Road pavements

Pavement failures
Themes of lecture

• Failure types of pavements
• Different types of rutting and cracking
• Causes of failures
• PSI – Present Serviceability Index
Pavement failures

Road deterioration:
- Slow process
- Last over many years

Failure types:
- Structural
- Non-structural

Main structural failures:
- Fatigue cracking
- Rutting

Serviceability – performance concept:
Carey & Irick, 1960, AASHO Road Test, 1962

End of pavement life: at acceptable level of serviceability
Serviceability – Performance Concept

Carey, Irick, 1960

Serviceability

New pavement

Failed pavement

Minimum level of performance

Number of ESAL passes or time

Design period (lifetime)

2.5
Serviceability – Performance Concept

Present Serviceability Index - PSI

- Rating the particular pavement-vehicle-human interaction for a particular speed

- Rating the surface appearance: cracking, patching, colour, shoulder condition, etc. …

0-1: Very Poor
1-2: Poor
2-3: Fair
3-4: Good
4-5: Very Good
Present Serviceability Index - PSI

Road characteristics are **objectively** measured

User’s **subjective** rating

Both are in correlation with **PSI**
Present Serviceability Index - PSI

FLEXIBLE PAVEMENT:

\[ PSI = 5.03 - 1.91 \cdot \log(1 + SV) - 1.38 \cdot RD^2 - 0.01 \cdot \sqrt{C + P} \]

RIGID PAVEMENT:

\[ PSI = 5.41 - 1.80 \cdot \log(1 + SV) - 0.09 \cdot \sqrt{C + P} \]

SV – slope of variance measured by Roughmeter
C – cracking (ft - feet)
P – patching (ft² – feet²)
RD – rut depth (inch)
Present Serviceability Index - PSI

YODER, WITZAK, 1975

FLEXIBLE PAVEMENT:

\[ \text{PSI} = 4.29 - 0.40 \cdot \sqrt{SV} \]

RIGID PAVEMENT:

\[ \text{PSI} = 4.81 - 0.47 \cdot \sqrt{SV} \]

SV – slope of variance measured
Design lifetimes

Determined by Pavement Management System (PMS)

t – pavement design lifetime (years)

**Asphalt pavements**
- motorways: 20 years
- major roads: 15 years
- minor roads: 10 years
- long-life pavements: 40 years

**Portland Cement Concrete (PCC) pavements**
- motorways: 40 years
- major roads: 30 years
Structural failures

**RUTTING:** Accumulated vertical permanent deformation due to the traffic loading

- **Structural rutting:** occurs due to vertical accumulated permanent deformations lower in the structure/subgrade
- **Non-structural rutting:** extends only to bituminous layers

**FATIGUE CRACKING:** Load associated fatigue
Structural failures

Road pavements
Each load pulse results in a small irrecoverable deformation. The permanent deformation increases by the cumulative effect of traffic.
Rutting

Each load pulse results in a small irrecoverable deformation. The permanent deformation increases by the cumulative effect of traffic.
Non-structural rutting

Narrow, deep with high „shoulders”

Restricted to bituminous layers
Non-structural rutting

Narrow, deep with high "shoulders"

Restricted to bituminous layers

Road pavements
Non-structural rutting

**Causes:**

- High *pavement temperature* during summer (above +50°C)
- Heavy wheel loads
- High tire pressures, super single tires
- Inadequate bituminous mixtures:
  - Low stiffness
  - High bitumen content
  - Bitumen viscosity is not suitable
  - Aggregate grading: high fines content
  - Aggregate quality problems

Construction mistakes: low degree of density, high air void content, mix segregation etc…
Structural rutting

Subgrade permanent deformation

Road pavements
Load associated fatigue

**Developing** due to tensile stress / strain repetitions caused by traffic loads.

**Crack initiation:** mostly at the bottom of the asphalt layer, the modulus is decreasing.

Crack propagation: from bottom to upward (top cracking)

Generally begins in the wheel path

**Pattern:** alligator cracking (chicken wire cracking)

**Criterion** for fatigue failure:

- 35-45% cracked area in the wheel path
- or 20-30% of entire pavement area is cracked
Load associated fatigue

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Edge fatigue cracks

Due to weak underlying support at the edge

**Pattern:** crescent shaped or fairly continuous with intersect of pavement edge

**Causes:** Weak lateral support of pavement edge

- Base / subbase weakness due to frost action or drainage defects
- Shoulder inadequate drainage
Edge fatigue cracks

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Causes:
- Weak lateral support of pavement edge
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Road pavements
Thermal cracking

Especially in the CTB (cement treated base) and concrete base

**Cause:** significant drop in temperature (low temperature cracking)

The thermal stress is greater than the fractural strength of the material

**Thermal fatigue cracking:** repeated low temperature (high stresses) and high temperature (low stress) cycle

The tensile strength of bituminous mixtures depend on temperature!

**Pattern:** transverse cracking occurs in regular intervals

Thermal cracking of asphalt layers: mostly occurs in countries with cold climate
Thermal cracking

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Road pavements
Reflection cracking

Cracks in CTB (cement treated base) „reflect” through the asphalt layer above

CTB layers are pre-cracked to control crack movement and delay reflection cracking
Reflection cracking mechanism

HMA overlay

Existing layer

Sub-base

Crack growth

Thermal expansion and contraction

Thermally induced fatigue

Crack growth

Traffic induced fatigue

Traffic movement

Thermal contraction

Crack growth

Warping

Temperature gradient giving greater contraction at surface

Surface initiated cracking

Road pavements
Inverted pavement

Delays reflection cracking

The lower base course has a good bearing capacity: small deflection

Good quality crushed stone layer modulus: 400-500 MPa

Thin granular layer: cannot relieve stresses during crack propagation

Thick granular layer: expensive
Longitudinal top-down cracking

**Pattern:** top-down longitudinal cracking at the surface in the wheel path near the wheel edge
it is a failure of surface mixture
should be sealed to avoid ingress of water

**Cause:** load induced excessive surface tensile and shear stresses near the wheel edge (truck tires, super single)
thermal lateral tensile stresses
mechanical and thermal stresses are summarized
poor mix quality (inadequate density, binder quality, mix segregation)
Longitudinal top-down cracking

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- Thermal lateral tensile stresses
- Mechanical and thermal stresses
- Poor mix quality (inadequate density, binder quality, mix segregation)
Super single tires

Road pavements
## Longitudinal top-down cracking

### Arand, Lorenzl, 1995  Lorenzl, 1996

<table>
<thead>
<tr>
<th></th>
<th>Keréknyomban a kerék alatt</th>
<th>Behajlás medence peremén</th>
<th>$R = 0.5 - 0.9$ m</th>
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</thead>
<tbody>
<tr>
<td><strong>(1)</strong> Termikus (kirogén) húzó-feszültség $\sigma_h(T)$ [MPa]</td>
<td><img src="image1" alt="Diagram" /></td>
<td><img src="image2" alt="Diagram" /></td>
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<td><strong>(2)</strong> Forgalmi terhelésből származó hajlító húzó-feszültség $\sigma_h(V)$ [MPa]</td>
<td><img src="image3" alt="Diagram" /></td>
<td><img src="image4" alt="Diagram" /></td>
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<tr>
<td><strong>(3)</strong> Húzó-feszültségek szuper-pozíciója $\sigma_h(T) + \sigma_h(V)$ [MPa]</td>
<td><img src="image5" alt="Diagram" /></td>
<td><img src="image6" alt="Diagram" /></td>
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Thank you for your attention!

Any question?