Pavement Design of Unpaved Roadways

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Overview

- FPInnovations – Who we are
- Introduction to unpaved roads
- Understanding distress and failure modes
- Structural design models
- Maintenance management
- Recommendations
- Conclusions
FPInnovations

We are one of the world’s largest private, not-for-profit, member based forest research and innovation centres

- >500 dedicated employees
- Membership of approximately 210 throughout Canada, including industrial members and government partners
- Partnerships with universities and other institutions
- Forest Operations, Wood Products and Pulp & Paper and Bio products

Strong presence in Alberta, we

- Help forest sector remain globally competitive
- Support economic development, jobs, diversification of communities
- Develop solutions to lower environmental impact of forest industry
- Provide science & technical support for government policy and priorities
- From genomics to market products (cover full value chain)
Introduction – Unpaved Resource Roads

- Are they really low-volume roads?
- Traffic volume can range from 50 to >1000 ADT
- Loads can range from 57 t to >150 t

Source: R. Douglas 1988
Introduction – Unpaved Resource Roads

- Often built from native “in-situ” or backfill materials
  - Subgrade and often base layers
- Quality control and QA not always rigorous
- Material specifications not always well understood and implemented
- Structural design rarely used
  - Rely on engineering judgment and trial/error
- Routine maintenance (grading) plays a key role on road performance and user satisfaction
- Geological context not well understood
Most Common Distresses
Dust

Causes
- Lack of fines (binder)
- Prolonged dry conditions
- Excessive winter sanding

Solutions
- Aim for fines content of 10 to 15% in the wearing course aggregate
- Plastic fines are needed
- Dust palliatives
Most Common Distresses
Corrugation (washboard)

Causes
- Lack of fines (binder)
- Acceleration zones
- Steep grades
- Trailer hop
- Air suspensions

Solutions
- Aim for fines content of 10 to 15% in the wearing course aggregate
- Plastic fines are needed
- Dust palliatives
Most Common Distresses

Loose material (raveling)

Causes

- Lack of fines (binder)
- Coarse material
- Sharp curves
- Grading when surface is too dry

Solutions

- Aim for fines content of 10 to 15% in the wearing course aggregate
- Plastic fines are needed
- Top diameter <25 mm
Most Common Distresses

Potholes

Causes

- Poor drainage (crown)
- Loose wearing course material
- Accumulation of water in ruts and corrugation
- Excessive moisture

Solutions

- Maintain crown at 4 to 6%
- Offer training for grader operators
- Slope meter in graders
Most Common Distresses

Ruts – Structural failure mode

Causes

- Inadequate aggregate thickness
- Poor subgrade soils
- High moisture levels
- Heavy axle loads

Solutions

- Review thickness design for desired traffic levels and axle loads
- Consider thicker aggregate layers
- Consider subgrade stabilization
- Consider subgrade/base geotextile separation/reinforcement
Designing Unpaved Roads

Structural design

- Appropriate layer thickness and materials capable of carrying imposed axial loads (base and sub-base layer) and minimizing the vertical pressure (strains) on the subgrade layer

Functional design

- Surfacing layer (wearing course) that provides a safe, smooth, workable and dust free “pavement” surface
Structural Design

- Thickness design

Axle loading

Wearing course
Base course
Sub-base
In-situ or backfill subgrade soils
Modes of rutting – Mode 0

- Post-compaction of non-saturated materials
- Mechanical compaction can reduce/eliminate this mode
- Compaction causes the material to stiffen and spread the load; reducing stress and rutting at subgrade layer

Modes of rutting – Mode 1

- Local shear close to wheel gives rise to heave adjacent to wheel path
- Caused by inadequate sheer strength in the aggregate
- No deformation at the subgrade
- Remedy is to improve aggregate quality and/or reduce tire pressure and axle loading
Modes of rutting – Mode 2

- The “pavement” as a whole is rutting
- Shear deformation within the subgrade with the granular layer following the subgrade
- Solution is to improve or thicken the aggregate so that the wheel loads are spread. Stress on the subgrade would be reduced
- Another solution is to reinforce the base/subgrade materials
Three Potential Structural Design Models

- AASHTO aggregate-surfaced roads (rut depth failure mode)
  - Design charts
  - Design catalogue
- USDA-Forest Service STP (Surface Thickness Program - rut depth failure mode)
- Critical Strain Method (CSM) developed for heavy trucks on mine roads
AASHTO (Design charts)
AASHTO Guide for Design of Pavement Structures, 1993

Inputs:
- Traffic ESALs
- Subgrade resilient modulus (Mr)
- Base and sub-base modulus (E)
- Design serviceability (PSI)
- Allowable rut depth (mm)
- Aggregate loss (mm)
AASHTO (Design charts)

- Nomographs are not user-friendly!
- Limited to a maximum of 400,000 ESALs
- Use aggregate loss equations with caution

- Output: Aggregate base thickness that can be converted to a sub-base
AASHTO (Design catalogue)

- Developed based on design charts
- 3 traffic levels (low, medium, high) = ranges of ESALs
- 5 roadbed soil qualities (very poor to very good)
- 6 U.S. Climatic regions (empirical data that can be implemented depending on the environment)
- Assumes good quality aggregate base course

➢ Output: Aggregate base thicknesses table
USDA-FS (Surface Thickness Program - STP)
USDA-Forest Service, 1996. Earth & aggregate surfacing design guide for LVRs

Inputs

- Traffic ESWLs
- Tire pressure
- Subgrade CBR
- Base CBR
- Terminal serviceability (allowable rut depth)
- Reliability factor

Output: Aggregate base thickness
Critical Strain Method (CSM)

Criteria: Vertical strain < Critical strain limit of materials

- Resilient modulus of each layer
- Choose layer thickness and calculate strain bulbs using a FEM – then adjust thicknesses
- Empirical equation developed for heavy loading conditions

\[ \varepsilon_{\text{max}} = 80,000/N^{0.27} \]

\( \varepsilon_{\text{max}} \) = limiting vertical strain (range of 1500 to 2000 micro-strains)
N = number of passes of the design axle load during road’s life
## Summary of Design Models

<table>
<thead>
<tr>
<th></th>
<th>AASHTO</th>
<th>STP</th>
<th>CSM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum ESALs</strong></td>
<td>400,000</td>
<td>70,000</td>
<td>n.a.</td>
</tr>
<tr>
<td><strong>Layers</strong></td>
<td>3</td>
<td>2</td>
<td>Multiple</td>
</tr>
<tr>
<td><strong>Design inputs</strong></td>
<td>Mr, E</td>
<td>CBR</td>
<td>Mr, E</td>
</tr>
<tr>
<td><strong>Failure mode</strong></td>
<td>Rut depth</td>
<td>Rut depth</td>
<td>Critical strains</td>
</tr>
<tr>
<td><strong>Design tool (software)</strong></td>
<td>Nomographs</td>
<td>DOS-based Excel</td>
<td>FEM needed</td>
</tr>
<tr>
<td><strong>Design technique</strong></td>
<td>Empirical</td>
<td>Empirical</td>
<td>Mechanistic</td>
</tr>
<tr>
<td><strong>Recommended for</strong></td>
<td>LVRs</td>
<td>Very LVRs</td>
<td>Mine haul roads, Very heavy trucks</td>
</tr>
</tbody>
</table>

**AASHTO STP CSM**

- **Maximum ESALs**: 400,000, 70,000, n.a.
- **Layers**: 3, 2, Multiple
- **Design inputs**: Mr, E, CBR, Mr, E
- **Failure mode**: Rut depth, Rut depth, Critical strains
- **Design tool (software)**: Nomographs, DOS-based Excel, FEM needed
- **Design technique**: Empirical, Empirical, Mechanistic
- **Recommended for**: LVRs, Very LVRs, Mine haul roads, Very heavy trucks
Challenges with Design Models

- No “off-the-shelf” software available
- Some software are offered by geosynthetic manufacturers
- Difficult to design for a long period given limitations of total ESALs (AASHTO and STP)
- None of the models take into account the impact of routine grading on rut development
- None of the models consider the impact of dust control on surface deterioration
Instruments for Field Measurements

- **Dynamic Cone Penetrometer (DCP)**
  - Profile of penetration resistance up to 1 m deep
  - Correlate to CBR

- **Clegg Impact Soil Tester (Clegg Hammer)**
  - Limited to top 150 mm
  - Correlate to CBR

- **LWD**
  - Modulus ($E_0$ and $M_r$) and deflection
Functional Design –
Recommended Material Specifications

Légère and Mercier, 2013
Paige-Green, 1989

\[ G_c = \frac{(P25 \text{ mm} - P2.36 \text{ mm}) \times P4.75 \text{ mm}}{100} \]

\[ S_p = (PI \times 0.5) \times P0.425 \text{ mm} \]
Functional Design – Aggregate Loss

- Surface aggregate wear is typically around 1-inch per year for high traffic roads
- AASHTO equation:

\[
GL = 0.12 + 0.1223 \times LT
\]

Where: \( GL \) = Gravel loss (inches)

\( LT \) = number of loaded trucks/1000

Example: 7000 trips = 1 inch

- Dust control / surface stabilization will significantly prolong aggregate life
Example of average road surface condition over time (between gradings)
Maintenance Management: FPInnovations’ FPDat Grader

- On-board datalogger for graders
- Machine performance (hours, fuel, specific machine activities, etc.)
- Sensor that detects blade up/down
- Navigation
- KPI display and production data
Centralized Data Hosting
Design Recommendations

- Choose a model that most closely matches your traffic volumes and loading
- Top “wearing course” layer (100 mm) should not be considered as a structural layer
- Aggregate loss must be considered
- Winter traffic volumes *may* be excluded from the total ESALs calculations
- Significant damage can be caused during spring thaw
Design Recommendations

- For heavy off-highway traffic (e.g., mining) consider using a strain-based approach
- A design catalogue may be appropriate for some jurisdictions
- Consider using reinforcement (geosynthetics) and/or stabilization for weak soils and/or to reduce aggregate thickness
- Dust palliatives can reduce maintenance costs, prolong aggregate life and improve safety
Conclusions

- Surface distress and failure modes are different from paved roads
- Structural design models exist but have limitations
- Seasonal impacts must be considered
- Selection of materials and QA/QC is important
- Maintenance management is important and tools are available
It’s all pretty simple in the end!
Thank you!

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