4.4 CORRELATION ANALYSIS ON SURVEYED RESULTS

As mentioned previously, the surveys conducted were as follows:

- Serviceability Surveys: PSI by visual assessment, PSI by measurement, roughness.

- Structural Deterioration Surveys: Deflection by Benkelman Beam (center and offset deflection), CBR (field and laboratory), stiffness of existing asphalt concrete.

The survey results and the radius of curvature of deflection calculated based on the deflection survey are shown in Appendix 4.2.2.

4.4.1 Correlation of PSI by Visual Assessment and Measurement

Based on the multi-regression analysis against surveyed values of PSI by visual assessment and by measurement, the following formulas were derived for AC and DBST surfaces. However, no relationship with a high correlation coefficient was introduced for PM surfaces. In PM surfaces, the irregularities measured by the Profilometer showed high values effected by the large size crushed stone included in PM surfaces. Good correlation was not observed for PM surfaces in this measurement method.

$$\text{AC} : \text{PSI} = 4.354 - 1.125 \log \sigma - 0.139\sqrt{C} - 0.039\, D^2$$
(correlation coefficient $R = 0.740$)

$$\text{DBST} : \text{PSI} = 4.354 - 1.579 \log \sigma - 0.098\sqrt{C} - 0.015\, D^2$$
(correlation coefficient $R = 0.725$)

Based on the formulas established, a simple checking on measured items, σ, C and D, which are highly influential with PSI, was done as follows:

INFLUENCE OF ITEM ON PSI

Surface Type	Description	Item		
		σ	C	D
AC	Measured Value (min)	0.84	0	0.5
	(max)	4.22	30	2.9
	Term Value (min)	0	0	0.01
	(max)	0.70	0.76	0.33
	Range of Term	0.70	0.76	0.32
	Degree of Influence (total range = 100)	39%	43%	18%
DBST	Measured Value (min)	1.20	0	0.5
	(max)	9.09	100	5.6
	Term Value (min)	0.13	0	0
	(max)	1.51	0.98	0.47
	Range of Term	1.38	0.98	0.47
	Degree of Influence (total range = 100)	49%	35%	16%

Note: Term value in the table means calculated value for each term in the formula (for example, where the measured value σ is 4.22, 1.125 $\log\sigma$ is 0.70).

As shown in the above table, cracking ratio (C) and irregularity (σ) mainly affect the PSI value at almost the same rate on an AC surface, while irregularity (σ) has a predominant influence on a DBST surface. The cracking ratio (C) follows it by a difference of 14%. Therefore, it is concluded that the PSI value can be practically assessed by measuring irregularity (σ) and cracking ratio (C).

Since a survey of PSI by measurement takes time and effort, it is not suitable to assess the serviceability of routes with long distances or when a number of routes must be surveyed within a short period of time. Therefore, it is recommended that PSI by measurement be applied only to check individual differences which result from PSI by visual assessment.

4.4.2 Correlation of PSI by Visual Assessment and Roughness

Roughness measured by MRM has generally been applied to assess serviceability of paved surfaces in feasibility studies which have recently been done by DOH.

The correlations between PSI by visual assessment and roughness measured on each case study section are shown in Figure 4.4.1 by surface type.

In the HRB Special Report [1], the following formula, which has been broadly applied in many rehabilitation studies, was established to express the relationship between PSI by visual

Source: 1. Method for Measuring Serviceability Index with Mays Ride Meter. Highway Research Board Special Report 133.

assessment and roughness:

$$PSI = 5e^{-\left[\frac{\ell n\,(M-Mo)}{\alpha}\right]^5}$$

where, M : Measured roughness
Mo : Roughness of surface under best condition
α : Coefficient

This formula was also adopted for the study.

From Figure 4.4.1, the following formula with a correlation coefficient of 0.761 was established:

$$PSI = 5e^{-\left[\frac{\ell n\,(M-Mo)}{8.493}\right]^5}$$

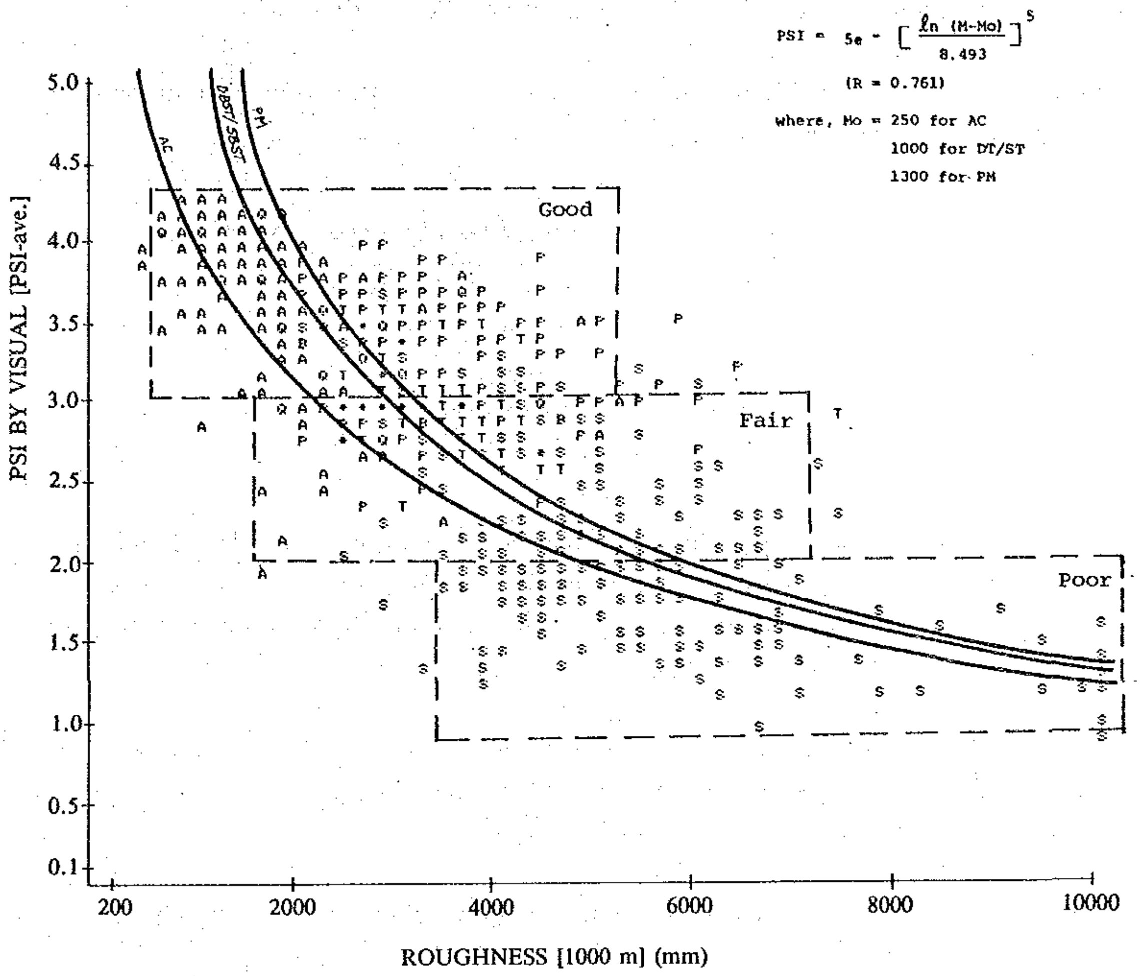
where, Mo : 250 mm/km for AC surfaces
1,000 mm/km for DBST surfaces
1,300 mm/km for PM surfaces

In the Second Provincial Road Project (SPRP) study, this formula was also introduced based on results surveyed. The α and Mo values obtained were similar to those derived in the study as shown below:

α : 8.280
Mo : 300 mm/km for AC surfaces
900 mm/km for DBST surfaces
1,400 mm/km for PM surfaces

PSI is determined by overall assessment of the irregularity, the cracking rate and the rut depth. On the other hand, roughness by MRM is only a measurement of the irregularity of pavement surface. However, there is a fairly good correlation between the two assessments.

It is recommended that roughness by MRM be generally applicable to assess the serviceability of the pavement because this can be surveyed easily in a short period and has enough practical accuracy to express PSI.



NOTE : (A) = AC (S) = ST (P) = PM (B) = AC & ST (T) = ST & PM (Q) = PM & AC (*) = ALL

FIGURE 4.4.1 RELATIONSHIP BETWEEN PSI BY VISUAL ASSESSMENT AND ROUGHNESS

4.4.3 Correlation of PSI by Visual Assessment and Center Deflection

In the Road Maintenance Manual of the Japan Road Association, the rehabilitation works corresponding to PSI values are shown as follows:

PSI AND CORRESPONDING REHABILITATION WORKS

PSI	Rehabilitation Works
3 - 2.1	Seal coat
2 - 1.1	Overlay
1 - 0	Reconstruction

PSI indicates only the surface condition of a pavement structure, not the degree of deterioration. To assess the strength of pavement structure, therefore, the measurement of deflection is usually required. If a good correlation is, however, found between PSI and deflection, it will be possible to practically determine the rehabilitation works to be applied based on PSI.

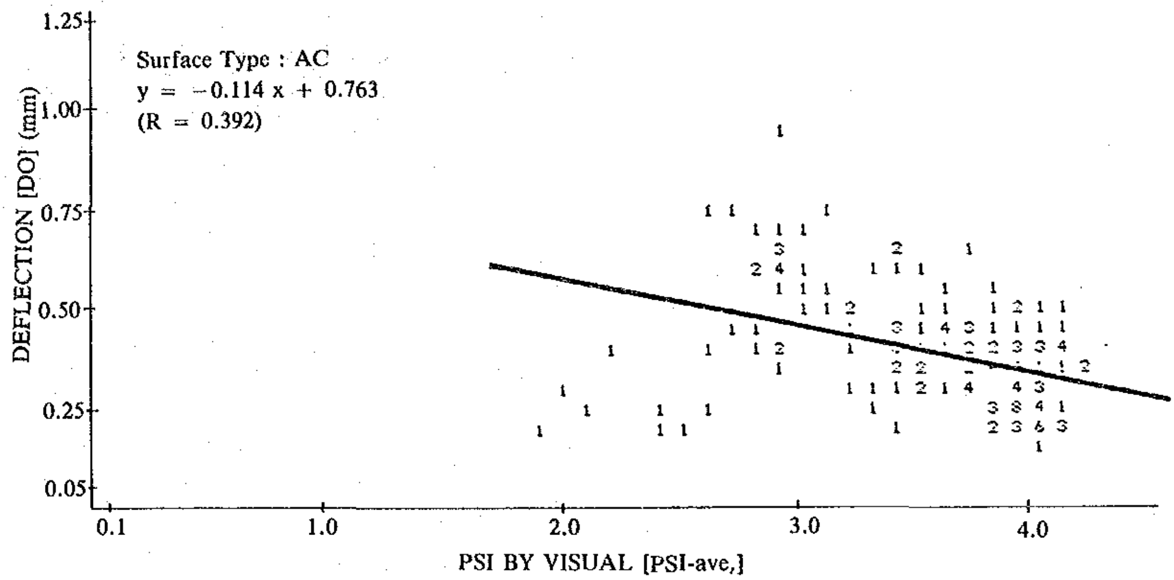
PSIs and deflections measured in the case study sections were plotted by surface type as shown in Figure 4.4.2 and the correlation was analyzed. However, no correlation with a high correlation coefficient was found in any surface type.

Based on these results, it was concluded that it is not practical to estimate the required thickness of overlay based on PSI.

4.4.4 Correlation of Center Deflection and Radius of Curvature of Deflection

A design method to determine overlay thickness based on the CBR value of the existing subgrade which is estimated from the radius of curvature of deflection has recently been developed and used. In the SPRP study, this method was applied and recommended for overlay design of flexible pavement.

In order to calculate the radius of curvature of deflection, deflection must be measured at several offset points as well as at a center point. This measurement is quite complicated and time-consuming. If the radius of curvature of deflection can be estimated from the center deflection, the measurement of deflection at the offset points can be omitted. For this reason, correlation of the center deflection and the radius of curvature of deflection was analyzed based on these two values measured in the case study sections. A method to calculate the radius of curvature is described in 4.5.



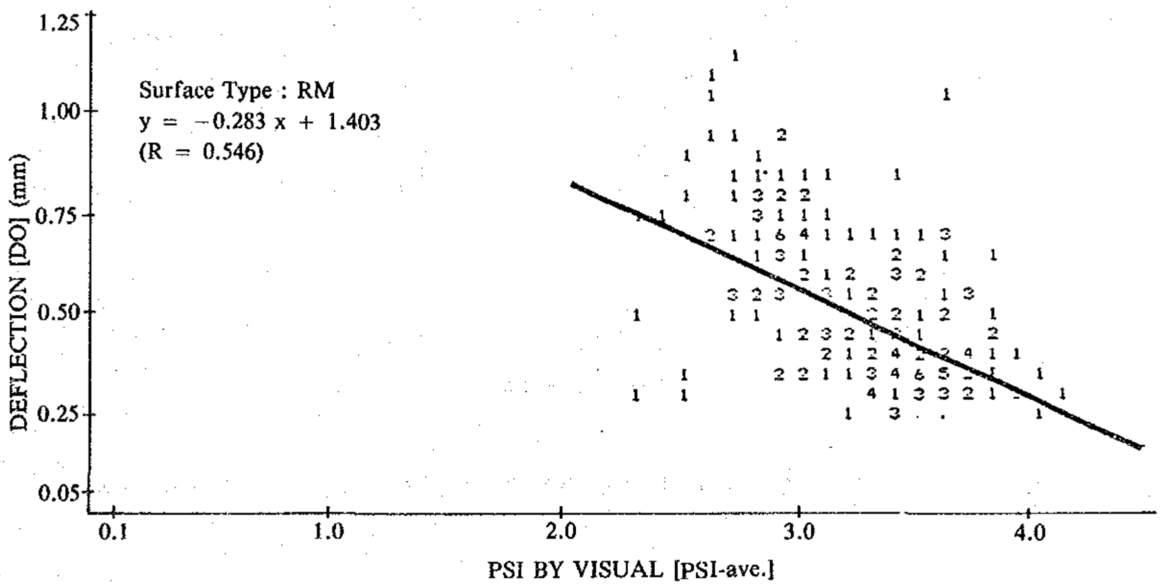


FIGURE 4.4.2 (1) RELATIONSHIP BETWEEN PSI BY VISUAL AND DEFLECTION

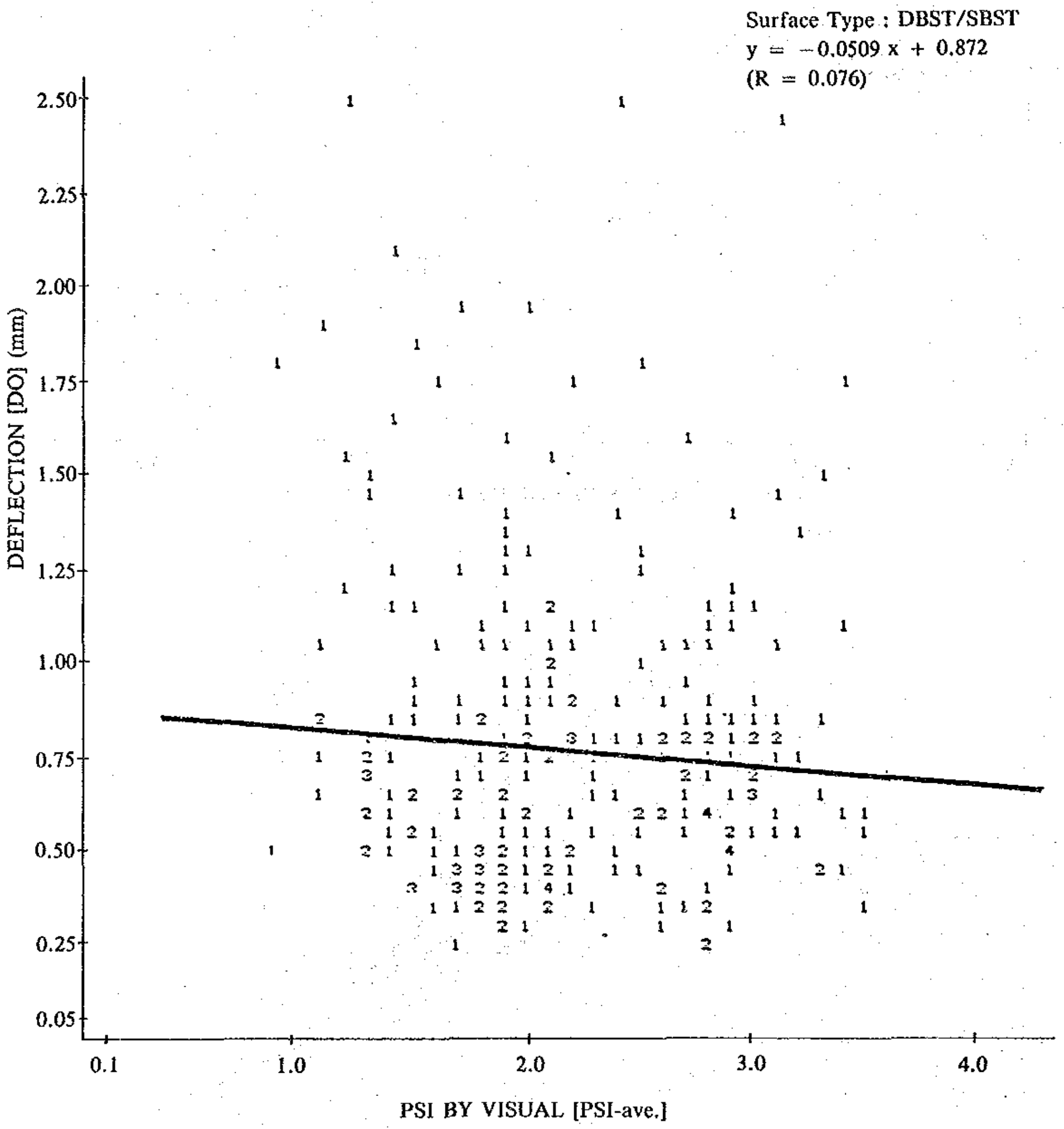


FIGURE 4.4.2 (2) RELATIONSHIP BETWEEN PSI BY VISUAL AND DEFLECTION

These two values plotted for each surface type are shown in Figure 4.4.3, and the correlation is shown in the following formula:

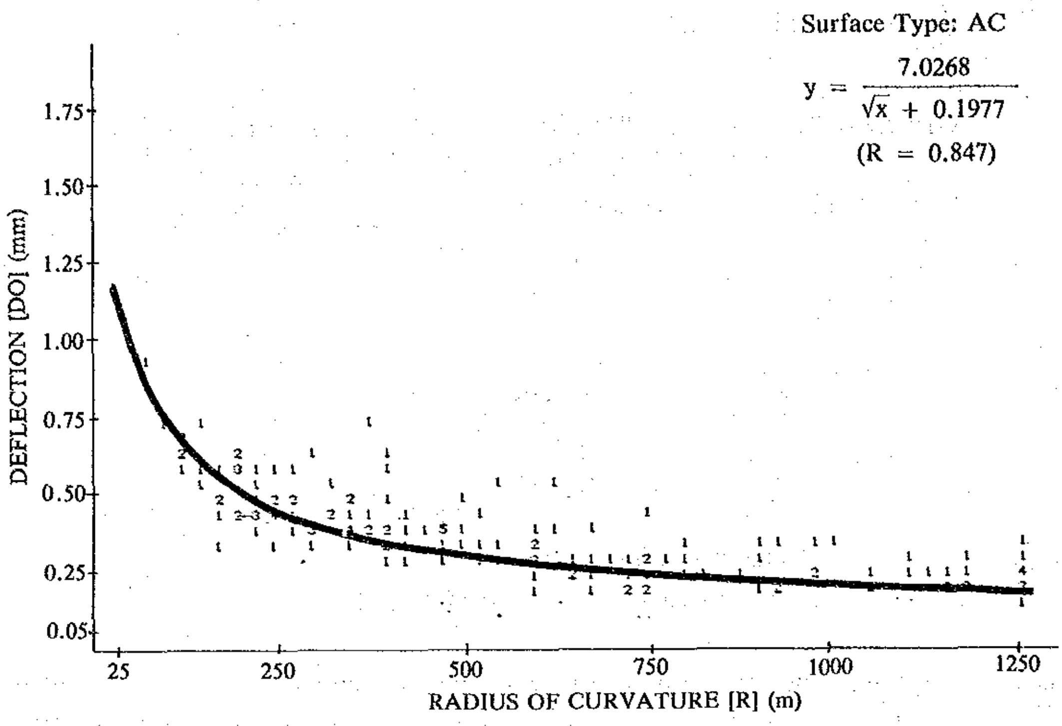
CORRELATION ON CENTER DEFLECTION AND RADIUS OF CURVATURE OF DEFLECTION

Surface Type	Formula	Correlation Coefficient
AC	$y = \dfrac{7.0268}{\sqrt{x} + 0.1977}$	0.847
PM	$y = \dfrac{10.5358}{\sqrt{x} + 6.3116}$	0.809
DBST	$y = \dfrac{8.7367}{\sqrt{x} + 2.4652}$	0.843

where, y : Center deflection (mm)
x : Radius of curvature of deflection (m)

As shown in this table, the correlation coefficient is high for all surface types. This shows that the radius of curvature of deflection can be estimated based on the center deflection with sufficient practical accuracy.

However, it cannot be concluded that such a good correlation will occur in every case, as CBRs of the subgrade in the case study sections were almost the same and at rather high values.



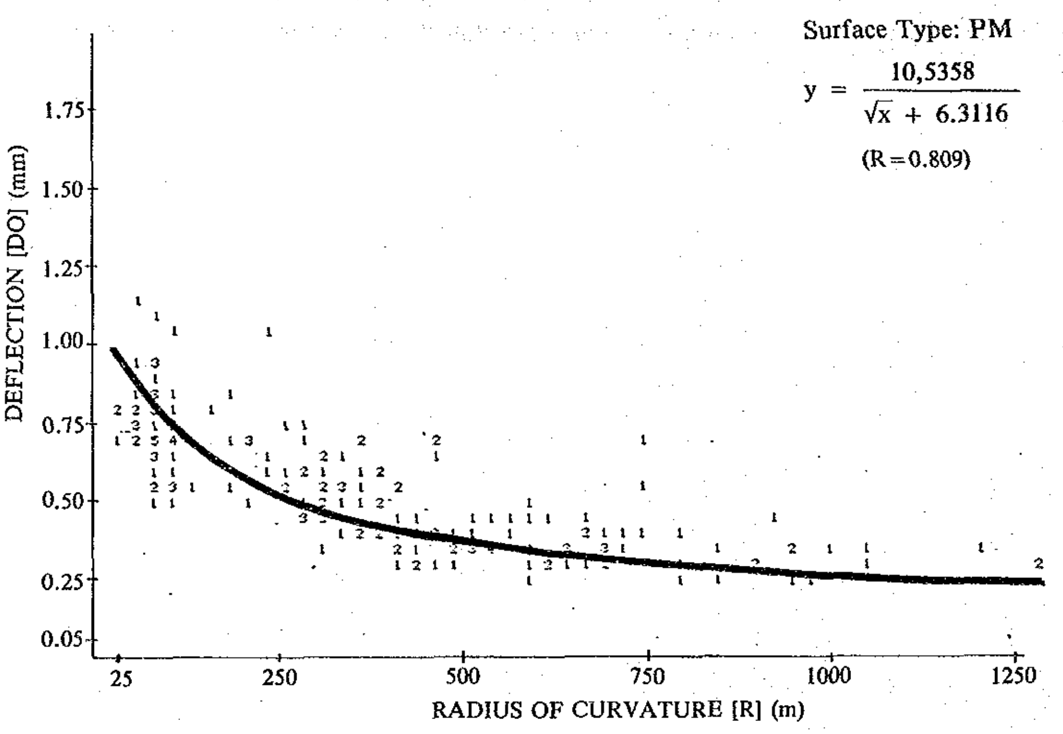


FIGURE 4.4.3 (1) RELATIONSHIP BETWEEN RADIUS OF CURVATURE AND DEFLECTION

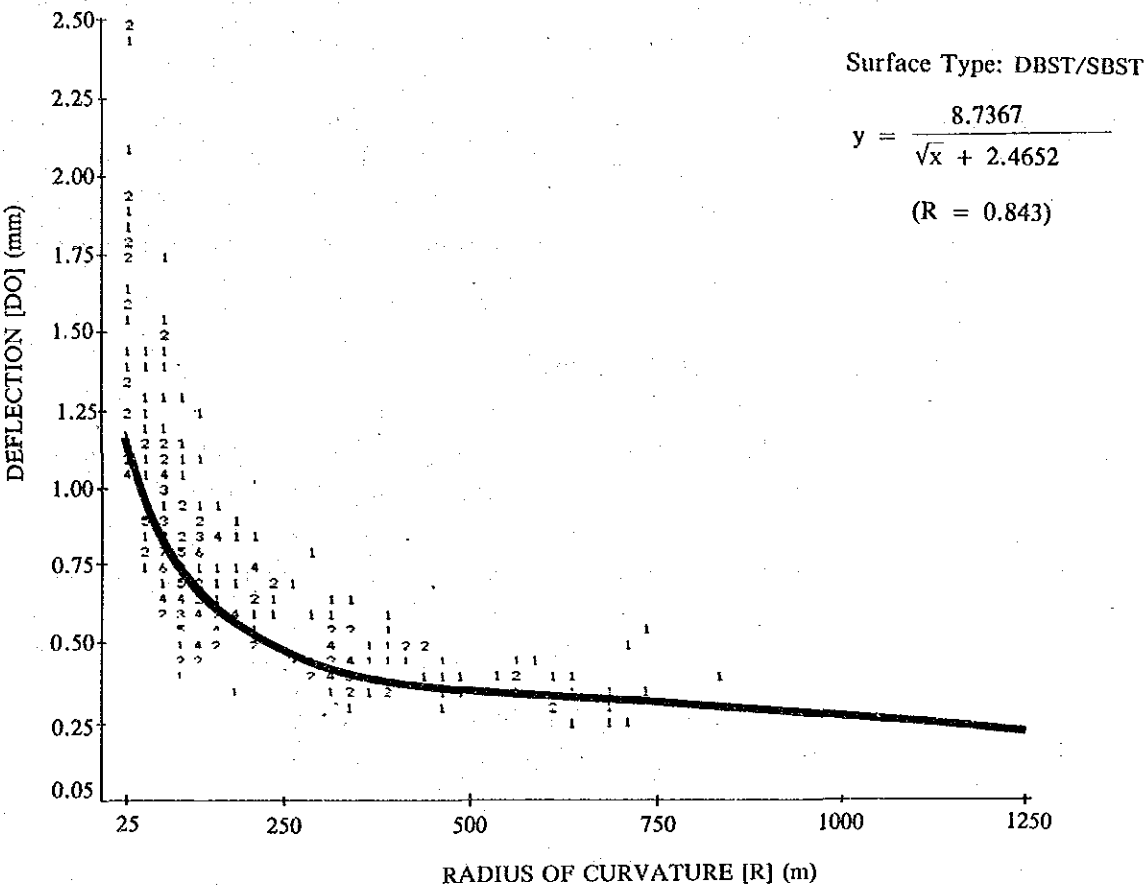


FIGURE 4.4.3 (2) RELATIONSHIP BETWEEN RADIUS OF CURVATURE AND DEFLECTION

4.4.5 Verification of CBR Estimated from Deflection

CBR values estimated from the deflection were compared with CBRs actually measured in the field and laboratory to verify the adequacy of the estimation.

Based on the method mentioned in Section 4.4.4, elastic moduli of the existing subgrade (Es) and pavement structure (Ep) were calculated from center deflection, radius of curvature of deflection and thickness of existing pavement. Since a relationship between CBR and the elastic modulus is generally expressed as follows, CBR of subgrade and pavement structure can be estimated from this relationship:

$$100\text{—}200 \text{ CBR} = \text{Elastic modulus}$$

CBR values estimated from the deflection show an average CBR of the whole depth of pavement structure composed of surface, base and subbase courses, while actual CBR tests were carried out for each layer of the courses. In order to compare with the results estimated from the deflection, CBR of the whole depth of pavement structure was calculated by the following formula:[1]

$$CBR_m = \left(\frac{h_1\, CBR_1^{\frac{1}{3}} + h_2 CBR_2^{\frac{1}{3}} \ldots\ldots + h_n\, CBR_n^{\frac{1}{3}}}{H} \right)^3$$

where,

	CBR_m	:	Average CBR
	$CBR_1 \ldots CBR_2$	:	CBR of each layer
	$h_1 \ldots h_2$	:	Thickness of each layer
	H	:	$h_1 + \ldots h_2$

In this formula, CBRs of surface courses were estimated under the following assumptions:

AC surface : Stiffness derived from the Shell method $\times \frac{1}{100}$

$$CBR = 20{,}000 \times \frac{1}{100}$$

PM surface : Stiffness of AC surface $\times \frac{1}{2} \times 1/100$

$$CBR = 20{,}000 \times \frac{1}{2} \times 1/100 = 100$$

Source: 1. Manual For Design and Construction of Asphalt Pavement, Japan Road Association

DBST surface : Negligible
CBR = 0

For CBRs of base and subbase courses, actually surveyed values were applied.

A comparison between CBR estimated from deflection and CBR actually measured is shown in Table 4.4.1. A good relationship was not found at the spot where field CBR tests were done but relatively close values could be estimated at the spots where only laboratory CBR tests of sampled materials were carried out. In order to verify the adequacy of CBR derived from the deflection, further comparative study will be required.

TABLE 4.4.1 COMPARISION BETWEEN CBR ESTIMATED FROM DEFLECTION AND ACTUALLY MEASURED

ROUTE NO.	TYPE	KM POST	SUBGRADE		PAVEMENT STRUCTURE	
			CBR IN FIELD & LABORATORY	ESTIMATE CBR	CBR IN FIELD & LABORATORY	ESTIMATE CBR
RT -224	AC	11 + 500	14.5 (11.9)	6.1	64.4 (63.1)	91.5
RT -224	AC	16 + 000	20.5 (20.2)	5.1	38.8 (16.6)	86.7
RH - 5	PM	21 + 500	20.9 (29.7)	3.7	38.7 (50.8)	122.1
RH - 5	PM	36 + 200	20.5 (25.7)	2.2	25.0 (47.2)	70.4
RH - 12	DT/ST	492 + 600	24.2 (22.0)	8.0	43.4 (70.3)	104.0
RH - 12	DT/ST	493 + 450	21.2 (22.7)	3.6	33.7 (56.6)	82.8
RH - 25	DT/ST	9 + 450	29.8 (26.0)	15.6	53.8 (68.5)	156.0
RH - 25	DT/ST	11 + 950	31.8 (15.2)	8.9	44.4 (49.4)	178.0
RT -224	AC	11 + 000	(9.8)	4.4	(36.8)	114.4
RT -224	AC	18 + 000	(8.3)	5.8	(37.9)	58.0
RH - 21	AC	124 + 000	(10.0)	18.5	(53.2)	148.0
RH - 21	AC	129 + 000	(11.9)	11.3	(76.5)	395.5
RH - 22	PM	3 + 000	(4.2)	-	(45.9)	-
RH - 22	PM	6 + 000	(4.9)	3.0	(41.0)	78.0
RH - 5	PM	25 + 000	(4.4)	7.6	(33.3)	212.8
RH - 5	PM	32 + 000	(6.0)	6.6	(33.9)	118.8
RH - 12	DT/ST	490 + 000	(2.9)	6.5	(56.3)	169.0
RH - 12	DT/ST	496 + 000	(2.2)	4.1	(39.4)	49.2
RH - 16	DT/ST	10 + 000	(3.6)	17.0	(58.8)	34.0
RH - 16	DT/ST	16 + 000	(2.9)	8.6	(51.8)	43.0
RH - 25	DT/ST	8 + 000	(11.0)	9.6	(39.7)	153.6
RH - 25	DT/ST	15 + 000	(11.3)	4.4	(41.6)	145.2
RH - 27	DT/ST	9 + 000	(5.3)	7.8	(40.1)	23.4
RH - 27	DT/ST	17 + 000	(2.5)	4.5	(36.9)	9.0

Note: ( ) : Laboratory CBR
- : No relationship could be analyzed in Figure 4.5.5.

4.4.6 Correlation of Fuel Consumption and Roughness

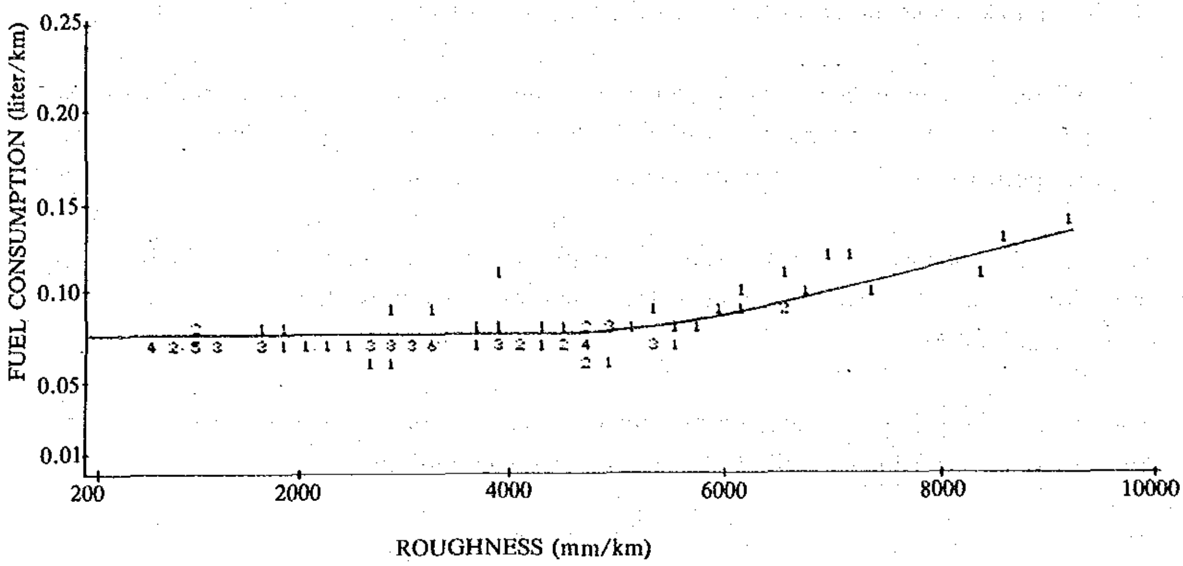
Figure 4.4.4 shows the relationship between fuel consumption and roughness at 1-km intervals.

The fuel consumption rate is practically constant at 0.0758 liter/km up to the roughness value of 5500 mm/km and increases to 0.1064 liter/km for roughness over 5500 mm/km.

This difference is mainly due to speed reduction because it was difficult to maintain the survey cruising speed of 60 km/h under conditions with roughness over 5500 mm/km. The overall average speed for sections with that roughness was 48 km/h.

The relationship between speed and fuel consumption is shown in Figure 4.4.5. The fuel consumption rate at 48 km/h on a good surface road was 13% more than the rate at 60 km/h, or 0.085 liter/km.

Therefore, a fuel consumption rate of approximately 0.0214 liter/km or 27% of the rate on a good surface can be attributed to poor surface conditions.



ROUGHNESS < 5500

VARIABLE	AVERAGE	STANDARD DEVIATION
X : ROUGHNESS (MM/KM)	X = 3107	S(X) = 1402
Y : FUEL CONSUMPTION (L/KM)	Y = 0.0758	S(Y) = 0.0075

NUMBER OF DATA = 81

ROUGHNESS >= 5500

VARIABLE	AVERAGE	STANDARD DEVIATION
X : ROUGHNESS (MM/KM)	X = 6850	S(X) = 1024
Y : FUEL CONSUMPTION (L/KM)	Y = 0.1064	S(Y) = 0.0162

NUMBER OF DATA = 15

FIGURE 4.4.4 RELATIONSHIP BETWEEN FUEL CONSUMPTION AND ROUGHNESS

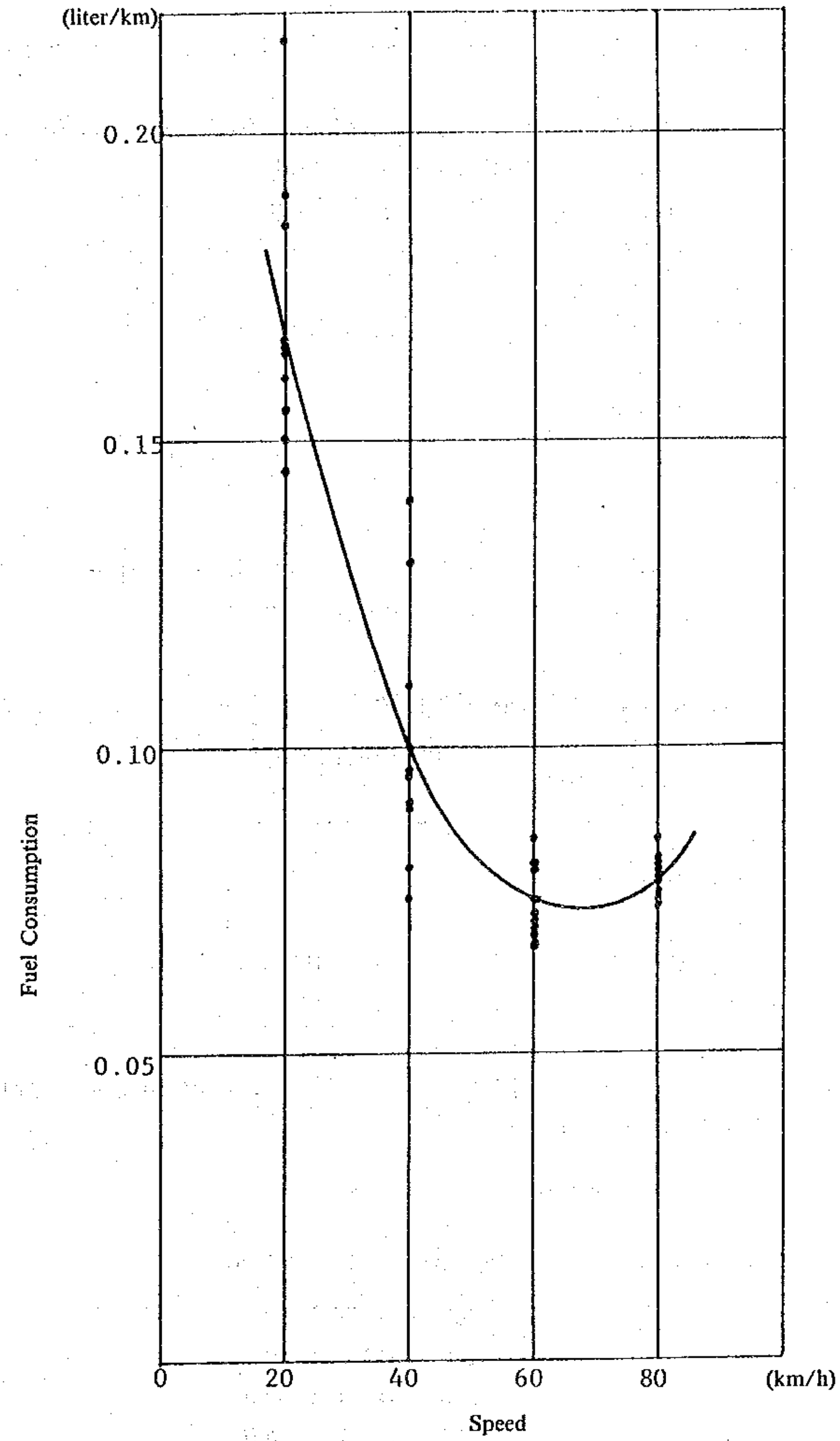


FIGURE 4.4.5 FUEL CONSUMPTION RATES AT DIFFERENT SPEEDS

4.5 COMPARATIVE STUDY OF DESIGN METHODS

The following 7 design methods were considered for the comparative study of design methods:

- Japan Road Association Method (Road Repair and Maintenance Manual) (JRA method)
- Asphalt Institute Method (The Asphalt Institute Manual No. 17) (AI method)
- TRRL Method (TRRL Report 571) (TRRL 571 method)
- TRRL Method in the Tropics (TRRL Report 444) (TRRL 444 method)
- Overlay Thickness Formula by Ruiz (Highway Research Record 129) (Ruiz method)
- California Method (DOH method)
- Method by Radius of Curvature and Deflection (EM method)

4.5.1 Description of Design Methods

1) JRA Method

Based on traffic volumes of heavy traffic at the 5th year after overlaying and on deflection, required thickness of overlay is determined by the following table:

REQUIRED OVERLAY THICKNESS (cm)

Deflection: D (mm)	Classification of Traffic				
	L	A	B	C	D
0.6 > D	-	-	-	4	4
0.6 ≤ D < 1.0	-	-	4	6	8
1.0 ≤ D < 1.5	-	4	6	10	12
1.5 ≤ D < 2.0	4	6	10	12	15
2.0 < D	6	10	12	15	-

The classification of traffic volume levels is determined as follows from an analysis of assumed cumulative numbers of ESA (wheel load 5,000 kg):

CLASSIFICATION OF TRAFFIC

Classification	Number of Heavy Trucks
L	100 > DAD
A	100 ≤ DAD < 250
B	250 ≤ DAD < 1000
C	1000 ≤ DAD < 3000
D	3000 ≤ DAD

Note: DAD: Daily average on design lane

2) AI Method

Design procedures are as follows:

- Initial traffic number (ITN) is derived from Figure 3.5.2 based on number of heavy trucks (daily average on design lane), average gross weight of heavy trucks and single axle load limit.

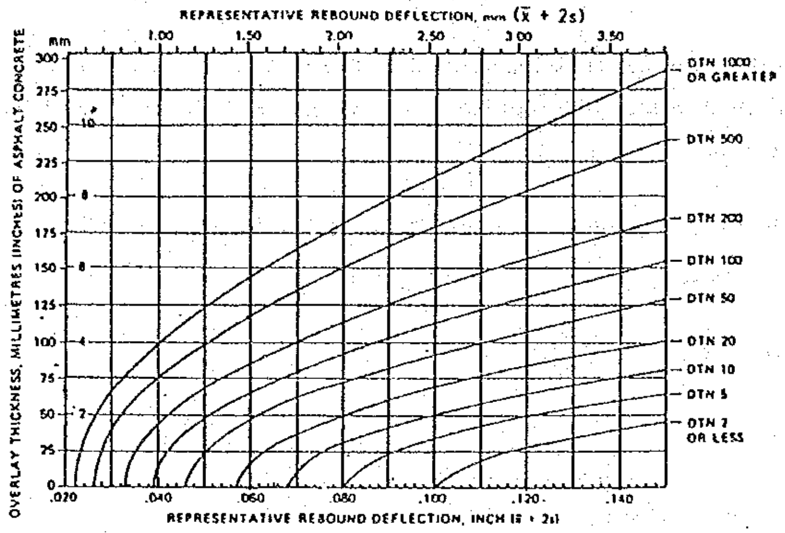
- ITN adjustment factor is calculated from the following formula:

$$\text{Factor} = \frac{(1 + r)^n - 1}{20r}$$

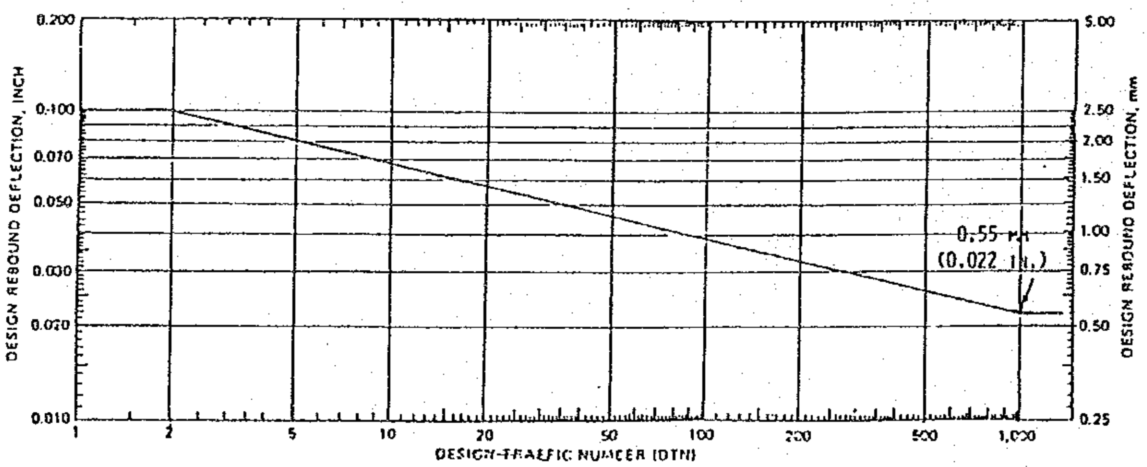
where, r : Annual growth rate
n : Design period (years)

- Design traffic number (DTN) is calculated by multiplying LTN by the adjustment factor.

- Overlay thickness required is derived from Figure 4.5.1 based on DTN and deflection.



Asphalt concrete overlay thickness required to reduce pavement deflection from a measured to a design deflection value (rebound test)



Design Rebound Deflection Chart

FIGURE 4.5.1 OVERLAY DESIGN—AI METHOD

3) TRRL 571 Method

Required overlay thickness is determined by the following procedures:

- Deflection after overlay is determined from Figure 4.5.2 by applying cumulative standard axles (8,200 kg).
- Required overlay thickness is derived from Figure 4.5.2 based on deflection after overlay and deflection measured.

4) TRRL 444 Method

Required overlay thickness is determined in the same way as in the TRRL 571 method by utilizing Figure 4.5.3.

5) Ruiz Method

In this method, required overlay thickness is derived from the following formula:

$$h = \frac{12}{0.434} \log \frac{Do}{Dh}$$

where, h : Overlay thickness
Do : Deflection measured
Dh : Deflection after overlay

This method does not specify the deflection after overlay, which was derived from the TRRL 444 method in Figure 4.5.3 and applied.

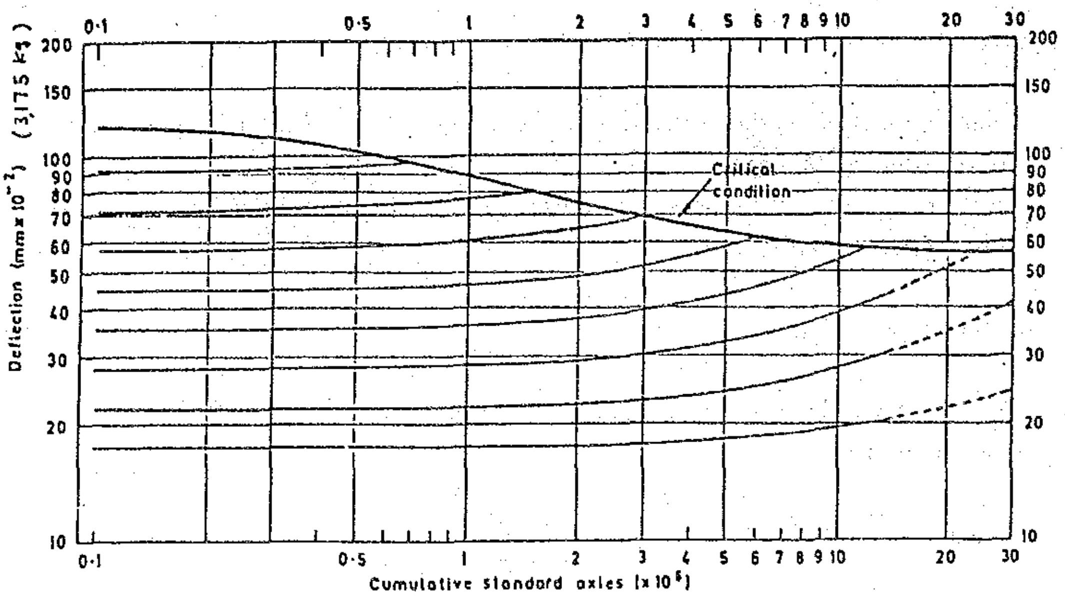
6) DOH Method

The following procedure is taken to determine overlay thickness:

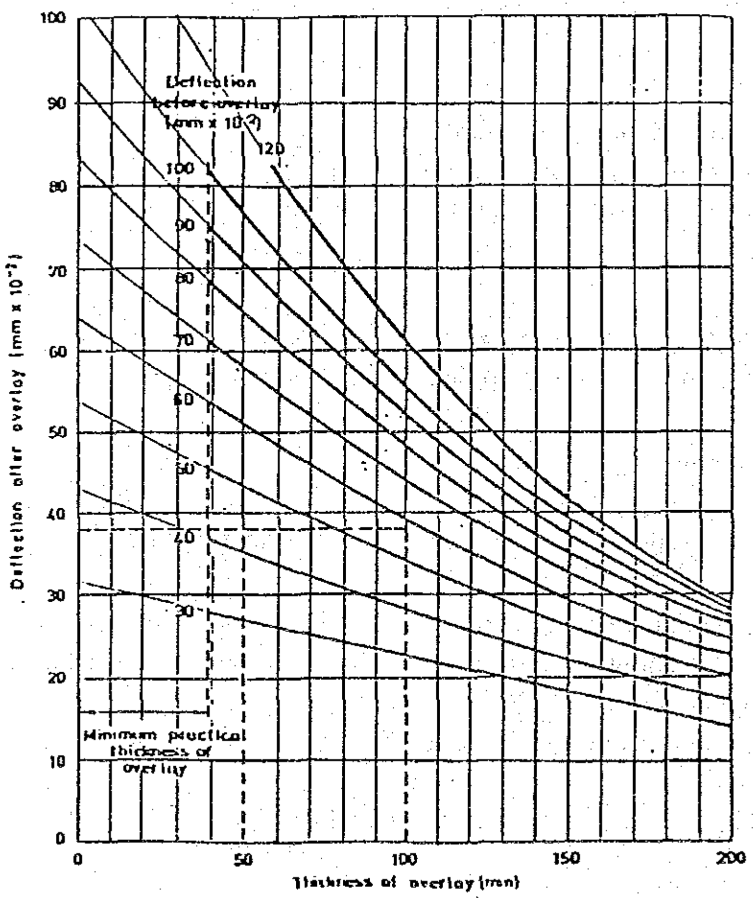
- Based on cumulative wheel load (2,268 t), allowable deflection is derived from Figure 4.5.4. DOH adopts a critical design line of a 2-inch AC surface to determine the allowable deflection.
- Percent reduction in deflection is calculated by the following formula:

$$\text{Percent reduction} = \frac{\text{Design deflection} - \text{Allowable deflection}}{\text{Design deflection}} \times 100$$

- From Figure 4.5.4, the thickness to be increased in gravel equivalent is derived by applying the percent reduction in deflection.

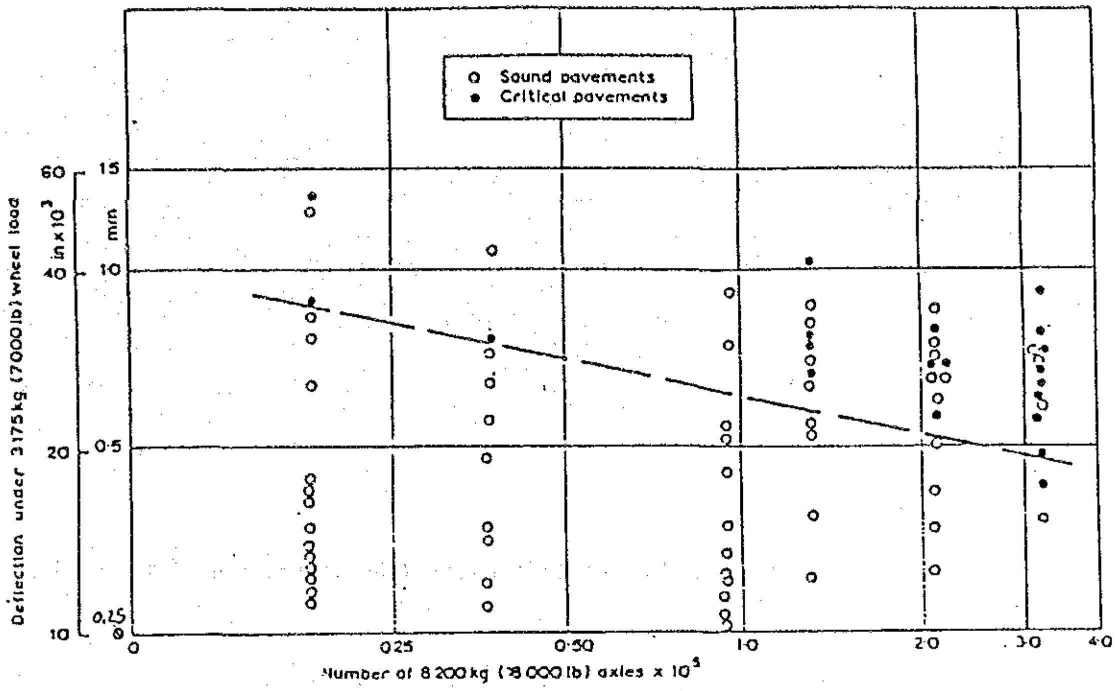


DEFLECTION-LIFE RELATIONSHIPS FOR PAVEMENTS WITH UNBOUND-BASES

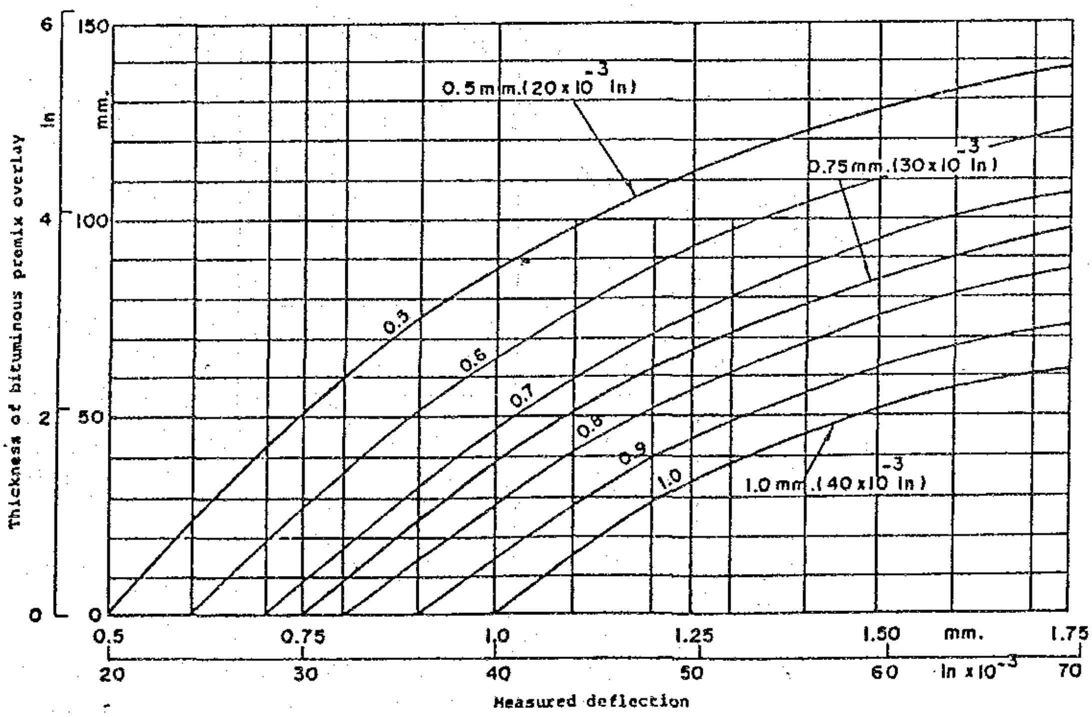


OVERLAY DESIGN CHART

FIGURE 4.5.2 OVERLAY DESIGN—TRRL METHOD

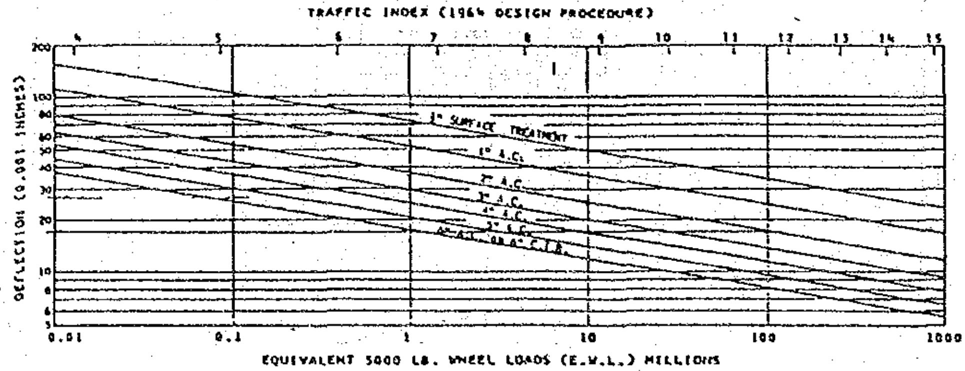


TENTATIVE DEFLECTION CRITERION CURVE FOR 75–100 mm (3 TO 4 in) BITUMEN MACADAM SURFACINGS ON CRUSHED STONE BASES IN A WT TROPICAL ENVIRONMENT

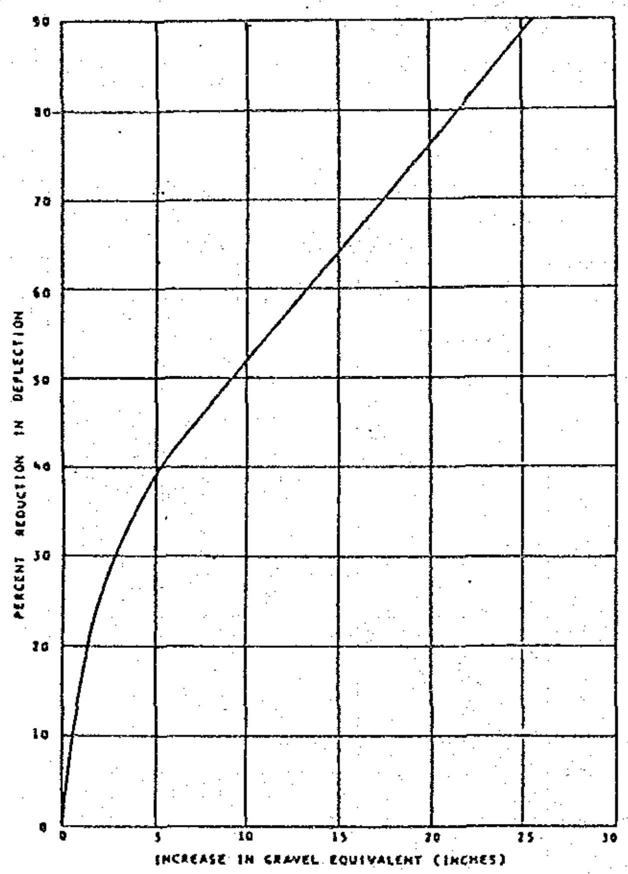


THE THICKNESS OF BITUMINOUS PREMIX OVERLAY REQUIRED TO REDUCE THE DEFLECTION OF A PAVEMENT TO DESIGNATED VALUES

FIGURE 4.5.3 OVERLAY DESIGN—TRRL METHOD IN THE TROPICS



Variation in tolerable deflection based on AC fatigue tests, California method of overlay design



Reduction in deflection resulting from pavement reconstruction, California method of overlay design

FIGURE 4.5.4 OVERLAY DESIGN—DOH METHOD

- Required overlay thickness is calculated by transforming the increase in gravel equivalent to different layers of new surface by using the following conversion factor:

  - Thickness of asphalt concrete = 0.5 times gravel equivalent
  - Thickness of base = thickness of gravel equivalent
  - Thickness of subbase = 1.5 times gravel equivalent
  - Thickness of subgrade = 2.0 times gravel equivalent

7) EM Method

In this method, required overlay thickness is determined based on the moduli of elasticity of subgrade (E_2) and pavement (E_1) calculated from the deflection.

The procedures are as follows:

- Radius of curvature of deflection (R) is calculated based on the results of deflection survey by the following formulas:

$$R = \frac{r^2}{f\delta}$$

$$f = \frac{2W}{Wr} = \frac{2W}{W-\delta}$$

where,

r	:	Distance from center point (cm)
W	:	Center deflection (cm)
Wr	:	Deflection at point r (cm)
δ	:	W - Wr
f	:	Coefficient dependent on distance

- To derive (E_2) and E_1/E_2, K was determined by applying the following values to Figure 4.5.5:

h	:	thickness of pavement (cm)
W	:	center deflection (cm)
a	:	radius of equivalent contact area (cm)

$$a = 12 + \frac{P}{1000}$$

where,

P	:	Wheel load (kg)
R	:	Radius of curvature of deflection (cm)

- Subgrade modulus (E_2) is calculated by the following formula:

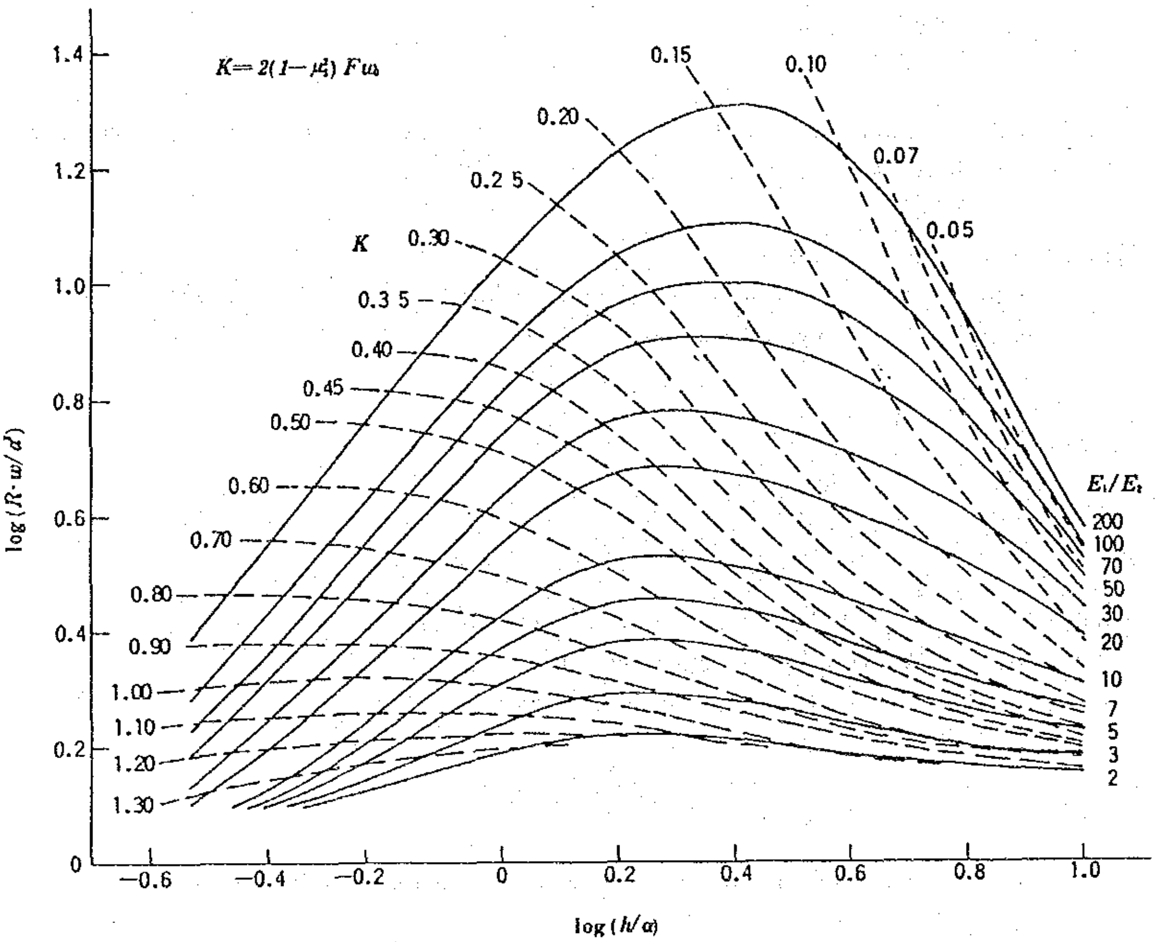


FIGURE 4.5.5 RELATIONSHIP BETWEEN RWo/a² AND h/a

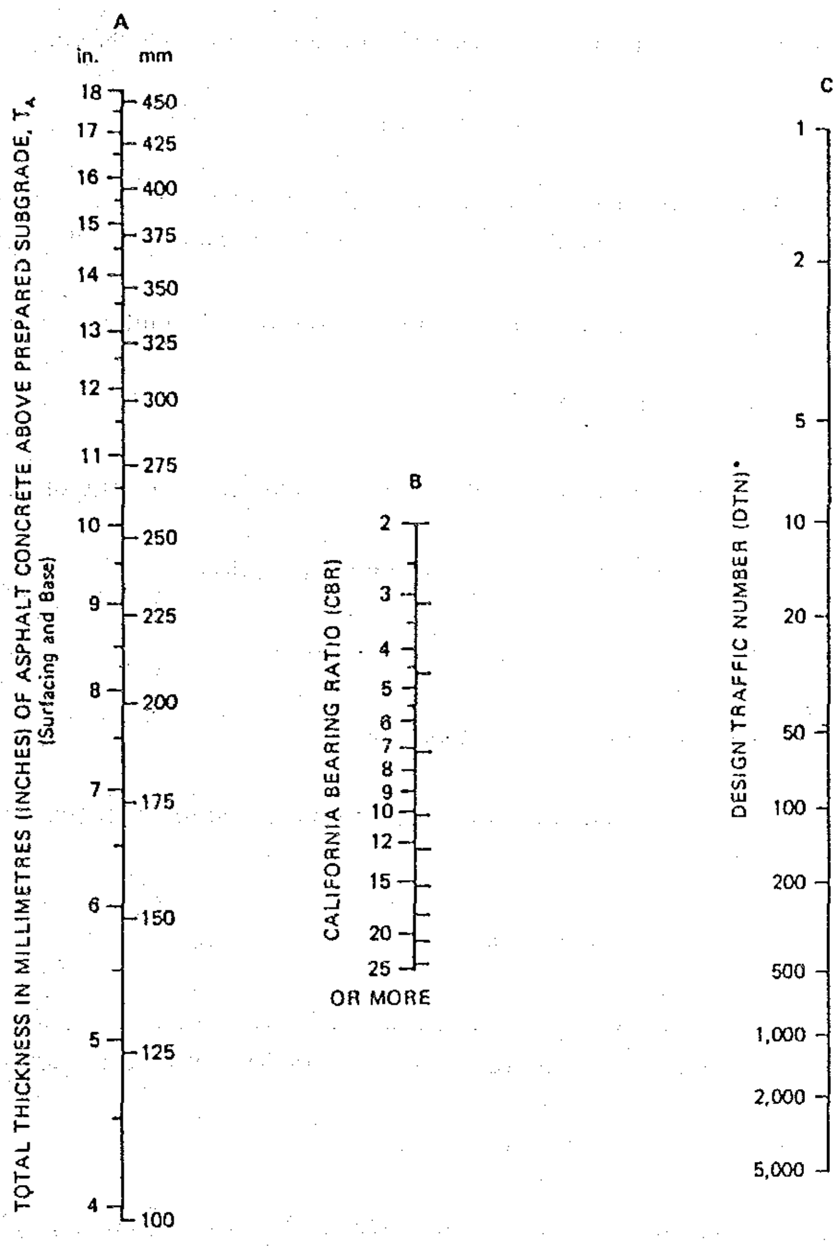


FIGURE 4.5.6 THICKNESS DESIGN CHART

$$E_2 = \frac{p \cdot a \cdot k}{W}$$

where, P : Contact pressure of wheel (kg/cm^2)

- Pavement modulus (E_1) is calculated by (E_2) and E_1/E_2.

- CBR of subgrade and pavement are derived from the following relation:

  100-200 CBR = Modulus of plasticity (E_1 and E_2)

- From Figure 4.5.6 shown in the AI method, the overlay thickness of asphalt concrete (TA) is derived by subgrade CBR estimated from deflection and DTN.

- Required overlay thickness is determined by the following formula:

$$DH = TA - Hp\ (Ac)$$

where, Hp (Ac) : Equivalent thickness of the existing pavement in units of AC

In the SPRP study, Hp is derived from the following assumption:

$$E_1 \times (He)^3 = E_2 \times 4 \times (Hp)^3$$

where, He : Thickness of the existing pavement

In the study, application of the idea of conversion factors shown in AI method was considered to determine Hp.

4.5.2 Comparative Study of Design Methods

To evaluate the overlay design methods, the thickness of overlay required by each design method was calculated by the following procedures to equalize design conditions:

1) Equalization of Standard Wheel Loads

Different standard wheel loads to calculate cumulative numbers of ESA are applied in each design method. Among them, in particular in the AI method, a different idea of design traffic number DTN estimated from the gross vehicle weight was adopted as follows:

STANDARD WHEEL LOAD FOR EACH DESIGN METHOD

Design Method	Standard Wheel Load (kg)
JRA	5,000
AI	DTN
TRRL 571	4,100
TRRL 444	4,100
Ruiz	4,100
DOH	2,268
EM	DTN *

Note: *: No specification, but the AI method was applied to determine overlay thickness based on CBR of existing subgrade estimated from deflection in the study.

For the comparative study, design standard wheel loads were equalized, except for DTN, to 4,100 kg (axle load 8.2 t) by adopting the following formula:

$$\alpha i = \left(\frac{P}{4,100}\right)^4$$

where, αi : Conversion factor to wheel load of 4,100 kg

In conversion of DTN to cumulative numbers of ESA (4,100 kg), the following formula was applied:

$$DTN = 5.6804 \times 10^{-5} \text{ ESA (4,100 kg)} - 6.6444$$

2) Equalization of Deflection

Design charts were established based on deflection measured with different wheel loads by each design method as shown below:

WHEEL LOAD IN DEFLECTION MEASUREMENT

Design Method	Wheel Load (kg)
JRA	5,000
AI	4,100
TRRL 571	3,175
TRRL 444	3,175
Ruiz	4,100
DOH	4,100
EM	4,100

These were equalized to deflection measured under 4,100 kg of wheel load on the assumption that a linear relationship exists between the deflection and the wheel load used for its measurement.

3) Application of JRA Method

In the JRA method, the required overlay thickness is determined based on measured deflection and traffic classification as mentioned in 4.5.1.1. The relationship between classification and cumulative number of ESA (10,000 kg) is as follows:

Traffic Classification	Number of ESA (10,000 kg) (10 years)
L	30,000 > N
A	30,000 ≦ N < 150,000
B	150,000 ≦ N < 1,000,000
C	1,000,000 ≦ N < 7,000,000
D	7,000,000 ≦ N < 35,000,000

The above numbers of ESA 10,000 kg were converted to those of ESA 8,200 kg as follows:

Traffic Classification	Number of ESA (8,200 kg) (10 years)
L	66,000 > N
A	66,000 ≦ N < 331,000
B	331,000 ≦ N < 2,211,000
C	2,211,000 ≦ N < 15,482,000
D	15,482,000 ≦ N < 77,412,000

Note: The above conversion was made in accordance with the following equation:
For L Traffic

$$30{,}000 \times \left(\frac{5{,}000}{4{,}100} \right)^4 = 66{,}000$$

4) Results of Comparative Study

All design methods employed in the comparative study, except for the EM method, can yield overlay thickness without considering the evaluation of the existing pavement structure. In design by the EM method, required overlay thickness was estimated on the assumption that the thickness of existing pavement with AC surface is 45 cm. A direct comparison of the EM method with other design methods, therefore, is not practical.

TABLE 4.5.1 (1) OVERLAY THICKNESS BY DESIGN METHOD

Deflection (mm)	Method	Number of ESA (million)					
		0.3	0.5	1	3	7	12
0.4	JRA	-	-	-	40	40	40
	AI	-	-	-	-	-	-
	TRRL 571	-	-	-	-	-	-
	TRRL 444	-	-	-	-	-	-
	RUIZ	-	-	-	-	-	-
	DOH	-	-	-	-	-	-
	EM	-	-	-	-	-	-
	Average	-	-	-	5	5	5
0.6	JRA	-	40	40	60	60	60
	AI	-	-	-	-	-	-
	TRRL 571	-	-	-	-	40	70
	TRRL 444	-	-	-	-	10	30*
	RUIZ	-	-	-	-	10	25
	DOH	-	-	-	5	20	30
	EM	-	-	-	-	-	-
	Average	-	5	5	10	20	30
0.8	JRA	-	40	40	60	60	60
	AI	-	-	-	-	35	60
	TRRL 571	-	-	-	20	75	105
	TRRL 444	-	-	-	30	50	60*
	RUIZ	-	-	-	25	45	60
	DOH	-	5	15	35	65	90
	EM	-	-	-	-	-	0
	Average	-	5	10	25	45	60
1.0	JRA	40	60	60	100	100	100
	AI	-	-	-	35	60	80
	TRRL 571	-	-	-	55	100	125
	TRRL 444	-	10	25	55	75	90
	RUIZ	-	10	25	50	70	85
	DOH	20	30	45	90	125	145
	EM	60	70	85	110	125	135
	Average	15	25	35	70	95	110

Note: - : Estimated by the trend of relationship shown in the Design Chart.
* : No overlay is required.

TABLE 4.5.1 (2) OVERLAY THICKNESS BY DESIGN METHOD

Deflection (mm)	Method	Number of ESA (million)					
		0.3	0.5	1	3	7	12
1.2	JRA	40	60	60	100	100	100
	AI	-	-	25	55	85	100
	TRRL 571	-	-	20	70	110	135
	TRRL 444	25*	35	50	80	100	110*
	RUIZ	15	30	45	75	95	110
	DOH	45	60	90	135	170	190
	EM	75	85	105	120	140	150
	Average	30	40	55	90	115	125
1.4	JRA	40	60	60	100	100	100
	AI	-	15	45	70	100	115
	TRRL 571	-	15	40	85	120	140
	TRRL 444	40*	50	65	95	115	125*
	RUIZ	35	50	65	90	115	125
	DOH	80	105	130	170	200	215
	EM	NA	NA	NA	NA	NA	NA
	Average	30	40	60	85	110	115
1.6	JRA	60	100	100	120	120	120
	AI	20	35	55	90	115	130
	TRRL 571	10	30	55	95	140	145
	TRRL 444	50*	65	80	110	125	135*
	RUIZ	50	65	80	110	130	145
	DOH	115	135	165	200	220	235
	EM	NA	NA	NA	NA	NA	NA
	Average	45	60	75	105	120	130

Note: - : No overlay is required.
* : Estimated by the trend of relationship shown in the Design Chart.
NA : The Design Chart was not applicable.

The required overlay thickness calculated by the 7 methods ranges from 0.4 mm to 1.6 mm in deflection and from 300,000 to 12,000,000 in cumulative number of ESA and is shown in Table 4.5.1 and Figure 4.5.7. The results are summarized as follows:

- At 0.4 mm of deflection, only the JRA method requires an overlay of 40 mm thick.

- At 0.6 mm of deflection, the JRA and TRRL 571 methods require almost the same thick overlay, while the TRRL 444 Ruiz and DOH methods require a thinner overlay than the above two methods. The AI and EM methods require no overlay.

- At 0.8 mm of deflection, the JRA, AI, TRRL 444 and Ruiz methods require almost the same thin overlay, while the TRRL 571 and DOH methods require a relatively thick overlay. The EM method requires no overlay.

- At 1.0 mm of deflection, the same results are shown as those at 0.8 mm of deflection. The EM method requires an overlay for the first time; the thickness is almost the same as that required by the DOH method.

- At 1.2 mm of deflection, the DOH method requires the thickest overlay followed by the EM and TRRL 571 methods. All other methods require an equivalent thickness of overlay.

- At 1.4 mm of deflection, the DOH method requires an extremely thick overlay. All other methods require almost an equivalent thickness of overlay.

- At 1.6 mm of deflection, the same results as those at 1.4 mm of deflection are observed.

It is apparent that the various overlay design methods result in significant differences in overlay requirements. These differences are due to the fact that the cumulative number of ESA at which the critical line indicating pavement life intersects with a given deflection level varies widely by method as shown in Figure 4.5.8.

These existing overlay design methods are not always established based on theoretical grounds. They were mainly developed by empirical ways reflecting actual conditions of soil, meteorology and construction practices of the countries and regions concerned. It is, therefore, very difficult to select an appropriate method for Thailand by desk work comparison alone.

Since the best criteria for selecting an overlay design method must be actual performance under various conditions, the study team recommends that a method be adopted from among those which give similar thickness and have been utilized extensively. The TRRL 444, Ruiz, AI and JRA methods yield similar results. Adoption of one of these methods is recommended.

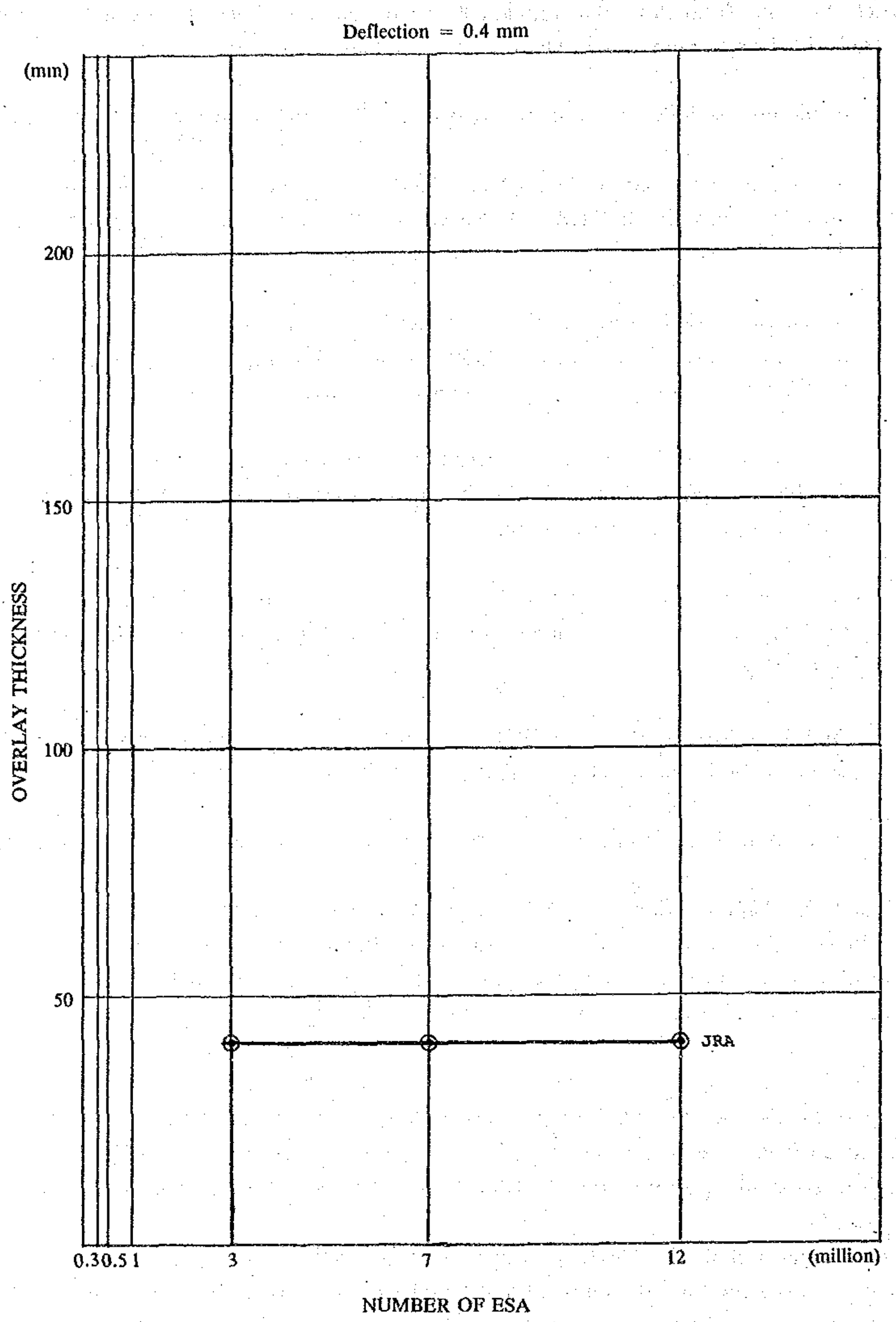


FIGURE 4.5.7 (1) OVERLAY THICKNESS BY DESIGN METHOD

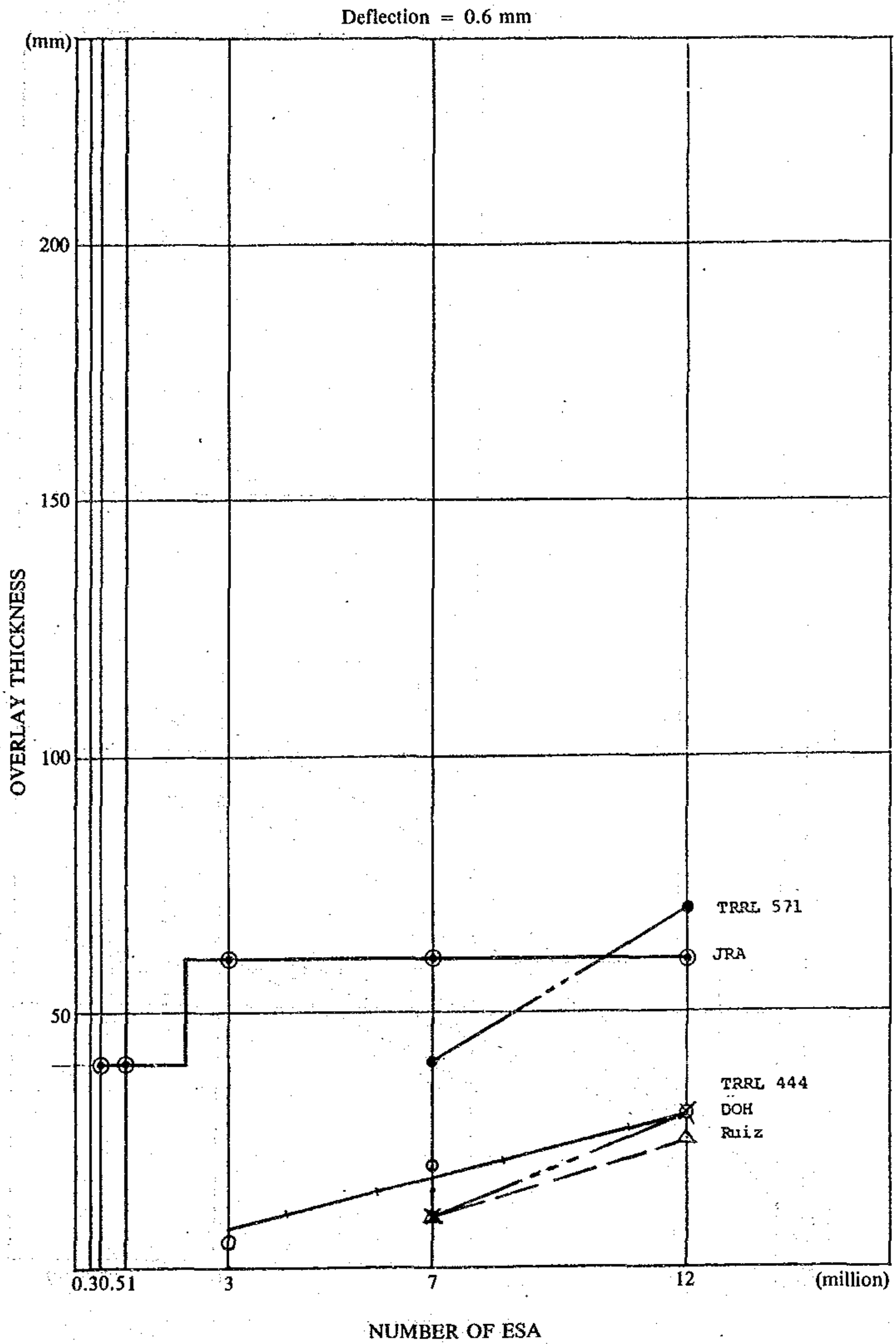


FIGURE 4.5.7 (2) OVERLAY THICKNESS BY DESIGN METHOD

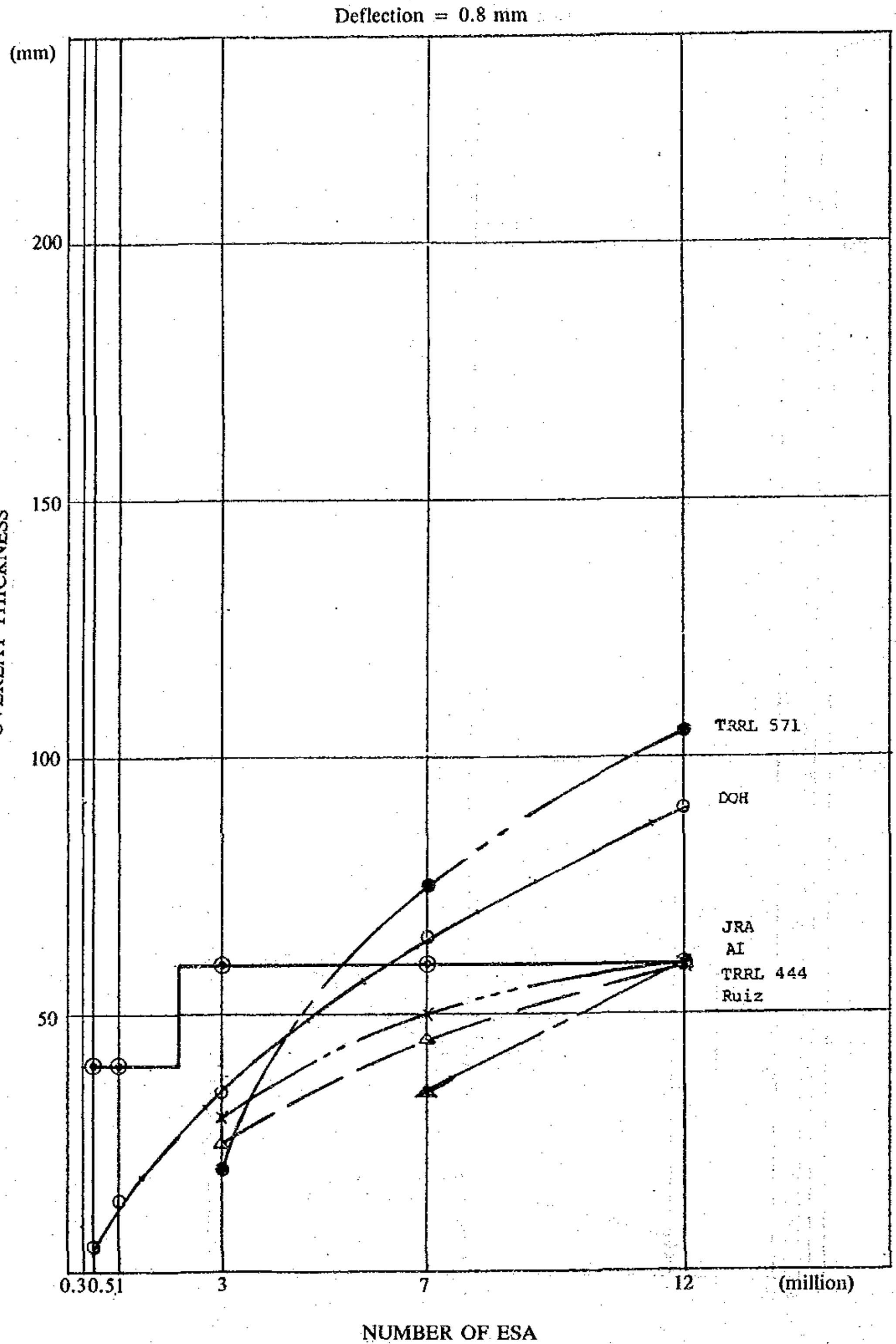


FIGURE 4.5.7 (3) OVERLAY THICKNESS BY DESIGN METHOD

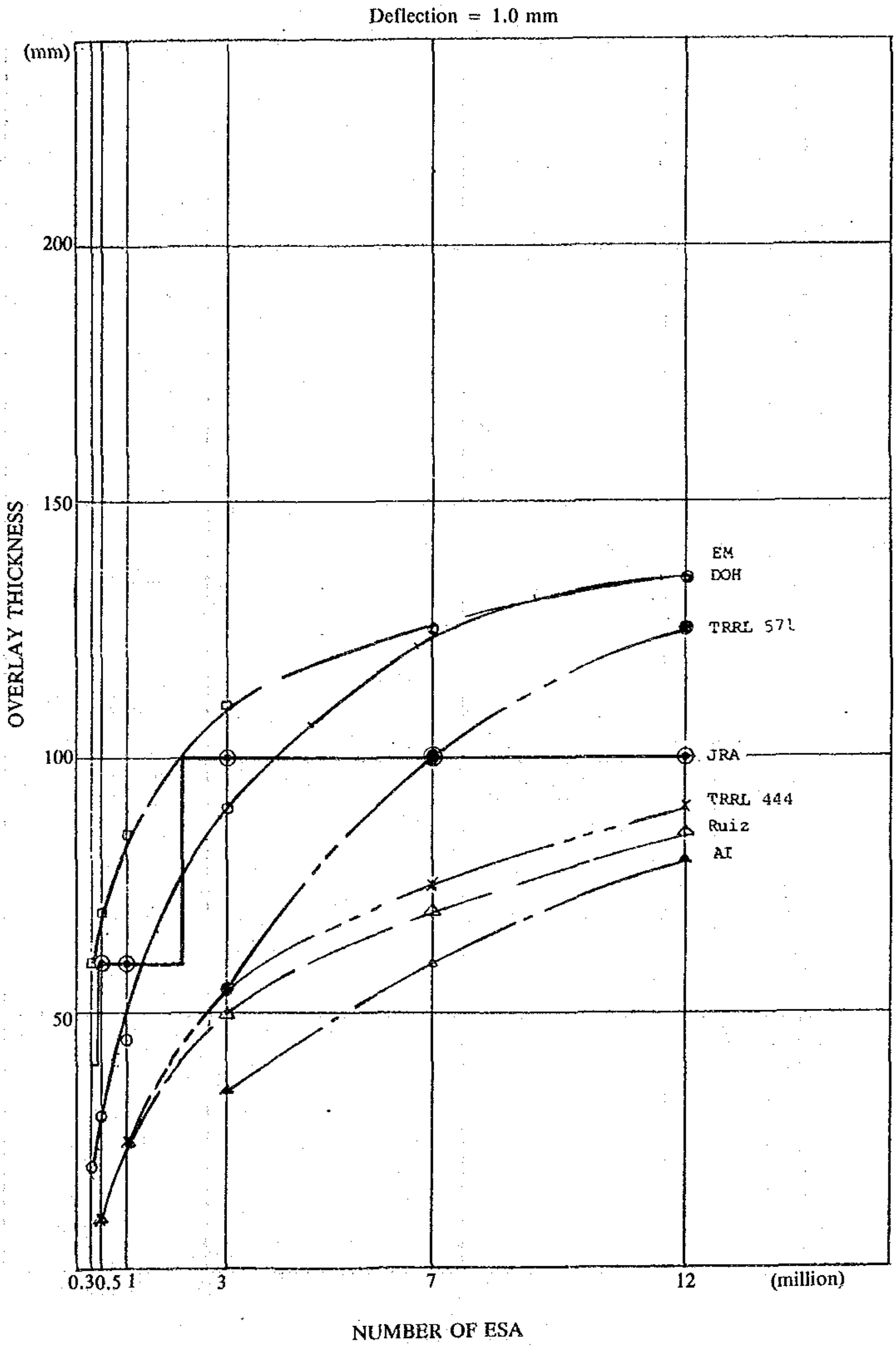


FIGURE 4.5.7 (4) OVERLAY THICKNESS BY DESIGN METHOD

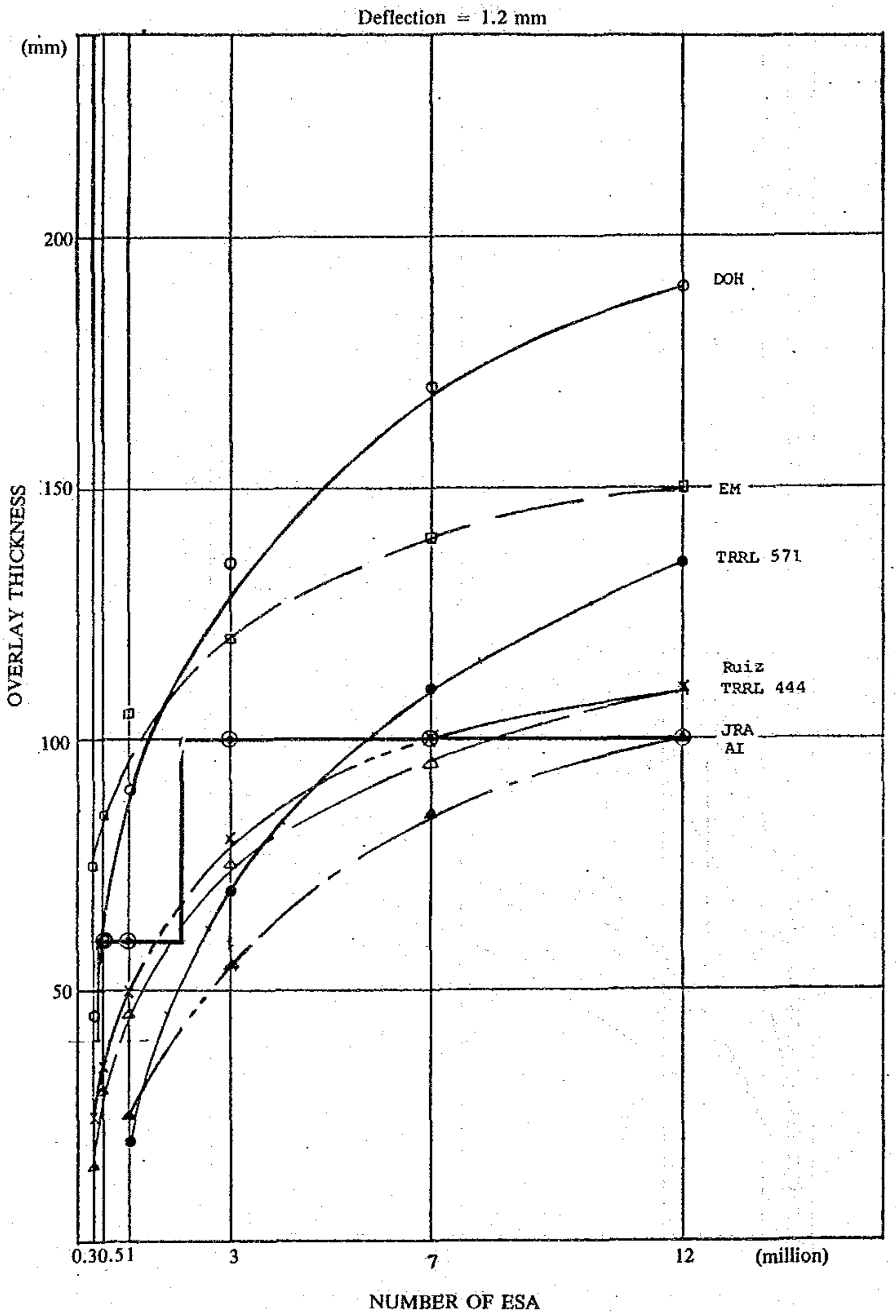


FIGURE 4.5.7 (5) OVERLAY THICKNESS BY DESIGN METHOD

Deflection = 1.4 mm

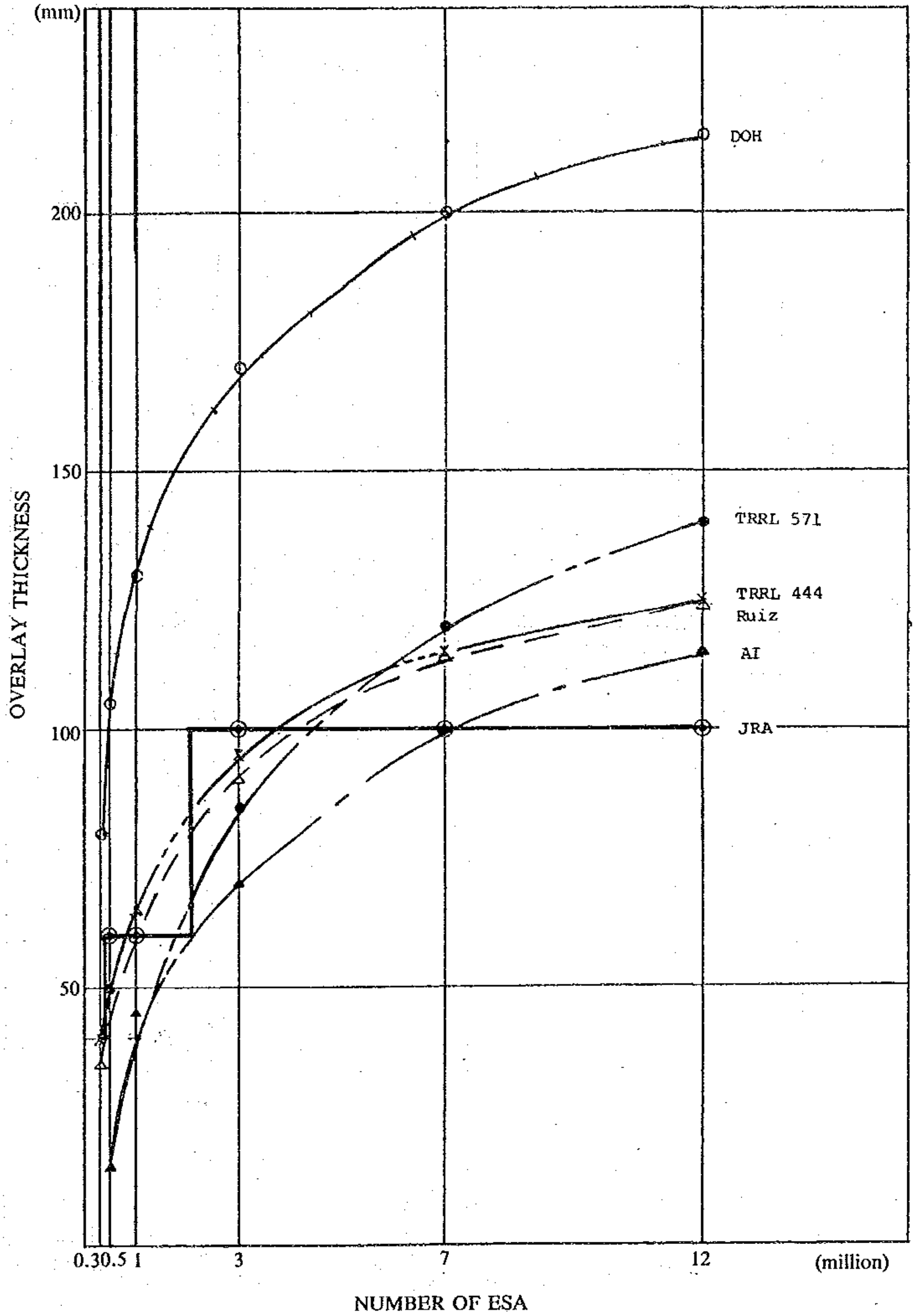


FIGURE 4.5.7 (6) OVERLAY THICKNESS BY DESIGN METHOD

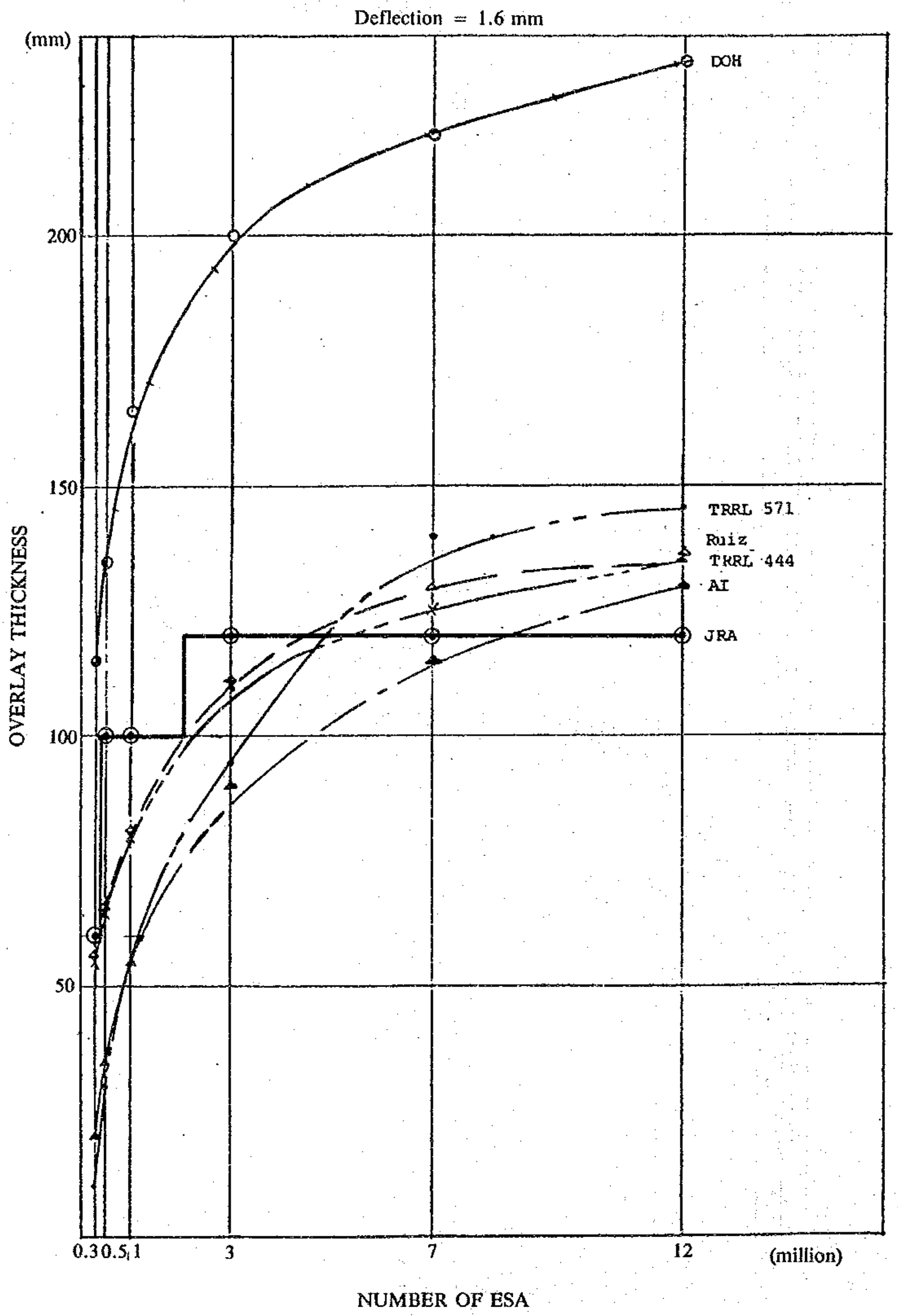


FIGURE 4.5.7 (7) OVERLAY THICKNESS BY DESIGN METHOD

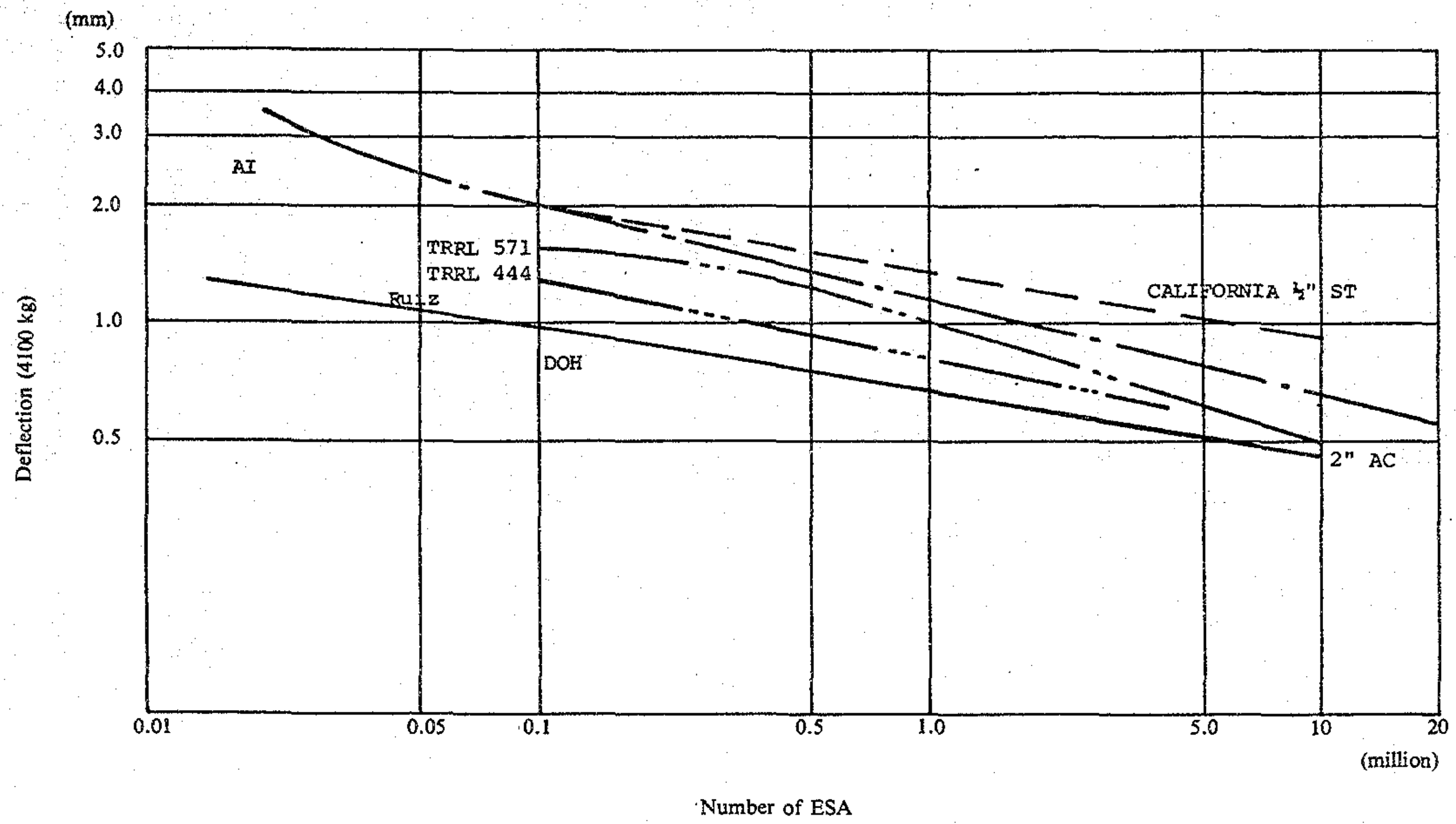


FIGURE 4.5.8 RELATIONSHIP BETWEEN DEFLECTION AND PAVEMENT LIFE

4.6 PLANNING STRATEGY AND PROCEDURES FOR REHABILITATION

The planning of rehabilitation can be divided into three stages:

- Stage I, identification of sections to be rehabilitated
- Stage II, determination of timing of rehabilitation
- Stage III, design of rehabilitation

Figure 4.6.1 illustrates the flow for rehabilitation planning and the various steps included in each stage. Factors which should be considered in each stage are discussed below.

4.6.1 Identification of Rehabilitation Sections

Sections to be rehabilitated should basically be selected based on the serviceability of the pavement, which may be expressed in terms of PSI. In principle, the strength of the pavement, which may be expressed by pavement deflection or CBR values, should not be the final determinant in selecting sections to be rehabilitated, since the main purpose of pavement is to ensure a smooth and comfortable passage of traffic and strength is required only to support this function. Only pavement surface conditions are involved in directly affecting traffic passage conditions.

It is desirable to use PSI by visual assessment or roughness in evaluating pavement serviceability. Only these two methods allow a large number of road sections to be evaluated in a short time.

Since the roughness value depends on the vehicle used for measurement, it is desirable to select the same specific vehicle model to measure roughness for all sections. PSI is a comprehensive evaluation measure which takes into account various factors such as surface unevenness, amount of cracking or patching and rut depth, whereas roughness indicates only the degree of unevenness of the pavement surface. However, as shown in Section 4.4.2, a good correlation exists between PSI and roughness. Therefore, roughness can be used as a substitute for PSI.

It is recommended that each Division Office conduct a survey of surface conditions by assessing PSI for each road section by visual inspection. Alternately, each Division Office may undertake a roughness survey by a standard vehicle equipped with MRM. A system of selecting road sections to be rehabilitated should be established based on the results of the above surveys by Division Offices.

A team of pavement experts should then scrutinize the sections selected by Division Offices by means of PSI. Measurements of physical properties for assessing PSI may optionally be carried out. These physical measurements, however, should be done only to crosscheck the results of PSI surveys by visual inspection since PSI itself is a subjective assessment.

The final results of this stage are PSI or roughness values assigned to each road section. Conversion of roughness to PSI can be done by means of the formulas shown in Section 4.4.2.

AASHTO indicates a PSI value of 2.5 as the threshold for rehabilitation. In this study, however, it was observed that PSI values of less than 2.0 indicated extremely poor surfaces and values of less than 1.5 complete deterioration. Therefore, it was decided that a PSI value of 2.0 should be the threshold value for immediate rehabilitation.

4.6.2 Determination of Rehabilitation Timing

In order to establish a long term rehabilitation plan, it is necessary to determine the timing when existing roads would deteriorate to the point of requiring rehabilitation.

A method to determine the timing frequently proposed in the past is to take a critical line presented in various pavement design methods and to determine the remaining life as the difference between the maximum cumulative ESA and the cumulative ESA from the opening to the present when the deflection is actually measured on the subject pavement. This method, however, does not take present surface conditions into account and may result in a mistake in which a good surface pavement is designated for rehabilitation. As shown in Section 4.4.3, measured deflection and surface conditions as expressed in PSI have little correlation.

For this reason, a model to estimate PSI change as a function of ESA and deflection was developed in this study. It is possible to determine the timing at which PSI reaches the 2.0 value. Details of the model are described in Section 4.8.2.

Analyses of the case study sections were conducted by adopting this model as described in Section 4.8. The results indicate the following rule of thumb: if PSI is more than 3.0, and deflection is less than 0.6 mm for the AI method and 0.45 mm for the DOH method, no rehabilitation is required within 7 years provided that the traffic volume is less than 800 vehicles/day.

4.6.3 Overlay Design Considerations

The thickness of overlay can be derived by the existing deflection and the cumulative ESA predicted for the design period.

The overlay thickness thus determined should be examined against construction limitations in practice, construction costs, work conditions and previous experience before implementation.

In Japan and the U.S., it is customary to limit the overlay thickness to 50 mm ~ 60 mm even *if a thicker overlay is called for by computation.*

A comparative analysis between overlay and reconstruction is desirable when the design overlay thickness becomes unduly thick.

It is very difficult to construct overlay thickness of less than 35 mm. Therefore, when the design overlay thickness is less than 35 mm, it is necessary to examine the possible extension of the design period so that the resulting thickness is in a reasonable range. If extension of the design period is more than 7 years, seal coating instead of overlay should be considered.

1) **Stage I**

Identification of Section to be Rehabilitated

↓

Preliminary Surveys

1) PSI by visual assessment
2) Roughness by MRM

↓

Detailed Survey (if necessary)

Measurement of profile (σ)
Cracking ratio (C) and
Rut depth (D)
$PSI = 4.354 - 1.125\sigma - 0.139\sqrt{C}\ 0.039\ D^2$ for AC surface
$PSI = 4.354 - 1.579\sigma - 0.098\sqrt{C}\ 0.015\ D^2$ for DBST surface

↓

Classification of Surface Conditions

PSI		Roughness*	Subjective Assessment	Riding Comfort	Rehabilitation Works Expected
5	AC PM DBST	250 1,300 1,000	Very good	Very good	Not required
4	AC PM DBST	790 1,840 1,540	Good	Good	Not required for the present
3	AC PM DBST	1,930 2,980 2,680	Fair	Aware of slight shocks	Sealing or patching
2	AC PM DBST	4,460 5,510 5,210	Poor	Discomfort during long journeys	Overlay
1	AC PM DBST	11,650 12,700 12,400	Very poor, almost deteriorated	Discomfort even during short journeys	Reconstruction

Note: * $PSI = 5e^{-\left[\frac{\ln(M-Mo)}{8.493}\right]^5}$

↓

FIGURE 4.6.1 (1) REHABILITATION PLANNING PROCEDURES

2) Stage II

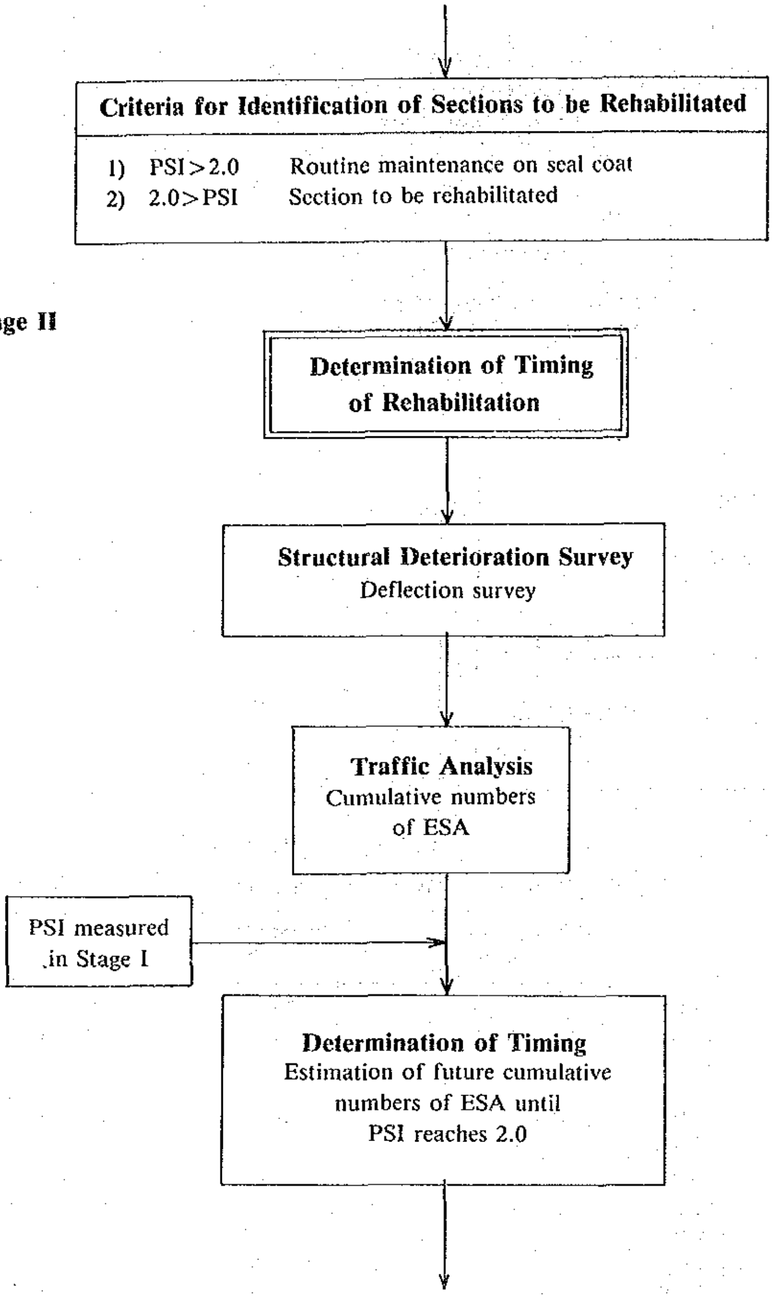


FIGURE 4.6.1 (2) REHABILITATION PLANNING PROCEDURES

3) **Stage III**

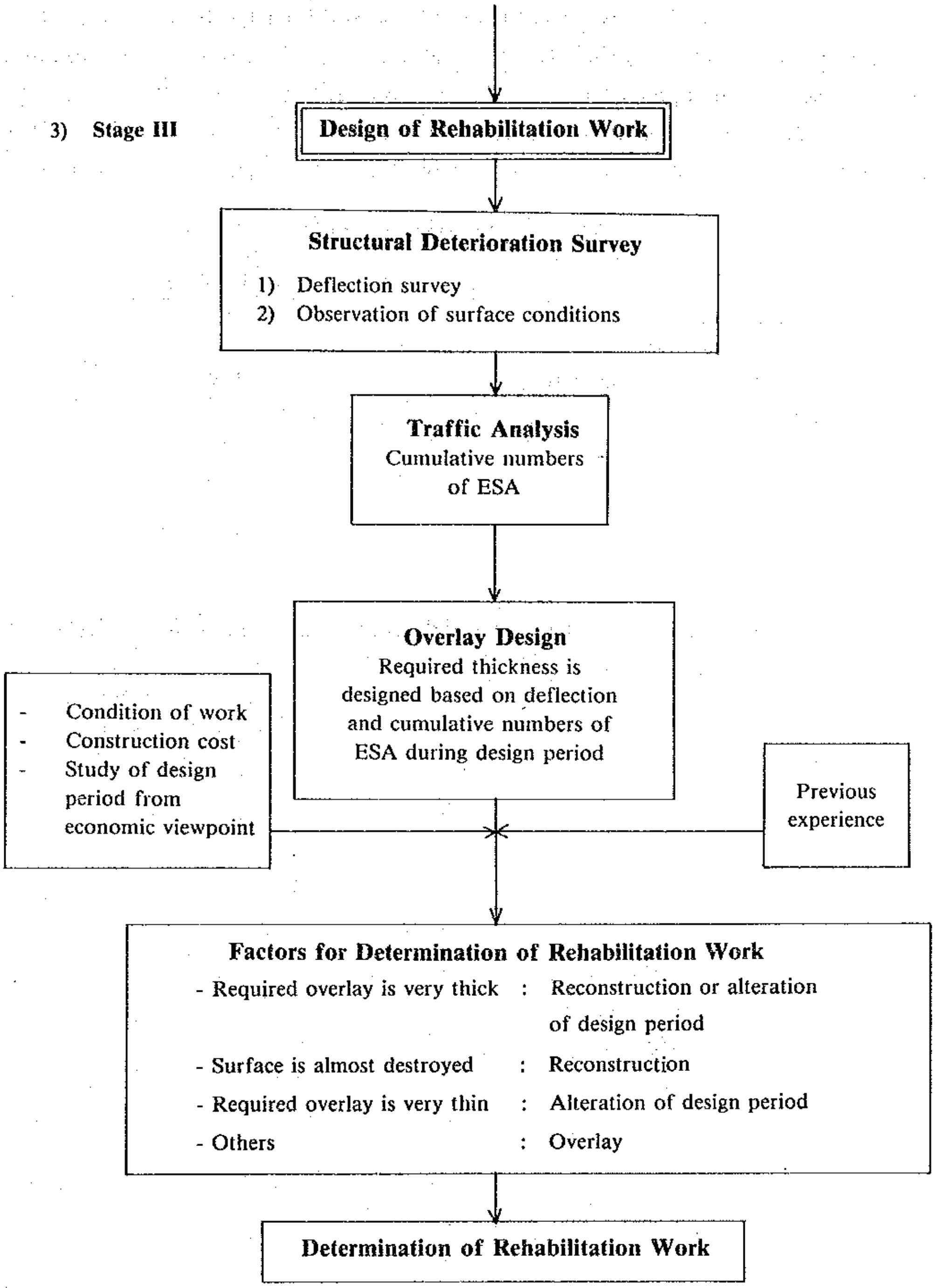


FIGURE 4.6.1 (3) REHABILITATION PLANNING PROCEDURES

4.7 CONSTRUCTION, MAINTENANCE AND ROAD USER COSTS

4.7.1 Construction Costs

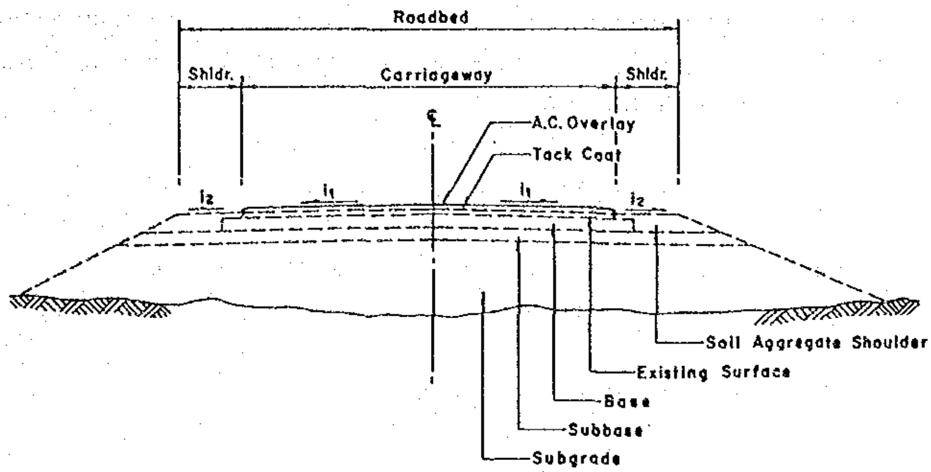
Cost items included were: asphalt overlay, tuck coat and shoulder formation. When the required overlay thickness was more than 120 mm, an overlay of 50 mm thickness and an aggregate base course with an appropriate thickness were assumed instead of a very thick asphalt overlay. Figure 4.7.1 shows typical cross sections for overlay and reconstruction sections. The cost of miscellaneous work was assumed to be 7% of the total of the above items.

UNIT COSTS BY WORK ITEM

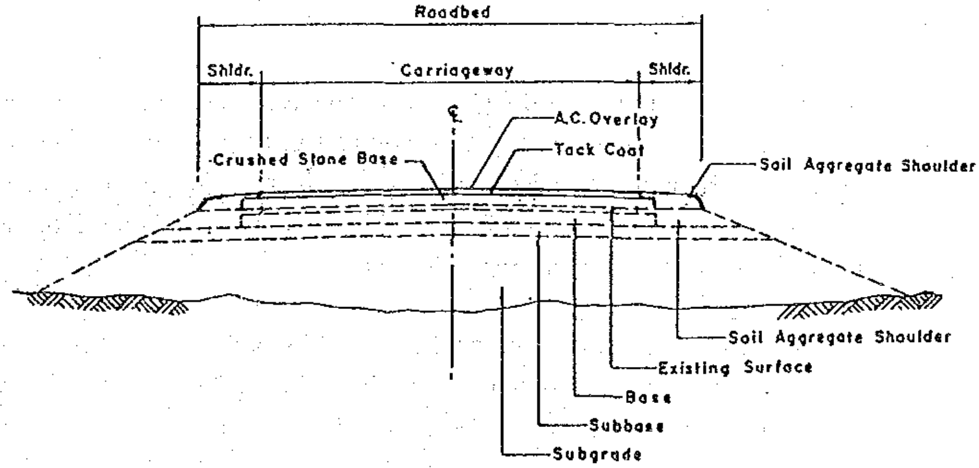
Item	Unit	Cost (baht)
Base Course		
Aggregate base	m^3	320
Shoulder, soil aggregate	m^3	120
Surface Course		
Asphalt concrete	ton	750
Tuck cost	m^3	12

It should be noted that reconstruction was assumed for section 18–19 of Route RH-27 since the existing PSI of the section is 1.17.

OVERLATY



OVERLAY WITH SHOULDERING



RECONSTRUCTION

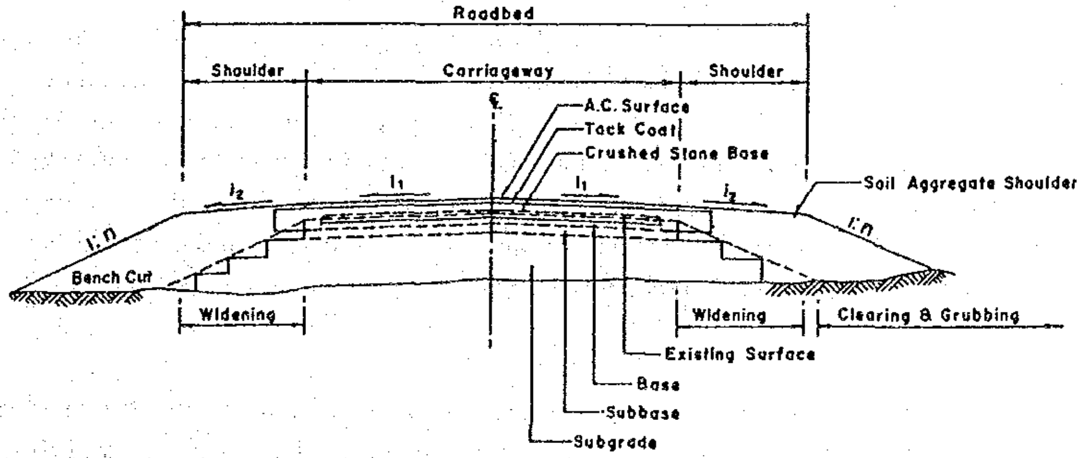


FIGURE 4.7.1 TYPICAL OVERLAY AND RECONSTRUCTION SECTIONS

4.7.2 Maintenance Costs

Recently a set of formulas and accompanying tables of factors were formulated by DOH which makes it possible to estimate the total maintenance cost for a given road section for the purpose of budget allocation. The formulas and tables are presented in FSH. Details of this method are presented in Section 3.6.2.

The formula for paved roads is as follows:

$$\text{Total Maintenance Cost} = \text{Standard cost} \times Kb \times \text{overhead factor} \times (1 + \text{emergency factor})$$

The following values were adopted for the current fiscal year:

Standard cost	:	8,200 baht/km/yr
Overhead factor	:	1.4
Emergency factor	:	0.15

For the study sections, the average 1983 ADT was 1640. The average estimated number of years after the last surfacing is 9.9 years. The average cumulative ESA is 1.06 million. Given these conditions, the total Kb value was calculated at 12.4% by the FSH method. The corresponding routine maintenance cost attributable to traffic and pavement strength therefore is 2,288 baht/km/yr. This figure is typical for older roads.

The Transport and Road Research Laboratory of the U.K. developed a set of equations for predicting the amount of patching work based on a study in Kenya. The maintenance work amount indicated by these equations, however, seems to be overestimated.

Most paved roads in Thailand have been constructed to have a structural number between 3.0 and 4.0. The overall average ESA in 1979 on provincial roads was 245 ESA/day/each way. The cumulative ESA would be in the order of 500,000 to 1 million. The amount of patching estimated by the TRRL method is 12.5 m^2/km to 380 m^2/km or 196 m^2/km per lane as an average. Assuming an average unit patching cost of 135 baht/m^2, 28,150 baht/km is required, which is 7 times the estimated maintenance cost derived from the actual expenditures of DOH. Even considering the non-variable portion of maintenance costs attributable to pavement and traffic, this discrepancy seems too great. Adoptation of the TRRL method, therefore, was abandoned.

A practical approach was taken to estimate routine maintenance cost. By the PSI deterioration model to be explained in Section 4.8.2, the maximum number of cumulative ESA for a pavement with a certain deflection level can be estimated for a given deflection actually measured or for the subsequent overlay life. The routine maintenance cost was assumed to be a linear function of cumulative ESA starting at 0 value immediately after the overlay or construction and reaching the above average value at the midpoint of overlay life.

The following formula was adopted in the rehabiliation evaluation model:

$$M = k\frac{2N}{N_{2.0}}$$

where,
- M : Routine maintenance cost baht/km/yr
- $N_{2.0}$: Maximum cumulative ESA
- N : Current cumulative ESA since the last overlay
- k : Constant: 2,288 baht

A current N is calculated from the existing PSI value.

4.7.3 VOC

The following assumptions on VOC factors were made:

1) Vehicle Type

For the evaluation of rehabilitation, the current vehicle type classification by DOH was adopted instead of those shown in Section 3.4.2.

The relationship between the two classification schemes is shown below:

RELATIONSHIP BETWEEN VEHICLE TYPE CLASSIFICATIONS

Classification by DOH	Share	Classification in Section 3.4.2
Car & Taxi (P/C)	100%	P/C
Light Bus (L/B)	24%	L/B
	76%	M/B
Heavy Bus (H/B)	100%	H/B
Light Truck (L/T)	88%	P/T
	12%	4/T
Medium Truck (M/T)	100%	6/T
Heavy Truck (H/T)	100%	10/T

2) Basic Costs of VOC Components

The basic cost values for each vehicle type classification by DOH were calculated based on the values shown in Section 3.4.3.

3) Road Classes

Paved roads were subdivided into three classes, good, fair and poor, according to PSI values. Travel speeds were determined by the results of field surveys on the study routes. Road classes and travel speeds are as follows:

AVERAGE TRAVEL SPEED BY ROAD CLASS
(ON LEVEL TANGENT ROADS) (Unit: km/h)

Vehicle Type	Paved		
	PSI ≥ 3	3 > PSI > 2	2 ≥ PSI
	Good (A)	Fair (B)	Poor (C)
P/C	80	64	40
L/B	72	56	40
H/B	72	56	40
L/T	72	56	40
M/T	64	56	40
H/T	64	56	40

The relationship of road classes between those shown in Section 3.4.3 and those in this Section are basically as follows:

RELATIONSHIP BETWEEN ROAD CLASSES

Classes in Section 3.4.3				Classes in this Section	
1.	Paved		———	(A)	Paved Good
2.	Laterite	Good	———	(B)	Paved Fair
3.	〃	Fair			
4.	〃	Poor	———	(C)	Paved Poor

4) VOC by Speed and Surface Condition

For the conversion indices of components of VOC, except for the fuel cost, the values in Section 3.4.3 were adjusted based on the difference in classification of vehicle types and the subdivision of road classes for paved road.

As for the fuel consumption cost on various surface conditions of paved road, the results of the fuel consumption survey shown in Section 4.4.6 were examined. It was found that fuel consumption on a poor paved road with a roughness over 5500 mm/km at 48 km/h was 24% higher than that on a good paved road at the same speed, whereas fuel consumption on a poor laterite road at 48 km/h was 26% higher than that on a good paved road at the same speed. Therefore, fuel consumption factors developed for poor laterite road were used to represent fuel consumption on poor paved roads. Fuel consumption rates on good and fair paved roads were assumed to be the same as the survey results shown in Section 4.4.6.

The resulting VOCs by surface condition and vehicle type are shown in Table 4.7.1. Conversion factors developed are presented in Appendix 4.7.1.

TABLE 4.7.1 VEHICLE OPERATING COST ON LEVEL TANGENT ROADS

Road Class (A) : Paved Road — Good

(Unit: baht/km)

Vehicle Type	Speed (km/h)	Fuel	Oil	Tires and Tubes	Repairs and Maintenance	Depreciation and Interest	Overhead	Crew	Total
PC	80	0.5212	0.0311	0.0931	0.1545	1.0183	-	-	1.8182
LB	72	0.5943	0.0388	0.1881	0.4778	0.9619	0.0897	0.2100	2.5606
HB	72	1.1271	0.0692	0.3087	0.8498	1.3159	0.4692	0.3750	4.5149
LT	72	0.5408	0.0346	0.0904	0.2004	0.7156	-	0.0150	1.5968
MT	64	0.8478	0.0692	0.1332	0.4611	0.7552	0.1742	0.2812	2.7219
HT	64	1.3254	0.0692	0.4545	0.3394	1.1625	0.1624	0.3438	3.8572

Road Class (B) : Paved Road — Fair

(Unit: baht/km)

Vehicle Type	Speed (km/h)	Fuel	Oil	Tires and Tubes	Repairs and Maintenance	Depreciation and Interest	Overhead	Crew	Total
PC	64	0.4638	0.0336	0.0844	0.1468	1.0590	-	-	1.7876
LB	56	0.5170	0.0420	0.1721	0.4634	1.2400	0.1164	0.2700	2.8209
HB	56	1.0031	0.0747	0.2824	0.7988	1.7122	0.6093	0.4821	4.9626
LT	56	0.4705	0.0374	0.0827	0.1944	0.9277	-	0.0193	1.7320
MT	56	0.8202	0.0747	0.1378	0.4816	0.8770	0.1980	0.3214	2.9107
HT	56	1.2822	0.0747	0.4705	0.3545	1.3500	0.1846	0.3929	4.1094

Road Class (C) : Paved Road — Poor

(Unit: baht/km)

Vehicle Type	Speed (km/h)	Fuel	Oil	Tires and Tubes	Repairs and Maintenance	Depreciation and Interest	Overhead	Crew	Total
PC	40	0.5785	0.0445	0.1050	0.2070	1.3340	-	-	2.2690
LB	40	0.6300	0.0622	0.2450	0.7119	2.2598	0.1630	0.3780	4.4499
HB	40	1.5554	0.1107	0.4020	1.2747	3.1867	0.8530	0.6749	8.0574
LT	40	0.5733	0.0554	0.1177	0.2986	1.5373	-	0.0270	2.6093
MT	40	1.2717	0.1107	0.1962	0.7684	1.6321	0.2772	0.4500	4.7063
HT	40	1.9881	0.1107	0.6698	0.5656	2.5125	0.2584	0.5501	6.6552

4.8 ECONOMIC EVALUATION

4.8.1 Introduction

The preceding sections show remarkable variations among existing design methods for pavement rehabilitation. For the wide variety of actual conditions of paved routes selected for this study, these methods yield radically different solutions. Two questions immediately come to mind. What is the range of difference in terms of economic costs and benefits among the various design methods? For a given design method, what is the best design period of rehabilitation, a single long period or a series of short periods?

An attempt to answer these questions was made by a computer model developed especially for this study. The model takes into account the costs of rehabilitation, maintenance and vehicle operation for each case study section and compares the total present value of each of the above costs over a study period of 7 years. It also compares costs and benefits for sections where rehabilitation is required.

The DOH and AI methods were selected for comparison, because the former gives thicker overlay and the latter is a representative of a group of methods yielding average thickness.

4.8.2 The Model

4.8.2.1 Overview

In the preceding sections, it was shown that deflection and PSI value for the case study sections have a poor correlation. This should come as no surprise as deflection under normal conditions remains at the same level until almost the very end of the pavement life, whereas the surface conditions deteriorate as traffic loading increases. Measured deflection values, therefore, cannot be a good indicator of timing for rehabilitation. The study team is of the opinion that the timing of rehabilitation should be determined on the basis of actual pavement conditions, and that the best overall indicator of surface conditions is PSI.

It was decided, therefore, that a model of road rehabilitation processes should be constructed around the concept of PSI.

Factors considered in the model are as follows:

Input Data

- Existing pavement strength
  The strength of existing pavement is expressed in terms of deflection actually measured.
- Traffic loading and future projections

Traffic loading in terms of daily ESA and future projections are described in Section 4.3.

- Actual PSI values

  Actual measured PSI values are presented in Section 4.2.1.

Items Determined by the Model

- Overlay timing

  This is determined as the year in which the PSI value reaches 2.0 or less.
- Pavement deterioration

  PSI of a pavement is determined by the number of years and cumulative traffic loading since the last overlay and the existing deflection.
- Overlay design period and thickness

  Depending on the existing deflection value, the overlay thickness is determined by the methods described in Section 4.8.2.3 for the given design period.
- Maintenance costs and residual value

  Maintenance costs and residual value are determined as described in Sections 4.7.2 and 4.8.2.4, respectively.
- Vehicle operating costs

  Vehicle operating costs are determined as described in Section 4.7.3.

The model proceeds in the following sequence:

1) From the existing PSI value, the maximum number of cumulative ESA is calculated which makes the value of PSI equal to 2.0 (terminal value).

2) The estimated number of cumulative ESA is converted to the number of years from 1985 by means of traffic projections.

3) The required overlay thickness is determined by two methods with design life periods of 4 years and 7 years.

4) If the resulting thickness is less than 3.5 cm, a design life period corresponding to 3.5 cm thickness is determined.

5) If the end of the overlay life period is before the end of the 7th year, a second overlay is similarly designed.

6) Thus the years of overlay construction and associated costs are determined.

7) PSI values for each year are calculated by a set of functions developed on the condition that PSI immediately after the operation is 5.0 and immediately before the next operation 2.0.

8) Vehicle operating costs are calculated in accordance with the surface condition types classified by PSI.

9) Maintenance costs are also calculated as a function of cumulative ESA.

10) Maintenance costs and VOCs for each year are calculated.

11) A separate stream of maintenance costs and VOCs are calculated for the case without any overlay.

12) The difference between 10) and 11) is taken to produce the benefit stream, and the residual value of overlay, if any, is added at the end of the 7th year to the benefit stream.

13) The costs of overlay in the implementing years form the cost stream.

14) An economic evaluation is made by calculating IRR and net present value from the cost and benefit streams.

15) In order to compare all the routes, the total cost of overlay, VOCs and maintenance costs are calculated for all sections including those sections not requiring overlay.

It should be noted that a major objective of the model is to compare the total costs by two different methods of overlay design. As shown in Section 4.5.2, the two methods yield radically different overlay thickness requirements for a given design life. For the purpose of comparison, pavement deterioration behavior under the two methods is assumed to be the same for a given design life although the overlay thicknesses vary. This is a rather unrealistic assumption but must be accepted for the purpose of comparison.

4.8.2.2 Pavement Deterioration

One finding of field tests in Kenya by TRRL of the U.K. was that pavement surface condition measured in terms of roughness is a linear function of cumulative axle loads since the last overlay. That is:

$$R = Ro + kN \quad \text{(1)}$$

where,
R : Present roughness value (R = M in the formula in 4.4.2)
Ro : Initial roughness (Ro = Mo in the formula in 4.4.2)
N : Number of cumulative axle loads
k : *Constant*

The relationship between PSI and roughness, R, was established in the following form as explained in Section 4.4.2:

$$PSI = 5e^{-\left[\frac{\ell n\ (R-Ro)}{a}\right]^5} \qquad (2)$$

By combining equations (1) and (2), PSI can be expressed as a function of cumulative axle loads, N, as shown below:

$$PSI = 5e^{-\left(\frac{\ell n\ N}{a}\right)^5}$$

Pavement life can be defined as the number of cumulative axle loads corresponding to the PSI value of 2.0, $N_{2.0}$. Therefore:

$$a = \frac{\ell n\ N_{2.0}}{[\ell n(5/2)]^{1/5}}$$

Overlay design charts specified by the AI and DOH methods indicate the maximum number of cumulative axle loads allowable for a given pavement deflection. The following equations were derived by the study team from the two design charts:

For the AI method,

$$N_{2.0} = 15.692 \times 10^5 \times D^{-4.1545} + 11340$$

For the DOH method,

$$N_{2.0} = 73468\ D^{-6.15}$$

where, D : Pavement deflection in mm after temperature adjustment

Therefore, for the AI method.

$$PSI = 5e^{-\left[\frac{\ell n\ N}{1.0176\ \ell n\ (15,692 \times 10^5\ D^{-4.1545} + 11340)}\right]^5}$$

and for the DOH method,

$$PSI = 5e^{-\left[\frac{\ell n}{11.40 - 6.258\ \ell n\ D}\right]^5}$$

The above equations represent pavement deterioration in such a way that PSI decreases as the number of cumulative axle loads increases for a given deflection.

Assuming that the history of deterioration of existing pavement follows the above relationships, the cumulative axle loads corresponding to existing PSI values can be calculated and the remaining life can be derived as the difference between the total life, $N_{2.0}$, and the existing number of cumulative axle loads, N.

The foregoing computational procedure indicates a method to determine the timing of pavement rehabilitation solely on the basis of existing surface conditions, deflection and future traffic loading. The method has the advantage of not being dependent on the past history of traffic loading, which is usually difficult to determine. The method, above all, does not call for rehabilitation work on a road with good surface conditions—a situation which may arise by using other methods which do not explicitly include present surface conditions as a determining factor.

A somewhat different approach was taken in determining pavement deterioration after overlay although the basic principle was the same.

Since the overlay design life was given as a set of discrete number of years for comparison purposes, the maximum number of cumulative axle loads, $N_{2.0}$, could be directly calculated from the number of years of design life. PSI values in the intermediate years were calculated by the following formulas:

$$PSI = 5e^{-\left(\frac{\ell n\ N}{a}\right)^5}$$

$$a = \frac{\ell n\ N_{2.0}}{\left[\ell n(5/2)\right]^{1/5}}$$

where, N : Number of cumulative axles since the last overlay

$N_{2.0}$: Maximum number of cumulative axles during the design life

4.8.2.3 Overlay Design

For each section of the case study routes, overlay requirements were determined based on the AI and DOH methods by the existing deflection and the traffic loading. The following describes factors and procedures taken in the process of overlay design:

1) Design Deflection Value

The deflection value derived from actual measurement at the site must be adjusted by the temperature at the time of measurement. DOH currently uses the following adjustment formula:

$$d = 0.0002 \times (90 - F_t)$$

where, d : Differential value for adjustment in inches
F_t : Surface temperature in Fahrenheit

Deflection values after adjustment at 20 points included in each 1-km long section were then averaged and the standard deviation was calculated. The design deflection was calculated by the following formula currently used by DOH:

$$D_d = D + 1.5 \times \sigma$$

where, D_d : Design deflection
D : Average deflection after adjustment
σ : Standard deviation

2) Overlay Design Procedures

Two different strategies were considered as described above. One was to set the overlay life as 7 years (one-overlay case) and the other was to place a thinner overlay twice in the 7 year period (two-overlay case). For each 1-km section of the case study routes, overlays were designed following the procedures specified in the AI and DOH methods. Details of design procedures to determine overlay thickness for a given design life or to determine the design life for a given thickness are shown in Appendices 4.8.1 and 4.8.2.

One-overlay case

- A cumulative ESA and design traffic number (No for both values) for a design life (Lo) of 7 years was calculated from traffic projections. (See Appendix 4.3.1)

- The required thickness of overlay (T_{Ao}) is determined from the design deflection (D_d) and the No by using Figure 4.5.1 for the AI method and Figure 4.5.4 for the DOH method.

- If the calculated thickness is less than 35 mm, the thickness is set at 35 mm and the L_o is recalculated by redetermining No corresponding to the thickness of 35 mm from Figures 4.5.1 or 4.5.4.

Two-overlay case

a) First Overlay

- A cumulative ESA and design traffic number (N_1) for a design life (L_1) of 4 years was determined from traffic projections.

- The overlay thickness (T_{A1}) can be estimated from D_d and N_1 in Figures 4.5.1 and 4.5.4.

- Similar to the procedure for design life of 7 years, if the resulting thickness is less than 35 mm, T_{A1} is set at 35 mm and the design life (L_1) is recalculated.

b) Second Overlay

- An overlay thickness (T_{Ao}) is determined for a design life of 7 years (Lo) starting from the beginning of the first overlay.

- The thickness of the second overlay (T_{A2}) and the design life (L_2) can be derived by the following formulas:

$$L_2 = L_o - L_1$$
$$N_2 = N_o - N_1$$
$$T_{A2} = T_{Ao} - 0.8 \times T_{A1}$$

- If the resulting T_{A2} is less than 35 mm, T_{A2} is set at 35 mm and the total thickness, including the contribution by the previous overlay (T_{Ao}'), is determined by the following formula:

$$T_{Ao}' = T_{A2} + 0.8 \times T_{A1}$$

- From the value of T_{Ao}', the maximum ESA (N_o) and subsequent design life (L_o') is determined by Figures 4.5.1 and 4.5.4. The design life (L_o') thus obtained is from the beginning of the first overlay.

- The design life of the second overlay of 35 mm (L_2) can be derived as the balance of the total design life (L_o'), less the life of the first overlay (L_1).

Figure 4.8.1 illustrates the procedures for overlay design.

4.8.2.4 Other Issues

1) Reconstruction Criteria

AASHTO indicates a PSI value of 1.5 as the failure point. In the visual assessment survey conducted by the study team, all assessors agreed that road sections with PSI below 1.5 would require reconstruction. It was therefore decided that road sections with PSI below 1.5 were to be reconstructed.

When the estimate overlay thickness exceeds 120 mm, the pavement was planned to be replaced with a combination of a 50-mm thick surface course and a crushed stone base course. An asphalt overlay of 120 mm is equivalent to 50 mm of an asphalt surface course with 140 mm of a crushed stone base course since the equivalent factor for a crushed stone base course is 0.5.

2) Residual Value

The residual value of overlay was assumed to be in proportion to the number of years remaining in the overlay life.

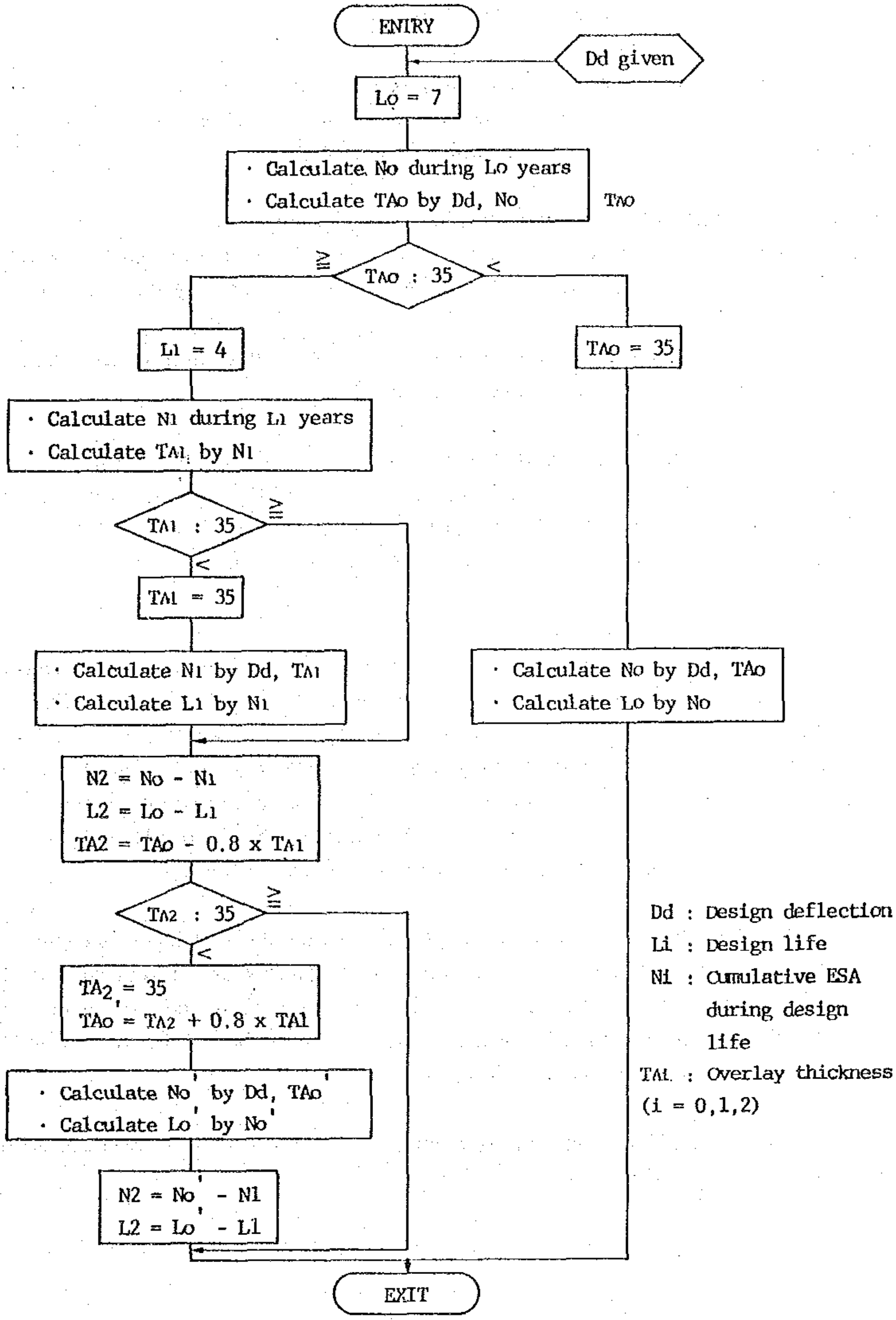


FIGURE 4.8.1 OVERLAY DESIGN PROCEDURES

4.8.3 Comparison of AI and DOH Methods

Overlay requirements, timing and thickness were estimated for all case study routes by the model described in the preceding sections. Estimates were made separately for the AI and DOH methods. The results were shown in Appendix 4.8.3.

Table 4.8.1 summarizes the overlay requirements of each route estimated by the two methods. For the coming 7-year period, overlays are required for 22 km sections on 4 routes when the AI method is applied, and for 35 km sections on 6 routes by the DOH method.

By the AI method, only 6 km sections were assessed to require thick overlays with stage construction, compared to 19 km sections by the DOH method.

It is noted that reducing the design life from 7 to 4 years does not reduce the required overlay thickness proportionately. The reason is that the thickness of the first overlay is considered 20% less when determining the thickness of the second overlay, but the combined total thickness of the first and the second overlay is considerably thicker than the overlay of the 7-year life.

The present value of overlay costs at various years are shown in Table 4.8.2 for each route. The discounted present values of overlays for all case study routes was 7.628 million baht by the AI method, only 45% of that by the DOH method. If a two-overlay case is adopted, the present value of overlay costs of all routes would be 20% less than that under a one-overlay case by the AI method. However, by the DOH method, the total present value of overlay costs under the two-overlay case was 2% more than the one-overlay case. This difference, however, is entirely due to the very thick overlays on RH-27.

It is noted that overlay costs, whatever the difference by method, are minor in comparison with the VOCs. The combined total discounted cost of overlays for all routes is only 1 to 2.5% of the total project cost including overlay, vehicle operating and road maintenance costs. Road maintenance costs, in particular, are on the order of 0.1% or less and are insignificant in terms of the total project cost.

In conclusion, the DOH method seems to require twice as many funds for overlays as other methods such as the AI method.

TABLE 4.8.1 SUMMARY OF OVERLAY REQUIREMENTS

Route No.	Section	AI Method									DOE Method								
		One-Overlay Case			Two-Overlay Case						One-Overlay Case			Two-Overlay Case					
		Year	AC	BC	Year	AC	BC	Year	AC	BC	Year	AC	BC	Year	AC	BC	Year	AC	BC
RT-224	14-15										1987	50	-	1987	35	-	1991	35	-
RH-21	-	No need for overlay									No need for overlay								
RH-22	2-3										1986	55	-	1986	35	-	1990	35	-
	5-6										1987	45	-	1987	35	-	1992	35	-
	6-7										1990	35	-						
RH-5	-	No need for overlay									No need for overlay								
RH-12	488-489	1985	35	-							1985	85	-	1985	55	-	1989	40	-
	489-490	1985	35	-							1985	35	-						
	490-491	1985	35	-							1985	35	-						
	491-492										1991	50	-	1991	35	-	1996	35	-
	493-494										1986	60	-	1986	40	-	1990	35	-
	494-495	1985	35	-							1985	55	-	1985	40	-	1989	35	-
	495-496										1988	35	-						
	496-497	1985	35	-							1985	35	-						
	497-498	1988	45	-	1988	35	-	1993	35	-	1985	50	210	1985	50	160	1989	50	-
RH-16	7-8										1989	35	-						
	8-9	1991	35	-							1985	45	-	1985	35	-	1990	35	-
	9-10										1991	35	-						
	10-11	1985	35	-							1985	40	-	1985	35	-	1991	35	-
	11-12										1986	35	-						
RH-25	10-11	1985	35	-							1985	35	-						
	11-12	1985	35	-							1985	35	-						
	12-13	1985	35	-							1985	35	-						
	13-14	1985	35	-							1985	35	-						
	14-15	1985	35	-							1985	35	-						
	15-16	1985	35	-							1985	35	-						
	16-17	1985	35	-							1985	35	-						
RH-27	9-10										1988	70	-	1988	50	-	1992	35	-
	10-11	1985	35	-							1985	60	-	1985	40	-	1989	35	-
	11-12	1985	50	-	1985	35	-	1989	35	-	1985	50	280	1985	50	240	1989	55	-
	12-13	1988	45	-	1988	35	-	1994	35	-	1985	50	230	1985	50	180	1989	50	-
	13-14										1985	50	330	1985	50	300	1989	50	-
	14-15	1985	65	-	1985	45	-	1989	35	-	1985	50	330	1985	50	300	1989	55	-
	15-16										1988	115	-	1988	90	-	1992	45	-
	16-17	1989	40	-	1989	35	-	1995	35	-	1985	50	200	1985	50	150	1989	50	-
	17-18	1985	55	-	1985	40	-	1989	35	-	1985	50	290	1985	50	250	1989	55	-
	18-19	1985	50	420	Reconstruction						1985	50	420	Reconstruction					

Note: AC: Asphalt concrete
BC: Base course

TABLE 4.8.2 SUMMARY OF TOTAL DISCOUNTED COSTS OF ROAD REHABILITATION

(Unit : thousand baht)

Route No.	Section	Length (km)	ADT	AI Method							
				ONE-OVERLAY CASE				TWO-OVERLAY CASE			
				Overlay Cost	VOC	RMC	Total	Overlay Cost	VOC	RMC	Total
RT-224	10-20	10	3827	0	172,521	22	172,543	0	172,521	22	172,543
RH- 21	120-133	13	2235	0	120,400	19	120,419	0	120,400	19	120,419
RH- 22	0-8	8	3007	0	84,976	45	85,021	0	84,976	45	85,021
RH- 5	20-39	19	1283	0	102,992	27	103,019	0	102,992	27	103,019
RH- 12	488-498	10	1038	2,469	43,831	64	46,364	1,623	43,864	65	45,552
RH- 16	7-12 13-18	10	1475	341	58,305	75	58,721	341	58,305	75	58,721
RH- 25	7-17	10	1206	1,904	52,006	34	53,944	1,904	52,006	34	53,944
RH- 27	9-19	10	813	2,914	31,089	82	34,085	2,232	31,032	80	33,344
TOTAL		90		7,628	666,120	368	674,116	6,100	666,096	367	672,563
				DOH Method							
RT-224	10-20	10	3827	383	173,325	35	173,743	369	173,360	35	173,764
RH- 21	120-133	13	2235	0	120,475	21	120,496	0	120,475	21	120,496
RH- 22	0-8	8	3007	785	84,409	66	85,260	762	84,523	68	85,353
RH- 5	20-39	19	1283	0	103,465	35	103,500	0	103,465	35	103,500
RH- 12	488-498	10	1038	4,421	44,127	75	48,623	3,898	44,159	77	48,134
RH- 16	7-12 13-18	10	1475	1,479	58,433	75	59,987	1,459	58,376	73	59,908
RH- 25	7-17	10	1206	1,904	52,006	35	53,945	1,904	52,006	35	53,945
RH- 27	9-19	10	813	7,949	30,986	79	39,014	8,863	31,092	88	40,043
TOTAL		90		16,921	667,226	421	684,568	17,255	667,456	432	685,143

TABLE 4.8.3 SUMMARY OF ECONOMIC EVALUATION FOR OVERLAY DESIGN AI METHOD

Route No.	Section	Overlay Year	ADT in Overlay Year	One-Overlay Case Overlay Cost (baht)	One-Overlay Case NPV (baht)	One-Overlay Case IRR (%)	Two-Overlay Case Overlay Cost (baht)	Two-Overlay Case NPV (baht)	Two-Overlay Case IRR (%)
RT - 224	-	-	-	-	-	-	-	-	-
RH - 21	-	-	-	-	-	-	-	-	-
RH - 22	-	-	-	-	-	-	-	-	-
RH - 5	-	-	-	-	-	-	-	-	-
RH - 12	488-489	1985	1,038	991,156	1,845,690	42.8	-	-	-
	489-490	1985	1,038	390,125	2,550,710	122.1	-	-	-
	490-491	1985	1,038	390,125	2,551,060	122.1	-	-	-
	494-495	1985	1,038	390,125	2,484,310	121.8	-	-	-
	496-497	1985	1,038	390,125	2,550,950	122.1	-	-	-
	497-498	1988	1,186	431,173	1,785,520	109.2	445,005	1,790,110	131.2
RH - 16	8- 9	1991	1,870	191,274	2,056,850	194.5	-	-	-
	10- 11	1985	1,475	377,540	3,238,340	154.7	-	-	-
RH - 25	10- 11	1985	1,206	314,617	3,496,230	191.0	-	-	-
	11- 12	1985	1,206	314,617	3,496,160	191.0	-	-	-
	12- 13	1985	1,206	314,617	3,496,100	191.0	-	-	-
	13- 14	1985	1,206	314,617	3,496,220	191.0	-	-	-
	14- 15	1985	1,206	314,617	3,496,000	190.9	-	-	-
	15- 16	1985	1,206	314,617	3,496,310	191.0	-	-	-
	16- 17	1985	1,206	314,617	3,495,810	190.9	-	-	-
RH - 27	10- 11	1985	813	314,617	1,834,980	111.7	-	-	-
	11- 12	1985	813	535,669	1,473,140	78.8	553,783	1,481,810	100.0
	12- 13	1985	941	347,720	1,282,280	100.0	312,541	1,342,370	124.2
	14- 15	1985	813	677,109	1,331,700	61.4	675,372	1,329,690	79.0
	16- 17	1989	979	280,502	1,235,970	115.7	279,054	1,260,940	129.6
	17- 18	1985	813	582,816	1,425,990	72.2	612,303	1,423,050	88.6
	18- 19	1985	813	1,061,740	947,071	28.8	-	-	-

TABLE 4.8.4 SUMMARY OF ECONOMIC EVALUATION FOR OVERLAY DESIGN DOH METHOD

Route No.	Section	Overlay Year	ADT in Overlay Year	One-Overlay Case Overlay Cost (baht)	One-Overlay Case NPV (baht)	One-Overlay Case IRR (%)	Two-Overlay Case Overlay Cost (baht)	Two-Overlay Case NPV (baht)	Two-Overlay Case IRR (%)
RT - 224	14- 15	1987	4,187	512,438	9,673,360	425.3	540,647	9,608,730	568.8
RH - 21	-	-	-	-	-	-	-	-	-
RH - 22	2- 3	1986	2,707	520,371	5,583,080	246.3	518,820	5,567,000	355.6
	5- 6	1987	2,856	389,447	5,322,950	309.3	407,985	5,357,100	375.6
	6- 7	1990	3,293	178,522	4,551,430	440.6	-	-	-
RH - 5	-	-	-	-	-	-	-	-	-
RH - 12	488-489	1985	1,038	991,156	1,760,050	41.6	-	-	-
	489-490	1985	1,038	406,578	2,390,450	120.8	-	-	-
	490-491	1985	1,038	390,125	2,447,350	121.5	-	-	-
	491-492	1991	1,334	336,519	1,438,430	112.1	328,178	1,441,000	147.9
	493-494	1986	1,084	697,459	1,864,850	77.1	721,978	1,834,930	103.5
	494-495	1985	1,038	722,691	2,028,510	79.8	778,999	1,967,080	98.7
	495-496	1988	1,186	330,382	1,886,860	135.7	-	-	-
	496-497	1985	1,038	390,125	2,446,850	121.5	-	-	-
	497-498	1985	1,038	1,210,190	1,541,020	45.3	1,506,910	1,238,310	43.3
RH - 16	7- 8	1989	1,736	285,469	2,220,630	178.5	-	-	-
	8- 9	1985	1,475	586,226	2,793,390	122.5	605,032	2,803,470	147.3
	9- 10	1991	1,870	218,163	1,934,230	192.2	-	-	-
	10- 11	1985	1,475	529,650	2,849,960	135.6	534,608	2,888,040	151.7
	11- 12	1986	1,539	384,477	2,757,670	158.6	-	-	-
RH - 25	10- 11	1985	1,206	314,617	3,496,300	191.0	-	-	-
	11- 12	1985	1,206	314,617	3,496,150	191.0	-	-	-
	12- 13	1985	1,206	314,617	3,495,990	190.9	-	-	-
	13- 14	1985	1,206	314,617	3,496,270	191.0	-	-	-
	14- 15	1985	1,206	314,617	3,495,730	190.9	-	-	-
	15- 16	1985	1,206	314,617	3,496,400	191.0	-	-	-
	16- 17	1985	1,206	314,617	3,495,210	190.9	-	-	-
RH - 27	9- 10	1988	941	515,511	1,114,490	66.2	559,607	1,065,980	83.1
	10- 11	1985	813	629,962	1,378,850	66.4	652,109	1,352,650	87.9
	11- 12	1985	813	1,099,770	909,037	34.6	1,391,410	612,626	29.2
	12- 13	1985	813	1,001,330	1,007,480	39.0	1,243,320	760,717	35.6
	13- 14	1985	813	1,198,210	810,597	30.8	1,509,540	494,498	24.7
	14- 15	1985	813	1,198,210	810,597	30.8	1,509,540	494,498	24.7
	15- 16	1988	941	817,535	812,462	38.9	870,727	754,644	43.7
	16- 17	1985	813	942,269	1,066,540	42.1	1,184,260	819,781	39.0
	17- 18	1985	813	1,119,460	889,349	33.8	1,411,100	592,938	28.4
	18- 19	1985	813	1,061,740	947,071	28.8	-	-	-

4.8.4 Selection of Design Period

For case study sections requiring rehabilitation within 7 years, a comparison was made between the case of applying an overlay with a design life of 7 years (one-overlay case) and the case of applying first an overlay with a design life of 4 years and then applying a second overlay with a minimum design life of 3 years (two-overlay case). For both cases, a comparison with the do-nothing case was made to calculate benefits in terms of savings in VOC and maintenance costs. The NPV and IRR were calculated for each of the two cases.

Tables 4.8.3 and 4.8.4 summarize the results by using the AI and DOH methods, respectively. Detailed tables showing cost and benefit streams for each section are presented in Appendix 4.8.4.

IRRs were high and roughly proportionate to AADT. The resulting IRRs in percent were on the order of one tenth of AADT. The reason for such high IRRs is obvious. The benefit is derived from VOC savings which are on the same order of magnitude as the difference in VOC on good paved road and on laterite road, which normally are sufficient to construct a new paved road, whereas the cost of overlay is only a portion of the total construction cost of a new paved road.

It is noted that in a number of instances the order of the two cases (the one- and two-overlay cases) in terms of IRR and NPV is reversed. For example, in Table 4.8.3 for RH-27, Section 14–15, the NPV is higher for the one-overlay case but the IRR is higher for the two-overlay case. This seemingly strange phenomenon happened because the cost streams of the two cases are very different. The former has one large sum at the beginning and none thereafter, while the latter has another large sum in the scond half of the stream. In these circumstances, NPV should be taken as the main index for comparison, rather than IRR which is not a suitable index for comparison.

The difference in NPV between the one- and two-overlay cases was minimal when the AI method was applied. The NPV of the one-overlay case was 4.7% less than the NPV of the two-overlay case at minimum and 0.2% more at maximum as shown in Table 4.8.4.

When the DOH method is applied, the difference in NPV is in favor of the one-overlay case. Most sections showed that the NPV of the one-overlay case exceeded that of the two-overlay case by as much as 39%.

This may seem strange considering that any cost outlays in later years are to be discounted at 12% per year. However, a reduction of design life from 7 to 4 years does not lead to a commensurate reduction in thickness. For example, the required thickness of overlay for RH-27, Section 18–19, under the DOH method is 190 mm for the one-overlay case and only 20 mm less for the two-overlay case. The cost of overlay is basically proportionate to the thickness. In addition, it is necessary to take into account in determining the thickness of the second overlay that the reduced strength of the first overlay must be compensated by additional thickness for the second overlay. Therefore, many savings in the present value of overlay cost cannot be realized by splitting the design life into shorter ones. Sometimes the net effect is negative.

The practical problem of administering overlay operations should also be taken into account. Shorter overlay design lives would increase the number of overlay operations in a given year and put an extra burden on the Regional Division Offices.

The study team recommends that a 7-year overlay design life be adopted.

4.8.5 Rehabilitation with Widening

Among the case study routes, there are some sections which are presently or will in future become substandard in pavement width and require widening. Table 4.8.5 summarizes these requirements.

TABLE 4.8.5 WIDENING REQUIREMENTS

Route No.	Existing Width		Widening Year	Desired Width		Remarks
	Pavement (cm)	Shoulder (cm)		Pavement (cm)	Shoulder (cm)	
RT - 224	6.0	1.5	1986	7.0	2.5	-
RH - 21	7.0	2.5	-	-	-	After year 2014
RH - 22	5.0	1.5	1985	6.5	2.25	-
RH - 5	6.0	1.0	1985	6.0	2.0	Shoulder only
RH - 12	6.2	1.5	1985	6.0	2.0	Shoulder only
RH - 16	6.0	1.5	1985	6.0	2.0	Shoulder only
RH - 25	5.0	2.0	1985	6.0	2.0	-
RH - 27	5.0	1.0	1990	6.0	2.0	-

Feasibility of widening was studied for RH-25 as an example.

RH-25 has 1206 vehicles per day at present. It should be classified as F_3 standard with a pavement width of 6.0 m and shoulder width of 2.0 m. Its existing pavement and shoulder width, however, are 5.0 m and 1.5 m, respectively, for its entire length of 10 km.

The embankment should be widened on both sides by 0.5 m to an average height of 1.0 m. Asphalt concrete with 35-mm thickness and 6-m width should be placed on top after tuck coating.

Construction costs were estimated as follows:

Overlay	$6 \text{ m} \times 10 \text{ km} \times 35 \text{ mm} \times 2.35 \times 750$ baht/ton
Tuck coat	$6 \text{ m} \times 10 \text{ km} \times 12$ baht/m^2
Additional embankment	$0.5 \text{ m} \times 1 \text{ m} \times 10 \text{ km} \times 2 \times 120$ baht/m^3
Miscellaneous work	7%
Total	6,014,740 baht

Average conditions of the route are as follows:

Existing PSI	:	1.901
Existing deflection	:	0.3471 mm (measured)
		0.5296 mm (design)

The computer model described in preceding sections was applied to the above. Table 4.8.6 summarizes the results.

The IRR was calculated at 127%, which can be compared with an IRR of 191% for the case without widening.

The widening of RH-25 is thus economically feasible.

TABLE 4.8.6 ECONOMIC EVALUATION FOR OVERLAY DESIGN (WIDENING)

Study Route : RH-25 (2071-0100) Section: 7-17

Surface Type : DT/ST Width of Road : 6.0 m

AI METHOD

One-Overlay Case (Unit: baht)

Year	ADT	Cumu-lative ESA (thousand)	PSI	Costs	Benefits		
				Overlay Cost	VOC Saving	RMC Saving	Total
1985	1206	111	4.6	6,014,740	7,274,180	45,685	7,319,860
1986	1271	229	4.3	-	7,664,620	45,581	7,710,150
1987	1339	352	4.2	-	8,061,610	45,368	8,106,980
1988	1414	481	4.0	-	8,514,500	45,198	8,559,700
1989	1478	616	4.0	-	8,900,900	45,020	8,945,920
1990	1544	757	3.9	-	9,290,590	44,833	9,335,430
1991	1614	904	3.8	−3,350,630	9,705,130	44,639	9,749,700
Total				2,664,110	59,411,500	316,274	59,727,800
Discounted Total				4,661,480	37,901,800	206,555	38,108,400

NPV : 33,446,900

B/C Ratio : 8.2

IRR : 126.9 %

DOH METHOD

One-Overlay Case (Unit: baht)

Year	ADT	Cumu-lative ESA (thousand)	PSI	Costs	Benefits		
				Overlay Cost	VOC Saving	RMC Saving	Total
1985	1206	111	4.6	6,014,740	7,274,180	45,702	7,319,880
1986	1271	229	4.4	-	7,664,620	45,581	7,710,200
1987	1339	352	4.2	-	8,061,610	45,455	8,107,070
1988	1414	481	4.1	-	8,514,500	45,322	8,559,830
1989	1478	616	4.0	-	8,900,900	45,184	8,946,090
1990	1544	757	3.9	-	9,290,590	45,039	9,335,630
1991	1614	904	3.9	−3,350,630	9,705,130	44,887	9,750,020
Total				2,664,110	59,411,500	317,170	59,728,700
Discounted Total				4,661,480	37,901,800	207,061	38,108,900

NPV : 33,447,400

B/C Ratio : 8.2

IRR : 126.9 %

4.9 CONCLUSIONS

The conclusions of the foregoing discussions are as follows:

1) Pavement surface conditions and deflection have little correlation.

2) Therefore, the assessment of surface conditions such as PSI should be given the first priority in determining pavement rehabilitation requirements.

3) Rehabilitation of existing pavements is highly economical.

4) However, rehabilitation requirements, particularly the design thickness of overlay, vary greatly depending on the design method applied.

5) Regardless of the design method used, a longer overlay design life such as 7 years is preferable to a shorter design life.

It is quite difficult to select the best method of overlay design only through a desk comparative analysis. An appropriate method can be determined only by an analysis of actual performance of overlay constructed under various conditions.

Actual practice in Japan and the U.S. often adopts a maximum overlay thickness of about 5 cm even if the design method calls for a much thicker overlay. This practice has proven practical over the years.

The overlay design method must be simple enough to be adopted widely by engineers, while maintaining the same standards. It should also not call for an exceedingly thick overlay which is unlikely to be implemented in practice. The study team, therefore, recommends that a simple method of overlay design be established specifically for Thailand. The JRA method with its simplicity and ease of application could be a good basis from which to develop such a method.

[redacted]