Workshop On Design And Rehabilitation Of Local Roadways For Ohio’s Counties

DESIGN OF ASPHALT STRUCTURAL OVERLAYS

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President & Executive Director
Flexible Pavements of Ohio
Overlay Design Resources

Part 3, Chapter 5, Rehabilitation Methods With Overlays

Asphalt Institute IS-139
Overlay Types:

Functional Overlays:
Correct functional deficiencies such as…
Surface Friction, Texture, Hydroplaning & Splash from Rutting, Potholes, Corrugation, Faulting, Blow-ups, Settlements, Heaves
What defines a “structural” asphalt overlay?

Overlays used to correct structural deficiencies arising from any conditions that adversely affect the load carrying capability of the pavement structure.
Conditions Affecting Load Carrying Capacity Of A Pavement

Structural Deficiencies:

• Cracking (fatigue)
  • Initiates from the bottom of the pavement – too much strain.

• Distortion (base materials)
  • Rutting in the subgrade

• Disintegration
  • Progressive and extensive loss of asphalt matrix through raveling
Rehabilitation Methods Using Asphalt Overlays

IMPORTANT!

For any overlay, whether to correct functional or structural distress, a proper assessment of the structural strength of the existing pavement should always be performed before the application of any treatment, to ensure the full benefit of the treatment is realized.
Overlay Design Considerations

• Pre-Overlay Repair (uniform strength condition desired)
• Reflection Crack Control
• Traffic Loadings (future ESALs)
• Sub-drainage (condition, improvements to be made?)
• Rutting (base layer vs. asphalt layer)
• Milling as part of rehab strategy
• Recycling (FDR, CIR, HIR)
Overlay Design Considerations

Rutting in Asphalt Layer

original profile
weak asphalt layer
shear plane

Functional Distress
Overlay Design Considerations

Rutting in Subgrade or Base

original profile

asphalt layer

weak subgrade or underlying layer

Structural Distress

subgrade deformation
Overlay Design Considerations (cont’d)

• Overlay Materials (mix type selection, buildup selection)
• Effective Strength of Existing Pavement:
  • Existing Flexible Pavement Condition
  • Existing PCC Slab Durability
• Design Equation Inputs:
  • Overlay Design Reliability
  • Overall Standard Deviation
Overlay Thickness Determination

Structural Capacity Deficiency Approach

To carry the future traffic a certain structural capacity (strength) is necessary

$SC_y$
Overlay Thickness Determination

There is within the *existing* pavement some structural capacity (strength).

\[ SC_{\text{exist}} \]
Overlay Thickness Determination

Structural Capacity of overlay provides the additional strength to carry future traffic.

$SC_{ol}$
Having determined the needed structural capacity (strength) to carry anticipated traffic in the future ($SC_y$), the additional structural capacity (strength) which must be obtained from the asphalt overlay will be equal to the difference between the needed structural capacity and the existing structural capacity.

$$SC_{ol} = SC_y - SC_{exist}$$
Overlay Thickness Determination

Asphalt Overlay of Flexible Pavement
Overlay Design

Overlay Thickness Determination
Asphalt Overlay of Flexible Pavement

SN

Structural Number—an abstract number that represents the structural strength required for a pavement to perform in accordance with the design criteria.
Overlay Design

Overlay Thickness Determination

Asphalt Overlay of Flexible Pavement

Structural Capacity is represented by the Structural Number of an asphalt pavement.

\[
SC \Rightarrow SN
\]
Overlay Design

Overlay Thickness Determination
Asphalt Overlay of Flexible Pavement

The following are true...

\[ SC_y \Rightarrow SN_y \]
\[ SC_{\text{exist}} \Rightarrow SN_{\text{exist}} \]
\[ SC_{\text{ol}} \Rightarrow SN_{\text{ol}} \]
Overlay Design

Overlay Thickness Determination

Asphalt Overlay of Flexible Pavement

We can now say that...

\[ SC_{ol} = SC_y - SC_{exist} \]

\[ SN_{ol} = SN_y - SN_{exist} \]
Overlay Design

Overlay Thickness Determination

Asphalt Overlay of Flexible Pavement

\[ SN_y \] we’ll call \( SN_f \)

...to represent the pavement structural number needed to carry the future traffic.
Overlay Design

Overlay Thickness Determination
Asphalt Overlay of Flexible Pavement

$$SN_{ol} = SN_f - SN_{exist}$$
Overlay Design

Overlay Thickness Determination

Asphalt Overlay of Flexible Pavement

How then do we determine the overlay thickness?

Solve for $SN_{ol}$
Overlay Design

Overlay Thickness Determination
Asphalt Overlay of Flexible Pavement

Once $SN_{ol}$ is known, the overlay thickness can be determined using the layer coefficient for asphalt.

**Definition**: Layer coefficient “a” is a unitless number representing the strength of a material per inch of thickness.
Overlay Design

Overlay Thickness Determination
Asphalt Overlay of Flexible Pavement

Once $SN_{ol}$ is known, the overlay thickness can be determined using the layer coefficient for asphalt.

$$SN_{ol} = a \times D$$

where $a =$ layer coefficient (0.36 → 0.43)

$D =$ thickness
Overlay Design

Overlay Thickness Determination
Asphalt Overlay of Flexible Pavement

\[ SN_{\text{ol}} = SN_f - SN_{\text{exist}} \]

How do we determine this?
Overlay Design

Overlay Thickness Determination
Asphalt Overlay of Flexible Pavement

Inputs to Determine $SN_f$:

- Future Traffic Loads (ESALs based on flexible model)
- Effective Soil Strength ($M_r$) exist. pvmt.
- Overlay Design Reliability ($R$)
- Overall Standard Deviation ($S_o$)
- Loss in Serviceability ($\Delta$ PSI)
Overlay Design

Overlay Thickness Determination
Asphalt Overlay of Flexible Pavement

\[ SN_{ol} = SN_f - SN_{exist} \]
Overlay Design

Overlay Thickness Determination

Asphalt Overlay of Flexible Pavement

Methods To Determine $SN_{\text{exist}}$

• Fatigue Damage from Traffic (Remaining Life)
• Nondestructive Deflection Testing (NDT)
• Visual Survey of Pavement Condition and Materials Testing

*** LIMITED ACCURACY ***
Overlay Design

Overlay Thickness Determination
Asphalt Overlay of Flexible Pavement

Method: Pavement Condition Survey

Pavement condition is evaluated for evidence of distresses that indicate loss in structural strength.
Overlay Design

Overlay Thickness Determination
Asphalt Overlay of Flexible Pavement

Method: Pavement Condition Survey

- % of Surface Area with Alligator Cracking (design lane)
- Number of Transverse Cracks per Mile
- Mean Rut Depth
- Evidence of Pumping at Cracks and at Pavement Edge
Overlay Design

Overlay Thickness Determination
Asphalt Overlay of Flexible Pavement

Method: Pavement Condition Survey

Using Table 5.2, Part 3, Chapter 5 of AASHTO Guide we can determine the approximate strengths (per inch of material) of the various layers in the existing pavement.
<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>SURFACE CONDITION</th>
<th>COEFFICIENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Surface</td>
<td>Little or no alligator cracking and/or only low-severity transverse cracking</td>
<td>0.35 to 0.40</td>
</tr>
<tr>
<td></td>
<td>&lt;10 percent low-severity alligator cracking and/or</td>
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<td>0.14 to 0.20</td>
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<tr>
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<td>&gt;5-10 percent medium- and high-severity transverse cracking</td>
<td>0.08 to 0.15</td>
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<tr>
<td>Stabilized Base</td>
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<tr>
<td>Granular Base or Subbase</td>
<td>No evidence of pumping, degradation, or contamination by fines</td>
<td>0.10 to 0.14</td>
</tr>
<tr>
<td></td>
<td>Some evidence of pumping, degradation, or contamination by fines</td>
<td>0.00 to 0.10</td>
</tr>
</tbody>
</table>
Overlay Design

Overlay Thickness Determination
Asphalt Overlay of Flexible Pavement

\[ SN = \text{Sum of the structural numbers for all layers of material in the pavement} \]

\[ SN = SN_{layer1} + SN_{layer2} + SN_{layer3} + \ldots \]

\[ SN = a_1*D_1 + a_2*D_2 + a_3*D_3 + \ldots \]
Overlay Design

Overlay Thickness Determination

Asphalt Overlay of Flexible Pavement

\[ SN_{\text{exist}} = SN_{\text{existlayer1}} + SN_{\text{existlayer2}} + SN_{\text{existlayer3}} + \ldots \]

\[ SN_{\text{exist}} = a_{1\text{exist}} \times D_{1\text{exist}} + a_{2\text{exist}} \times D_{2\text{exist}} + a_{3\text{exist}} \times D_{3\text{exist}} + \ldots \]

Where do we find this information?
Overlay Design

Overlay Thickness Determination
Asphalt Overlay of Flexible Pavement

Use Table 5.2 to determine layer coefficients for existing pavement materials.

Use cores or historical data to determine thickness of the existing pavement layers.
Overlay Design

Overlay Thickness Determination
Asphalt Overlay of Flexible Pavement

\[ SN_{ol} = SN_f - SN_{exist} \]
Overlay Design

Overlay Thickness Determination
Asphalt Overlay of Flexible Pavement

\[ \text{SN}_{ol} = a_{ol} \times D_{ol} \]

\[ D_{ol} = \frac{\text{SN}_{ol}}{a_{ol}} \]
Overlay Design

Overlay Thickness Determination
Asphalt Overlay of Flexible Pavement

Summary of Design Steps

1. Determine Existing Pavement Design and Construction
   • Thickness and material type of each layer
   • Available subgrade soil information

2. Traffic Analysis
   • Predicted future 18-kip ESALs in the design lane over the design period
Overlay Design

Overlay Thickness Determination
Asphalt Overlay of Flexible Pavement

Summary of Design Steps (cont’d)

3. Condition Survey
- Percent of surface area with alligator cracking
- Percent of transverse cracking
- Mean rut depth
- Evidence of pumping at cracks and at pavement edges
Summary of Design Steps (cont’d)

4. Determination of Required Structural Number for Future Traffic ($SN_f$)
   • Effective design subgrade resilient modulus
   • Design serviceability loss ($\Delta$PSI)
   • Overlay design Reliability ($R$)
   • Overall standard deviation ($S_o$) for flexible pavement
Overlay Design

Overlay Thickness Determination
Asphalt Overlay of Flexible Pavement

Summary of Design Steps (cont’d)

5. Determination of Effective Structural Number of the Existing Pavement ($SN_{\text{exist}}$)
   • Method: Condition survey w/ materials testing
   • Method: Nondestructive deflection testing (NDT)
   • Method: Fatigue damage from traffic (Remaining Life)
Overlay Design

Overlay Thickness Determination
Asphalt Overlay of Flexible Pavement

Summary of Design Steps (cont’d)

6. Determination of Overlay Thickness

\[ D_{ol} = \frac{SN_{ol}}{a_{ol}} = \frac{(SN_f - SN_{exist})}{a_{ol}} \]
Overlay Design

Overlay Thickness Determination
Asphalt Overlay of Flexible Pavement

EXAMPLE
PROBLEM
**Example Problem:** Determine the asphalt overlay thickness needed to ensure pavement structural sufficiency for the design period.

- Existing pavement buildup and condition:
  - 3” asphalt surface with greater than 10% having low severity alligator cracking
  - 8” granular base having some evidence of pumping and degradation
  - Drainage quality of exiting pavement is poor. Percent of time pavement structure is exposed to moisture levels approaching saturation is 15%
Example Problem: Solution

- Design Inputs:
  - Design Reliability(R)=80%
  - Overall Standard Deviation ($S_o$)=0.45
  - Loss in Serviceability($\Delta$PSI)=2.0
  - Subgrade Soil (CBR)=4, $EM_r=CBR \times 1200=4800$
  - Truck Factors – ODOT averages per truck in urban areas:
    - Type B trucks (tractor-trailer) = 1.04
    - Type C trucks (single unit, 6 or more tires) = 0.41
  - Design lane truck traffic:
    - 50 Type B, 5 days/week, average loads
    - 50 Type C, 5 days/week, average loads
  - Design period = 15 yrs.
Example Problem: Solution cont’d

- Design axle loads (ESALs):
  - Type B 50_{TRUCKS} \times 1.04_{FACTOR} \times 5_{DAYS} \times 52_{WEEKS} \times 15_{YEARS} = 203,000
  - Type C 50 \times 0.41 \times 5 \times 52 \times 15 = 80,000
  - Total design ESALs = 283,000
- $SN_f = 2.95$
- Determine $SN_{exist}$ for asphalt pavement using condition survey method.
  - Thickness of existing asphalt surface, $D_1 = 3”$
  - Structural coefficient of asphalt surface, $a_1$, based on condition survey = 0.25 (Table 5.2, Part 3, Chapter 5)
  - Thickness of base, $D_2 = 8”$
  - Structural coefficient of base, $a_2$, based on condition survey = 0.05
  - Drainage coefficient of base, $m_2 = 0.7$ (Table 2.4, Part 2, Chapter 2)
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<tr>
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<td>0.00 to 0.10</td>
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</table>
Table 2.4. Recommended $m_1$ Values for Modifying Structural Layer Coefficients of Untreated Base and Subbase Materials in Flexible Pavements

<table>
<thead>
<tr>
<th>Quality of Drainage</th>
<th>Less Than 1%</th>
<th>1-5%</th>
<th>5-25%</th>
<th>Greater Than 25%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>1.40-1.35</td>
<td>1.35-1.30</td>
<td>1.30-1.20</td>
<td>1.20</td>
</tr>
<tr>
<td>Good</td>
<td>1.35-1.25</td>
<td>1.25-1.15</td>
<td>1.15-1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Fair</td>
<td>1.25-1.15</td>
<td>1.15-1.05</td>
<td>1.00-0.80</td>
<td>0.80</td>
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<tr>
<td>Poor</td>
<td>1.15-1.05</td>
<td>1.05-0.80</td>
<td><strong>0.80-0.60</strong></td>
<td>0.60</td>
</tr>
<tr>
<td>Very poor</td>
<td>1.05-0.95</td>
<td>0.95-0.75</td>
<td>0.75-0.40</td>
<td>0.40</td>
</tr>
</tbody>
</table>
Example Problem: Solution cont’d

- Calculate \( SN_{\text{exist}} \):
  - \( SN_{\text{exist}} = a_1 \cdot D_1 + a_2 \cdot D_2 \cdot m_2 \)
  - \( SN_{\text{exist}} = 0.25 \cdot 3 + 0.05 \cdot 8 \cdot 0.7 = 1.03 \)

- Calculate \( SN_{\text{ol}} \):
  - \( SN_{\text{ol}} = SN_f - SN_{\text{exist}} \)
  - \( SN_{\text{ol}} = 2.95 - 1.03 = 1.92 \)

- Calculate \( D_{\text{ol}} \) (inches):
  - \( D_{\text{ol}} = \frac{SN_{\text{ol}}}{a_{\text{ol}}} \) (ODOT Pgmt. Design Mnl, Sec. 400, \( a_{\text{ol}} = 0.43 \))
  - \( D_{\text{ol}} = 1.92 \div 0.43 = 4 \frac{1}{2} \text{ inch overlay} \)
Overlay Design Resources

Limitations:

• For use in designing overlays for traffic having less than 100 heavy trucks per day.

• “Heavy trucks” are defined as heavy commercial vehicles, normally 2-axle, 6-tire units or larger. Pickup and light duty trucks excluded. Trucks with heavy duty wide base tires are included.

• Reference MS-17 for heavier traffic pavements.
Outline of Procedure:

1) Each course of the existing pavement is assigned a factor based on condition.

2) Factor is used to convert the thickness of the course to an equivalent thickness of asphalt concrete.

3) Sum of the equivalent thickness for each course is deducted from the calculated total design thickness ($T_A$) needed for the pavement to carry the traffic for the design period (20 years, 3% annual growth rate).
<table>
<thead>
<tr>
<th>Pavement Course</th>
<th>Minimum Requirements</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASPHALT CONCRETE</td>
<td>Stable, generally uncracked with little or no deformation in the wheel paths</td>
<td>0.9 – 1.0</td>
</tr>
<tr>
<td></td>
<td>Stable, some fine cracking or slight deformation in the wheel paths</td>
<td>0.7 – 0.9</td>
</tr>
<tr>
<td></td>
<td>Appreciable cracking and crack patterns, or appreciable deformation in the wheel paths</td>
<td>0.5 – 0.7</td>
</tr>
</tbody>
</table>
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Equivalent Thickness Factors:

<table>
<thead>
<tr>
<th>EMULSIFIED OR CUTBACK ASPHALT MIXTURES</th>
<th>Stable, generally uncracked and exhibiting little deformation in the wheel paths</th>
<th>0.7 – 0.9</th>
</tr>
</thead>
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<tr>
<td></td>
<td>Stable, some fine cracking, some raveling or aggregate degradation, and slight deformation in the wheel paths</td>
<td>0.5 – 0.7</td>
</tr>
<tr>
<td></td>
<td>Extensive cracking, considerable raveling or aggregate degradation, appreciable deformation in the wheel paths and lack of stability</td>
<td>0.3 – 0.5</td>
</tr>
</tbody>
</table>
Stable, undersealed and generally uncracked \(0.9 - 1.0\)

Stable, undersealed, some cracks but no pieces smaller than about one square metre (yard) \(0.7 - 0.9\)

Appreciably cracked and faulted, cannot be undersealed. Slab fragments, ranging in size from approximately one to four square metres (yards) have been well-seated on the subgrade by heavy pneumatic rolling \(0.5 - 0.7\)

Pavement broken into small pieces, 0.6m (2 ft) or less in maximum dimension. Use upper part of range when subbase is present; lower part of range when slab is on subgrade \(0.3 - 0.5\)
**Equivalent Thickness Factors:**

<table>
<thead>
<tr>
<th>AGGREGATE</th>
<th>Characteristics</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granular subbase or base—reasonably well-graded, hard aggregates with some plastic fines and CBR not less than 20. Use upper part of range if P.I. is 6 or less; lower part of range if P.I. is more than 6</td>
<td>0.1 - 0.2</td>
<td></td>
</tr>
<tr>
<td>SOIL</td>
<td>Improved subgrade or native subgrade, in all cases</td>
<td>0</td>
</tr>
</tbody>
</table>
**THE DESIGN PROCEDURE**

**STEP 1:**
Using the approximate number of heavy trucks per day and existing subgrade condition determine typical thickness of full-depth asphalt ($T_A$) from Table 2

<table>
<thead>
<tr>
<th>Average Number of Heavy Trucks per Day in Design Lane</th>
<th>Subgrade Category</th>
<th>( T_A ) (mm)</th>
<th>( T_A ) (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Poor*</td>
<td>Medium**</td>
<td>Good to Excellent**</td>
</tr>
<tr>
<td>5 or less</td>
<td>165 (6.5)</td>
<td>115 (4.5)</td>
<td>100 (4) min.</td>
</tr>
<tr>
<td>10</td>
<td>180 (7)</td>
<td>125 (5)</td>
<td>100 (4) min.</td>
</tr>
<tr>
<td>20</td>
<td>200 (8)</td>
<td>150 (6)</td>
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<tr>
<td>30</td>
<td>215 (8.5)</td>
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<td>230 (9)</td>
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<tr>
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<td>240 (9.5)</td>
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</tr>
<tr>
<td>100</td>
<td>250 (10)</td>
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</tr>
</tbody>
</table>
THE DESIGN PROCEDURE

STEP 2:
Determine the effective thickness of the existing pavement ($T_e$). *(The effective thickness is the thickness the existing pavement would be if it could be converted to full-depth asphalt.)*

Conversion:

$$T_e = T_1 \cdot \text{Factor}_{\text{LAYER1}} + T_2 \cdot \text{Factor}_{\text{LAYER2}} + T_3 \cdot \text{Factor}_{\text{LAYER3}}$$
THE DESIGN PROCEDURE

STEP 3:
Determine the thickness of the overlay by subtracting the effective thickness of the existing pavement ($T_e$) from the typical thickness of full-depth asphalt needed for the soil condition and anticipated truck traffic.

Thickness of asphalt overlay = $T_A - T_e$ (inches)
Example Problem: Determine the asphalt overlay thickness needed to ensure pavement structural sufficiency for the design period.

Given: A secondary road carrying an average of 10 heavy trucks per day. The existing pavement consists of 1 ½ inch asphalt concrete surface course exhibiting large cracks and some rutting in the wheel paths, over 6 inches of untreated crushed stone base containing some plastic fines. The subgrade is in the “medium” category. Find the required overlay thickness.
Example Problem: Solution

STEP 1:
Using the approximate number of heavy trucks per day and existing subgrade condition determine typical thickness of full-depth asphalt ($T_A$) from Table 2

**TABLE 2**

<table>
<thead>
<tr>
<th>Average Number of Heavy Trucks per Day in Design Lane</th>
<th>Subgrade Category</th>
<th>Typical Thickness of Full-Depth Asphalt, $T_A$, mm (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Poor*</td>
<td>mm (in.)</td>
</tr>
<tr>
<td></td>
<td>Medium**</td>
<td>mm (in.)</td>
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</table>
Example Problem: Solution

STEP 2:
Determine the effective thickness of the existing pavement ($T_e$). *(The effective thickness is the thickness the existing pavement would be if it could be converted to full-depth asphalt.)*

Conversion:

$$T_e = T_{\text{ASPHALT}} \times \text{Factor}_{\text{ASPHALT}} + T_{\text{CR-STONE}} \times \text{Factor}_{\text{CR-STONE}}$$
STEP 2 cont’d:
Asphalt layer is described as exhibiting large cracks and some rutting in the wheel paths.

Use Factor = 0.6
Example Problem: Solution cont’d

STEP 2 cont’d:
Stone layer is described as untreated crushed stone base containing some plastic fines.
Use Factor = 0.15

<table>
<thead>
<tr>
<th>AGGREGATE</th>
<th>Granular subbase or base—reasonably well-graded, hard aggregates with some plastic fines and CBR not less than 20. Use upper part of range if P.I. is 6 or less; lower part of range if P.I. is more than 6</th>
<th>0.1 - 0.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOIL</td>
<td>Improved subgrade or native subgrade, in all cases</td>
<td>0</td>
</tr>
</tbody>
</table>
Example Problem: Solution cont’d

STEP 2 cont’d:
Conversion:

\[ T_e = T_{\text{ASPHALT}} \times \text{Factor}_{\text{ASPHALT}} + T_{\text{CR-STONE}} \times \text{Factor}_{\text{CR-STONE}} \]

\[ T_e = 1.5 \times 0.6 + 6 \times 0.15 \]

\[ T_e = 0.9 + 0.9 = 1.8 \text{ inches} \]
STEP 3:
Determine the thickness of the overlay by subtracting the effective thickness of the existing pavement ($T_e$) from the typical thickness of full-depth asphalt needed for the soil condition and anticipated truck traffic.

Thicknass of asphalt overlay $= T_A - T_e$ (inches)

$= 5 - 1.8 \approx 3 \frac{1}{4}$ inch overlay
DESIGN OF ASPHALT STRUCTURAL OVERLAYS

QUESTIONS?

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