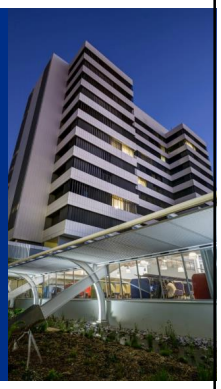
SARF
RIDING QUALITY
COURSE



5 November 2015

Contents

- 8:00 to 9:00
  Introduction to road riding quality
  Definitions and concepts involved in riding quality
- **9:00 to 10:00**
  Measuring riding quality
- 10:30 to 12:30
  Analysing riding quality data
- 13:30 to 15:00
  Interpreting riding quality data
  Riding quality and Vehicle-Pavement Interaction
- 15:30 to 16:30
  Effects of riding quality on road users and costs

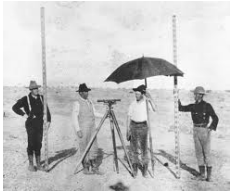
Measuring riding quality

Measurement principles

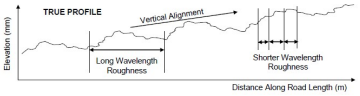
- Road profile
- Response type Road Roughness Measurements

Road profiles

- Rod and level
- Dipstick
- Profilers



Road profiles



- Two-dimensional slice of the road surface, taken along an imaginary line
- Shows the design grade, roughness, and texture
- Width of the line is not standard
- Profiler
  - instrument used to produce a series of numbers related in a well-defined way to a true profile
  - works by combining three ingredients
    - reference elevation
    - height relative to reference
    - longitudinal distance

What Can You Do With Profiles

- Four broad categories of profiler applications
  - To monitor condition of road network for pavement management systems
  - To evaluate quality of newly constructed or repaired sections
  - To diagnose condition of specific sites and determine appropriate remedies
  - To study the condition of specific sites for research

Profiles

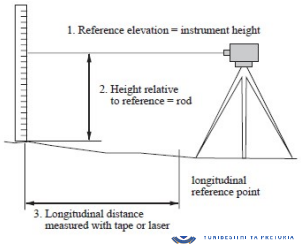
- True profile contains more information than we can use
- Profiler is valid if it provides the same statistical values that would be obtained from the true profile
- Statistics from two or more valid profilers are directly comparable, with no conversion required
- Statistics from valid profilers are stable over time
- No single device is the best reference for every use - validity of profiler depends on its intended use

Static profilers

- Rod and level measurements
- Dipstick
- Walking profilometer

Static profilers - Rod and level measurements

- Elevation measures at close intervals of 300 mm or less
- Height measures 0.5 mm or less



Static profilers - Dipstick

- Can be used to collect relatively small quantity of pavement profile measurements
- Consists of an inclinometer enclosed in a case supported by two legs separated by 305 mm
- Operator “walks” dipstick down a premarked pavement section by alternately pivoting the instrument about each leg
- Readings recorded sequentially as operator traverses section
- Device records 10 to 15 readings per minute
- Software analysis provides profile accurate to ± 0.127 mm

[redacted]

IRI Dipstick issues

- Variations between path followed by profiler and Dipstick path
- Features recorded by profiler that Dipstick missed because of differences in sampling intervals
- Discrepancies caused when footpads of the Dipstick bridge over narrow, downward features that are measured by the profiler
- Features that are recorded by profiler but are underestimated by Dipstick because footpad of device may not rest in deepest part of a feature

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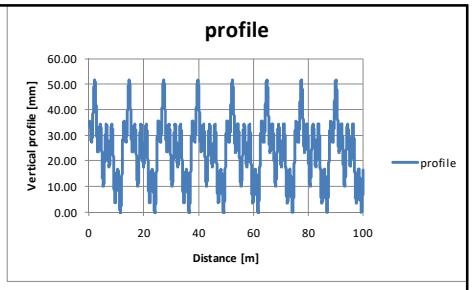
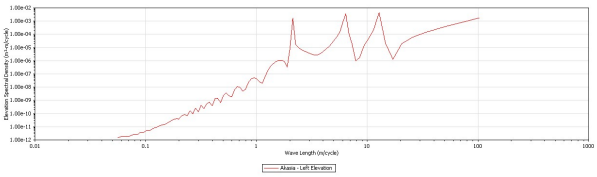
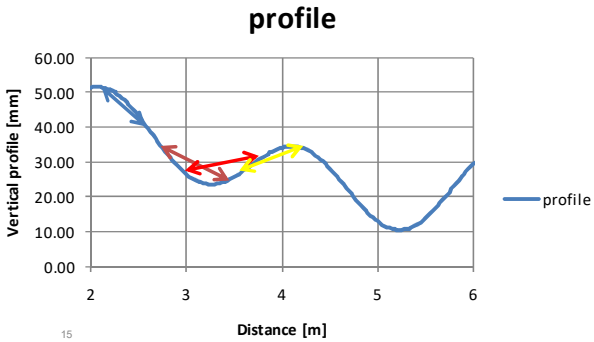
Example

IRI 30.07 m/km

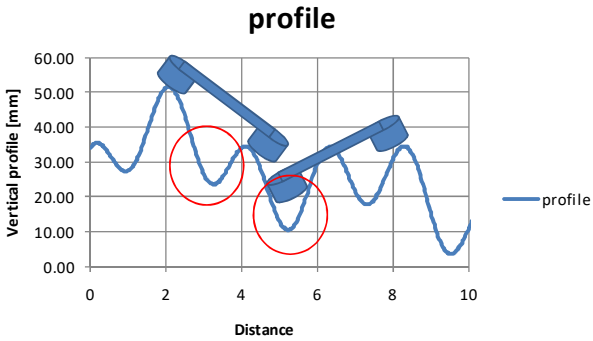




Example Dipstick



Example Dipstick



Static profilers –Profilometers / Profilographs

- Profilographs available for many years
- Exist in variety of different forms, configurations brands
- Not practical for network condition surveys
- Most common use for rigid pavement construction inspection, quality control, and acceptance
- Sensing wheel, mounted to provide for free vertical movement at the center of the frame
- Deviation against a reference plane, established from the profilograph frame recorded on graph paper from motion of sensing wheel
- Can detect very slight surface deviations or undulations up to about 6 m in length

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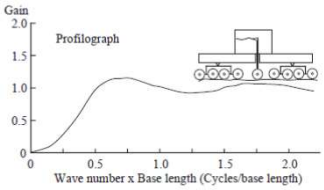
Static profilers –Profilometers / Profilographs



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Dynamic profilometer

- Various available
- Laser measurement of profile with acceleration measurements
- Decide on detail required for evaluation, number of lasers etc.

Dynamic profilometer

- Inertial reference provided by accelerometer
- Data processing algorithms convert vertical acceleration measure to inertial reference that defines instant height of accelerometer in host vehicle
- Height of ground relative to reference is distance between accelerometer and the ground directly under the accelerometer
- Measured with a non-contact sensor such as laser transducer
- Longitudinal distance picked up from vehicle speedometer

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Response Type Road Roughness Measurement

- Adequate for routine monitoring of pavement network and providing an overall picture of condition of the network
- Output can provide managers with general indication of overall network condition and maintenance needs
- Measure vertical movements of rear axle of vehicle relative to vehicle frame
- Installed in vehicles with a displacement transducer on body located between middle of axle and body of a passenger car or trailer
- Transducer detects small increments of axle movement relative to vehicle body
- Output data - actual axle body movement versus time of travel

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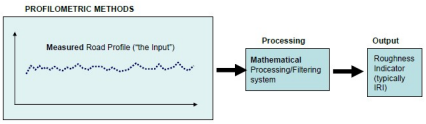
Response Type Road Roughness Measurement

- Disadvantage
  - measured axle body movement vs. time depends on dynamics of the particular measurement vehicle
  - not been stable with time
  - not been transportable
- Because of these two effects, profiling devices are becoming more popular



Response Type Road Roughness Measurement

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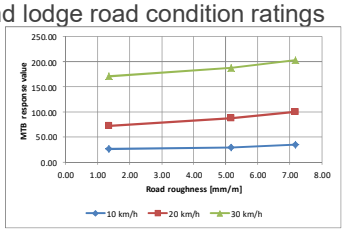
Response Type Road Roughness Measurement

- Specific applications
- Mountain bike and lodge road condition ratings



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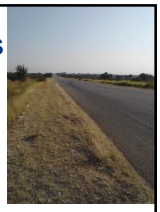
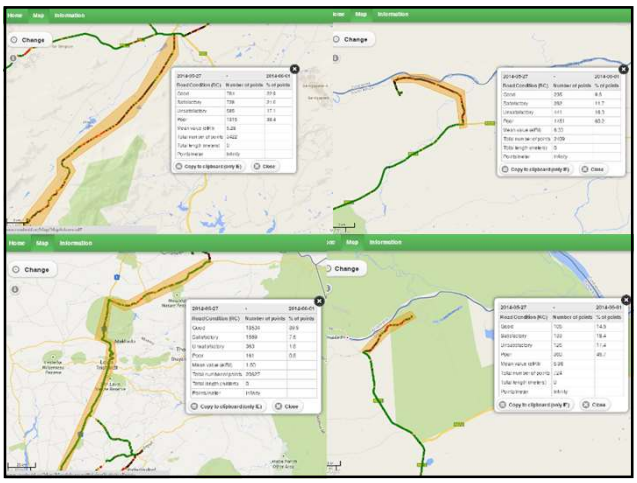
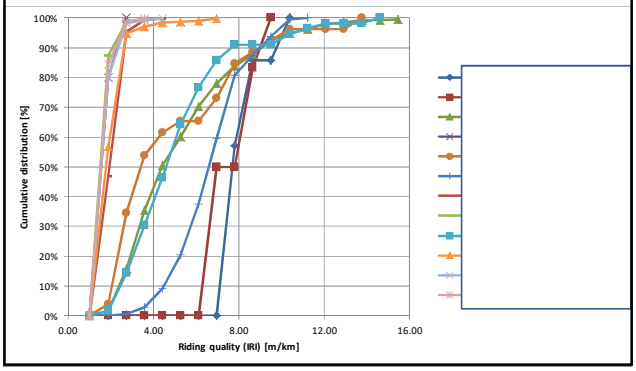
Response Type Road Roughness Measurement - Roadroid



- Local evaluation of App
- Evaluate effects of
  - vehicle type (hatchback and LDV)
  - vehicle load (driver and +100 kg)
  - tyre inflation pressure (100% and 80%)
  - Speed (40, 60, 80 km/h)
- Samsung Galaxy S3 with RoadRoid app
- Profilometer-based IRI
- 2 local rural roads

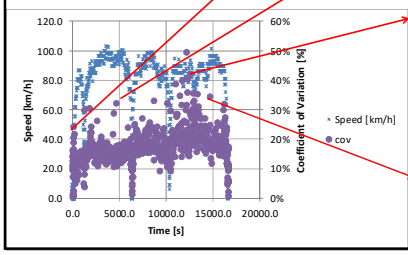


Road roughness analysis



Vehicle accelerometer-based data

SATC paper Monday



Spectral analysis

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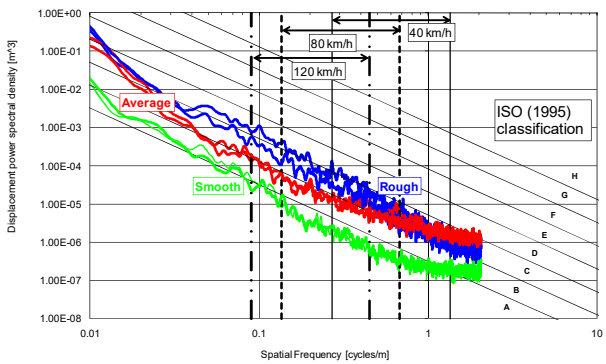
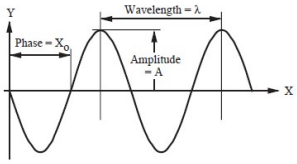
ISO classification



Wave analysis



- Sine and cosine waves are both called sinusoids
- Defined by a wavelength, amplitude, and phase
- Wave number - number of cycles per unit length
- Takes at least two samples per cycle to "see" a sinusoid

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Frequency response

- Useful way to describe input/output behaviour
- Linear system - output proportional to input
- Sinusoidal input to linear system causes sinusoidal output with same wavelength
- Frequency response plot shows ratio of output to input for a sinusoid
- Output can be completely defined by amplitude and phase

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Frequency response

- Amplitude frequency response plot shows ratio of output amplitude to input amplitude
- Amplitude ratio is called gain

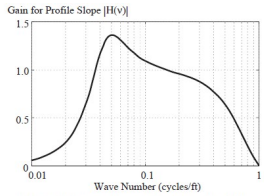

Figure 7. Wave-number response of the quarter-car filter for PI.

Power Spectral Density (PSD) analysis

- Typical road profile has no direct resemblance to a pure sinusoid
- Encompasses a spectrum of sinusoidal wavelengths
- PSD function - statistical representation of importance of various wave numbers
- Profiles can be decomposed into a series of sinusoids
- Mathematical transform exists that computes amplitudes of sinusoids that could be added together to construct profile - Fourier transform
- Fourier transform can be scaled such that it shows how variance of profile is "spread out" over set of sinusoids - PSD function
- PSD function shows how variance is distributed over wave number

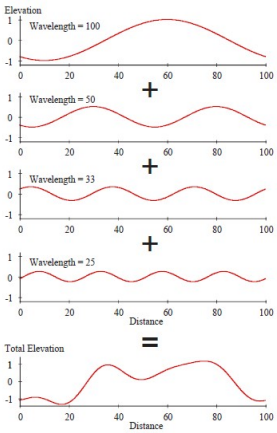

Figure 15. Mathematical construction of a profile from sinusoids.

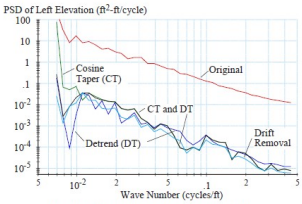

Figure 17. Effects of various profile conditioning methods.

Measurement errors

- Profiler operation
- Features of a valid profiler
- Sources of variation
- Common measurement errors
  - Extraneous spikes
  - Surface texture
  - Missing accelerometer signal

Error background

- Accuracy is a lack of error
- The smaller the error, the better the accuracy
- Repeatability is the ability to obtain repeat measures with the same instrument at (nearly) the same time
  - defined by the variation of the profile indices taken for each run
  - characterize through standard deviation of measurements (units match those of index)
  - does not affect mean value obtained with a profiler
  - network condition - repeatability probably not of great concern
  - newly built or repaired roads, (bonus penalty schemes) repeatability assumes greater importance

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Error background

- Reproducibility is ability to repeat measures with a different profiler of same basic design
- Conduct measures on a set of test sites, taking repeat measures with both instruments on each site
  - number of repeats that should be taken depends on repeatability of instruments and testing methodology
  - reproducibility is not of as much interest as portability
- Portability is ability to repeat measures with completely different profiler designs
  - standard for portability - true profile
- Accepted method for establishing that profiler is valid for measuring an index - test against static method (rod and level or Dipstick)

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Causes of profiling error

- Profiling involves
  - User
  - Profiler
  - Road
- Errors caused by
  - User
  - Profiler
  - Road

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Causes of profiling error

- Errors caused by
  - User
- Profiling different line – different true profile
  - two variables locate line being profiled
    - longitudinal starting position
    - lateral position

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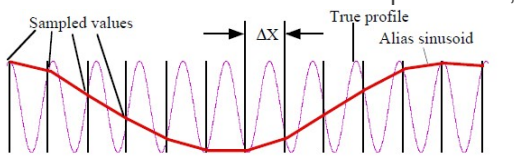
Causes of profiling error

- Errors caused by
  - Profiler
- Valid measurement of profile requires that all parts of system function correctly
  - Accelerometer
  - height sensor
  - speed sensor
  - power supplies
  - electronic signal conditioning
  - analog-to-digital converter
  - Computer
- Each part of the process involves some error

Causes of profiling error

- Errors caused by
  - Profiler
- Aliasing
  - interaction between choice of sample interval,



Causes of profiling error

- Errors caused by
  - Road
- True profile may change with time
  - PCC slab change daily in response to heating and cooling (slab curl)
  - IRI changes of 20 per cent observed
  - Seasonal changes
    - ground moisture
  - Traffic effects
  - Aggregate loss
  - Etc
- Variations due to changes in true profile not errors
- Profiler captures current profile

Surfacing related errors

- Texture involves variations that occur over short distances that involve wavelengths of several inches or less
  - Wavelengths outside range of interest for most profile analyses
    - affect performance of some instruments
  - Aliasing
  - Absorbing / inadequate reflection of ultrasonic or laser measurements
- Cracks do not directly affect vehicle dynamics
  - affect roughness indices
  - laser image inside crack

How Accurate Should a Profile Be?

- Required profiler accuracy depends on application
- Network monitoring requires high measurement efficiency
  - time significant constraint
  - random errors in measurement average out for individual sections of road and do not affect the big picture
- Diagnostic applications require accuracy and inspection of profiles
  - may be desirable to show properties of road on scale such that trouble spots can be located to within 10 or 20 meters
  - accuracy of greater concern for diagnostic applications
  - measures not just for statistical data base - describe exact condition of a particular section of pavement

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Profile classes

- Different classes of profiling methods defined
- Indicate accuracy of a profiler
- Class 1 instrument must be so accurate that random error is negligible
  - IRI usually within 2% of the truth

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Profile classes

Device class	Class requirements / characteristics
Class 1 – Precision profiles	Highest standard of accuracy Requires precision measurement and computation 2% accuracy over 320 m Repeatability of 0.3 m/km (paved), 0.5 m/km (all road types)
Class 2 – Non-precision profiles	Requires measurement and computation Includes devices not capable of Class 1 accuracy
Class 3 – IRI estimates from correlations	No profile measurement required All response type devices Calibrated through correlation outputs with specific road sections
Class 4 – Subjective ratings and uncalibrated devices	Includes subjective ratings Includes devices for non-calibrated response and profilometric measurements

Accuracy requirements

Device class	Max logitudinal sampling interval [mm]	Vertical resolution [mm]
Class 1 – Precision profiles	< 25	≤ 0.1
Class 2 – Non-precision profiles	25 < and ≤ 150	0.1 < and ≤ 0.2
Class 3 – IRI estimates from correlations	150 < and ≤ 300	0.2 < and ≤ 0.5
Class 4 – Subjective ratings and uncalibrated devices	> 300	> 0.5