Faculty of Engineering
Department of Civil Engineering

Maintenance of transportation networks
by Prof. Mahmoud Enieb

1

Example

- During asphalt pavement inspection of link (100*7.5) M, from desert road in Egypt Nov. 2019, the following table showing distress type and severity with quantity. Determine:
- Density for each distress.
- Total deduct value DV
- Corrected total deduct value CDV
- Rating of PCI value

2

1. Alligator Cracking SqM
2. Block Cracking SqM
3. Edge Cracking M
4. Long & Trans Cracking M
5. Slippage Cracking SqM
6. Corrugation SqM
7. Depression SqM
8. Shoving SqM
9. Rutting SqM
10. Swell SqM
11. Sags and Bumps M
12. Lane/Shoulder Drop Off M
13. Bleeding SqM
14. Polished aggregate SqM
15. Weathering/Ravelling SqM
16. Potholes **count**
17. Patching & Util Cut Patching SqM

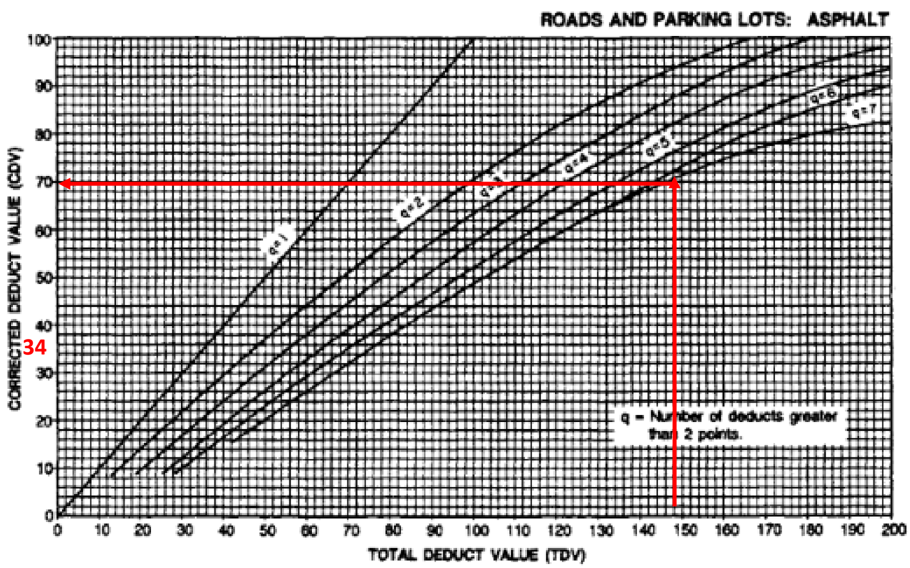
DISTRESS SEVERITY	QUANTITY				Total	Density%	Deduct value
1L	2*2	1*2	1*4				
1M	1*5	2*3					
2M	2*3	2*4					
2H	3*2	5*3					
6L	3*1	4*3					
6H	3*2	2*5					
8M	2*8	2*3					
8L	2*6	5*2					
13H	3*4	2*6					
13M	3*5	2*3					
15L	4*5						
Total	q =						
Corrected deduct value CDV							

3

1. Alligator Cracking SqM
2. Block Cracking SqM
3. Edge Cracking M
4. Long & Trans Cracking M
5. Slippage Cracking SqM
6. Corrugation SqM
7. Depression SqM
8. Shoving SqM
9. Rutting SqM
10. Swell SqM
11. Sags and Bumps M
12. Lane/Shoulder Drop Off M
13. Bleeding SqM
14. Polished aggregate SqM
15. Weathering/Ravelling SqM
16. Potholes **count**
17. Patching & Util Cut Patching SqM

DISTRESS SEVERITY	QUANTITY				Total	Density%	Deduct value
1L	2*2	1*2	1*4		10	10/750*100=1.3	12
1M	1*5	2*3			11	1.46	24
2M	2*3	2*4			13	1.7	5
2H	3*2	5*3			21	2.8	15
6L	3*1	4*3			15	2.0	3
6H	3*2	2*5			16	2.1	41
8M	2*8	2*3			22	2.9	19
8L	2*6	5*2			22	2.9	10
13H	3*4	2*6			24	3.2	10
13M	3*5	2*3			21	2.8	6
15L	4*5				20	2.67	2
Total	q = 8						148
Corrected deduct value CDV							70

4



5

Rating	Failed	V. poor	Poor	Fair	Good	V. Good	Excellent
PCI	0-10	11-25	26-40	41-55	56-70	71-85	86-100

Pavement Condition Index PCI = 100 – CDV

PCI = 100 – 70 = 30

Rating of inspection section is poor

6

#	Deduct Values											Total	q	CDV
1	41	24	19	15	12	10	10	6	5	3	2	148	8	70
2	41	24	19	15	12	10	10	5	5	3	2	147	7	70
3	41	24	19	15	12	10	5	5	5	3	2	142	6	70
4	41	24	19	15	12	5	5	5	5	3	2	137	5	72
5	41	24	19	15	5	5	5	5	5	3	2	130	4	74
6	41	24	19	5	5	5	5	5	5	3	2	120	3	74
7	41	24	5	5	5	5	5	5	5	3	2	105	2	74
8	41	5	5	5	5	5	5	5	5	3	2	86	1	86
	Max. Corrected Deduct Values = 86													

7

Rating	Failed	V. poor	Poor	Fair	Good	V. Good	Excellent
PCI	0-10	11-25	26-40	41-55	56-70	71-85	86-100

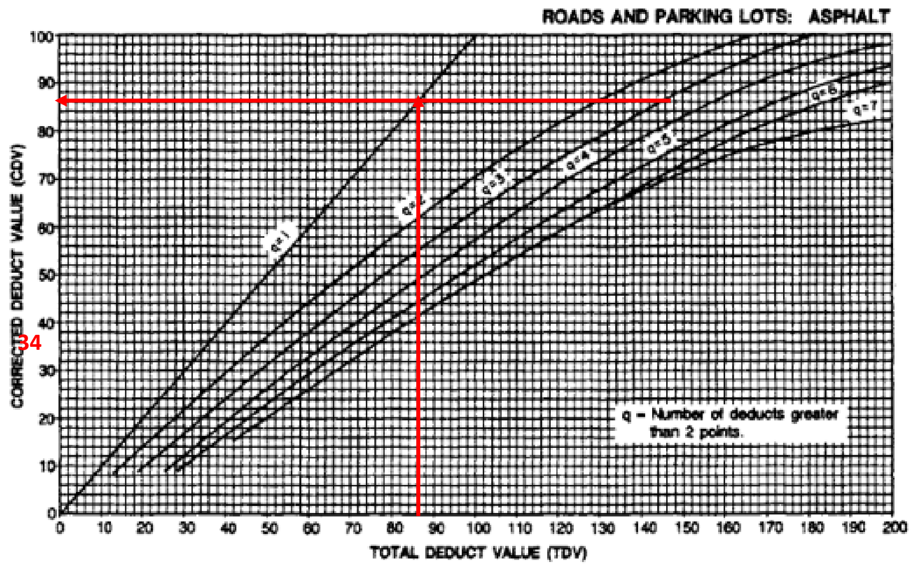
Pavement Condition Index PCI = 100 – CDV

PCI = 100 – 86 = 14

Rating of inspection section is very poor

http://www.mediafire.com/download/glnam93cnfk3ukl/PAVER+5.2.rar

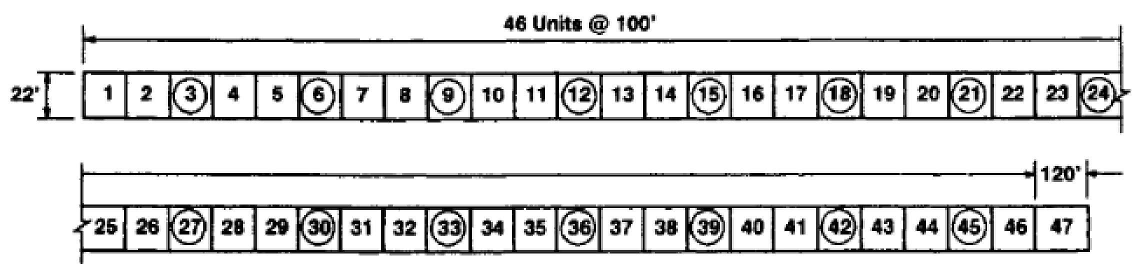
8



9-Sep-24 Prepared By: Prof. Mahmoud Enieb 9

9

Section Length = 4600+120 = 4720 ft



Example of Systematic Random Sampling.

9-Sep-24 Prepared By: Prof. Mahmoud Enieb 10

10

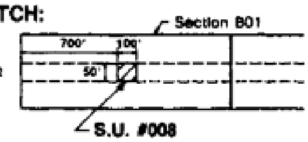
No. of Sample Units in Section (N)	No. of Units to be Inspected (n)
1 to 5	1
6 to 10	2
11 to 15	3
16 to 40	4
over 40	10% (round up to next whole sample unit)

Example of Network Level Sampling Criteria Used by Some Agencies.

AIRFIELD ASPHALT PAVEMENT CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT

BRANCH R1230 SECTION B01 SAMPLE UNIT 008
SURVEYED BY MYS DATE MAR/15/92 SAMPLE AREA 5000 sf

SKETCH:



41. Alligator Cracking
42. Bleeding
43. Block Cracking
44. Corrugation
45. Depression
46. Jet Blast
47. Jt. Reflection (PCC)
48. Long. & Trans. Cracking
49. Oil Spillage
50. Patching
51. Polished Aggregate
52. Raveling/Weathering
53. Rutting
54. Shoving from PCC
55. Slippage Cracking
56. Swell

DISTRESS SEVERITY	QUANTITY									TOTAL	DENSITY %	DEDUCT VALUE
48 L	10	20	17							47	0.94	4.8
48 M	7	9								16	0.32	6.7
41 L	53									53	1.06	21.0
45 L	10	5								15	0.3	1.6
53 L	20	45	10							75	1.5	17.1
53 M	25									25	0.5	20.1

Fig. Example Airfield AC Sample Unit Condition Survey Sheet

Calculating the PCI

- The PCI is calculated for each inspected sample unit. The PCI cannot be computed for the entire pavement section without computing the PCI for the sample units first.
- The PCI calculation is based on the deduct values—weighing factors from 0 to 100 that indicate the impact each distress has on pavement condition.
- A deduct value of 0 indicates that a distress has no effect on pavement structural integrity and/or surface operational condition, whereas a value of 100 indicates an extremely serious distress.

Calculation of a Sample Unit PCI for Asphalt Surfaced Pavements and Unsurfaced Road

- The calculation steps are similar for roads and airfields. They are summarized in Figure 3-17. Following is a description of each step.
- Step 1: Determine deduct values.
- la. Add the totals for each distress type at each severity level and record them under "Total" on the survey form. For example, following figure shows two entries for distress type 48M. The distress is added and entered under "Total" as 16.
- Quantities of distress are measured in square feet (square meters), linear feet (meters), or number of occurrences, depending on the distress type.

Calculation of a Sample Unit PCI for Asphalt Surfaced Pavements and Unsurfaced Road

- 1 b. Divide the quantity of each distress type at each severity level by the total area of the sample unit, and then multiply by 100 to obtain the percentage of density per sample unit for each distress type and severity.
- lc. Determine the deduct value for each distress type and severity level combination from the distress deduct value curves. Past figure shows an example of a deduct curve for distress type 41, "Alligator Cracking," for airfield pavements.
- Deduct curves for all distresses are provided in Appendix B (for asphalt roads),
- Appendix D (for asphalt airfield), and Appendix F (for unsurfaced roads).

Step 2: Determine the maximum allowable number of deducts (m).

- 2a. If only one individual deduct value (or none) is > 5 for airfields and unsurfaced roads, or > 2 for surfaced roads, the total deduct value is used in place of the maximum corrected deduct value (CDV) in Step 4 and the PCI computation is completed; otherwise, the following steps should be followed.
- 2b. List the individual deduct values in descending order. For example, the values in previous Figure would be sorted as follows: 21,20.1,17.1,6.7,4.8, and 1.6

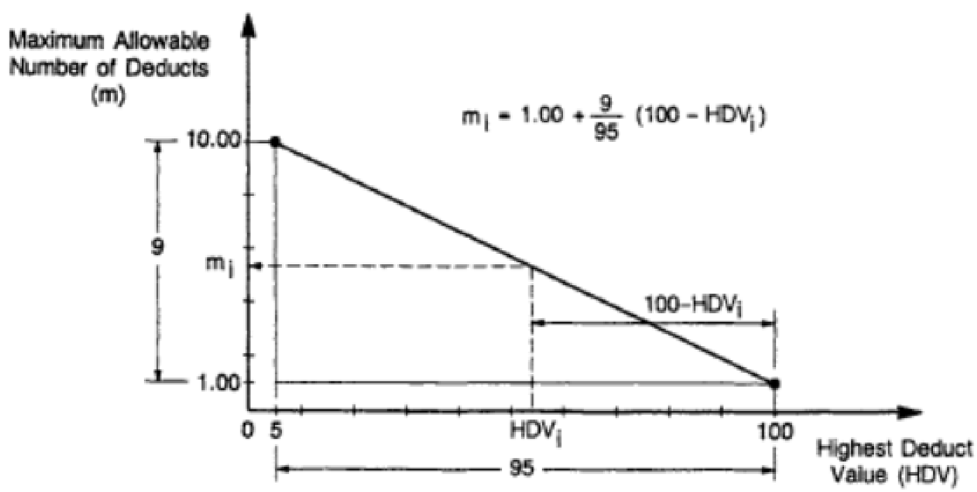
Step 2: Determine the maximum allowable number of deducts (m).

- 2c. Determine the allowable number of deducts, m (Fig. 3-19), using the following formulas:
- $m_i = 1 + (9/95)(100\text{-HDV})$ (for airfields and unsurfaced roads)
- $m_i = 1 + (9/98)(100\text{-HDV})$ (for surfaced roads)
- where:
- m_i = allowable number of deducts, including fractions, for sample unit i.
- HDVi = highest individual deduct value for sample unit i.
- For the example, in Figure 3-12:
- **$m_i = 1 + (9/95)X(l00\text{-}21.0) = 8.48$**

9-Sep-24 Prepared By: Prof. Mahmoud Enieb 17

17

Step 2: Determine the maximum allowable number of deducts (m).



(a) Airfield Pavements

9-Sep-24 Prepared By: Prof. Mahmoud Enieb 18

18

Step 2: Determine the maximum allowable number of deducts (m).

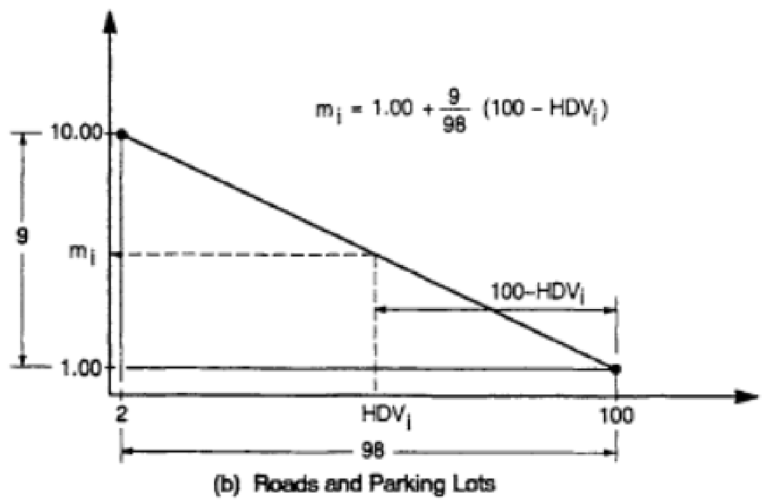


Figure 3-19. Determination of Maximum Allowable Deducts (m).

Step 2: Determine the maximum allowable number of deducts (m).

- 2d. The number of individual deduct values is reduced to m, including the fractional part.
- If fewer than m deduct values are available, then all of the deduct values are used.
- For the example in previous Figure, all the deducts are used since they are less than m.

Step 3: Determine the maximum corrected deduct value (CDV). The maximum CDV is determined iteratively as follows:

- 3a. Determine the number of deducts with a value > 5.0 for airfields and unsurfaced roads, and > 2 for surfaced roads. For the example in previous Figure, q=4.
- 3b. Determine total deduct value by adding all individual deduct values. In the current example, the total deduct value is 71.3
- 3c. Determine the CDV from q and total deduct value by looking up the appropriate correction curve. Following Figure shows the correction curve for asphalt surfaced airfield pavements. Other correction curves are provided at the end of the individual deduct curves in Appendices B through F.

#	Deduct Values										Total	q	CDV
1	21	20.1	17.1	6.7	4.8	.1.6					71.3	4	37
2	21	20.1	17.1	5.0	4.8	.1.6					69.6	3	43
3	21	20.1	5.0	5.0	4.8	.1.6					57.5	2	38
4	21	5.0	5.0	5.0	4.8	.1.6					42.4	1	42.4
5													

PCI Calculation Sheet for Example Sample Unit Shown in previous Figure

PCI = 100 – 43 = 57

Rating	Failed	V. poor	Poor	Fair	Good	V. Good	Excellent
PCI	0-10	11-25	26-40	41-55	56-70	71-85	86-100

Pavement Condition Index PCI = 100 – CDV

PCI = 100 – 43 = 57

Rating of inspection section is Good

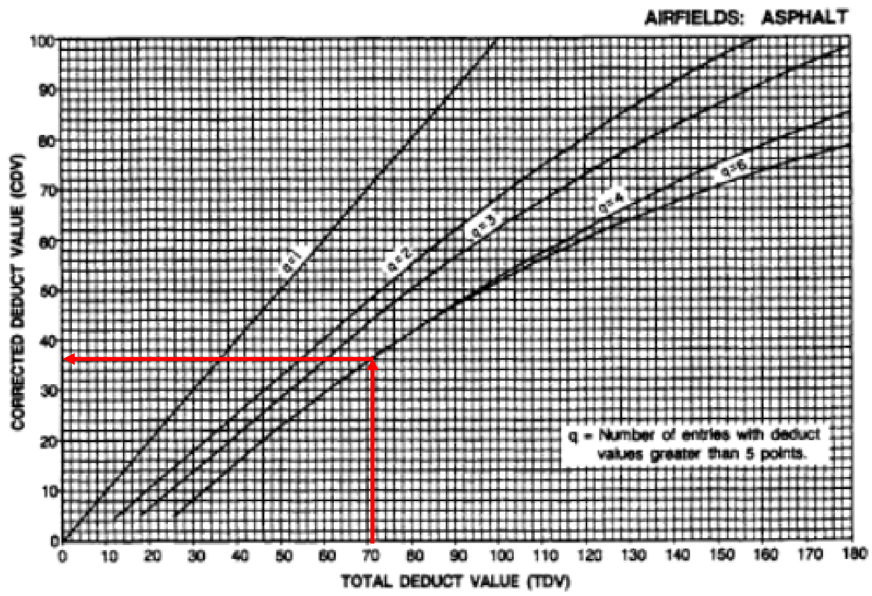


Figure 3-20. Correction Curves for AC Surfaced Airfield Pavements.

Calculation of the PCI for a Section

- If all surveyed sample units are selected either by using the systematic random technique or on the basis of being representative of the section, and are equal in size, the PCI of the section is determined by averaging the PCIs of the sample units inspected. If the inspected sample units were not equal in size, area weighted averaging should be used as shown in the following equation:
- PCI_s = PCI of pavement section
- PCI_r = area weighted average PCI of random sample U
- PCI_{ri} = PCI of random sample unit number i
- A_{ri} = area of random sample unit number i
- R = total number of inspected random sample units

$$PCI_s = PCI_r = \frac{\sum_{i=1}^{R} PCI_{ri} \times A_{ri}}{\sum_{i=1}^{R} A_{ri}}$$

Calculation of the PCI for a Section

$$PCI_a = \frac{\sum_{i=1}^{A} (PCI_{ai} \times A_{ai})}{\sum_{i=1}^{A} A_{ai}}$$

$$PCI_s = PCI_r = \frac{\sum_{i=1}^{R} PCI_{ri} \times A_{ri}}{\sum_{i=1}^{R} A_{ri}}$$

$$PCI_s = \frac{PCI_r \left(A_s - \sum_{i=1}^{A} A_{ai} \right) + PCI_a \times \sum_{i=1}^{A} A_{ai}}{A_s}$$

where

PCI_a = area weighted average PCI of additional sample units

PCI_{ai} = PCI of additional sample unit number *i*

A_{ai} = area of additional sample unit *i*

A_s = total section area

Example

- For example, if in a section of 60,000 sq ft, five random sample units were inspected and determined to have PCIs of 56 (5,000 sq ft), 72(5,000 sq ft), 65(5,000 sq ft) 69(4,000 sq ft) and 61(4,000 sq ft), and two additional sample units with PCIs of 42(3,500 sq ft) and 39(3,000 sq ft) were included, the PCI of the section would be:
- PCI_r = [(56*5000)+(72*5000)+(65*5000)+(69*4000)+(61*4000)]/(5000+5000+5000+4000+4000) = 64.56=64.6
- PCI_a = [(42*3500)+(39*3000)]/(3500+3000) = 40.6
- PCI_s = [64.4*(60000 – 6500) + 40.6*(6500)] / 60000 = 61.8 = 62

SECTION EVALUATION

TABLE 9.1 Distresses in Asphalt Pavements

Types of Distress	Structural	Functional
Alligator or fatigue cracking	×	
Bleeding		×
Block cracking	×	
Corrugation		×
Depression		×
Joint reflection cracking	×	
Lane/shoulder dropoff or heave		×
Lane/shoulder separation		×
Longitudinal and transverse cracking	×	
Patch deterioration	×	×
Polished aggregate		×
Potholes	×	×
Pumping and water bleeding	×	×
Raveling and weathering		×
Rutting		×
Slippage cracking	×	
Swell	×	×

Code	Distress	Cause
Asphalt-Surfaced Roads and Parking Areas		
01	Alligator cracking	Load
02	Bleeding	Other
03	Block cracking	Climate
04	Bumps and sags	Other
05	Corrugation	Other
06	Depression	Other
07	Edge cracking	Load
08	Joint reflection	Climate
09	Lane/shoulder drop-off	Other
10	Longitudinal and transverse cracking	Climate
11	Patching and utility cut patching	Other
12	Polished aggregate	Other
13	Potholes	Load
14	Railroad crossings	Other
15	Rutting	Load
16	Shoving	Load
17	Slippage cracking	Other
18	Swell	Other
19	Weathering and ravelling	Climate

Section Evaluation Summery

- 1. overall condition Rating – 15 - PCI

Rating	Failed	V. Poor	Poor	Fair	Good	V. Good	Excellent
PCI	0-10	11-25	26-40	41-55	56-70	71-85	86-100

- 2. Variation of condition within section – PCI
  - a. Localized Random Variation (Yes, No)
  - b. Systematic Variation (Yes, No)
- 3. Rate of Deterioration of condition --- PCI
  - a. Long-term Period (Since construction or last overall repair) (Low, Normal, High)
  - b. Short-term period (1 year) (Low, Normal, High)

9-Sep-24 Prepared By: Prof. Mahmoud Enieb 31

31

Section Evaluation Summery

- 4. Distress Evaluation
- a. Cause
  - Load Associated Distress -80- Percent deduct value
  - Climate/Durability Associated -20- Percent deduct value
  - Other ( ) Associated Distress -0- Percent deduct value
- b. Moisture (Drainage) Effect on Distress (Minor, Moderate, Major)

9-Sep-24 Prepared By: Prof. Mahmoud Enieb 32

32

Section Evaluation Summery

- 5. Deficiency of Load-Carrying Capacity (No, Yes)
- 6. Surface Roughness (Minor, Moderate, Major)
- 7. Skid resistance/Hydroplaning potential (Minor, Moderate, Major)
- 8. Previous Maintenance (Low, Medium, High)
- 9. comments
- ---

a. Overall condition.

- The PCI of a pavement section describes the section's overall condition.
- The PCI, and thus the section condition rating (e.g., good or very good), is based on many field tests and represents the collective judgment of experienced pavement engineers.
- In turn, the overall condition of the section correlates highly with the needed level of M&R.

b. Variations of the PCI within section.

- PCI variation within a section can occur on a:
- 1- localized random basis,
- 2- and/or a systematic basis.

2.a- localized random variation:

- When a PCI value of a sample unit in the section is less than the sample unit critical PCI value, a localized random variation exists.
- For example, if the mean PCI of a section is 59, any sample unit with a PCI of less than 42 should be identified as a localized bad area by circling "Yes" under item 2a on the form. This variation should be considered when determining M&R needs.

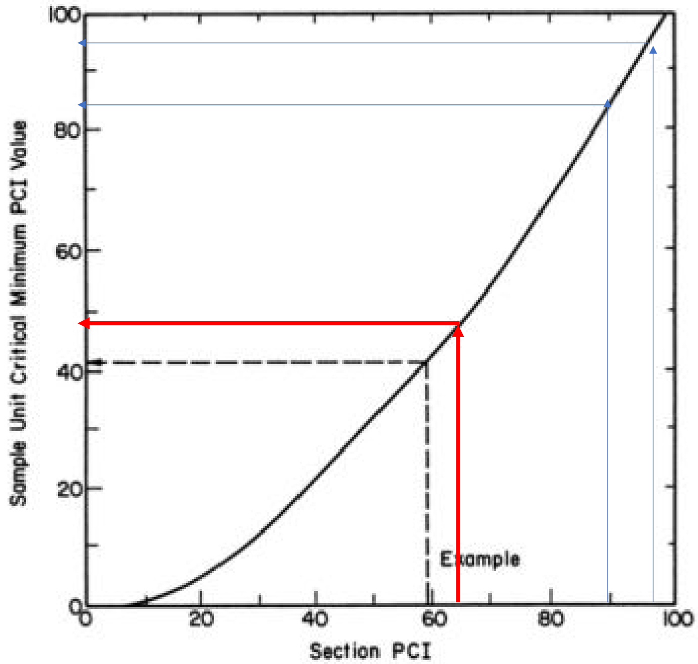


Figure 4-5. Procedure to determine critical minimum sample unit PCI based on mean PCI of section.

37

2-b Systematic variation:

- Systematic variation occurs whenever a large, concentrated area of a section has significantly different condition.
- For example, if traffic is channeled into a certain portion of a large parking lot, that portion may show much more distress or be in a poorer condition than the rest of the area.

38

3. Rate of deterioration of condition - PCI

- Both the long- and short-term rate of deterioration of each pavement section should be checked.
- a- The long-term rate:
- is measured from the time of construction or time of last overall M&R (such as an overlay).
- The rate is determined as low, normal, or high using figures 4-3 through 4-6.

Asphalt concrete (AC) pavements

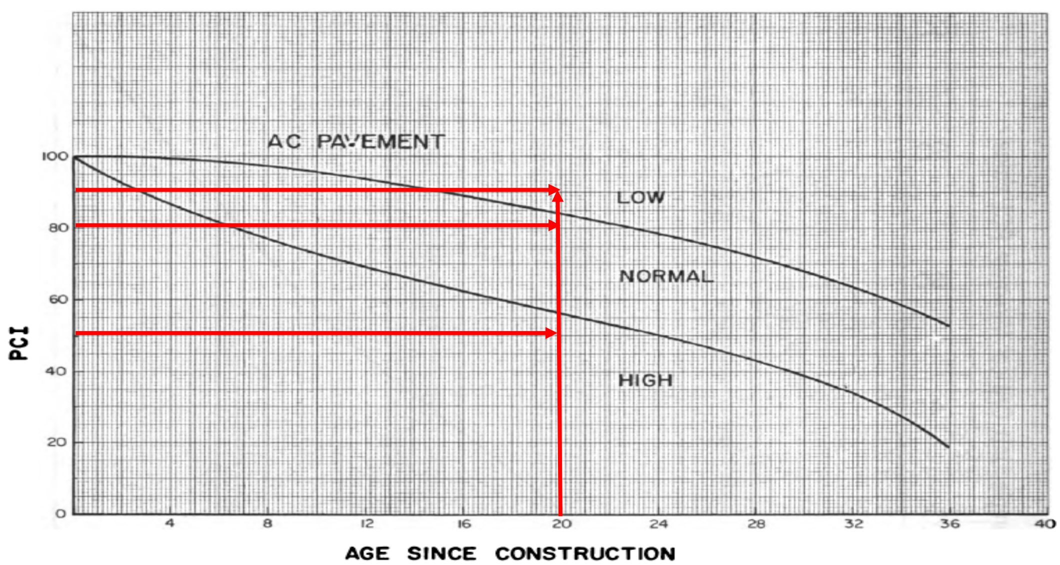
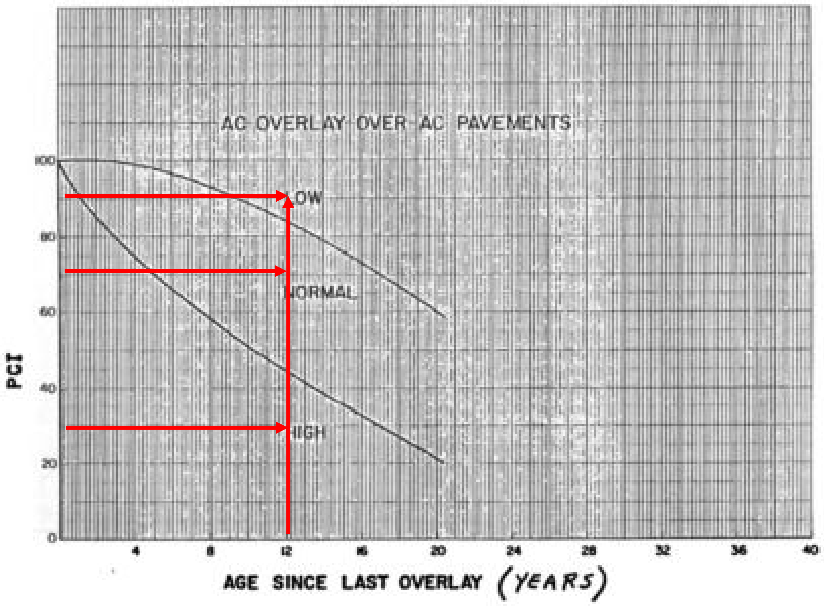


Figure 4-3. Determination of long-term rate of deterioration for asphalt concrete (AC) pavements.

Asphalt concrete (AC) overlay over AC Pavements

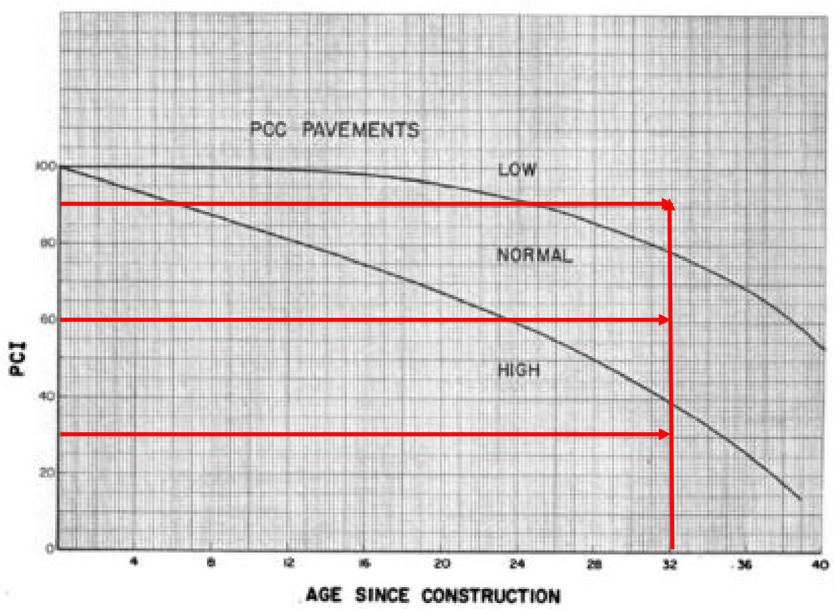


9-Sep-24 Prepared By: Prof. Mahmoud Enieb 41

Figure 4-4. Determination of long-term rate of deterioration for asphalt concrete (AC) overlay over AC pavements.

41

Portland cement concrete (PCC) pavements



9-Sep-24 Prepared By: Prof. Mahmoud Enieb 42

Figure 4-5. Determination of long-term rate of deterioration for Portland Cement Concrete (PCC) pavements.

42

Asphalt concrete (AC) overlay over Portland cement

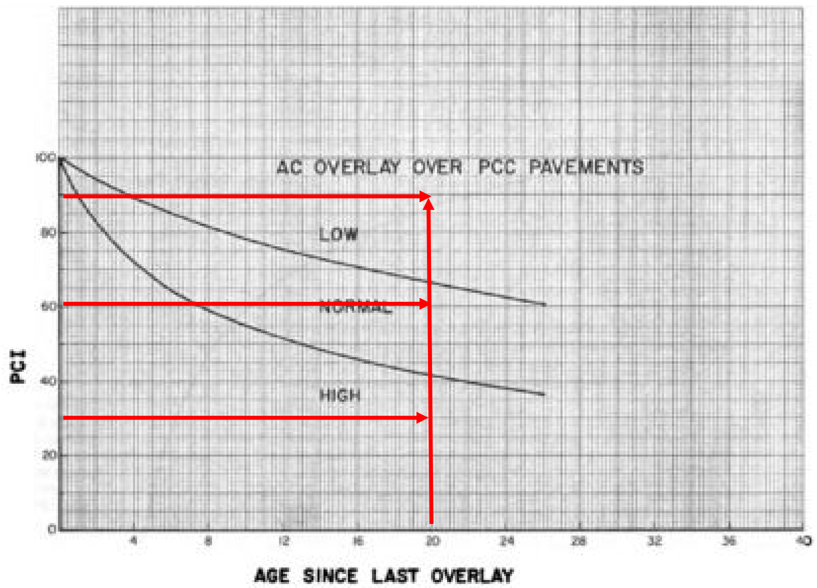


Figure 4-6. Determination of long-term rate of deterioration for asphalt concrete (AC) overlay over Portland Cement Concrete (PCC) pavements.

3. Rate of deterioration of condition - PCI

- The figures are for four pavement types respectively: asphalt concrete pavements (AC), AC overlay over AC pavements, Portland cement concrete (PCC) pavements, and AC overlay over PCC pavements.
- Example, an AC pavement that is 20 years old with a PCI of 50 is considered to have a high long-term rate of deterioration with respect to other AC pavements.

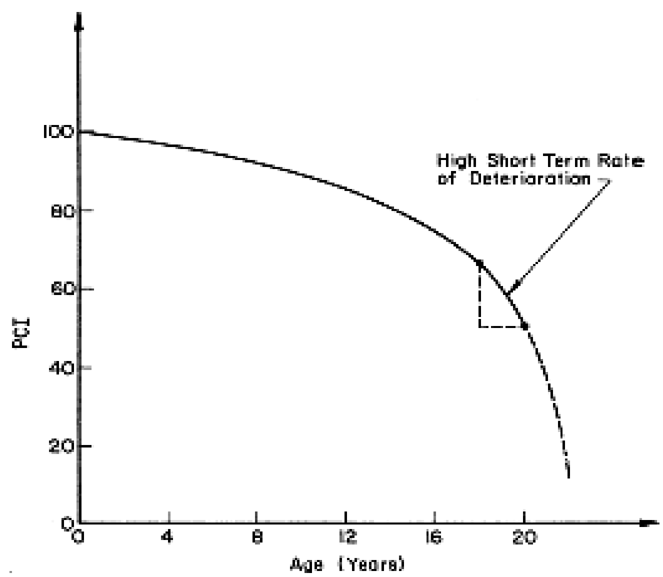
3. Rate of deterioration of condition - PCI

- b- Short-term deterioration:
- (i.e., a drop in PCI during the last year) should also be determined.
- In general, whenever the PCI of a section decreases by 7 or more PCI points in a year, the deterioration rate should be considered high.
- If the loss in PCI points is 4 to 6, the short-term deterioration rate should be considered normal.
- If the loss in PCI points is less than 3 the short-term deterioration rate should be considered low.

9-Sep-24 Prepared By: Prof. Mahmoud Enieb 45

45

High short-term rate of deterioration



9-Sep-24 Prepared By: Prof. Mahmoud Enieb 46

46

4- Distress Evaluation

- For evaluation purposes, distresses have been classified into three groups based on cause. These groups are:
- 1-Load associated,
- 2- Climate/durability associated,
- 3-and other factors.
- In addition, the effect of drainage on distress occurrence should always be investigated.

Code	Distress	Cause
	Asphalt-Surfaced Roads and Parking Areas	
01	Alligator cracking	Load
02	Bleeding	Other
03	Block cracking	Climate
04	Bumps and sags	Other
05	Corrugation	Other
06	Depression	Other
07	Edge cracking	Load
08	Joint reflection	Climate
09	Lane/shoulder drop-off	Other
10	Longitudinal and transverse cracking	Climate
11	Patching and utility cut patching	Other
12	Polished aggregate	Other
13	Potholes	Load
14	Railroad crossings	Other
15	Rutting	Load
16	Shoving	Load
17	Slippage cracking	Other
18	Swell	Other
19	Weathering and ravelling	Climate

4- Distress Evaluation

- The following steps should be followed to determine the primary cause or causes of pavement condition deterioration for a given pavement section:

(1) *Step 1.* The total deduct values (TDVs) attributable to load, climate/durability, and other associated distresses are determined separately. In the example being considered (fig. 4-1) the following distresses and TDVs were measured on an asphalt section of pavement.

Distress type	*Distress density over section*	*Severity level*	*Deduct value*	*Probable cause*
Alligator cracking	10	M	47	Load
Transverse cracking	3	M	17	Climate/durability
Rutting	5	L	21	Load
Total			85	

The TDV attributable to load is 68; the TDV attributable to climate durability is 17.

4- Distress Evaluation

(2) *Step 2.* The percentage of deducts attributable to load, climate/durability, and other factors can be computed as described below; the following is based on the example in (1) above:

$$\text{Load} = \frac{68}{85} \times 100 = 80 \text{ percent}$$ 68/85*100=80%

$$\text{Climate/durability} = \frac{17}{85} \times 100 = 20 \text{ percent}$$ 17/85*100=20%

$$\text{Total} = 100 \text{ percent}$$

5- Deficiency of load-carrying capacity

- Before it can be determined whether an existing pavement section is strong enough to support a particular traffic condition, it is necessary to determine the pavement's load-carrying capacity.
- REMEMBER
- CBR : The California bearing ratio (CBR) is a penetration test for evaluation of the mechanical strength of natural ground, subgrades and base courses beneath new carriageway construction.

5- Deficiency of load-carrying capacity

- CBR Test is performed by measuring the pressure required to penetrate soil or aggregate The measured pressure is then divided by the pressure required to achieve an equal penetration on a standard crushed rock material.

EXAMPLE :

- assume an asphalt pavement section has the following structural composition:

Layer	*Thickness*	*California bearing ratio (CBR)*
Subgrade		10
Base	10 inches	40
Surface	4 inches	—

EXAMPLE :

- Further assume that this pavement section is a Class A road subjected to the following traffic load:

Traffic type	*Vehicles/day*	*Percent of total traffic*
Passenger cars	1400	85
Two-axle trucks	200	12
Trucks with three or more axles	50	3

EXAMPLE :

- We need to determine design index. it's obtained from table below:

Table 4-3. Design Index for Flexible Pavements for Roads and Streets, Traffic Categories I Through IV[a]

Class road or street	Category I	Category II	Category III	Category IV
A	3	4	5	6
B	3	4	5	6
C	3	4	4	6
D	2	3	4	5
E	1	2	3	4
F	1	1	2	3

EXAMPLE :

- We need to determine design index. its obtained from table below:

Category I. Traffic essentially free of trucks (99 percent group 1, plus 1 percent group 2).

Category II. Traffic including only small trucks (90 percent group 1, plus 10 percent group 2).

Category III. Traffic including small trucks and a few heavy trucks (85 percent group 1, plus 14 percent group 2, plus 1 percent group 3).

Category IV. Traffic including heavy trucks (75 percent group 1, plus 15 percent group 2, plus 10 percent group 3).

Group 1. Passenger cars and panel and pickup trucks.
Group 2. Two-axle trucks.
Group 3. Three-, four-, and five-axle trucks.

[a] From TM 5-822-5.

EXAMPLE :

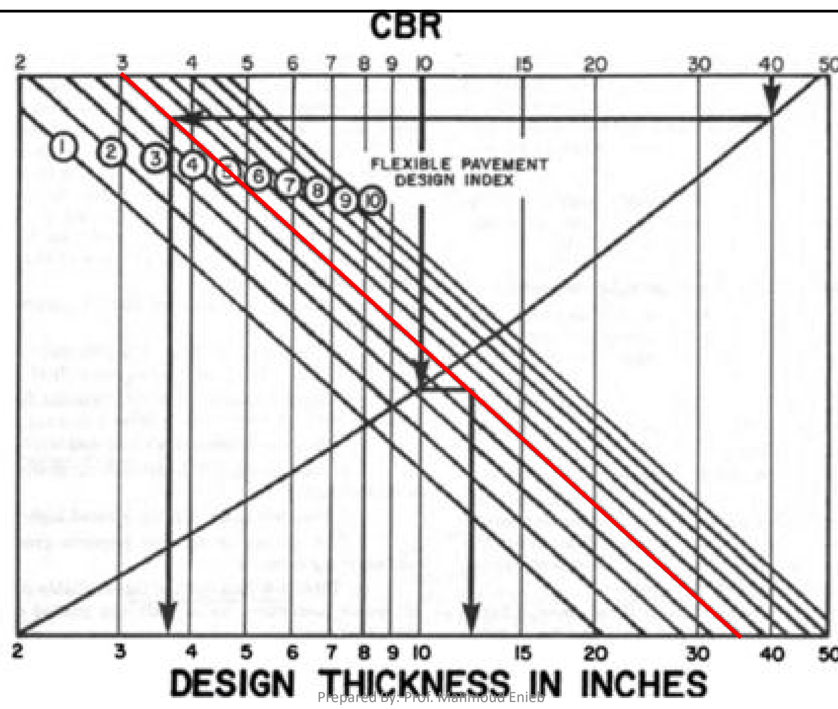
- We need to determine design index. it's obtained from table below:

Category I. Traffic essentially free of trucks (99 percent group 1, plus 1 percent group 2).
Category II. Traffic including only small trucks (90 percent group 1, plus 10 percent group 2).
Category III. Traffic including small trucks and a few heavy trucks (85 percent group 1, plus 14 percent group 2, plus 1 percent group 3).
Category IV. Traffic including heavy trucks (75 percent group 1, plus 15 percent group 2, plus 10 percent group 3).

Group 1. Passenger cars and panel and pickup trucks.
Group 2. Two-axle trucks.
Group 3. Three-, four-, and five-axle trucks.

The design index for this pavement section is 5.

* From TM 5-822-5.



- Based on the information in figure 4-8, the pavement thickness required over a CBR of 10 is 12-inch inches; over a CBR of 40, the required thickness is 4.0 inches.
- Therefore, this pavement section is structurally strong enough for the load it is carrying. and load-carrying capacity deficiency is circled "No" in our example,

6- Surface roughness

- Pavement roughness refers to irregularities in the pavement surface that affect the smoothness of the ride.
- Surface roughness is an important operational condition.
- Minor, moderate, or major surface roughness can be determined by riding over the pavement section at its speed limit and observing its relative riding quality.
- In our example, surface roughness was moderate; so "Moderate" was circled at line 6.

7- Skid resistance

- Skid resistance and is only of concern for high-speed-traveled roads and airfields. Pavement sections where skid is not of concern should be listed as such on the pavement evaluation sheet. Otherwise, skid resistance must be directly measured with special equipment.
- Distresses that can cause skid resistance are:
- bleeding,
- polished aggregates,
- In our example, skid resistance of "Minor" was circled.

8- Previous maintenance.

- the amount and types of maintenance previously applied to a pavement section must be determined before a new strategy is selected.
- The evaluation of previous maintenance can be based on the incidence of permanent patching (asphalt pavements),
- large areas of patching (more than 5 square feet), and/or slab replacement (concrete pavement).

8- Previous maintenance.

- Patching and/or slab replacement ranging between 1.5 and 3.5 percent (based on surface area for asphalt and number of slabs for concrete) is considered normal;
- more than 3.5 percent is considered high,
- and less than 1.5 percent is considered low.
- In our example, figure 4-1, patching was in excess of 3.5 percent; so "High" was circled at line 8.

Project

- In June 2019, a civil engineering student studied a section of an asphalt road and calculated PCI for each sample unit as follows:

Sample unit number	PCI
1	65
2	42
3	70
5	72
7	80
8	43
9	65

- The student gathered information about the section properties and summarized it in the following points:
- Road constructed in 2002.
- After 8 years of construction, an AC overlay applied on the road.
- Section dimensions (22 X 945) ft
- Length of the sample unit = 105 ft.
- Samples 2 and 8 are additional samples.
- Based on the previous information ,answer the questions below :

- (1) Determine if there is a localized random variation within the section or not.
- (2) Determine long term PCI deterioration within the section.
- 3) Following table summarizes distresses density through the section.

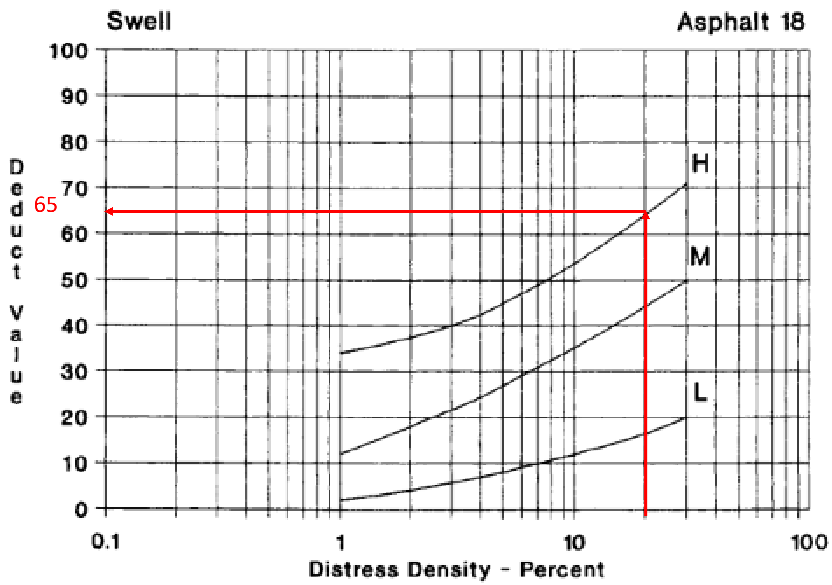
Distress Type	Severity	Density within the Section
Swelling	H	20
Shoulder drop off	M	10
Alligator cracking	M	30

- (a) Calculate the percentage of deducts attributable to: Load, climate and other factor.
- (b) Arrange distresses causes (load, climate and other) in an ascending order and find corrected deduct value CDV.
- (From the minor cause to the major cause).

- (4) Table below summarizes the structural composition of the section :

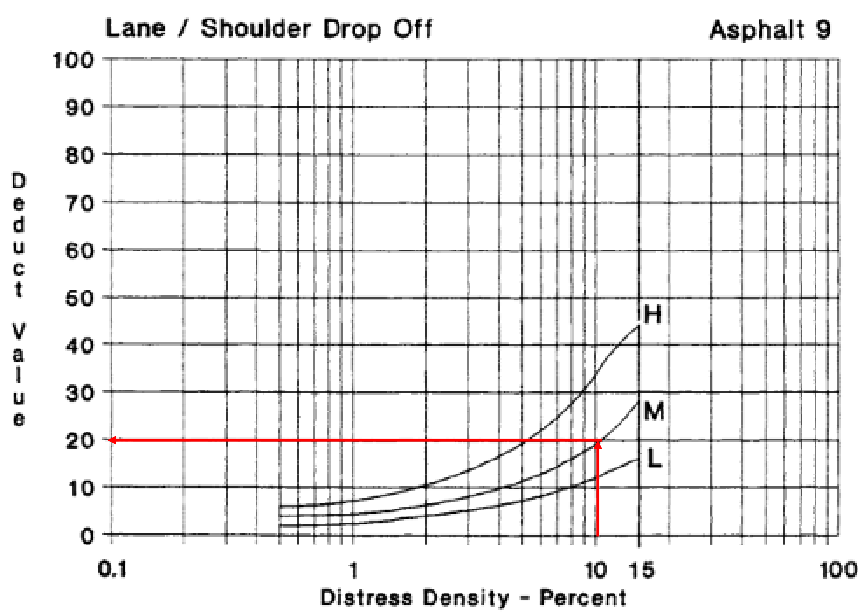
Layer	Thickness	CBR
Subgrade	----	8
Base	10	30
Surface	2	-----

- Is there a deficiency in load carrying capacity for this section? (design index for this road is 2) .



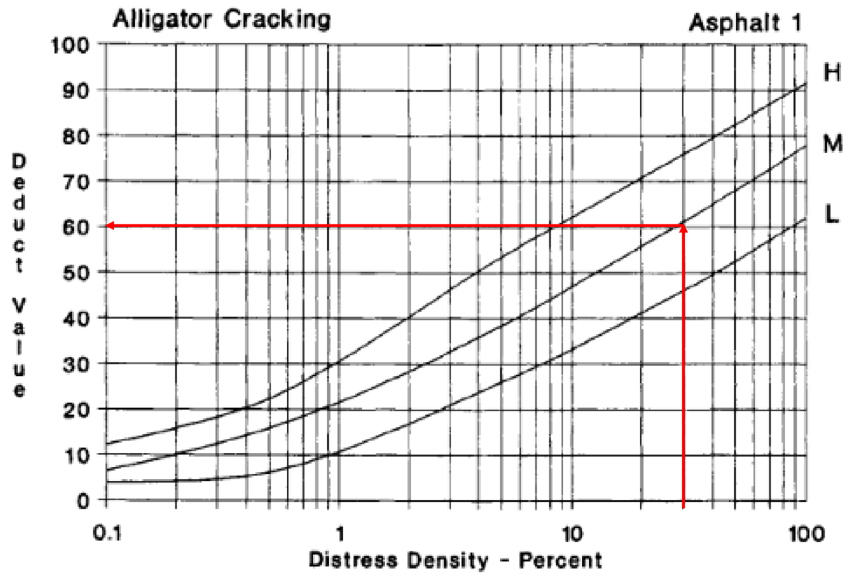
9-Sep-24 Prepared By: Prof. Mahmoud Enieb 69

69



9-Sep-24 Prepared By: Prof. Mahmoud Enieb 70

70



9-Sep-24 Prepared By: Prof. Mahmoud Enieb 71

71

Distress Type	Distress density over section	Severity level	Deduct value	Probole cause
Swelling	20	H	65	other
Shoulder drop off	10	M	20	other
Alligator cracking	30	M	60	Load
Total			145	

9-Sep-24 Prepared By: Prof. Mahmoud Enieb 72

72

4- Distress Evaluation

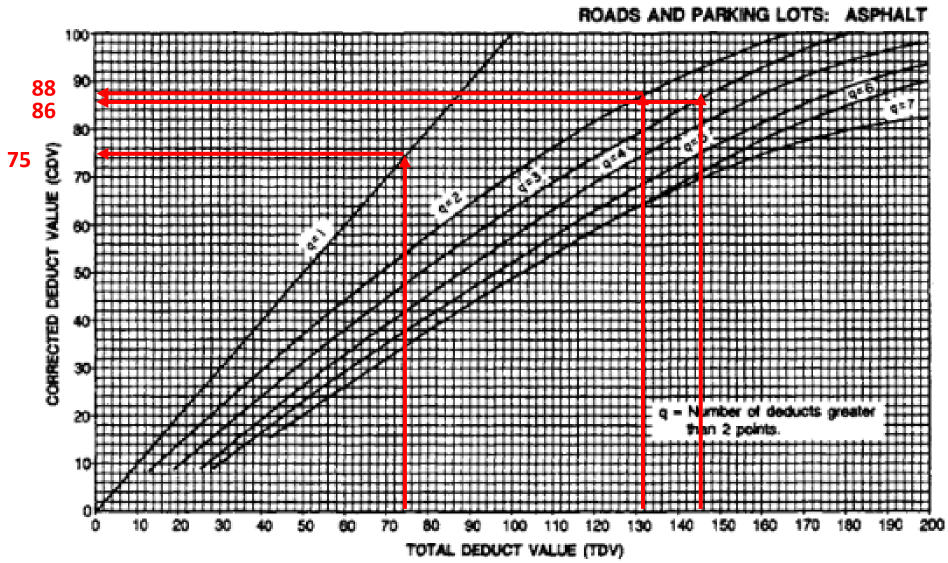
The percentage of deducts attributable to load and other factors, can be computed as described below;

Load = 60/145*100 = 41%

Other = 85/145*100 = 59%

mi = 1+ (9/95)X(l00-65) = 4.3

#	Deduct Values				Total	q	CDV
1	65	60	20		145	3	86
2	65	60	5		130	2	88
3	65	5	5		75	1	75
	Max. Corrected Deduct Values =						88



9-Sep-24 Prepared By: Prof. Mahmoud Enieb 75

75

PCI = 100 – CDV = 100 – 88 = 12

Rating	Failed	V. Poor	Poor	Fair	Good	V. Good	Excellent
PCI	0-10	11-25	26-40	41-55	56-70	71-85	86-100

Rating is very poor

9-Sep-24 Prepared By: Prof. Mahmoud Enieb 76

76

Solution

- Section area is 20790 sq ft, five random sample units were inspected and determined to have PCIs of 65 (2310 sq ft), 70(2310 sq ft), 72(2310 sq ft) 80(2310 sq ft) and 65(2310 sq ft), and two additional sample units with PCIs of 42(2310 sq ft) and 43(2310 sq ft) were included, the PCI of the section would be:
- PCI_r = [(65+70+72+80+65)]/ (5) = 70.4
- PCI_a = [(42*2310)+(43*2310)]/(2310+2310) = 42.5
- PCI_s = [70.4*(20790 – 4620) + 42.5*(4620)] / 20790 = 64.2 = 64

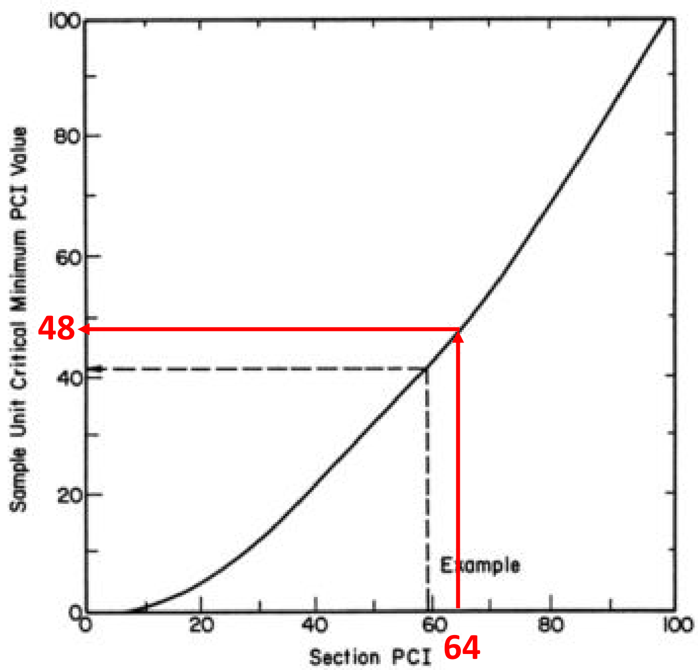
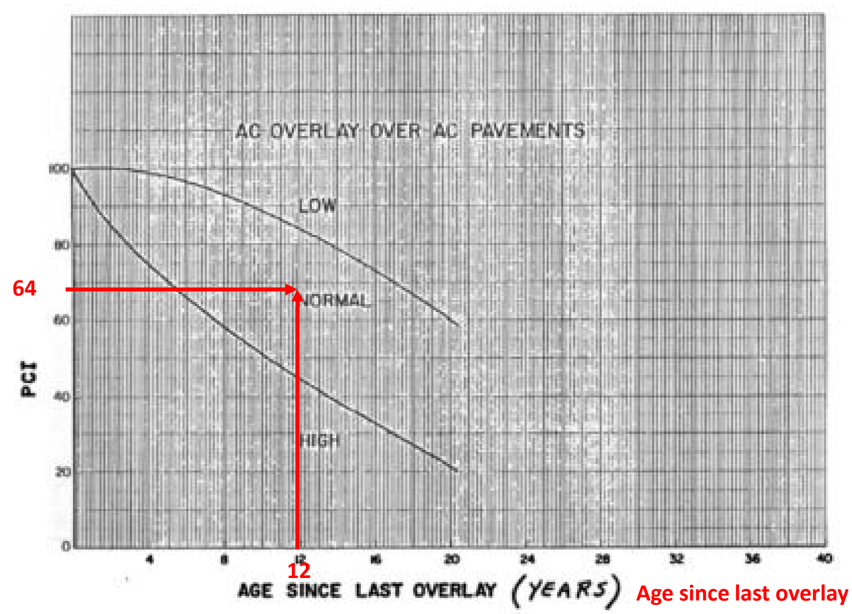


Figure 4-5. Procedure to determine critical minimum sample unit PCI based on mean PCI of section.

Sample unit number	PCI
1	65
2	42 Localized
3	70
5	72
7	80
8	43 Localized
9	65

Systematic variation occurs whenever a large, concentrated area of a section has significantly different condition. In this project No significantly different condition

Asphalt concrete (AC) overlay over AC Pavements



Age since last overlay = 2022 –(2002+8) = 12 yrs.

Figure 4-4. Determination of long-term rate of deterioration for asphalt concrete (AC) overlay over AC pavements.

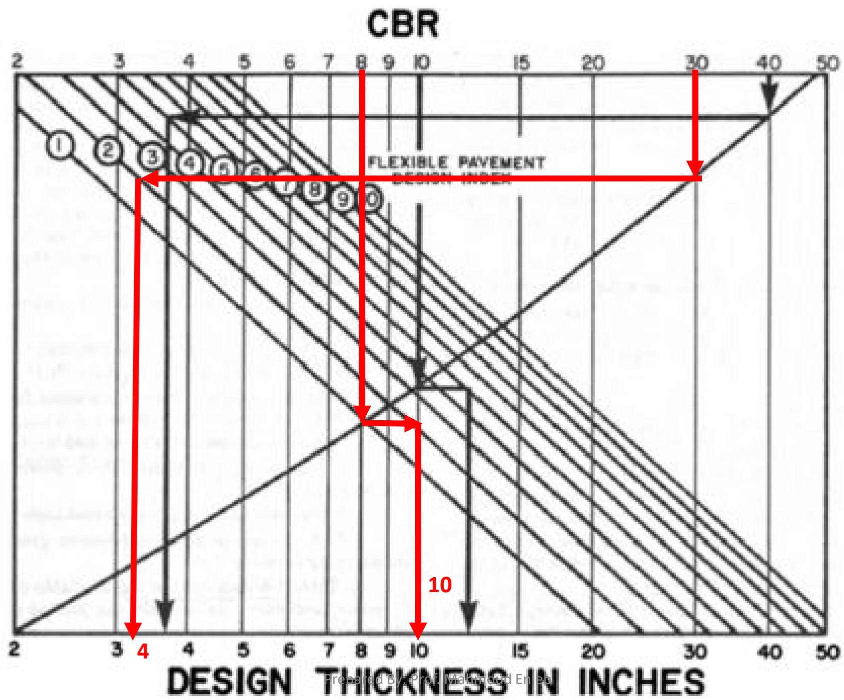
Section Evaluation Summery

- 1. overall condition Rating – 12 - PCI

Rating	Failed	V. Poor	Poor	Fair	Good	V. Good	Excellent
PCI	0-10	11-25	26-40	41-55	56-70	71-85	86-100

- 2. Variation of condition within section – PCI
  - a. Localized Random Variation (Yes, No)
  - b. Systematic Variation (Yes, No)
- 3. Rate of Deterioration of condition --- PCI
  - a. Long-term Period (Since construction or last overall repair) (Low, Normal, High)

Code	Distress	Cause
Asphalt-Surfaced Roads and Parking Areas		
01	Alligator cracking	Load
02	Bleeding	Other
03	Block cracking	Climate
04	Bumps and sags	Other
05	Corrugation	Other
06	Depression	Other
07	Edge cracking	Load
08	Joint reflection	Climate
09	Lane/shoulder drop-off	Other
10	Longitudinal and transverse cracking	Climate
11	Patching and utility cut patching	Other
12	Polished aggregate	Other
13	Potholes	Load
14	Railroad crossings	Other
15	Rutting	Load
16	Shoving	Load
17	Slippage cracking	Other
18	Swell	Other
19	Weathering and ravelling	Climate



9-Sep-24 Prepared By: Prof. Mahmoud Enieb 83

83

EXAMPLE :

- Based on the information in previous figure, the pavement thickness required over a CBR of 8 is 10-inch inches; over a CBR of 30, the required thickness is 4 inches.

- Therefore, this pavement section is not structurally strong enough for the load it is carrying, and load-carrying capacity deficiency is circled “Yes" in project.

9-Sep-24 Prepared By: Prof. Mahmoud Enieb 84

84

Bituminous Materials

- Bituminous materials are used widely all over the world in highway construction and maintenance.
- These **hydrocarbons** are found in natural deposits or are obtained as a product of the distillation of crude petroleum.
- The bituminous materials used in highway construction are either
- Asphalts or
- Tars.

SOURCES OF ASPHALT

- Asphalt is obtained from seeps or pools of natural deposits in different parts of the world
- or as a product of the distillation of crude petroleum
- **Natural Deposits مستودعات طبيعية**
- Natural deposits of asphalt occur as either native asphalt or rock asphalt.
- The largest deposit of native asphalt is known to have existed in Iraq several thousand years ago.

Asphalt Sources

1. Natural asphalt
   A. Native asphalt.
   B. Rock asphalt:
      i. Sand stone
      ii. Lime stone
2. Petroleum Asphalt

Petroleum asphalt is obtained from fractional distillation of petroleum.

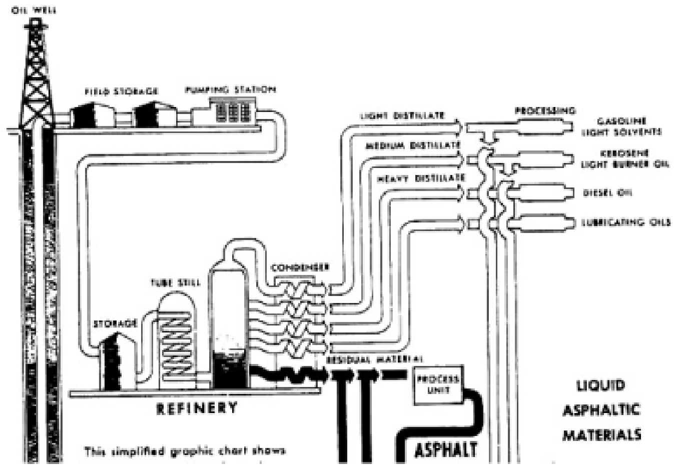
   A. Asphalt cement: (pure asphalt for Road AC).
   B. Liquid asphalt:(cutback (asphalt + petroleum)
   C. Asphalt emulsion: (asphalt + water)
      (B&C for maintenance)

top

- Gasoline
- Kerosene
- Diesel oil
- Lubricating oil
- Asphalt or paraffin or mixed

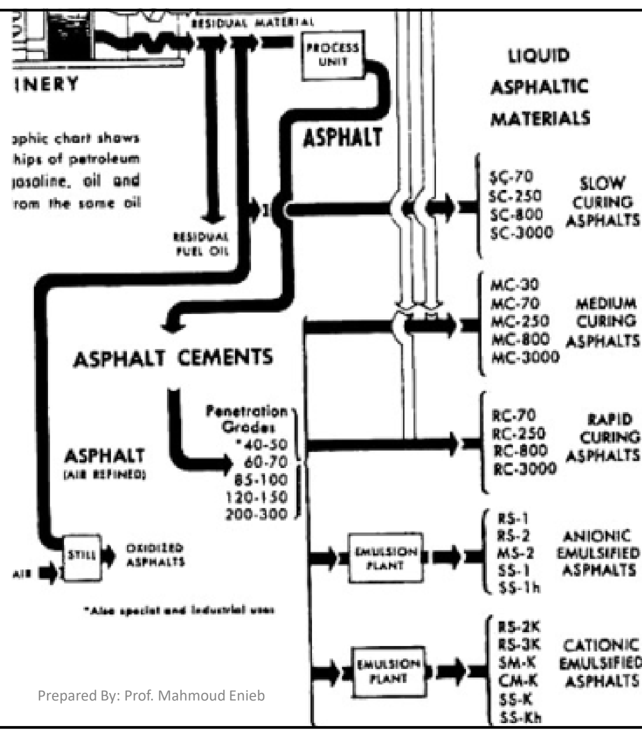
residual

Petroleum asphalt obtained by fractional distillation



9-Sep-24 Prepared By: Prof. Mahmoud Enieb 89

89



9-Sep-24 Prepared By: Prof. Mahmoud Enieb 90

90

Petroleum Asphalt

- The asphalt materials obtained from the distillation of petroleum are in the form of different types of asphalts, which include:
- Asphalt cements,
- Slow-curing liquid asphalts,
- Medium-curing liquid asphalts,
- Rapid-curing liquid asphalts, and
- Asphalt emulsions.

Bituminous materials consist of:

- Asphalt is obtained mainly from petroleum.
- All bituminous materials consist primarily of bitumen and have strong adhesive properties with colors ranging from **dark brown to black**.
- They vary in consistency from **liquid to solid**; thus, they are divided into **liquids, semisolids, and solids**.
- Asphalt grade (consistency) is expressed ether **penetration or viscosity**.

Solids, to liquids.

- The solid form is usually hard and brittle at normal temperatures but will flow when subjected to long, continuous loading.
- The liquid form is obtained from the semisolid or solid forms by heating, dissolving in solvents, or breaking the material into minute particles and dispersing them in water with an emulsifier to form an asphalt emulsion

Asphalt Cutbacks

- **Slow-Curing Asphalts**
- Slow-curing (SC) asphalts can be obtained directly as *slow-curing straight run asphalts* through the distillation of crude petroleum or
- as *slow-curing cutback asphalts* by "cutting back" asphalt cement with a heavy distillate, such as **diesel oil.**
- SC-70, SC-250, SC-800, or SC-3000, where the numbers relate to the approximate **kinematic viscosity in centistokes, cSt,** (10^{-6} m^2/s) at 60 ^oC (140F).
- **Penetration (200-300) units**

Medium-Curing Cutback Asphalts

- Medium-curing (MC) asphalts are produced by *fluxing,* or cutting back, the residual asphalt with **light fuel oil or kerosene**.
- The fluidity of medium-curing asphalts depends on the amount of solvent in the material.
- MC-3000, for example, may have only 20 percent of the solvent by volume, whereas
- MC-70 may have up to 45 percent.
- These medium-curing asphalts can be used for the construction of pavement bases, surfaces, and surface treatments.
- **Penetration is usually 120 to 150**

Rapid-Curing Cutback Asphalts

- Rapid-curing (RC) cutback asphalts are produced by blending asphalt cement with a:
- **Gasoline or naphtha** البنزين أو النفثا generally is used as the solvent for this series of asphalts.
- The grade of rapid-curing asphalt required dictates the amount of solvent to be added to the residual asphalt cement.
- For example, **RC-3000** requires about 15 percent of distillate, whereas
- **RC-70** requires about 40 percent.
- These grades of asphalt can be used for jobs similar to those for which the MC series is used.
- **Penetration is usually 85 to 100**

Notes

- RC70, MC70 and SC70 have the same hardness (same viscosity).
- MC70 < MC3000 (viscosity)
- SC70: 70:- kinematic viscosity in centistoke = 10^{-6} m^2/s

Emulsified Asphalts المستحلبات الاسفلتية

- Emulsified asphalts are produced by breaking asphalt cement, usually of 100 to 250 penetration range, into minute particles and dispersing them in water with an emulsifier.
- At 65^{o}C of steam water & agent and asphalt cement at 121^{o}C then pumping to mill with pumping also then asphalt emulsion was getting.

Asphalt emulsion categories

- The asphalt emulsion return to the state of original asphalt cements, three categories exist:
- Rapid setting (RS).
- Medium setting (MS).
- Slow setting (SS).

9-Sep-24 Prepared By: Prof. Mahmoud Enieb 99

99

Asphalt emulsions are classified

- **Anionic**, (-ve charge).
- **Cationic**, (+ve charge).
- **Non-ionic** (no charge).
- The aggregate have different charge also:
- **Silica** (-ve charge).
- **Lime stone** (+ve charge).

9-Sep-24 Prepared By: Prof. Mahmoud Enieb 100

100

A cationic emulsion (C)

- A cationic emulsion is identified by placing the letter "C" in front of the emulsion type;
- No letter is placed in front of anionic and non-ionic emulsions. For example,
- **CRS-2** denotes a cationic emulsion rapid setting with viscosity 2, and
- **RS-2** denotes either an anionic or non-ionic emulsion rapid setting with viscosity 2.

Emulsified asphalts are used

- Emulsified asphalts are used in cold-laid plant mixes and road mixes (mixed in-place) for several purposes, including
- the construction of highway pavement surfaces,
- bases and
- in surface treatments

Cold-Mix, Cold-Laid Asphalt Mixture

- Emulsified asphalts and low-viscosity cutback asphalts are used to produce cold-mix asphalt mixtures. They also can be used immediately after production or stockpiled مخزونfor use at a later date.
- The production process is similar to that of the hot-mix asphalts, except that the mixing is done at normal temperatures, and it is not always necessary to dry the aggregates. However, saturated aggregates and aggregates with surface moisture should be dried before mixing.

Seal Coats طبقة لزق

- Seal coats are usually single applications of asphalt material that may or may not contain aggregates.
- The three types of seal coats commonly used in pavement maintenance are
- 1. Fog seals, سميكة
- 2. Slurry seals الطبقة الختامية, a semiliquid mixture, typically of fine particles of manure, cement, or coal suspended in water and
- 3. aggregate seals.

Fog Seal طبقة لصق سميكة

- Fog seal is a thin application of emulsified asphalt, usually with **no aggregates** added.
- Slow-setting emulsions, such as **SS-1, SS-1H, CSS-1, and CSS-1H**, normally are used for fog seals.
- The emulsion is sprayed at a rate of **0.45 to 0.90 lit/m^2** after it has been diluted with clean water. تم تخفيفه بالماء النظيف

105

Fog Seal

- Fog seals are used mainly to:
- Reduce the infiltration of air and water into the pavement
- Prevent the progressive separation of aggregate particles from the surface downward or from the edges inward (raveling) in a pavement (Raveling is mainly caused by insufficient compaction during construction carried out in wet or cold weather conditions)
- Bring the surface of the pavement to its original state

106

Slurry Seal طبقة ختامية

- Slurry seal is a uniformly mixed combination of a slow-setting asphalt emulsion (usually **SS-1**), fine aggregate, mineral filler, and water.
- Mixing can be carried out in a conventional plastic mixer or in a wheelbarrow عربة اليد if the quantity required is small.
- It usually is applied with an average thickness of 1⁄16 to 1⁄8 inches (1.5-3 mm)

Slurry Seal

- Slurry seal is used as a **low-cost maintenance** material for pavements carrying **light traffic**.
- Note, however, that although the application of a properly manufactured slurry seal coat will fill cracks of about **1⁄4 in.** or more and
- provide a fine-textured surface, existing cracks will appear through the slurry seal in a short time

Aggregate Seals

- Aggregate seals are obtained by spraying asphalt, immediately covering it with aggregates, and then rolling the aggregates into the asphalt.
- Asphalts used for aggregate seals are usually the **softer grades** of paving asphalt and the heavier grades of liquid asphalts.
- Aggregate seals can be used to restore the surface of old pavements

Prime Coats

- *Prime coats* are obtained by spraying asphalt binder materials onto non-asphalt base courses. Prime coats are used mainly to:
- Provide a waterproof surface on the base
- Fill capillary voids in the base
- Facilitate the bonding of loose mineral particles
- Facilitate the adhesion of the surface treatment to the base .

Prime Coats

- Medium-curing cutbacks normally are used for prime coating with MC-30 recommended for priming a dense flexible base and MC-70 for more granular-type base materials.
- The rate of spray is usually between 1.0 and 1.5 lit/m^2 for the MC-30 and between 1.4 and 2.7 lit/m^2 for the MC-70.
- The amount of asphalt binder used, however, should be the maximum that can be absorbed completely by the base within 24 hours of application under favorable weather conditions.
- The base course must contain a nominal amount of water to facilitate the penetration of the asphalt material into the base.

9-Sep-24 Prepared By: Prof. Mahmoud Enieb 111

111

Tack Coats

- A tack coat is a thin layer of asphalt material sprayed over an old pavement to facilitate the bonding of the old pavement and a new course which is to be placed over the old pavement.
- In this case, the rate of application of the asphalt material should be limited, since none of this material is expected to penetrate the old pavement.
- Rapid-curing cutback asphalts such as RC-70 also may be used as tack coats.
- Asphalt emulsions such as SS-1, SS-1H, CSS-1, and CSS-1H normally are used for tack coats after they have been thinned with an equal amount of water.
- The rate of application varies from 0.25 to 0.7 lit/m^2 of the thinned material.
-

9-Sep-24 Prepared By: Prof. Mahmoud Enieb 112

112

Tack Coats

- Sufficient time must elapse between the application of the tack coat and the application of the new course to allow for adequate curing of the material through the evaporation of most of the diluent in the asphalt emulsion.
- This curing process usually takes several hours in hot weather but can take more than 24 hrs in cooler weather.
- When the material is satisfactorily cured, it becomes a highly viscous, tacky film.

Surface Treatments

- Asphalt surface treatments are obtained by applying a quantity of asphalt material and suitable aggregates on a properly constructed flexible base course to provide a suitable wearing surface for traffic.
- Surface treatments are used to protect the base course and to eliminate the problem of dust on the wearing surface.
- They can be applied as a single course with thicknesses varying from 1⁄2 to 3⁄4 in. or a multiple course with thicknesses varying from 7⁄8 to 2 inches.

Surface Treatments

- A single-course asphalt treatment is obtained by applying a single course of asphalt material and a single course of aggregates.
- The rate of application of the asphalt material for a single course varies from 0.6 to 1.9 lit/m^2 depending on the gradation of the aggregates used; the rate of application of the aggregates varies from 0.004 to 0.017 m^3/m^2.

Surface Treatments

- Multiple-course asphalt surface treatments can be obtained either as a double asphalt surface treatment consisting of two courses of asphalt material and aggregates or as a triple asphalt treatment consisting of three layers.
- The multiple course surface treatments are constructed by first placing a uniform layer of coarse aggregates over an initial application of the bituminous materials and then applying one or more layers of bituminous materials and smaller aggregates, with each layer having a thickness that is approximately equal to the nominal maximum size of the aggregates used for that layer.
- The **maximum aggregate size** of each layer subsequent to the initial layer usually is taken as **one-half** that of the aggregates used in the preceding layer.

Table 18.10 Quantities of Materials for Bituminous Surface Treatments

Surface Treatment		*Aggregate*			*Bituminous Material*[a]
Type	*Application*	*Size No.*[b]	*Nominal Size (Square Openings)*	*Typical Rate of Application, ft^3/yd^2*	*Typical Rate of Application, gal/yd^2*
Single	Initial	5	1 to ½ in.	0.50	0.42
		6	¾ to ⅜ in.	0.36	0.37
		7	½ in. to No. 4	0.23	0.23
		8	⅜ in. to No. 8	0.17	0.19
		9	No. 4 to No. 16	0.11	0.13
Double	Initial	5	1 to ½ in.	0.50	0.42
	Second	7	½ in. to No. 4	0.25	0.26
Double	Initial	6	¾ to ⅜ in.	0.36	0.37
	Second	8	⅜ in. to No. 8	0.18	0.20
Triple	Initial	5	1 to ½ in.	0.50	0.42
	Second	7	½ in. to No. 4	0.25	0.26
	Third	9	No. 4 to No. 16	0.13	0.14
Triple	Initial	6	¾ to ⅜ in.	0.36	0.37
	Second	8	⅜ in. to No. 8	0.18	0.20
	Third	9	No. 4 to No. 16	0.13	0.14

Note: The values are typical design or target values and are not necessarily obtainable to the precision indicated.
[a]Experience has shown that these quantities should be increased slightly (5 to 10 percent) when the bituminous material to be used was manufactured for application with little or no heating.
[b]According to Specification D448.
SOURCE: *Annual Book of ASTM Standards, Section 4, Construction*, Vol. 04.03, Road and Paving Materials; Pavement Management Technologies, American Society for Testing and Materials, Philadelphia, PA, 2007.

Crack Sealing (AC Pavement)

- ***Definition***
- Crack sealing is the process of cleaning and sealing or resealing of cracks in AC pavement.
- This technique is used to fill longitudinal and transverse cracks, including joint reflection cracks from underlying PCC slabs, that are wider than 1/8 in.

Design/Technique Crack Sealing

- The technique consists of the following steps:
- 1. Remove old sealant and form a sealant reservoir. Use a vertical spindle router or hand tools.
- a. Remove the loose material along edges.
- b. The sealant reservoir depth should be at least the width of the crack plus 1/4 in.
- 2. After routing, clean the crack using compressed air (do not sandblast). Vacuum or sweep up the debris.
- 3. Apply sealant. Do not overfill the crack; fill to 1/8 in. below the pavement surface.

Full-Depth Patching (AC Pavement)

- ***Definition***
- This technique involves replacing the full depth of the AC layer and may include replacement of the base and subbase layers.

Full-Depth Patching (AC Pavement)

- *Use*
- Full-depth patching is used to repair structural and material related distresses such as:
- alligator cracking, rutting, and corrugation.
- In the case of slippage cracking where the failure may be limited to the top AC layer, the depth of the patch may be limited to the top AC layer if it can be removed easily.

Full-Depth Patching (AC Pavement)

- *Design/Technique*
- Square off the area to be patched and mark off at least 6 in. to 12 in. beyond the distressed area.
- Make cuts to form straight lines with vertical sides.
- The patch boundary does not have to be rectangular.
- After cutting, remove material from the cut area.

Full-Depth Patching (AC Pavement)

- *Design/Technique*
- a. If base course or subgrade is damaged, remove and replace the material, and compact. As a minimum, compact the base course in place.
- b. After compaction, thoroughly clean the pavement surface outside the repair area to avoid debris الحطام getting into the tack coat or patching material.

9-Sep-24 Prepared By: Prof. Mahmoud Enieb 123

123

Full-Depth Patching (AC Pavement)

- 3. Apply a light tack coat to the sides of the patch area and prime the bottom.
- a. Backfill and compact in 2 in. to 3 in. lifts with a dense-graded hot mix asphalt to the same grade as the existing asphalt.
- The use of a vibrating roller is strongly recommended. If rutting is present, rolling may be done transversely so that the roller will rest on the patch material and not on the old pavement.
- b. Seal 1 in. to 1.5 in. past edges of patch to avoid water infiltration

9-Sep-24 Prepared By: Prof. Mahmoud Enieb 124

124