Step 6; Remaining Life Factor Determination

Step six in the overlay design analysis is determination of the remaining life factor, $F_{RL}$. $F_{RL}$ is an adjustment factor applied to the effective capacity parameter ($SN_{xeff}$ or $D_{xeff}$) to reflect a more realistic assessment of the weighed effective capacity during the overlay period. This factor is dependent upon the remaining life value of the existing pavement prior to overlay ($R_{LX}$) and the remaining life of the overlaid pavement system after the overlay traffic (and subsequent serviceability) has been reached ($R_{Ly}$). As a consequence, both of these values ($R_{LX}$ and $R_{Ly}$) must be known.

AASHTO Guide 1986 recommends the following methods aside from NDT approach to determine the remaining life of the existing pavement, $R_{LX}$.

- Traffic Approach
- Time Approach
- Serviceability Approach
- Visual Condition Survey Approach

Table 8.3-1 provides general guidance to estimate visual condition factors. After Cx value has been determined Figure 8.3-3 can be used to estimate the $R_{Lx}$ value.

The remaining life of overlaid pavement, $R_{Ly}$ is directly set in selection of the desired terminal serviceability for $SC_y$, by the following equation.

$$R_{Ly}=(N_{fy}-y)/N_{fy}$$

Where; $N_{fy}$ ; Ultimate number of traffic repetitions to failure.

y ; Design overlay traffic

Knowing estimate of both $R_{LX}$ and $R_{Ly}$, the remaining life factor, $F_{RL}$, can be estimated from Figure 8.3-4.

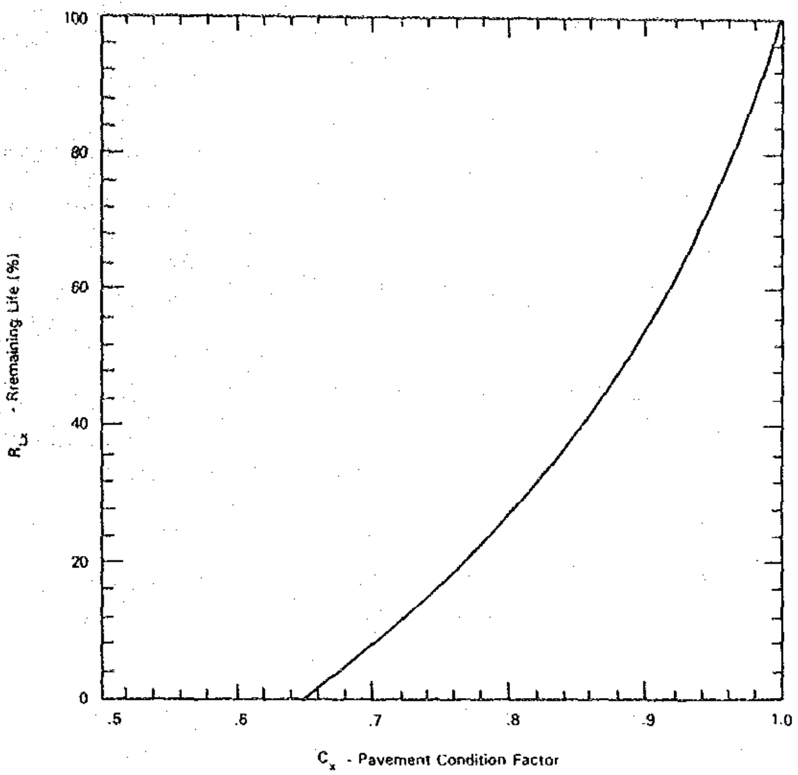



Figure 9.4-3 Remaining life estimate predicted from pavement condition factor.



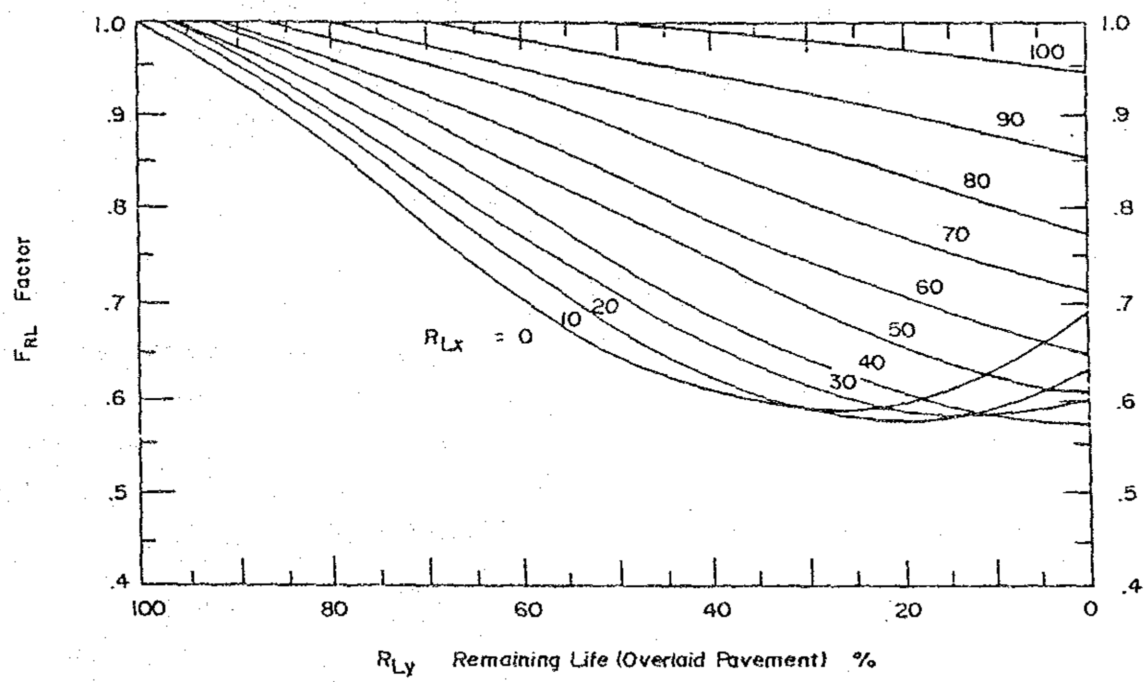



Figure 9.4-4 Remaining life factor as a function of remaining life of existing and overlaid pavements.

Step 7; Overlay Design Analysis

The final step is overlay design analysis which are discussed in the following sections, separately.

## 9.4.3 Overlay Design Analysis for Rigid Overlay-Rigid Existing

Three potential types of rigid overlay over rigid existing are presently proposed; full bond, partial bond and unbonded.

For the pavements with severe structural defect and extensive cracks, only unbonded overlay method can be applied, which was, therefore, adopted in this Study.

Overlay equation for unbonded type is:

$$D_{OL}^{2} = D_{y}^{2} - F_{LR} (D_{xeff})^{2}$$

Where:

$D_{OL}$ ; Required thickness of overlay
$D_y$ ; Total structure capacity required for overlay traffic
$F_{LR}$ ; Remaining life factor
$D_{xeff}$ ; $2r.D_0$
Effective structural capacity of existing pavement

## 9.4.4 Overlay Design Analysis for Flexible-Rigid Existing

Flexible overlays over existing rigid pavement is a significant and often used rehabilitation overlay strategy. Problems associated with this method is the reflective cracking potential of the asphalt overlay over the existing pavement. At present, there are several techniques which minimize/eliminate reflective cracking distress. Use of thick AC overlays method is recommended.

Overlay equation to be used for normal structural approach based on visual condition factor is expressed;

$$SN_{ol} = SN_y - F_{RL} (A\ 2r.D_o + SN_{xeff} - rp)$$
$$h_{ol} = SN_{ol}/A$$

Where:

$D_o$ ; Existing PCC layer thickness 23 cm

$A_{2r}$ ; The structural layer coefficient of the existing cracked PCC pavement layer. This value has been related to the value of the visual condition factor C.

$SN_{xeff-rp}$; The effective (in situ) structural capacity of all remaining pavement layers above the subgrade except for the existing PCC layer (Subbase)

$A_{ol}$ ; Structural layer coefficient of overlay material

$h_{ol}$ ; Required thickness of Asphalt Overlay

Reflective cracking of asphalt overlays over existing rigid pavement is a complex phenomena. To account for the possibility of reflective cracking, the value of overlay thickness must be compared to minimum asphalt overlay thicknesses which, in general, have been effective in minimizing the effect of reflective cracking. These minimum thicknesses are a function of the existing PCC slab length and maximum temperature difference expected within a year. The Asphalt Institute recommends 4 inches (10 cm) which is also recommended for the country.

### 9.4.5 Overlay Design Analysis for Flexible Overlay -Flexible Existing

The basic equation for determining the required SN value due to a flexible overlay over an existing flexible pavement is:

$$SN_{ol} = SN_y - F_{RL}\ SN_{xeft}$$
$$h_{ol} = SN_{ol}/A_{ol}$$

Where:

$A_{ol}$; Structural layer coefficient of overlay material

$h_{ol}$; Required thickness of asphalt overlay

## 9.5 Design Outputs

The basic design was carried out by an electric computer, the outputs of which are reported in Appendix 9-2, Table 9.5-1 summarizes the outputs of analysis.

It is noted that this basic structural design was made based on the assumptions previously mentioned, therefore, the adjustments may be mandatory depending on designer's decisions.

The major design criteria to be adjusted includes the following .

- Analysis period
- Performance period
- Reliability
- Traffic growth rate
- Terminal serviceability

The following are also recommended to be adjusted in accordance with actual conditions.

- Material properties
- Pavement studied characteristics

### PCC RECONSTRUCTION
*Required Thickness of Slab (cm)*

| | TRAFFIC LOADING CLASS \ CBR | 2 | 3 | 4 | 6 | 8 | 10 | 15 | 20 | DESIGN PERFORMANCE PERIOD |
|---|---|---|---|---|---|---|---|---|---|---|
| LIGHT TRAFFIC LOADING ROAD | L-1 | 15 | | | | 13 | | | | |
| | L-2 | 18 | | | 15 | | | | | 20 YEARS |
| | L-3 | 20 | | | 18 | | | | | |
| HEAVY TRAFFIC LOADING ROAD | A | | | | | 23 | | 20 | | |
| | B | | 25 | | | | | | | |
| | C | | | | | | 28 | | | |
| | D | | | | 30 | | | | | 15 YEARS |
| | E | | | | | | | | | |
| EXTRA-HEAVY TRAFFIC LOADING ROAD | F | | | | | 33 | | | | |
| | G | | | | | | | | | |
| | H | | | | 35 | | | | | |
| | I | | | | | | | | | 12 YEARS |
| | J | (10.4) | (11.3) | | | | | | | |

Note ; 1. Provision of Filter Layer is required for CBR less than 3.
2. For CBR less than 2, improvement method for weak subgrade should be applied.
3. ( ) Shows initial performance period less than design even adopting 35 cm. PCC slab.

### AC RECONSTRUCTION
Required Structural Number

| | TRAFFIC LOADING CLASS \ CBR | 2 | 3 | 4 | 6 | 8 | 10 | 15 | 20 | DESIGN PERFORMANCE PERIOD |
|---|---|---|---|---|---|---|---|---|---|---|
| LIGHT TRAFFIC LOADING ROAD | L-1 | | | 2.5 | | | 2.1 | | 1.7 | |
| | L-2 | | 3.0 | | | | | | | 15 YEARS |
| | L-3 | | 3.5 | | 3.0 | | 2.5 | | | |
| HEAVY TRAFFIC LOADING ROAD | A | | 4.0 | | | 3.5 | 3.0 | 2.5 | | |
| | B | | 4.5 | 4.0 | | | | | 3.0 | 12 YEARS |
| | C | | | | | | 4.0 | | | |
| | D | | | | | | | | | |
| | E | | | | | 4.5 | | | | 8 YEARS |
| EXTRA-HEAVY TRAFFIC LOADING ROAD | F | | | 5.0 | | | | | 3.5 | |
| | G | | | | | | | | | |
| | H | | 5.5 | | | | | 4.0 | | |
| | I | | | | | | | | | 6 YEARS |
| | J | | | | | | | | | |

Note ; 1. An improvement method for weak subgrade with CBR less than 3 is required to improve it to CBR more than 3.
2. For CBR less than 2, improvement method for weak subgrade should be applied.

Figure 9.5-1(1) PAVEMENT STRUCTURE CAPACITY OF INITIAL PAVEMENT STRUCTURES

RIGID OVERLAY – RIGID EXISTING

Required Thickness of PCC Overlay (cm)

| | TRAFFIC LOADING CLASS \ CBR | 2 | 3 | 4 | 6 | 8 | 10 | 15 | 20 | DESIGN PERFORMANCE PERIOD |
|---|---|---|---|---|---|---|---|---|---|---|
| LIGHT TRAFFIC LOADING ROAD | L-1 | | | | | | | | | 20 YEARS |
| | L-2 | | | | | 13 | | | | |
| | L-3 | 15 | | | | | | | | |
| HEAVY TRAFFIC LOADING ROAD | A | 20 | | | | 18 | | | | 15 YEARS |
| | B | | 23 | | | 20 | | | | |
| | C | | 25 | | | 23 | | | | |
| | D | | | | | 28 | | | 25 | |
| | E | 30 | | | | | | | | |
| EXTRA-HEAVY TRAFFIC LOADING ROAD | F | | | | | 30 | | | | |
| | G | | | | | | | | | |
| | H | | | | | 33 | | | | 12 YEARS |
| | I | | | | | | | | | |
| | J | (10.4) | (11.2) | | | | | | | |

Note ; ( ) Shows initial performance period less than design even adopting 33 cm Rigid Overlay.

FLEXIBLE OVERLAY – RIGID EXISTING

Required Thickness of AC Overlay (cm)

| | TRAFFIC LOADING CLASS \ CBR | 2 | 3 | 4 | 5 | 8 | 10 | 15 | 20 | DESIGN PERFORMANCE PERIOD |
|---|---|---|---|---|---|---|---|---|---|---|
| LIGHT TRAFFIC LOADING ROAD | L-1 | | | | | | | | | 15 YEARS |
| | L-2 | | | | | 5 | | | | |
| | L-3 | 8 | | | | | | | | |
| HEAVY TRAFFIC LOADING ROAD | A | 13 | | | | | | | | 12 YEARS |
| | B | (10.8) | 13 | | | | | | | |
| | C | (6.0) | 15 | 13 | | | 10 | | | |
| | D | | | | | | | | | 8 YEARS |
| | E | | (7.0) | 15 | 13 | | | | | |
| EXTRA-HEAVY TRAFFIC LOADING ROAD | F | | (4.9) | (7.7) | | | | | | |
| | G | | | (6.0) | | 13 | | | | |
| | H | NOT | | | 15 | | | | | 6 YEARS |
| | I | APPLICABLE | | | | | | | | |
| | J | | | | | | | | | |

Note ; ( ) Shows initial performance period less than design even adopting 15 cm Flexible Overlay.

Figure 9.5-1(2) PAVEMENT STRUCTURE CAPACITY OF INITIAL PAVEMENT STRUCTURES

## FLEXIBLE OVERLAY – FLEXIBLE EXISTING

*Required Thickness of AC Overlay (cm)*

| | TRAFFIC LOADING CLASS \ CBR | 2 | 3 | 4 | 6 | 8 | 10 | 15 | 20 | DESIGN PERFORMANCE PERIOD |
|---|---|---|---|---|---|---|---|---|---|---|
| LIGHT TRAFFIC LOADING ROAD | L-1 | 8 | 5 | | | | | 3 | | 10 YEARS |
| | L-2 | 10 | | | 5 | | | | | |
| | L-3 | | 10 | | 8 | | | | | |
| HEAVY TRAFFIC LOADING ROAD | A | | | 10 | | | | | 5 | 5 YEARS |
| | B | | | | | 10 | | | | |
| | C | | | | | | | 8 | | |
| | D | | | | | | | 10 | | 5 YEARS |
| | E | | | | | | | | 10 | |
| EXTRA-HEAVY TRAFFIC LOADING ROAD | F | | NOT | APPLICABLE | | | | | | |
| | G | | | | | | | | | |
| | H | | | | | | | | | 5 YEARS |
| | I | | | | | | | | | |
| | J | | | | | | | | | |

Figure 9.5-1(3) PAVEMENT STRUCTURE CAPACITY OF INITIAL PAVEMENT STRUCTURES

# CHAPTER 10

# SELECTION OF PAVEMENT REHABILITATION METHODS

# CHAPTER 10
# SELECTION OF PAVEMENT REHABILITATION METHODS

This chapter deals with the selection of most appropriate rehabilitation methods which involves the discussions on the technical adequacy and costs in terms of both, initial construction cost and total discounted cost. The total discounted cost required for the total analysis period, including maintenance and succeeding rehabilitation costs, is a principle indicators for cost comparison of pavement structures.

The economic viability of rehabilitation methods is discussed in Chapter 13.

## 10.1 Economic Consideration

### 10.1.1 New Construction

The economic pavement types may differ by traffic loadings to be imposed, bearing capacity of roadbed soil on which the pavement are laid, structural conditions and enviromental conditions.

The comparative analysis on PCC and AC pavement for new constructions are provided to select the most economical pavements types in accordance with traffic loading classes and CBR values.

(1) Structural Capacity for Comparison

In analyzing the most economic pavements types, it is essential that both pavements, PCC and AC, with the same structural capacity should be determined depending on traffic loading, CBR value and the performance period of initial pavement structure. From the output of the basic structure design discussion in Chapter 9, the required structural capacity (the thickness of concrete slab for rigid pavement and the structural number of flexible pavement) is determined under the given conditions of traffic loading class, CBR value and design performance period of the initial structure. See Figure 9.5-1. As an example, Figure 10.1-1 shows the thickness of PCC and structural number of AC pavement required for CBR value of 8 under all classes of traffic loading.

(2) Comparison on Initial Construction Costs

Initial Construction Cost

Initial construction costs of PCC and AC pavement are estimated as follows.

TABLE 10.1-1 UNIT COST OF MAIN MANTERIALS

| M a t e r i a l s | Unit | Unit Cost (₱) |
|---|---|---|
| . Portland Cement | bag | 48.50 |
| . Concrete Class A delivered | $m^3$ | 795.75 |
| . Portland Cement Concrete Pavement | $m^3$ | 1,196.70 |
| . Asphalt Concrete | ton | 751.50 |
| . Bituminous Concrete Surface Course | M.T. | 1,061.95 |
| . Aggregate Subbase | $m^3$ | 208.55 |
| . Crushed Aggregate Base Course | $m^3$ | 276.65 |
| . Mechanically Stabilized Base Course | $m^3$ | 334.36 |

TABLE 10.1-2 INITIAL CONSTRUCTION COST

| | PCC Pavement | | | AC Pavement | |
|---|---|---|---|---|---|
| Thickness | Including Shoulder (₱) | Excluding Shoulder (₱) | Structural Number | Including Shoulder (₱) | Excluding Shoulder (₱) |
| - | - | - | 1.3 | 1,382 | 1,188 |
| - | - | - | 1.7 | 1,784 | 1,465 |
| 13 cm 1/ | 1,747 | 1,444 | 2.1 | 2,250 | 1,909 |
| 15 cm 1/ | 1,934 | 1,614 | 2.5 | 2,550 | 2,125 |
| 18 cm 1/ | 2,215 | 1,871 | 3.0 | 3,096 | 2,610 |
| 20 cm | 2,402 | 2,042 | 3.0 | 3,096 | 2,610 |
| 23 cm | 2,683 | 2,298 | 3.5 | 3,558 | 2,947 |
| 25 cm | 2,870 | 2,552 | 3.5 | 3,588 | 2,947 |
| 28 cm | 3,152 | 2,724 | 4.0 | 3,960 | 3,265 |
| 30 cm | 3,339 | 2,895 | 4.0 | 3,960 | 3,265 |
| 33 cm | 3,620 | 3,151 | 4.5 | 4,446 | 3,647 |
| 35 cm | 3,807 | 3,321 | 4.5 | 4,446 | 3,647 |
| - | - | - | 5.0 | 5,559 | 4,739 |
| - | - | - | 5.5 | 6,065 | 5,120 |

NOTE: 1/ Not applicable because of minimum thickness required.

## Economic Types

The economic pavement type should not be determined based on the initial construction cost alone. It should be also evaluated based on the total discounted cost which include the initial construction cost, second and third rehabilitation costs, maintenance cost among others. However, only the initial constructions are discussed in case of new construction. The discussion on total discounted costs for rehabilitation methods mentioned in the following section can be referred.

The benefit evaluation derived from rehabilitation works may be excluded in economic type evaluation since traffic cost for any type of rehabilitation may not be so different providing that maintenance works will be performed to provide the reasonable road surface.

Figure 10.1-1 shows the thickness of PCC pavement and the structural number of AC required for CBR value of 8 under each traffic loading class and the corresponding initial construction cost of both pavement types.

This figure simply demonstrates that the PCC pavement is economical comparing with the AC pavement under all traffic loading classes. It is true for all values of CBR except less than 3 and higher than 20 which are very special subgrades.

## Minimum Thickness of PCC Slab

It is noted that there is a limitation on thickness of concrete slab from the engineering point of view.

AASHTO Guide 1986 recommends the minimum PCC slab thickness to be 5 inches (13 cm) to 7 inches (18 cm) for low volume roads depending on the quality of roadbed soil. Mean PCC modulus of rupture is 600 psi (42 $kg/cm^2$).

TRRL requires 15 cm for unreinforced concrete with 28 $MN/m^2$ (285.42 $kg/cm^2$) crushing strength.

JRA regulates the minimum thickness of 15 cm for concrete with 45 $kg/cm^2$ and 20 cm for 40 $kg/cm^2$.

Considering the flexural strength of concrete/of 580 psi (40$kg/cm^2$) at 28 days (525 psi at 14 days) (40 $kg/cm^2$) required in BPH Memo Circular, the study adopted 20 cm as the minimum slab thickness in this country.

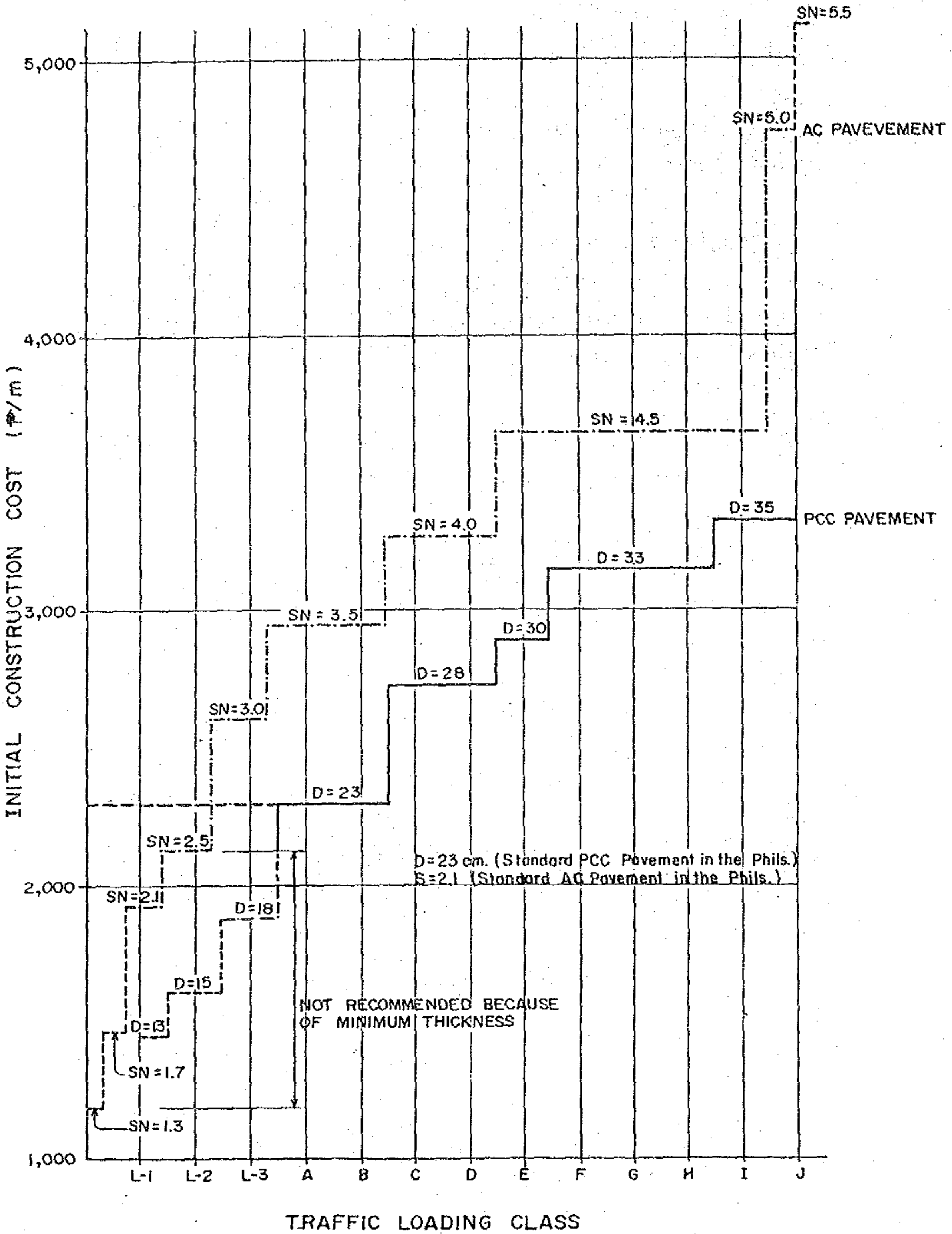



Figure 10.1-1 INITIAL CONSTRUCTION / (NEW CONSTRUCTION)
COST OF PCC AND AC PAVEMENTS
(CBR 8)

NOTE: D= Thickness of Slab (cm.)
SN= Structural Number
Cost in ₱ per meter with 6.7m in road width excluding shoulder.

### 10.1.2 Rehabilitation for Both Lanes

As pavement rehabilitation methods, the following five (5) are compared to analyze the most economical types according to traffic loading classes and CBR values. However, rigid overlay may not be recommended for implementation since this type has very limited experience in any country.

- PCC Reconstruction
- AC Reconstruction
- Flexible (AC) Overlay - Rigid Existing
- Rigid (PCC) Overlay - Rigid Existing
- Flexible (AC) Overlay - Flexible Existing

The analysis was made using the outputs of the basic structure design which includes initial construction costs and total discounted costs, among others. Refer to Appendix 16.3 of Volume II.

(1) Economic Pavement Types by Traffic Loading Classes

As representative example of computer analysis, Figure 10.1-2 and 10.1-3 demostrate the initial construction costs of the initial pavement structures and the total discounted cost including maintenance costs, respectively. These figures show all cases of traffic loading, but only for CBR values of 4, 6 and 8.

These two figures summarize that when both lanes are planned to be reconstructed/overlaid, AC Overlay (rigid existing) is the most economical type, follow by PCC Reconstruction and AC Reconstruction. PCC Overlay (rigid existing) is only showed in figure for the purpose of reference.

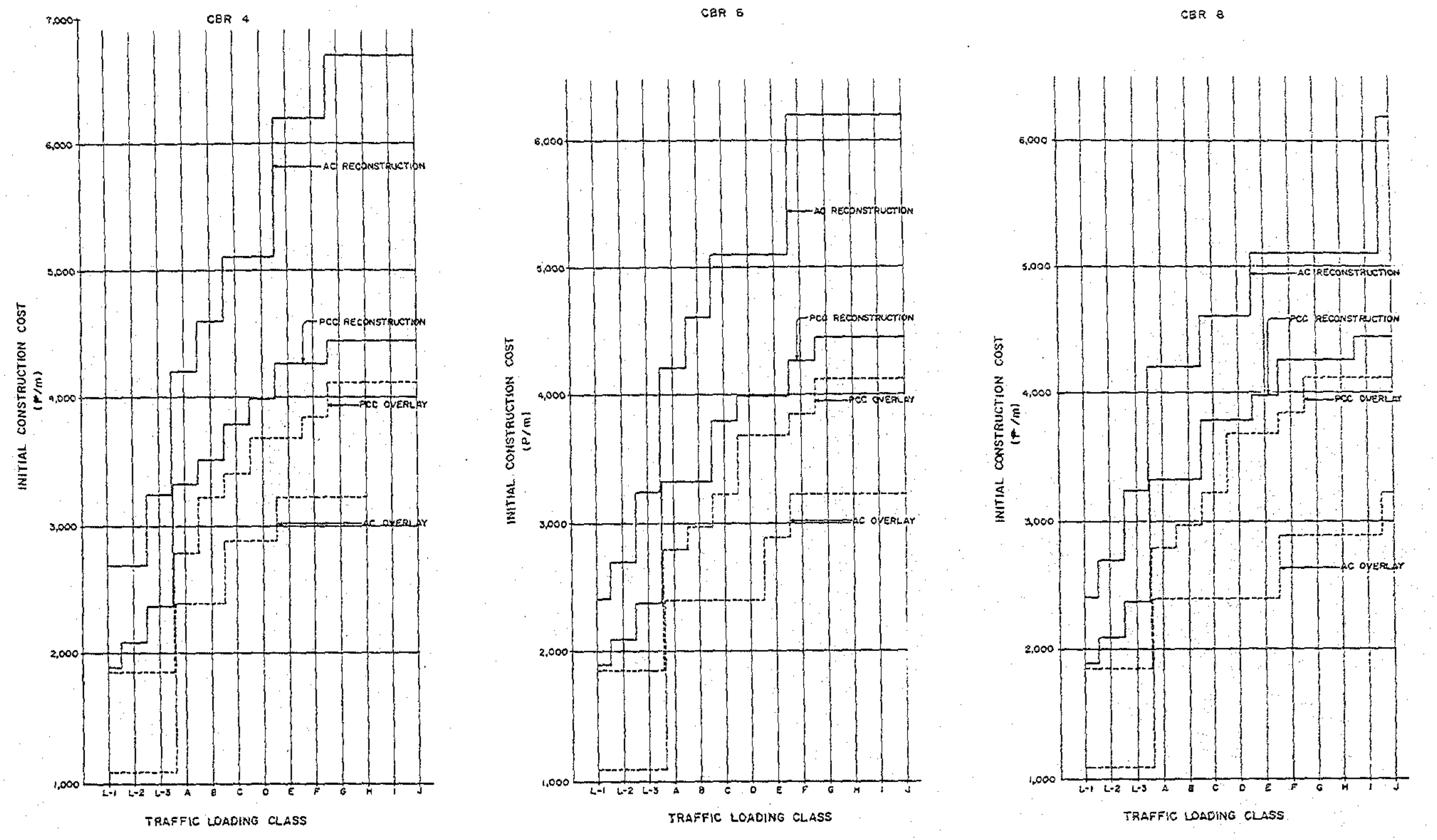



Figure 10.1-2 INITIAL CONSTRUCTION COST VS. TRAFFIC LOADING CLASS

Note : 1) Construction Cost for Reconstruction/Overlay of both lanes

2) Cost in ₱ per meter with 6.7 m. in road width

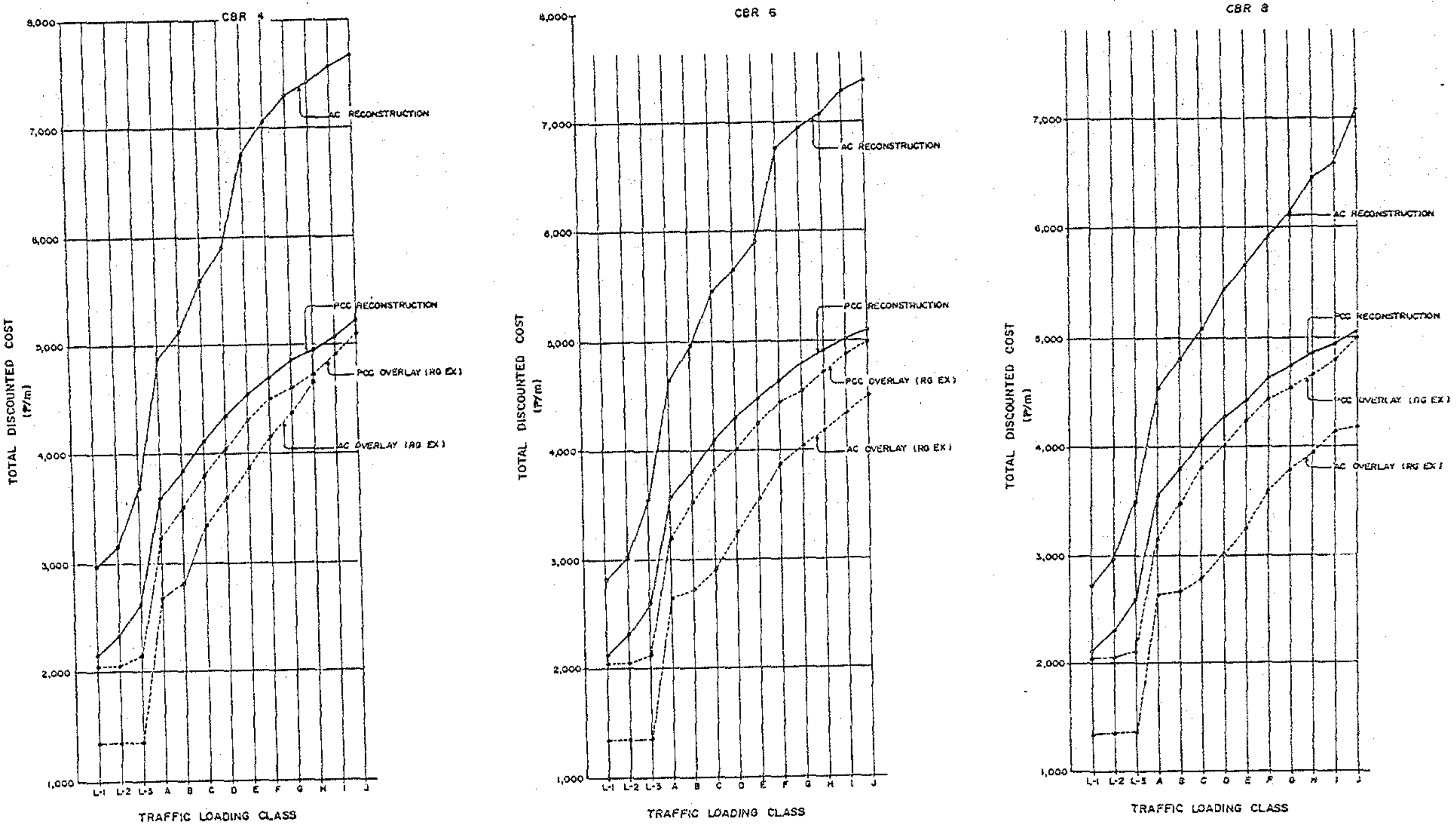



Figure 10.1-3 TOTAL DISCOUNTED COST VS. TRAFFIC LOADING CLASS

Note : 1) Discounted Cost for *Reconstruction / Overlay* of both lanes
2) Cost in ₱ per meter with 6.7 m. in Road width

The representative comparisons are shown in Table 10.1-3 for the cases of Traffic Loading Classes C and G under CBR value of 6.

TABLE 10.1-3 COST COMPARISON BETWEEN PAVEMENT TYPES

| Initial Construction Cost (₱/both lanes,m) CBR=6 | | | | |
|---|---|---|---|---|
| Traffic Loading Class | C | | H | |
| AC Overlay | 2,394 | (1.00) | 3,232 | (1.00) |
| PCC Reconstruction | 3,798 | (1.59) | 4,454 | (1.38) |
| AC Reconstruction | 5,112 | (2.14) | 6,204 | (1.92) |
| Total Discounted Cost (₱/both lanes, m) CBR=6 | | | | |
| AC Overlay | 2,907 | (1.00) | 4,183 | (1.00) |
| PCC Reconstruction | 4,094 | (1.41) | 4,925 | (1.10) |
| AC Reconstruction | 5,468 | (1.88) | 7,094 | (1.70) |

(2) Economic Pavement Types CBR

The initial construction costs and total discounted cost for each CBR value under the traffic loading classes of B, E and I are shown in Figure 10.1-4 and 10.1-5 respectively.

Regardless of CBR values, AC overlay is still the most economical type, followed by PCC Reconstruction and AC Reconstruction. Only exception is the initial construction cost for the case that CBR values are more than 15 and traffic loading classes are heavier than E.

It is concluded that when the both lanes are planned to be rehabilitated, AC Overlay is recommended as the most economical method, followed by PCC Reconstruction and AC Reconstruction in order. Only for the case, CBR values are more than 20, AC reconstruction may be slightly economical comparing with PCC reconstruction.

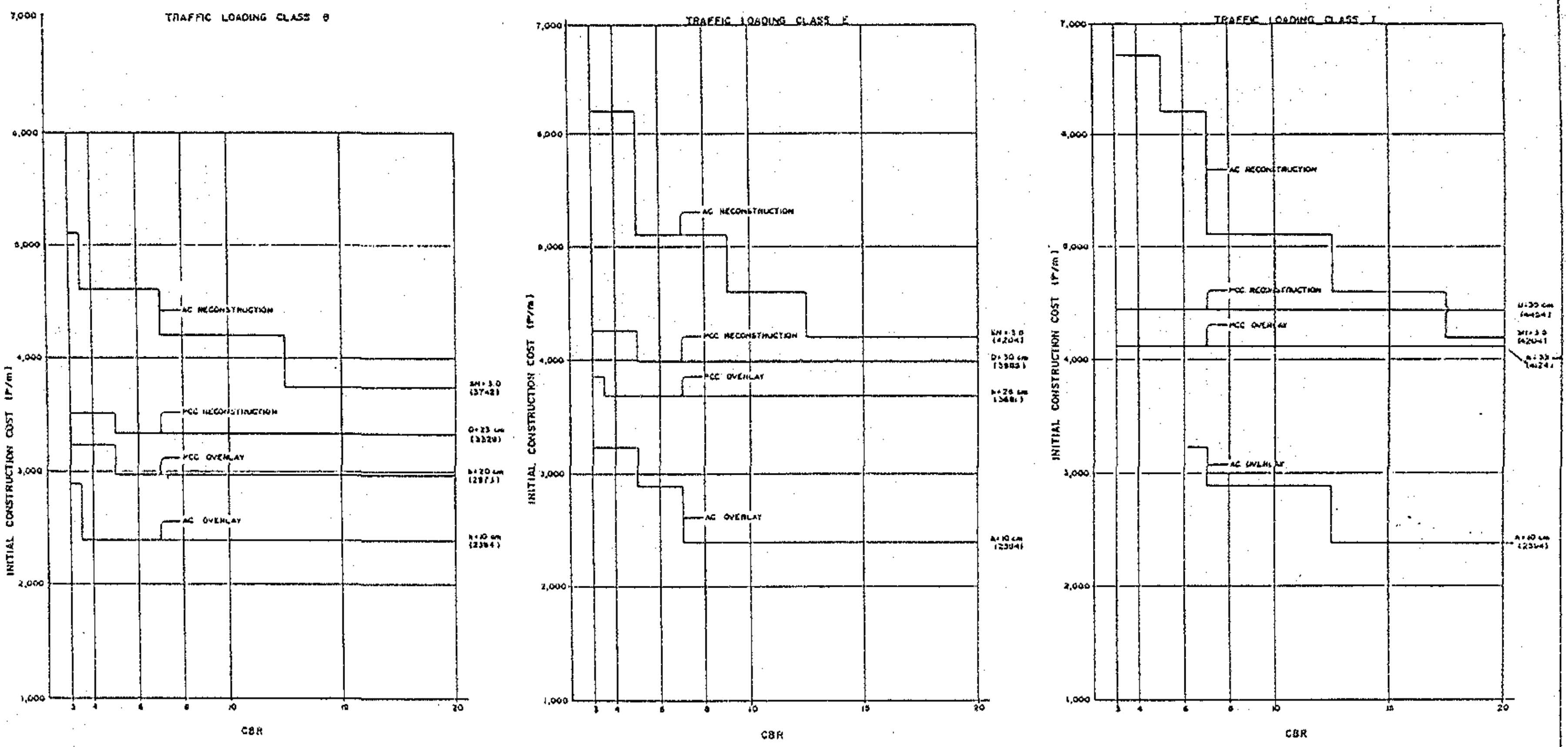



Figure 10.1-4 INITIAL CONSTRUCTION COST VS. CBR
Note : 1) Construction Cost for Reconstruction / Overlay of both lanes
2) Cost in 'P' per meter with 6.7 m. in width

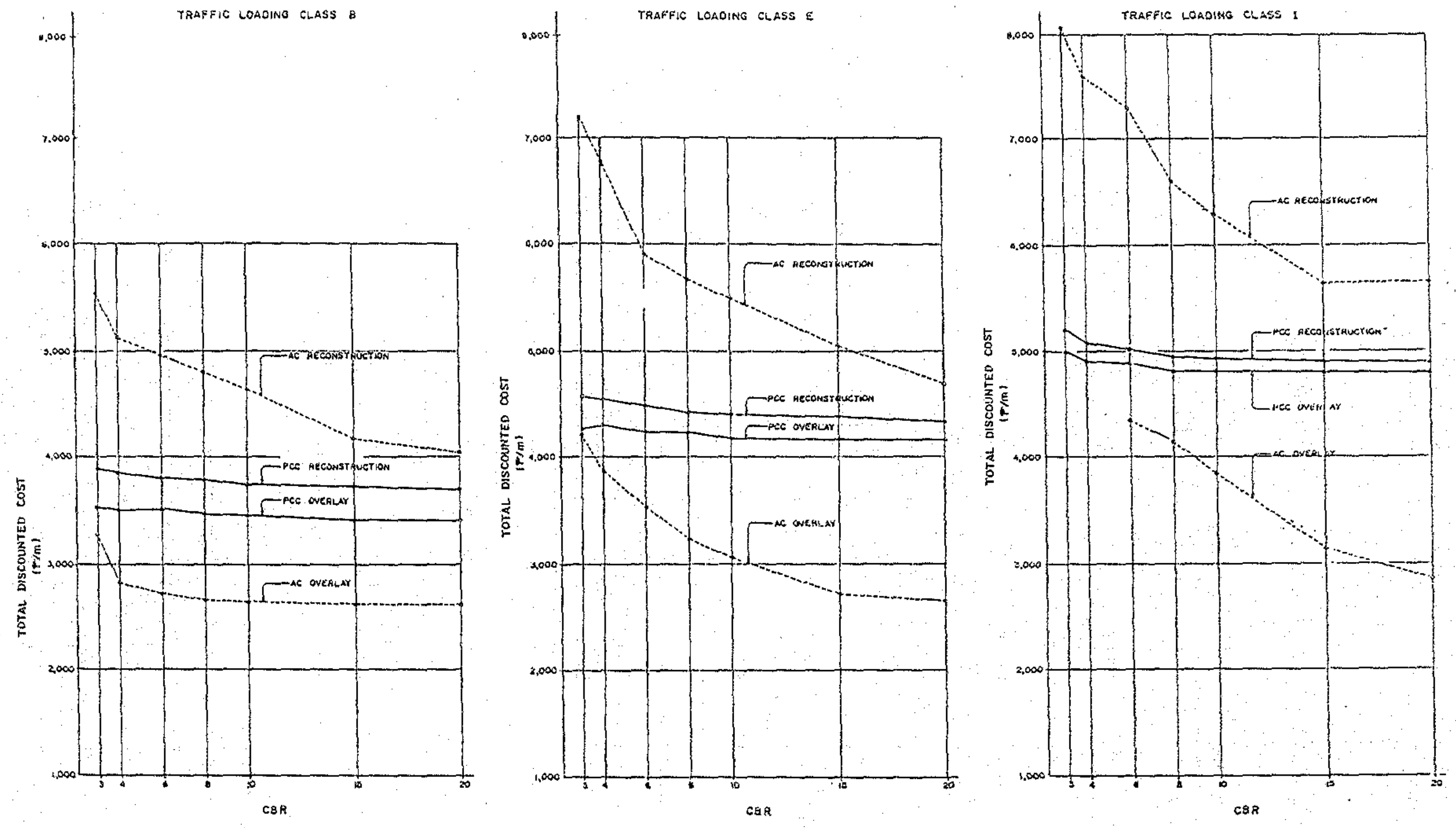



Figure 10.1–5 TOTAL DISCOUNTED COST VS. CBR
Note : 1) Discounted Cost for Reconstruction/Overlay of both lanes
2) Cost in ₱ per meter with 6.7 m. in Road width

### 10.1.3 PCC Reconstruction (One-Lane) and AC Overlay (Two-Lanes)

(1) Assumed Conditions for Comparative Study

It was remarkably observed during the field investigation that the concrete pavements of Manila bound of North Study Sections are seriously deteriorated, but the opposite lane are not so much. This fact can be proved by the weight of vehicles and axle loads.

The many sections of Manila bound require the urgent rehabilitation at present, while the rehabilitation for the opposite lane may be deffered depending on its remaining life of the existing pavement structures predicted.

As the rehabilitation methods for this case, the following two alternatives were proposed.

Method 1; PCC Reconstruction of One-Lane deteriorated

The opposite lane which does not require the rehabilitation at present will be rehabilitated by PCC reconstruction after XP years when the pavement condition will reach to RRI less than 2.5.

Method 2; AC Overlay of Both Lanes

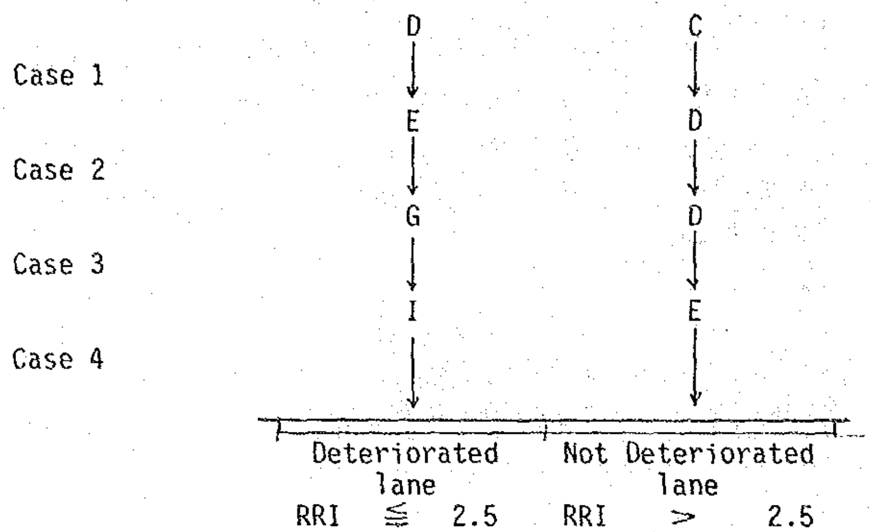
The minimum thickness of AC overlay is 10 cm so that both lanes may be overlaid at present because of the tapering of overlaid asphalt concrete.

In order to evaluate both methods, a comparative study was done using an electric computer. The output are presented in Appendix 17-1 of Volume II.

The pavement conditions assumed for the comparative study are the following three cases as shown in Figure 10.1-6

Figure 10.1-6 Assumed Conditions for Comparative Study

(TRAFFIC LOADING CLASSES)




(2) Comparison on Initial Costs

Since the initial cost of Method I is almost half of two lanes PCC reconstruction, PCC reconstruction of one lane is economical, about 80% of two lanes AC overlay for traffic loading classes less than E, but almost same for more than F.

(3) Comparison on Total Discounted Costs

The total discounted costs for two methods were calculated including the initial cost, the second and third reconstruction/overlays and the maintenance cost for the analysis period of 25 years. The remaining life of the not-deteriorated lane is expressed with XP which is the year that the lane will be deteriorated and rehabilitation will be undertaken.

The output of the analysis are reported in Appendix 17-1 of Volume II, so as Figure 10.1-7 shows an example of the initial construction costs while Figure 10.1-8 presents the total discounted costs for CBR values of 6.

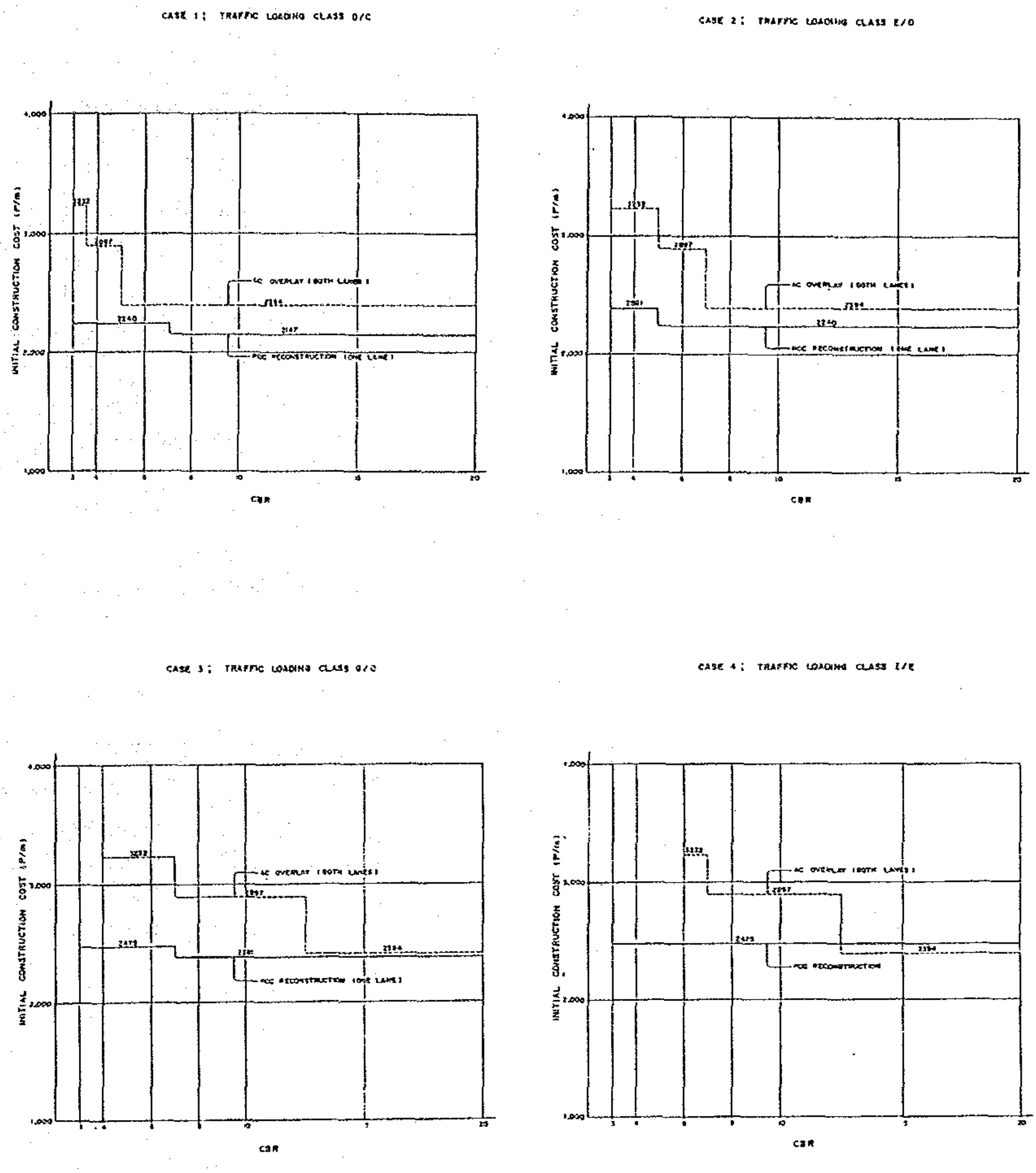



Figure 10.1-7 INITIAL CONSTRUCTION COST OF AC OVERLAY (Both Lanes) AND PCC RECONSTRUCTION (One Lane)

NOTE: COST = P/m

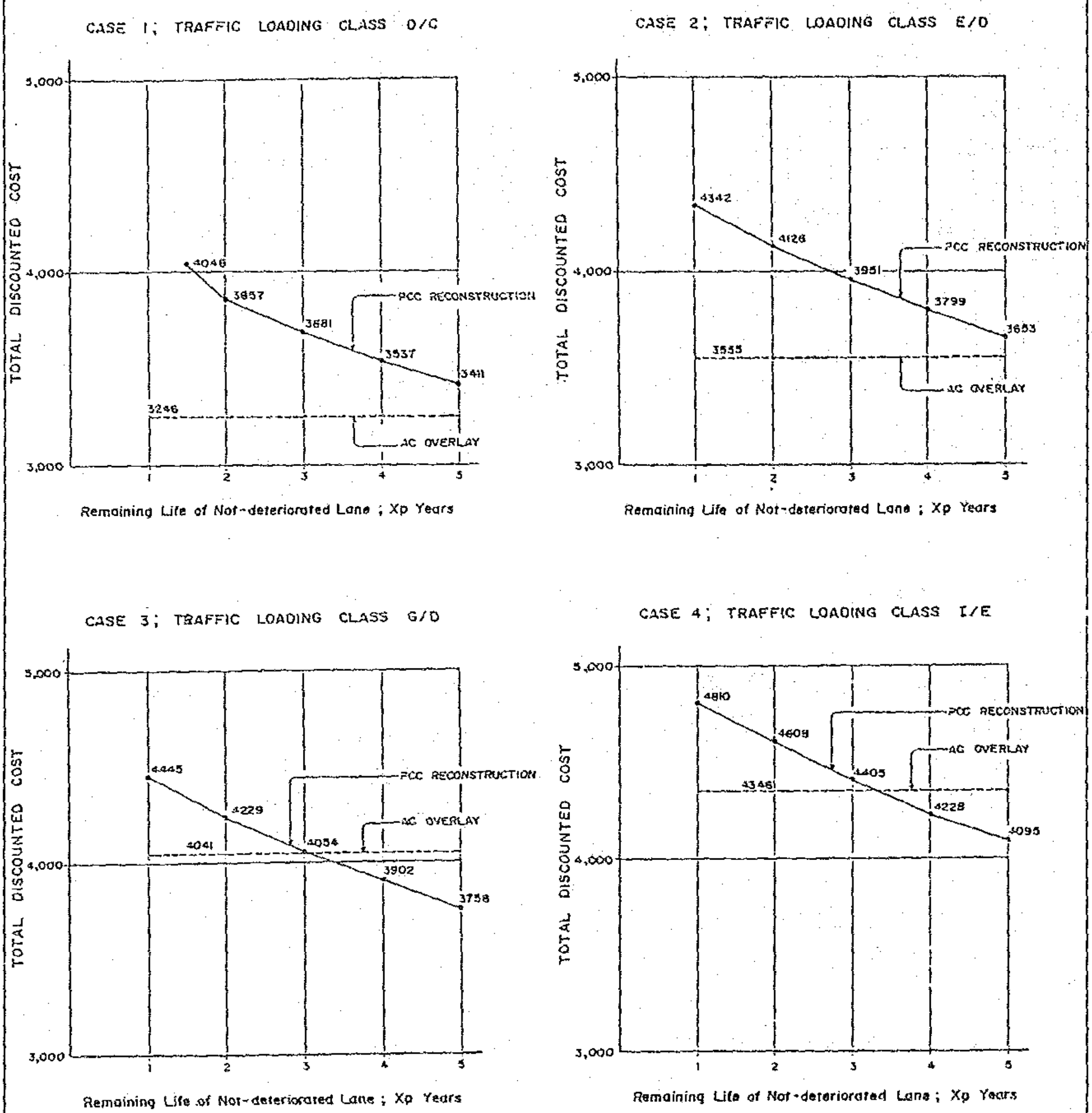



Figure 10.1-8 PCC RECONSTRUCTION AND AC OVERLAY
CBR 6

Note: 1) Discounted Cost for Reconstruction / Overlay of Both Lanes
2) Cost in ₱ per meter with 6.7m in Road Width

According to the output of comparative analysis, the economic pavement type of two method depends on CBR values, traffic loading classes and remaining life of pavement of not-deteriorated lane. The observation are summarized in Table 10.1-4

TABLE 10.1-4 COMPARISON ON PCC RECONSTRUCTION (ONE-LANE) AND AC OVERLAY (TWO-LANES)

| CBR Value | Traffic Loading Class | Remaining Life XP | Economic Pavement Type |
|---|---|---|---|
| Less Than 4 | All Cases | All Cases | PCC Reconstruction (One-Lane) |
| 6 | More than F | More than 4 years | PCC Reconstruction (One-Lane) |
| | | Less than 3 years | AC Overlay (Two-Lanes) |
| | Less than E | All Cases | AC Overlay (Two-Lanes) |
| More than 8 | All Cases | All Cases | AC Overlay (Two-Lanes) |

## 10.1.4 Conventional Discussion on Economic Pavement Types in the Philippines

It is widely said in this country that the concrete pavement is permanent structure but costly type, and the asphalt concrete pavement is temporary but cheap.

This conventional opinion on pavement type may be explained by the following observations.

Standard Pavement Structures in the Philippines

As shown in figure 12.2-1, standard types of pavement in the Philippines are established. Table 10.1-5 shows the structural components of standard pavement for major highways and their costs. AC pavement with the structural number 3.5 which is analyzed to have almost same structural capacity with PCC slab of 23 cm thickness is also shown for the comparison.

When comparing the costs of standard sections of PCC and AC pavements, AC is of course cheaper type than PCC. However, in comparing with both pavements which should have the same capacity, PCC might be more economical than AC types.

Performance Period of Standard Pavement Structures in the Philippines

The performance period of the standard pavement structures in the Philippines were analyzed for the average traffic laoding for major highways, as shown in Table 10.1-6.

Traffic loading class C means the number of ESAL's application less than $0.4 \times 10^6$ during the performance period and D less than $0.7 \times 10^6$. For these classes of traffic loading, the standard AC pavement may have considerably short performance period less than 2.2 years and PC may have a little short of less than 8.6 years.

TABLE 10.1-5 STANDARD PAVEMENT STRUCTURES IN THE PHILIPPINES AND COSTS

Unit: ₱ per M of 2 lanes excluding shoulder

| Standard PCC Pavement | Thickness | Cost |
|---|---|---|
| PCC Slab | 23 | 1844.1 |
| Aggregate Base | 15 | 278.1 |
| Aggregate Subbase | 0 - 20 | 0-279.4 |
| T O T A L | 38 - 58 | 2122.2-2401.6 |

| Standard AC Pavement | | |
|---|---|---|
| Bituminous Asphalt | 5 - 7.6 | 840.8 -1270.1 |
| Aggregate Base | 20 | 370.7 |
| Aggregate Subbase | 20 - 30 | 279.5 - 419.2 |
| T O T A L | 45 1/ - 57.6 2/ cm | 1491.0 -2060.0 |

| AC Pavement with SN = 3.5 (comparable with PCC 23cm) | | |
|---|---|---|
| Bituminous Asphalt | 10 | 1681.6 |
| Aggregate Base | 30 | 556.0 |
| Aggregate Subbase | 30 | 419.2 |
| T O T A L | 70 cm. | 2656.8 |

NOTE: 1/ Total Thickness 45 cm. = Structural Number 2.1

2/ Total Thickness 57.6cm = Structural Number 2.8

TABLE 10.1-6 PERFORMANCE PERIODS OF STANDARD PAVEMENT STRUCTURES IN THE PHILIPPINES

CBR value of 8

| | | Traffic Loading Class C | Traffic Loading Class D |
|---|---|---|---|
| PCC | Thickness 23 cm | 8.6 years | 5.3 years |
| AC | SN = 2.1 1/ | less than 1 year | less than 1 year |
| AC | SN = 2.8 1/ | 2.2 years | 1.3 years |
| AC | SN = 3.5 2/ | 7.3 years | 4.4 years |

NOTE: 1/ Structural Number of Standard AC Pavement in the Philippines

2/ Structural Number of AC Pavement comparable with PCC Thickness 23 cm slab.

## 10.2 Engineering Considerations

As discussed in Chapter 9, AC overlay, One-lane PCC Reconstruction and Two-lane PCC Reconstruction are recommended as the pavement rehabilitation methods. Among the three AC overlay is the most economical followed by-one-lance PCC and Two-lane PCC reconstruction.

However, selection of pavement rehabilitation methods is a very complex engineering problem. There is no infalliable method even for selecting the most prefered alternatives. Rather the selection process requires considerable engineering judgement, creativity and flexibility.

Decision factors when choosing the prefered solution involve the following, among others.

Technical Considerations

- Existing pavement condition
- Types, severity and extents of pavement distress

Monetary Considerations

- Initial Cost
- Total discounted cost based on life-cycle cost analysis

Non-Monetary Considerations

- Service life
- Duration of construction
- Traffic control problems
- Reliability
- Constructibility
- Maintenability

Monetary and Non-Monetary Considerations are discussed in the previous Chapter. Detailed with in this section is the judgement on applicability of AC overlay.

(1) Criteria based on Observation on Pavement Condition

Rehabilitation for restoration/strengthening of structural capacity is divided into two major categories; reconstruction and overlay. While reconstruction does not involve any technical problem in its application provided that it is properly constructed, overlay should be investigated on its applicability. Roadbed and subsurface drainage conditions are major factors to be considered in investigating the applicability of overlay. Final judgement shall be based on detailed pavement condition data.

In the absence of such detailed data, the following criteria may be adopted to determine if overlay rehabilitation can be applied or not.

<u>Conditions/Pavement distress on which overlay can be applied.</u>

Distress primarily caused by traffic and by concrete slab material are considered in this group, as follows:

- Blow-up (Infiltration of the compressive materials)
- Corner Break
- Faulting of Transverse Joints and Cracks
- Joint Seal Damage of Transverse Joint
- Longitudinal Cracks (only those of cracks caused by traffic loading or poor slab materials)
- Longitudinal Joint Faulting
- Popouts
- Reactive Aggregate Distress
- Sealing and Map Cracking or Crazing (Line Cracks on upper surface slab)
- Spalling (Transverse and Longitudinal Joint/Cracks) (only those cracking, breaking or shipping of slab edge caused by infiltration of incompressible materials)

- Transverse and Diagonal Cracks
- (only low to medium severity level of cracks)
- Peeling (Removal of Surface)
- Pathole
- RRI more than 2 without evidence of distress mentioned below
- Preferable minimum length of overlay section is more than 500 m.

<u>Conditions /Pavement Distress on which overlay may be hardly applied</u>.

Distress primarily caused by subgrade/subbase materials and drainage are considered in this group, as follows:

- Heavy depression (localized settlement area) in one slab. (caused by settlement or consolidating of subgrade/subbase)
- Lane/shoulder Drop-off (suspicious to settlement or consolidation of subgrade/subbase)
- Pumping and Water Bleeding (suspicious to voids causing loss of support)
- Block Cracking (Random Crack, Third Stage Cracks) (Multiple irregular breaks or the separation of slab) caused by localized break subgrade/subbase)
- Slab Rocking (suspicious to bearing capacity and uneven settlement)
- Subgrade with CBR values less than 6 (because of short performance period less than 5 years especially, for loading classes heavier than F.)
- RRI less than 1.5
- No remarkable difference in elevation between fragments in one slab
- Bad drainage conditions

It is, however, noted that if deficiencies mentioned above will be improved/removed, the overlay may be applied.

(2) Criteria based on Craking Index and Deflection

Japan Road Association proposes the rehabilitation criteria for reinforced concrete pavement based on cracking index and deflection measured by Benkelman Test. See Figure 10.2-1.

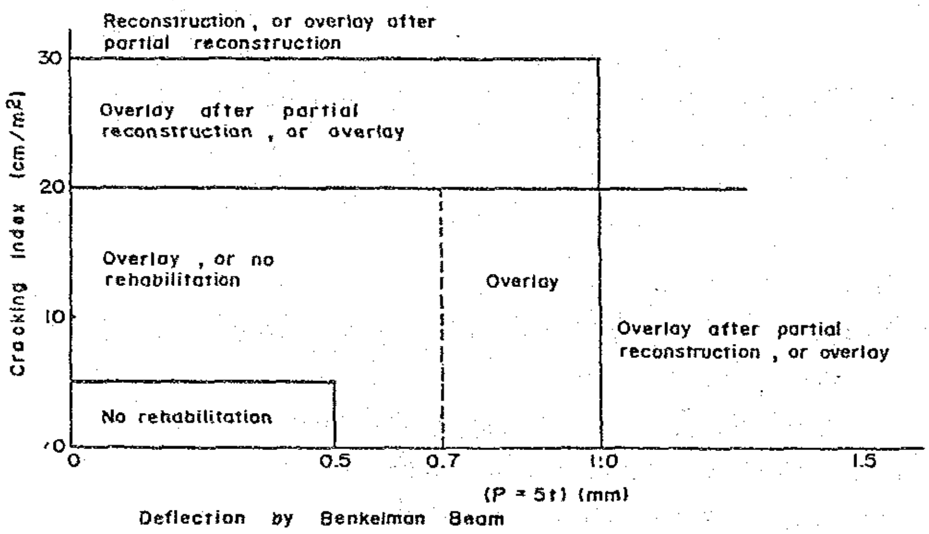



Figure 10.2-1 Criteria for Selection of Rehabilitation Method Recommended by Japan Road Association

## 10.3 Recommended Structural Capacities

(1) Recommended Pavement Types

New Construction

- PCC Pavement
- AC Pavement

Rehabilitation

- 1-Lane PCC Reconstruction
- 2-Lane PCC Reconstruction
- 2-Lane AC Overlay (PCC Existing)

2-lane AC reconstruction was not recommended for PCC pavement rehabilitation because of cost and constructibility as well as maintainability.

Rigid overlay-rigid existing was not also proposed because of limited experiments. But, test works for this types of overlays may be recommended wherever applicable.

AC overlay-AC existing could not be studied because the Study road are all concrete pavements

(2) Recommended Pavement Structural Capacities

Table 10.3-1 summarizes the recommended pavement structural capacities according to traffic loading classes and CBR values. The structural capacities recommended in this table do not necessarily tally with the output of basic structural design because of the following reasons.

For PCC new/reconstruction pavements, the minimum thickness of 20 cm is recommended even for light traffic loading class because of the concrete strength required in the specification and probable construction error.

And, for the extra heavy traffic loading, the thickness of PCC slab should be decided upon the consideration on policy of traffic regulation implementation and performance period of initial pavement structures. It is noted that the PCC pavements with 30 cm thickness will last for 15 to 20 years, if traffic regulation will be implemented.

For AC pavements, the structural numbers for light traffic loading by basic structural design are reduced by about 0.5 considering the performance periods of initial pavement structures. As to the extra heavy traffic loading, the structural number of 4.5, 5.0 or 5.5 should be selected with the consideration mentioned above.

As to AC overlay-rigid existing, the minimum thickness of 10 cm AC overlay is recommended considering reflective cracking as previously mentioned. Special caution should be paid to 5 cm AC overlay for light traffic loading. This 5 cm overlay has a limited experiments, therefore, the performance may not be warranted.

And, for extra heavy traffic loading, the same comments made for PCC pavement may be made.

(3) Cost Comparison on PCC and AC Pavements

Figure 10.3-1 shows the recommended structural capacities and initial construction costs of PCC and AC pavements for CBR value of 8. See Figure 10.3-2.

As far as the initial construction costs, AC pavement is economical for the traffic loading classes of L-1 and L-2, and expensive for more than A. For L-3, the difference is very marginal.

It is highly noted that the costs used in the Guide are November 1986 prices nearside Metro Manila, therefore, the costs should be adjusted in different localities and construction conditions.

### PCC New / Reconstruction

PCC THICKNESS

| TRAFFIC LOADING CLASS (XIO⁶) \ CBR | | 2 | 3 | 4 | 6 | 8 | 10 | 15 | 20 | PERFORMANCE PERIOD |
|---|---|---|---|---|---|---|---|---|---|---|
| LIGHT TRAFFIC LOADING | L-1 (0.005) | | | | | | | | | MORE THAN 25 YEARS |
| | L-2 (0.01) | APPLY MIN. THICKNESS 20cm | | | | | | | | |
| | L-3 (0.03) | | | | | | | | | |
| HEAVY TRAFFIC LOADING | A (0.1) | | | | 23 | | | | | 15 YEARS |
| | B (0.2) | 25 | | | | | | | | |
| | C (0.4) | 28 | | | 25 | | | | | |
| | D (0.7) | | | | 28 | | | | | |
| | E (1.0) | 30 | | | | | | | | |
| EXTRA HEAVY TRAFFIC LOADING | F-J (1.5 ~ 3.5) | 30 OR 33 OR 35 1/ | | | | | | | | 5~12 YEARS |

### AC NEW/RECONSTRUCTION

STRUCTURAL NUMBER

| TRAFFIC LOADING CLASS (XIO⁶) \ CBR | | 2 | 3 | 4 | 6 | 8 | 10 | 15 | 20 | PERFORMANCE PERIOD |
|---|---|---|---|---|---|---|---|---|---|---|
| LIGHT TRAFFIC LOADING | L-1 (0.005) | 2.1 | | 1.7 | | | | 1.7 | | 10~16 YEARS |
| | L-2 (0.01) | 2.5 | | 2.1 | | | | | | |
| | L-3 (0.03) | 3.0 | | 2.5 | | | | 2.1 | | |
| HEAVY TRAFFIC LOADING | A (0.1 | 4.0 | | 3.5 | | 3.0 | | 2.5 | | 8~14 YEARS |
| | B (0.2 | 4.5 | | 4.0 | | 3.5 | | 3.0 | | |
| | C (0.4) | 5.0 | | 4.5 | | 4.0 | | | | |
| | D (0.7) | | | | | | | 3.5 | | |
| | E (1.0) | | | 5.0 | | 4.5 | | | | |
| EXTRA-HEAVY TRAFFIC LOADING | F-J (1.5 3.5) | 4.0 OR 5.0 OR 5.5 1/ | | | | | | | | 5 ~ 8 YEARS |

### AC OVERLAY-PCC EXISTING

OVERLAY THICKNESS (cm)

| TRAFFIC LOADING CLASS (XIO⁶) \ CBR | | 2 | 3 | 4 | 6 | 8 | 10 | 15 | 20 | PERFORMANCE PERIOD |
|---|---|---|---|---|---|---|---|---|---|---|
| LIGHT TRAFFIC LOADING | L-1~L-3 (0.005 ~ 0.03) | | | | APPLY MINIMUM THICKNESS 5cm. 2/ | | | | | MORE THAN 30 YEARS |
| HEAVY TRAFFIC LOADING | A (0.1) | | | | | | | | | 12~30 YEARS |
| | B (0.2) | NOT | | | | | | | | |
| | C' (0.4) | RECOMMENDED | | | APPLY MIN.THICKNESS | | | | | |
| | D (0.7) | | | | 10cm. | | | | | |
| | E (1.0) | | | | | | | | | |
| EXTRA-HEAVY TRAFFIC LOADING | F-J (1.5) (3.5) | | | | 15 | 13 | | 10 | | 5~12 YEARS |

NOTE : 1/ DECIDED FROM THE TRAFFIC REGULATION IMPLEMENTATION AND ENGINEERING AND ECONOMIC CONSIDERATIONS

2/ NO WARRANT ON PERFORMANCE DUE TO LIMITED EXPERIMENTS

FIGURE 10.3-1 RECOMMENDED STRUCTURAL CAPACITY

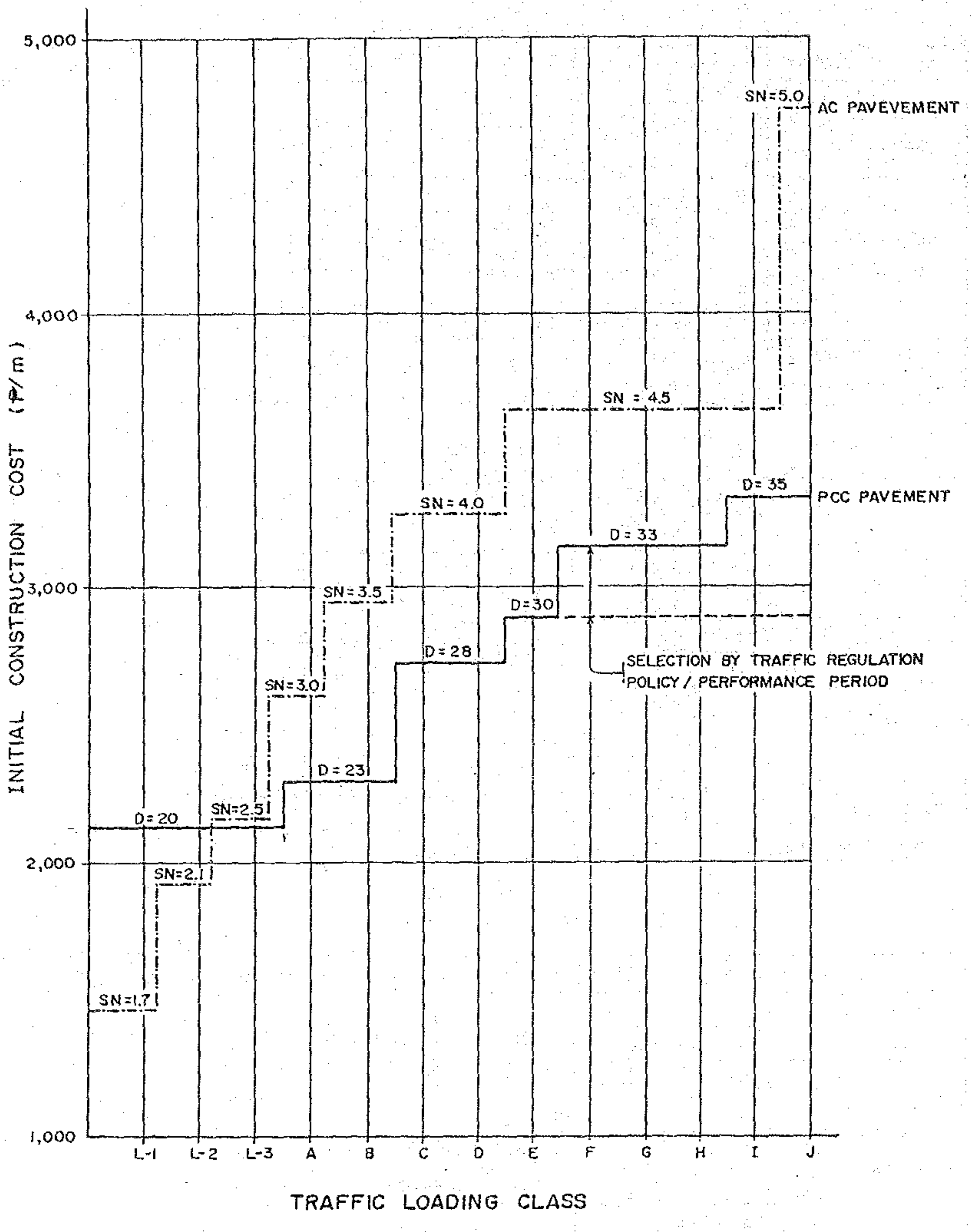



Figure 10.3-2 INITIAL CONSTRUCTION / (NEW CONSTRUCTION) COST OF PCC AND AC PAVEMENTS (CBR 8)

NOTE : D = Thickness of Slab (cm.)
SN = Structural Number
Cost in ₱ per meter with 6.7m in road width excluding shoulder.

# CHAPTER 11

# WEAK SUBGRADE IMPROVEMENT DESIGN

## CHAPTER 11
## 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 include soft soil composed of 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.

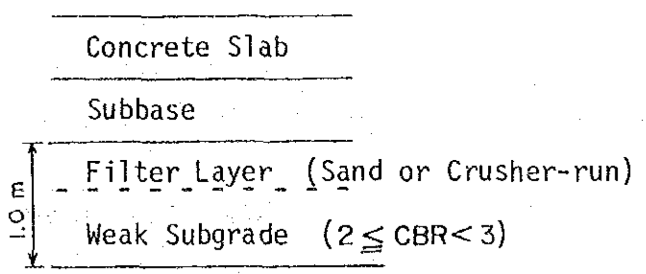
In concrete pavement design, the provision of filter layer is recommended where CBR values are equal or higher than 2 but less than 3. Where CBR values are less than 2, the application of methods mentioned above are recommended.

### 11.1 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 11.1 - 1 FILTER-LAYER

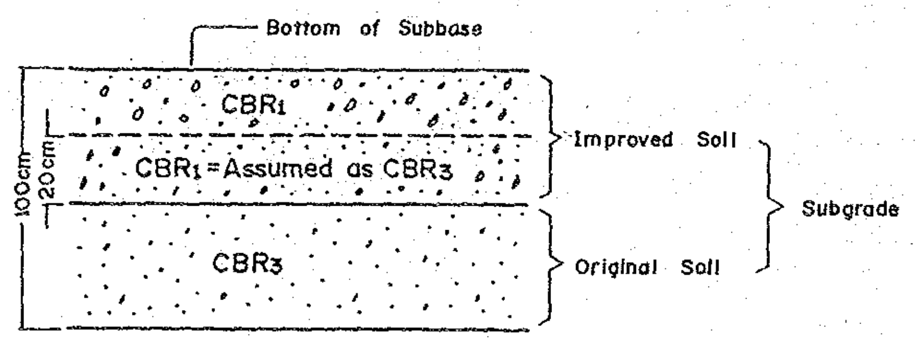


## 11.2 Soil Replacement Method

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 11.2-1 Average CBR




$$\text{Average CBR} = \left[ \sum_{i=1}^{n} \frac{h_i \cdot CBR_i^{1/3}}{100} \right]^3$$

Where;

$h_i$; Thickness of $i$ layer (cm)

$\Sigma h_i = 100$ cm

$CBR_i$; 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.

## 11.3 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 11.3-1.

## TABLE 11.3-1 CHARACTERISTICS AND STABILIZATION EFFECT OF ROADBED SOIL

APPLICABILITY TO SUBGRADE: X Unadvisable; △ Sometimes unadvisable

STABILIZATION EFFECT: ◎ Always effective; o Mostly effective; △ Sometimes effective

| SOIL CLASSIFICATION | | | APPLICABILITY TO SUBGRADE | | | | STABILIZATION EFFECT | | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | STRENGTH (CBR) | TRAFFICA-BILITY | PI | SURFACE STABILITY | STABILIZER CEMENT | STABILIZER SLACKED LIME | STABILIZER 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

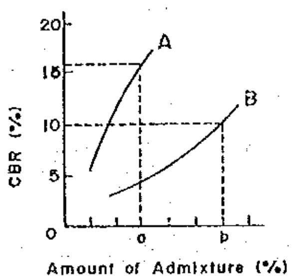
Mix design for soil stabilization is conducted in the following process.

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 11.3-1, 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.

Fig. 11.3-1 Relation between Amount of Admixture and CBR Value

Average CBR

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.

## 11.4 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 $kg/m^3$, and for cement stabilized soil, it is determined based on test mixture to attain a target unconfined compressive strength of 30 to 50 $kg/cm^2$.

Figure 11.4-1shows the example of sandwich method.

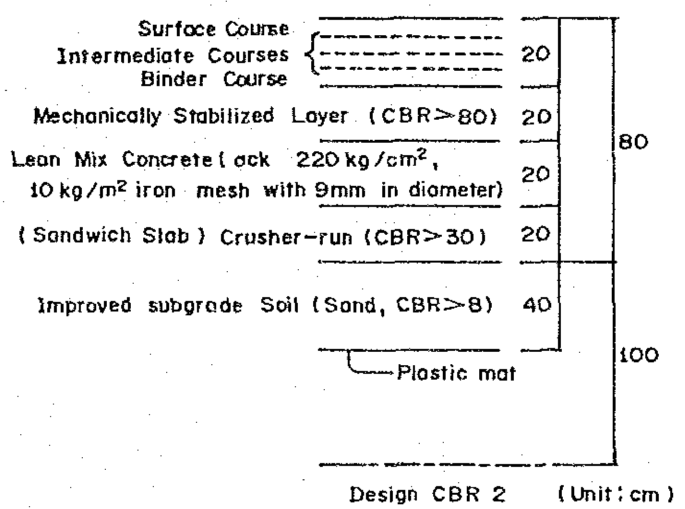



Figure 11.4-1 Example of Pavement Design Applying Sandwich Method for Subgrade Construction

# CHAPTER 12

# PAVEMENT SUBSURFACE DRAINAGE DESIGN

# CHAPTER 12

# PAVEMENT SUBSURFACE DRAINAGE DESIGN

## 12.1 General

### (1) 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 consists of three methods as summarized in Table 12.1-1. To obtain adequate pavement drainage, the provision of three types of drainage systems 1) surface drainage, 2) groundwater (sub-surface) drainage, and 3) structural drainage should be considered. In this Chapter, however, discussed is only subsurface drainage system including for new construction and rehabilitation.

The chapter is the extract from the following Guide/Text.

- AASHTO Guide for Design of Pavement Structures 1986 AASHTO
- Pavement Subsurface Drainage Systems
  National Cooperative Highway Research Program
  Synthesis of Highway Practice 6
  Transport Research Board , November 1982

TABLE 12.1-1 METHODS FOR TREATING WATER IN PAVEMENTS

| | |
|---|---|
| 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)

(2) Effects of Water

Water is always present in soil and granular pavement material in some form, but the forms that concern the pavement design are free water, capillary water, bound moisture and water vapor.

There are many sources of the water that reaches the pavement structure and its immediate vicinity. The most abundant and often overlooked source is undoubtedly atmospheric precipitation, by which surface water is supplied from rain.

This water reaches the pavement structural in several ways;

- Cracks in the pavement surface
- Infiltration through the shoulders
- Infiltration from the side ditches
- Free water from pavement base (Source of free water for the subbase and the subgrade)
- High groundwater table

Free water in the base, subbase, and subgrade is of particular concern because it can decrease the pavement strength in the following ways;

- Reducing the apparent cohesion by lowering the capillary forces
- Reducing the friction by reducing the effective mass of materials below the water table
- For quickly applied loads, possibly reducing the strength by the development of increased and/or oscilating pore pressure

(3) Movement of Water

Water and moisture move through soils in response to an energy gradient. This gradient may be supplied by elevation (force of gravity), capillary forces, osmotic forces, and temperature or pressure difference.

1) Saturation Flow

Saturation flow in soil involves the movement of free water using a hydraulic gradient (head) supplied by elevation. The equation generally used for the computation of the flow of water through soils is based on experiments by Darcy and is called Darcy's Law.

$$Q = (K.i)\ A = Vd \cdot A$$

Where:

$Q$ = quantity of flow ($cm^3/s$)

$K$ = coefficient of permeability (hydraulic conductivity) (cm/s)

$i$ = hydraulic gradient (cm/cm)

$A$ = cross sectional area normal to the direction of flow ($cm^2$)

2) Unsaturated Flow

Unsaturated flow includes flow caused by energy gradients supplied by capillary forces, temperature differences, and osmotic pressure. The flow of water is due to the total energy gradient. By including the energy gradient caused by capillary forces, Darcy's law, originally for saturated flow only, can be extended for use in unsaturated flow conditions as follows;

$$q = Ku \left( \frac{\Delta h}{\Delta l} + \frac{\Delta hc}{\Delta l} \right)$$

Where:

$q$ = unit rate of flow (cm/s)

= unsaturated permeability (cm/s)

$\frac{\Delta h}{\Delta l}$ = energy gradient due to the change in elevation head, (cm/cm)

$\frac{\Delta hc}{\Delta l}$ = energy gradient due to the change in capillary forces (cm/c,)

## 12.2 Pavement Subsurface Drainage Design

Design process of pavement subsurface drainage system are illustrated in Figure12.2-1.

### 12.2.1 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 coarse 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)

An inflow-outflow criterion where 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)

Design infiltration = 1 hr. duration/1 yr. frequency x $\partial$

$\partial$ = 0.5~0.67 (PCC pavement)

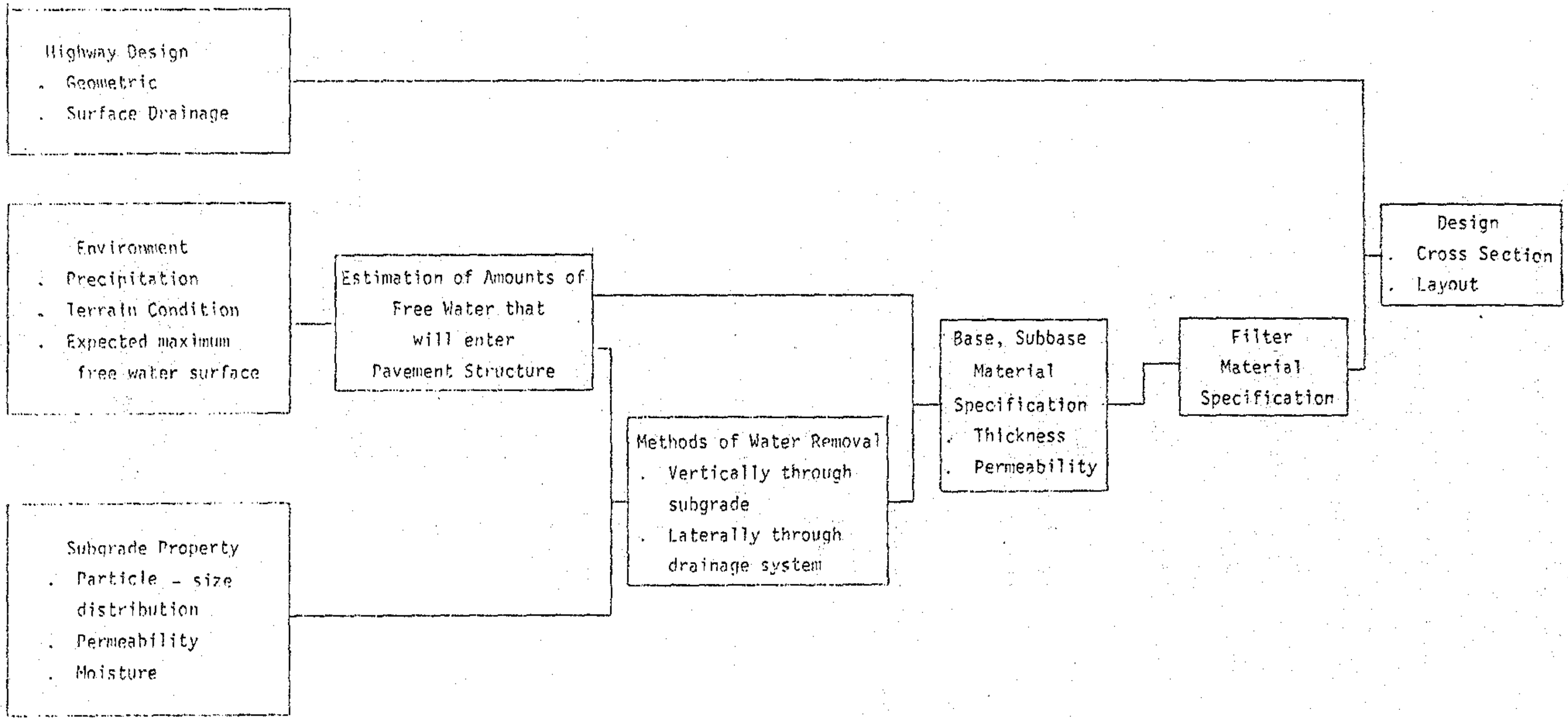
$\partial$ = 0.33~0.65 (AC pavement)

2) Rigemay (Criterion 3)

For rigid pavements

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

FIGURE 12.2-1 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 $ft^2$/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)

### 12.2.2 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 usedas 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

$$K = \frac{Ne\ L^2}{2\ t\ 50\ (H + L \tan \alpha)}$$

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) |
| t50 | = | Time for 50 percent drainage (days) |
| H | = | Thickness of drainage layer (ft) |
| $\alpha$ | = | Angle of slope of drainage layer |
| q | = | Quantity of inflow ($ft^3$/day/ft. of pavement) |
| S | = | Slope of drainage path |

TABLE 12.2-1 PERMEABILITY OF GRADED AGGREGATES

| Percent Passing | Sample Number | | | | | |
|---|---|---|---|---|---|---|
| | 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 12.2-2 EFFECTS OF PERCENTAGE PASSING 200 MESH SIEVE ON COEFFICIENT OF PERMEABILITY OF DENSE GRADED AGGREGATE, FEET PER DAY

| Types of Fines | Percent Passing No. 200 Sieve | | | |
|---|---|---|---|---|
| | 0 | 5 | 10 | 15 |
| Silica or Limestone | 10 | 0.07 | 0.08 | 0.03 |
| Silt | 10 | 0.08 | 0.001 | 0.0002 |
| Clay | 10 | 0.01 | 0.0005 | 0.00009 |

12.2.3 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;

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

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.

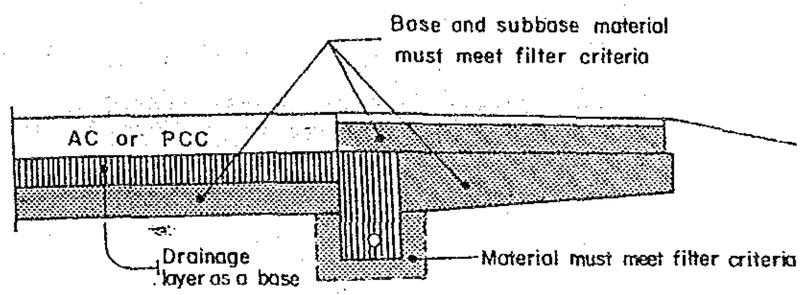
The filter should be so coarse as possible.

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

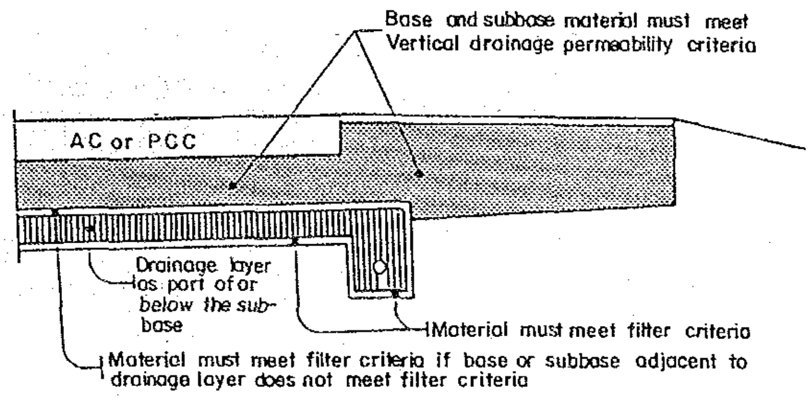
(c) It must be strong enough to carry the loads applied and, for aggregate filters, to distribute live loads to the subgrade.

Location of material that must meet filter criterion is shown in Figure. 12.2-2.

A. Base is used as the drainage layer




B. Drainage layer is part of or below the subbase




NOTE: Filter fabrics may be used inlieu of material, soil, or aggregate, depending on economic considerations.

FIGURE 12.2-2 EXAMPLE OF DRAINAGE LAYER IN PAVEMENT STRUCTURE

## 12.3 Quality of Drainage by AASHTO Guide 1986

In AASHTO Guide, 1986, the effect of drainage in pavement design is considered by modifying the structural layer coefficient, $m_i$, (for flexible pavement) and $cd_1$, (for rigid pavements) as a function of:

- the quality of drainage (e.g. the time required for the pavement to drain), and
- the percent of time the pavement structure is exposed to moisture levels approaching saturation

Table 12.3-1 shows the general definitions corresponding to different drainage levels from pavement structure.

TABLE 12.3-1 QUALITY OF DRAINAGE

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

Recommended structural layer coefficient, mi for flexible pavement and load transfer coefficient, Cd for rigid pavement are shown in Table 12.3-2 and 12.3-3, respectively.

TABLE 12.3-2 RECOMMENDED $M_i$ VALUES FOR MODIFYING STRUCTURAL LAYER COEFFICIENTS OF UNTREATED BASE AND SUB-BASE MATERIALS IN FLEXIBLE PAVEMENTS

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

TABLE 12.3-3 RECOMMENDED VALUES OF DRAINAGE COEFFICIENT, $C_d$, FOR RIGID PAVEMENT DESIGN

| Quality of Drainage | Percent of Time Pavement Structure is Exposed to Moisture Levels Approaching Saturation | | | |
|---|---|---|---|---|
| | Less Than 1% | 1 - 5% | 5-25% | Greater Than 25% |
| Excellent | 1.25 - 1.20 | 1.20 - 1.15 | 1.15 - 1.10 | 1.10 |
| Good | 1.20 - 1.15 | 1.15 - 1.10 | 1.10 - 1.00 | 1.00 |
| Fair | 1.15 - 1.10 | 1.10 - 1.00 | 1.00 - 0.90 | 0.90 |
| Poor | 1.10 - 1.00 | 1.00 - 0.90 | 0.90 - 0.80 | 0.80 |
| Very Poor | 1.00 - 0.90 | 0.90 - 0.80 | 0.80 - 0.70 | 0.70 |

## 12.4 Typical Subdrainage Systems

The lateral drainage layer design 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 12. 4-1

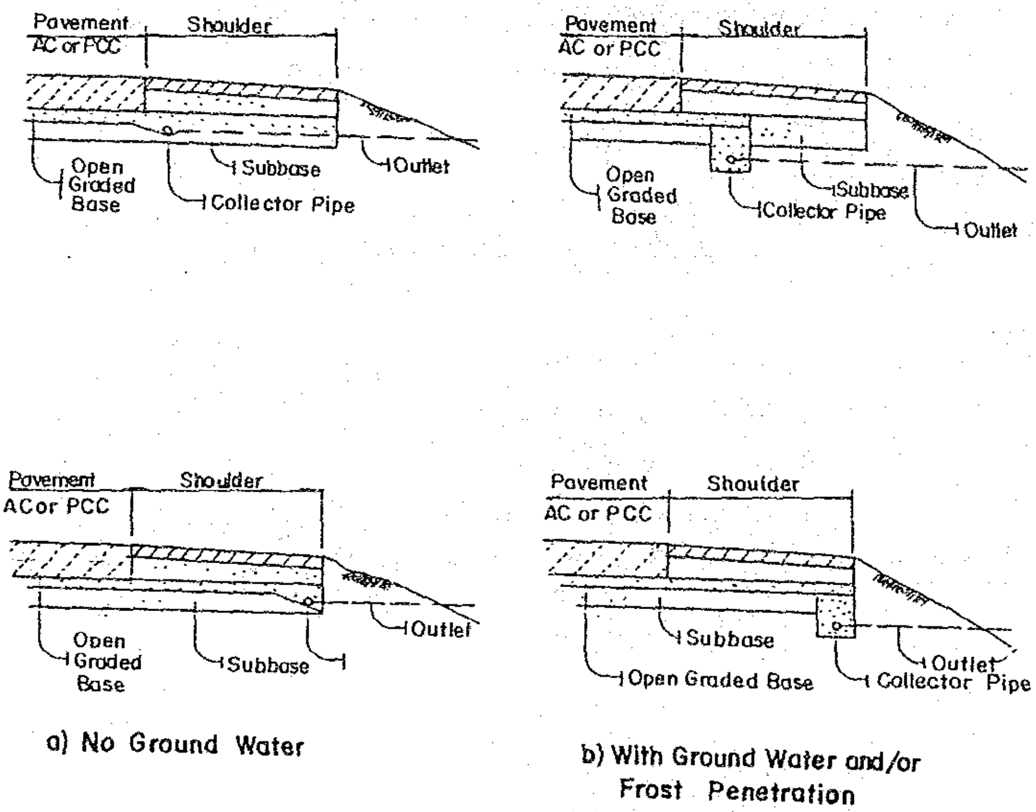



FIGURE 12. 4-1 TYPICAL CROSS SECTIONS OF SUBDRAINAGE SYSTEMS

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. The design of such systems includes consideration of:

- the type of pipe used
- the location and depth of transverse and longitudinal collectors and their outlets
- slope of the collectors pipes
- the size of pipes
- provision for adequate filter protection

The example of layout of proposed subdrainage system is shown in Figure 12. 4-2.

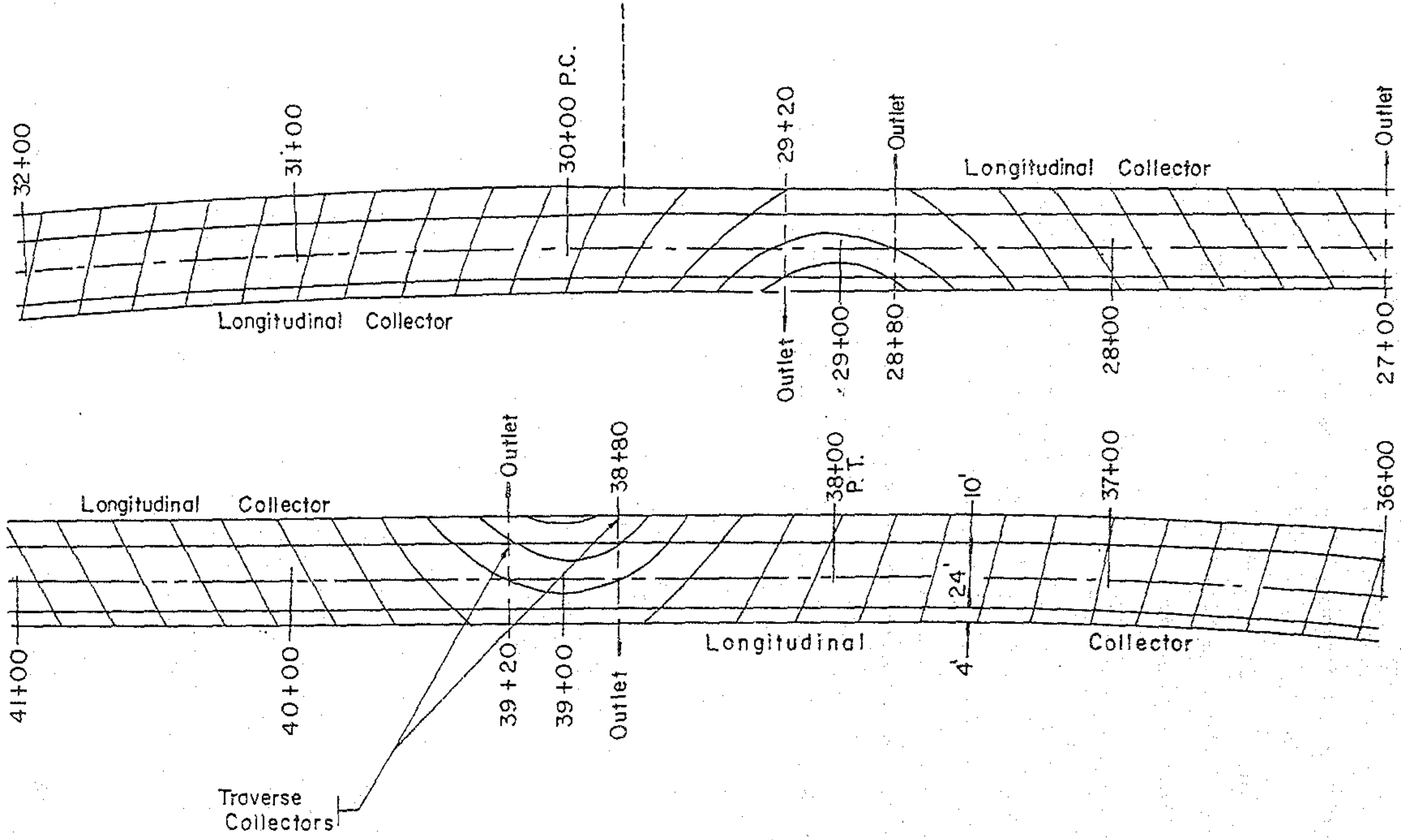



FIGURE 12.4-2 Layout of Proposed Drainage System Showing Direction of Flow in Drainage Layer

## 12.5 Rehabilitation or Maintenance of Existing Pavements

Subsurface moisture conditions should be considered when planning the rehabilitation or maintenance of existing pavements. Repaving, overlays, recycling, or patching an existing pavement will be wasteful if the pavement distress is caused by moisture in the base, subbase, or subgrade materials and the existing surface and/or subsurface drainage conditions are not corrected.

The Asphalt Institute has posed four general questions that should be answered by surface and subsurface drainage investigations:

1. Is the original design adequate for drainage of the existing road?
2. What changes in design are necessary to ensure that drainage inadequacies, which may be a contributing factor to structural distress, are corrected?
3. If the original drainage system design was adequate, have environmental or structural changes taken place since it was built that require reconstruction of the system?
4. Does present or projected land use in areas adjacent to the road indicate that surface drainage flow patterns have changed or are likely to change, thus rendering existing drainage facilities inadequate?

When conditions indicate that moisture is a contributing cause of the pavement distress, the following questions should be addressed:

1. Is the surface drainage system adequate, functioning properly, and removing the surface water from the vicinity of the pavement structure?
2. Is the subsurface drainage system, other than the specifically for drainage of the pavement structure, adequate, functioning properly, and removing water from the vicinity of the pavement structure?
3. Is the structural design of the present pavement sufficient if the moisture problem is solved?

4. What are the permeabilities and capillary potentials of the base, subbase, and subgrade that are under the existing pavement, and how is the moisture entering the pavement structure?

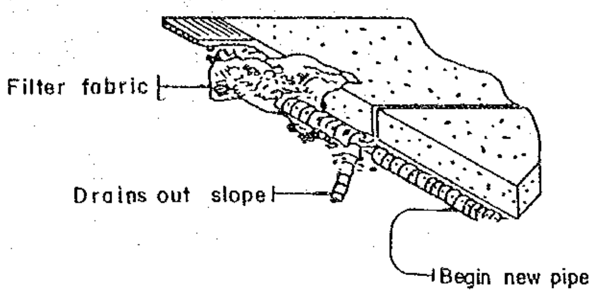
The following categories of problems related to the above questions should be identified:

- Shallow side ditches
- Blockage of subsurface drainage due to widening
- Permeable shoulders and medians
- Repaving rigid pavements
- Impermeable aggregate drainage layers
- Reduction of drainage capacity of curbed pavements because of overlays
- Water in open-graded bases (trench section)
- Drainage of open-graded plant-mix seals

Longitudinal Subdrains

The installation of pavement subdrains can, in most cases, improve the long-term load-carrying and load distribution properties of the base, subbase, and subgrade materials, but it cannot save a pavement structure that does not have sufficient design strength of thickness. When pavement longitudinal subdrains are installed in shoulders of existing pavements, it is important to know the permeability and capillary potential of the materials adjacent to the proposed drain. The success or failure of these drains depends on these properties and how the moisture is entering the structure. Figure 12.5-1 is a sketch of a typical longitudinal drain installation.

When use of the longitudinal drain is considered, it is important to know which free water is to be drained. The free water that is entering the pavement structure at the pavement-shoulder joint can almost always be removed by longitudinal drains. Water entering the structure through center-line joints and lateral cracks or joints that has to reach the longitudinal drain through the base or subbase will not be drained effectively if the permeability of the material is low.



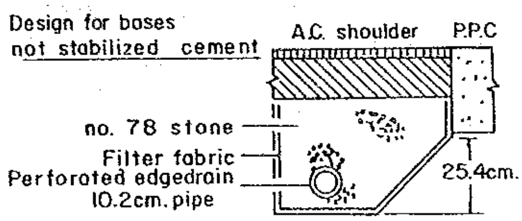




FIGURE 12.5-1 Edge Drain Details

Where there is some doubt as to the effectiveness of longitudinal drains, it is recommended that test sections at least 60 to 90 m long be located in typical areas where it is thought that side drains will be beneficial.

It should be noted, however, that flow from the newly installed drain does not in itself indicate an improved condition because in some cases the infiltration rate at the pavement edge has been increased during the installation of the drain.

The installation of longitudinal drains must be done carefully. A section of low-permeability material must not be left between the layer to be drained and the new drain. The strength and the support characteristics under the existing pavement should not be damaged.

When longitudinal drains are installed under the above conditions, they will prevent moisture from entering the pavement structure from a wet shoulder area, but they will also block moisture from leaving the structure and may, in the balance, be detrimental. Where longitudinal drains will not function, extra effort should be put into sealing the pavement surface until redesign and reconstruction of the pavement incorporating the necessary pavement subsurface drainage facilities can be accomplished.

# CHAPTER 13

# ECONOMIC EVALUATION ON PAVEMENT REHABILITATION

# CHAPTER 13

# ECONOMIC EVALUATION ON PAVEMENT REHABILITATION

## 13.1 Economic Evaluation

### (1) Quantifiable Benefit

Pavement benefits accrue primarily from direct reductions in transportation costs of the road users. These include vehicle operation cost, travel time, accidents discomfort. As agency costs, maintenance cost saving and salvage (or residual) value are also considered.

Among those , quantified are;

- Road Traffic cost
  - . running cost
  - . fixed cost
  - . time cost

- Maintenance Cost

- Salvage Value
  - . Salvage value is usually considered in estimating the total discounted cost of construction/rehabilitation cost.

In case of partial closure of the road on a yearly basis (during wet season, impassable) two subsequent traffic cost calculations should be attempted, identifying the period of, say bad condition, and the period of impassable condition. In the latter case alternative detour routes should be identified and included in the analysis.

The traffic cost savings are calculated by the following formula:

$$TCS = \sum_{vt} [(TC\ w/o,_{vt} - TC\ with,_{vt}) \times L \times AADT_{vt} \times 365]$$

Where:

TCS = Annual traffic cost savings

TC w/o, vt = Traffic cost per Km in "without project case" Changeable according to road surface. Usually, "bad surface condition" or PSI/RRI of 2.0 may be assumed providing that adequate maintenance works will be applied.

TC with, vt = Traffic cost per Km in "with project case"

Changeable according to road surface. The initial PSI/RRI of 4.5 can be assumed for rigid pavement. The terminal serviceability index should be selected by design criteria.

vt = Vehicle type

L = Improvement length

AADT vt = Annual average daily traffic

(2) Road Surface Condition

Highway Planning Mannual, Volume 5 of DPWH suggests the following main definitions to be used as a general guide in assessing objectively surface conditions.

Table 13.1-1 Main Definition of Surface Condition.

| | | |
|---|---|---|
| Good | : | No evidence of cracking, deformation, rutting or corrugation. Patched areas are less than 1 per cent of the total surface and distributed over the full kilometer or less than 3 per cent of the total surface if confined to 100 meters of the kilometer. It permits smooth travel. |
| Fair | : | If the pavement or travelled - way contains cracks, potholes, patching, corrugations and rutting not affecting more than 20 per cent of the surface. Travelling is relatively smooth although characterized by some infrequent bumps and maneuvering. |
| Bad | : | Pavement or travelled-way, heavily corrugated, breaking up or rutted and containing cracks and failures, patched or unpatched,,affecting more than 20 per cent of the surface. Travelling becomes uncomfortable especially at higher speeds than the desirable ones (20-30 kph). |
| Very Bad | : | Just passable for vehicles with 2-wheel drive. The speed varies from 10-20 Km./Hour. |

The correlations between the main definition of surface conditions in Table 13.1-1 and present serviceability index (PSI)/Rehabilitation Requirement Index (RRI) were analyzed under the Feasibility Study. And, the following loose correlations were established only for the purpose of estimating road traffic cost.

Table 13.1-2 Correlation between Surface Condition and Index.

| Surface Condition | Present Serviceability Index/ Rehabilitation Requirements Index |
|---|---|
| Good | 4 or more |
| Fair | 3 |
| Bad | 2 |
| Very Bad | 1 or less |

(3) Extra length and Time

Aside from these conventional economic indicators, dl and dt values can be analyzed. The dl-system simulates the extra running costs incurred by vehicles operation on roads with substandard surface conditions. Such extra costs are transformed into imaginary road lengths called dl, which actually expresses the extra running costs. The dt-system similarly simulates travel times on various road conditions. The dt value expresses operating time.

(4) Maintenance Cost

Saving in maintenance cost is the benefit derived from the pavement rehabilitation project. Difference in maintenance costs between without and with projects should be estimated.

## 13.2 Economic Indicators

Correlations between pavement rehabilitation works and the economic indicators are summarized in the Section. These are developed through undertaking the Feasibility Study.

Figure 13.2-1 shows the relationship between construction cost and AADT. Construction cost is dependent on traffic loading class and subgrade CBR. Figure 12.2-2 indicates IRR against AADT.

- IRRs are closely correlated with AADT in any rehabilitation method. They increase remarkably with the increase of AADT.
- Little difference is found between IRRs in 2-lane PCC reconstruction and in 1-lane PCC reconstruction.
- For the same AADT, 2-lane AC overlay shows a higher IRR than 2-lane/1-lane PCC reconstruction. It is due to lower initial construction cost.

Figures 13.2-3 and 13.2-4 show the relationships between dl/dt-values and AADT, and between dl-/dt-values and heavy vehicle composition, respectively. The findings in these figures are as follows:

- Both dl- and dt-values per vehicle are well correlated with heavy vehicle composition. The dl-values increase and the dt-values decrease as heavy vehicle composition becomes higher.
- Both values are also correlated with AADT as result of the correlation found in the study sections between AADT and heavy vehicle composition.
- The dl-and dt-values are the highest in case of 1-lane PCC reconstruction and the lowest in case of 2-lane AC overlay. The lower dl-and dt-values in AC overlay are due to its shorter performance period. The difference in the dl-and dt-values between 2-lane and 1-lane PCC

reconstructions are caused by the different assumptions made for the succeeding rehabilitation methods. In case of 2-lane PCC Reconstruction, the future rehabilitations are assumed to be carried out by AC overlay method, while in case of a-lane PCC reconstruction, the same methods are assumed to be repeated individually for each lane. PCC reconstruction has a longer performance period than AC overlay and accordingly the average performance period in 1-lane PCC reconstruction is longer than that in 2-lane PCC reconstruction.

These figures may be used for planning of the similar projects to roughly estimate construction cost, IRR and dl~/dt values.

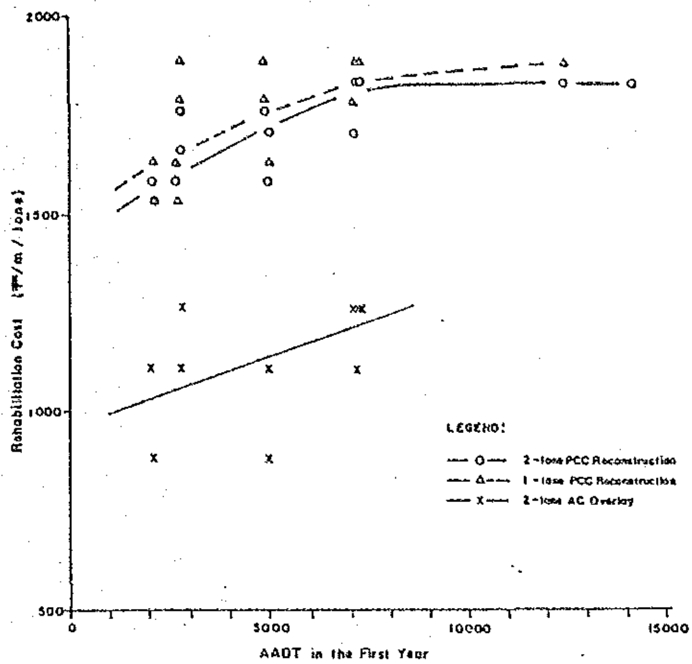



Figure 13.2 - 1 Relationship between AADT and Rehabilitation Cost

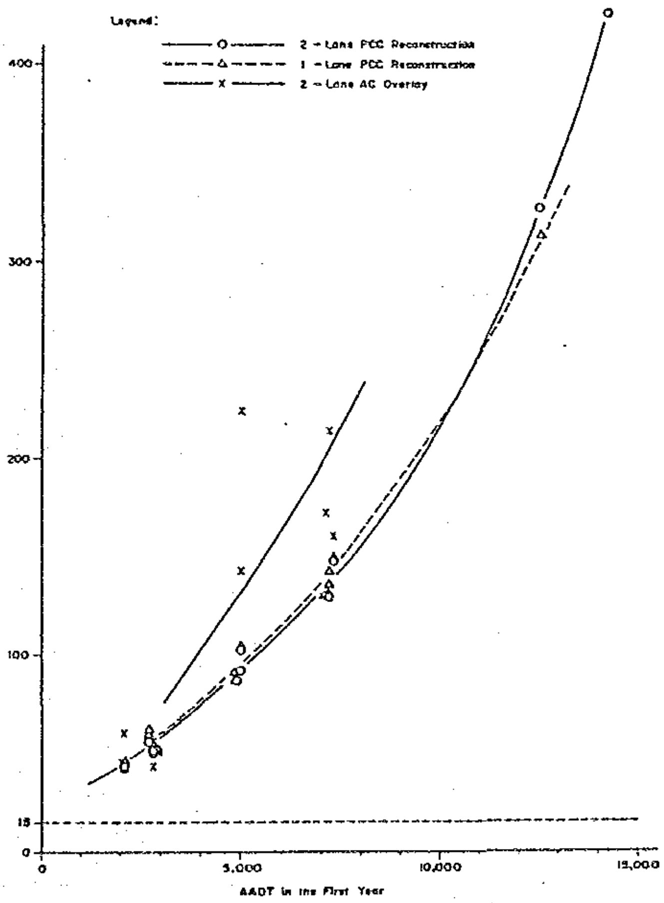



FIGURE 13.2 - 2 Relationship Between AADT and IRR

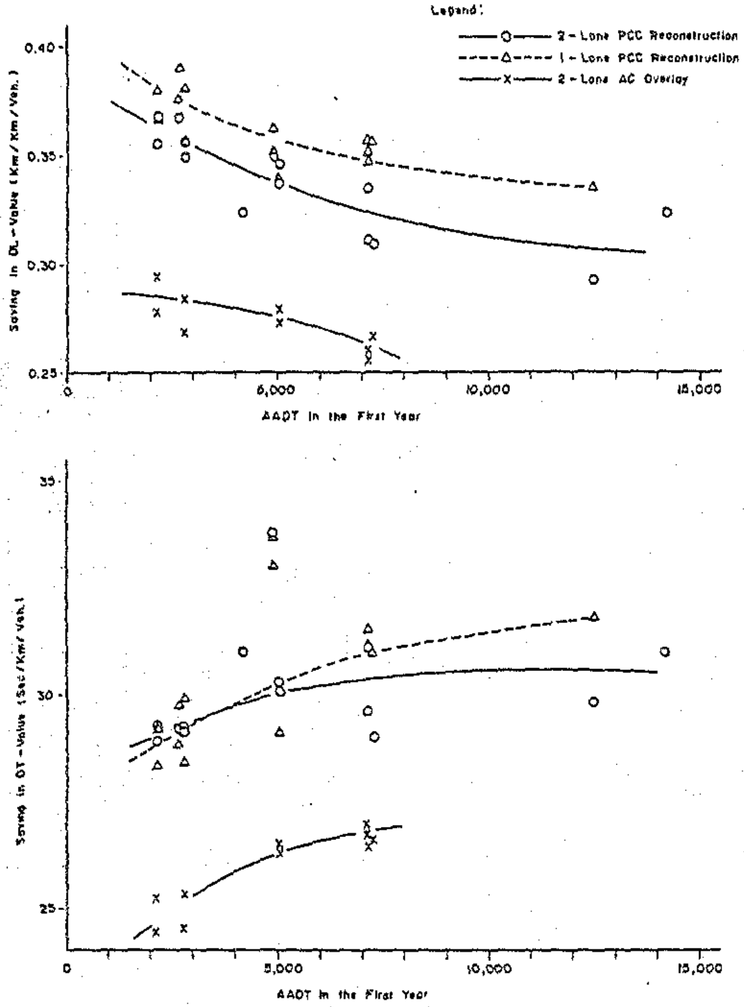



FIGURE 13-2-3 Relationship Between AADT and DL-/ DT-Values

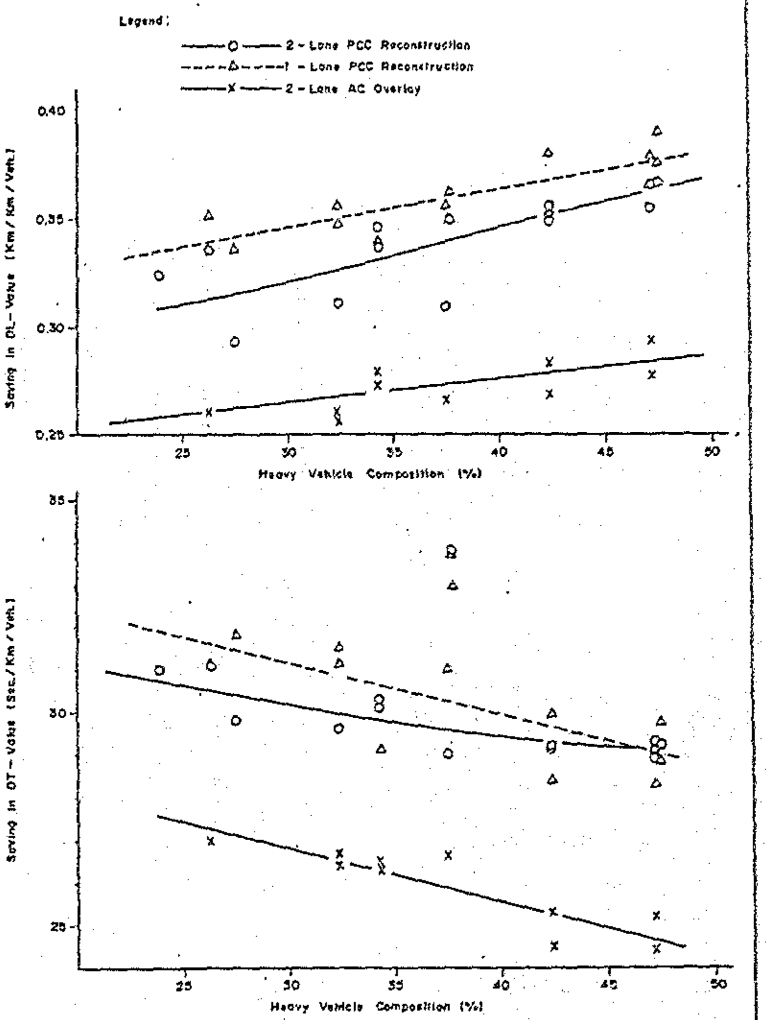



FIGURE 13.2-4 Relationship Between Heavy Vehicle Composition and DL- / DT - Values

# APPENDIX

# APPENDIX 2-1

# LIST OF REFERENCES

# APPENDIX 2-1

The Main Guide/Text used as reference are as follows.

AASHTO

- AASHTO Guide for Design of Pavement Structure, 1986; American Association of State Highway and Transprotation Official. (AASHTO)

- The AASHO Road Test, Report 5, Pavement Research, National Academy of Sciences - National Research Council, 1962

- AASHTO Interim Guide for Design of Pavement Structures, 1972; (AASHTO)

PCA

- Thickness Design for Concrete Highway and Street Pavements, 1984; Portland Cement Association.

- Guide to Concrete Resurfacing Designs and Selection Criteria 1981, Portland Cement Association

AI

- Thickness Design Asphalt Pavements for Highways and Streets Manual Series No. 1 (MS-1) September 1981, The Asphalt Institute.

- Asphalt Overlays for Heavily-Traffic PCC Pavements Information Series No. 177 February 1981, The Asphalt Institute

- Asphalt Overlays and Pavement Rehabilitation, Manual Series No. 17 (MS-17), November 1977, the Asphalt Institute

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Organization for Economic Cooperation and Development
October 1978.

# APPENDIX 3-1
# EFFECTIVE MODULUS OF SUBGRADE REACTION
# (K-VALUE)

## EFFECTIVE MODULUS OF SUBGRADE REACTION (K)

Since the effective K value is dependent upon several different factors besides the roadbed soil resilient modulus, it should be evaluated for each type of subbase.

Assuming MR and ESB for dry and wet seasons in the country, the trial calculations were attempted to estimate k value corrected for loss of support for unbound granular material and the fine grained or natural subgrade materials. See Table 12.4-2 and 12.4-3.

However, the very small values were obtained because of remarkable influence due to loss of support (LS). LS is the factor to account for loss of support beneath concrete slab movement. LS of 1 to 3 is suggested for the material in AASHTO Guide 1986.

Another reason in obtaining the small value of k may be the lack of data to estimate the seasonal modulus of roadbed. The Guide suggests as follows:

The seasonal resilient modulus values of roadbed (subgrade) should be determined under the seasonal moisture condition. The purpose of identifying seasonal moduli is to quantify the relative damage a pavement is subjected to during each season of the year. Two different procedures for determining the seasonal variation are offered. One method is obtained by a relationship between resilient modulus and moisture content, through Laboratory Resilient Modulus Tests (AASHTO T274). An alternative procedure is to back calculate the resilient modulus for different seasons using deflection measured on in-service pavements by deflection measuring system such as non-destructive deflection testing (NDT).

The assumed values to estimate modulus of elasticity were made based on data shown in Reference.

The procedure and assumed values for evaluation are as follows.

Step 1 Seasonal roadbed soil resilient modulus value ($M_R$, Psi) 5000 psi for wet and 65000 for dry season

Step 2 Subbase elastic (resilient) modulus value for each season ($E_{SB}$; psi)
15,000 psi for wet and 25,000 psi for dry season

Step 3 Composite Modulus of subgrade reaction ($K_{\infty}$, pci), Figure 1

Step 4 Modulus of subgrade reaction modified due to the effect of rigid foundation (if rigid foundation is less than 10 feet below the surface of subgrade) (K value, Pci), Figure 2

Step 5 Relative damage of thickness of slab due to 18 kip ESAL and calculate average relative damage (Ur), Figure 3

Step 6 Effective Modulus of subgrade reaction corresponding to average relative damage (K, pci), Figure 4

Step 7 Loss of support due to subbase erosion and/or different vertical support

| | (LS) |
|---|---|
| Unbound Granular Materials | 1.0 to 3.0 |
| (E = 15,000 to 45,000 psi) | |
| Fine Granular or Natural Subgrade Material | |
| (E = 3,000 to 40,000 psi) | 2 to 30.0 |

Step 8 Effective Modulus of Subgrade reaction for potential loss of subbase support (K, pci), Figure 3-1-4

TABLE 1 EFFECTIVE MODULUS OF SUBGRADE REACTION

Subbase: Type Unbound Granular Material
Thickness (inches) 10
Loss of Support, LS 2.0
Depth to Rigid Foundation (feet); greater than 10 (Semi-infinite)
Projected Slab Thickness (inches) 9

| Month | Roadbed Modulus MR (Psi) | Subbase Modulus $E_{SB}$ (Psi) | Composite K-Value (Pci) | K-Value On Rigid Foundation (pci) | Relative Damage Ur. |
|---|---|---|---|---|---|
| January | 6,500 | 25,000 | 410 | - | 0.68 |
| February | 6,500 | 25,000 | 410 | - | 0.68 |
| March | 6,500 | 25,000 | 410 | - | 0.68 |
| April | 6,500 | 25,000 | 410 | - | 0.68 |
| May | 6,500 | 25,000 | 410 | - | 0.68 |
| June | 5,000 | 15,000 | 320 | - | 0.77 |
| July | 5,000 | 15,000 | 320 | - | 0.77 |
| August | 5,000 | 15,000 | 320 | - | 0.77 |
| September | 5,000 | 15,000 | 320 | - | 0.77 |
| October | 5,000 | 15,000 | 320 | - | 0.77 |
| November | 5,000 | 15,000 | 320 | - | 0.77 |
| December | 6,500 | 25,000 | 410 | - | 0.68 |

Summation $\sum$ Ur = 8.70

Average Ur = $\sum$ Ur/n = 8.70/12 = 0.73
Effective Modulus of Subgrade Reaction; K (pci) = 340
Corrected for Loss of Support ; K (pci) = 34

TABLE 2 EFFECTIVE MODULUS OF SUBGRADE REACTION

Subbase: Type; Fine Grained or Natural Subgrade Materials

Thickness (inches) 10

Loss of Support, LS; 2.5

Depth to Rigid Foundation (feet); greater than 10 (Semi-infinite)

Projected Slab Thickness (inches); 9

| Month | Roadbed Modulus MR (Psi) | Subbase Modulus $E_{SB}$ (Psi) | Composite K-Value (Pci) | K-Value On Rigid Foundation (pci) | Relative Damage Ur |
|---|---|---|---|---|---|
| January | 6,000 | 20,000 | 360 | - | 0.73 |
| February | 6,000 | 20,000 | 360 | - | 0.73 |
| March | 6,000 | 20,000 | 360 | - | 0.73 |
| April | 6,000 | 20,000 | 360 | - | 0.73 |
| May | 6,000 | 20,000 | 360 | - | 0.73 |
| June | 4,000 | 15,000 | 250 | - | 0.04 |
| July | 4,000 | 15,000 | 250 | - | 0.04 |
| August | 4,000 | 15,000 | 250 | - | 0.04 |
| September | 4,000 | 15,000 | 250 | - | 0.04 |
| October | 4,000 | 15,000 | 250 | - | 0.04 |
| November | 4,000 | 15,000 | 250 | - | 0.04 |
| December | 6,000 | 20,000 | 360 | - | 0.73 |
| | | | Summation $\sum Ur$ | = | 9.42 |

Average $\overline{Ur} = \sum Ur/n = 9.42/12 = 0.79$

Effective Modulus of Subgrade Reaction; K (pci) = 280

Corrected for Loss of Support ; K (pci) = 20

Example:

$D_{SB}$ = 6 inches

$E_{SB}$ = 20,000 psi

$M_R$ = 7,000 psi

Solution: $k_\infty$ = 400 pci

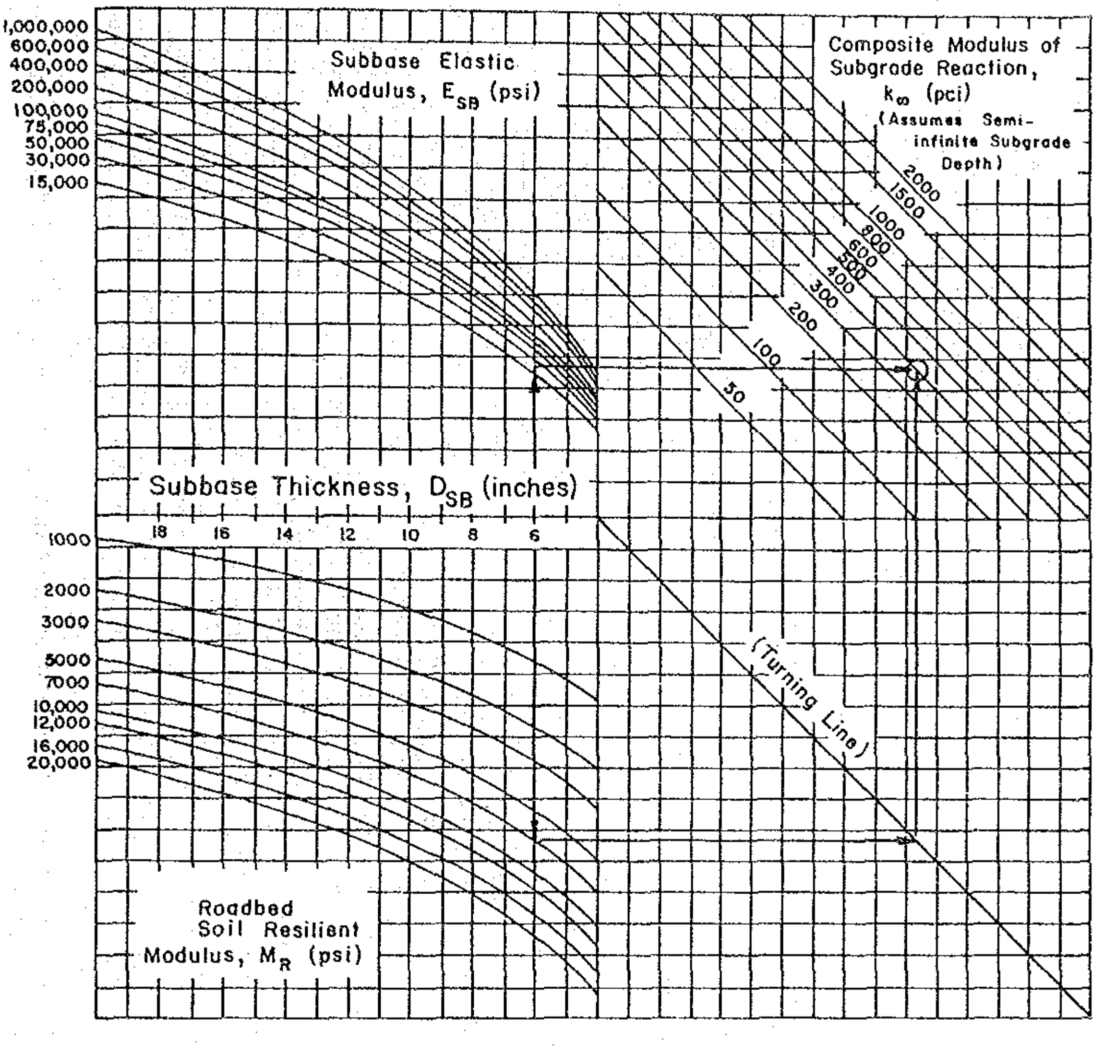



Chart for estimating composite modulus of subgrade reaction, $k_\infty$, assuming a semi-infinite subgrade depth. (For practical purposes, a semi-infinite depth is considered to be greater than 10 feet below the surface of the subgrade.)

FIGURE 1 COMPOSITE MODULUS OF SUBGRADE REACTION

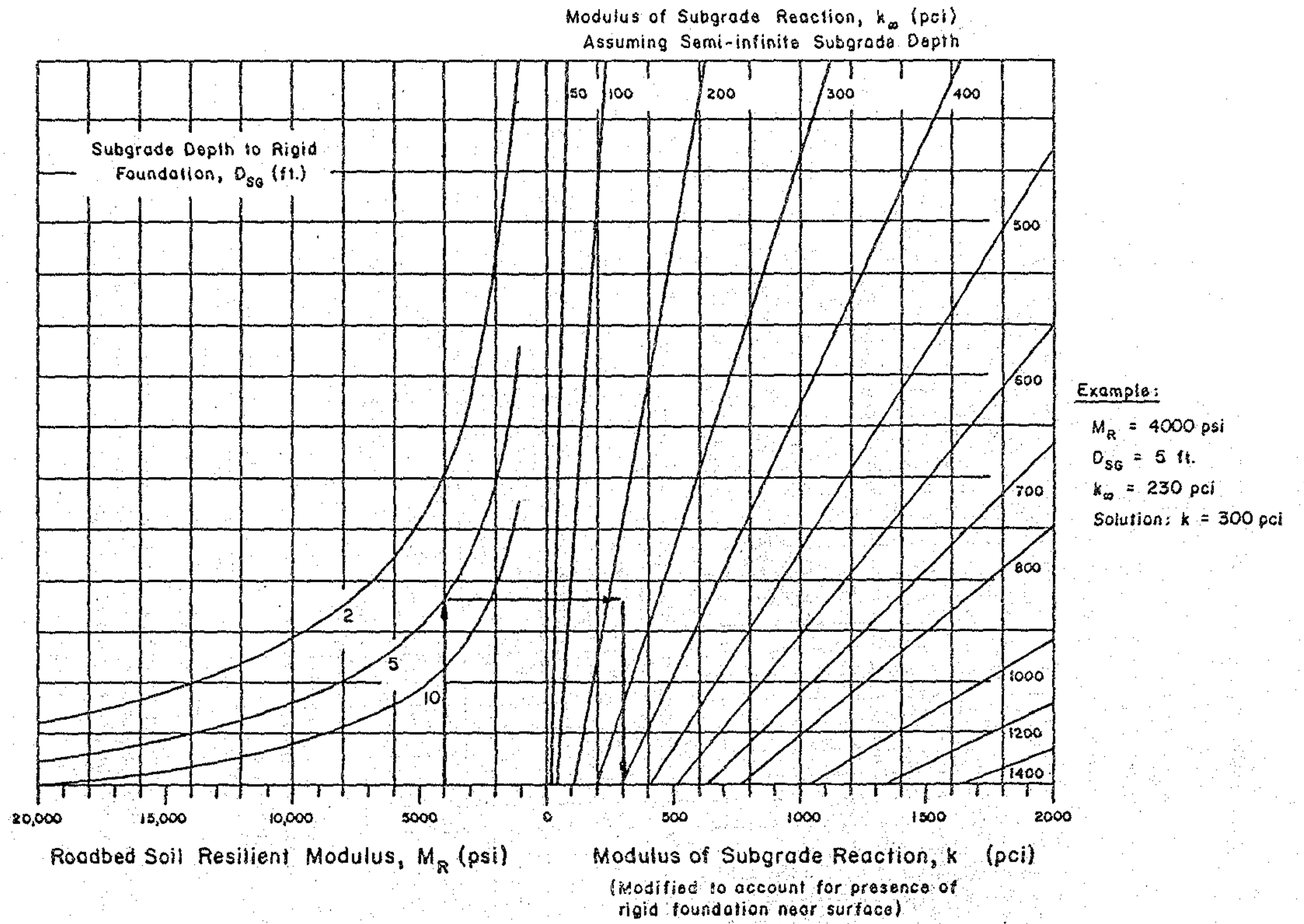



**Chart to modify modulus of subgrade reaction to consider effects of rigid foundation near surface (within 10 feet).**

FIGURE 2 MODULUS OF SUBGRADE REACTION MODIFIED DUE TO RIGID FOUNDATION

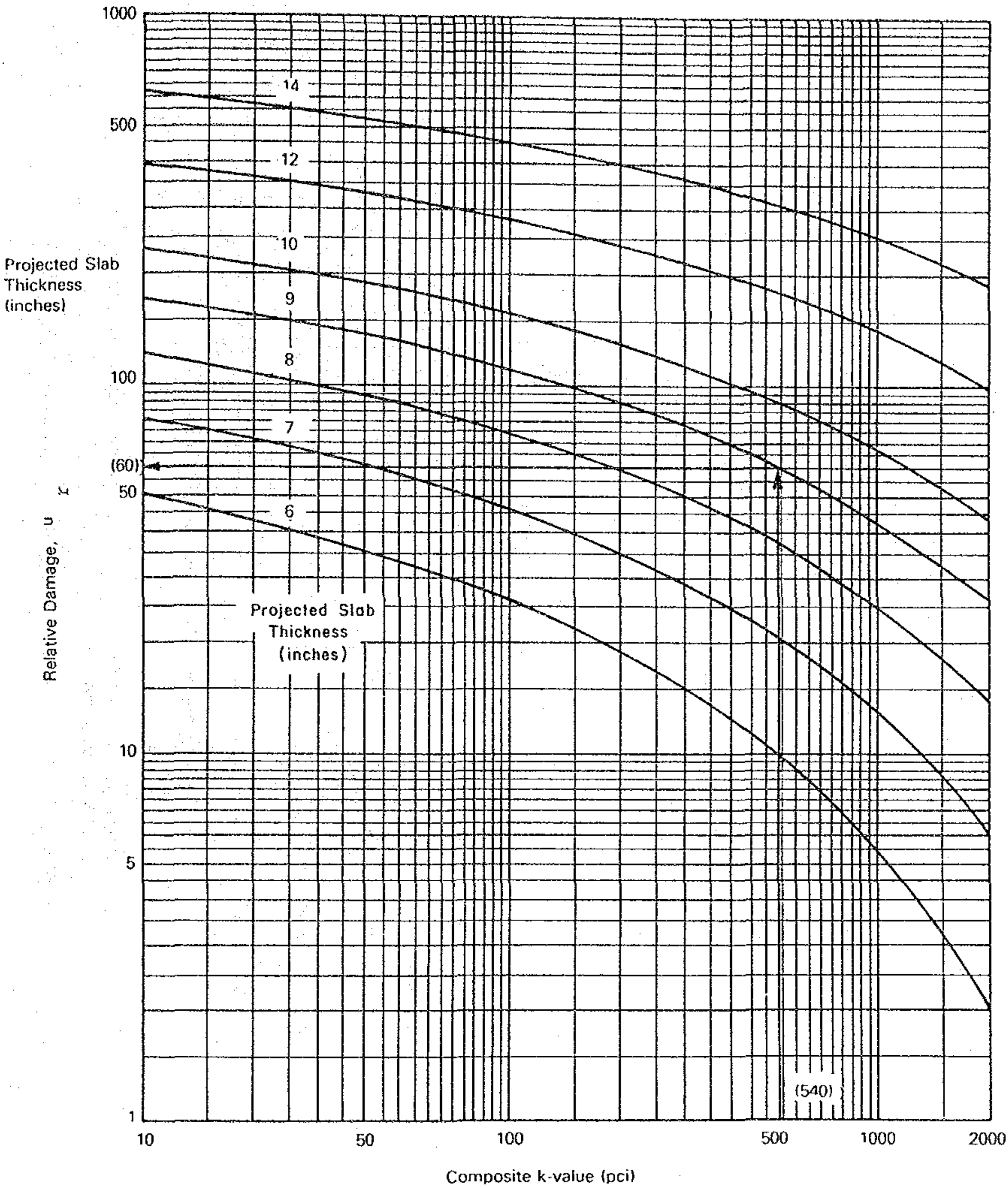
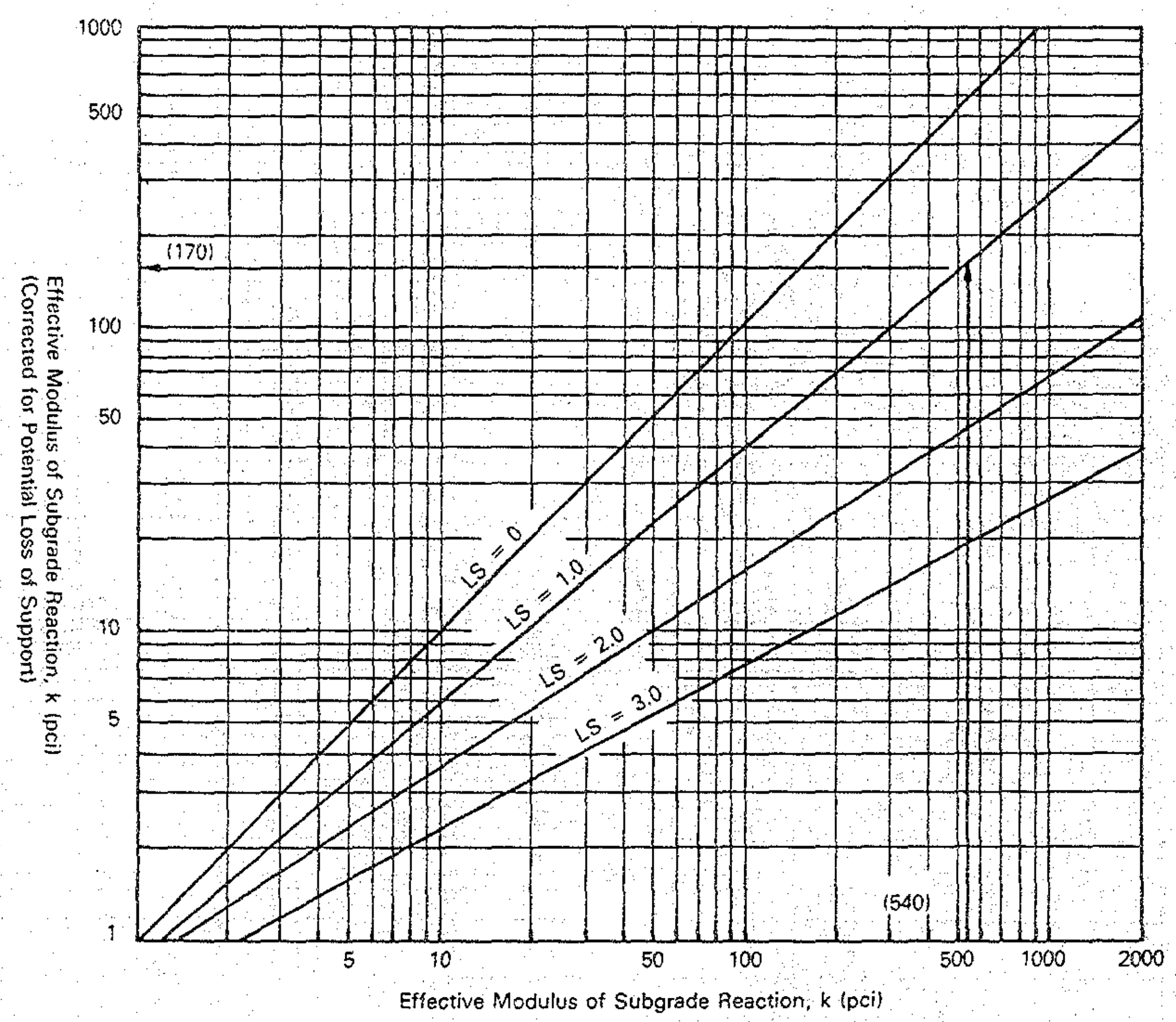



Chart for estimating relative damage to rigid pavements based on slab thickness and underlying support.

FIGURE 3 RELATIVE DRAINAGE OF THICKNESS OF SLAB




**Correction of effective modulus of subgrade reaction for potential loss of subbase support (6).**

FIGURE 4 EFFECTIVE MODULUS OF SUBGRADE REACTION

# Reference

## Reference 1) Wave Velocity Measurements by TRRL

TRRL measured the Rayleigh wave velocity in each of the soil bay and the results were related to measurements of the in situ CBR of the soils. Based on the analysis of this measurement, the relationship, $E = 100$ CBR ($kg/cm^2$) was widely adopted. However, TRRL comments that the wide adoption of this relationship is in many ways unfortunate since it relates the structural design procedure to a generally unreliable field test. In situ CBR values are not normally representative of the equilibrium subgrade strength under a pavement. Refer to Figure (Re-1).

## Reference 2) Alconbury Hill Experiment

In 1957 the wave velocity technique was used to study the dynamic elastic modulus of the exposed subgrade of the Alconbury Hill experimental road.

There is approximately linear relationship between Young's modulus and in situ CBR. For CBR values less than 7 percent, the relationship is $E = 13.3$ CBR ($MN/m^2$) or $E = 140$ CBR ($kg/cm^2$). The slope of the relationship increases slightly with increasing plasticity of the soil. The points which fall below the line $E = 100$ CBR ($kg/cm^2$) were mainly obtained on particularly stony areas of the boulder clay. Refer to Figure (Re-2).

Source; The Design and Performance of Road Pavement, 1977, TRRL

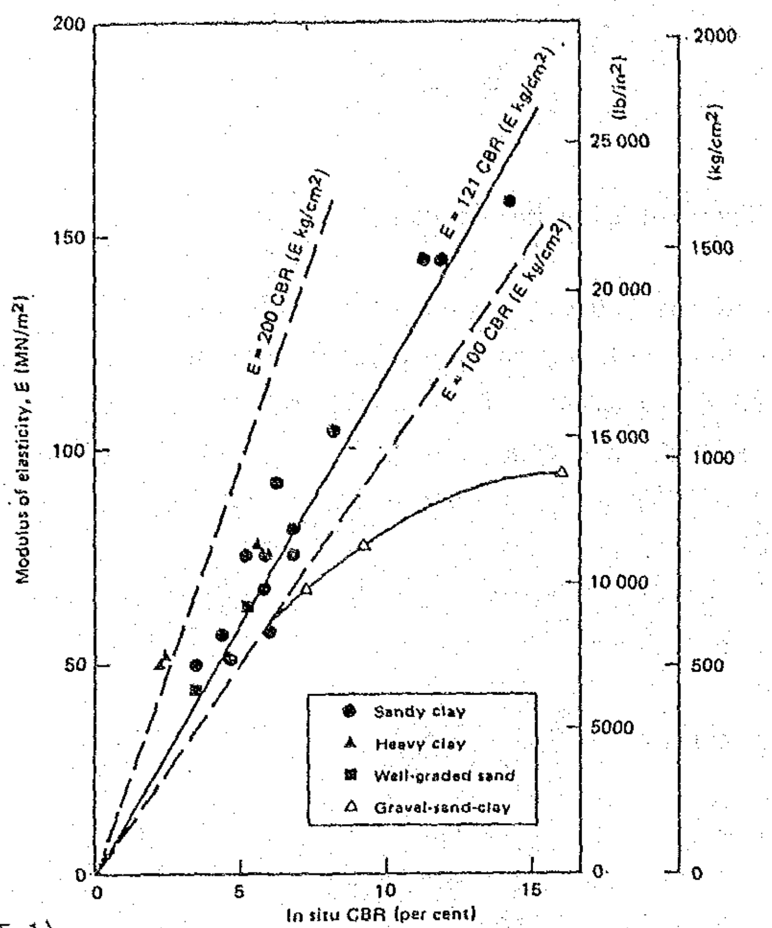



FIGURE (RE-1) Relationships between *in situ* CBR values and modulus of elasticity determined from Rayleigh wave velocity.

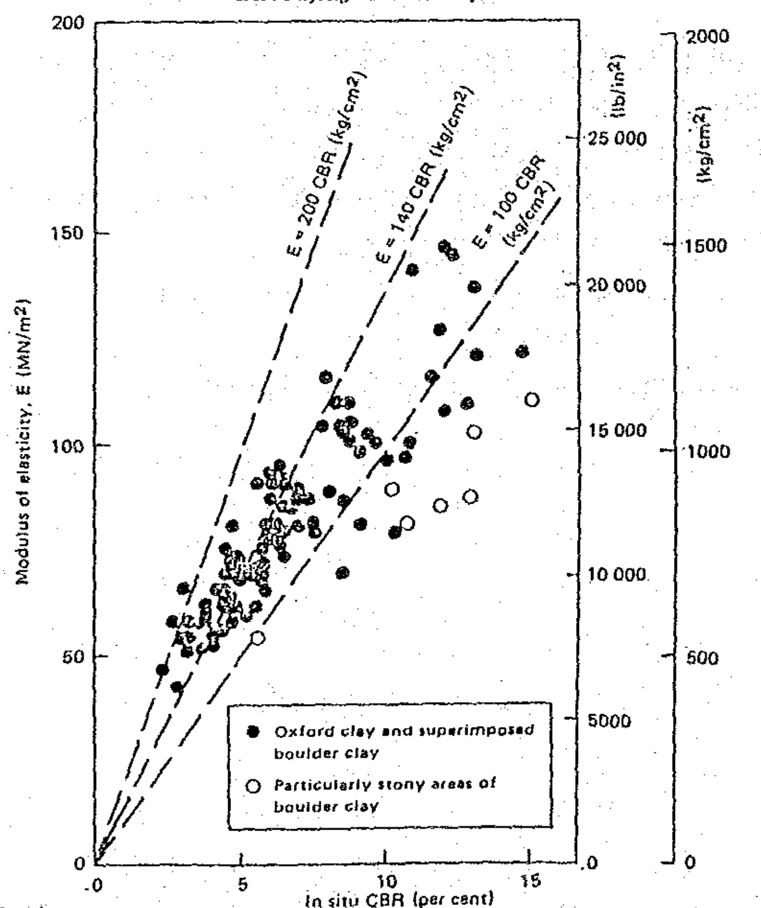



FIGURE (RE-2) Relationship between *in situ* CBR value and modulus of elasticity determined from Rayleigh wave velocity in exposed subgrade of the Alconbury Hill experimental road.

# APPENDIX 3-2
# SPECIFICATION REQUIREMENTS

TABLE 1

SPECIFICATIONS FOR SUBBASE MATERIAL

1. Grading

| Standard Seive Sizes | | 1972 Grading A | 1972 Grading B | 1976 Class A | 1976 Class B | JRA C-40 | JRA C-30 | JRA C-20 |
|---|---|---|---|---|---|---|---|---|
| 88.9 mm. | 4 in. | - | - | - | - | - | - | - |
| 76.2 mm. | 3 in. | 100 | - | 100 | - | - | - | - |
| 63.5 mm. | 2½ in. | - | - | - | - | - | - | - |
| 50.8 mm. | 2 in. | - | - | - | - | 100 | - | - |
| 38.1 mm. | 1½ in. | - | 100 | 80-100 | 100 | 95-100 | 100 | - |
| 31.7 mm. | 1¼ in. | - | - | - | - | - | 95-100 | - |
| 25.4 mm. | 1 in. | - | - | - | - | - | - | 100 |
| 19.1 mm. | 3/4 in. | - | - | - | - | 50- 80 | 55- 85 | 95-100 |
| 12.7 mm. | 1/2 in. | - | - | - | - | - | - | 60- 90 |
| 9.52 mm. | 3/8 in. | - | - | 45-100 | - | - | - | - |
| 4760 μ | No. 4 | 30- 70 | 30- 70 | 30- 85 | 60-100 | 15- 40 | 15- 45 | 20- 50 |
| 2380 μ | No. 8 | - | - | - | - | 5- 25 | 5- 30 | 10- 35 |
| 2000 μ | No. 10 | - | - | 15- 65 | 40- 90 | - | - | - |
| 1190 μ | No. 16 | - | - | - | - | - | - | - |
| 590 μ | No. 30 | - | - | - | - | - | - | - |
| 420 μ | No. 40 | - | - | 5- 35 | 15- 50 | - | - | - |
| 297 μ | No. 50 | - | - | - | - | - | - | - |
| 149 μ | No. 100 | - | - | - | - | - | - | - |
| 74 μ | No. 200 | 0- 15 | 0- 15 | 0- 15 | 2 - 15 | - | - | - |

| | 1972 | 1976 | JRA |
|---|---|---|---|
| 2. Maximum Dimension | . Less than two-thirds of the required thickness of the layer in which it is to be placed. | . Less than two-thirds of the required thicness of the layer in which it is to be placed. | . Less than one half (½) of the compacted thickness of the construction layer nor larger than 100 mm. |
| 3. Los Angeles Abrasion Test | . none | . Maximum abrasion loss,50%. | . Maximum abrasion loss, 50%. |
| 4. Liquid Limit (LL) and Plasticity index (PI) | . LL $\leq$ 25 and PI $\leq$ 6 | . LL $\leq$ 35 and PI $\leq$ 11 | . PI $\leq$ 6 |
| 5. CBR Value | . none | . Shall have a soaked CBR-value of not less than 25%, corresponding to 98% of the maximum dry density. | . Modified CBR of 20% or more, at a density corresponding to 95% of the maximum dry density. |

TABLE 2

SPECIFICATION FOR BASE COURSE MATERIAL

1. Grading

| Standard Sieve Sizes | | 1972 Grading A | 1972 Grading B | 1972 Grading C | 1972 Grading D | 1976 Class A | 1976 Class B | 1976 Class C | JRA M-40 | JRA M-30 | JRA M-25 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 88.9 mm. | 4 in. | - | - | - | - | - | - | - | - | - | - |
| 76.2 mm. | 3 in. | - | - | - | - | - | - | - | - | - | - |
| 63.5 mm. | 2 ½ in. | - | - | - | - | - | - | - | - | - | - |
| 50.8 mm. | 2 in. | 100 | - | - | - | 100 | 100 | - | 100 | - | - |
| 38.1 mm. | 1 ½ in. | - | 100 | - | - | 80-100 | 80-100 | - | 95-100 | 100 | - |
| 31.7 mm. | 1 ¼ in. | - | - | - | - | - | - | - | - | 95-100 | 100 |
| 25.4 mm. | 1 in. | 55- 85 | - | 100 | - | 60-100 | 60-100 | 100 | - | - | 95-100 |
| 19.1 mm. | 3/4 in. | - | 60- 90 | - | - | 50- 85 | 55- 85 | 75-100 | 60- 90 | 60- 90 | - |
| 12.7 mm. | 1/2 in. | - | - | - | - | - | - | - | - | - | 55- 85 |
| 9.52 mm. | 3/8 in. | 35- 60 | 40- 70 | 45- 75 | 50- 80 | - | - | - | - | - | - |
| 4760 μ | No. 4 | 25- 50 | 30- 55 | 35- 60 | 40- 65 | 25- 45 | 35- 60 | 40- 60 | 30- 65 | 30- 65 | 30- 65 |
| 2380 μ | No. 8 | - | - | - | - | - | - | - | 20- 50 | 20- 50 | 20- 50 |
| 2000 μ | No. 10 | 20- 40 | 25- 45 | 30- 60 | 30- 55 | 15- 35 | 25- 50 | 25- 45 | - | - | - |
| 1190 μ | No. 16 | - | - | - | - | - | - | - | - | - | - |
| 590 μ | No. 30 | - | - | - | - | - | - | - | - | - | - |
| 420 μ | No. 40 | 8- 20 | 10- 25 | 15- 30 | 15- 35 | 8- 22 | 15- 30 | 12- 25 | 10- 30 | 10- 30 | 10- 30 |
| 297 μ | No. 50 | - | - | - | - | - | - | - | - | - | - |
| 149 μ | No. 100 | - | - | - | - | - | - | - | - | - | - |
| 74 μ | No. 200 | 2- 8 | 4- 10 | 5- 15 | 5- 15 | 2- 9 | 8- 15 | 5- 12 | 2- 10 | 2- 10 | 2- 10 |

| | 1972 | 1976 | JRA |
|---|---|---|---|
| 2. Los Angeles Abrasion Test | ≤ 50% | ≤ 40% | For Penetration Macadam, ≤40%, For Mechnical, Bituminous and Cement Stabilization, ≤50% |
| 3. Soundness Test | none | < 12% | < 20% |
| 4. CBR Value | none | Minimum soaked CBR - value of 80% | Mechanical Stabilization, 80% min., Cement and Lime Stabilization, 20% min. |
| 5. Sand Equivalent Test | none | > 50% | |
| 6. Liquid Limit (LL) and Plasticity Index (PI) | LL ≤ 35 and PI ≤ 6 | LL ≤ 25 and PI ≤ 6 | Mechanical Stabilization, PI ≥ 4; Bituminous and Cement Stabilization, PI ≥ 9; Lime Stabilization, PI = 9 to 18. |
| 7. Clay, Clay Agglomerates | nône | none | ≤ 0.25% |
| 8. Soft Pieces | none | none | ≤ 5.0% |
| 9. Flat or Elongated Particles | none | none | ≤ 10.0% |

## TABLE 3

### SPECIFICATIONS FOR PORTLAND CEMENT AGGREGATE MATERIAL

| 1. Grading | | 1972 | 1972 | 1972 | 1972 | 1976 | 1976 | JRA | JRA |
|---|---|---|---|---|---|---|---|---|---|
| | | FINE | Coarse | | | Combined | | | |
| Standard Sieve Sizes | | | Grading A | Grading B | Grading C | Class E | Class F | Fine | Coarse |
| 88.9 mm. | 4 in. | - | - | - | - | - | - | - | - |
| 76.2 mm. | 3 in. | - | - | - | - | 100 | - | - | - |
| 63.5 mm. | 2½ in. | - | - | 100 | - | 95-100 | - | - | - |
| 50.8 mm. | 2 in. | - | 100 | 95-100 | - | 80- 95 | 100 | - | 100 |
| 38.1 mm. | 1 ½ in. | - | 95-100 | - | 100 | 65- 87 | 80-100 | - | 95-100 |
| 31.7 mm. | 1¼ in. | - | - | - | - | - | - | - | - |
| 25.4 mm. | 1 in. | - | - | 35- 70 | 95-100 | 50- 75 | 50- 86 | - | - |
| 19.1 mm. | 3/4 in. | - | 35- 70 | - | - | 45- 66 | 45- 75 | - | 35- 70 |
| 12.7 mm. | ½ in. | - | - | 10- 30 | 25- 60 | - | - | - | - |
| 9.52 mm. | 3/8 in. | 100 | 10- 30 | - | - | 38- 55 | 38- 55 | 100 | 10- 30 |
| 4760 μ | No. 4 | 95-100 | 0- 5 | 0- 5 | 0- 10 | 30- 45 | 30- 45 | 90-100 | 0- 5 |
| 2380 μ | No. 8 | - | - | - | - | 23- 35 | 23- 38 | 80-100 | - |
| 2000 μ | No. 10 | - | - | - | - | - | - | - | - |
| 1190 μ | No. 16 | 45- 80 | - | - | - | 17- 27 | 17- 33 | 50- 80 | - |
| 590 μ | No. 30 | - | - | - | - | 10- 17 | 10- 22 | 25-65 | - |
| 420 μ | No. 40 | - | - | - | - | - | - | - | - |
| 297 μ | No. 50 | 10- 30 | - | - | - | 4- 9 | 4- 10 | 10- 35 | - |
| 149 μ | No. 100 | 2- 10 | - | - | - | 1- 3 | 1- 3 | 2- 10 | - |
| 74 μ | No. 200 | 0- 3 | 0- 1 | 0- 1 | 0- 1 | 0- 2 | 0- 2 | - | - |
| 2. Los Angeles Abrasion Test | | | | ≤ 45% | | | ≤ 40% | | ≤ 35% |
| 3. Soundness Test | | | | none | | | ≤ 12% | | ≤ 12% |
| 4. Decantation Test (%) | | | | none | | | none | | Fine ≤3%<br>Coarse ≤1% |
| 5. Flakiness Index | | | | none | | | none | | ≤5% |
| 6. Percentage of Soft | | | | none | | | ≤ 5% | | ≤5% |
| 7. Clay, Clay Agglomerate | | | | none | | | none | | ≤0.25% |

## TABLE 4
### SPECIFICATIONS FOR ASPHALT CONCRETE AGGREGATE MATERIAL

1. Grading

| Standard Sieve Sizes | | 1972 Composite | 1976 Class A | 1976 Class B | 1976 Class C | JRA Fine Graded | JRA Dense Graded |
|---|---|---|---|---|---|---|---|
| 88.9 mm. | 4 in. | - | - | - | - | - | - |
| 76.2 mm. | 3 in. | - | - | - | - | - | - |
| 63.5 mm. | 2½ in. | - | - | - | - | - | - |
| 50.8 mm. | 2 in. | - | - | - | - | - | - |
| 38.1 mm. | 1½ in. | - | - | - | - | - | - |
| 31.7 mm. | 1¼ in. | - | - | - | - | - | - |
| 25.4 mm. | 1 in. | - | 100 | - | - | - | 100 |
| 19.1 mm. | 3/4 in. | 100 | 80-100 | 100 | - | 100 | 95-100 |
| 12.7 mm. | 1/2 in. | 85-100 | - | 80-100 | 100 | 95-100 | 75- 95 |
| 9.52 mm. | 3/8 in. | - | 60- 80 | 70- 90 | 80-100 | - | - |
| 4760 μ | No. 4 | 40- 60 | 48- 65 | 50- 70 | 55- 75 | 65- 80 | 52 -72 |
| 2380 μ | No. 8 | - | 35- 50 | 35- 50 | 35- 50 | 50- 65 | 40- 60 |
| 2000 μ | No. 10 | 25- 45 | - | - | - | - | - |
| 1190 μ | No. 16 | - | - | - | - | - | - |
| 590 μ | No. 30 | 15- 30 | 19- 30 | 18- 29 | 18- 29 | 25- 40 | 25- 45 |
| 420 μ | No. 40 | - | - | - | - | - | - |
| 297 μ | No. 50 | - | 13- 23 | 13- 23 | 13- 23 | 12- 27 | 16- 33 |
| 149 μ | No. 100 | - | 7- 15 | 8- 16 | 8- 16 | 8- 20 | 8- 21 |
| 74 μ | No. 200 | 4- 10 | 1- 8 | 4- 10 | 4- 10 | 4- 10 | 6- 11 |

| | 1972 | 1976 | JRA |
|---|---|---|---|
| 2. Los Angeles Abrasion Test | $\leq$ 40% | $\leq$ 40% | $\leq$ 30% |
| 3. Soundness Test | none | $\leq$ 12% | $\leq$ 12% |
| 4. Sand Equivalent Test | none | $\geq$ 45% | none |
| 5. Liquid Limit (LL) and Plasticity Index (PI) | none | All aggregates shall be non-plastic | none |
| 6. Flakiness Index | none | $\leq$ 35%* | none |
| 7. Clay, clay agglomerates | none | none | $\leq$ 0.25% |
| 8. Soft Pieces | none | none | $\leq$ 5% |
| 9. Flat or Elongated Particles | none | none | $\leq$ 10% |

* The flakiness index of the aggregate ratained on the 9.5 mm (3/8 in.) sieve

TABLE 5

MARSHALL TEST REQUIREMENT FOR ASPHALT CONCRETE

| | 1972 | 1976 | | | | J R A Dense Graded |
|---|---|---|---|---|---|---|
| | | Binder Coarse | | Wearing Coarse | | |
| | | Minimum | Maximum | Minimum | Maximum | |
| Marshall Stability, min., kg. | - | 544 | - | 544 | - | 500 |
| Flow Value (1/100 cm.) | - | 20 | 40 | 20 | 40 | 20 - 40 |
| Air Voids (%) | - | 3 | 8 | 3 | 6 | 3 - 6 |
| Aggregate Voids Filled With Asphalt Cement (%) | - | 60 | 75 | 70 | 80 | 70 - 85 |
| Number of Blows for Compaction | - | - | - | - | - | 75 |

# APPENDIX 3-3
# TEST RESULT ON CEMENT, AGGREGATE AND CONCRETE BY TECHNICAL UNIVERSITY OF THE PHILIPPINES

(1) Philippines Portland Cement

Materials

Four brands of portland cement are selected on the basis of mortar strength. These are National, Island, Filipinas, and Union portland cements. In testing for the mortar strength of cement, two types of sand are used. One is Toyoura sand, the Japanese standard sand, and the other is Porac sand passing in NO. 50 and retained in No. 200. The fine particles (passing No. 200) are mostly silt and clay and therefore must be removed. The purpose for using a local sand is in connection with an attempt to established a Philippine standard sand, and the choice is based on its abundance and a little advantage in its percentage of fines.

Test Results

Table 1 presents the results of the tests conducted on cement except the mortar strengths. The values are the averages of three trials.

TABLE 1 PHYSICAL PROPERTIES OF PORTLAND CEMENT

| Cement Brand | Fineness (Sieve Method) % | Specific Gravity | Consistency w/c % | Setting Time h:m | |
|---|---|---|---|---|---|
| | | | | Initial | Final |
| Island Portland Cement | 89.4 | 3.10 | 30.1 | 2:22 | 3:30 |
| Filipinas Portland Cement | 91.2 | 2.97 | 30.2 | 1:13 | 2:42 |
| Union Portland Cement | 93.5 | 3.02 | 34.4 | 3:09 | 4:23 |
| Natioal Portland Cement | 94.2 | 3.13 | 33.5 | 3:29 | 5:09 |

Conclusion

As far as the four cements tested are concerned, all passed the requirement regarding the time of setting set forth in the ASTM C 150. The fineness which is measured in a different unit from that required by the ASTM passes the Japanese standard for Type I portland cements which is from 90 to 95%. The mortar strengths achieved are lower than those set forth in the ASTM, but can not be said to be failing because of the different water cement ratio employed, which controls strength. The specific gravity, although not required by the Building Code, which is from 2.97 to 3.13 is just a little lower than foreign portland cements of the same type (about 3.15 for Japan and US). Although cements of higher specific gravity are more favorable, the importation of such is not justifiable.

(2) Aggregate

Materials

There are several aggregate from different sources which are commonly used in concrete construction in Metro Manila. Six kinds of fine aggregates and ten of coarse aggregates were choosen as shown in Table 2. The coarse aggregates were washed while fine aggregates were allowed to pass the 7.45 mm sieve prior to testing.

Test Results

The summary of the test results are presented in Table 3 and 4 for fine aggregate and course aggregate, respectively.

TABLE 2 LIST OF AGGREGATES AND VISUAL DESCRIPTION

| | | Name/Source | Visual Description |
|---|---|---|---|
| Coarse Aggregates | Crushed Gravels | Angono | Angular, Rough Surface, Combination of Grayish and Reddish Brown Particles with Crushed Bricks |
| | | Batangas | Sub-Angular to Angular, Grayish |
| | | Bulacan | Sub-Angular to Sub-Rounded, Grayish in Color |
| | | Laguna | Angular to Sub-Angular in Shape, Light Gray in Color |
| | | Montalban | Angular in Shape, Charcoal Gray in Color |
| | Ordinary Gravels | Batangas | Sub-Angular to Sub-Rounded in Shape, Grayish in Color |
| | | Bulacan | Sub-Rounded to Rounded in Shape, Grayish in Color |
| | | Laguna | Angular in Shape, Light Gray in Color |
| | | Montalban | Sub-Rounded to Rounded in Shape, Combination of Grayish, Grayish, Brownish, and Whitish Particles |
| | | Rizal | Sub-Angular to Sub-Rounded In Shape, Grayish in Color with a Few Whitish Particles |
| Fine Aggregates | | Batangas | Blackish Gray in Color, Smooth Surface With Mineral,Particles And Clay Silt Particles |
| | | Bulacan | Grayish in Color, Rough Texture |
| | | Cavite | Brownish Gray in Color, Rough Texture, With Abundant Organic Material, Bad Odor |
| | | Porac | Blackish Gray in Color, Smooth Texture, With Mineral and Silt Particles |
| | | Rizal | Grayish in Color, Rough Texture With Mineral Particle Notably Silica |
| | | Tarlac | Whitish Gray in Color, Rough in Texture with Abundant Silica Particles |

TABLE 3 PHYSICAL PROPERTIES OF FINE AGGREGATES

| Name/Source | Unit Weight kg/cu.m. | Specific Gravity | Absorption % | Salt Content % |
|---|---|---|---|---|
| Batangas | 1,468 | 2.62 | 3.80 | 0.02 |
| Bulacan | 1,508 | 2.52 | 3.30 | 0.02 |
| Cavite | 1,284 | 2.16 | 12.12 | 0.10 |
| Porac | 1,517 | 2.50 | 2.83 | 0.02 |
| Rizal | 1,362 | 2.50 | 3.10 | 0.02 |
| Tarlac | 1,428 | 2.40 | 3.76 | 0.02 |

TABLE 4 PHYSICAL PROPERTIES OF COARSE AGGREGATES

| | Name/Source | Unit Weight kg/cu. m. | Specific Specific | Absorption % | Los Angeles Abrasion Ratio % |
|---|---|---|---|---|---|
| Crushed Gravel | Angono | 1,594 | 2.67 | 2.77 | 17.51 |
| | Batangas | 1,791 | 2.86 | 1.74 | 15.53 |
| | Bulacan | 1,831 | 2.77 | 1.39 | 18.85 |
| | Laguna | 1,568 | 2.47 | 3.44 | 34.78 |
| | Montalban | 1,739 | 2.86 | 0.86 | 18.90 |
| Ordinary Gravel | Batangas | 1,806 | 2.77 | 1.42 | 16.48 |
| | Bulacan | 1,804 | 2.77 | 1.67 | 13.60 |
| | Laguna | 1,577 | 2.53 | 3.66 | 26.90 |
| | Montalban | 1,688 | 2.78 | 1.41 | 22.70 |
| | Rizal | 1,685 | 2.64 | 2.86 | 20.20 |

Conclusion

The results of the physical properties tests on ten coarse and six fine aggregates from different sources near Metro-Manila as presented in this paper show that all sands tested are suitable for concrete mix, except Cavite sand. Cavite sand exhibited poor qualities such as high salt content, high absorption, low specific gravity and low unit weight.

All the gravels tested appear to have properties suitable for concrete mix. An exception is with regards to particle-size distribution. It is shown that only Laguna ordinary gravel passes the criteria for particle-size distribution as specified in the ASTM. However, as been mentioned, the use of gap-graded aggregates does not necessarily mean poor concrete.

As pointed out above, for small jobs where testing of aggregates maynot be practical a knowledge of properties of aggregates with the application of established empirical relationships, proportioning of materials could be ascertained. It is in this view that the results presented here could be useful and could form as a basis in proportioning materials in concrete mix.

However, it should be noted that the properties of the aggregates presented in this paper as determined from the tests performed do not constitute the sole basis in the selection of aggregates for concrete mix. Other factors such as cost, availability, and other physical or mechanical properties not included in this study should also be considered.

(3) Concrete

Concrete inorder to be a useful construction product must meet minimum compression, flexural, shear or bond strength requirements. Strength of concrete is principally dependent on the water-cement ratio. In general, factors that affect compressive strength also affect flexural, shear and, bond strengths. To control or check the strength of concrete in bridges, buildings, and other structures where principal stresses are compressive, cylinder samples are obtained and tested in compression. In concrete pavements where the stresses are bending, beam samples are tested for flexural strength. Standard Specifications specify a minimum compressive strength of 3000 psi and a minimum flexural strength of 325 psi.

Concrete must be durable to withstand the effects of service conditions such as weathering and chemical action. Like strength, durability of concrete is dependent upon the water-cement ratio. Specifications for concrete exposed to weathering limit the water-cement ratio to 0.80 by volume, or 6.0 gallons of water per bag of cement.

## Materials

Mixing ratio of concrete for test are shown in Table 5.

TABLE 5 MIXING RATIO OF CONCRETE

| Mix Code: | A - I - 1 | | W/C = .5 | | Total/Mix |
|---|---|---|---|---|---|
| Material | S.G. | 1 Cu. m. | 10 lit. | 46 lit. | |
| Cement (kg) Nat. Portland | 3.13 | 300.00 | 3.00 | 13.80 | 72.00 |
| Sand (kg) Porac | 2.50 | 825.92 | 8.26 | 37.99 | 198.22 |
| Gravel (kg) Montalban Ord. | 2.78 | 1,122.52 | 11.23 | 51.64 | 269.40 |
| Water (kg) | 1.00 | 150.00 | 1.50 | 6.90 | 36.00 |
| Mix Code: | A - I - 1 | | W/C = .6 | | Total Mix |
| Material | S.G. | 1 Cu. m. | 10 lit. | 46 lit. | |
| Cement (kg) Nat. Portland | 3.13 | 300.00 | 3.00 | 13.80 | 72.00 |
| Sand (kg) Porac | 2.50 | 792.00 | 7.92 | 36.44 | 190.12 |
| Gravel (kg) Montalban Ord. | 2.78 | 1,076.65 | 10.77 | 49.53 | 258.40 |
| Water (kg) | 1.00 | 180.00 | 1.80 | 8.28 | 43.20 |
| Mix Code: | A - I - 1 | | W/C = 0.7 | | Total Mix |
| Material | S.G. | 1 Cu. m. | 10 lit. | 46 lit. | |
| Cement (kg) Nat. Portland | 3.13 | 300.00 | 3.00 | 13.80 | 72.00 |
| Sand (kg) Porac | 2.50 | 758.42 | 7.58 | 34.89 | 182.02 |
| Gravel (kg) Montalban Ord. | 2.78 | 1,030.78 | 10.31 | 47.42 | 247.39 |
| Water (kg) | 1.00 | 210.00 | 2.10 | 9.66 | 50.40 |

Test Results

Table 6, 7 and 8 summarize effects of W/C, gravels and sands, respectively. Table 9 presents the overall evaluation.

| W / C (%) | CURING CONDITION | COMPRESSIVE STRENGTH (kg/sq.cm.) | | | SPLIT-TENSION STRENGTH (kg/sq.cm.) | | | BENDING STRENGTH (kg/sq.cm.) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 3 DAYS | 7 DAYS | 28 DAYS | 3 DAYS | 7 DAYS | 28 DAYS | 3 DAYS | 7 DAYS | 28 DAYS |
| 50 | CURED | 115.74 ( 40 %) | 195.12 ( 67 %) | 292.21 ( 100 %) | 14.84 ( 59 %) | 17.50 ( 70 %) | 24.95 ( 100 %) | 25.23 ( 60 %) | 32.29 ( 77 %) | 42.00 ( 100 %) |
| | UNCURED | 105.04 ( 36 %) | 179.53 ( 61 %) | 243.03 ( 83 %) | 11.48 ( 46 %) | 14.52 ( 58 %) | 21.22 ( 85 %) | 25.10 ( 60 %) | 27.82 ( 66 %) | 39.14 ( 93 %) |
| 60 | CURED | 84.48 ( 39 %) | 138.30 ( 64 %) | 214.86 ( 100 %) | 9.99 ( 68 %) | 13.10 ( 90 %) | 14.62 ( 100 %) | 20.70 ( 53 %) | 25.72 ( 66 %) | 39.18 ( 100 %) |
| | UNCURED | 90.08 ( 42 %) | 140.06 ( 65 %) | 146.58 ( 68 %) | 7.64 ( 52 %) | 11.91 ( 81 %) | 12.79 ( 87 %) | 17.25 ( 44 %) | 22.56 ( 58 %) | 28.98 ( 74 %) |
| 70 | CURED | 38.96 ( 25 %) | 77.98 ( 51 %) | 154.38 ( 100 %) | 6.68 ( 53 %) | 10.22 ( 81 %) | 12.69 ( 100 %) | 15.82 ( 48 %) | 23.16 ( 70 %) | 32.92 ( 100 %) |
| | UNCURED | 44.56 ( 29 %) | 77.48 ( 50 %) | 104.18 ( 67 %) | 5.86 ( 46 %) | 9.96 ( 78 %) | 10.41 ( 82 %) | 15.23 ( 46 %) | 18.10 ( 55 %) | 18.40 ( 56 %) |

TABLE 6 Effect of W/C on the strength of concrete. Type of cement, type of gravel, type of sand, and S/A are maintained constant (Nat. Portland, Montalban Ordinary, Porac, and S/A=45%). Values in parentheis () are percentages of strength based on the 28-day strength of cured concrete.

| GRAVEL | CURING CONDITION | COMPRESSIVE STRENGTH (kg/sq.cm.) | | | SPLIT-TENSION STRENGTH (kg/sq.cm.) | | | BENDING STRENGTH (kg/sq.cm.) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 3 DAYS | 7 DAYS | 28 DAYS | 3 DAYS | 7 DAYS | 28 DAYS | 3 DAYS | 7 DAYS | 28 DAYS |
| Montalban Ordinary | CURED | 84.40 (39 %) | 138.30 (64 %) | 214.86 (100 %) | 9.99 (68 %) | 13.10 (90 %) | 14.62 (100 %) | 20.70 (53 %) | 25.72 (66 %) | 39.18 (100 %) |
| | UNCURED | 90.08 (42 %) | 140.06 (65 %) | 146.58 (68 %) | 7.64 (52 %) | 11.91 (81 %) | 12.79 (87 %) | 17.25 (44 %) | 22.56 (58 %) | 28.98 (74 %) |
| Batangas Ordinary | CURED | 100.14 (38 %) | 165.04 (63 %) | 260.86 (100 %) | 11.50 (48 %) | 16.62 (70 %) | 23.74 (100 %) | 19.86 (55 %) | 27.13 (75 %) | 36.38 (100 %) |
| | UNCURED | 106.70 (41 %) | 163.61 (63 %) | 177.46 (68 %) | 10.26 (43 %) | 12.49 (53 %) | 14.77 (62 %) | 18.52 (51 %) | 18.64 (51 %) | 23.30 (64 %) |
| Bulacan Ordinary | CURED | 89.70 (41 %) | 132.89 (61 %) | 217.09 (100 %) | 9.66 (35 %) | 14.80 (57 %) | 26.13 (100 %) | 17.95 (47 %) | 24.77 (65 %) | 37.08 (100 %) |
| | UNCURED | 94.73 (44 %) | 127.00 (59 %) | 156.61 (72 %) | 9.48 (36 %) | 13.34 (51 %) | 13.36 (51 %) | 15.84 (42 %) | 19.31 (51 %) | 25.32 (67 %) |
| Laguna Ordinary | CURED | 96.30 (43 %) | 130.82 (59 %) | 221.86 (100 %) | 11.02 (48 %) | 15.95 (69 %) | 22.96 (100 %) | 18.97 (50 %) | 26.54 (69 %) | 38.26 (100 %) |
| | UNCURED | 100.20 (45 %) | 140.38 (63 %) | 184.46 (83 %) | 10.15 (44 %) | 14.59 (64 %) | 19.70 (86 %) | 17.32 (45 %) | 22.16 (58 %) | 32.69 (85 %) |
| Rizal Ordinary | CURED | 81.01 (38 %) | 129.55 (61 %) | 212.95 (100 %) | 9.23 (41 %) | 15.04 (67 %) | 22.50 (100 %) | 17.27 (59 %) | 26.06 (88 %) | 29.48 (100 %) |
| | UNCURED | 95.33 (45 %) | 128.91 (61 %) | 145.47 (68 %) | 9.80 (44 %) | 13.08 (58 %) | 12.28 (55 %) | 14.05 (48 %) | 16.20 (55 %) | 23.08 (78 %) |
| Angono Crushed | CURED | 112.68 (51 %) | 143.88 (65 %) | 221.86 (100 %) | 13.98 (55 %) | 17.04 (67 %) | 25.52 (100 %) | 21.78 (64 %) | 25.80 (76 %) | 33.90 (100 %) |
| | UNCURED | 127.32 (57 %) | 152.15 (69 %) | 209.76 (95 %) | 14.69 (58 %) | 18.62 (73 %) | 23.44 (92 %) | 19.68 (58 %) | 26.36 (78 %) | 32.94 (97 %) |
| Batangas Crushed | CURED | 84.93 (37 %) | 126.21 (55 %) | 227.59 (100 %) | 11.94 (71 %) | 12.61 (75 %) | 16.85 (100 %) | 18.28 (55 %) | 23.83 (71 %) | 33.47 (100 %) |
| | UNCURED | 91.99 (40 %) | 137.51 (60 %) | 197.35 (87 %) | 9.72 (58 %) | 15.89 (94 %) | 18.06 (107 %) | 20.78 (62 %) | 22.60 (68 %) | 32.90 (98 %) |
| Bulacan Crushed | CURED | 89.28 (37 %) | 137.23 (57 %) | 242.23 (100 %) | 11.66 (61 %) | 13.10 (69 %) | 19.00 (100 %) | 16.52 (43 %) | 24.90 (65 %) | 38.04 (100 %) |
| | UNCURED | 91.51 (38 %) | 145.15 (60 %) | 221.70 (92 %) | 10.00 (53 %) | 16.88 (89 %) | 16.90 (89 %) | 17.00 (45 %) | 25.74 (68 %) | 32.75 (86 %) |
| Laguna Crushed | CURED | 110.93 (43 %) | 154.70 (60 %) | 259.74 (100 %) | 7.84 (49 %) | 9.30 (58 %) | 16.04 (100 %) | 18.82 (50 %) | 26.35 (70 %) | 37.51 (100 %) |
| | UNCURED | 114.27 (44 %) | 171.57 (66 %) | 226.64 (87 %) | 13.04 (81 %) | 10.23 (64 %) | 13.46 (84 %) | 19.25 (51 %) | 25.89 (69 %) | 33.54 (89 %) |
| Montalban Crushed | CURED | 82.57 (35 %) | 129.87 (54 %) | 239.05 (100 %) | 10.64 (48 %) | 17.33 (77 %) | 22.39 (100 %) | 21.91 (60 %) | 29.99 (82 %) | 36.78 (100 %) |
| | UNCURED | 97.53 (41 %) | 147.06 (62 %) | 172.52 (72 %) | 10.59 (47 %) | 15.46 (69 %) | 15.51 (69 %) | 21.08 (57 %) | 24.62 (67 %) | 24.41 (66 %) |

TABLE 7 Effect of Gravel on the strength of concrete. Type of cement, type of sand, W/C, and S/A are maintained constant (Nat. Portland, Porac, W/C=60%, and S/A=45%). Values in parenthesis () are the percentages of strength based on the 28-day strength of cured concrete.

| SAND | CURING CONDITION | COMPRESSIVE STRENGTH (kg/sq.cm.) | | | SPLIT-TENSION STRENGTH (kg/sq.cm.) | | | BENDING STRENGTH (kg/sq.cm.) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 3 DAYS | 7 DAYS | 28 DAYS | 3 DAYS | 7 DAYS | 28 DAYS | 3 DAYS | 7 DAYS | 28 DAYS |
| Porac | CURED | 82.57 (35 %) | 129.87 (54 %) | 239.05 (100 %) | 10.64 (48 %) | 17.33 (77 %) | 22.39 (100 %) | 21.91 (60 %) | 29.99 (82 %) | 36.78 (100 %) |
| | UNCURED | 97.53 (41 %) | 147.06 (62 %) | 172.52 (72 %) | 10.59 (47 %) | 15.46 (69 %) | 15.51 (69 %) | 21.08 (57 %) | 24.62 (67 %) | 24.41 (66 %) |
| Tarlac | CURED | 91.04 (43 %) | 131.62 (63 %) | 209.77 (100 %) | 10.55 (48 %) | 11.31 (51 %) | 22.20 (100 %) | 18.78 (61 %) | 24.83 (80 %) | 30.96 (100 %) |
| | UNCURED | 91.35 (44 %) | 125.23 (60 %) | 200.54 (96 %) | 10.34 (47 %) | 13.60 (61 %) | 23.73 (107 %) | 16.97 (55 %) | 25.31 (82 %) | 35.99 (116 %) |
| Bulacan | CURED | 105.57 (38 %) | 171.09 (62 %) | 277.56 (100 %) | 11.37 (50 %) | 17.52 (78 %) | 22.56 (100 %) | 20.72 (53 %) | 31.37 (80 %) | 39.13 (100 %) |
| | UNCURED | 112.87 (41 %) | 137.51 (50 %) | 234.28 (84 %) | 13.29 (59 %) | 15.77 (70 %) | 21.85 (97 %) | 24.98 (64 %) | 26.67 (68 %) | 35.24 (90 %) |
| Batangas | CURED | 121.28 (44 %) | 176.18 (64 %) | 275.18 (100 %) | 9.60 (36 %) | 15.80 (59 %) | 26.82 (100 %) | 22.70 (61 %) | 29.36 (79 %) | 36.97 (100 %) |
| | UNCURED | 121.91 (44 %) | 189.87 (69 %) | 222.82 (81 %) | 11.99 (45 %) | 13.30 (50 %) | 21.94 (82 %) | 22.49 (61 %) | 28.69 (78 %) | 35.66 (96 %) |
| Cavite | CURED | 125.10 (51 %) | 171.25 (70 %) | 243.83 (100 %) | 12.40 (74 %) | 13.55 (80 %) | 16.87 (100 %) | 21.02 (75 %) | 26.04 (93 %) | 28.07 (100 %) |
| | UNCURED | 123.63 (51 %) | 170.13 (70 %) | 243.19 (100 %) | 12.42 (74 %) | 13.68 (81 %) | 16.04 (95 %) | 23.46 (84 %) | 24.85 (89 %) | 28.42 (101 %) |
| Rizal | CURED | 88.74 (41 %) | 139.42 (64 %) | 216.45 (100 %) | 11.00 (47 %) | 15.95 (68 %) | 23.35 (100 %) | 20.22 (53 %) | 25.30 (67 %) | 37.98 (100 %) |
| | UNCURED | 89.54 (41 %) | 136.24 (63 %) | 215.17 (99 %) | 11.23 (48 %) | 15.12 (65 %) | 17.69 (76 %) | 18.28 (48 %) | 22.69 (60 %) | 29.32 (77 %) |

TABLE 8 Effect of Sand on the strength of concrete. Type of cement, type of gravel, W/C, and S/A are maintained constant (Nat. Portland, Montalban Crushed, W/C=60%, and S/A=45%). Values in parenthesis () are percentages of strength based on the 28-day strength of cured concrete.

| TEST TYPE | CURING CONDITION | RANGE OF STRENGTH (kg/sq.cm.) | | | AVERAGE STRENGTH (kg/sq.cm.) | | |
|---|---|---|---|---|---|---|---|
| | | 3 DAYS | 7 DAYS | 28 DAYS | 3 DAYS | 7 DAYS | 28 DAYS |
| COMPRESSION | CURED | 81.01 - 125.10 [ 44.09 ] | 126.21 - 176.18 [ 49.97 ] | 209.77 - 277.56 [ 67.79 ] | 97.59 ( 41 %, 41 %) | 145.19 ( 62 %, 62 %) | 236.06 ( 100 %, 100 %) |
| | UNCURED | 89.54 - 127.32 [ 37.78 ] | 125.23 - 189.87 [ 64.64 ] | 145.47 - 243.19 [ 97.72 ] | 103.26 ( 44 %, 44 %) | 147.49 ( 62 %, 62 %) | 196.97 ( 83 %, 83 %) |
| SPLIT-TENSION | CURED | 7.84 - 13.98 [ 6.14 ] | 9.30 - 17.52 [ 8.22 ] | 14.62 - 26.82 [ 12.2 ] | 10.79 ( 50 %, 5 %) | 14.60 ( 68 %, 6 %) | 21.44 ( 100 %, 9 %) |
| | UNCURED | 7.64 - 14.69 [ 7.05 ] | 10.23 - 18.62 [ 8.39 ] | 12.28 - 23.73 [ 11.45 ] | 10.98 ( 51 %, 5 %) | 14.26 ( 67 %, 6 %) | 17.43 ( 81 %, 7 %) |
| BENDING | CURED | 16.52 - 22.70 [ 6.18 ] | 23.83 - 31.37 [ 7.54 ] | 28.07 - 39.18 [ 11.11 ] | 19.70 ( 55 %, 8 %) | 26.53 ( 75 %, 11 %) | 35.60 ( 100 %, 15 %) |
| | UNCURED | 14.05 - 24.98 [ 10.93 ] | 16.20 - 28.69 [ 12.49 ] | 23.08 - 35.99 [ 12.91 ] | 19.13 ( 54 %, 8 %) | 23.49 ( 66 %, 10 %) | 30.30 ( 85 %, 13 %) |

TABLE 9 Overall evaluation of the average strength and the range of strength (W/A=60% and S/A=45%). Values in parenthesis () are the percentages of strength, the first one is based on the average 28 day strength of cured concrete, and the second one is based on the average 28-day compressive strength of cured concrete. The value inside the bracket [] is the difference between the maximum and minimum strength.

# APPENDIX 4-1
# AXLE LOAD EQUIVALENCY FACTORS

TABLE 1 AXLE LOAD EQUIVALENCY FACTORS FOR RIGID PAVEMENTS, SINGLE AXLES AND $p_t$ of 2.5

| Axle Load (kips) | Slab Thickness, D (inches) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 2 | .0002 | .0002 | .0002 | .0002 | .0002 | .0002 | .0002 | .0002 | .0002 |
| 4 | .003 | .002 | .002 | .002 | .002 | .002 | .002 | .002 | .002 |
| 6 | .012 | .011 | .010 | .010 | .010 | .010 | .010 | .010 | .010 |
| 8 | .039 | .035 | .033 | .032 | .032 | .032 | .032 | .032 | .032 |
| 10 | .097 | .089 | .084 | .082 | .081 | .080 | .080 | .080 | .080 |
| 12 | .203 | .189 | .181 | .176 | .175 | .174 | .174 | .173 | .173 |
| 14 | .376 | .360 | .347 | .341 | .338 | .337 | .336 | .336 | .336 |
| 16 | .634 | .623 | .610 | .604 | .601 | .599 | .599 | .599 | .598 |
| 18 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 20 | 1.51 | 1.52 | 1.55 | 1.57 | 1.58 | 1.58 | 1.59 | 1.59 | 1.59 |
| 22 | 2.21 | 2.20 | 2.28 | 2.34 | 2.38 | 2.40 | 2.41 | 2.41 | 2.41 |
| 24 | 3.16 | 3.10 | 3.22 | 3.36 | 3.45 | 3.50 | 3.53 | 3.54 | 3.55 |
| 26 | 4.41 | 4.26 | 4.42 | 4.67 | 4.85 | 4.95 | 5.01 | 5.04 | 5.05 |
| 28 | 6.05 | 5.76 | 5.92 | 6.29 | 6.61 | 6.81 | 6.92 | 6.98 | 7.01 |
| 30 | 8.16 | 7.67 | 7.79 | 8.28 | 8.79 | 9.14 | 9.35 | 9.46 | 9.52 |
| 32 | 10.8 | 10.1 | 10.1 | 10.7 | 11.4 | 12.0 | 12.3 | 12.6 | 12.7 |
| 34 | 14.1 | 13.0 | 12.9 | 13.6 | 14.6 | 15.4 | 16.0 | 16.4 | 16.5 |
| 36 | 18.2 | 16.7 | 16.4 | 17.1 | 18.3 | 19.5 | 20.4 | 21.0 | 21.3 |
| 38 | 23.1 | 21.1 | 20.6 | 21.3 | 22.7 | 24.3 | 25.6 | 26.4 | 27.0 |
| 40 | 29.1 | 26.5 | 25.7 | 26.3 | 27.9 | 29.9 | 31.6 | 32.9 | 33.7 |
| 42 | 36.2 | 32.9 | 31.7 | 32.2 | 34.0 | 36.3 | 38.7 | 40.4 | 41.6 |
| 44 | 44.6 | 40.4 | 38.8 | 39.2 | 41.0 | 43.8 | 46.7 | 49.1 | 50.8 |
| 46 | 54.5 | 49.3 | 47.1 | 47.3 | 49.2 | 52.3 | 55.9 | 59.0 | 61.4 |
| 48 | 66.1 | 59.7 | 56.9 | 56.8 | 58.7 | 62.1 | 66.3 | 70.3 | 73.4 |
| 50 | 79.4 | 71.7 | 68.2 | 67.8 | 69.6 | 73.3 | 78.1 | 83.0 | 87.1 |

TABLE 2 AXLE LOAD EQUIVALENCY FACTORS FOR RIGID PAVEMENTS, TANDEM AXLES AND $p_t$ of 2.5

| Axle Load (kips) | Slab Thickness, D (inches) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 2 | .0001 | .0001 | .0001 | .0001 | .0001 | .0001 | .0001 | .0001 | .0001 |
| 4 | .0006 | .0006 | .0005 | .0005 | .0005 | .0005 | .0005 | .0005 | .0005 |
| 6 | .002 | .002 | .002 | .002 | .002 | .002 | .002 | .002 | .002 |
| 8 | .007 | .006 | .006 | .005 | .005 | .005 | .005 | .005 | .005 |
| 10 | .015 | .014 | .013 | .013 | .012 | .012 | .012 | .012 | .012 |
| 12 | .031 | .028 | .026 | .026 | .025 | .025 | .025 | .025 | .025 |
| 14 | .057 | .052 | .049 | .048 | .047 | .047 | .047 | .047 | .047 |
| 16 | .097 | .089 | .084 | .082 | .081 | .081 | .080 | .080 | .080 |
| 18 | .155 | .143 | .136 | .133 | .132 | .131 | .131 | .131 | .131 |
| 20 | .234 | .220 | .211 | .206 | .204 | .203 | .203 | .203 | .203 |
| 22 | .340 | .325 | .313 | .308 | .305 | .304 | .303 | .303 | .303 |
| 24 | .475 | .462 | .450 | .444 | .441 | .440 | .439 | .439 | .439 |
| 26 | .644 | .637 | .627 | .622 | .620 | .619 | .618 | .618 | .618 |
| 28 | .855 | .854 | .852 | .850 | .850 | .850 | .849 | .849 | .849 |
| 30 | 1.11 | 1.12 | 1.13 | 1.14 | 1.14 | 1.14 | 1.14 | 1.14 | 1.14 |
| 32 | 1.43 | 1.44 | 1.47 | 1.49 | 1.50 | 1.51 | 1.51 | 1.51 | 1.51 |
| 34 | 1.82 | 1.82 | 1.87 | 1.92 | 1.95 | 1.96 | 1.97 | 1.97 | 1.97 |
| 36 | 2.29 | 2.27 | 2.35 | 2.43 | 2.48 | 2.51 | 2.52 | 2.52 | 2.53 |
| 38 | 2.85 | 2.80 | 2.91 | 3.03 | 3.12 | 3.16 | 3.18 | 3.20 | 3.20 |
| 40 | 3.52 | 3.42 | 3.55 | 3.74 | 3.87 | 3.94 | 3.98 | 4.00 | 4.01 |
| 42 | 4.32 | 4.16 | 4.30 | 4.55 | 4.74 | 4.86 | 4.91 | 4.95 | 4.96 |
| 44 | 5.26 | 5.01 | 5.16 | 5.48 | 5.75 | 5.92 | 6.01 | 6.06 | 6.09 |
| 46 | 6.36 | 6.01 | 6.14 | 6.53 | 6.90 | 7.14 | 7.28 | 7.36 | 7.40 |
| 48 | 7.64 | 7.16 | 7.27 | 7.73 | 8.21 | 8.55 | 8.75 | 8.86 | 8.92 |
| 50 | 9.11 | 8.50 | 8.55 | 9.07 | 9.68 | 10.14 | 10.42 | 10.58 | 10.66 |
| 52 | 10.8 | 10.0 | 10.0 | 10.6 | 11.3 | 11.9 | 12.3 | 12.5 | 12.7 |
| 54 | 12.8 | 11.8 | 11.7 | 12.3 | 13.2 | 13.9 | 14.5 | 14.8 | 14.9 |
| 56 | 15.0 | 13.8 | 13.6 | 14.2 | 15.2 | 16.2 | 16.8 | 17.3 | 17.5 |
| 58 | 17.5 | 16.0 | 15.7 | 16.3 | 17.5 | 18.6 | 19.5 | 20.1 | 20.4 |
| 60 | 20.3 | 18.5 | 18.1 | 18.7 | 20.0 | 21.4 | 22.5 | 23.2 | 23.6 |
| 62 | 23.5 | 21.4 | 20.8 | 21.4 | 22.8 | 24.4 | 25.7 | 26.7 | 27.3 |
| 64 | 27.0 | 24.6 | 23.8 | 24.4 | 25.8 | 27.7 | 29.3 | 30.5 | 31.3 |
| 66 | 31.0 | 28.1 | 27.1 | 27.6 | 29.2 | 31.3 | 33.2 | 34.7 | 35.7 |
| 68 | 35.4 | 32.1 | 30.9 | 31.3 | 32.9 | 35.2 | 37.5 | 39.3 | 40.5 |
| 70 | 40.3 | 36.5 | 35.0 | 35.3 | 37.0 | 39.5 | 42.1 | 44.3 | 45.9 |
| 72 | 45.7 | 41.4 | 39.6 | 39.8 | 41.5 | 44.2 | 47.2 | 49.8 | 51.7 |
| 74 | 51.7 | 46.7 | 44.6 | 44.7 | 46.4 | 49.3 | 52.7 | 55.7 | 58.0 |
| 76 | 58.3 | 52.6 | 50.2 | 50.1 | 51.8 | 54.9 | 58.6 | 62.1 | 64.8 |
| 78 | 65.5 | 59.1 | 56.3 | 56.1 | 57.7 | 60.9 | 65.0 | 69.0 | 72.3 |
| 80 | 73.4 | 66.2 | 62.9 | 62.5 | 64.2 | 67.5 | 71.9 | 76.4 | 80.2 |
| 82 | 82.0 | 73.9 | 70.2 | 69.6 | 71.2 | 74.7 | 79.4 | 84.4 | 88.8 |
| 84 | 91.4 | 82.4 | 78.1 | 77.3 | 78.9 | 82.4 | 87.4 | 93.0 | 98.1 |
| 86 | 102. | 92. | 87. | 86. | 87. | 91. | 96. | 102. | 108. |
| 88 | 113. | 102. | 96. | 95. | 96. | 100. | 105. | 112. | 119. |
| 90 | 125. | 112. | 106. | 105. | 106. | 110. | 115. | 123. | 130. |

TABLE 3 AXLE LOAD EQUIVALENCY FACTORS FOR RIGID PAVEMENTS, TRIPLE AXLES AND $p_t$ of 2.5

| Axle Load (kips) | Slab Thickness, D (inches) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 2 | .0001 | .0001 | .0001 | .0001 | .0001 | .0001 | .0001 | .0001 | .0001 |
| 4 | .0003 | .0003 | .0003 | .0003 | .0003 | .0003 | .0003 | .0003 | .0003 |
| 6 | .001 | .001 | .001 | .001 | .001 | .001 | .001 | .001 | .001 |
| 8 | .003 | .002 | .002 | .002 | .002 | .002 | .002 | .002 | .002 |
| 10 | .006 | .005 | .005 | .005 | .005 | .005 | .005 | .005 | .005 |
| 12 | .011 | .010 | .010 | .009 | .009 | .009 | .009 | .009 | .009 |
| 14 | .020 | .018 | .017 | .017 | .016 | .016 | .016 | .016 | .016 |
| 16 | .033 | .030 | .029 | .028 | .027 | .027 | .027 | .027 | .027 |
| 18 | .053 | .048 | .045 | .044 | .044 | .043 | .043 | .043 | .043 |
| 20 | .080 | .073 | .069 | .067 | .066 | .066 | .066 | .066 | .066 |
| 22 | .116 | .107 | .101 | .099 | .098 | .097 | .097 | .097 | .097 |
| 24 | .163 | .151 | .144 | .141 | .139 | .139 | .138 | .138 | .138 |
| 26 | .222 | .209 | .200 | .195 | .194 | .193 | .192 | .192 | .192 |
| 28 | .295 | .281 | .271 | .265 | .263 | .262 | .262 | .262 | .262 |
| 30 | .384 | .371 | .359 | .354 | .351 | .350 | .349 | .349 | .349 |
| 32 | .490 | .480 | .468 | .463 | .460 | .459 | .458 | .458 | .458 |
| 34 | .616 | .609 | .601 | .596 | .594 | .593 | .592 | .592 | .592 |
| 36 | .765 | .762 | .759 | .757 | .756 | .755 | .755 | .755 | .755 |
| 38 | .939 | .941 | .946 | .948 | .950 | .951 | .951 | .951 | .951 |
| 40 | 1.14 | 1.15 | 1.16 | 1.17 | 1.18 | 1.18 | 1.18 | 1.18 | 1.18 |
| 42 | 1.38 | 1.38 | 1.41 | 1.44 | 1.45 | 1.46 | 1.46 | 1.46 | 1.46 |
| 44 | 1.65 | 1.65 | 1.70 | 1.74 | 1.77 | 1.78 | 1.78 | 1.78 | 1.79 |
| 46 | 1.97 | 1.96 | 2.03 | 2.09 | 2.13 | 2.15 | 2.16 | 2.16 | 2.16 |
| 48 | 2.34 | 2.31 | 2.40 | 2.49 | 2.55 | 2.58 | 2.59 | 2.60 | 2.60 |
| 50 | 2.76 | 2.71 | 2.81 | 2.94 | 3.02 | 3.07 | 3.09 | 3.10 | 3.11 |
| 52 | 3.24 | 3.15 | 3.27 | 3.44 | 3.56 | 3.62 | 3.66 | 3.68 | 3.68 |
| 54 | 3.79 | 3.66 | 3.79 | 4.00 | 4.16 | 4.26 | 4.30 | 4.33 | 4.34 |
| 56 | 4.41 | 4.23 | 4.37 | 4.63 | 4.84 | 4.97 | 5.03 | 5.07 | 5.09 |
| 58 | 5.12 | 4.87 | 5.00 | 5.32 | 5.59 | 5.76 | 5.85 | 5.90 | 5.93 |
| 60 | 5.91 | 5.59 | 5.71 | 6.08 | 6.42 | 6.64 | 6.77 | 6.84 | 6.87 |
| 62 | 6.80 | 6.39 | 6.50 | 6.91 | 7.33 | 7.62 | 7.79 | 7.88 | 7.93 |
| 64 | 7.79 | 7.29 | 7.37 | 7.82 | 8.33 | 8.70 | 8.92 | 9.04 | 9.11 |
| 66 | 8.90 | 8.28 | 8.33 | 8.83 | 9.42 | 9.88 | 10.17 | 10.33 | 10.42 |
| 68 | 10.1 | 9.4 | 9.4 | 9.9 | 10.6 | 11.2 | 11.5 | 11.7 | 11.9 |
| 70 | 11.5 | 10.6 | 10.6 | 11.1 | 11.9 | 12.6 | 13.0 | 13.3 | 13.5 |
| 72 | 13.0 | 12.0 | 11.8 | 12.4 | 13.3 | 14.1 | 14.7 | 15.0 | 15.2 |
| 74 | 14.6 | 13.5 | 13.2 | 13.8 | 14.8 | 15.8 | 16.5 | 16.9 | 17.1 |
| 76 | 16.5 | 15.1 | 14.8 | 15.4 | 16.5 | 17.6 | 18.4 | 18.9 | 19.2 |
| 78 | 18.5 | 16.9 | 16.5 | 17.1 | 18.2 | 19.5 | 20.5 | 21.1 | 21.5 |
| 80 | 20.6 | 18.8 | 18.3 | 18.9 | 20.2 | 21.6 | 22.7 | 23.5 | 24.0 |
| 82 | 23.0 | 21.0 | 20.3 | 20.9 | 22.2 | 23.8 | 25.2 | 26.1 | 26.7 |
| 84 | 25.6 | 23.3 | 22.5 | 23.1 | 24.5 | 26.2 | 27.8 | 28.9 | 29.6 |
| 86 | 28.4 | 25.8 | 24.9 | 25.4 | 26.9 | 28.8 | 30.5 | 31.9 | 32.8 |
| 88 | 31.5 | 28.6 | 27.5 | 27.9 | 29.4 | 31.5 | 33.5 | 35.1 | 36.1 |
| 90 | 34.8 | 31.5 | 30.3 | 30.7 | 32.2 | 34.4 | 36.7 | 38.5 | 39.8 |

# APPENDIX 5-1
# CATEGORIZATION OF PAVEMENT DISTRESS

CATEGORIZATION OF CONCRETE PAVEMENT DISTRESS

1. Blow-up
2. Corner Break
3. Depression
4. Faulting of Transverse Joints and Cracks
5. Joint Seal Damage of Transverse Joints
6. Lane/shoulder Drop-Off or Heave
7. Longitudinal Cracks
8. Longitudinal Joint Faulting
9. Popouts
10. Pumping and Water Bleeding
11. Reactive Aggregate Distresses
12. Scaling, Map Cracking, Crazing
13. Spalling (Transverse and Longitudinal Joint/Crack)
14. Transverse and Diagonal Cracks

A. Block Cracking, Random, Third Stage Crack
B. Peeling
C. Slab Rocking
D. Pothole, Chuck-Hole

## Blow-up

Description:

Most blow-ups occur during the spring and hot summer at a transverse joint or wide crack. Infiltration of incompressible materials into the joint or crack during cold period results in high compressive stresses in hot periods. When this compressive pressure becomes too great, a localized upward movement of the slab or shattering occurs at the joint or crack. Blow-ups are accelerated due to a spalling away of the slab at the bottom creating reduced joint contact area. The presence of "D" cracking of freeze-thaw damage also weakens the concrete near the joint resulting in increased spalling and blow-up potential.

Severity Levels:

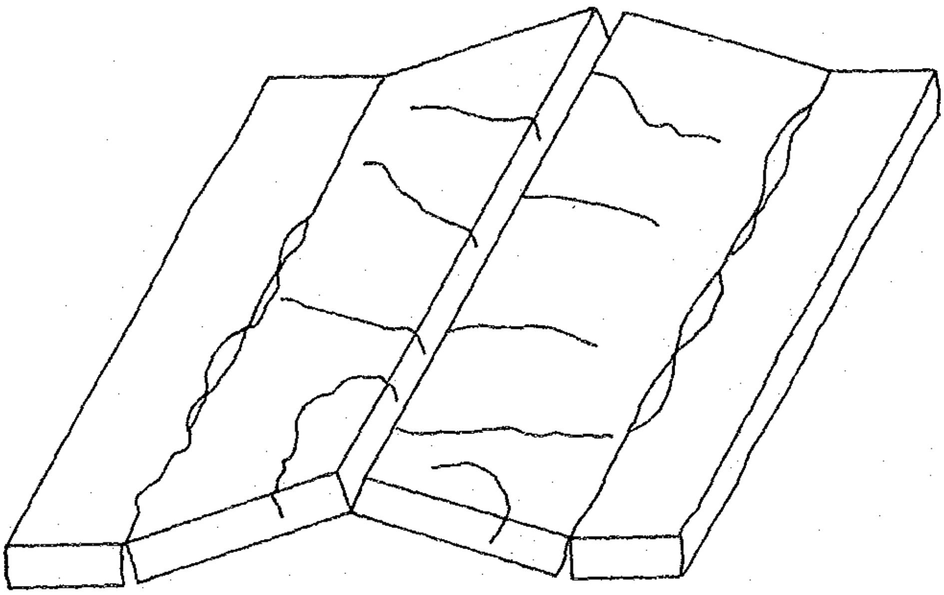
L - Blow-up has occured but only caused some bounce of the vehicle which creates no discomfort.

M - Blow-up causes a significant bounce of the vehicle which creates some discomfort. Temporary patching may have been placed because of the blow-up.

H - Blow-up causes excessive bounce of the vehicle which creates substantial discomfort, and/or safety hazard, and/or vehicle damage, requiring a reduction in speed for safety.

How to measure:

Blow-ups are measured by counting the number existing in each uniform section. Severity level is determined by riding in a mid-to full-sized sedan weighing approximately 3,000 to 3,800 lb. (13.3-16.9 kN) over the uniform section at the posted speed limit. The number is not as important as the fact that initial blow-ups signal a problem with "lengthening" or gradual downhill movement and others should be expected to occur until the maximum distance is down to 1,000 feet between blow-ups, the distance required to develop full restraint of an interior section.



BLOWUP (BUCKLING)

## Corner Break

Description:

A corner break is a crack that intersects the joints at a distance less than 6 feet (1.8 m) on each side measured from the corner of the slab. A corner break extends vertically through the entire slab thickness. It should not be confused with a corner spall, which intersects the joint at an angle througn the slab and is typically within 1 foot (0.3 m) from the slab corner. Heavy repeated loads combined with pumping, poor load transfer across the joint, and thermal curling and moisture warping stresses result in corner breaks.

Severity Levels:

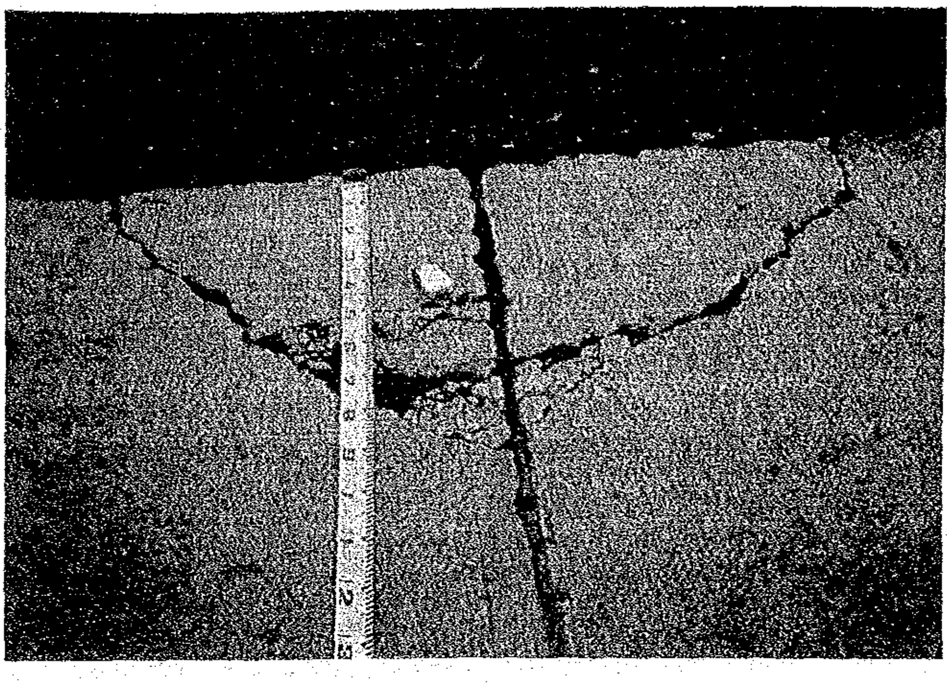
L - Crack is tight (hairline). Well-sealed cracks are considered tight. No faulting or break -up of broken corner exists. Crack is not spalled.

M - Crack is working and spalled at medium severity, but break-up of broken corner has not occured. Faulting of crack of joint is less than 1/2 inch (13 mm). Temporary patching may have been placed because of corner break.

H - Crack is spalled at high severity, the corner piece has broken into two or more pieces, or faulting of crack or joint is more than 1/2 inch (13 mm).

How to measure:

Corner breaks are measured by counting the number that exists in the uniform section. Different levels of severity should be counted and recorded separately. Corner breaks adjacent to a patch will be counted as "patch adjacent slab deterioration."



## Depression

Description:

Depressions in concrete pavements are localized settled areas. There is generally significant slab cracking in these areas due to uneven settlement. The depressions can be located by stains caused by oil droppings from vehicles and by riding over the pavement. Depressions can be caused by settlement or consolidation of the foundation soil or can be "built-in" during construction. They are frequently found near culverts. This is usually caused by poor compaction of soil and around the culvert during construction. Depressions cause slab cracking, roughness, and hydroplaning when filled with water of sufficient depth.

Severity Levels:

L - Depressions causes a distinct bounce of vehicle which creates no discomfort.

M - Depression causes significant bounce of the vehicle which creates some discomfort.

H - Depression caused excessive bounce of the vehicle which creates substantial discomfort, and/or safety hazard, and/or vehicle damage, requiring a reduction in speed for safety.

How to measure:

Depressions are measured by counting the number that exists in each uniform section. Each depression is rated according to its level of severity. Severity level is determined by riding in a mid-to-full-sized sedan weighing approximately 3,000 to 3,800 lb. (13.3-16.9 kN) over the uniform section at the posted speed limit.