ZAVOD ZA GRADBENIŠTVO SLOVENIJE

SLOVENIAN NATIONAL BUILDING AND CIVIL ENGINEERING INSTITUTE

MONITORING TRAFFIC LOADING FOR OPTIMIZED ASSESSMENT OF BRIDGES

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Slovenia?

Outline

1. Why optimised bridge assessment?
2. Condition assessment of bridges
3. Structural safety of bridges
4. Bridge-WIM and bridge assessment
5. KPIs from Bridge-WIM
6. Conclusions

Why optimised bridge assessment?

- Because we do not want to spend money for avoidable rehabilitations!
- Fortunately:
  - bridges are stronger than we think
  - load effects are less than in the codes
- Despite being deteriorated bridges are likely safe, but…
- … how to prove their actual safety?

Design vs. assessment

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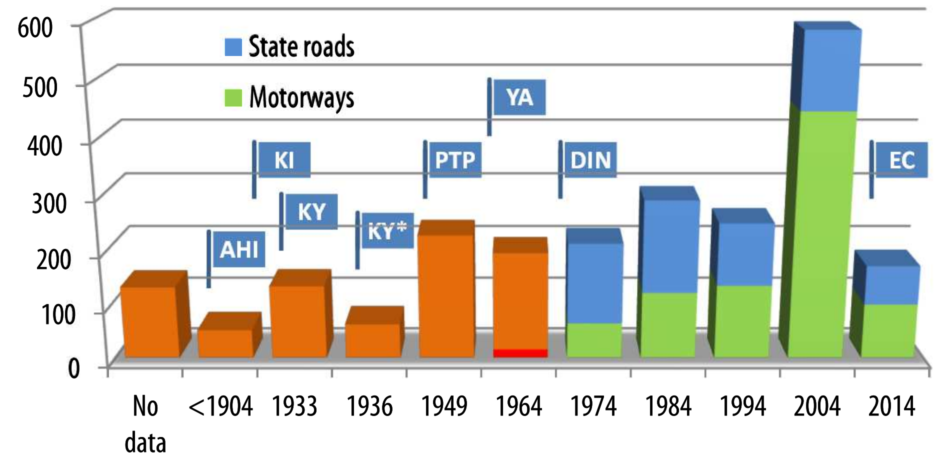
- new bridges shall be designed conservatively, due to uncertainties about increasing loading & decreasing capacity

- assessment should be optimal:
  - expensive to post, strengthen or replace a bridge
  - capacity and loading can be measured/monitored

B- WIM

Slovenian bridges

- 2553 state bridges:
  - DRSI 1414
  - DARS 1139
  - municipalities??
- age:
  - 35 % over 45 years
  - ≈ 150 over 100 years



- bridge codes and traffic loading:
  - in 114 years 8 codes with different loading schemes
  - safety of ≈ 59% of bridges on state roads and ≈ 1% on motorways questionable
- capacity reduces with time and due to deterioration

Bridges (and pavements) must be maintained!

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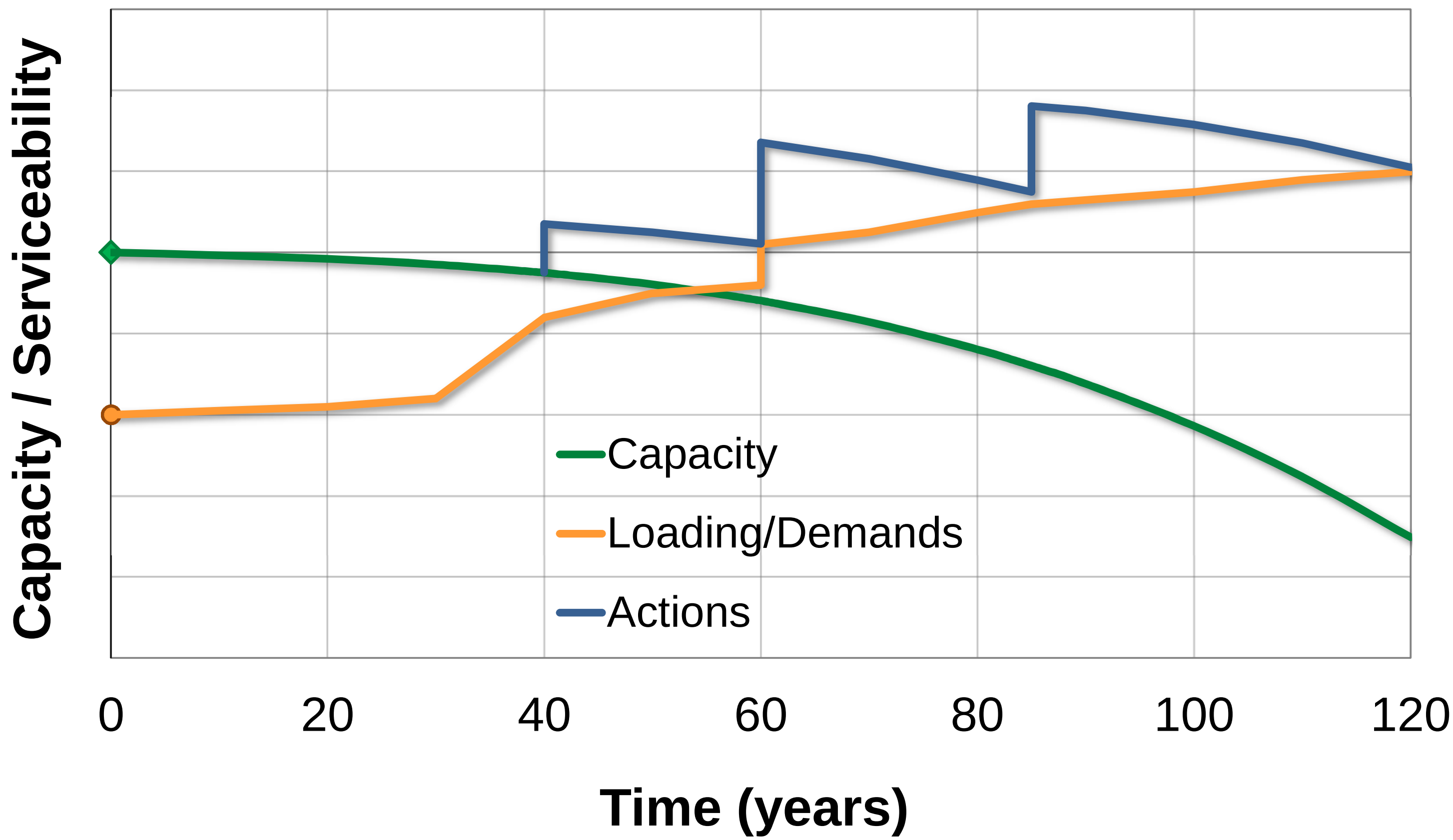

Questions for optimised bridge assessment

1. What is the condition of the structure?
2. What is its carrying capacity?
3. What is the real traffic loading?
4. What are the load effects due to loading?

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Deterioration of bridges is …

- … affected by:
  - construction:
    - design / <u>state of knowledge</u> / **<u>details</u>**
    - quality control
    - technologies applied
    - selection of contractors
  - use and aging:
    - environment (earthquakes, **<u>high waters</u>**)
    - accidents, impacts of vehicles, trains and vessels
    - maintenance
    - …
- … quantified through <u>bridge inspections</u>

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Key question: is the bridge safe?

Capacity > Loading . safety factor

Structural safety assessment

Verification that a bridge can carry specified loads:

- probabilistic methods
- deterministic methods

$$R \geq S \qquad \frac{R_d}{\gamma_R} \geq \gamma_D . G_D + \gamma_L . G_L . k_d + \gamma_A . G_A$$

$$RF = \frac{\Phi . R_d - \gamma_D . G_D}{\gamma_L . G_L . k_d} > 1.0$$

Damaged bridge

≠

Unsafe bridge

(and vice-versa)

Traffic loading

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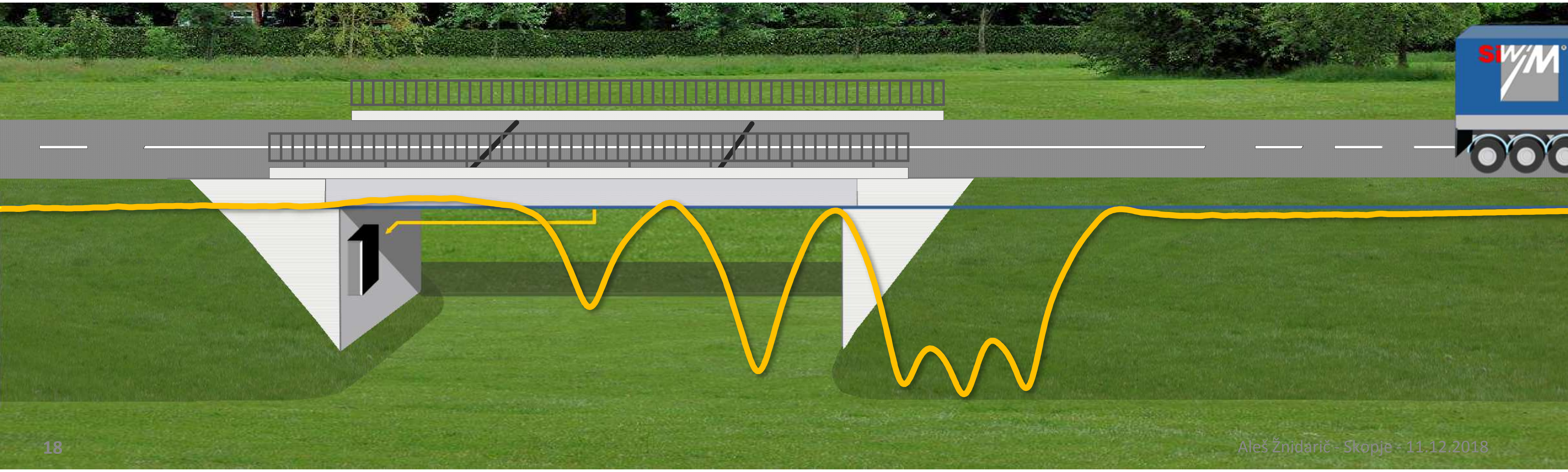
Measurements of traffic loading

- traffic counters – no information about axle loads
- weighing systems

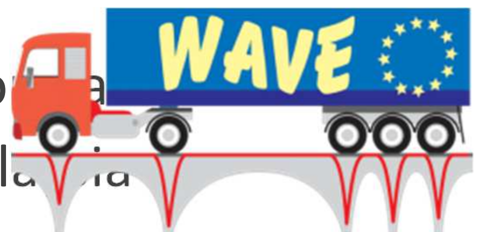
Static weighing

Bridge WIM system …

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



Bridge WIM system



- since 1979
- research in Europe from 1993 to 1999
- SiWIM® since 2000
- …00 installatio… a…
  …including Mala…ia
- strain measurements
- developments and applications in Europe, USA, Japan, Korea…
- measures bridge performance under traffic

Typical bridges

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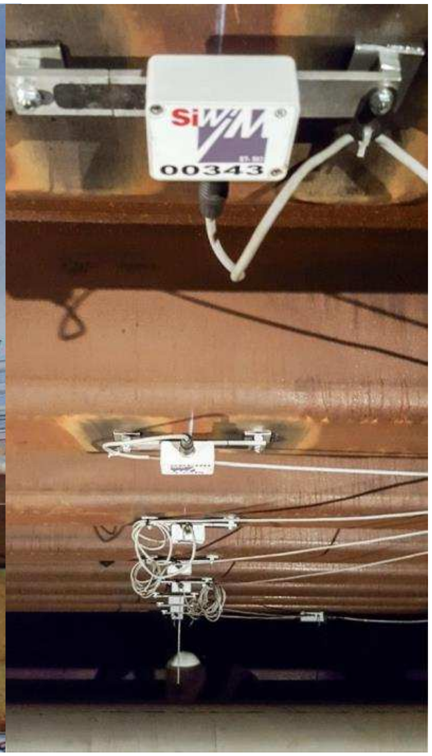
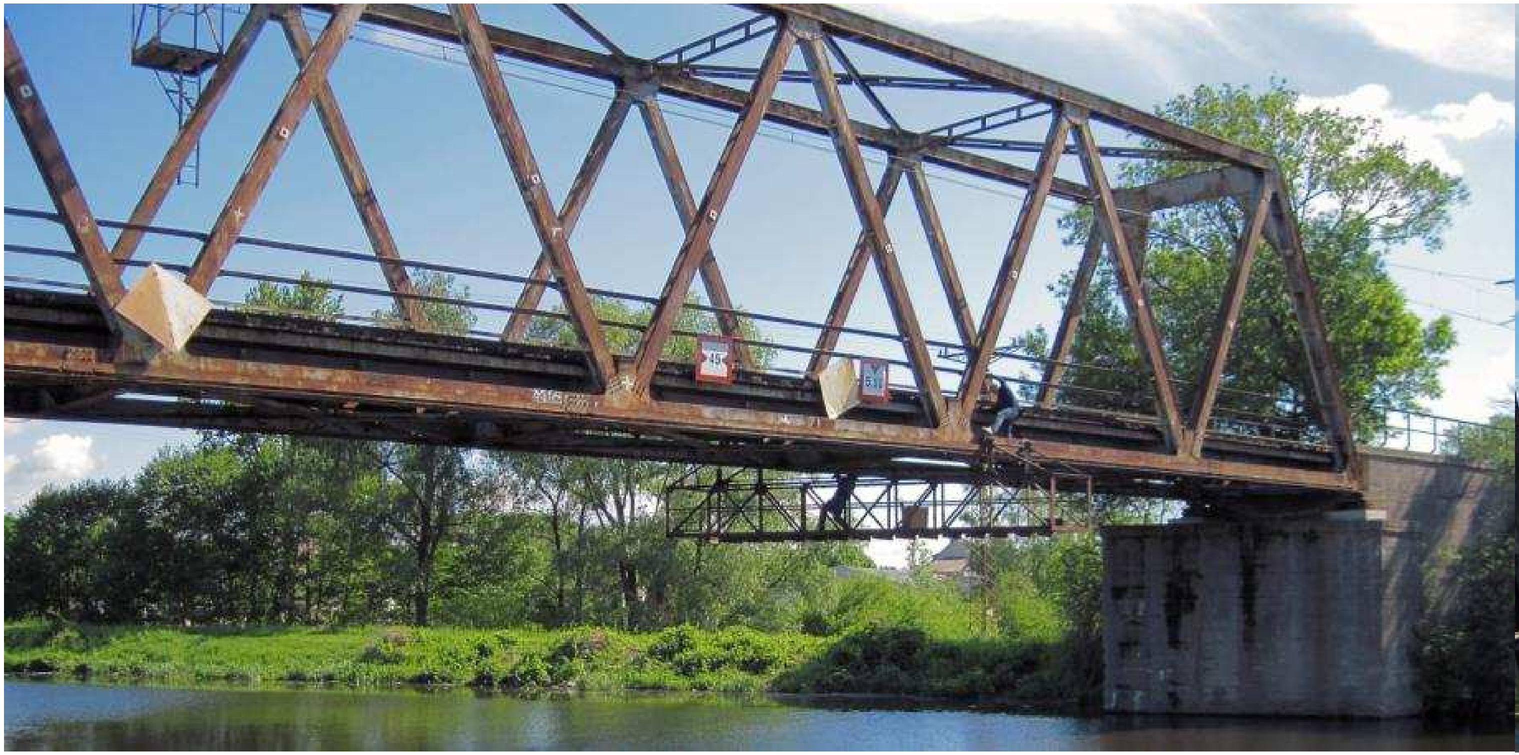
Viaduc de Millau – France



Neiporet railway truss – Poland



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Modelling of traffic load effects on bridges

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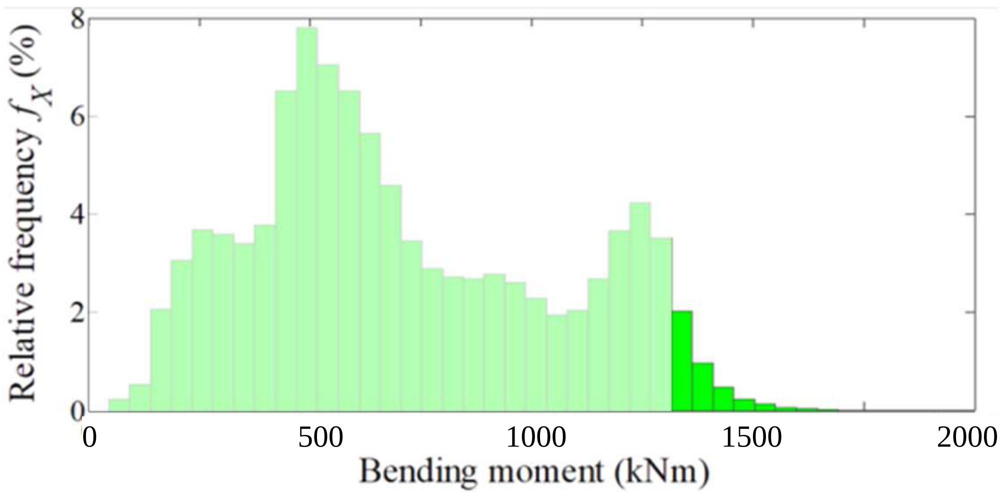
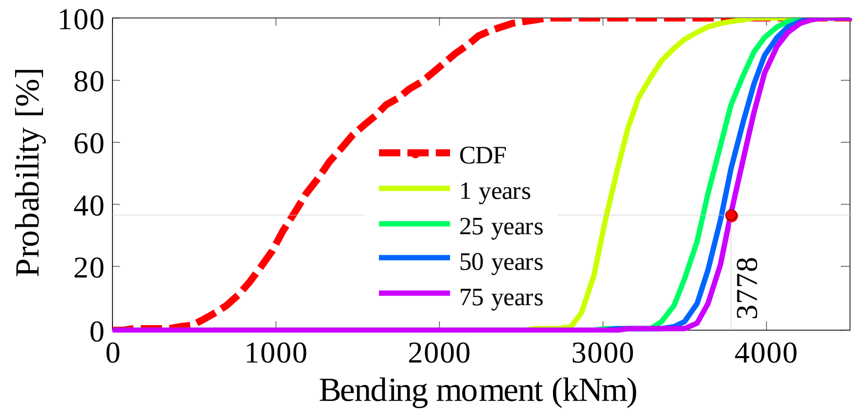
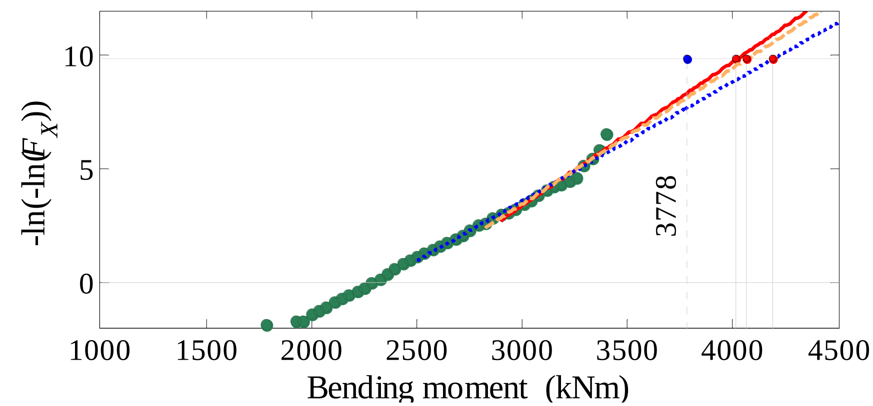
- traffic loads & bridge condition/capacity change over time
- should be assessed differently for existing & new bridges
- important how:
  - how traffic loading is transformed into load effects / stresses / strains?
  - how traffic loading distributes over structural elements?
  - what is the dynamic amplification of traffic loading?
  - how special heavy transports are accounted for?

MODELS
vs.
MEASUREMENTS

Modelling of traffic load effects on bridges







Behaviour of bridges

Numerical models

Load tests:

- with pre-weighed vehicles
- with SiWIM B-WIM system:
  - Influence lines
  - GDF
  - DAF

B-WIM for bridge assessment

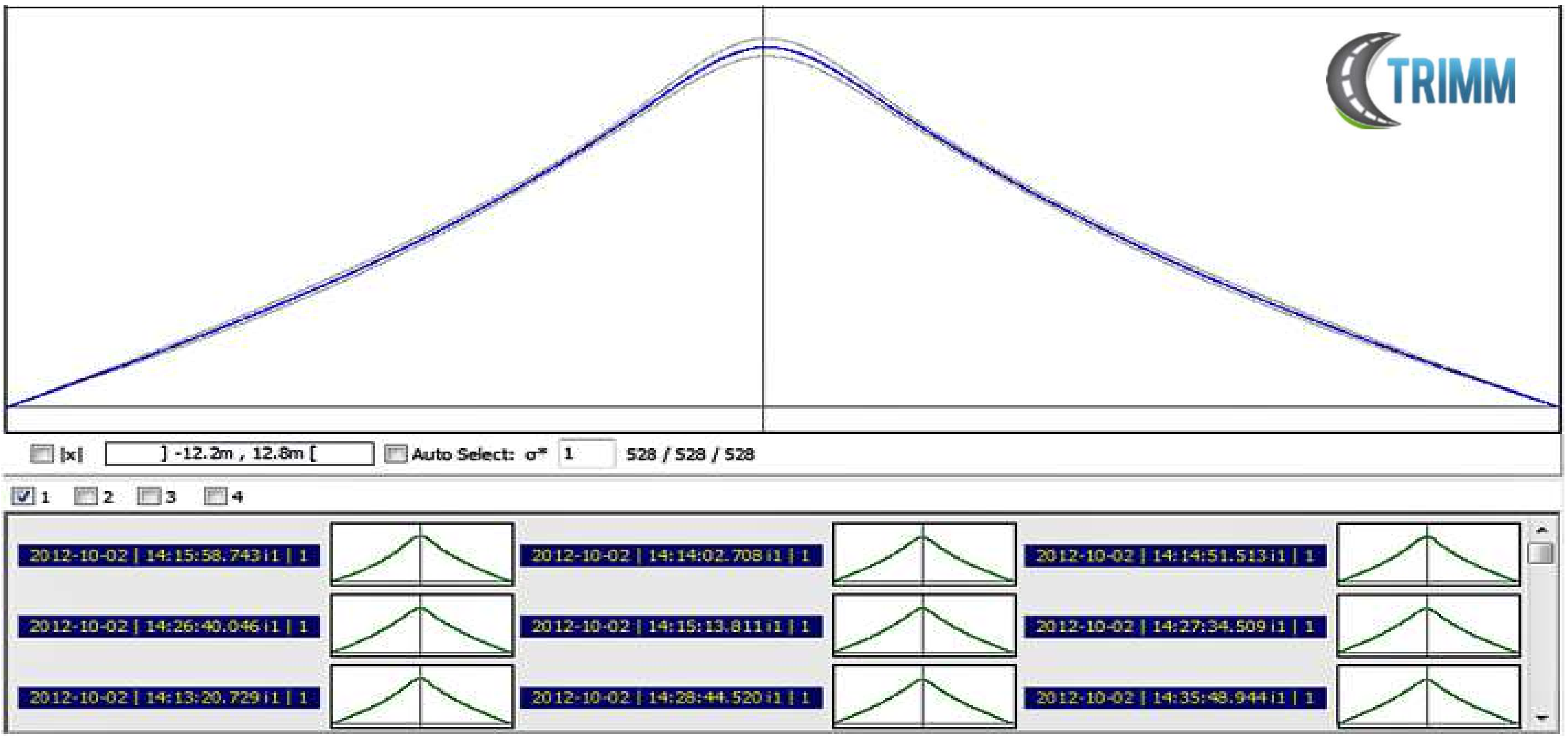
5 parameters that improve structural analysis:

1. Axle loads, spacings, speed, vehicle class…, for assessment of actual traffic loading – from any WIM system
2. Strain records

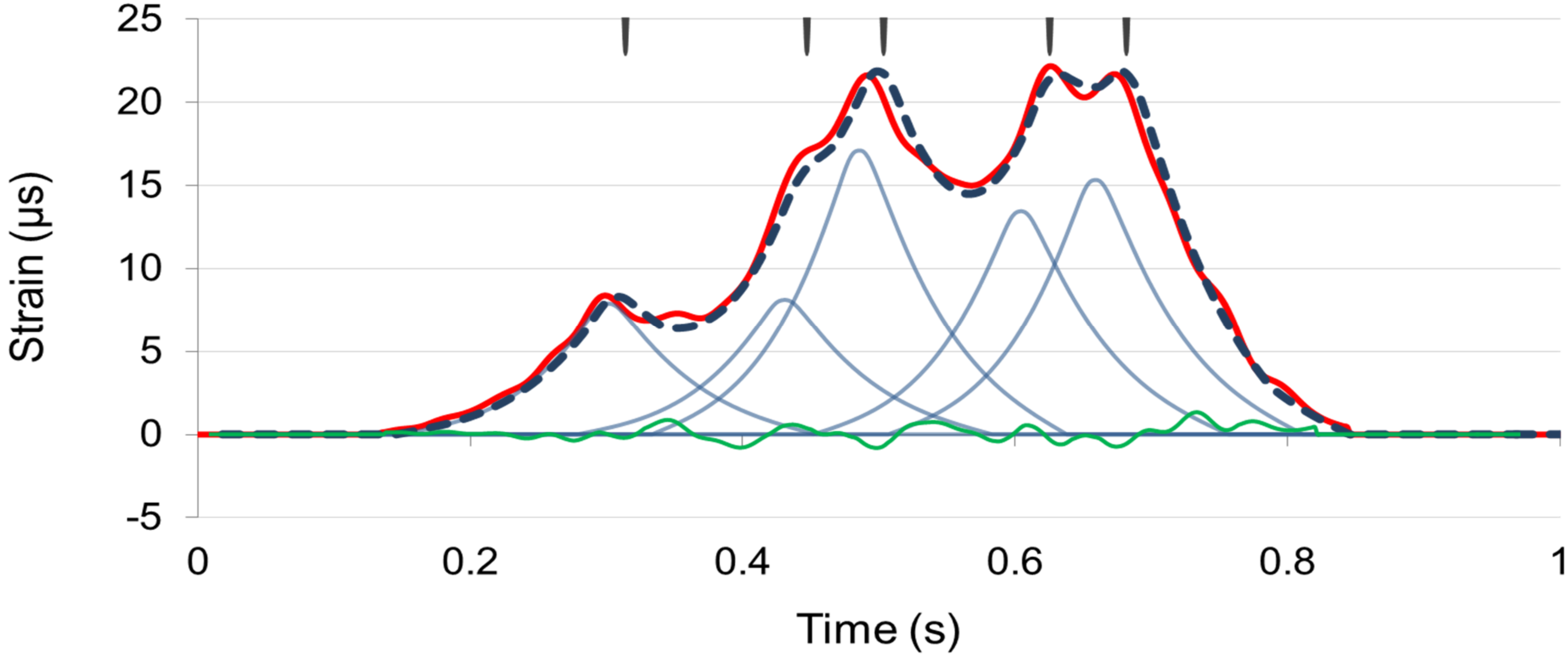
… and 3 measured structural parameters:

3. Influence lines – IL
4. Distribution of traffic loading over structural members – GDF
5. Dynamic loading – DAF

Measurements of bridge KPI – Influence line

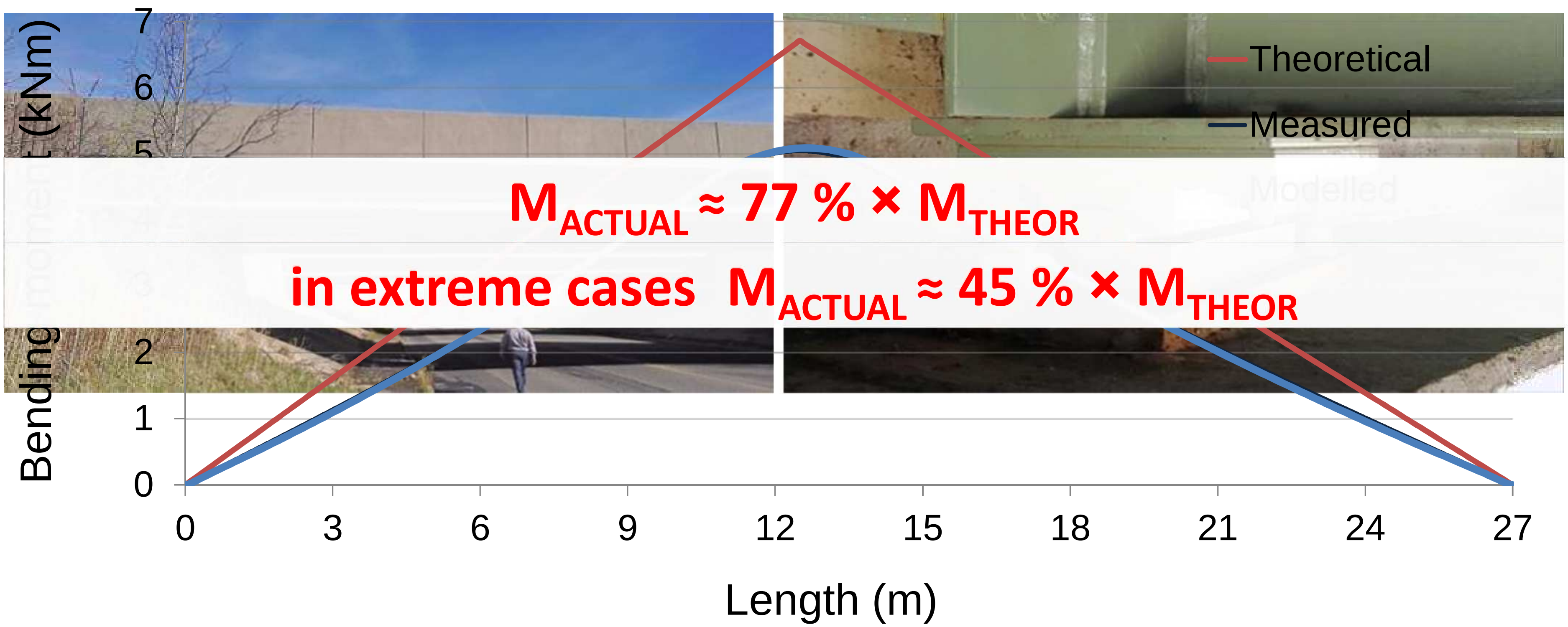


Influence Line implementation in B-WIM



27-m long New Jersey underpass

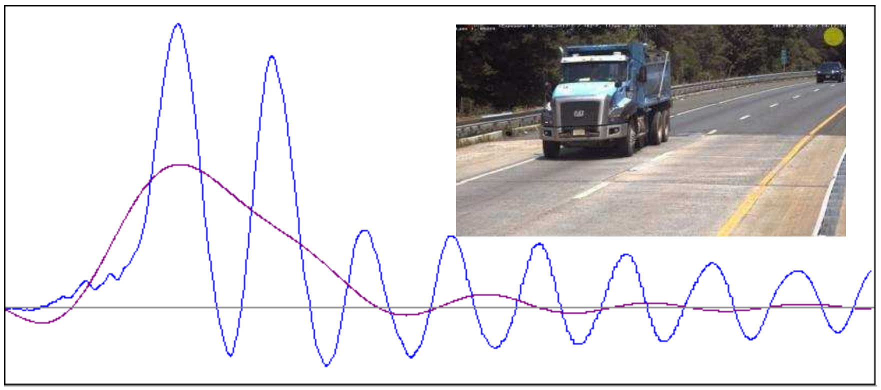
Measurements of bridge KPI – Influence line

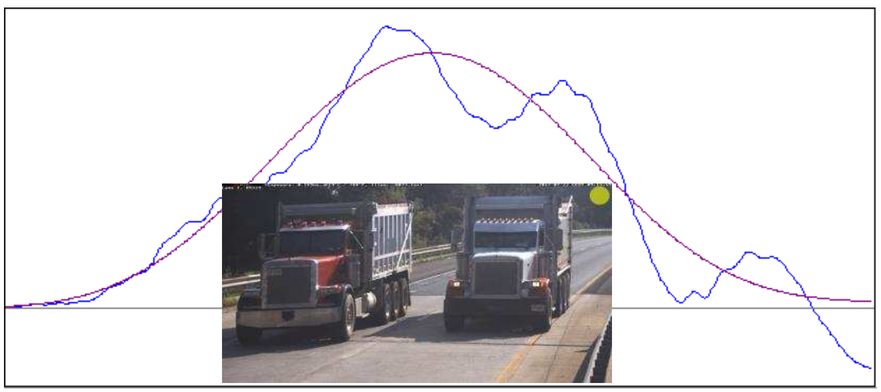


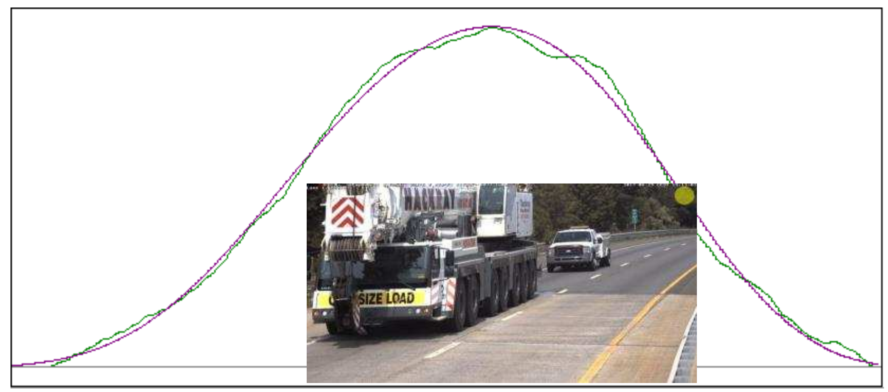
$M_{ACTUAL} \approx 77\ \% \times M_{THEOR}$

in extreme cases $M_{ACTUAL} \approx 45\ \% \times M_{THEOR}$

Dynamic response of the bridge

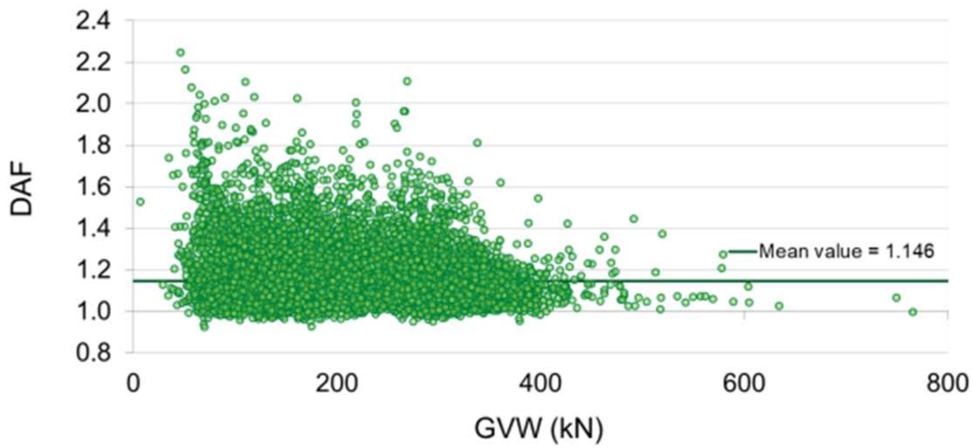


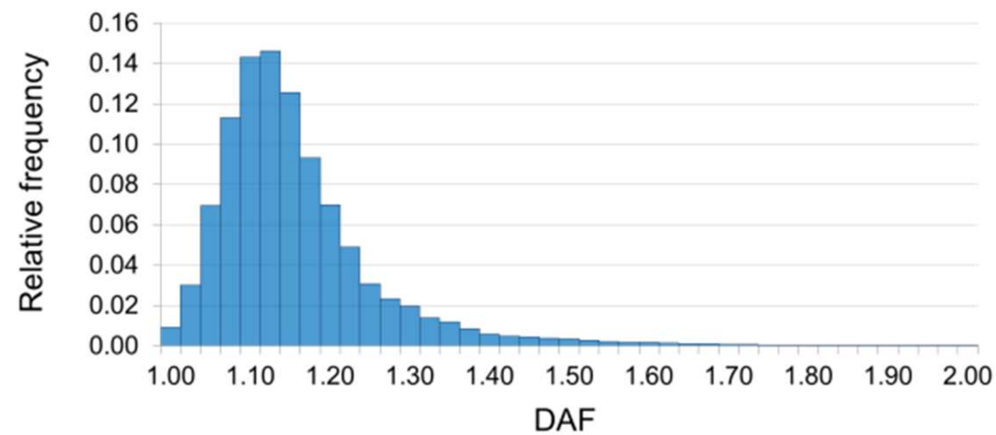




Measurements of bridge KPI – DAF

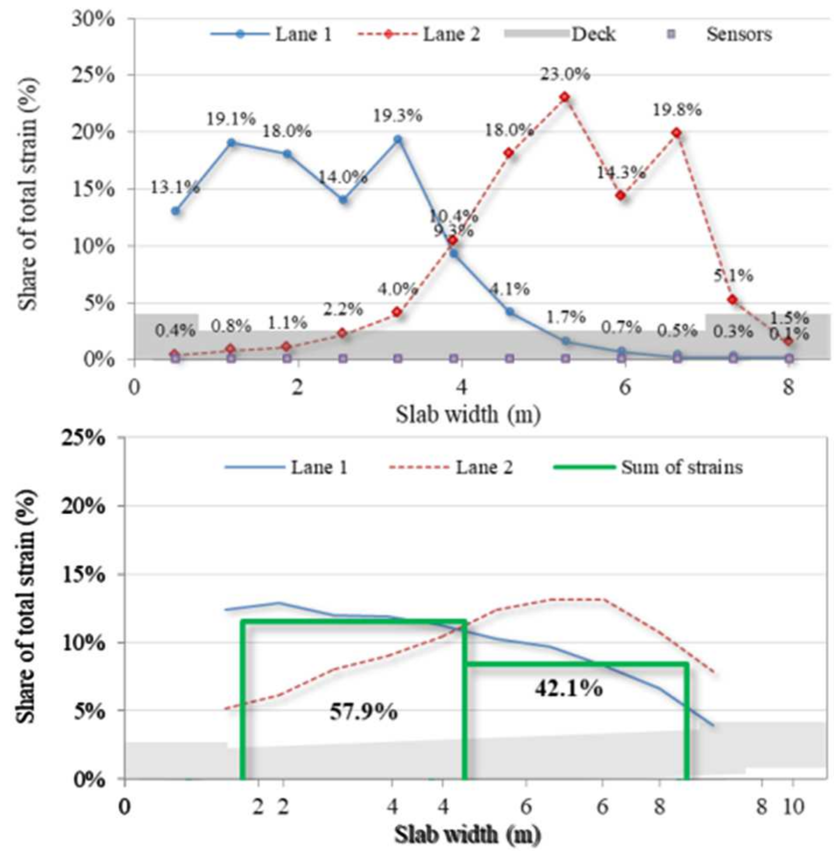
$$DAF = \frac{S_{total}}{S_{static}}$$





Bridge KPI – GDF

- measured & statistically evaluated (mean & standard deviation) of:
  - Girder Factors – GDF
  - Lane Factors – LF
- can be very different than in theory
- can vary a lot from one bridge to the other



Safety assessment procedure

Calculation of structural safety:

$$R \geq G \qquad\qquad RF = \frac{\Phi . R_d - \gamma_D . G_D}{\gamma_L . G_L . DAF} > 1.0$$

- benefits from B-WIM results:
  - traffic data
  - information about true structural behaviour (load test)

Case study

- since 2004 structural safety assessed for 154 deficient bridges
- step-by-step analysis applied:
  1. Initial assessment:
     - dedicated inspection
     - assessment loading schemes based on WIM data
     - lower dynamic amplification based on WIM data
     - reduced safety factors
     - simple analytical models
  2. Assessment with SiWIM B-WIM and material testing

Case study

- after initial assessment 118 of 154 bridges found safe for the existing traffic conditions
- another 23 bridges proven safe after repeating the analysis with SiWIM B-WIM and material testing
- only 13 bridges of 154 required safety-related actions:
  - postings
  - strengthening or replacement

Case study cost savings

- replacement value of all deficient bridges app. 50 – 100 M€
- initial optimised analysis, with realistic traffic loading, reduced costs to 26%
- use of SiWIM B-WIM and material testing left 13 bridges that required actions, which further reduced costs to **9 %!**
- less traffic delays: indirect costs would typically be at least twice the direct ones

Benefits of WIM for bridges

- any WIM:
  - measures the true traffic loading
- B-WIM in addition:
  - measures the true behaviour of bridges
- as a result :
  - higher safety levels can be demonstrated
  - traffic restrictions can often be released or removed

To conclude

How safe are old deteriorated bridges?

- pretty safe, but the structural safety must be proven
- the approach is different than for new bridges

Important to understand what happens with bridges:

- they are generally more robust than we think
- details play a key role
- regular inspection and preventive maintenance are absolutely crucial
- must be clear when risk of collapse is unacceptably high

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European B-WIM/assessment projects

ZAG

COST 323

WAVE

COST 345

ARCHES

SAMARIS

HEroad

TRIMM

BRIDGEMON

risk assessment of ageing infrastructure
Re-gen