT 400)	:	DBST/BMP
. 1st year ESAL	8,000 (AADT 400) – 30,000 (AADT 1,000)	:	AC
. 1st year ESAL	30,000 (AADT 1,000) – Over	:	PCC

Secondary Major/Minor Roads

. 1st year ESAL	0 – 3,000 (AADT 200)	:	Gravel
. 1st year ESAL	3,000 (AADT 200) – 8,000 (AADT 400)	:	DBST/BMP
. Over 8,000		:	Same as primary major roads

However, it is to be noted that the discussion on economic pavement types involves uncertainty in performance prediction and traffic prediction, an overestimation may result. Moreover, the results of economic analysis can be sensitively affected by the economic condition in the country as represented by such factors as prices of pavement materials, construction cost, construction conditions in locality and acceptance of pavement condition by the users since the serviceability which is the basis of pavement structural analysis depends on a subjective judgment by the users.

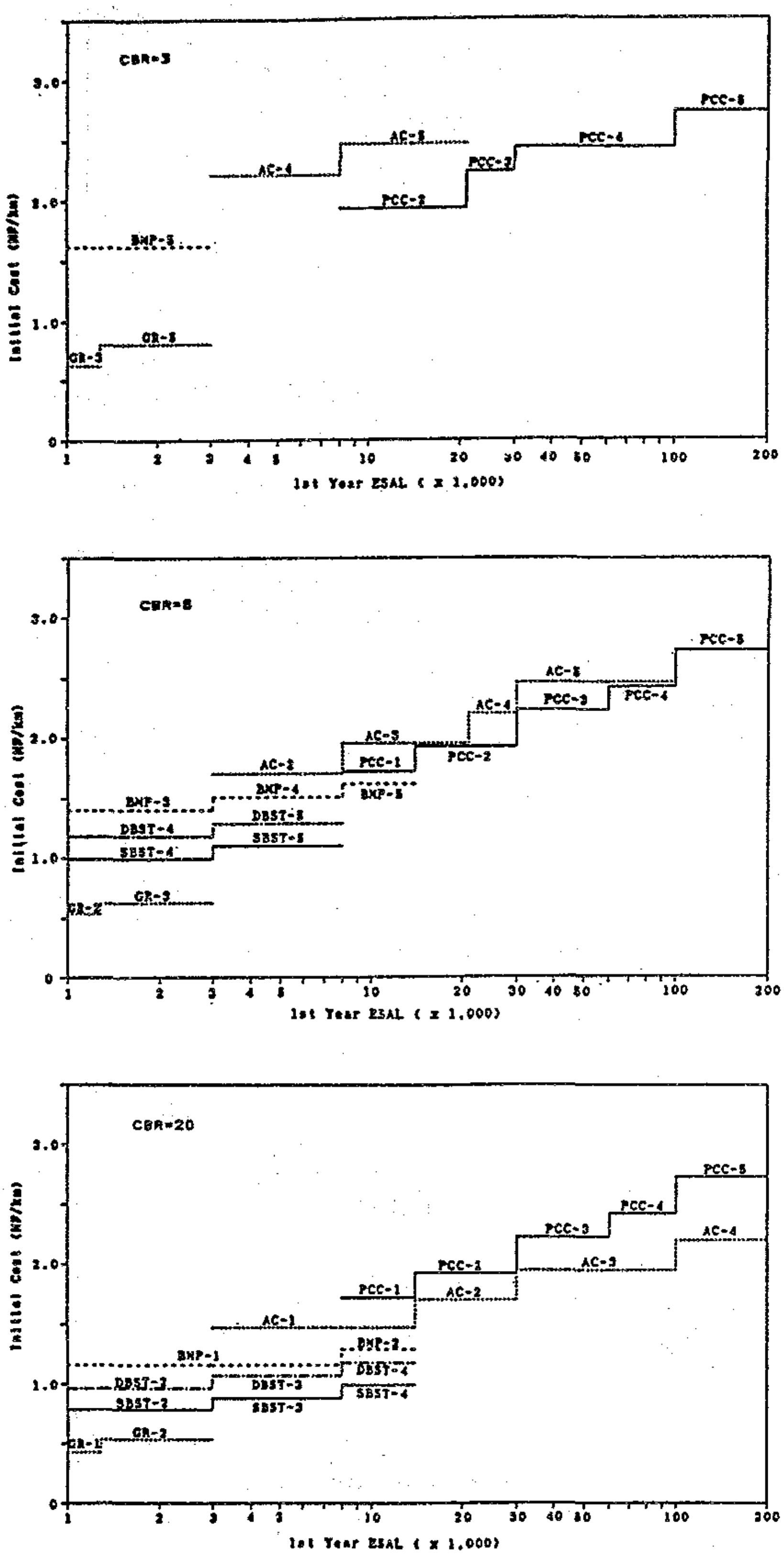


FIGURE 9.5-1 INITIAL COST OF PAVEMENT STRUCTURES

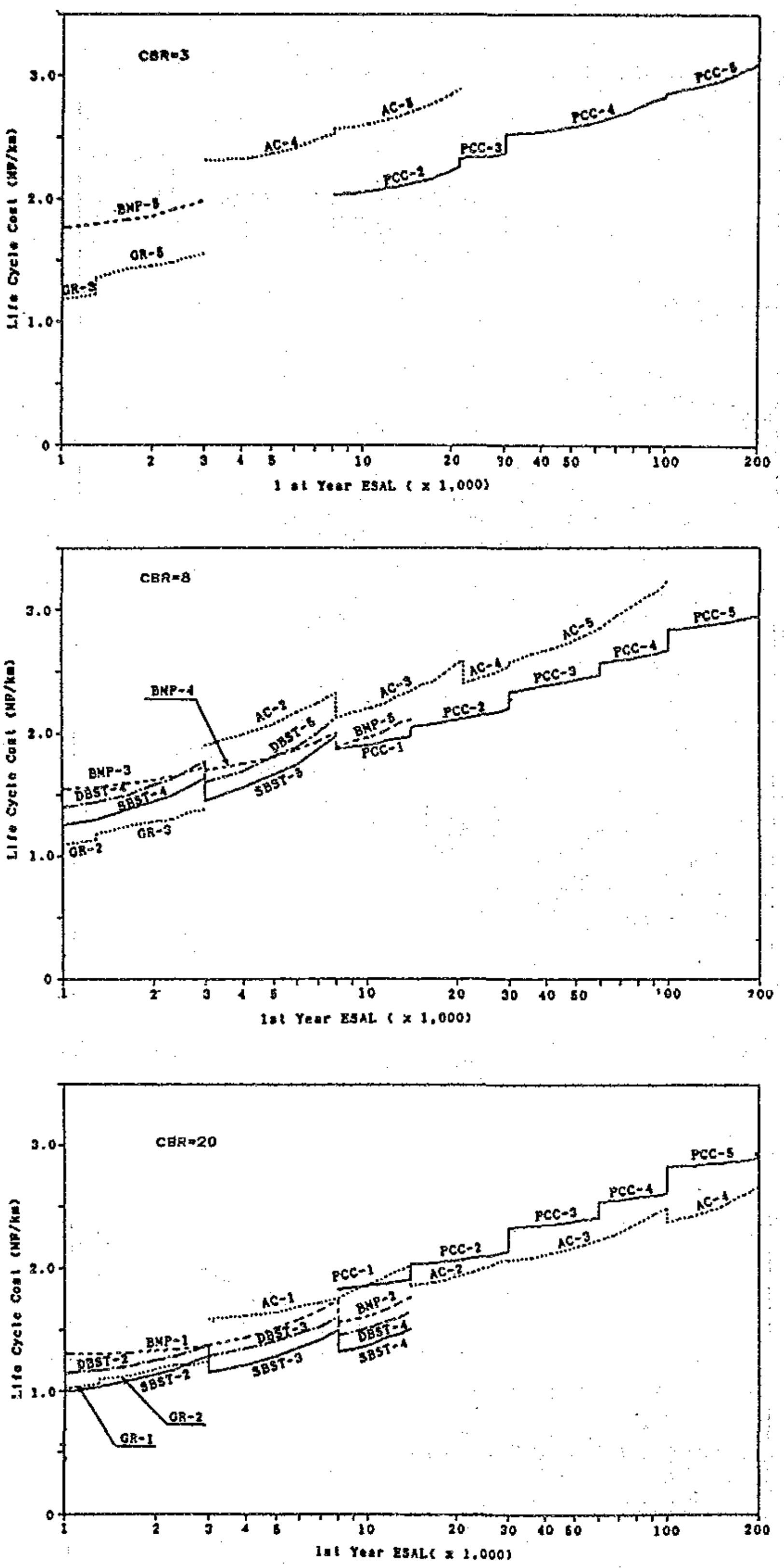
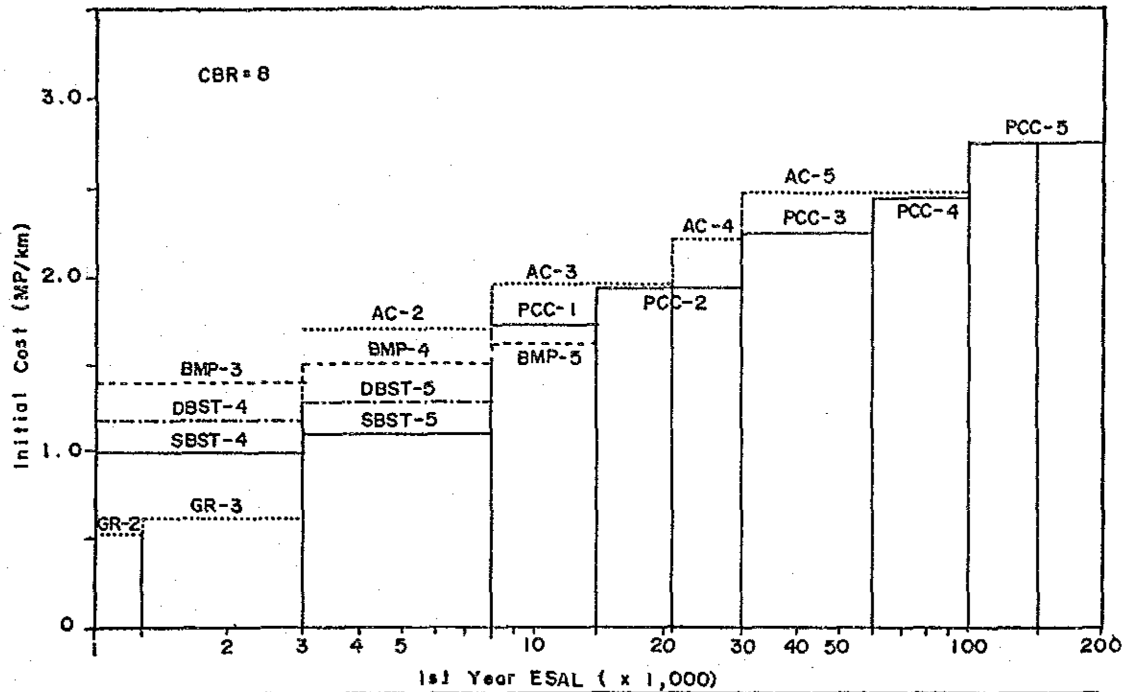


FIGURE 9.5-2 LIFE CYCLE COST OF PAVEMENT STRUCTURES



Traffic Loading Class	Light Loading Traffic						Heavy Loading Traffic			
	R_{1-1}	R_{1-2}	R_{2-1}	R_{2-2}	R_{3-1}	R_{3-2}	A_{1-1}	A_{1-2}	A_{2-1}	A_{2-2}
No. of ESAL in 1st Year	1,300	3,000	8,000	14,000	21,000	30,000	60,000	100,000	150,000	200,000
Assumed AADT	100	200	400	600	800	1,000	1,500	2,000	3,000	4,000
Recommended Pavement Types: Primary Major Roads	GR	DBST / BMP		AC/PCC			PCC			
Recommended Pavement Types: Secondary Major/Minor Roads	GR		DBST/BMP	AC/PCC			PCC			

FIGURE 9.5-3 AN EXAMPLE OF RECOMMENDATION ON PAVEMENT TYPES

CHAPTER 10

RECOMMENDATION ON DESIGN AND CONSTRUCTION OF LOW-CLASS PAVEMENTS

The discussions on low-class pavements in this Study include the assessment of the existing condition of low-class pavements, structural design of new pavements and construction of experimental pavements as well as follow-up observation of the performance of the constructed experimental pavements, which is to be continued for more than five (5) years.

This Chapter, therefore, summarizes the tentative conclusion regarding design and construction of low-class pavements and omits evaluation of the performance of experimental pavements, and therefore, is subject to review.

10.1 RECOMMENDATION ON PAVEMENT PROJECT ADMINISTRATION

10.1.1 Development of Standard Pavement Types

The selection of the most preferred pavement type is a complex task, for which there is no infallible method. The selection process requires considerable engineering judgment, creativity and flexibility, and at the same time, involves both monetary and non-monetary considerations such as:

- Initial Cost
- Total Life Cost
- Limited Project Funding
- Traffic Volume and Type
- Road Class
- Desired Service Life
- Reliability
- Duration of Construction
- Traffic Control Problems (lane closure availability)
- Constructibility (available materials and equipment, contractor expertise and manpower)
- Maintainability
- Natural Environment
- Agency Policies

The most economical pavement types were discussed based only on the life cycle cost analysis in Chapter 9. The analyszed results are summarized below:

i) Gravel surfaced roads (Gr) may be adopted for very low-volume traffic roads (assumed ADDT for primary major roads being 100, and 200 for others) to serve for a performance period of 3 to 4 years.

ii) Single bituminous surface treatment (SBST) may not be recommendable because of its: 1) short performance period (3 to 5 years), 2) lack of imperviousness to water, 3) required high skillfulness in construction techniques.

iii) Double bituminous surface treatment (DBST) may be applicable for roads with less than 400 AADT for a performance period of 5 to 8 years.

iv) Bituminous penetration macadam pavement (BMP) is not economical compared with DBST, though it provides a longer performance period - 8 to 10 years.

v) The portland cement concrete pavement (PCC) and asphalt cement pavement (AC) are recommended for roads with traffics of more than 400 AADT. The performance periods of AC and PCC are 10 to 15 and 15 to 20 years, respectively.

vi) It should be noted that PCC tends to be more economical than AC excepting when the CBR of the subgrade is more than 20. The assumed price of cement used in the analysis is ₱100.00 per bag and that of asphalt concrete ₱10,200.00 per metric ton.

The above is an example of recommendation on pavement types made based only on the life-cycle cost analysis using the average costs of pavement materials. It is, therefore, highly recommended that a similar study be conducted by the agency to establish the standard type of pavement, with such non-monetary factors as constructibility and maintainability as well as relevant government policies also taken into account.

10.1.2 Establishment of Pavement Rehabilitation Criteria

As the present serviceability index (PSI) defined by AASHTO is estimated based on subjective assessments by road users, the dominant factor is roughness. The AASHTO Guide for Design of Pavement Structures 1986 adopts this concept for the design of pavements for new constructions as well as for rehabilitation.

However, the physical deterioration of pavements is likely to induce a decision to initiate maintenance or rehabilitation. This may apply particularly to pavements in this country whose initial roughness (just after construction) is relatively high.

Accordingly, the rehabilitation requirement index (RRI) for PCC pavements was proposed in the Feasibility Study of Road Improvement Project on the Pan-Philippine Highway as well as in this study for bituminous surface treatment (BST), bituminous penetration macadam pavement (BMP) and asphalt cement pavement (AC), but not for gravel surfaced roads. Just as road users evaluate the riding quality by PSI, highway/maintenance/construction engineers assess the extent and degree of pavement deterioration and evaluate the necessity of rehabilitation using the RRI as the basis. RRI is obtained from measurement of cracking, patching and roughness. Compared with PSI, RRI is more closely related to physical deterioration, especially cracking.

10.1.3 Pavement Construction in Rainy Season

The weather condition is one of the important factors in construction works, particularly in pavement construction in which the control of water contents greatly affects the quality of accomplished works.

The construction procedures for pavements to be adopted for the rainy season differ entirely from those for the dry season. The climate conditions affect not only work schedules and construction methods that require certain pavement materials but also the pavement types to be constructed.

Moreover, climate conditions call for additional costs for both parties; the Government and contractors. The Government must spend additional maintenance costs and rehabilitation costs since all pavement types constructed during rainy seasons tend to deteriorate earlier than expected, while, contractors are often forced to make a heavy outlay for idling equipment and manpower to wait for the limited workable days during rainy seasons. It is extremely difficult to control water contents of pavement materials to be used for the construction of the subgrade, subbase and base course. Such materials that conform with the design and specification requirements are hard to procure.

No special recommendation on the problem was presented in this Study, but to recommend that the construction schedule be set up so that pavement work can be done only during the dry season, except when urgent completion of pavement work is needed.

This problem may not be solved by contractors alone, being rather a policy-related issue that must be handled by the Government. Therefore, it is highly recommended that the Government establish appropriate guidelines regarding the construction of pavements for the rainy season.

10.2 RECOMMENDATION ON PAVEMENT DESIGN

10.2.1 Structural Design of Pavement

The design Guidelines, Criteria and Standard for Public Works and Highways prepared by the Bureau of Design are well-developed guidelines. However, as the guidelines adopt the AASHTO Interim Guide Method, Road Note 29 and Group Index Method, it is recommended that the new guidelines published by AASHTO, that is, the AASHTO Guide for Design of Pavement Structures, 1986 be used with the following suggestions.

(1) Reliability

Reliability is the probability that any particular type of deterioration (or combination of deterioration manifestations) will remain below or within the permissible level during the design life.

In this Study, the lowest level of reliability, 50 percent was adopted. The Government is recommended to establish its policy on this matter to ensure uniform design of pavements.

(2) Performance Period of Initial Pavement Structures

To ensure uniformity in pavement design and realize planned rehabilitation, the performance period for initial pavement structures must be established according to road classes, traffic loading classes and pavement types.

In this Study, the following performance periods are recommended.

TABLE 10.2-1 PERFORMANCE PERIOD OF INITIAL PAVEMENT STRUCTURES (Year)

Traffic Loading Class	Gravel	SBST	DBST	BMP	AC	PCC
Light Loading Class 1/	3-4	3-5	5-8	8-10	10-15	15-20
Heavy Loading Traffic 2/	-	-	-	-	8-14	15
Extra Heavy Loading 2/	-	-	-	-	5- 8	5-12

Note:
1/ This Study
2/ Feasibility Study, the Road Improvement Project on the Pan-Philippine Highway

(3) Soil Support Value

The AASHTO Guide 1986 provides the roadbed soil resilient modulus for flexible pavements and modulus of subgrade reaction for rigid pavements.

It is recommended that the Government develop these soil support values in relation to the CBR values of subgrades, by taking into consideration the local conditions including the soil characteristics in the locality and workmanship of subgrade preparations.

(4) Layer Coefficients (Flexible Pavements)

To ensure uniform design of pavements, the structural layer coefficients of subbase, base and surface courses shall be developed in relation to the specification requirements, cost analysis construction method and the past performance of pavements.

(5) Drainage

A subsurface drainage system shall be incorporated in pavement design as suggested by AASHTO. The improvements in performance to good drainage shall be measured by the quality of drainage governed by the percent of time it takes pavement structure exposed to moisture levels to reach saturation.

10.2.2 Serviceability of Pavement

The primary measure of serviceability is the present serviceability index (PSI) which ranges from 0 (impassable road) to 5 (perfect road). Selection of the lowest allowable PSI or terminal serviceability index (Pt) is based on the lowest index that will be corrected before rehabilitation, resurfacing or reconstruction becomes necessary.

In the Study, the following serviceability was assumed.

TABLE 10.2-2 SERVICEABILITY

	Major Road		Minor Road	
	Initial Serviceability	Terminal Serviceability	Initial Serviceability	Terminal Serviceability
PCC	4.5	2.5	4.5	2.0
AC	4.2	2.5	4.2	2.0
BMP	-	-	4.2	1.5
SBST/DBST	-	-	4.2	1.5
GR 1/	-	-	3.5	0.5

Note: 1/ For gravel - surfaced roads (GR), total loss was assumed to be 3.0.

Since the selection of Pt greatly affects the design of initial pavement structures as well as the timing of rehabilitation works, it is recommended that the Government provides guidance on the selection of serviceability for road classes and pavement types.

10.2.3 Upgrading of Initial Pavement Types (Planned Rehabilitation)

In general, planned rehabilitation or a stage construction approach should be considered for pavement improvement projects, because the initial investment cost may become huge when the initial pavement structure is designed to withstand the total traffic expected over the whole analysis period (generally 25 years).

This is especially true if life-cycle economic analyses are to be performed, where the trade-offs between the thickness design of the initial pavement structure and any subsequent overlay can be evaluated. Moreover, a planned rehabilitation approach is desirable particularly where the present traffic volume is rather low while the expected traffic growth rate is high, or when long-term predictions are uncertain.

For this reason, it is recommended that in addition to the planned rehabilitation of a simple overlay, upgrading of the initial pavement type (the construction of a low-class pavement at the initial stage and upgrading to a higher pavement type at the rehabilitation stage) be conducted.

Typical examples of the upgrading rehabilitation approach are discussed hereunder.

(1) Upgrading from Gravel Road to Bituminous Surfacing

If existing surface gravel on gravel roads are composed of well-graded gravel and are well-maintained so as to provide a good drainage condition, the existing gravel layer can be utilized as a part of the base course of new pavements, thus minimizing the thickness of the base course layer to be rehabilitated at a later stage.

If the existing gravel on existing roads are maintained to a reasonably fair/good drainage condition, the existing gravel layer can be stabilized by being blended with a) selected granular materials or b) Portland cement, and the layer may be used as a stabilized base for new bituminous type pavements.

In this connection, it is essential that stabilization techniques for existing gravel layers by a road mixing method be developed. However, it is of even greater importance that gravel-surfaced roads be constructed with well-graded gravel base materials on a well-prepared subbase and subgrade so as to provide a favorable drainage system.

When this approach is adopted, the rehabilitation timing must be carefully examined, while maintaining and keeping a close watch over the existing gravel road to enable action before it reaches total deterioration.

(2) Upgrading from DBST/BMP to AC

When double bituminous surface treatment (DBST) or bituminous penetration macadam pavements (BMP) deteriorate, the surface layer of these existing pavements can be used as the base course of a new asphalt cement pavement (AC) by adopting the in-situ base recycling method.

The surface layer of existing pavements are broken into fragments and mixed with the existing base course materials, and then blended with Portland cement. By this in-situ recycling method, the stabilized base course for a new pavement can be produced.

This method calls for a firmly constructed DBST or BMP placed over a well-prepared subbase as well as a subgrade with a favorable drainage system.

The rehabilitation timing must be carefully assessed. Otherwise, it may lead to an excessive deterioration of the surface layer and even of the base course of existing DBST or BMP, and the recycling method will be no longer applicable.

10.3 RECOMMENDATION ON PAVEMENT CONSTRUCTION

10.3.1 Conformity with Design and Specification Requirements

The construction of pavements shall strictly conform to the design and specification requirements of projects. The purpose of the design and specification are to ensure that (1) the assumed values used in the design are met, (2) the contractor understands what is required by the designer, (3) the contractor receives proper payments, and (4) the mutual responsibilities during construction are understood.

The pavement design shall conform with:

- Quality design (paving mixture design) of the various pavement components
- Thickness design of pavement structures

  The adequacy of thickness design is dependent on changes in the quality of the pavement materials. It is, therefore, essential that the construction procedures provide materials that are consistent with the design assumption.

Cost estimate shall be based on the complete undertaking of works and the operation involved in its performance, including the following:

- Unit price of materials in competitive market condition
- Efficiency of equipment operation
- Construction condition in locality including accessibility to job site
- Construction schedule which takes unworkable days into account
- Material sources
- Temporary/provisional works and materials required
- Corporate indirect costs and reasonable profit

It shall be clearly understood that the contractor is legally responsible for the completion of a project within the stipulated time, while conforming with the design and specification requirements, and at reasonably established costs.

10.3.2 Construction Management

Efforts to establish a systematic and realistic construction schedule for the project is only a tool used to warrant high-quality accomplishment of the project for the concerned agency, and profit to the contractor.

Unless the schedule is solely supported by the following sub-item schedules, it cannot be called either a systematic schedule or a realistic schedule.

i) Equipment Schedule

- Purchase or own
- Timing for project availability
- Maintenance system

ii) Material Schedule

- Borrow from a material source or material supplier
- Delivery procedure/method
- Stock piled at jobsite

iii) Manpower Schedule

- Experienced personnel
- Skillful labor
- Unskillful labor

iv) Financial Schedule

10.3.3 Recommendation on Construction Procedures

(1) Subgrade

The subgrade shall meet the design and specification requirements and be compacted to the design thickness.

When the bearing strength of a subgrade is less than the value assumed in the design, the structural design of the pavement shall be revised in accordance with actual field conditions.

(2) Subbase Course

Local materials of sandy gravel are widely used as aggregates for the subbase. When local materials that conform to the specification requirements are not available, the following stabilization methods are recommended for positive adoption.

a) Mechanical Stabilization

Combined aggregates may be produced by blending more than two (2) kinds of local materials which are then tested to confirm conformance with the grading requirements, liquid limit, plasticity index and bearing strength.

b) Cement Stabilization

By road-mixing aggregates with a proper amount of portland cement, the subbase can be stabilized so as to to conform with the specification requirements.

(3) Base Course

The DPWH Standard Specifications 1988 prescribe provision for the aggregate base course, crushed aggregate base course, lime stabilized road mix base course, portland cement stabilized road mix base course and asphalt stabilized road mix base course.

When base course materials conforming to specification and design requirements are not available during detailed engineering or construction, these stabilization methods shall be positively adopted.

(4) Gravel Surface Course

In order to prevent dust during the dry season and muddy surface during the rainy season, the surface course shall be preferably composed of sandy gravel of a mix proportion of gravel (5): sand (4): silt (1). Over-sized cobbles and boulders more than 50 mm should be avoided to provide a flat and smooth surface.

(5) Bituminous Surface Treatment and Bituminous Penetration Macadam Pavement

- The single bituminous surface treatment (SBST) requires high skillfulness in constructing the layer impervious to water.

- A construction technique for the double bituminous treatment (DBST) and bituminous penetration macadam pavement (BMP) shall be developed.

- As regards the construction equipment for DBST and BMP, provision of such equipment as an asphalt distributor or aggregate spreader and power broom are highly recommended.

- Table 10.3-1 shows a set of major equipment and work forces for equipment-oriented construction and labor-based construction.

TABLE 10.3-1 MAJOR EQUIPMENT SET AND WORK FORCES FOR DBST AND BMP CONSTRUCTION

Construction	Major Equipment	Work Forces	Remarks
Equipment Oriented Construction Method	1 - Asphalt distributor 1 - Aggregate spreader 1 - Power broom 2 - Rollers 2 - Hand rollers 2 - Asphalt kettle	4 - Operators 1 - Driver 3 - Skilled workers 7 - Unskilled workers	Aggregates: Considerable amount of stock of each size aggregate from crushhing plant is required.
Labor Based Construction Method	1 - Asphalt sprayer 1 - Aggregate spreading device 1 - Roller 1 - Hand roller 1 - Asphalt kettle	2 - Operators 2 - Skilled workers 15-20 - Unskilled workers	Aggregates: In case of labor-based aggregate production near the site, the following are required: 1 portable small crusher 1 crusher man 1 skilled worker 10 unskilled workers