Longitudinal Profile Irregularities

Pavement irregularities ranges...

... and their corresponding features.
0. Unevenness | Roughness Characterization. IRI:

Sample Profile:

IRI\textsubscript{20}:

IRI Calculation: Dynamic Response of the Golden Car moving at 80 km/h aggregated at given intervals (20 m, 100 m, 1 km,...)
1. Spectrum Analysis. Fourier Transform and PSD:

Sample Profile:

Profile Spectrum:

Consider Profile as a sum of sines

\[ y = f(x) \approx \sum A_i \cdot \sin(\lambda_i \cdot x) \]
1. Spectrum Analysis. Fourier Transform and PSD:

**Sample Profile:**

![Profile Graph]

**Power Spectral Density:** Calculate the distribution of the energy of the unevenness on the profile in terms of m/cycle.

![Spectral Density Graph]
2. Profile Decomposition using digital filters:

Sample Profile: \( \lambda_1 \) \( \lambda_2 \) \( \lambda_3 \) ...

wavelengths \( \lambda_1 > \lambda_2 > \lambda_3 > ... \)
3. Wavelet Transform:

Sample Profile:

Waveform: Daubechies_3

Correlation with a pattern (waveform) with a scale factor $a_i$ along the profile

Scale Factor $a_1$:

Scale Factor $a_2$:
Different analysis, different results:

0. Dynamic Response of a defined system:
- Position Information: YES
- Frequency Information: NO
  - IRI: Accumulate Response of the dynamic system vs. position

1. Spectrum Analysis:
- Position Information: NO
- Frequency Information: YES
  - Fourier Transform: Amplitude vs. wavelength
  - PSD: Energy vs. wavelength

2. Profile Decomposition:
- Position Information: YES
- Frequency Information: YES
  - Filtered Profile: Amplitude vs. Position. Each filtered profile is related with a wavelength range

3. Wavelet Transform:
- Position Information: YES
- Frequency Information: YES
  - Transformed Profile: Amplitude vs. Position. Each transformed profile is related with a wavelength value or range
Sample of a concrete slabs spectrum analysis

- Objective of the presentation
  - Show the use of singular techniques in order to analyze a singular "pavement"

- Tunnel made by a Tunnel Boring Machine

- Pavement characteristics
  - Continuous series of transversal beams
  - Gaps between beams filled on site
  - Bituminous pavement extended on top of beams
Schematic of pavement longitudinal section

- Base layer made of concrete slabs

Portorož, Slovenia
Methodology for the analysis

- Estimation of the theoretic profile of the base layer
- Collection of the real concrete base layer profile
  - Laser profiler
- Comparison of the base profiles (theoretic and real)
  - Spectrum analysis
- Control of the evolution of the profile during the works to verify the lamination of the irregularities through the extension of the bituminous layers
  - Laser profiler
  - Spectrum analysis
- Spectrum analysis can be used because the pavement has a continuous and repetitive characteristic that appears every 1.20 meters (during the full tunnel section over 2 km)
Theoretic profile

- **Steps**
  - Every 90 cm one step 30 cm long
  - Height of steps: 3 cm
  - Obtained profile provides an IRI similar to that of the real concrete profile

- **Spectrum**
  - Peaks at: 0.24, 0.40, 0.60 and 1.20 meters wavelengths
Real base concrete profile

- Continuous concrete base layer

- On the spectrum of the profile the following wavelengths appear:
  - 0.30 meters
  - 0.41 meters
  - 0.61 meters
  - 1.22 meters
  - 2.03 meters

- Other irregularities from the real concrete base appear although the peaks at those wavelength are predominant
Ways of solution

- Proceed with grinding works in order to improve the quality of the base layer
- Place several thin asphalt layers to reduce the effect of the irregular base layer
  - Verify the improvement made by those thin layers
- Solution adopted
  - THIN LAYERS
The profiles obtained during the works

- Obtained with a laser profiler for every layer
  - Base
  - Binder
  - Surface
The effect of the bituminous layers

- Spectrum analysis of the three layers (base, binder and surface)
  - **Binder**
    - Almost eliminates all the peaks (only 1.22 meters peak stays)
  - **Surface**
    - Removes the remaining peak values produced by the base structure
Summary of results

- It has been shown that the effect of the base layer irregularities has been removed by the thin asphalt layers.
- There remain irregularities that still provide roughness (IRI).

<table>
<thead>
<tr>
<th>Wavelength (meters)</th>
<th>Elevation spectral density (m²-m/cycle)</th>
<th>Elevation spectral density referenced to concrete layer elevation spectral density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SURFACE</td>
<td>BINDER</td>
</tr>
<tr>
<td>0.30</td>
<td>3.151E-08</td>
<td>7.436E-08</td>
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<tr>
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<td>1.9%</td>
<td>4.4%</td>
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<tr>
<td>0.41</td>
<td>3.429E-08</td>
<td>1.590E-07</td>
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<tr>
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<td>4.3%</td>
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<tr>
<td>0.61</td>
<td>6.201E-08</td>
<td>3.985E-07</td>
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<td>0.6%</td>
<td>3.6%</td>
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<tr>
<td>1.22</td>
<td>5.109E-07</td>
<td>1.619E-05</td>
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<tr>
<td></td>
<td>1.2%</td>
<td>37.0%</td>
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</tbody>
</table>

Layer | Average IRI (mm/m) |
-------|-------------------|
SURFACE | 2.26 |
BINDER | 3.58 |
BASE | 17.04 |
Conclusions:

- IRI is a good index to survey the roads Unevenness and Roughness. It can be used for a Network level study. High IRI values can indicate some localized problems.

- There exist several tools for the advanced analysis of road profiles. Each procedure brings up different information about the profile.

- The application of this analysis is not easily applicable to a Network level, but it is useful for specific sections.