Long-Term Performance Monitoring of a Staffordshire Bridges Using Digital Twin

Case Study

Dr. Farhad Huseynov

Senior Research Associate

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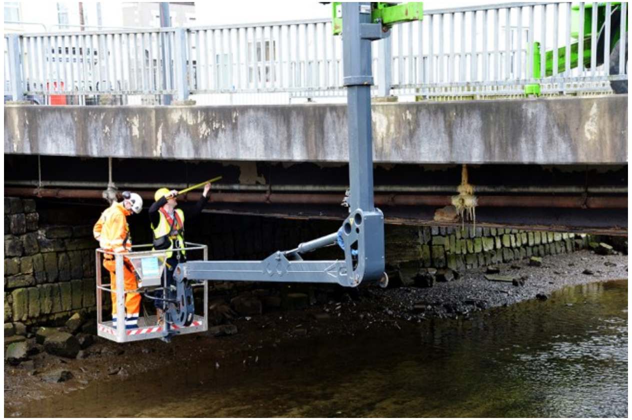
Motivation – Challenges and limitations of current practice

- Current practice largely depend on *visual inspections*
  - Subjective
  - Expensive and time-consuming
  - Prone to errors
- 20% of 155,000 bridges in UK reported as structurally deficient to some degree *(Das, 1997)*
- The number of substandard council-maintained road bridges in the UK has risen by 35% *(RAC Foundation Report, 2018)*
- Huge impact on the economy and the environment



Bridges are stronger than we think!

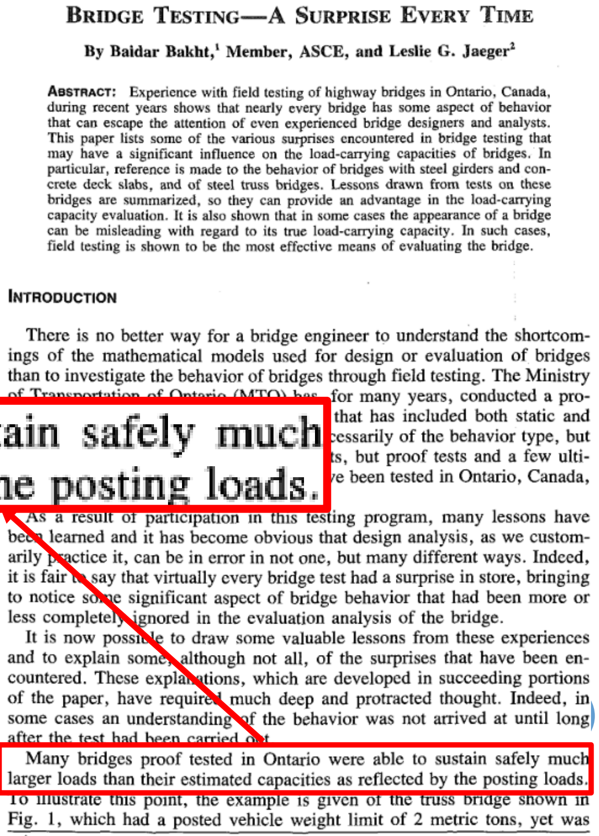
Bridge 7R, Delware. US

Capacity
Actual > 17x Estimated
(McConnell et, al. 2015)

Many bridges proof tested in Ontario were able to sustain safely much larger loads than their estimated capacities as reflected by the posting loads.

The Örnsköldsvik Bridge, Sweden

Capacity
Actual > 5 x Design
(Puurula et, al. 2015)



BRIDGE TESTING—A SURPRISE EVERY TIME

By Baidar Bakht,[1] Member, ASCE, and Leslie G. Jaeger[2]

ABSTRACT: Experience with field testing of highway bridges in Ontario, Canada, during recent years shows that nearly every bridge has some aspect of behavior that can escape the attention of even experienced bridge designers and analysts. This paper lists some of the various surprises encountered in bridge testing that may have a significant influence on the load-carrying capacities of bridges. In particular, reference is made to the behavior of bridges with steel girders and concrete deck slabs, and of steel truss bridges. Lessons drawn from tests on these bridges are summarized, so they can provide an advantage in the load-carrying capacity evaluation. It is also shown that in some cases the appearance of a bridge can be misleading with regard to its true load-carrying capacity. In such cases, field testing is shown to be the most effective means of evaluating the bridge.

INTRODUCTION

There is no better way for a bridge engineer to understand the shortcomings of the mathematical models used for design or evaluation of bridges than to investigate the behavior of bridges through field testing. The Ministry of Transportation of Ontario (MTO) has ... for many years, conducted a pro- ... that has included both static and ... essarily of the behavior type, but ... ts, but proof tests and a few ulti- ... e been tested in Ontario, Canada,

As a result of participation in this testing program, many lessons have been learned and it has become obvious that design analysis, as we customarily practice it, can be in error in not one, but many different ways. Indeed, it is fair to say that virtually every bridge test had a surprise in store, bringing to notice some significant aspect of bridge behavior that had been more or less completely ignored in the evaluation analysis of the bridge.

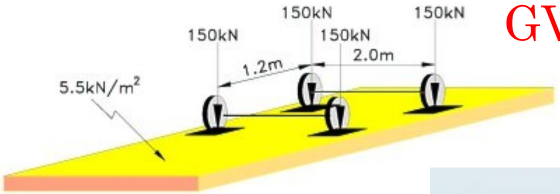
It is now possible to draw some valuable lessons from these experiences and to explain some, although not all, of the surprises that have been encountered. These explanations, which are developed in succeeding portions of the paper, have required much deep and protracted thought. Indeed, in some cases an understanding of the behavior was not arrived at until long after the test had been carried out.

Many bridges proof tested in Ontario were able to sustain safely much larger loads than their estimated capacities as reflected by the posting loads. To illustrate this point, the example is given of the truss bridge shown in Fig. 1, which had a posted vehicle weight limit of 2 metric tons, yet was

Sources of additional strength reserve

- Uncertainties involved in bridge design/assessment codes
  - Structural behaviour
  - Material Resistance
  - Loading condition and etc.

Load Model 1 (Eurocode)



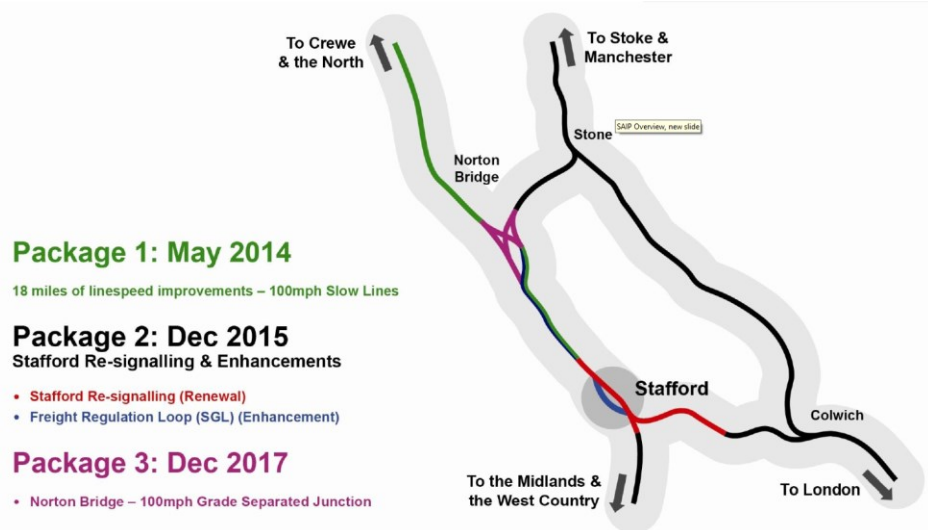
GVW= ~ 67 tons
+ *UDL*

The load models in Eurocode do not describe actual loads.
(Cl. 4.2.1.(1) – EN 1991-2)

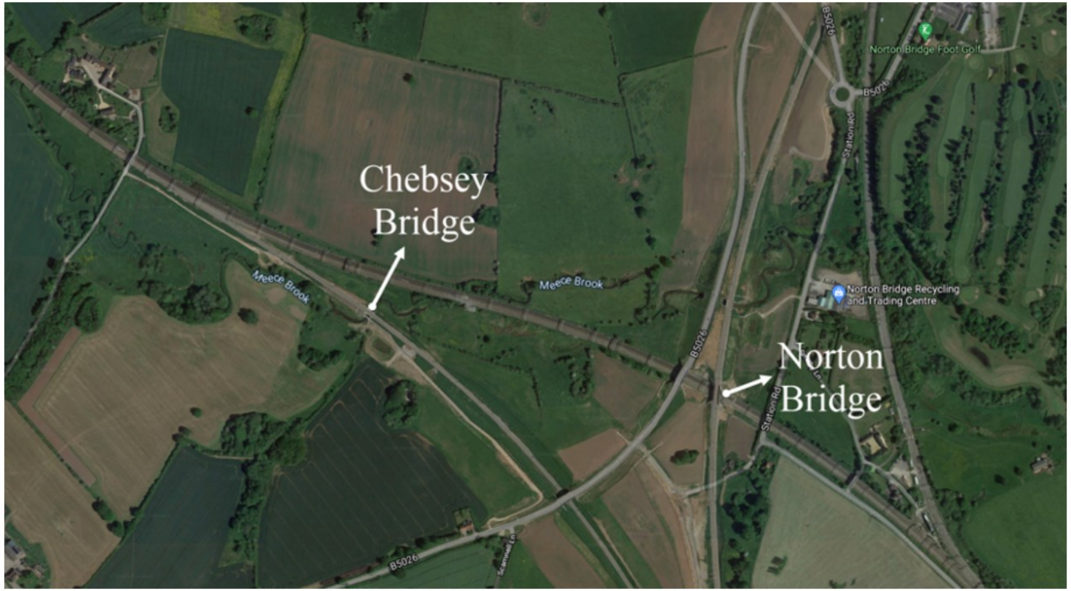
max. allowable GVW = 40 tons

They are derived to produce the most onerous load actions on any bridge spanning between 2m to 200m of any structural configuration.

Staffordshire Bridges Project - First Some Background…



- Staffordshire Area Improvement project
- Flyover to reduce the bottleneck
- Norton Bridge project - 10 new bridge construction
- 2 new bridges were instrumented


Chebsey
Bridge
Norton
Bridge
Meece Brook
Meece Brook
Norton Bridge Foot Golf
Norton Bridge Recycling
and Trading Centre
B5026
B5026
B5026
B5026
Station Rd


Perth
St Andrews
Loch Lomond
& The
Trossachs
National Park
Edinburgh
Glasgow
Paisley
Ayr
Dumfries
United
Kingdom
Newcastle
upon Tyne
Sunderland
Durham
North
Pennines
AONB
Lake District
National Park
North York
Moors
National Park
Isle of Man
Yorkshire
Dales
National Park
York
Leeds
Hull
Blackpool
Great Britain
Manchester
Liverpool
Warrington
Sheffield
Chester
Nottingham
Derby
Snowdonia
National Park
Leicester
Peterborough
Norwich
Birmingham
Cambridge
Ipswich
ENGLAND
WALES
Colchester
Luton
Cotswolds
AONB
Oxford
Swansea
Cardiff
Bristol
Swindon
London
Bath
North Wessex
Downs AONB
Canterbury
Southampton
Brighton
Bournemouth
Exeter
Torquay
Newquay
Plymouth
Truro
St Ives
Penzance
Falmouth

Norton Bridge

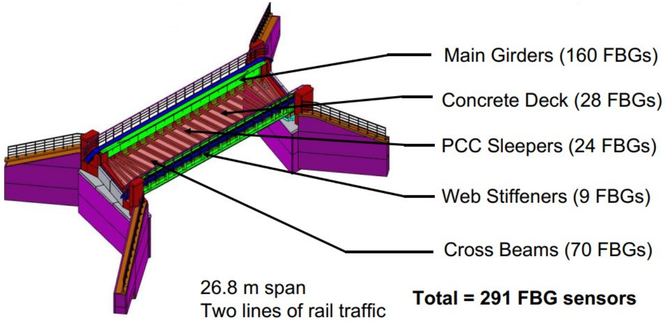
- Composite bridge half-through
- With steel I girders and cast-in-site RC deck
- Span Length: 26.8m

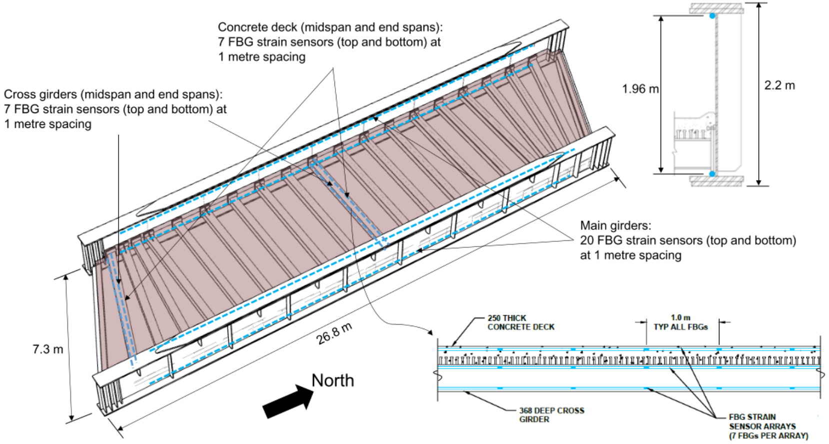
Chebsey Bridge

- Precast concrete bridge
- Span length: 11.9m

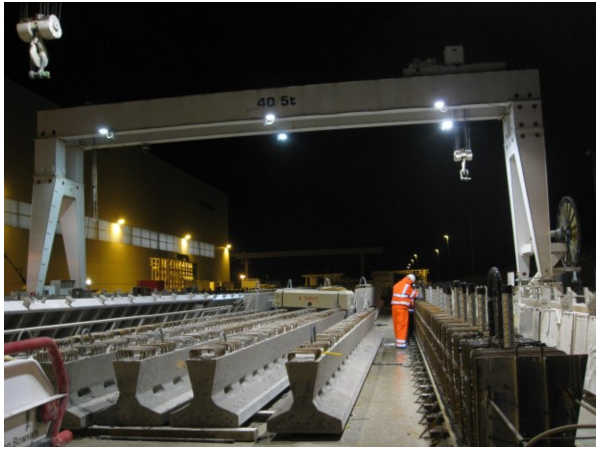
Two most common bridge types in the UK infrastructure network

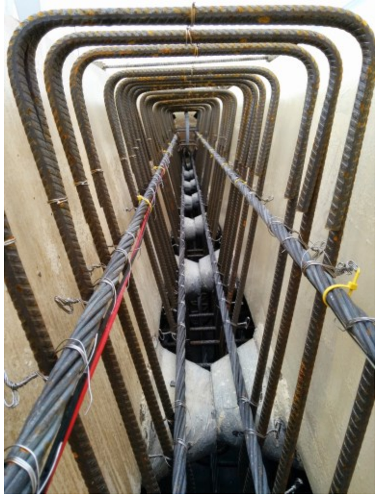
Instrumentation – Norton Bridge (2015)

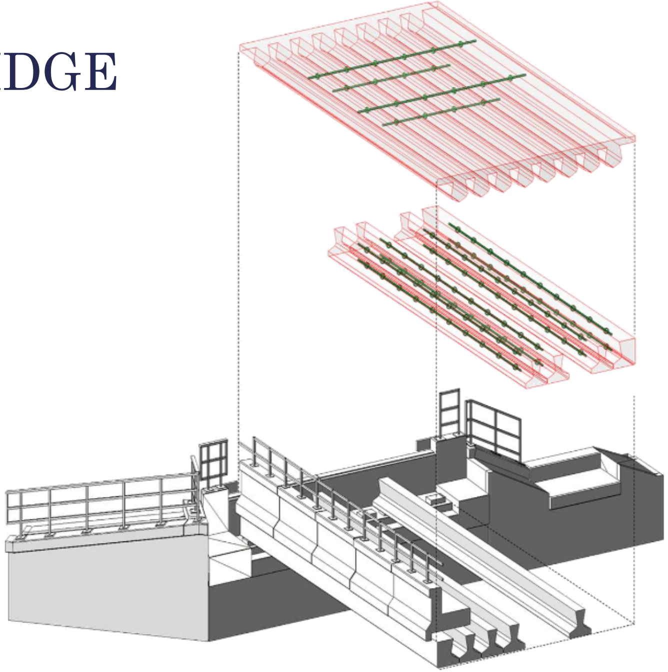


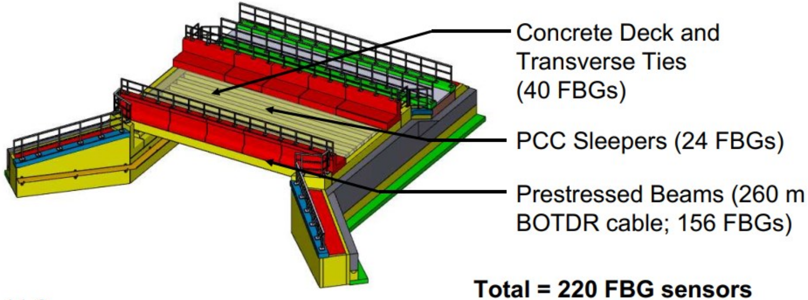


Instrumentation – Chebsey Bridge









11.9 m span
Single line of rail traffic

Total = 220 FBG sensors
+ 260 m BOTDR

PHASE I & II – COMPLETED (2017)

Main objective

- Feasibility of fibre-optic sensors for long term monitoring
- Time-dependent behaviour such as prestress loss, creep, shrinkage
- Load distribution path across the deck

Phase III - Bridge performance monitoring using digital twins

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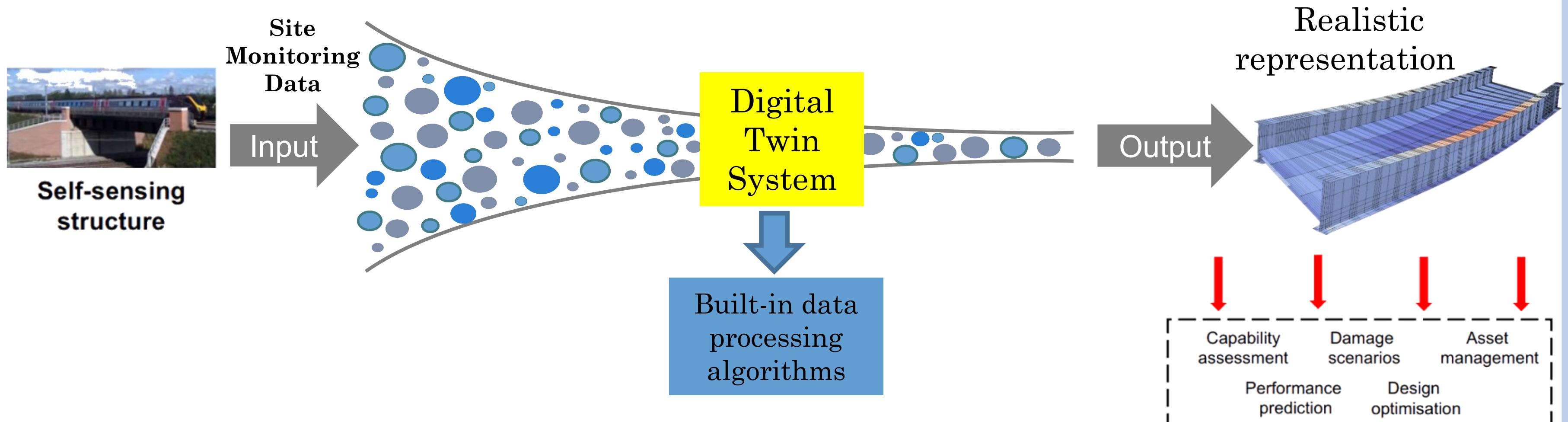


Eliminate Uncertainties

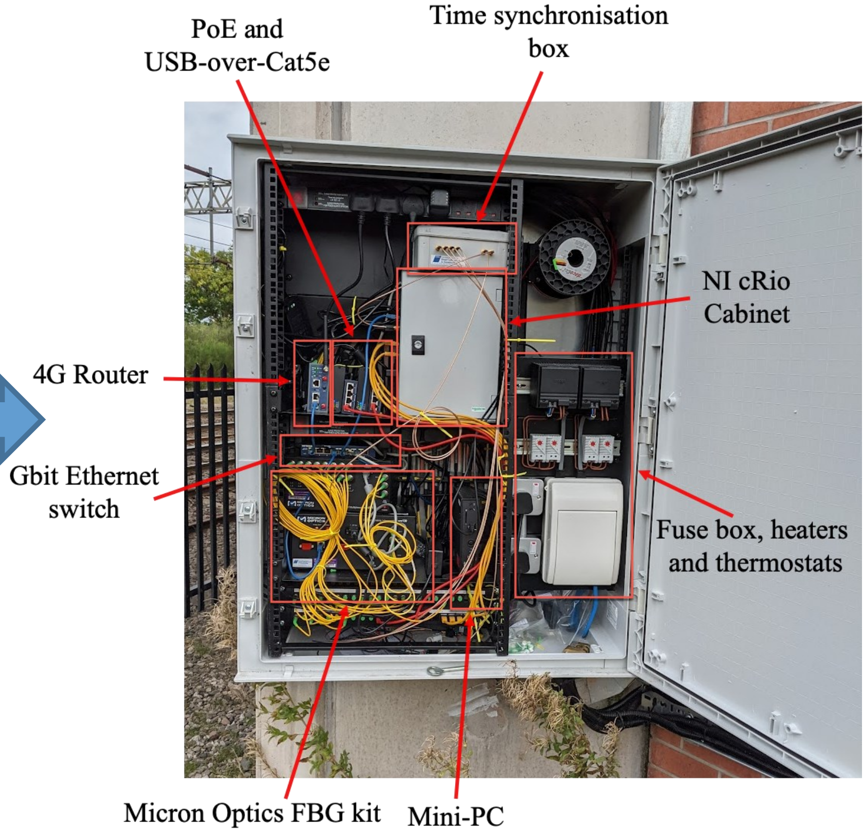
Loading:
- Dead load
- Superimposed deal load
- Creep, Shrinkage, Temperature
- **Traffic Loading**

Structural configuration
- Boundary conditions
- structural stiffness
- contribution of non-structural elements,
- Skew effect
- transverse load distribution of the deck

etc.

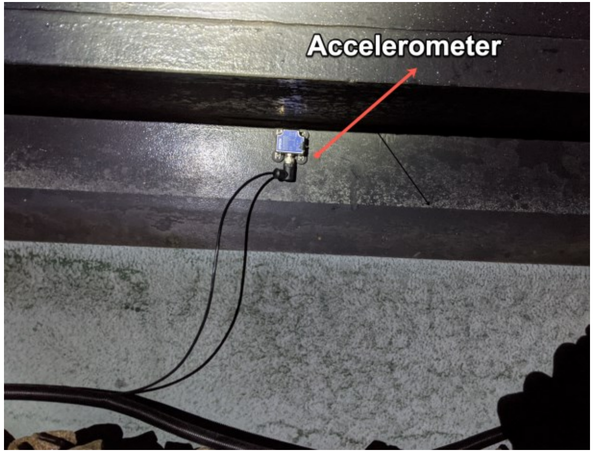
Remote Monitoring system and Additional Sensor installation

Mains power was installed in January 2021

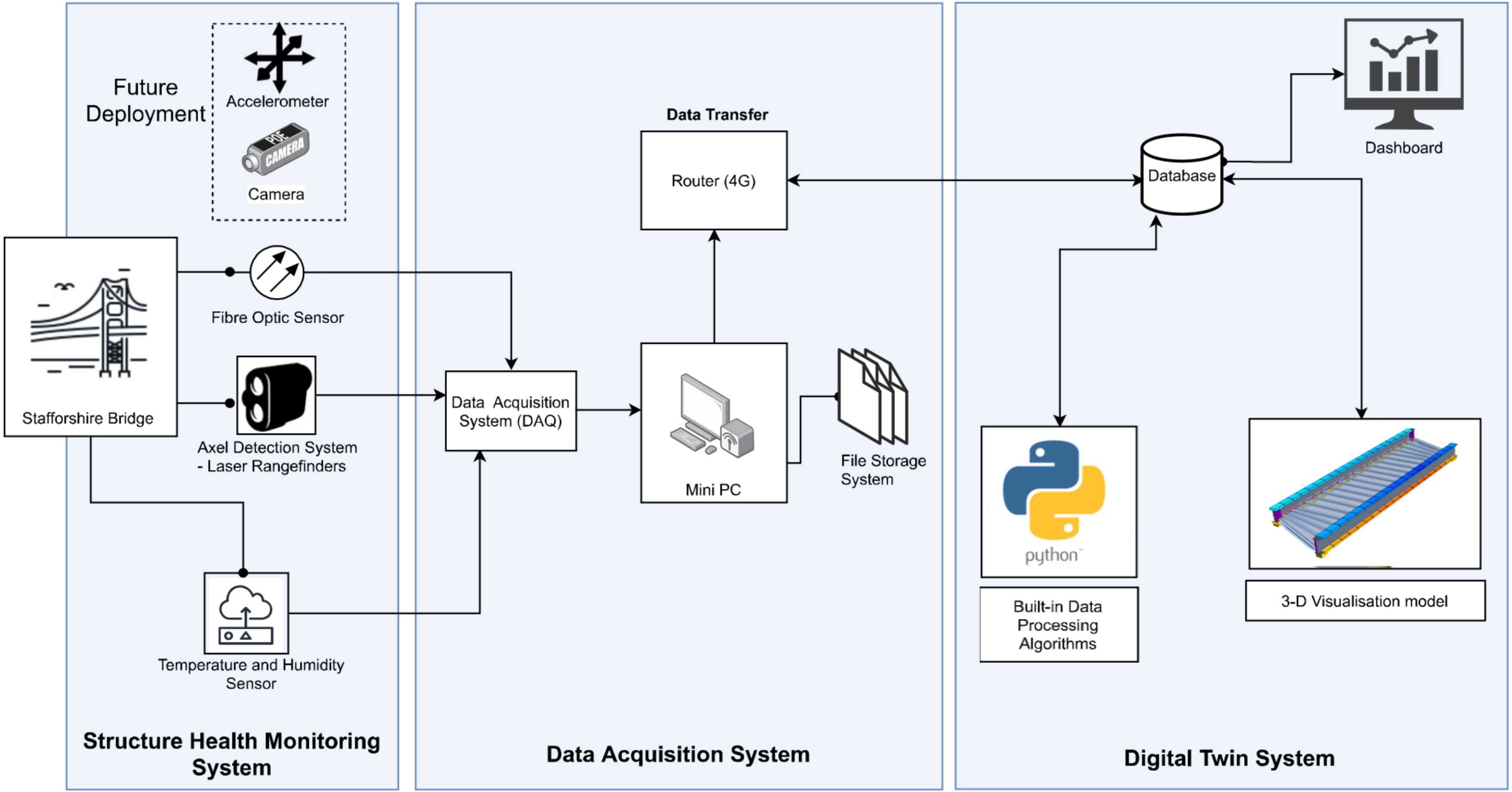


Cabinet was installed in November 2021

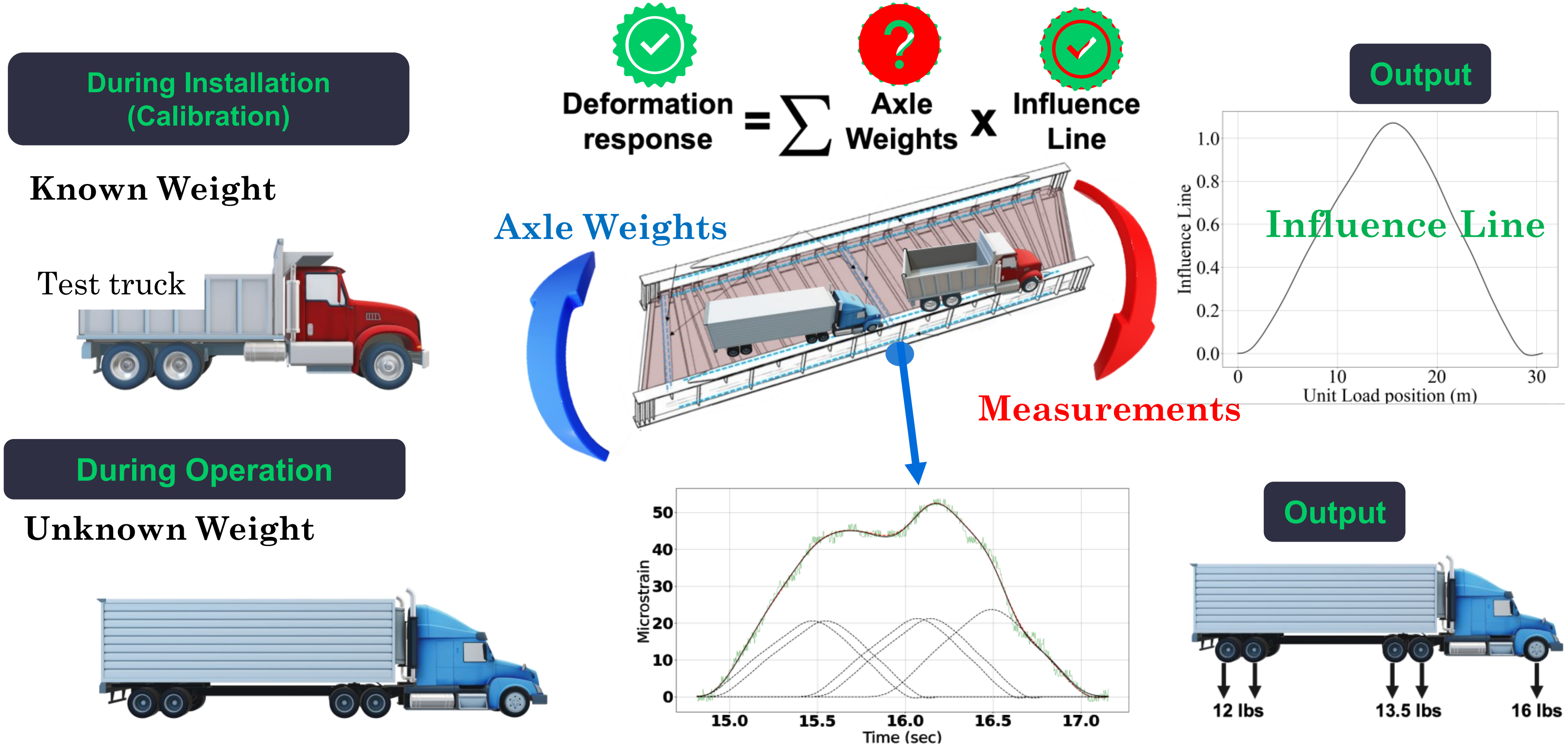
Additional Sensor Installation



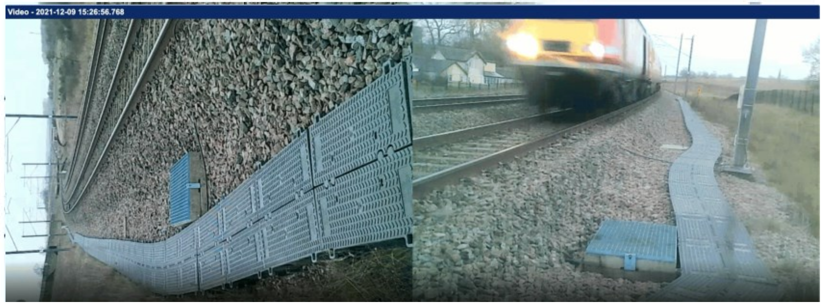
Performance Monitoring System

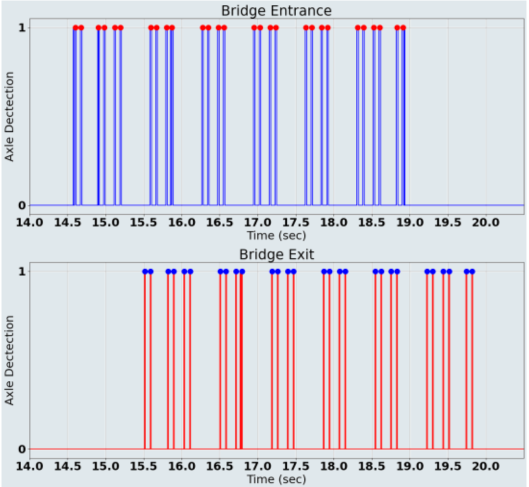


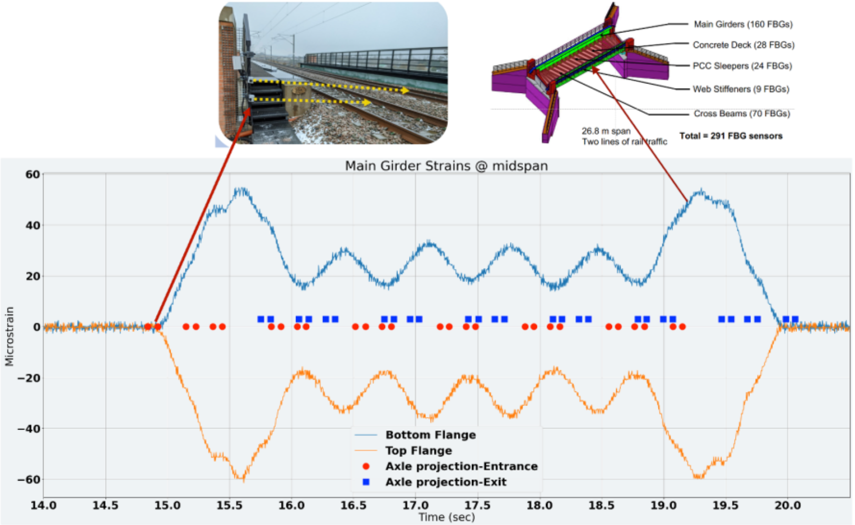
Setting up a real-time train load monitoring system using Bridge Weigh-In-Motion Technology



B-WIM calibration – Flying Banana Train Crossing



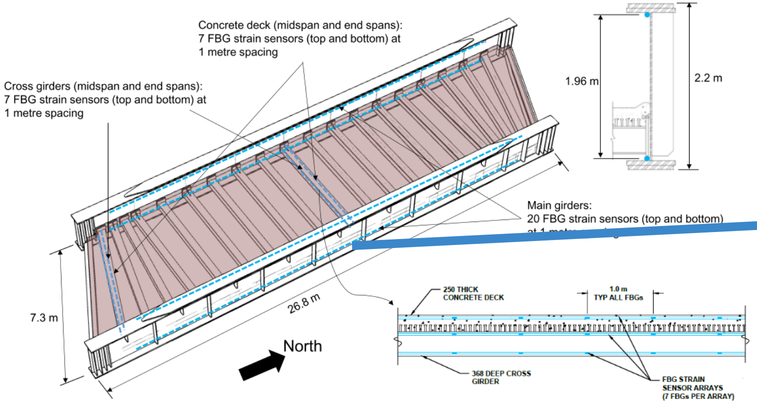


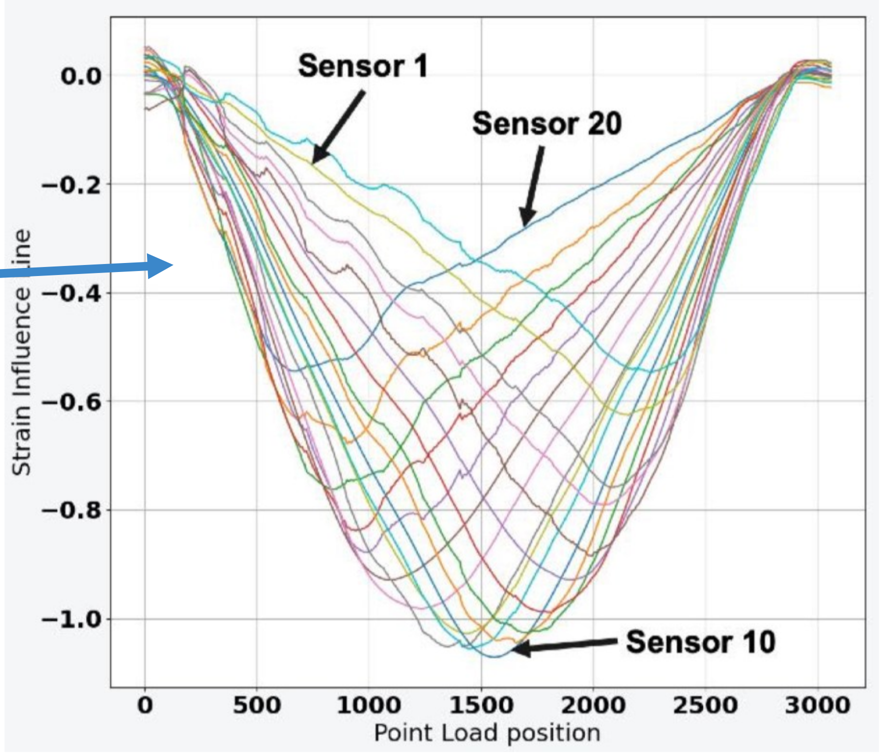


NMT Axle Weights

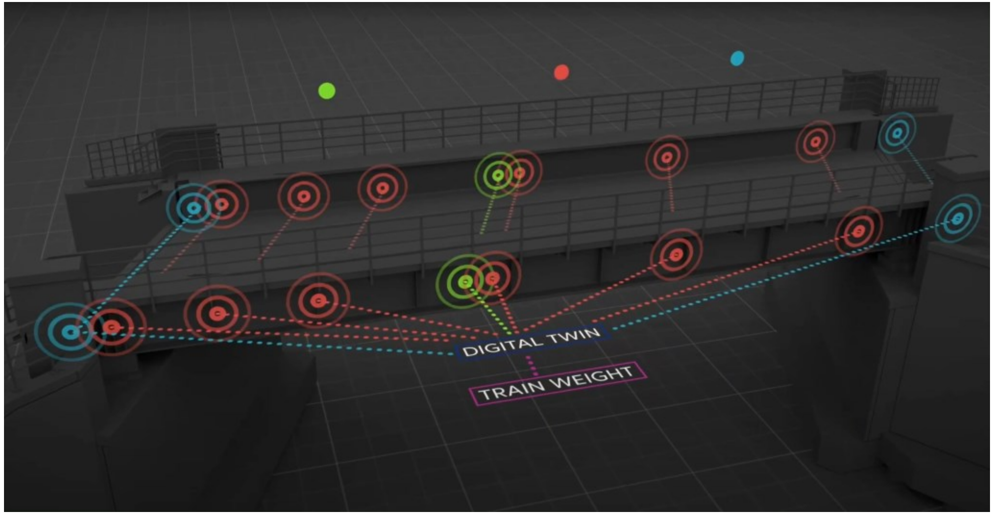
	0
0	18.72
1	18.72
2	18.32
3	18.32
4	10.96
5	10.96
6	9.2
7	9.18
8	10
9	10.08
10	10.04
11	9.94
12	10.98
13	11.02
14	10.98
15	10.96
16	9.34
17	9.36
18	9.36
19	9.32
20	10.16
21	10.2
22	10.2
23	10.2
24	18.32
25	18.32
26	18.72
27	18.72

B-WIM Calibration





Final Remarks



- What are the actual load effects the bridges are experiencing?
- How much the structural capacity is utilized?
- What is hidden strength reserve of a bridge?
- Are we using our assets efficiently?
- Can we increase the network productivity?
  - Increase speed
  - Easy weight restrictions
- Can we reduce the safety factors
- Can we design more efficient structures?

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CONSTRUCTION INNOVATION HUB

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Paul Fidler
Senior
Computer Associate

Vladimir Vilde
Computer Vision
Scientist

Dr. Farhad Huseynov
Senior Bridge Engineer

Dr. Miguel Bravo-Haro
Structural Engineer/
Data Scientist/
Software Developer

Dr. Sam Cocking
Research Associate

CSIC Cambridge Centre for Smart Infrastructure & Construction

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THANK YOU

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