DESIGN & CONSTRUCTION OF RIGID AND FLEXIBLE PAVEMENTS
• Composition of Road Pavement:
  – Pavement Crust (Structure)
  – Sub Grade
  – Formation
Functions

• Good Riding Surface
• Resistance to weathering and vehicle load conditions
• Structural Stability to transfer wheel loads safely
Parameters for Pavement Design

• Traffic - Volume & Composition
• Material Characteristics
• Sub Grade strength
• Temperature, Rainfall and Drainage conditions
Types of Pavements

- Flexible
- Rigid
- Composite Pavements
- Semi Rigid / Semi Flexible
- Roller Compacted Concrete
FLEXIBLE PAVEMENTS
(TYPICAL CROSS SECTION)
Load Dispersion in Flexible Pavements

Diagram showing the layers of a flexible pavement:
- Sub Grade
- Sub Base
- Base
- Black Topping

Dimensions: 300mm and 45°
Design of Flexible Pavements

• Functional Layer

• Not Necessary for Situations Where the Motorised Traffic is <150 and Annual Rainfall <500mm

• Not Necessary for Situations Where the Motorised Traffic is <50 and Annual Rainfall <1000mm

• Recommended Surfacing Layers
  – One/Two Coat Surface Dressing
  – PMC+Seal Coat
Design Approach and Criteria

• Vertical compressive strain at the top of the sub-grade

• Horizontal tensile strain at the bottom of the bituminous layer

• Pavement deformation within the bituminous layer
Critical Locations in Pavement

- **A**
- **B**
- **C**
- **D**
- **B**
- **M**
- **A**
- **B**
- **GRANULAR**
- **BASE**
- **GRANULAR**
- **SUB-BASE**
- **C**
- **SUB GRADE**
Design Procedure

- Initial Traffic in terms of number of commercial vehicles per day (CVPD)
- Traffic growth rate during the design life in percentage
- Design life in number of years
- Vehicle damage factor (VDF)
- Distribution of commercial traffic over the carriageway.
Computation of Design Traffic

\[ A = P \times (1+r)^{(n+x)} \]

Where

\( A \) = Design Traffic (CVPD)
\( P \) = No. of CVPD at Last Count
\( r \) = Annual Growth Rate of Commercial Traffic
\( n \) = No. of Years Between the Last Count and the Year of Completion of Construction
\( x \) = Design Life (Years)
Annual Fluctuations in ADT

- Harvesting Season
- Lean Season

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California Bearing Ratio (CBR)

CBR = \frac{(\text{Load taken by the Soil at Standard Penetration})}{(\text{Load Taken by Standard Crushed Aggregates at the Same Penetration Level})} \times 100

Penetration Levels: 2.5mm and 5mm

Design CBR after Soaking for Four Days

If Rainfall is <500mm, No Soaking is Required
Pavement Thickness

- Sub grade Strength CBR Value
- Traffic Parameter (standard commercial vehicle)
- Total pavement thickness from the design curves
- Pavement composition decided based on rainfall and the motorised traffic conditions
<table>
<thead>
<tr>
<th>Curve</th>
<th>CVPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0 - 15</td>
</tr>
<tr>
<td>B</td>
<td>15 - 45</td>
</tr>
<tr>
<td>C</td>
<td>45 - 150</td>
</tr>
<tr>
<td>D</td>
<td>150 - 450</td>
</tr>
</tbody>
</table>
RRM Curves for Flexible Pavement Design
Table 6: Guidelines on Surfacing for Rural Roads

<table>
<thead>
<tr>
<th>Surfacing</th>
<th>1500+</th>
<th>1000-1500</th>
<th>500-1000</th>
<th>0-500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thin Bituminous Surfacing (2-Coat S,D)</td>
<td>Bituminous Surfacing (PMC + Seal Coat)</td>
<td>Bituminous Surfacing (PMC + Seal Coat)</td>
<td>Thin Bituminous Surfacing (2-Coat S,D)</td>
<td></td>
</tr>
<tr>
<td>Single Coat Surface Dressing</td>
<td>Thin Bituminous Surfacing (2-Coat S,D)</td>
<td>Bituminous Surfacing (PMC + Seal Coat)</td>
<td>Thin Bituminous Surfacing (2-Coat S,D)</td>
<td></td>
</tr>
<tr>
<td>Unsealed Surface (Gravel Road)</td>
<td>Single Coat Surface Dressing</td>
<td>Thin Bituminous Surfacing (2-Coat S,D)</td>
<td>Thin Bituminous Surfacing (2-Coat S,D)</td>
<td></td>
</tr>
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<td></td>
</tr>
</tbody>
</table>

Motorised Vehicles: 0 – 50, 50 – 150, 150+ (Excluding 2wheelers)
Thickness of crust required for different traffic (CBR 2)
Thickness of crust required for different traffic (CBR 4)

- **A**: 125 (Sub-base course), 20 (Base Course), 20 (Surfacing)
- **B**: 150 (Sub-base course), 25 (Base Course), 25 (Surfacing)
- **C**: 260 (Sub-base course), 30 (Base Course), 30 (Surfacing)
- **D**: 315 (Sub-base course), 30 (Base Course), 30 (Surfacing)
Table 7: Gradation Requirements for Subbase Aggregate

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent Passing Designated Sieve</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>63 mm</td>
<td>100</td>
</tr>
<tr>
<td>50 mm</td>
<td>97 – 100</td>
</tr>
<tr>
<td>37.5 mm</td>
<td></td>
</tr>
<tr>
<td>25 mm</td>
<td>65-79</td>
</tr>
<tr>
<td>19 mm</td>
<td></td>
</tr>
<tr>
<td>12.5 mm</td>
<td>45-59</td>
</tr>
<tr>
<td>9.5 mm</td>
<td></td>
</tr>
<tr>
<td>4.75 mm</td>
<td>28-42</td>
</tr>
<tr>
<td>0.425 mm</td>
<td>9-17</td>
</tr>
<tr>
<td>0.075 mm</td>
<td>4 – 8</td>
</tr>
</tbody>
</table>

Liquid Limit not to exceed 25
### Table 8: Gradation Requirements for Base Aggregate

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent Passing Designated Sieve</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>50 mm</td>
<td>100</td>
</tr>
<tr>
<td>37.5 mm</td>
<td>97 – 100</td>
</tr>
<tr>
<td>25 mm</td>
<td></td>
</tr>
<tr>
<td>19 mm</td>
<td>67 – 81</td>
</tr>
<tr>
<td>9.5 mm</td>
<td></td>
</tr>
<tr>
<td>4.75 mm</td>
<td>33-47</td>
</tr>
<tr>
<td>0.425 mm</td>
<td>10-19</td>
</tr>
<tr>
<td>0.075 mm</td>
<td>4-8</td>
</tr>
</tbody>
</table>

Liquid Limit not to exceed 25 and PI not to exceed 6
Fig. 4  Nomograph for Computing Soaked CBR Value from Sieve Analysis Data
Base Requirements

• Majority of the Load is Taken up by Base

• Types of Base Courses
  – Water Bound Macadam
  – Wet Mix Macadam
  – Crusher Run Macadam
  – Crushed Rock Base
  – Dry Lean Concrete
  – Soft Aggregate Base Course
  – Lime Fly-Ash Concrete
Local Material

• Since hard material is becoming scarce and leads being more, use of load material is encouraged.
• Soils:
  – Lateritic Soils
  – Moorum / Red Soils
  – Desert Sands
  – Alluvial Soils
  – Clays including Black cotton
Local Material (Contd…)

• Soft Aggregate:
  – Granules
  – Kankar
  – Dhandla
  – Laterite
  – Soft Stone / Sand Stone
  – Brick aggregate
Design of Flexible Pavements - Example

• Design Data
  – Subgrade CBR = 2%
  – Initial Traffic Intensity = 70 Motorised Vehicles
  – Commercial Vehicles = 30 (>3 T Laden Weight)
  – Average Annual Growth Rate = 6%
  – Average Annual Rainfall = 1600mm
  – Design Life = 10 Years
Design of Flexible Pavements - Example

• Computations
  – Design Traffic = 30*(1+0.06)^10
    = 54 CVPD

• From Graph:
  – Traffic Classification – “C”
  – Design CBR = 2%
  – Total Thickness = 715 mm
Design of Flexible Pavements - Example

• Design Crust Details
  – Total Pavement Thickness = 715mm
  – Capping Layer = 100mm
  – GSB = 370mm
  – WBM = 225mm
  – Surface = PMC+Seal Coat (For 125 Veh /Day Motorised Traffic and 1600mm of Rainfall)
Design of Flexible Pavements - Example

DESIGN CHART FOR CBR = 2%

A  B  C  D
150 150 225 225
275 365 370 455
100 100 100 100
Surface  WBM  GSB  Capping
Design Guidelines

- Earthen Shoulders of 1.875m Each Shall be Provided with LL<25% and PI<6%

- In Case of Problematic Soils, One Meter Wide Gravel Shoulders are Recommended by NRRDA.

- Suggested Composition for Shoulders is 67% of Gravel+33% of Stone Dust/Fly-Ash/Sand

- Compacted Thickness of Shoulder Shall be = Base+Surface Course Thicknesses
Rigid Pavement Design

• IRC:15-2002 “Standard Specifications and Code of Practice for Construction of Concrete Roads”
Factors Governing Rigid Pavement Design

• Design Wheel Load (5100 Kg)
• Traffic Intensity
• Annual Growth Rate of Traffic (CVPD)
• Temperature Differential
• Strength of Subgrade in Terms of Modulus of Subgrade Reaction (K)
Factors Governing Rigid Pavement Design

- Concrete Flexural Strength
- Modulus of Elasticity
- Poisson’s Ratio
- Coefficient of Thermal Expansion
- Modulus of Subgrade Reaction Corresponding to CBR

<table>
<thead>
<tr>
<th>CBR Values %</th>
<th>2</th>
<th>3</th>
<th>5</th>
<th>7</th>
<th>10</th>
<th>15</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>K-Value Kg/cm³</td>
<td>2.1</td>
<td>2.8</td>
<td>4.2</td>
<td>4.8</td>
<td>5.5</td>
<td>6.2</td>
<td>6.9</td>
</tr>
</tbody>
</table>
Factors Governing Rigid Pavement Design

\[ A = P \times (1+r)^{n+x} \]

Where
- \( A \) = Design Traffic Intensity (CVPD)
- \( r \) = Rate of Growth of Traffic
- \( n \) = Number of Years between the Last Traffic Counts and the Year of Construction
- \( x \) = Design Life
**Design Procedure**

- Calculate Load Stress at the Edge Region Using Modified Westergaard’s Equation (IRC:58)
- Calculate Residual Strength Which is Given by
  \[(\text{Flexural Strength of Concrete} - \text{Load Stress at the Edge Region})\]
- Calculate Temperature Stress at the Edge Region Using the Equation Given in IRC:58
- Calculate Factor of Safety Which is Given by
  \[(\text{Residual Strength}/\text{Temperature Stress at the Edge Region})\]
Rigid Pavements – Stress Conditions

• Corner Stress
• Edge Stress
• Interior Stress
• Temperature Differential Stress
CALCULATION OF STRESSES

• Edge stress:

\[ \sigma_{le} = 0.529 \frac{P}{h^2} (1 + 0.54\mu)(4 \log_{10} \frac{l}{b} + \log_{10} b - 0.4048) \]

where
\( \sigma_{le} \) = load stress in the edge region, kg/ cm\(^2\)
\( P \) = design wheel load, kg,
\( h \) = pavement slab thickness, cm
\( \mu \) = Poisson’s ratio for concrete
\( E \) = Modulus of elasticity for concrete, kg/ cm\(^2\)
\( k \) = Modulus of subgrade reaction of the pavement foundation, kg/ cm\(^3\)
\( l \) = radius of relative stiffness, cm

\[ \frac{Eh^3}{12(l - h^2)k} = 4 \]

\[ b = 1.6a^2 \times h^2 - 0.675h \]
• Temperature stress

\[ \sigma_{te} = \frac{E \alpha \Delta t}{2c} \]

where

\( \sigma_{te} \) = temperature stress in the edge region,

\( \Delta t \) = maximum temperature differential during day between top and bottom of the slab,

\( \alpha \) = Coefficient of thermal expansion of concrete,

\( E \) = Modulus of elasticity of concrete

\( c \) = bradbury’s constant
• **Corner Stress**

\[
\sigma_{l_e} = \frac{3P}{h^2} \left[1 - \left(\frac{a\sqrt{2}}{l}\right)^{1.2}\right]
\]

where \( \sigma_{l_e} \) = load stress in the corner region, other notations remaining the same as in the case of the edge stress formula.

\( a \) = dependent on load and tyre pressure

\[ a = P \quad \frac{1}{2} \left(\frac{\sqrt{2}}{l}\right) \]

\( p \) = radius of relative stiffness

\[ l = \text{radius of relative stiffness} \]

\[ EG^3 = 4 \sqrt{\frac{12(l - h^2)}{k}} \]
FIG 1: Edge Stresses in Rigid Pavement
(Single axle load = 6 tonnes)
(Tyre Pressure=5kg/cm²)
FIG 2 : Corner Stresses in Rigid Pavement
(Single axle load = 6 tonnes)
(Tyre Pressure=5kg/cm²)
Corner load stress design parameters

\[ P = 5100 \text{ kg}, \quad a = 15 \text{ cm} \]
\[ E = 3 \times 10^4 \text{ kg/cm}^2, \quad \mu = 0.15 \]

\[ k = 30 \text{ kg/cm}^3 \]
\[ k = 15 \]
\[ k = 10 \]
\[ k = 8 \]
\[ k = 6 \]

Corner load stress \( \sigma \) (kg cm\(^{-1}\))

Slab thickness, \( h \) (cm)

Fig. 2. Design chart for calculation of corner load stress
CHART FOR DETERMINATION OF COEFFICIENT C: (Bradbury’s Constant)

<table>
<thead>
<tr>
<th>L/l or W/l</th>
<th>C</th>
<th>L/l or W/l</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.000</td>
<td>7</td>
<td>1.030</td>
</tr>
<tr>
<td>2</td>
<td>0.040</td>
<td>8</td>
<td>1.077</td>
</tr>
<tr>
<td>3</td>
<td>0.175</td>
<td>9</td>
<td>1.080</td>
</tr>
<tr>
<td>4</td>
<td>0.440</td>
<td>10</td>
<td>1.075</td>
</tr>
<tr>
<td>5</td>
<td>0.720</td>
<td>11</td>
<td>1.050</td>
</tr>
<tr>
<td>6</td>
<td>0.920</td>
<td>12</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Where $L =$ slab length ; $W =$ slab width ; $l =$ radius of rel. stiffness

$E I = \frac{E G^3}{4} \frac{1}{12(l-h^2) k}$
FIG. 6: DESIGN CHART FOR CALCULATION OF TEMPERATURE STRESSES

Design parameters:

\[ E = 8 \times 10^3 \text{kg/cm}^2 \]
\[ c = 10 \times 10^4 / \Delta t \text{ C}^{-1} \]

Edge temperature stress (Kgf/cm²) vs. temperature differential (°C)
Design Procedure

• If the Factor of Safety is <1 or Far in Excess of 1, Change the Trial Thickness of Cement Concrete Slab and Repeat the Above Steps

• After Ensuring Sufficient Factor of Safety, Calculate Load Stress for the Corner Region Using the Formula Given in IRC:58

• If the Load Stress at the Corner Region is < Concrete Flexural Strength, Repeat all the Above Steps with Different Design Parameters Otherwise, Finalise the Thickness and Spacings for Implementation
Material Properties

- Cement: 33 grade or 43 grade
- Minimum cement: 350 Kg/m$^3$
- Maximum cement: 425 Kg/m$^3$
- Coarse aggregates:
  - AIV: shall be $< 30\%$ for wearing surfaces
  - LA abrasion value $< 35\%$
- Maximum nominal size: 25 mm
Material Properties

• Water Absorption: 2% maximum
• Fine Aggregates: as per IS: 383
• Concrete Requirements
  – Minimum flexural strength: 45 Kg/cm\(^2\)
  – Required compressive strength: 315 to 360 Kg/m\(^2\)
  – Water cement ratio: 0.5 maximum
DESIGN PROCEDURE

• Step 1 Stipulate design values for the various parameters.

• Step 2 ‘Decide joint spacing and land-widths (vide para 5.1).

• Step 3 Select tentative design thickness of pavement slab.

• Step 4 : Ascertain maximum temperature stress for the critical edge region from Equation (7) or Fig. 3.

• Step 5 : Calculate the residual available strength of concrete for supporting traffic loads.

• Step 6 : Ascertain edge load stress from Equation (4) or Fig. 1~and calculate factor of safety thereon.
DESIGN A CEMENT CONCRETE PAVEMENT

• Data Given:

Traffic Volume : 150 veh/day
Soaked CBR : 4
Wheel load : 5.1 T
Concrete strength
for M 30 : 46.0 kg/cm²
l : 67.33 cm
Corresponding
K value : 3.5 kg/cm² (From table)

Since sub – base is provided k value increased by 20%
K value : 3.5 x 1.2 = 4.2 kg/cm²
Assume slab thickness 15 cm
From graph, edge load stress for $k = 4.2$ is $41.03 \text{ kg/cm}^2$

Temp. Stress:
For $L$ & $W$ assuming $450 \text{ cm} \times 375 \text{ cm}$

\[
\begin{align*}
L & = 450 = 6.68; \\
W & = 375 = 5.57 \\
l & = 67.33 \\
l & = 67.33
\end{align*}
\]
From graph, for \( L = 6.68 \), \( C = 0.995 \) temp diff (Table 4 VI-7)

the temperature difference is 12.50

For \( c = 0.995 \)
\( t = 12.5 \)

Temperature stress \( \sigma t_e = 18.65 \text{ kg/cm}^2 \)

Total stress \( = 41.03 + 18.65 = 59.88 \text{ kg/cm}^2 \)
Hence, not safe \( > 46 \text{ kg/cm}^2 \)

Now assume for 20 Cm thick
edge load stress \( = 26 \text{ km/cm}^2 \)
temp stress \( = 15.64 \text{ kg/cm}^2 \)
Total stress < 46 safe \( = \text{Total 42.25 kg/cm}^2 < 46 \text{ kg/cm}^2 \)
Thank You