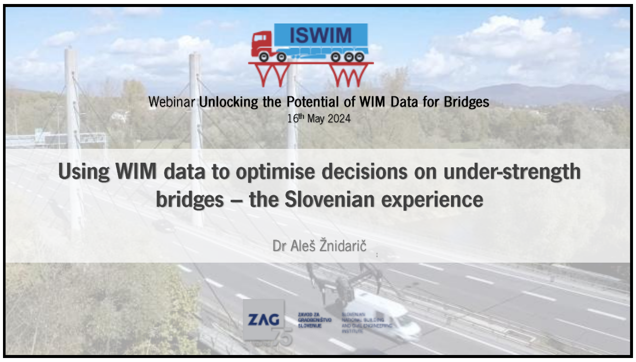

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Content

1. Safety of bridges and Bridge-WIM
2. Monitoring bridge performance with Bridge-WIM systems
3. Case study

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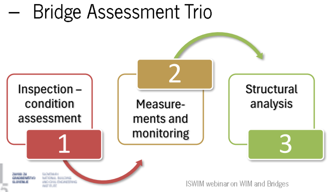
Traffic loading and bridges

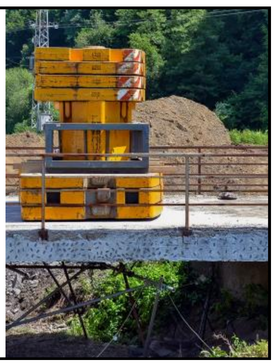
4

Structural safety of bridges

R > S

- bridge condition/capacity
- Bridge Assessment Trio





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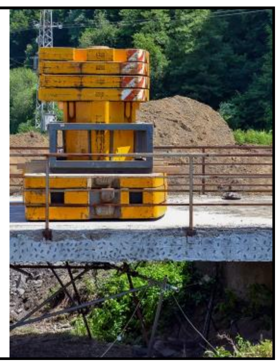
Structural safety of bridges

R > S

- bridge condition/capacity
- measurements and monitoring:
  - material characteristics and damage extent
  - actual traffic loads **WIM**
  - transformation into load effects/stresses/strains
  - distribution across the structure
  - dynamic amplification **B-WIM**



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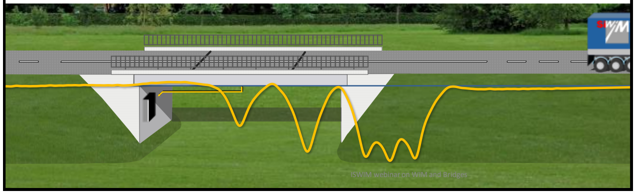
Bridge WIM system…

… or **B-WIM** is a measuring device that uses an existing instrumented structure – a bridge or a culvert – to *'weigh'* road vehicles or trains in motion, at normal operating speed.



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Bridge WIM system

- since 1979
- research in Europe from 1993 to 1999
- ® system since 200
- 000 installations … the gl

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Bridge WIM system

- since 1979
- research in Europe from 1993 to 1999
- SiWIM® system since 2000
- >5000 installations, 30 countries
- strain measurements
- developments in Europe, USA, Asia…
- main benefits:
  - portable, does not disturb traffic
  - measure bridge performance under traffic

Žnidarič, A., Kalin, J., Kreslin, M. (2018). *Improved accuracy and robustness of bridge weigh-in-motion systems*. Structure and Infrastructure Engineering, 14(4), 412–424

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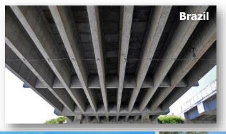
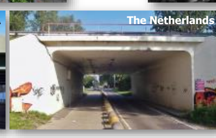
Typical bridges for B-WIM installation





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Viaduc de Millau – France

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Moerdijk bridge – the Netherlands

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Nieporęt railway truss bridge – Poland

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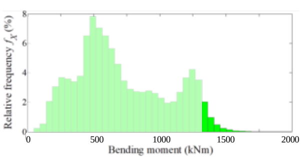
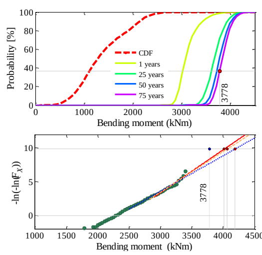
Modelling traffic load effects on bridges





- Long-term simulations
- Fatigue

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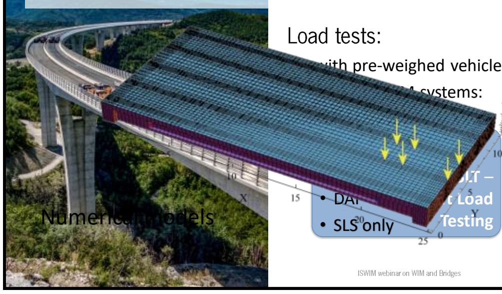
Bridge performance under traffic



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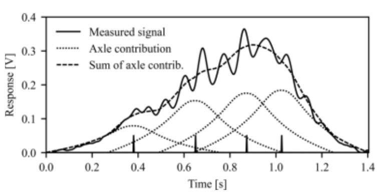
Measurement of bridge KPIs – Influence line

- SiWIM® calculates IL from each loading event
- mean IL used:
  - by SiWIM®
  - to calibrate structural model



Žnidarič, A., Kalin, J., & Kreslin, M. (2018). *Improved accuracy and robustness of bridge weigh-in-motion systems.* Structure and Infrastructure Engineering, 14(4), 412–424

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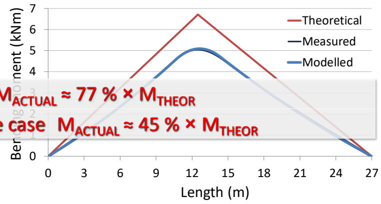
Measurement of bridge KPIs – Influence line

- IL measured from each loading event
- always different than in theory



$M_{ACTUAL} \approx 77\ \% \times M_{THEOR}$

Extreme case $M_{ACTUAL} \approx 45\ \% \times M_{THEOR}$

Žnidarič, A., Kalin, J. (2020). *Using bridge weigh-in-motion systems to monitor single-span bridge influence lines*. Journal of Civil Structural Health Monitoring, 10:743–756

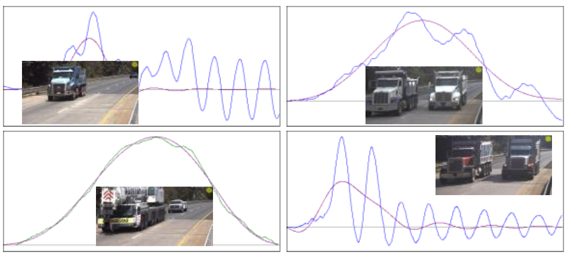
Measurement of bridge KPI – GDF

- measured & statistically evaluated (mean & STD):
  - Girder Factors – GDF
  - Lane Factors – LF
- substantial differences btw. bridges

	1	2	3	4	5	6
Driving lane	0.12	0.19	0.24	0.23	0.16	0.07
Fast lane	0.02	0.08	0.14	0.20	0.26	0.30

Žnidarič, A., Kalin, J. (2020). *Using bridge weigh-in-motion systems to monitor single-span bridge influence lines*. Journal of Civil Structural Health Monitoring, 10:743–756

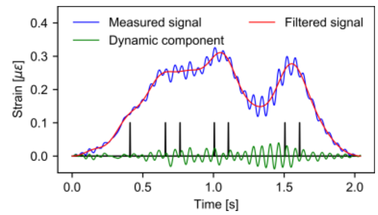
Dynamic response of a bridge



Measurement of dynamic amplification

$$DAF = \frac{S_{total}}{S_{static}}$$

- 1000s bridge responses



Measurement of dynamic amplification

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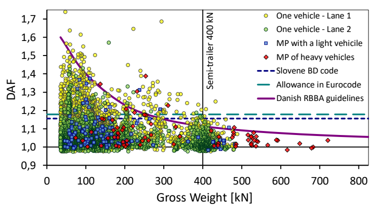
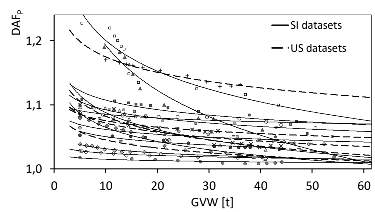


34-m bridge – 5004 measured DAF values

Measurement of dynamic amplification

$$DAF = \frac{S_{total}}{S_{static}}$$

- 1000s bridge responses
- 5 US and 12 SI bridges

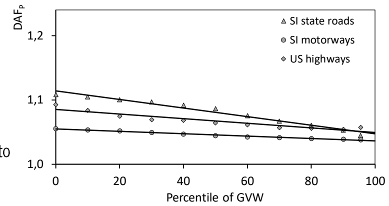


17 datasets, 202 to 747 000 DAF values

Measurement of dynamic amplification

$$DAF = \frac{S_{total}}{S_{static}}$$

- 1000s bridge responses
- 5 US and 12 SI bridges
- in line with theory, how to implement it in codes?



Kalin, J., Anžlin, A., Kreslin, M., Žnidarič, A. (2022). *Measurements of Bridge Dynamic Amplification Factor Using Bridge Weigh-in-Motion Data*, Structure & Infrastructure Engineering, 18 (8), 1164-1176

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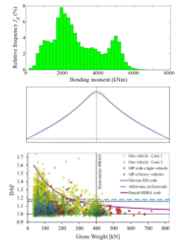
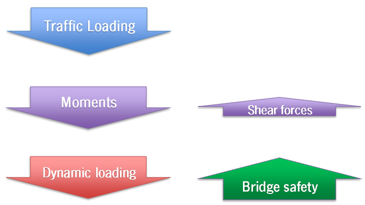
B-WIM benefits for safety assessment of bridges





More reliable information, less uncertainty of results
Site-specific, time-dependant information

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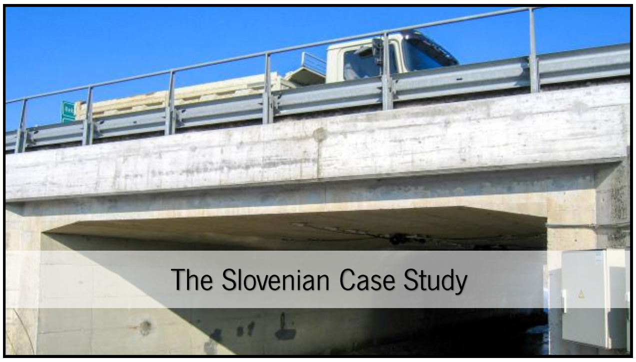

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Safety Assessment in Slovenia

Bridge Assessment Recommendations:
- Rating Factor approach:

$$RF = \frac{\Phi\, R - S_D\, \gamma_D}{S_L\, \gamma_L\, DAF}$$

- developed:
  - rating/assessment loading schemes from WIM
  - procedures to select safety factors γ_D and γ_L
  - procedure to select capacity reduction factor Φ

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Case study Slovenia

- 2006-14: 154 very bad & critical bridges
- initial assessments: 118 bridges found safe
- 36 bridges: **SLT,** material testing and detailed analysis:
  - 23 bridges found safe
  - **13 bridges** posted, strengthened or replaced

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Case study Slovenia – costs

- replacement value of all bridges **100** M€
- initial safety assessment **26 M€**
- use of SLT, material testing and detailed analysis left 13 bridges for **9** M€ cost

Indirect costs at least twice the direct ones!

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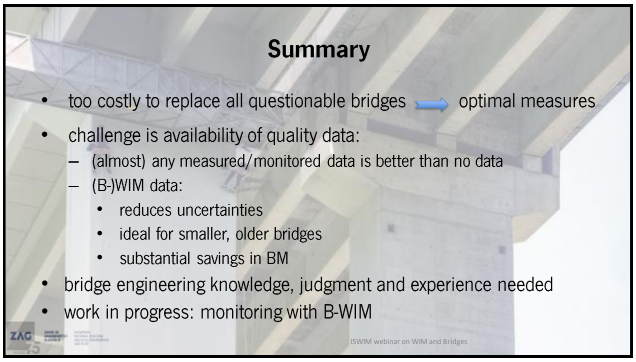
Summary
• too costly to replace all questionable bridges → optimal measures
• challenge is availability of quality data:
– (almost) any measured/monitored data is better than no data
– (B-)WIM data:
• reduces uncertainties
• ideal for smaller, older bridges
• substantial savings in BM
• bridge engineering knowledge, judgment and experience needed
• work in progress: monitoring with B-WIM
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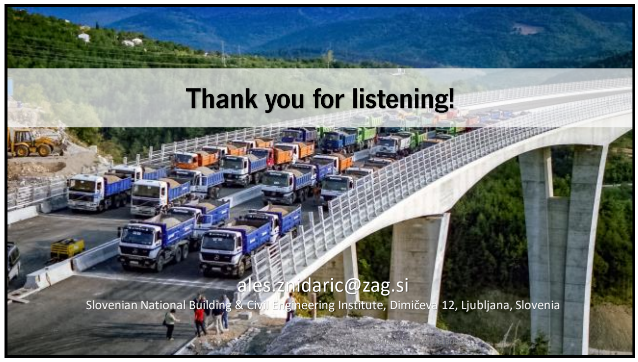
Thank you for listening!
ales.znidaric@zag.si
Slovenian National Building & Civil Engineering Institute, Dimičeva 12, Ljubljana, Slovenia

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