Track Stiffness Measurements and Applications

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Background

• Experience
  – Founder of EBER Dynamics. 2011 --
  – Former technical responsible of track measurements at Banverket. 1996 - 2010
  – PhD within track stiffness. 2009
What is vertical track stiffness?

Applied force / track deflection

How much do the rail deflect during a train passage?

– Normal deflection on a new track: 0.5 – 4 mm
Obvious example of hanging sleepers
Which parts contribute to deflection?
How is track stiffness built up?

Illustration from Selig & Waters 1994
Track stiffness – complex area

Track stiffness varies with:
– Preload, frequency, dynamic amplitude and position along the track
Motive for track stiffness measurements:

• **Complement to track geometry measurements**
  – Early indications of degradation, better maintenance planning
  – Hanging sleepers, high sleeper/ballast forces, large rail bending moments (rail-crack-propagation etc)

• **Geotechnical characterization**
  – Stiff/soft tracks
  – Vibration
  – Transition zones

• **Indicator of root cause at problem sites**

• **Verification**
  – New track
  – After maintenance
Measurement of track stiffness

• **Standstill measurements**
  – Track Loading Vehicle (TLV), Impact hammer, Train passage

• **Rolling measurements**
  – Static (deflection of ordinary wheelset)
  – Dynamic (vibration due to oscillating mass)
RSMV
(Rolling Stiffness Measurement Vehicle)

Measurement speed: < 50 km/h
Dynamic load: < 50 Hz, < 60 kN
Static axle load: 180 kN
RSMV
(Rolling Stiffness Measurement Vehicle)
Dynamic excitation

Acceleration in frequency domain
\[ f = \frac{v}{\lambda} \]

Several peaks from excitation and train-track interaction

- Chose speed – excitation frequency combination with care
Early example of relevance

Continuous stiffness measurements, West coast line in Sweden, east track w37 2001, 20 km/h 5,7 Hz

Longitudinal level, rms-value over 20 meters, 2000 - 2001
Good example, two turnouts in Germany designed with transition zones

High speed line Berlin – Hannover ($v_{\text{max}} = 200 \text{ km/h}$)  
station Buschow (track 6185-1, km 152,4)  

ballast track, concrete sleeper  
Switches: elastic rip-plate support (ERL),  
Support stiffness: ERL: 17,5 kN/mm  
Track: Support stiffness: 60 kN/mm  

Direction of travel

W 714  
EW 60-500-1:12-fakop-r B  
ERL  
trailing move

W 715  
EW 60-3000/1500-1:18-fb-fakop-r B  
ERL  
facing move
Bad example from Sweden, tunnel with adjacent turnouts
Bad example from Sweden, tunnel with adjacent turnouts

RSMV stiffness measurement, Citytunnel 2011-05-25, track 74 (partly track 4)
Repeatability and soft soil

40 km/h, 11.4 Hz, 6 repetitive runs

7 km/h, 3 – 20 Hz
Stiffness phase = Delay of response
RSMV-measurements the Netherlands, file: 1703240214, part 16

Phase delay [degrees]

Track stiffness [kN/mm]

Position along the track [km]

Excitation frequency 7.3 Hz

EBER DYNAMICS
Latest development: EBER Track Lab - ETL

- Multiple measurements close to loaded axle.
- Eliminate track geometry
- Adjust model to estimate structural parameters
  - Stiffness
  - Damping
  - Mass
  - Etc.
Measure track geometry (level) in several positions – at different distance from the load (wheel)

Estimate a deflection curve with a model to relate measurement with structural parameters, as for example:

- Vertical track stiffness
- Track damping
- Critical velocity
- Etc.

\[ EI \frac{\partial^4 w(x, t)}{\partial x^4} + m \frac{\partial^2 w(x, t)}{\partial t^2} + c \frac{\partial w(x, t)}{\partial t} + kw(x, t) = Q \delta(x - vt) \]
Track degradation, iron-ore line

Direction of loaded trains

Plot showing peak to mean value of longitudinal level 1-25 m [mm] over position [km] with dates and stiffness gradient for different positions.
Critical speed – direct estimate

• The dynamics under a running vehicle will indicate critical speed behaviour well below $v_{cr}$.
• With a new method, this behaviour can be measured.
• Simulations show adequate estimation of $v_{cr}$ already at the speed of $0.4v_{cr}$.
• If used at existing line speeds, the method will give a very good first estimate for the project.
• Tested on known problem sites with good results
• Main network of Denmark monitored.

$$v^2_{cr} = \frac{2}{m} \sqrt{kEI}$$
Results from Lammhults mosse
Lammhultsmosse, ~165 km/h
Usage in Sweden

• Research measurements
  – EU-projects
• Inventory before increase of axleload
• Special investigations as regards e.g.
  – Vibrations
  – Soft soils
  – USP
  – Critical speed
• Initial investigations on relation to track degradation

Main focus has been on geotechnical issues.
## Pros & Cons

<table>
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<tr>
<th>Method</th>
<th>Pros (+)</th>
<th>Cons (-)</th>
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| **RSMV (Rolling Stiffness Measurement Vehicle)** | - Dynamic measurements  
- Magnitude and phase  
- Detailed investigation | - Low speed.  
- Require extra loco etc.  
- Only fully loaded |
| **EVS (EBER Vertical Stiffness)** | - At same time as track geometry quality.  
- Speed.  
- Cheap (certainly if combined with track geometry) | - Accuracy.  
- Calibration |
| **ETL (EBER Track Lab)**       | - At same time as track geometry quality.  
- Speed.  
- More structural parameters than only stiffness.  
- Dynamic characteristics possible to detect. | - Not fully tested.  
- Requires more sensors. |
Conclusions

- Different alternatives for testing
  - RSMV, EVS, ETL
  - Large measurement campaign, speed important
  - Static/dynamic properties

- Many examples of usage in Sweden
  - Inventory of geotechnical properties.
  - Good examples of relation to degrading track, although no one-to-one relationship.