Workshop on the Mechanistic Design & Evaluation of Unsealed & Chip-Sealed Pavements

University of Canterbury Workshop
November 2002
Base Course Deformation & Subgrade Failure Criterion

Dr. Vincent Janoo
US Army COE
ERDC/CRREL
Hanover, NH, USA 03755
Mechanistic Design/Process Process

- Pavement Structure
  - Analytical Tools (Multi-layered, FEM)
    - Stress, Strain Displacement
      - Failure Criteria
      - Performance Criteria
    - Load History
      - Material Properties (Elastic, Plastic, Viscous)
        - MET?
          - No
            - Analytical Tools (Multi-layered, FEM)
              - Stress, Strain Displacement
                - Failure Criteria
                - Performance Criteria
          - Yes
            - End
FACTORS AFFECTING FAILURE OF SUB-SURFACE LAYER

• EXCESSIVE LOADING

• SEASONAL FACTORS
  – Change in material properties ($f(\omega)$)
  – Drainage
Failure Criteria

- Subgrade rutting – limiting the strain on top of the subgrade.

- Asphalt fatigue cracking – limiting the tensile strain ($\varepsilon_h$) at bottom of AC layer.
Failure Criteria

• Not aware of base course failure criterion
Subgrade Failure Criteria

- Ottawa, Illinois, USA
- 1956 to 1960
- A – 6 (ML) subgrade
- Test speed – 56 km/hr
- Channelized traffic
- 1,114,000 axle loads applied over ~ 2 year period.
Subgrade Failure Criteria

• PRIMARY
  – Provided data for current AASHTO thickness design.
  – Basis of design – limit loss of serviceability over design life

• SECONDARY
  – Failure criteria for mechanistic pavement design
    (Shell, Asphalt Institute)
Subgrade Failure Criteria

- Subgrade failure criterion
  - Based on one soil, one location
  - Most failure occurred in subbase
  - Most failure occurred during the spring thaw
  - Subbase material properties estimated from CBR
Current Research

Improved Subgrade Failure Criteria for Mechanistic Design

Funded by

- Federal Highway Administration
- State Department of Transportation
  - Pooled Fund Study (17 States)
Frost Effects Research Facility

- 2,700 m² environmentally controlled building.
- Facility is 56 m long by 31 m wide.
- 12 test cells, 6.4 m wide.
  - 8 cells are 7.6 m long and 2.4 m deep.
  - 4 cells are 11.3 m long and 3.7 m deep.
- Cells can be made impermeable to simulate the raising and lowering of the water table.
- Ambient air temperature within the facility can be controlled from -4 °C to 24 °C with a ± 2 °C tolerance.
- The temperature can be further reduced or increased using surface panels (-32 °C to 49 °C).
• Accelerated testing
  – Load (HVS)
  – Climate
• Controlled environments
  – Temperatures: -37 to 49 °C
  – Water table
  – Freeze/thaw (6 cycles/year)
• Full-scale pavement sections
  – Surface course
  – Base and subgrade
• Test basins
  – Flexible, to 30 x 15 x 4 m
• Instrumentation
  – Temperature
  – Moisture
  – Stress
  – Strain
  – Profilometer
75 mm AC

3 m Subgrade
Heavy Vehicle Simulator

Wheel Load .................. 20 – 100 kN roadway  
Up to 200 kN airfield
Test Wheel .................. Single, Dual or Aircraft
Tire Pressure ............... 550 – 757 kPa on roads; 
up to 1450 kPa on airfields
Repetitions/Per Hour ...... 600 (uni-directional)
Trafficked Length .......... Approximately 7 m
Trafficked Width .......... Variable up to 1.5 m
Trafficked Pattern .......... Variable
Power .......................... Electric
LASER PROFILOMETER FOR SURFACE RUT MEASUREMENTS
Instrumentation

Stress Cells
Coil Gages
(Strain)

4” (102 mm) diameter

9” (229 mm) diameter, 200 psi (1379 kPa)
Base Course Failure
Fines were Non-Plastic Modified Proctor

\[ \gamma_d = 2162 \text{ kg/m}^3 \]

\[ \omega = 6 \% \]
LOCATION OF $\varepsilon$MU (STRAIN) GAGES

AC

BASE

SUBGRADE

76 mm

229 mm
Load = 63 kN
Tire Pressure = 746 kPa
TYPICAL STRAIN MEASUREMENT IN BASE COURSE

Load = 63 kN
Tire Pressure = 746 kPa
## TEST DATA

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<thead>
<tr>
<th>Test Section</th>
<th>Subgrade</th>
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<th>Base</th>
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</table>
Load = 79 kN
Tire Pressure = 688 kPa
Load Repetitions

Load = 62 kN
Tire Pressure = 721 kPa

Bottom strains ~ 30-50% of Top
SM subgrade

Permanent Deformation (mm) vs. Load Repetitions

- 80 kN, 690 kPa
- 89 kN, 748 kPa
Permanent Deformation (mm)

- 67 kN, 716 kPa
- 81 kN, 707 kPa
- 63 kN, 746 kPa
- 61 kN, 787 kPa
- 71 kN, 705 kPa

CL subgrade
<table>
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<tr>
<th>Case</th>
<th>Ratio</th>
<th>Stress Reduction Factor</th>
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<tr>
<td>FERF to AASHTO Road</td>
<td>(26/41)</td>
<td>0.63</td>
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<tr>
<td>FERF to State Highway</td>
<td>(19.5/41)</td>
<td>0.48</td>
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</table>

The stress reduction factor can be approximated by the equation:

\[ y = 0.003326 \times x^2 - 0.6126 \times x + 47.3 \]
Vertical Strain (µstrain)

- CL subgrade
  - $y = 256583 x^{-0.363}$

- SM subgrade
  - $y = 8148 x^{-0.236}$

Rut Depth = 25 mm

Speed = 100 km/hour
Conclusions

- We have developed a new subgrade failure criterion as a function of subgrade type.
- Deformation of the base course is a function of the subgrade type.
- Higher percentage of rutting is in the base course.
- Preliminary failure criterion for base course as a function of subgrade type is presented.
ANY QUESTIONS????

[Image of a cracked road]