Design of Flexible Pavement Overlays

Postgraduate Studies
Highways Engineering

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(AASHTO 1993 Method) …….. (1.5 weeks)

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5. Design of Overlays

5.1. Types of Overlays

An overlay is any operation that consists of laying either Portland Cement Concrete (PCC) or Hot Mix Asphalt (HMA) over an existing pavement structure. This is different than a total replacement of the structure, and is typically done when there is only minor to modest damage to the existing pavement structure. There are four types of overlays:

1. HMA Overlays on Asphalt Pavements: HMA overlay is the predominant type of resurfacing on asphalt pavements. Design methods ranging from engineering judgment to mechanistic-empirical procedures have been used.

2. HMA Overlays on PCC Pavements: HMA overlays have been used extensively on PCC pavements; however, this type of overlay is the most difficult to analyze mechanistically because it involves two different types of materials. The major problem in the design of HMA overlays on PCC pavements is reflection cracking, defined as the fractures in an overlay or surface that reflect the crack or joint pattern in the underlying layer due to: the horizontal movement (attributed to temperature and moisture changes) and the differential vertical movement due to traffic loadings.
To minimize the reflection cracking in HMA overlays on PCC pavements :
1. Design a thicker HMA overlay.
2. Crack and seat the existing PCC slab into smaller sections .
3. Use a crack relief layer with drainage system .
4. Saw and seal joints in a HMA overlay.
5. Use a stress-absorbing membrane interlayer with an overlay.
6. Incorporate a fabric membrane interlayer with an overlay.

3. PCC Overlays on Asphalt Pavements: The use of PCC overlays on asphalt pavements is somewhat uncommon. However, they have been used very successfully in the United States and other countries. It can be cost effective if the asphalt pavement is severely distressed and must be used only as a foundation for the PCC overlay. Reflection cracks is a problem, to prevent this, all cracks of high severity in the existing asphalt pavement should be repaired and sealed.

4. PCC Overlays on PCC Pavements: Three types of PCC overlay may be used for PCC pavements: un bonded, bonded, and partially bonded .

5.2. Overlays Design Methods

1. Asphalt Institute Method (AI-1983)
2. Portland Cement Association Method (PCA)
3. AASHTO Method

5.3. AASHTO Design Method

- The overlay design procedures presented for first time the 1986 AASHTO Design Guide. It was avoided by most state highway agencies because the determination of the remaining life factor was complex and yielded conflicting results.
- Further investigation and the overlay design approach has been revised to exclude remaining life considerations to develop a new design guide that was published in 1993 AASHTO Design Guide.

5.4. Design Concepts

Pavement overlay can involve a number of pavement sections with length ranging from a few hundred feet to several miles. This depends on the analysis sections so that the thickness of overlay for each section can be designed. There are two approach for design oval thickness:

5.4.1. Uniform Section Approach

The project is divided into sections of various lengths, each with relatively uniform characteristics. Each uniform section is considered independently and overlay design inputs representing the average of the section are obtained. The historical data should be consulted construction and maintenance records, types and thicknesses of layer materials, sub-grade, traffic, pavement conditions, and so on.

5.4.2. Point-By-Point Approach

Point-By-Point Approach Overlay thicknesses are determined for specific points along the uniform design section—for example; every 300 ft (91 m). All required inputs are determined for each point, so that the overlay thickness can be designed.

5.5. Structural Deficiency

- The overlay design procedures presented here provide an overlay thickness to correct the structural deficiency of a pavement and increase its ability to carry loads over a future design period .as shown in Figure 5.1.

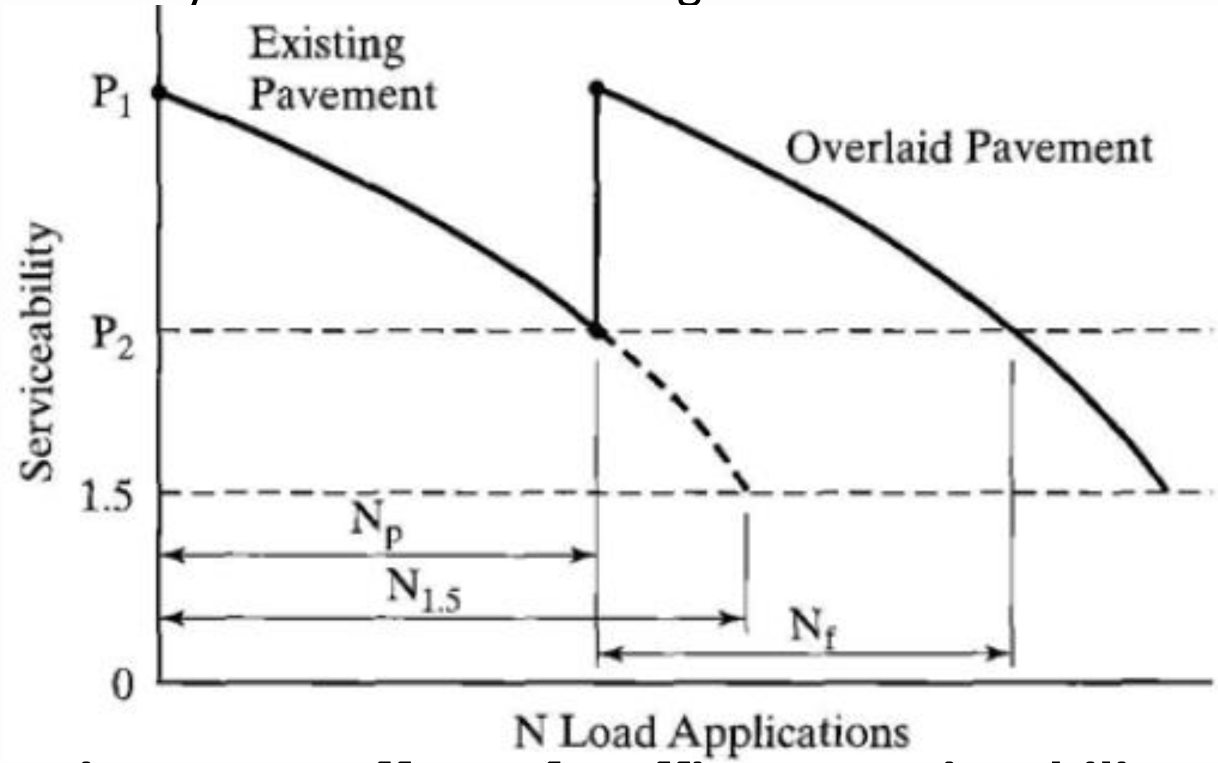

Figure 5.1. Effect of traffic on serviceability.

- Structural capacity, SC, is a general term that can be applied to flexible, rigid, and composite pavements. For flexible pavements, SC is expressed by a structural number, SN; for rigid pavements, by the PCC thickness, D ; and for existing composite pavements, by an equivalent slab thickness.

- To upgrade the pavement condition to the serviceability (**P_i**), additional structural capacity, SC_{oL}, in the form of an overlay is required. So the basic equation for overlay design is:

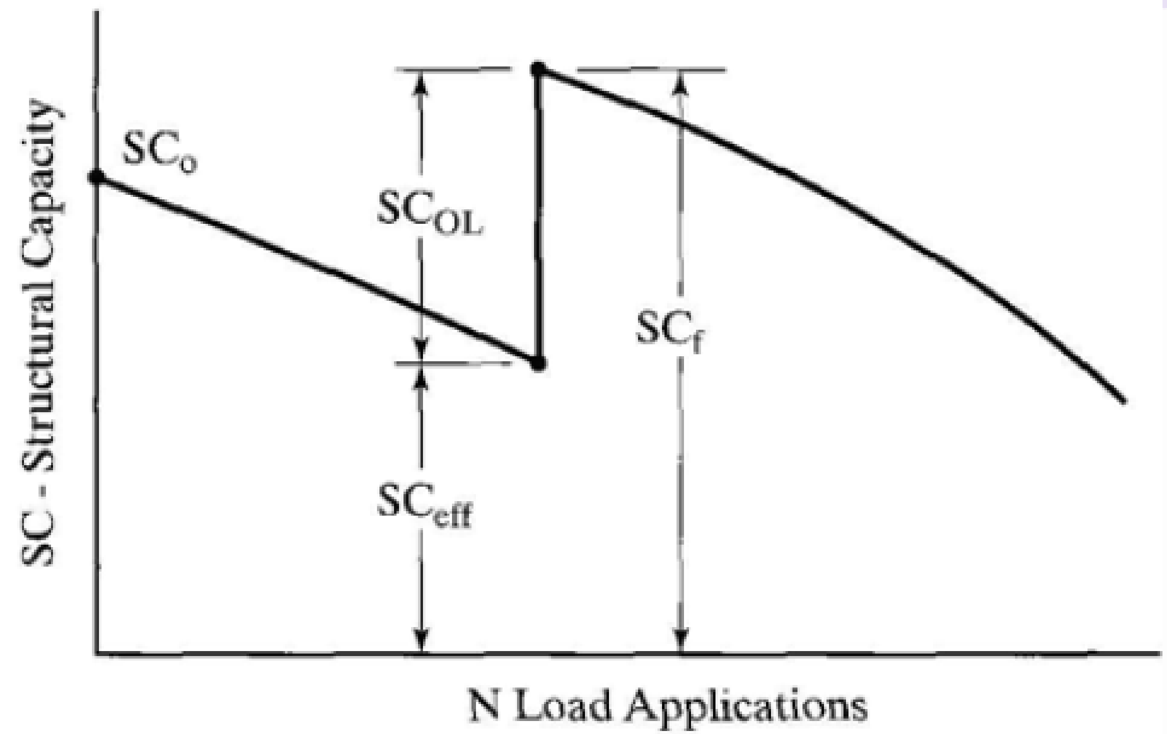

Figure 5.1. Effect of traffic on structural capacity.

$$(SC_{OL})^n = (SC_f)^n - (SC_{eff})^n \quad \dots\dots\dots (1)$$

Where:
SC_{OL} = SN of overlay.
Sc_{eff} = SN of existing pavement.
SC_f = SN of a new pavement
n = a constant, 2 for rigid pavement and 1 for flexible pavement.

5.6. Evaluation of Effective Structural Capacity (SC_{eff}) of Existence Pavement

The most difficult part of overlay design is the determination of SC_{eff}. Three alternative methods can be used: visual condition survey and material testing, nondestructive deflection testing, NDT, and remaining life from fatigue damage by traffic.

5.6.1. Visual Survey and Materials Testing

- Using the visual survey of existing pavement conditions, beginning with a review of all available information regarding the design, construction, and maintenance history. This should be followed by a detailed survey to identify the type, amount of severity, and location of surface distresses.
- Materials testing should include a coring and testing program to verify or identify the cause of the observed surface distress and materials properties such as binder grade, thicknesses, aggregate, so on.
- The condition survey method and data collected are used for determining SN_{eff} as shown in Equation (2) which is th e same equation as that is used for design the new pavement.

$$SN_{eff} = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3 \quad \ldots\ldots\ldots..(2)$$

Notes:

- Drainage coefficients m_2 and m_3 *is the same as in the new pavement.*
- Depending on the types and amounts of deterioration, the layer coefficients assigned to in-service pavements should in most cases be smaller than those originally assigned to the new pavements, except for unbound granular materials that show no sign of degradation or contamination. Table 1 can be used as a suggested layer coefficients for existing materials.

Table 1: Suggested layer coefficients

Table 5.2. Suggested Layer Coefficients for Existing AC Pavement Layer Materials

MATERIAL	SURFACE CONDITION	COEFFICIENT
AC Surface	Little or no alligator cracking and/or only low-severity transverse cracking	0 35 to 0 40
	< 10 percent low-severity alligator cracking and/or < 5 percent medium- and high-severity transverse cracking	0 25 to 0 35
	> 10 percent low-severity alligator cracking and/or < 10 percent medium-severity alligator cracking and/or > 5–10 percent medium- and high-severity transverse cracking	0 20 to 0 30
	> 10 percent medium-severity alligator cracking and/or < 10 percent high-severity alligator cracking and/or > 10 percent medium- and high-severity transverse cracking	0 14 to 0 20
	> 10 percent high-severity alligator cracking and/or > 10 percent high-severity transverse cracking	0 08 to 0 15
Stabilized Base	Little or no alligator cracking and/or only low-severity transverse cracking	0 20 to 0 35
	< 10 percent low-severity alligator cracking and/or < 5 percent medium- and high-severity transverse cracking	0 15 to 0 25
	> 10 percent low-severity alligator cracking and/or < 10 percent medium-severity alligator cracking and/or > 5–10 percent medium- and high-severity transverse cracking	0 15 to 0 20
	> 10 percent medium-severity alligator cracking and/or < 10 percent high-severity alligator cracking and/or > 10 percent medium- and high-severity transverse cracking	0 10 to 0 20
	> 10 percent high-severity alligator cracking and/or > 10 percent high-severity transverse cracking	0 08 to 0 15
Granular Base or Subbase	No evidence of pumping, degradation, or contamination by fines	0 10 to 0 14
	Some evidence of pumping, degradation, or contamination by fines	0 00 to 0 10

The following notes apply to Table 1 :

1. All the distresses are as observed at the pavement surface .
2. Patching all high-severity alligator cracking is recommended . The layer coefficients of the AC surface and stabilized base should reflect the amount of high-severity cracking remaining after patching .
3. In addition to evidence of pumping noted during condition survey, samples of base material should be obtained and examined for evidence of erosion, degradation, contamination by fines, and durability, and layer coefficients should be reduced accordingly.
4. The percentage of transverse cracking is the linear feet of cracking per square foot of pavement, expressed as a percentage .
5. Coring and testing are recommended for the evaluation of all materials, especially stabilized layers.
6. There may be other types of distresses (e .g., surface raveling or stripping of an AC layer, freeze-thaw damage to a cement-treated base) which, in the opinion of the engineer, would affect the performance of the overlay . These should be considered by decreasing the structural coefficient of the layer exhibiting the distress .

5.6.2. Nondestructive Deflection Testing (NDT):

In flexible pavements, NDT is used to estimate the roadbed soil resilient modulus and to provide a direct estimate of SN_{eff}. Some agencies apply NDT to backcalculate the moduli of individual layers and then us these moduli to estimate but this approach was not recommended in the 1993 guide.

- To determine the modulus of the subgrade, the deflection of a sensor far from the load can be used as shown in Figure (5.3).
- According to the Boussinesq equation for a homogeneous half space (**Equation 3**) and using the backcalculation for determining the subgrade resilient modulus from a single measurement .

$$d_r = \frac{P(1-\nu^2)}{\pi r M_R} \quad \text{...... (3)}$$

in which d_r = surface deflection at a distance r from the load,
P = point load , v = Poisson's ratio,
r = distance from the load,
and M_R = resilient modulus.

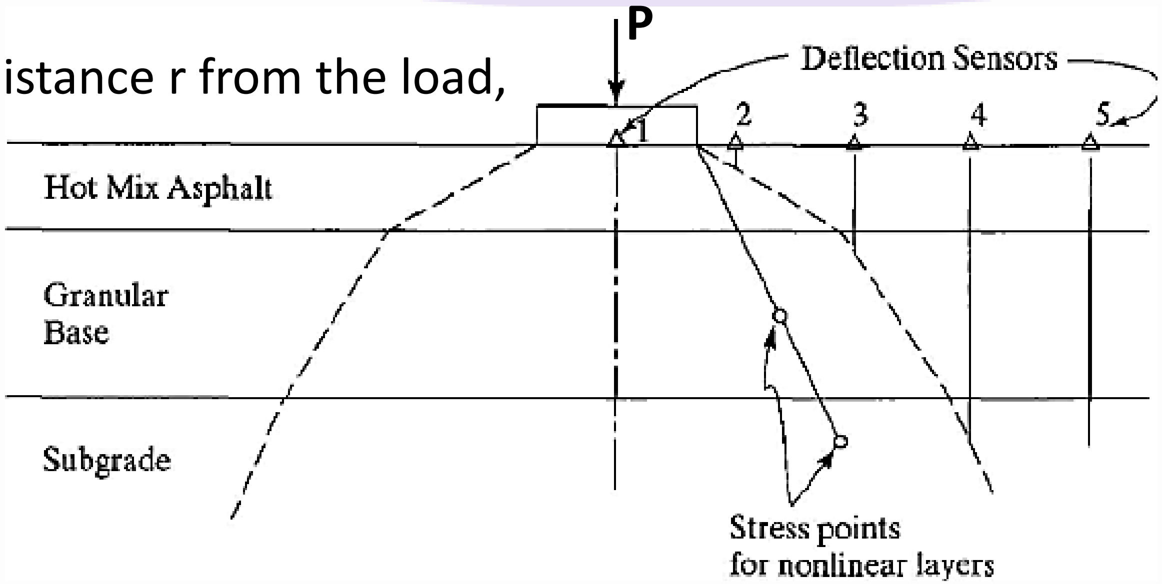

Figure 5.3. Stress zone within pavement structure .

- AASHTO added a coefficient (C = 0.33) to Equation (3) to consider the difference between the back-calculated M_R and the design M_R, and assuming a Poisson's ratio of 0.5, to be the final equation:

$$M_R = C\left(\frac{0.24P}{d_r r}\right) \quad \text{............ (4)}$$

$$r = 0.7\sqrt{a^2 + \left(D \times \sqrt[3]{\frac{E_P}{M_R}}\right)^2} \quad \text{......(5)}$$

Note: The location selected to back-calculation of the subgrade modulus must be far enough from the load to eliminate the effect of any layers above but also close enough that the deflection is not too small to be measured accurately, so the 5th sensors is recommended and must be checked after back-calculation using Equation (5).

Where: a= radius of load plate, D = total thickness of pavement layers above the subgrade, and E_p = effective modulus of all pavement layers above the subgrade.

- To estimate SN_{eff} , it is necessary to determine E_p first, from the formula (Equation 6):

$$\frac{M_R d_o}{qa} = 1.5\left\{\frac{1}{\sqrt{1+\left[\left(\frac{D}{a}\right)^3\sqrt{\frac{E_p}{M_R}}\right]^2}} + \frac{1-\frac{1}{\sqrt{1+\left(\frac{D}{a}\right)^2}}}{\left(\frac{E_P}{M_R}\right)}\right\} \quad \text{................ (6)}$$

Where: d_o = deflection measured at the center of the load plate after adjustment to a standard pavement temperature of 68°F, q = pressure on load plate.

- Equation (6) is based on a Poisson's ratio of 0.5, with E_p as the only unknown, and can be solved by iteration via a computer or spreadsheet.
- Figure (5.6) is a chart for determining E_p when a = 5 .9 in. (150 mm) as a solving for Equation (6). If *a is* not equal to 5 .9 in. (150 mm), Equation (6) must be used.
- Figure (5.7) can be used to determine the temperature adjustment factor for granular or asphalt-treated base, Figure (5.8) for cement- or pozzolanic - treated base.
- After E_p *is* determined, SN_{eff} can be computed by Equation (7).

$$\mathbf{SN_{eff} = 0.0045D\sqrt[3]{E_p}} \quad \text{............. (7)}$$

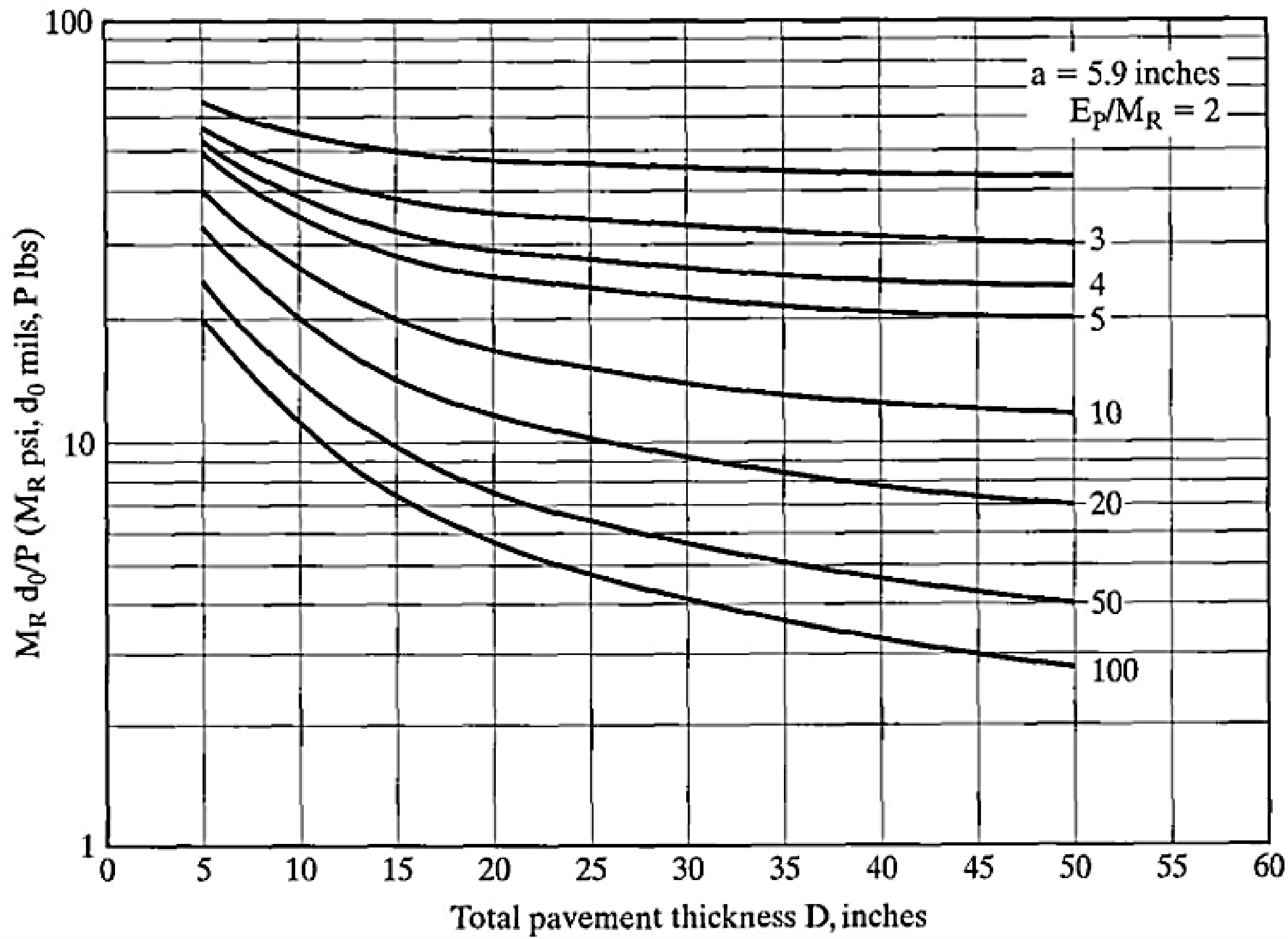

Figure 5.6. Chart for determining E_P/M_R, based on Equation (6).

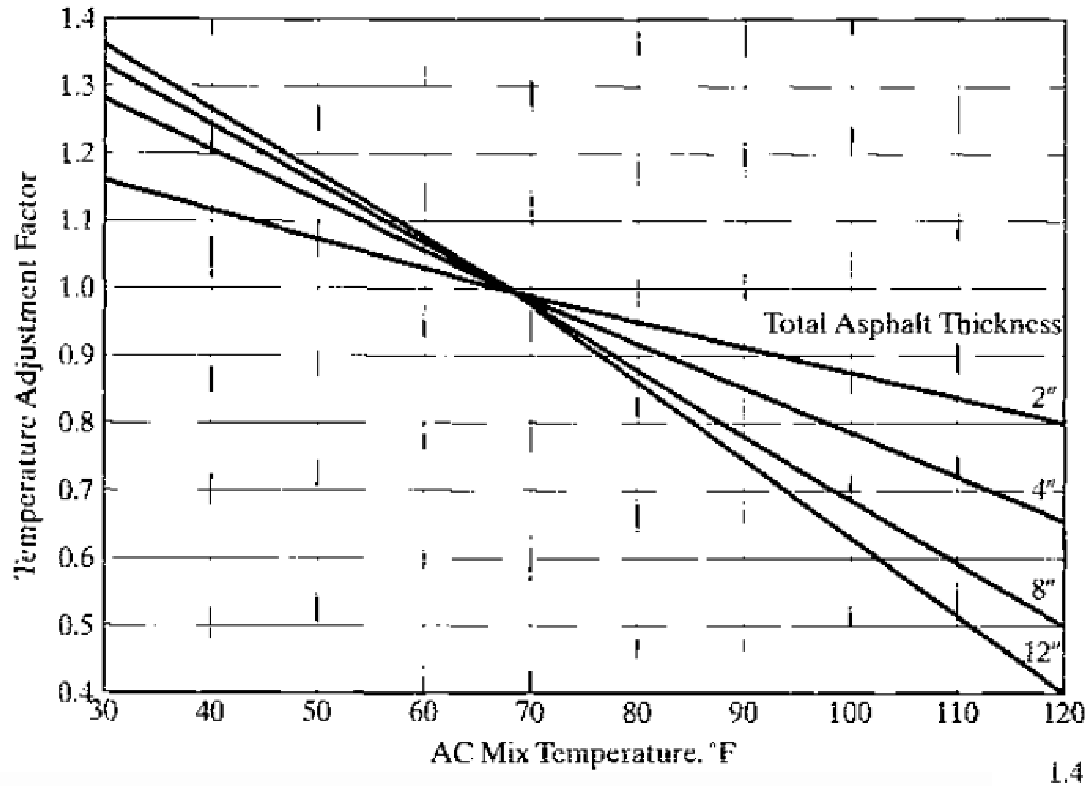

Figure 5.7. Adjustment of d_o for asphalt pavement with granular or asphalt-treated base.

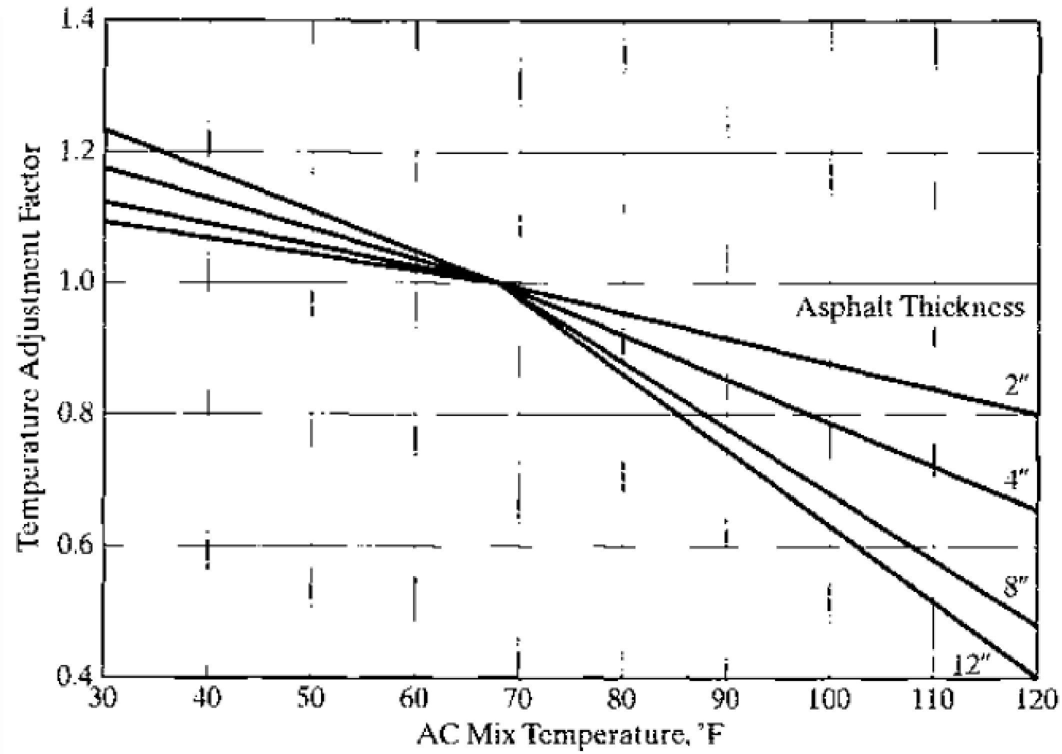

Figure 5.8. Adjustment of d_o for asphalt pavement with cement or pozzolanic - treated base.

- Figure 5.9 is a chart for determining $\mathbf{E_p/M_R}$ based on a Burmister's Two-Layers Theory solved by KENLAYER and using dimensionless ratio. This chart is similar to chart in Figure 5.6. but more generic chart for using.

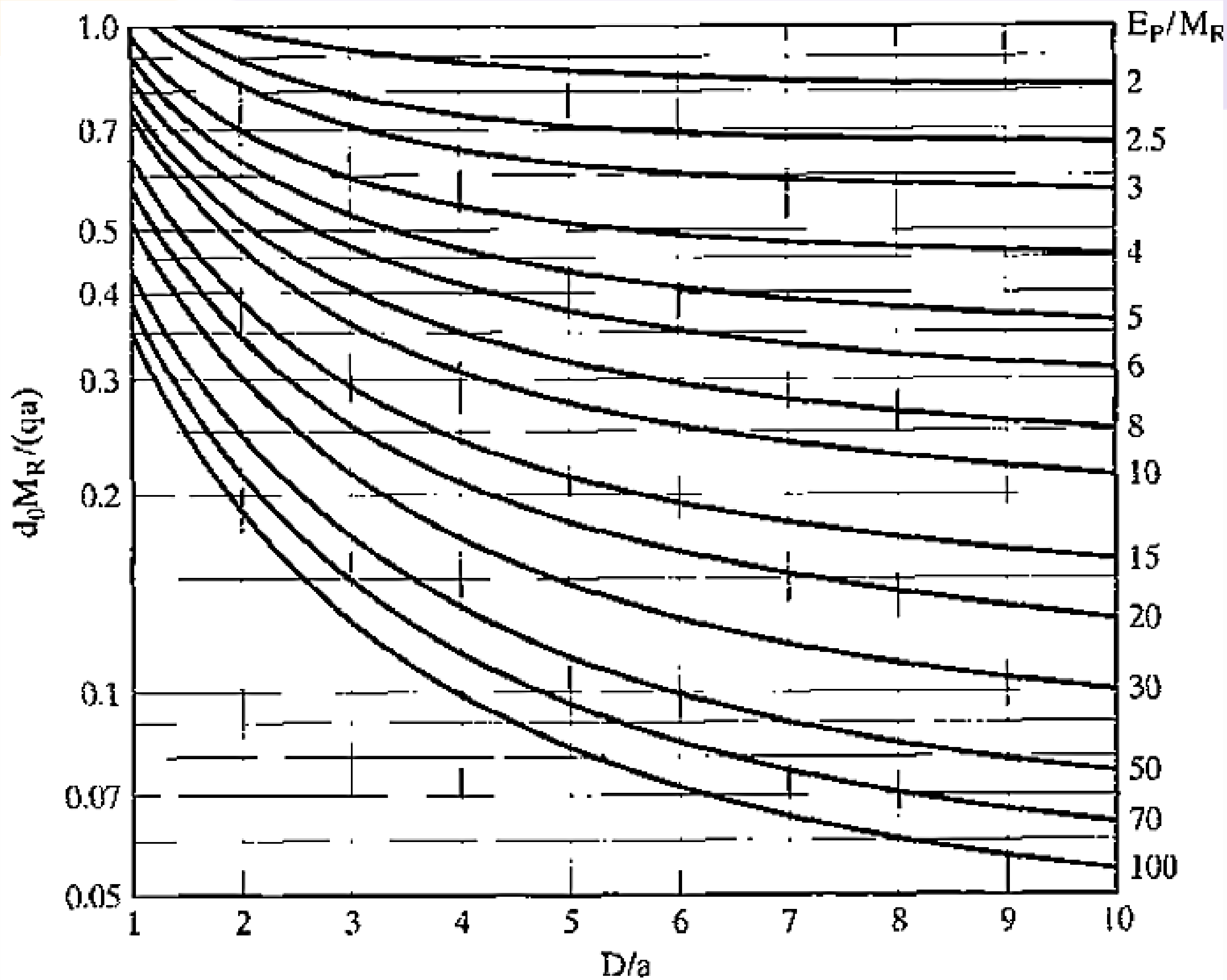

Figure 5.9. Chart for determining E_p/M_R based on a Burmister's Two-Layers Theory

<u>Example 1:</u> An NDT test was made on a flexible pavement using a 5.9 in (150 mm) load plate. The thickness of AC is 4.25 in. (108 mm) and that of granular base is 8 in. (203 mm). The temperature of AC at the time of the test is 80°F (°C). The total load applied on the plate is 9000 ib (40 kN). The deflection at the center of plate is 0.0139 in. Or (13.9 mil) (0.35 mm); that at a distance of 36 in. (0.91 mm) is 0.00355 in. (0.09 mm). Estimate M_R and SN_{eff}.

<u>Solution</u>:

- From Equation (4), M_R = (0.24 x 9000)/(0 .00355 *X* 36) = 16,900 psi (117 MPa) .

Assuming that C = 0.33, So M_R = 0.33 x 16,900 = 5580 psi (38 .5 MPa).

With AC temperature of 80°F and AC thickness of 4.25 in. (108 mm), from Figure 5.7, the temperature adjustment factor for d_o *is* 0.92, *so* d_o = 0.92 x 0.0139 = 0.0128 in. (0.33 mm).

$(M_R d_o)IP$ = (16900 x 12.8)/9000 = 24.0 and *D* = *4.25* + 8 = 12.25 in. (311 mm),

from Figure 5.6, E_p/M_R = 8 .5, or **E_p = 8.5 *X* 16,900 = 143,650 psi (991 MPa).**

From Equation (7). SN_{eff} = 0.0045 x 12.25 *X* $(143,650)^{1/3}$ = 2.88.

The placement of the sensor at a distance of 36 in. (0.91 m)

Check with Equation (5), ***r*** = $0.7\text{x}\{(5.9)^2+[12.25 \text{ x } (8.5)^{1/3}]^2\}^{0.5}$ = 17.98 in. (457 mm) (Min. distance).

It is sufficient, because it exceeds the Min. distance.

- Using Figure 5.9. **E_p= 169,000 psi (1160 MPa),** which is slightly greater than the 143,650 psi

(991 MPa) obtained by Figure 5.6.

5.6.3. Remaining Life after Fatigue Damage by Traffic

The remaining life (RL) in percent, can then be computed by Equation (8).

$$RL = 100\left(1 - \frac{N_p}{N_{1.5}}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where: as shown in Figure 5.1. N_p is the actual traffic in 18-kip ESAL the pavement has carried to date.

$N_{1.5}$ is the total traffic that pavement could be expected to carry to failure (PSI = 1.5 and reliability 50%) (estimated by the pavement design equations or nomographs).

Using Equation (9) $Sc_{eff.}$ Can be calculated based on deterring condition factor (CF) from Figure 5.10.

$$SC_{eff.} = CF \times SC_o \ \ldots\ldots\ldots\ldots (9)$$

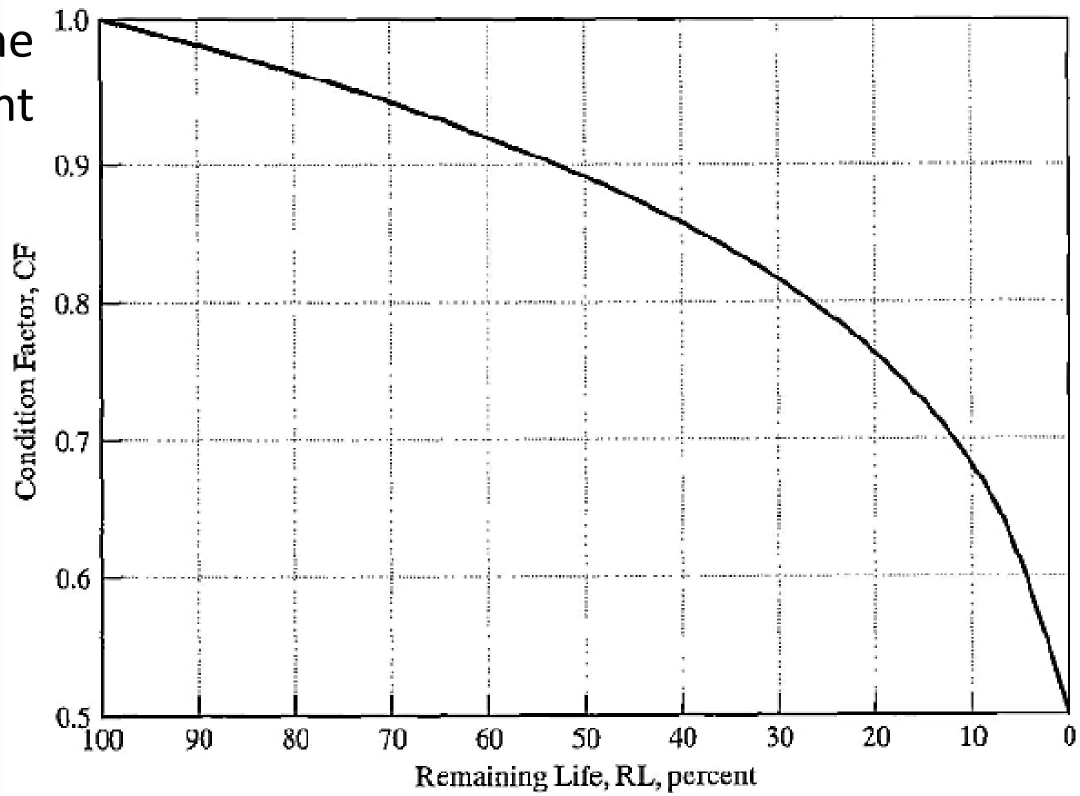

Figure 5.10. Relationship between condition factor and remaining life .

Note: There are uncertainties involved in each method, so the three cannot be expected to provide equivalent estimates . The designers should use all three methods whenever possible and select the best estimate through their own judgment.

5.7. Overlay Design Methodology

The 1993 AASHTO design guide discussed seven cases of overlays. Step-by-step procedures for each case were described, including feasibility, pre-overlay repair, reflection crack control, sub-drainage, and thickness design. Herein, only the overlay thickness design according to:

1. SC is defined by SN.
2. NDT is used to determine M_R and then E_p can be calculated.
3. E_p is used directly to compute SN_{eff}.
4. Reliability: Based on field testing, it appears that a design reliability level of 95 percent and an overall standard deviation of 0.49 for any type of AC overlay; these values are recommended for most projects by state highway agencies.
5. AC overlay can be determined using Equation (10).

$$D_{OL} = \frac{SN_{OL}}{a_{OL}} = \frac{SN_f - SN_{eff}}{a_{OL}} \quad \text{.....................} \quad (10)$$

Where a_{oL} = structural layer coefficient of the overlay material. It is suggested that all three methods, if available, be used to evaluate SN_{eff} and that the most appropriate value be selected, based on the engineering judgment of the designer and the past experience of the agency.

Example 3:

Determine AC overlay of conventional AC pavement. Existing pavement: AC surface 4.25 in., granular base 8 in ., M_R = 5634 psi (by NDT, sandy silt, sandy gravel). Nf = 2,400,000 (flexible ESALs), R = 95%, Se = 0.45, $p1$ = 4.2, $p2$ = 2.5.

Solution:

Find SN_f : SN_f = 4.69 (using Equation (11) W18 trial and error).

$$\log W_{18} = Z_R S_0 + 9.36 \log(SN + 1) - 0.20 + \frac{\log[\Delta PSI/(4.2 - 1.5)]}{0.4 + 1094/(SN + 1)^{5.19}} + 2.32 \log M_R - 8.07 \quad \text{................ (11)}$$

Find SN_{eff} by NDT: $SN_{eff} = 0.0045 \times 12.25 \, X \, (143{,}650)^{1/3}$ = **2.88** (see **Example 1**) .

Find SN_{eff} by condition survey : a_l = 0.35, a_2 = 0.14 (see **Table 1**), m_1 = 1.00, m_2 = 1 .00.

S_{Neff} = 0.35 x 4.25 + 0.14 x 8 = **2.61** (by **Equation 2**) .

Find SN_{eff} by remaining life method: N_P = 400,000, a_1 = 0.44, a_2 = 0.14,

SN = (0.44 x 4.25 +0 .14 x 8) = 2.99,

R = 50%, p_i =4.2, p_2 = 1.5, $N_{1.5}$ = 1,140,161 (Using **Equation 11**).

From Equation (8), RL = 100(1 — 400,000/1,140,161) = 65.

From Figure 5.10, CF = 0.93 **or** SN_{eff} = 0.93 x 2.99 = **2.78**. (Using **Equation 9**).

Find D_{oL}:

Note: It can be seen that the values of SN_{eff} by the three methods are not very much different. This is a coincidence, because in many cases they vary a great deal.

If the smallest SN_{eff} , **2.61**, is used, with a_{oL} = 0.44, from Equation (10):

D_{oL} = (4.69 — 2 .61)/0 .44 = **4.73** in. of AC .