Monitoring and Data Interpretation of Arch Bridges

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Current Projects

1. (automated) Geometry-based diagnosis
   - Tool for interpreting existing geometry
2. (automated) Image-based damage detection
3. Understanding dynamic response (3D)
4. Measure/monitor long-term degradation
   - Locate progressive damage
   - Determine source of damage
   - Evaluate previous repair work

- (Modelling… not today)

How to effectively use technology / data?

Source: www.worldatlas.com

Geometry-based diagnosis

- Simon Ye, Stephen Pendrigh (Meng students)
- Sinan Acikgoz (Postdoc)
- Matt DeJong (PI)

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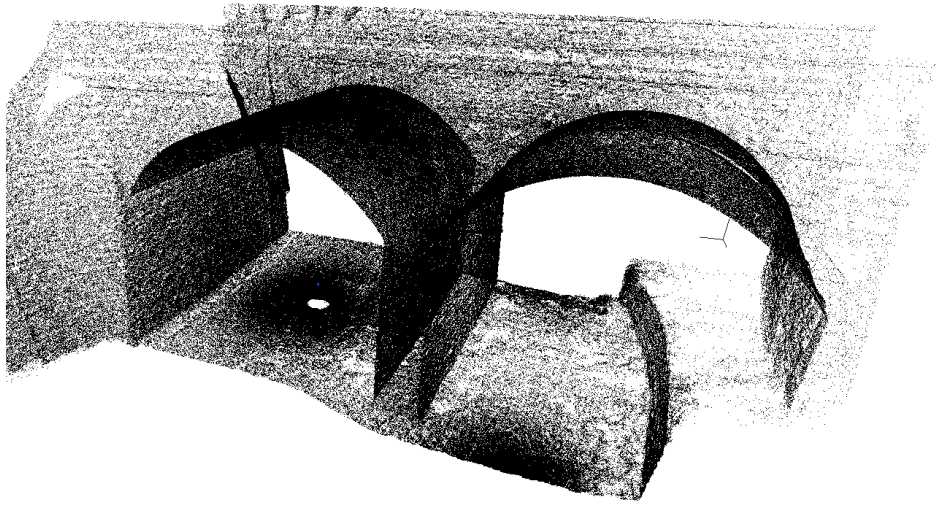
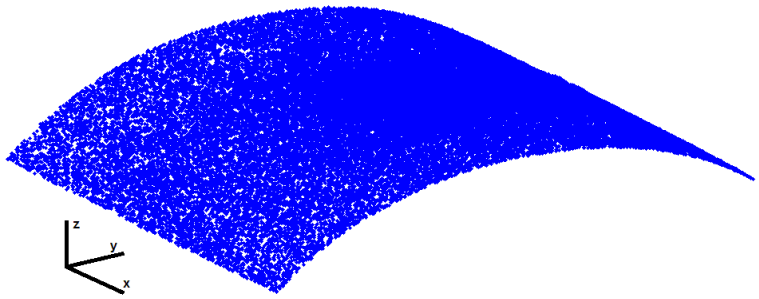
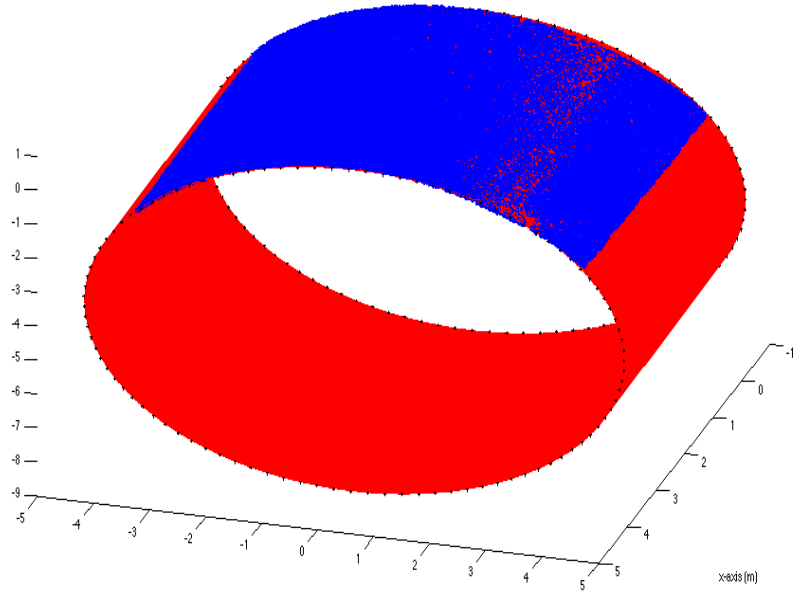
Geometry-based diagnosis using laser scanning

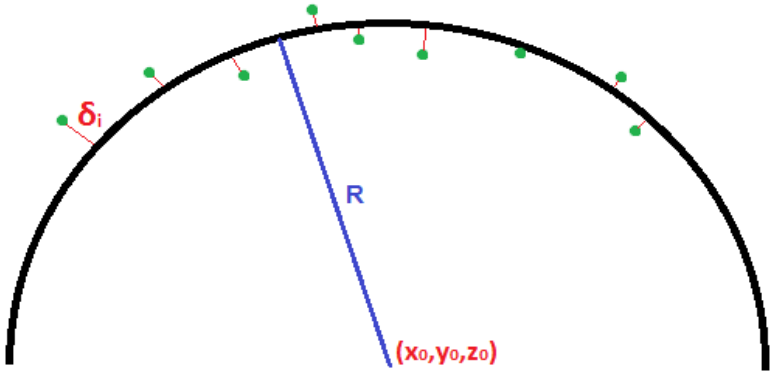
- Extensive research on load capacity
  - Have good methods to predict this
- Big problem of existing settlements/deformations/damage, cyclic loading, gradual degradation.
  - Must quantify current conditions and deterioration rate



Bristol Rail Bridge



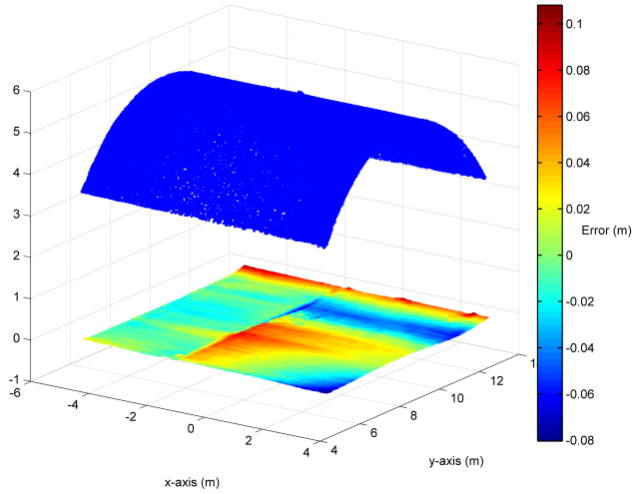


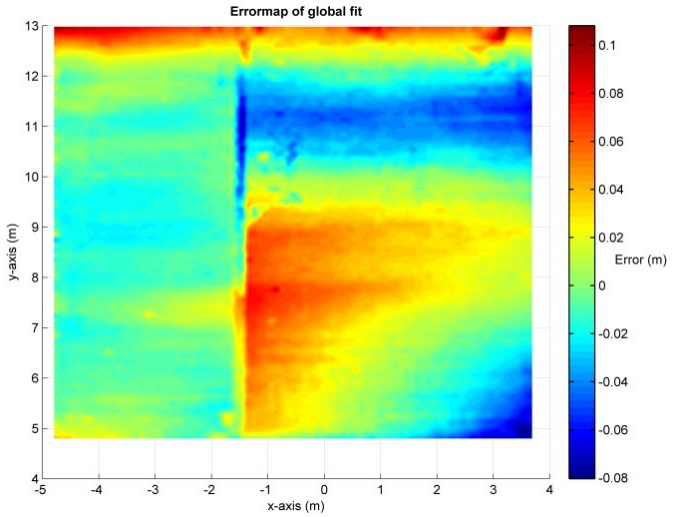


Bristol Rail Bridge (South arch)

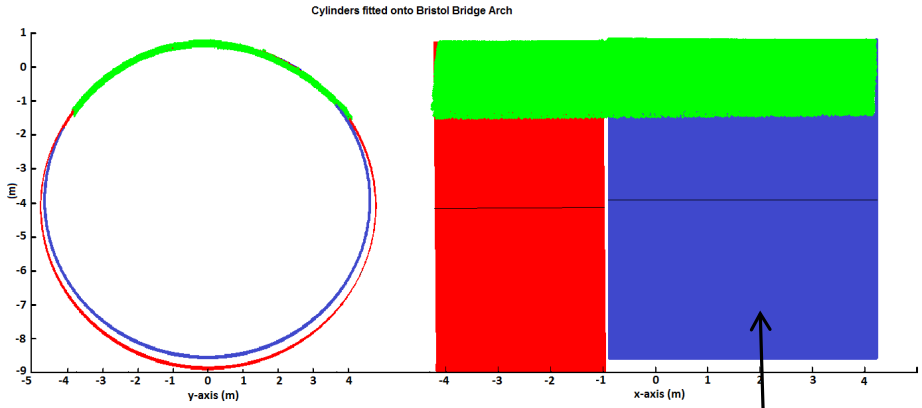
North

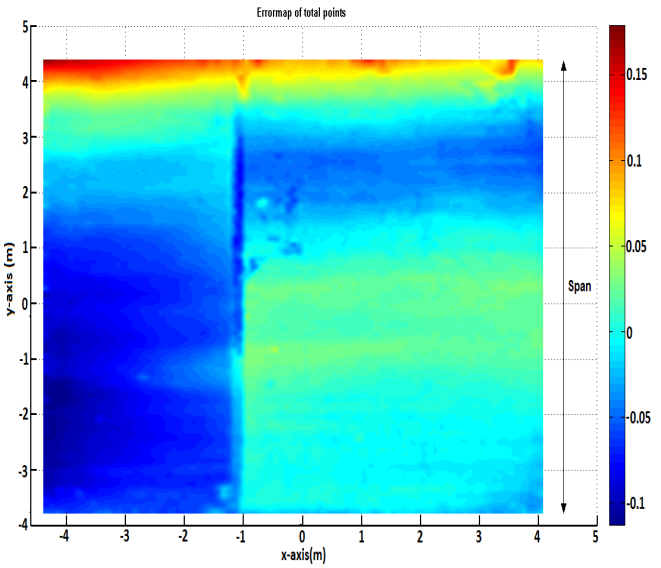
South Arch:





South Arch (re-fit):





Only fit half

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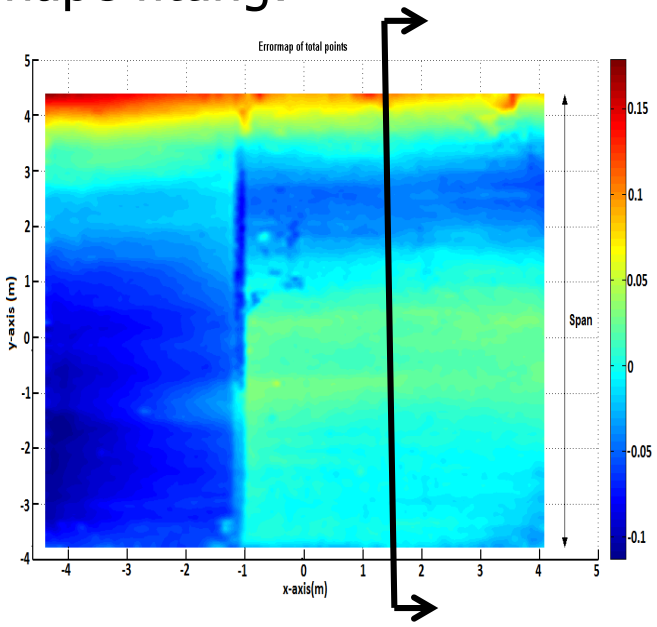
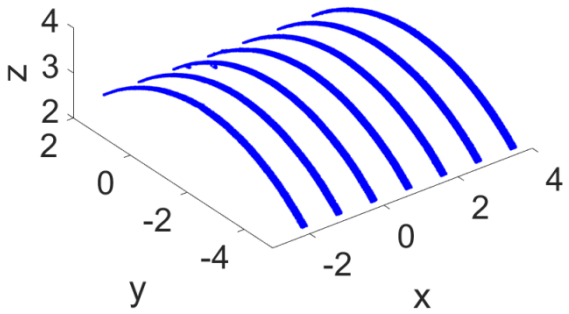
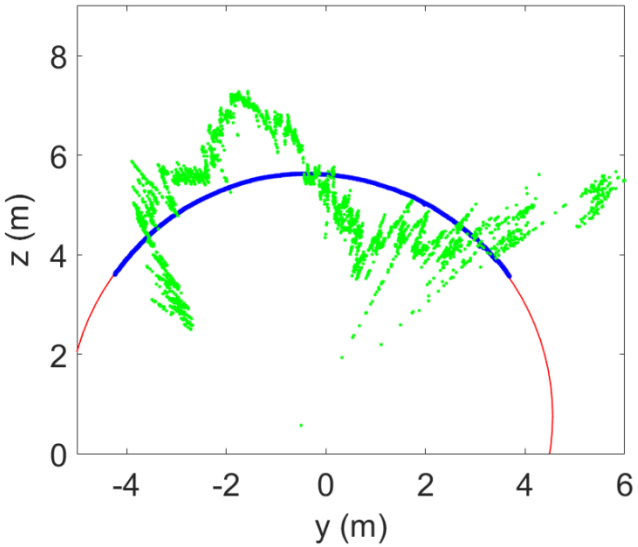
3D shape fitting:



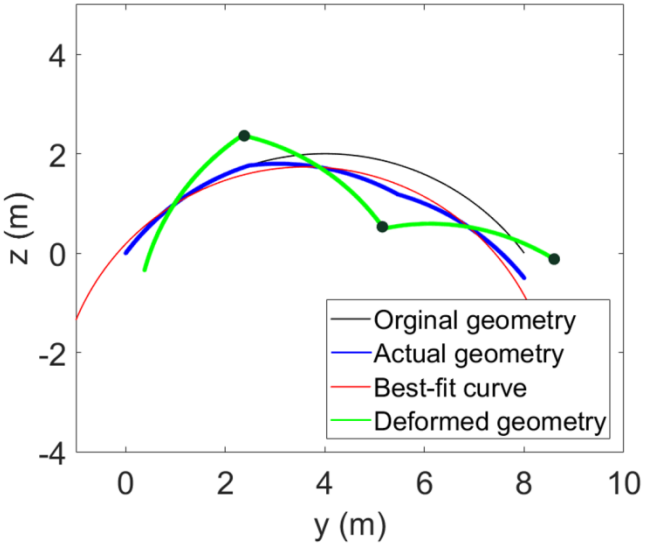
"2D" shape fitting (strips):



Example data:



Interpretation:



Arch mechanism database:

Example data:

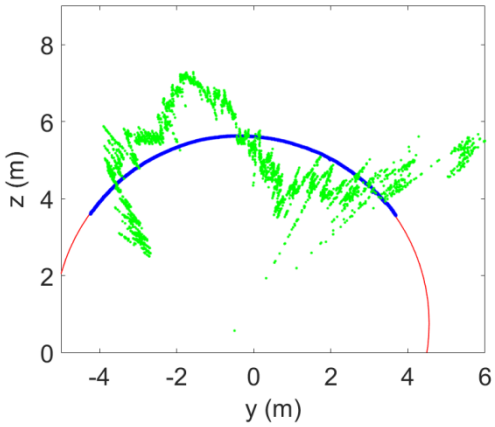
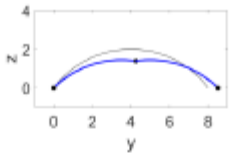
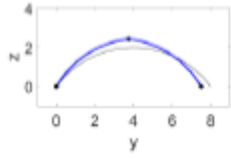
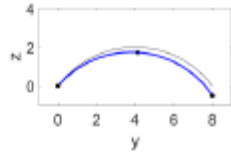
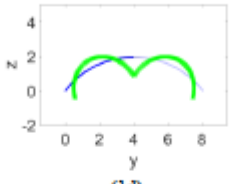
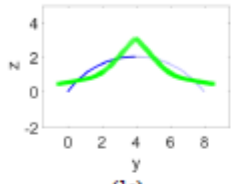
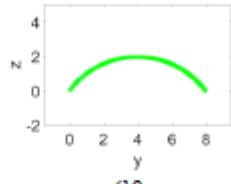
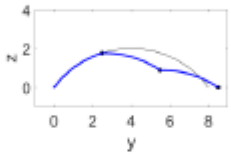
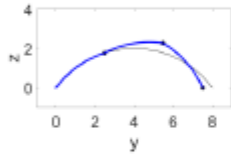
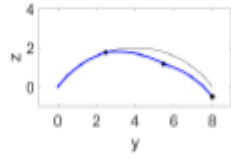
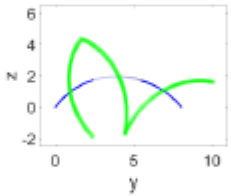
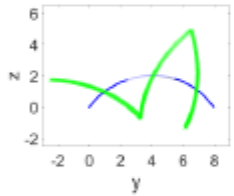
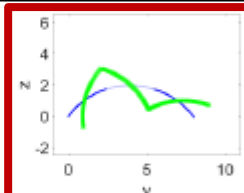
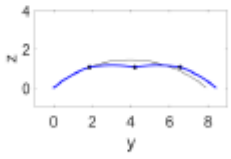
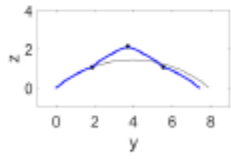
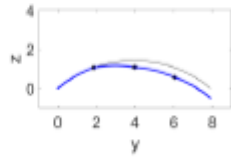
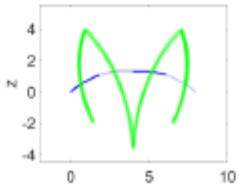
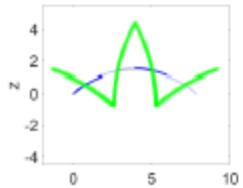
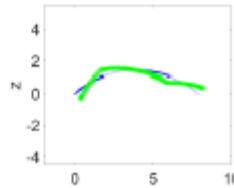


Table 4: Theoretical arch mechanism database

	Opening	Closing	Settlement of right pier
Complete mechanism			
Schematic diagram	 (1a)	 (1b)	 (1c)
2D error map	 (1d)	 (1e)	 (1f)
Partial asymmetric mechanism			
Schematic diagram	 (2a)	 (2b)	 (2c)
2D error map	 (2d)	 (2e)	 (2f)
Partial symmetric mechanism			
Schematic diagram	 (3a)	 (3b)	 (3c)
2D error map	 (3d)	 (3e)	 (3f)

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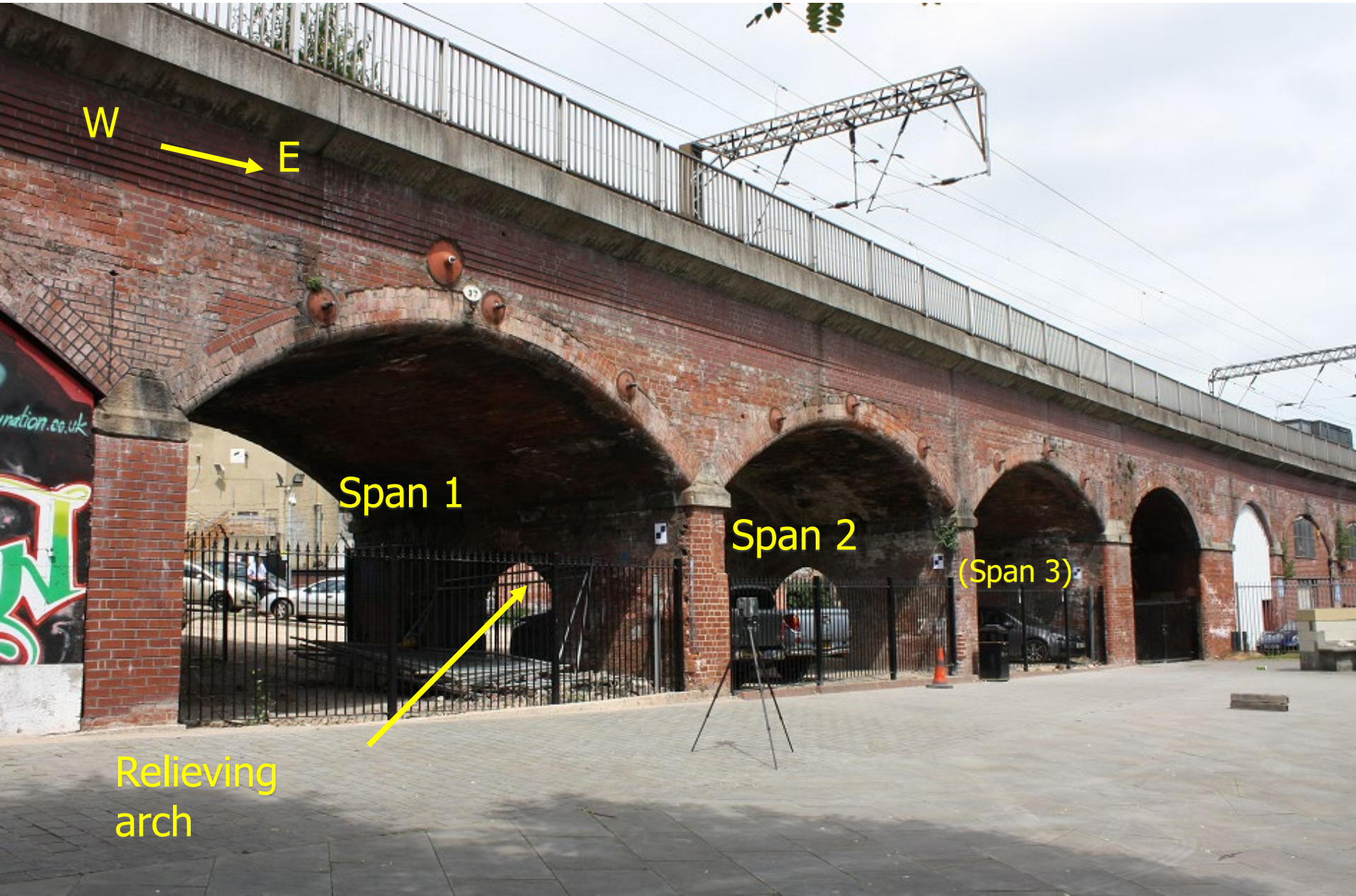
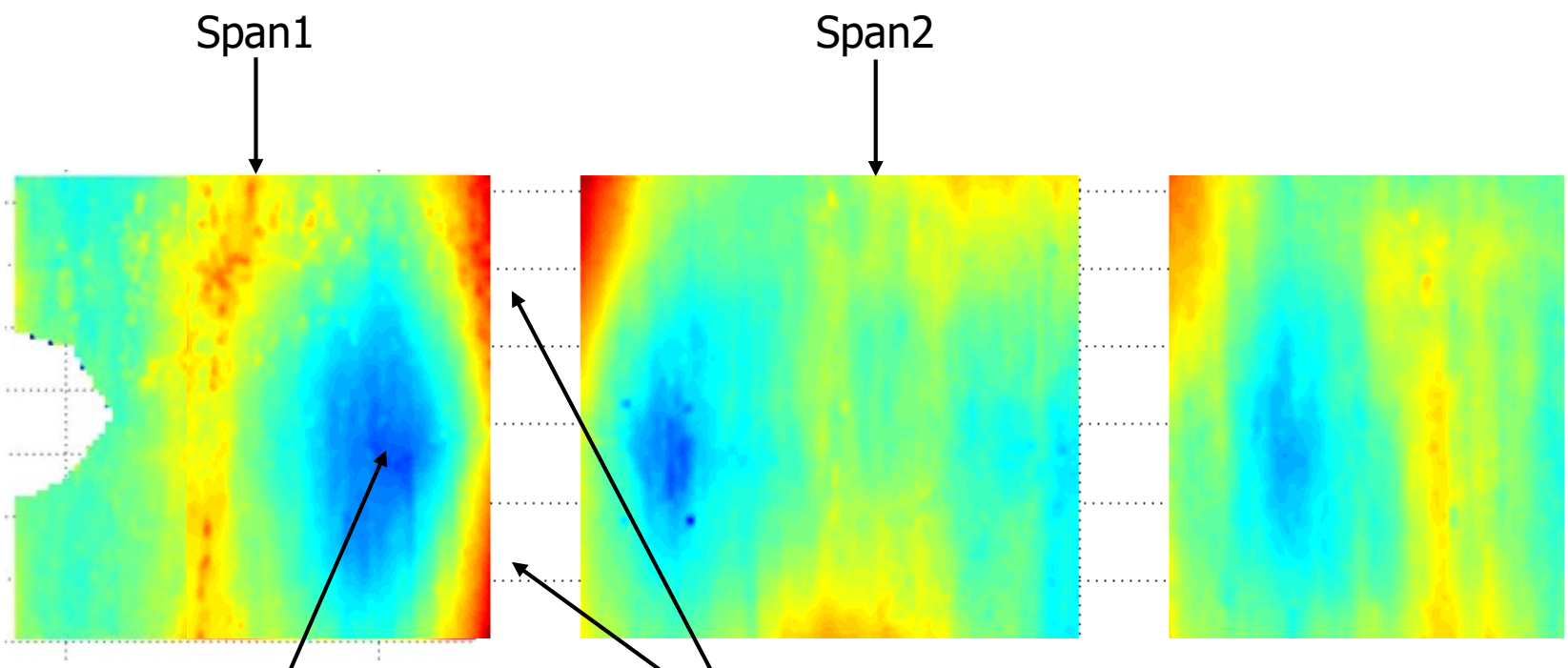
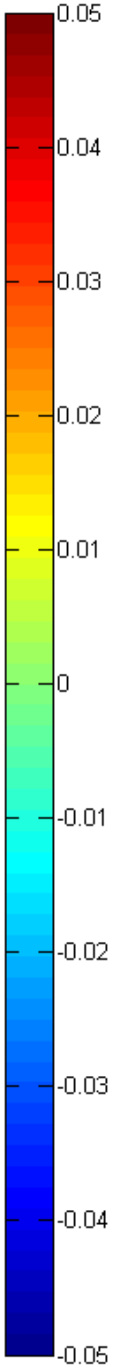
Rail Viaduct, Leeds



Laser-scan results – Investigated historic movements





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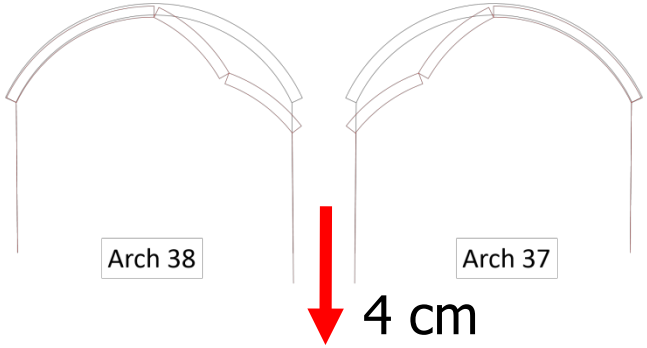
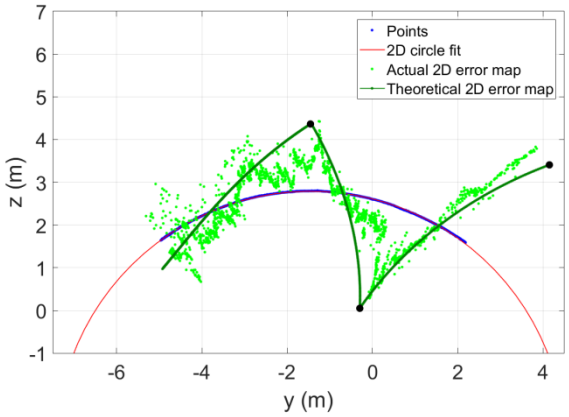
Settlement due to relieving arch

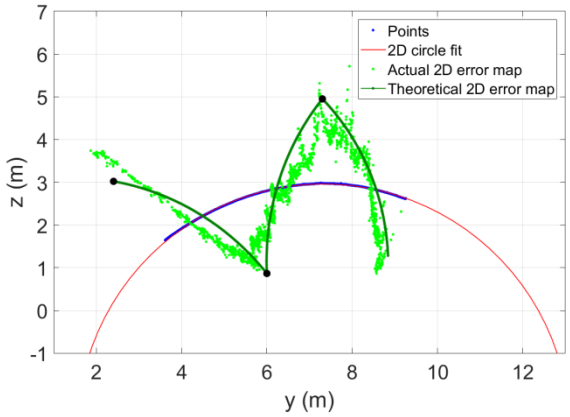
Section through centreline (above relieving arch):



Interpretation:

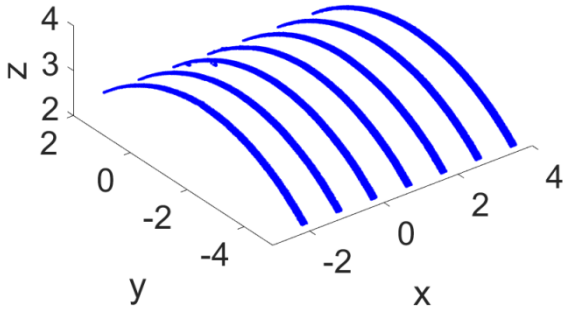


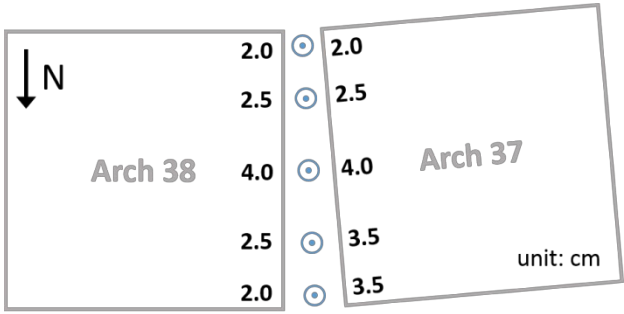
(a) Arch 38, centreline, relative west (right) pier settlement of 4 cm



(b) Arch 37, centreline, relative east (left) pier settlement of 4 cm

Across width:





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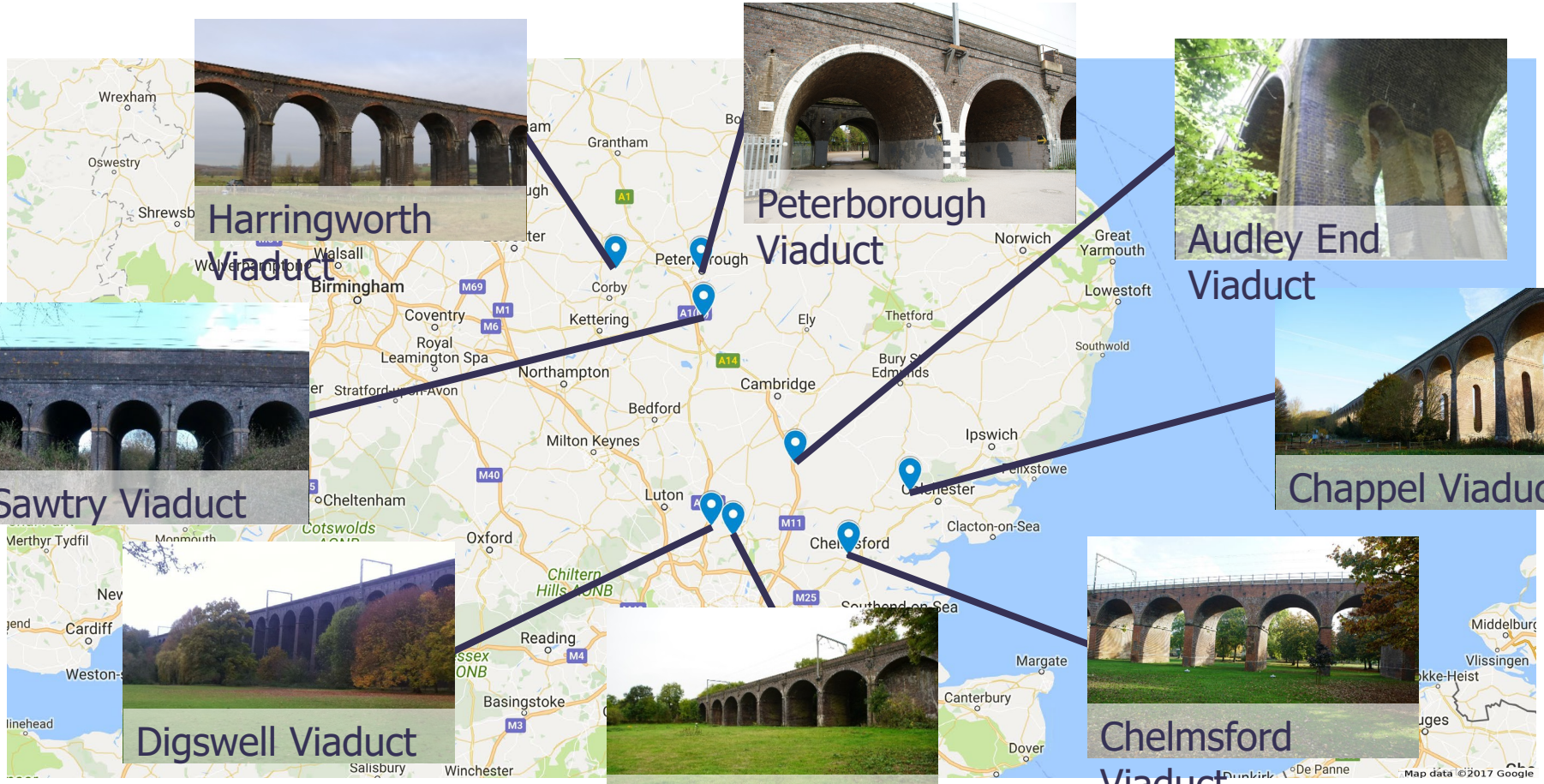
Ye et al. (2018) "Mapping deformations and inferring movements of masonry arch bridges using point cloud data", *Engineering Structures*.

Broader application



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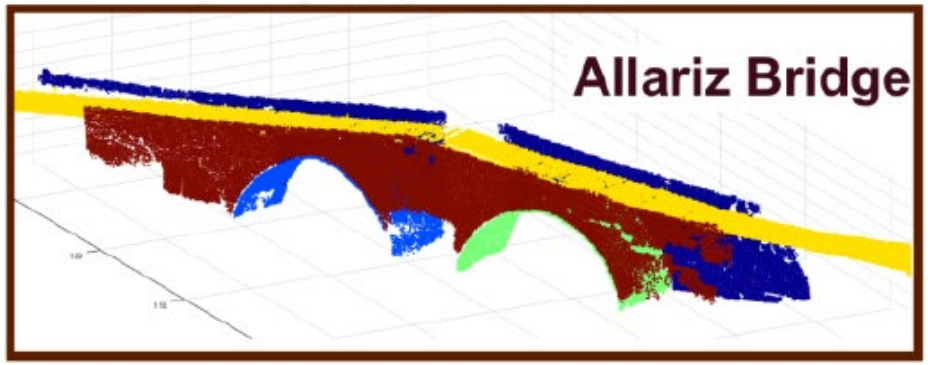
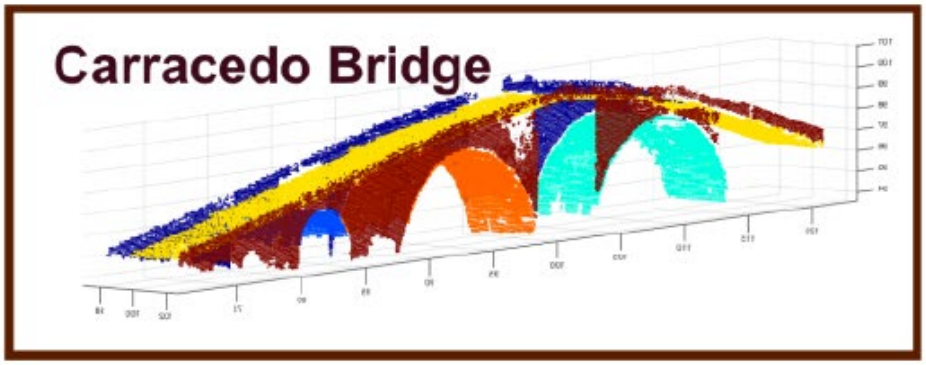
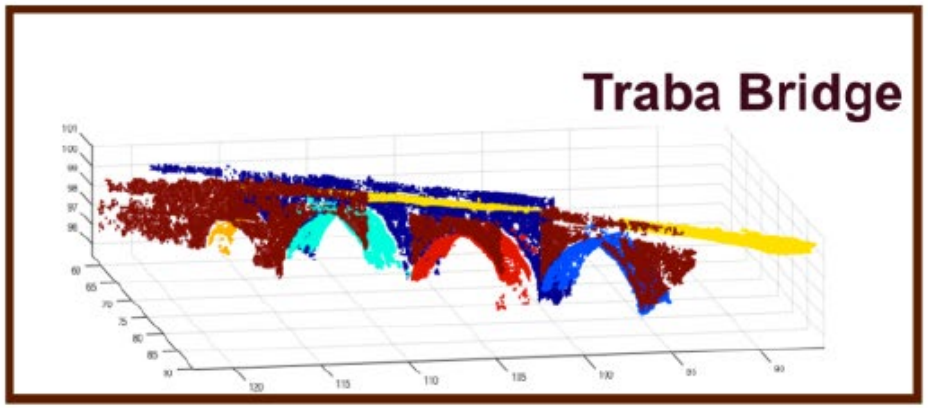
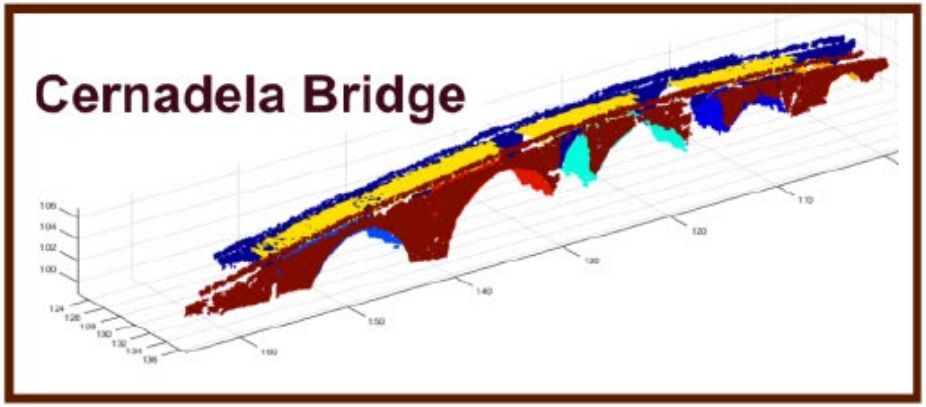
Automated Segmentation









Automating the visual inspection of masonry arch bridges

- Dan Brackenbury (PhD student)
- Matt DeJong (PI)

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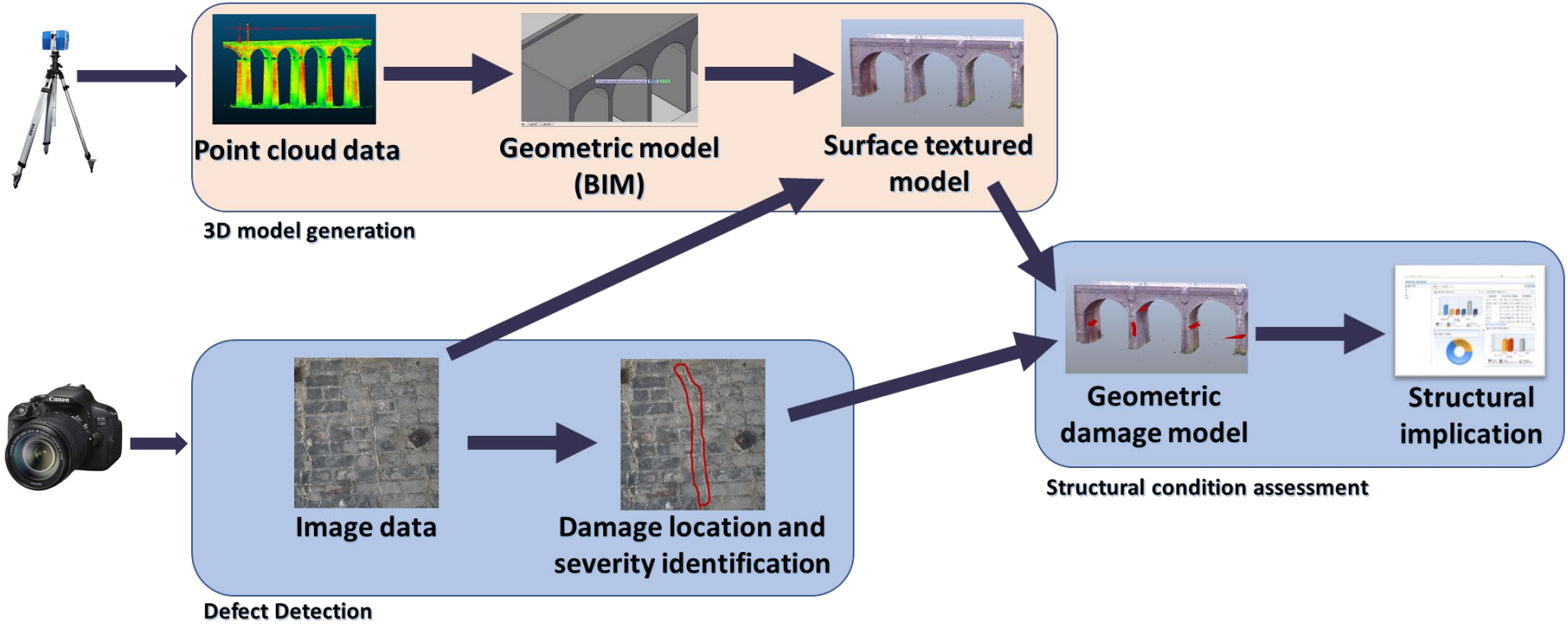
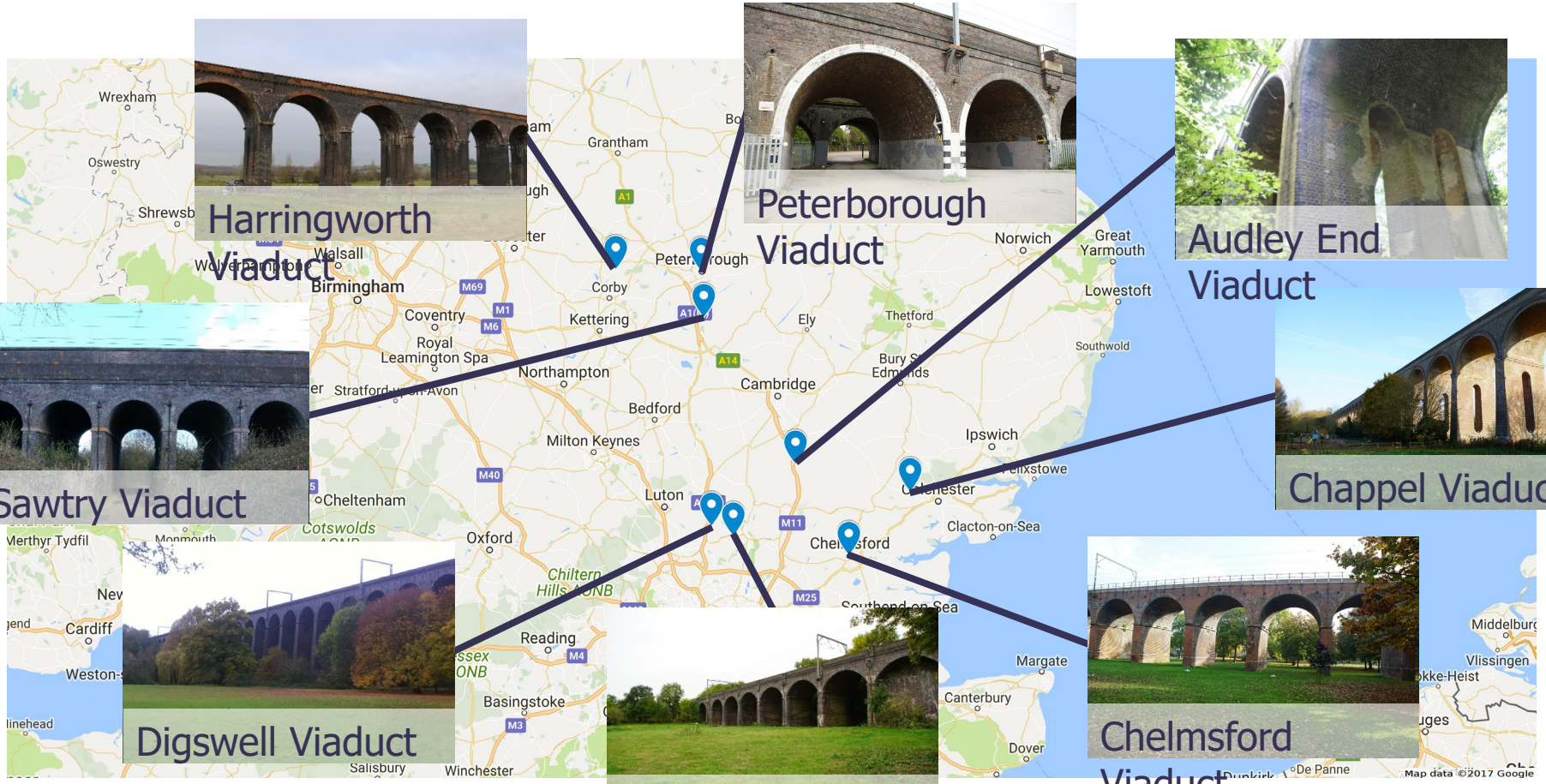
Overview


Point cloud data
Geometric model (BIM)
Surface textured model
3D model generation
Image data
Damage location and severity identification
Defect Detection
Geometric damage model
Structural implication
Structural condition assessment

Data collection



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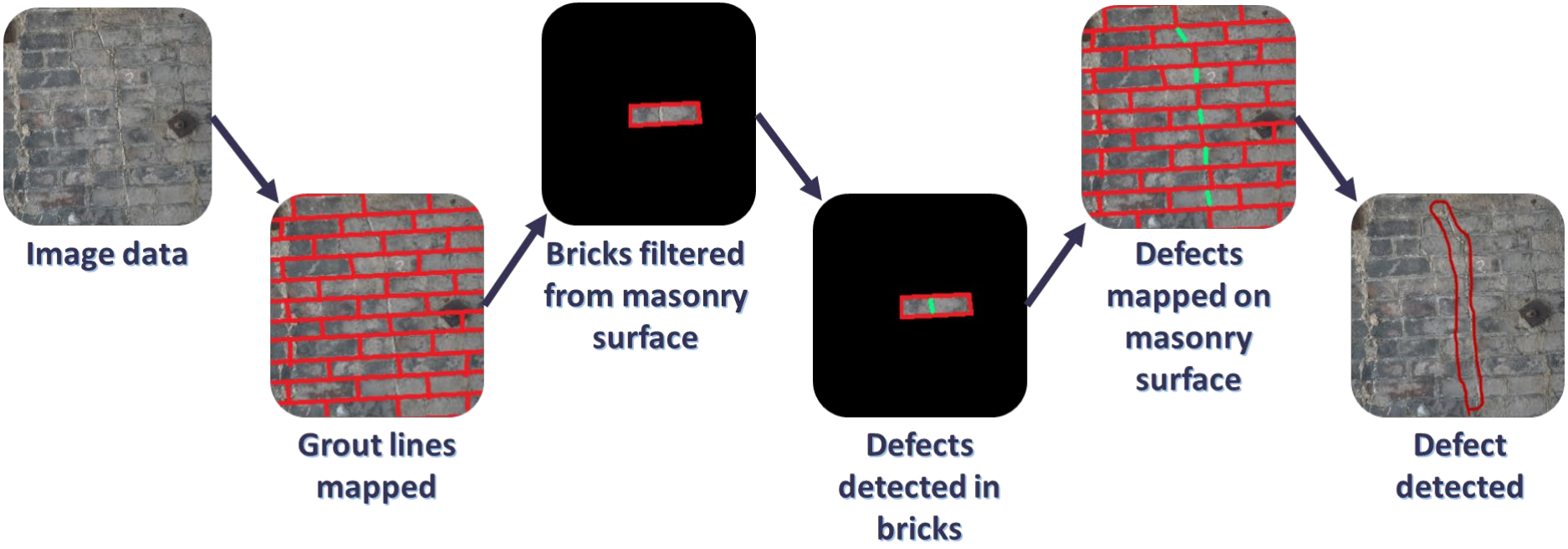
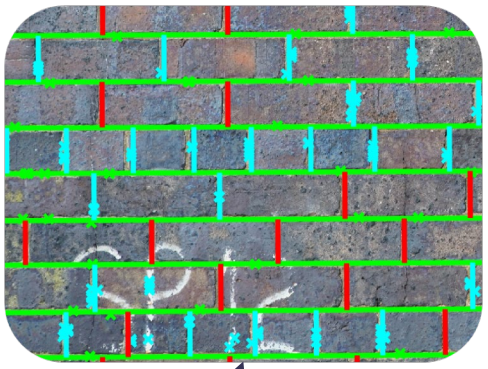
Methodology



Grout Line masking

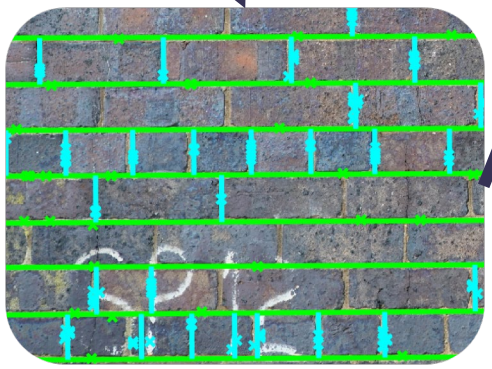
Image data

Line Detection



Pattern detection

Edge detection



Grout line plotting

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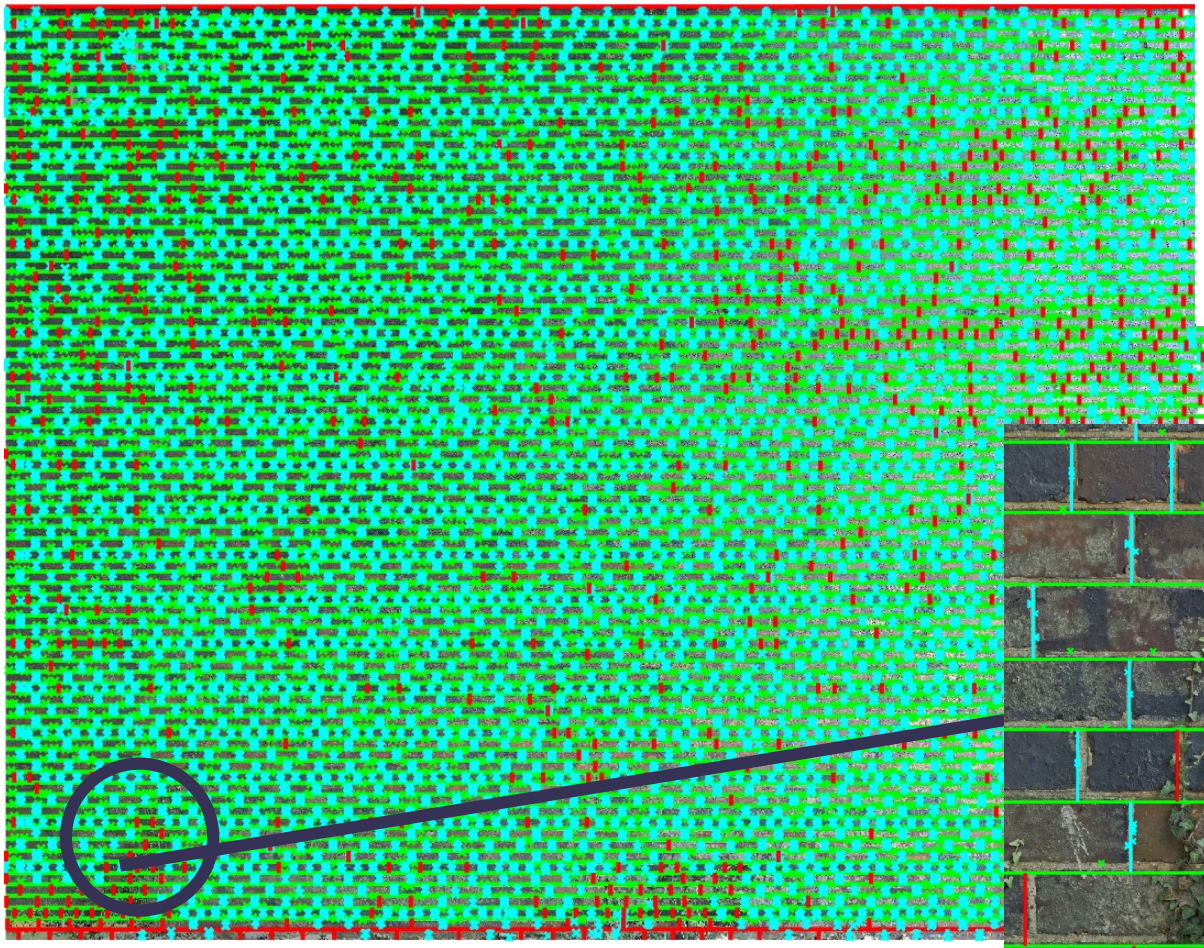
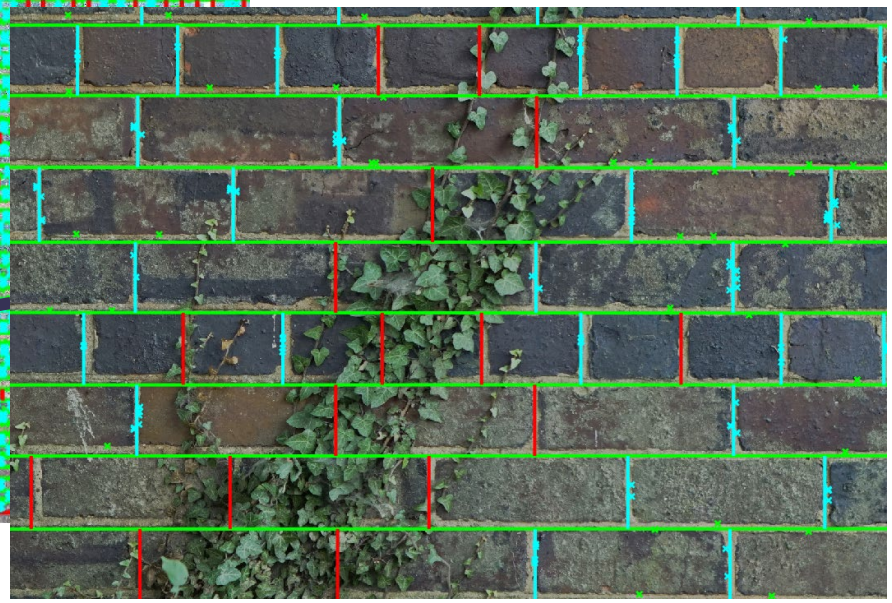
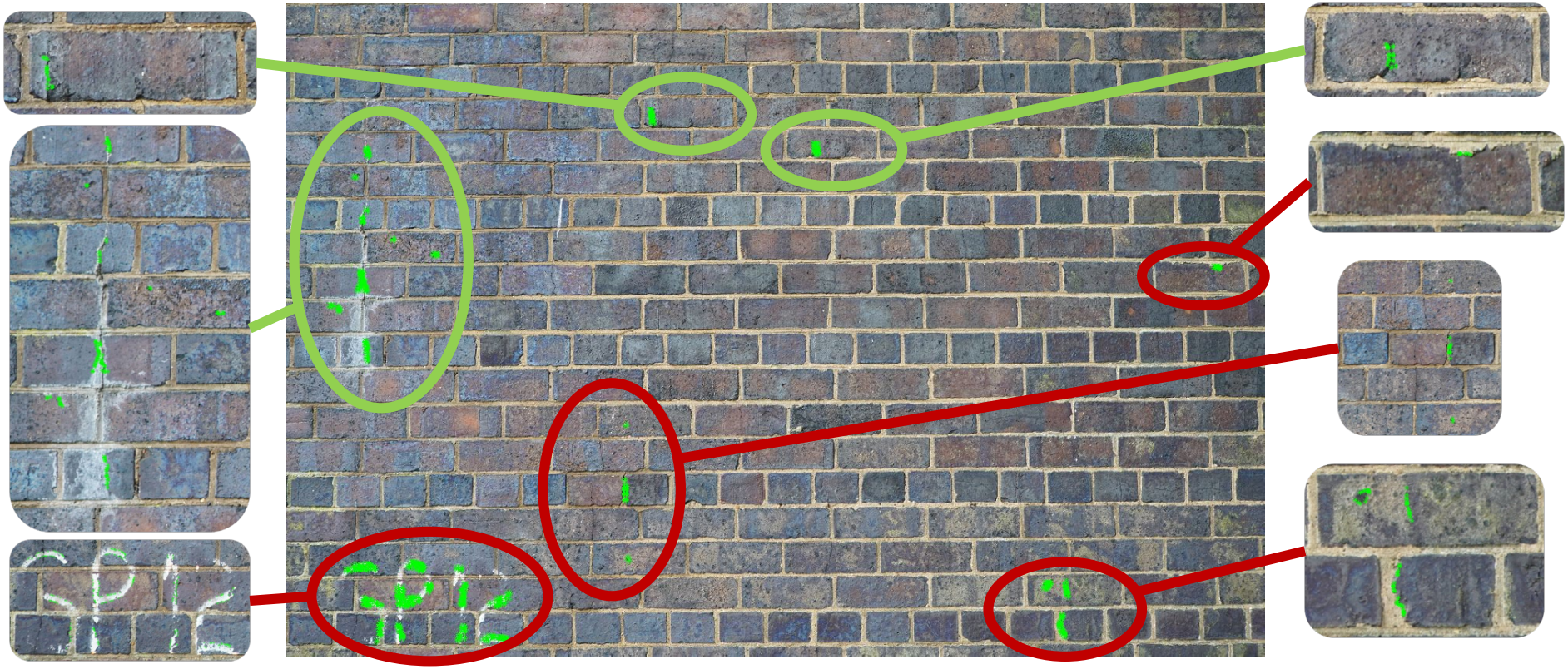
Example grout line masking output

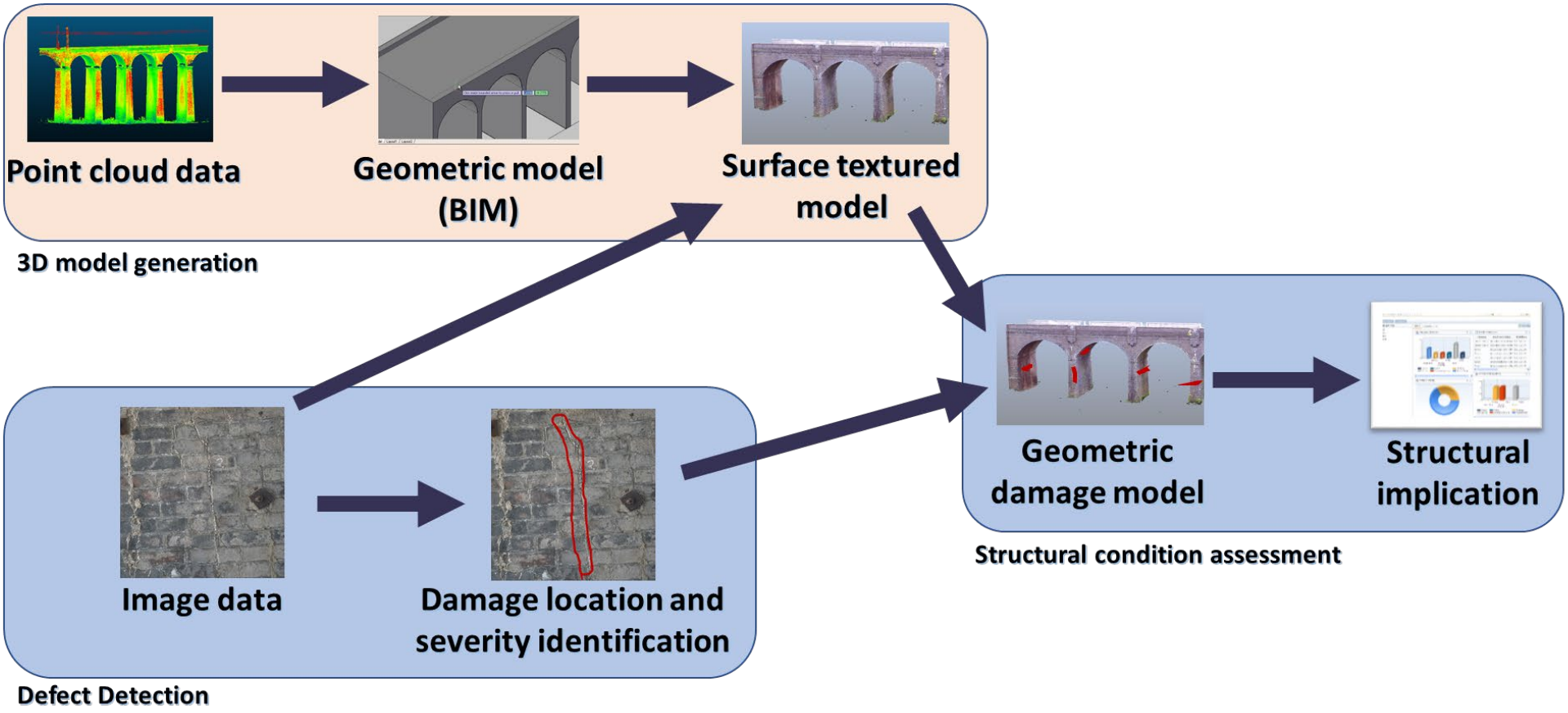




Example Defect Detection Output



Big picture


Point cloud data
Geometric model (BIM)
Surface textured model
3D model generation
Image data
Damage location and severity identification
Defect Detection
Geometric damage model
Structural implication
Structural condition assessment

Train-Bridge Interaction Monitoring

(understanding dynamic response)

- Sinan Acikgoz (post-doc)
- Kenichi Soga (Co-I)
- Matt DeJong (PI)

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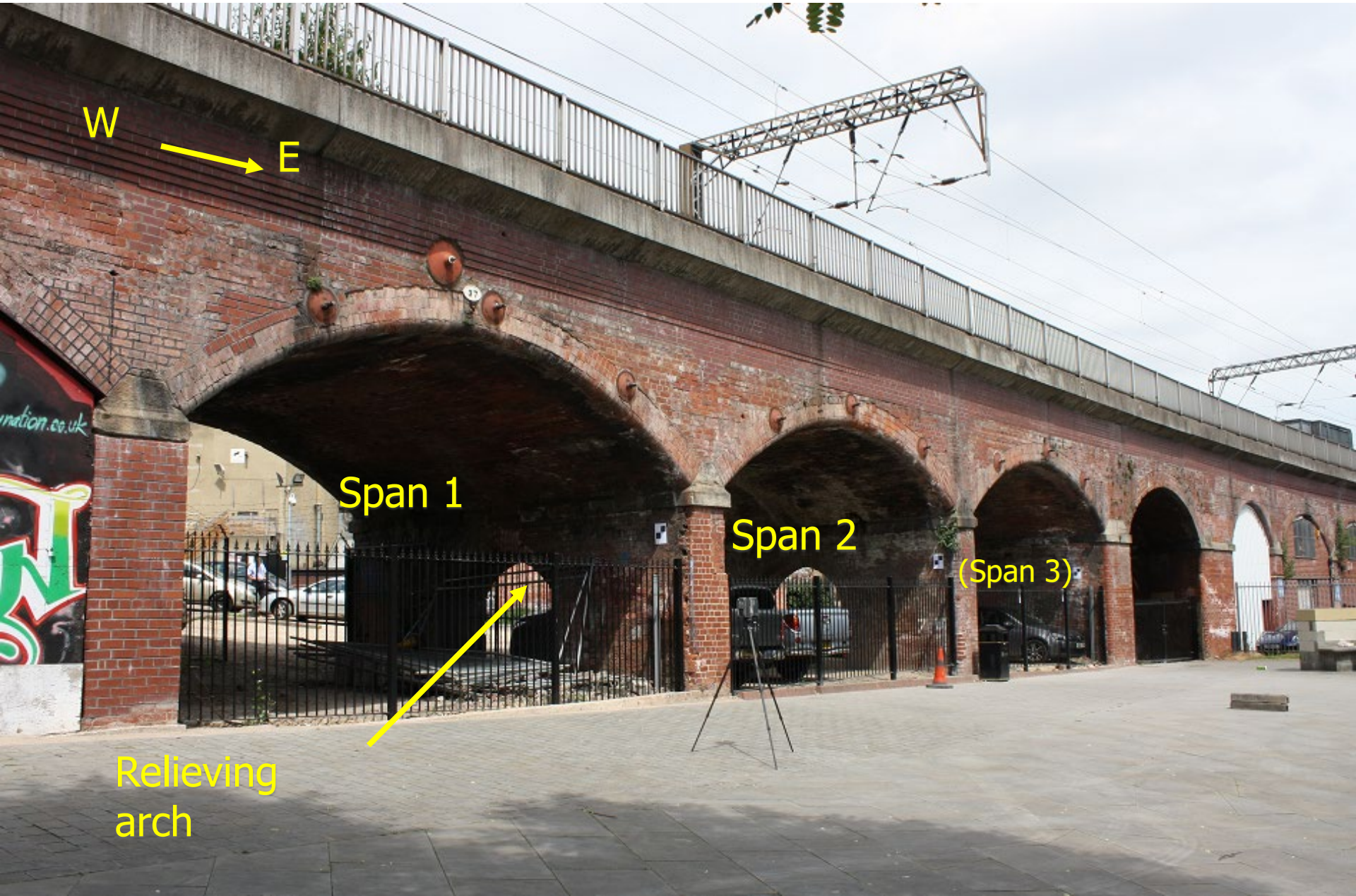
NetworkRail

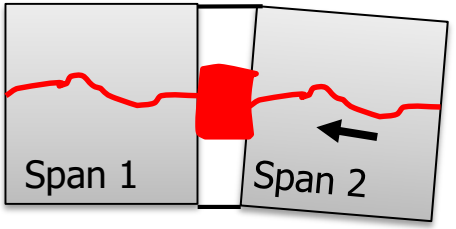
EPSRC Engineering and Physical Sciences Research Council

Innovate UK

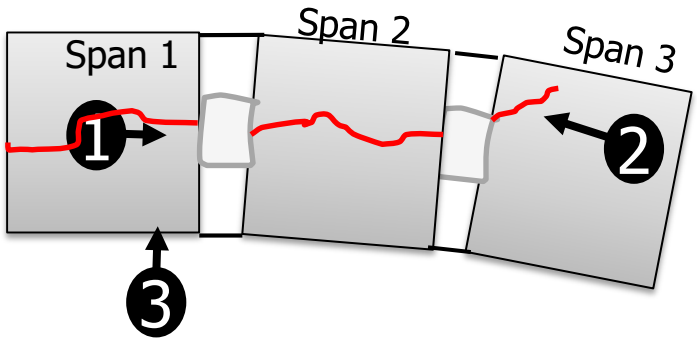
Rail Viaduct, Leeds

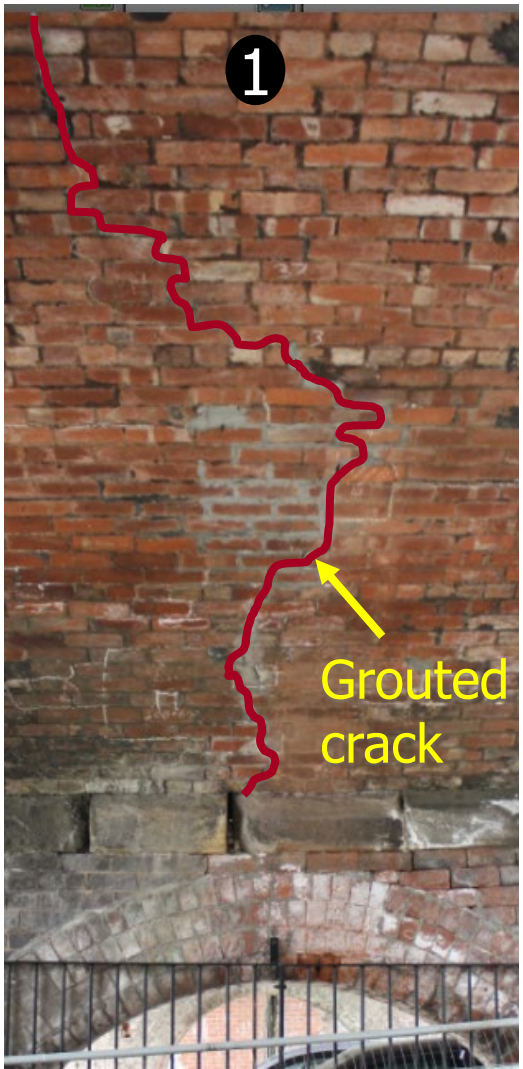


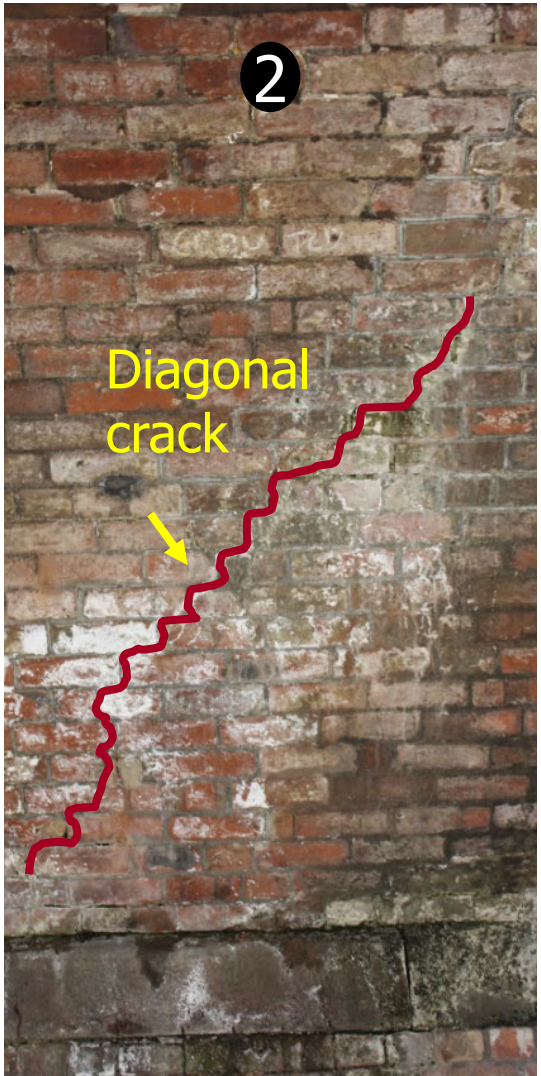
Existing Damage



Existing Damage

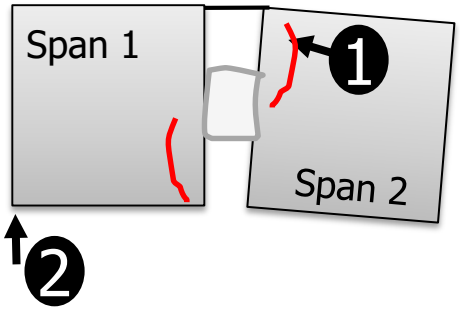


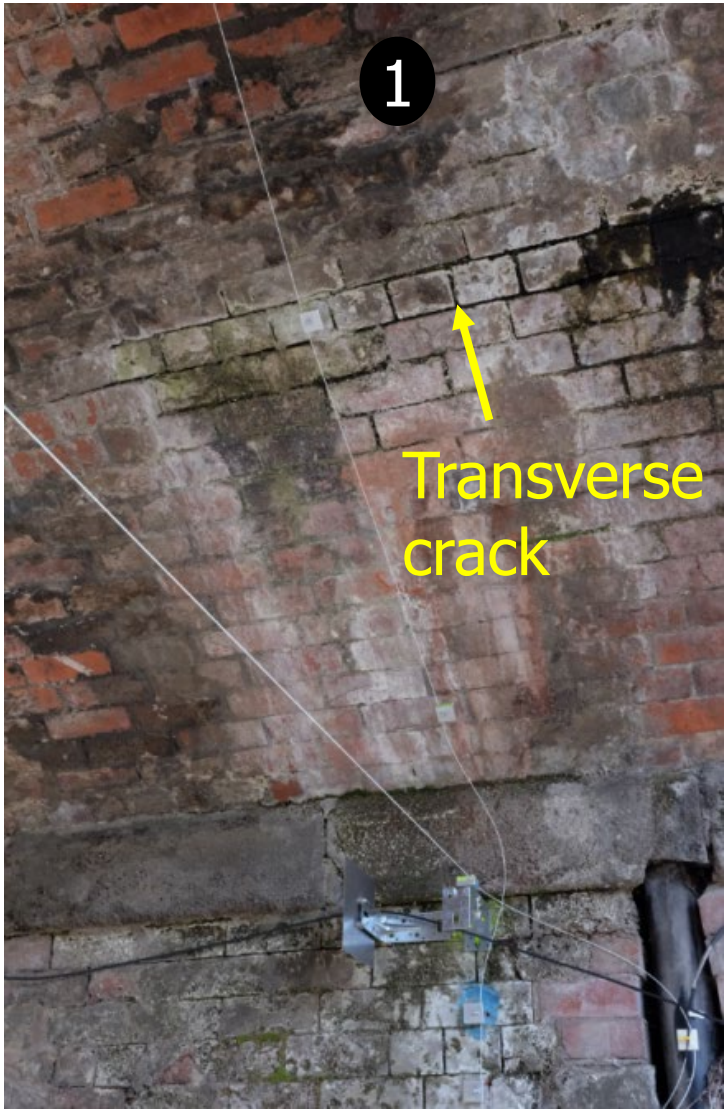


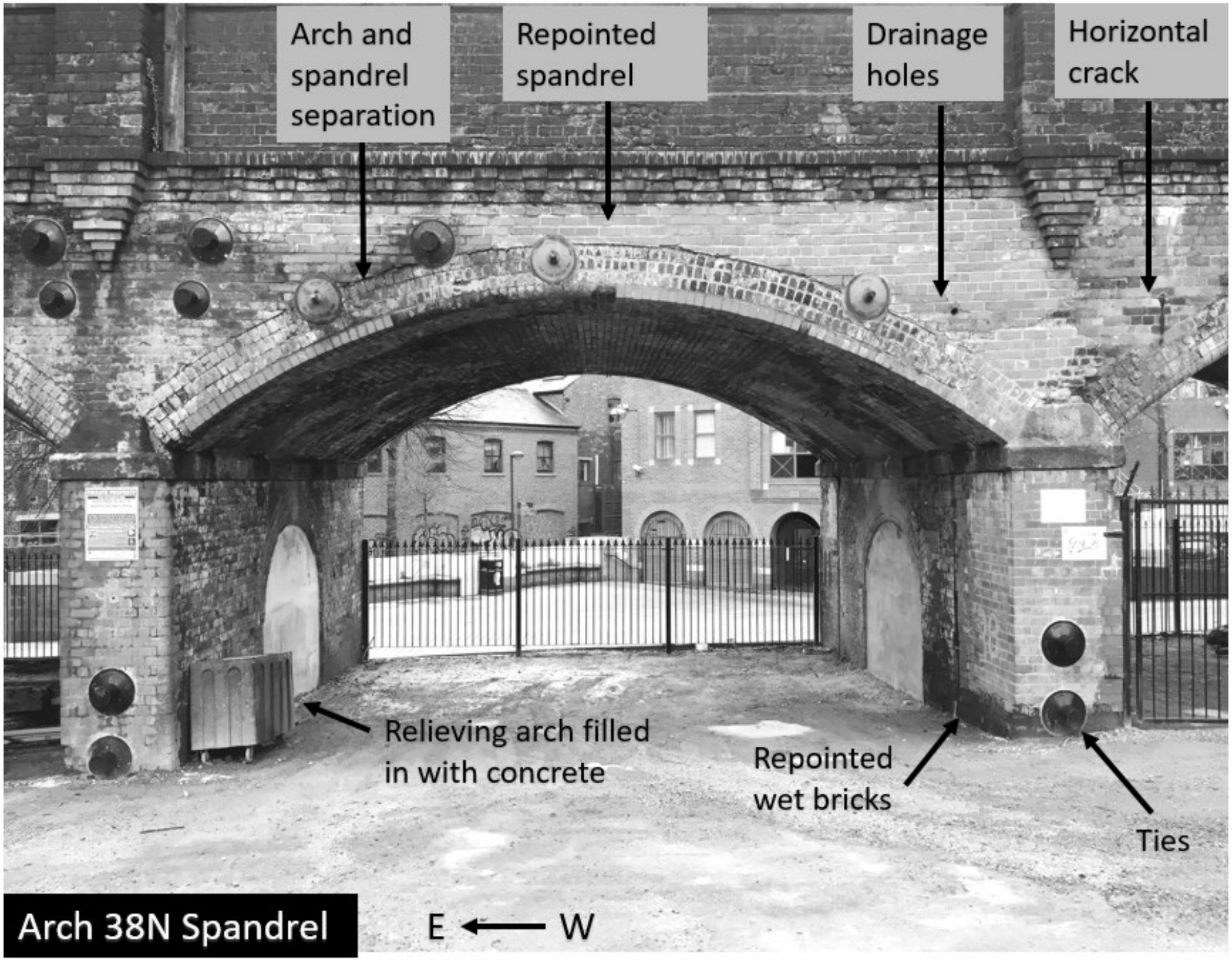


- Cause? Torsion?
- Effect on dynamic response?

Existing Damage






Arch and spandrel separation
Repointed spandrel
Drainage holes
Horizontal crack
Relieving arch filled in with concrete
Repointed wet bricks
Ties
Arch 38N Spandrel
E ← W

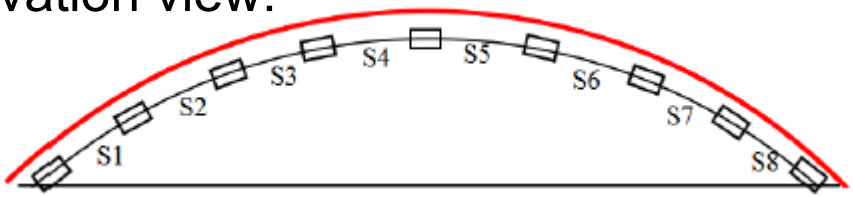
Objectives

- To understand cause of past damage and characterise the dynamic response of the damaged bridge.

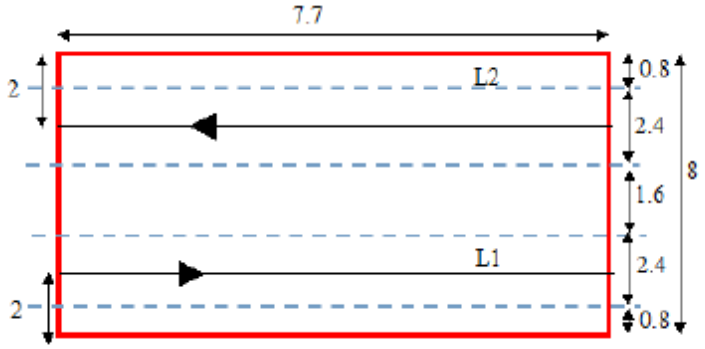
- Use this information to improve structural assessment and asset management.

Sensing techniques: Fiber Bragg Grating (FBG)

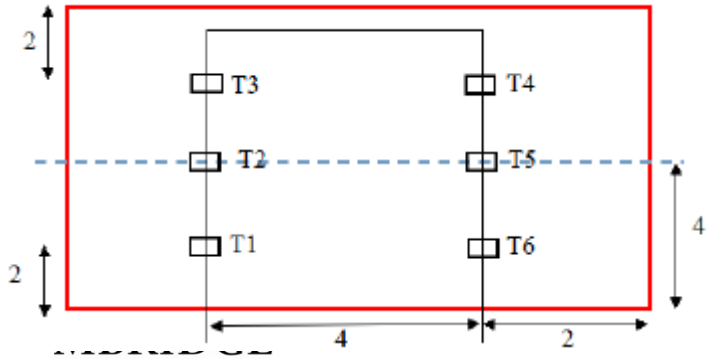
Elevation view:



Plan view:



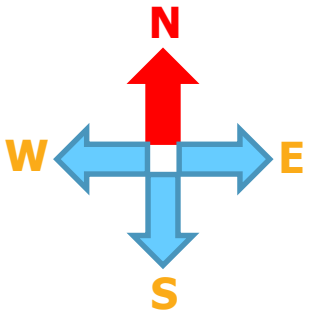
Plan view:



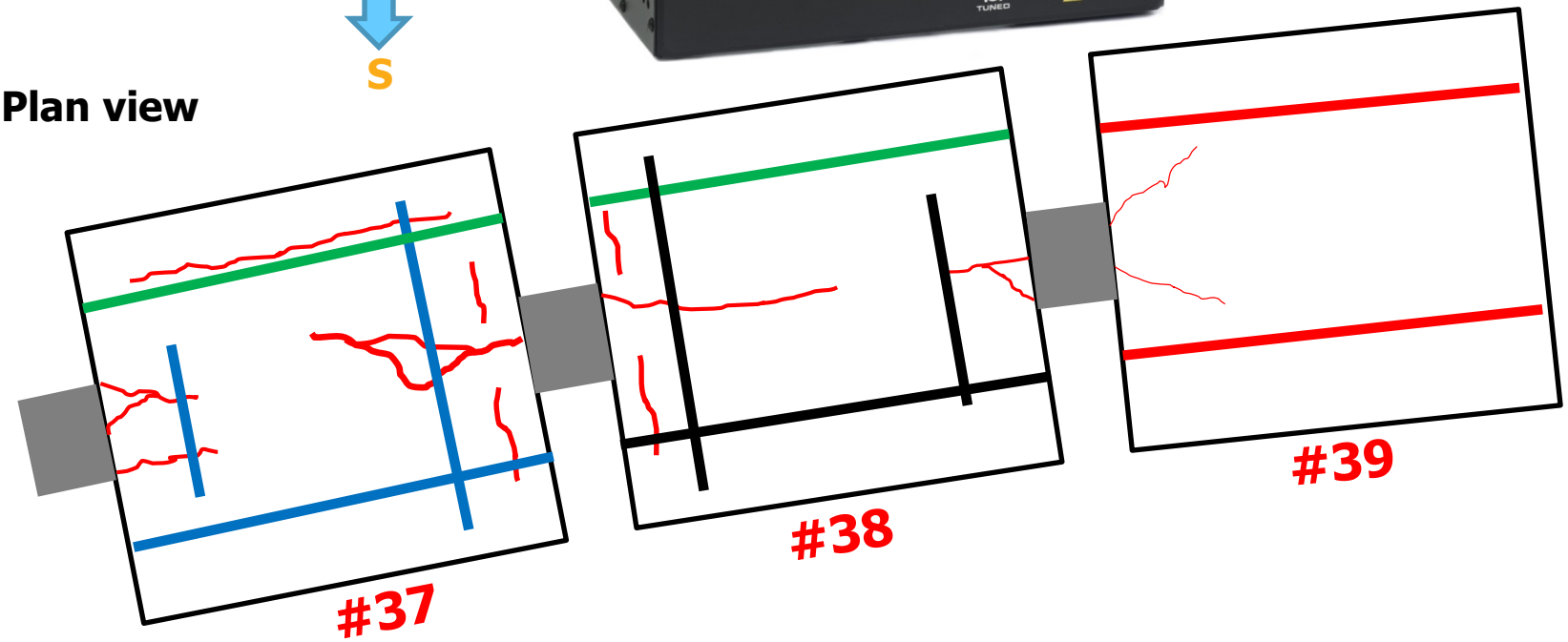
Why FBG?

- Measure dynamic strain (1 kHz)
- High precision (5$\mu\varepsilon$ error)
- Cover large areas
- Reliable in demanding environments
- Understand 3D dynamic response (strain distributions)

FBG “Arrays”



Plan view



4 channels = 80 strain sensors!

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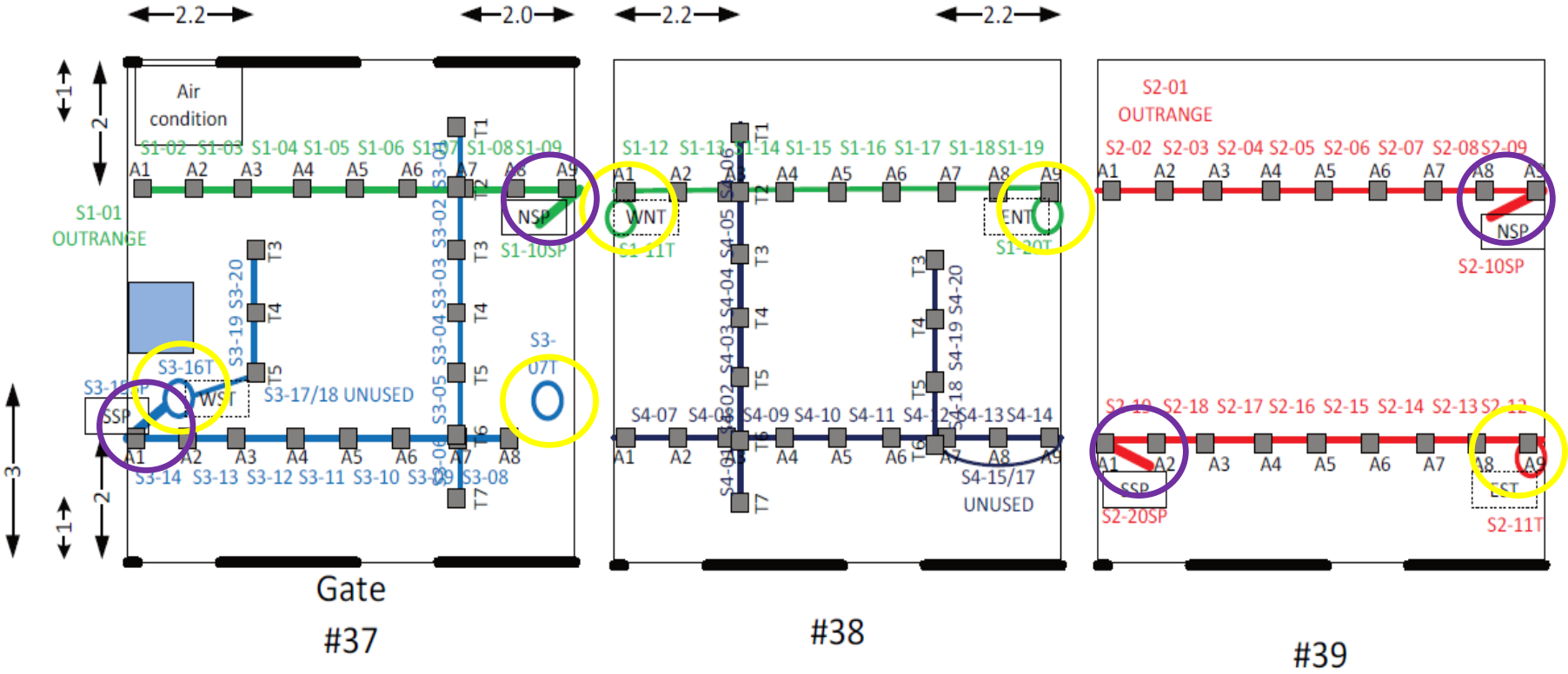
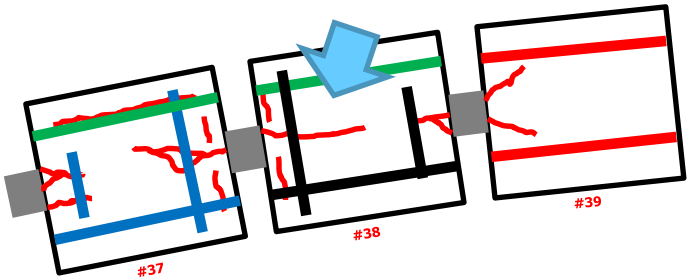
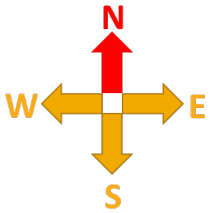
Compensate Temperature
Temperature sensors
Sensor attached to the steel wire

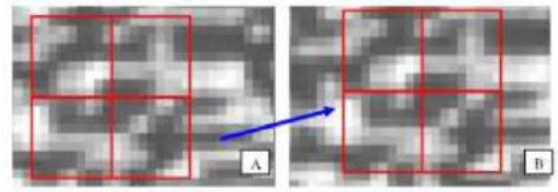

2.2
2.0
2.2
2.2
Air condition
S1-01 OUTRANGE
S1-02 S1-03 S1-04 S1-05 S1-06 S1-07 S1-08 S1-09
A1 A2 A3 A4 A5 A6 A7 A8 A9
NSP
S1-10SP
S3-16T
S3-17/18 UNUSED
S3-14 S3-13 S3-12 S3-11 S3-10 S3-09 S3-08
S3-
07T
WNT
S1-11T
S1-12 S1-13 S1-14 S1-15 S1-16 S1-17 S1-18 S1-19
S4-07 S4-08 S4-09 S4-10 S4-11 S4-12 S4-13 S4-14
S4-15/17 UNUSED
S2-01 OUTRANGE
S2-02 S2-03 S2-04 S2-05 S2-06 S2-07 S2-08 S2-09
S2-10SP
S2-18 S2-17 S2-16 S2-15 S2-14 S2-13
S2-20SP
S2-11T
Gate
#37
#38
#39


#37
#38
#39


N
W
E
S

Sensing techniques

Videogrammetry (Imetrum)



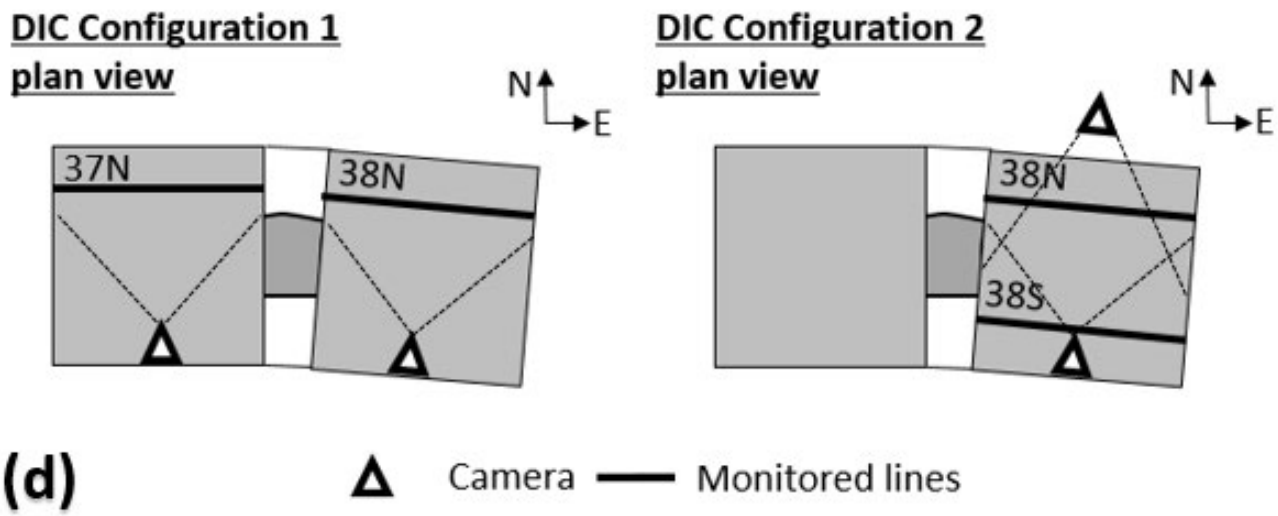
- Measure dynamic displacements (0.1mm error)
- Understand dynamic response mechanisms

Laser scanning

- Measure structural geometry (2mm error)
- Quantify historic settlements and previous damage using point clouds

Videogrammetry

(c)



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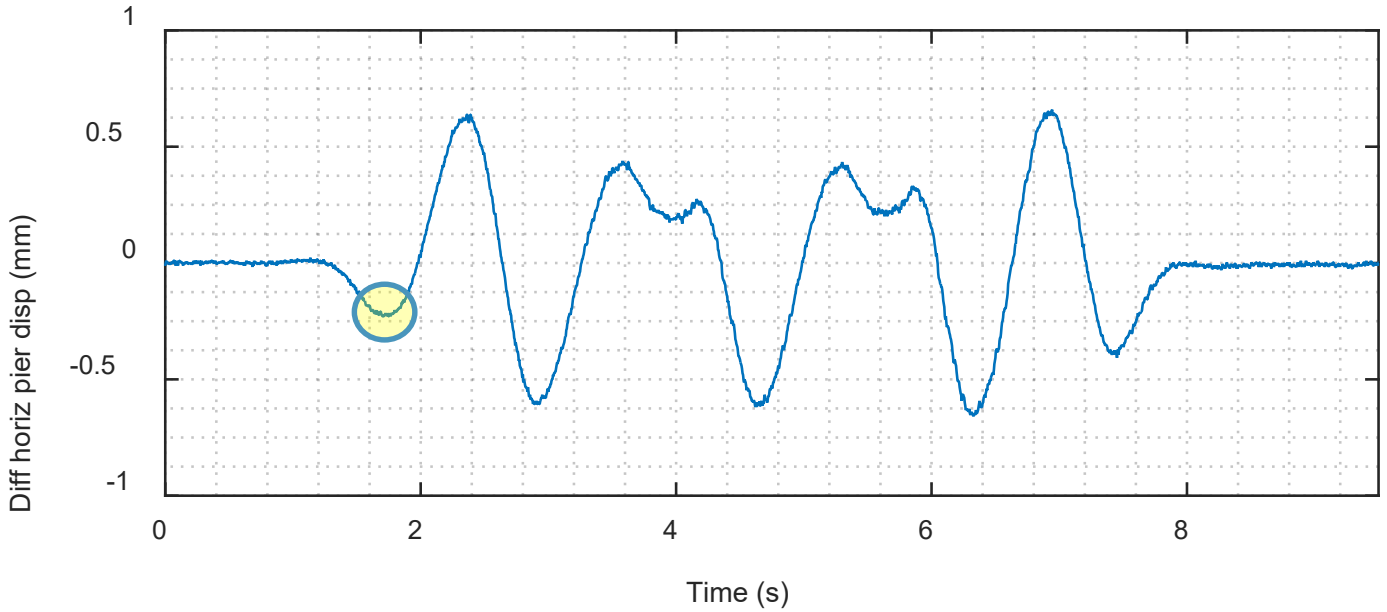
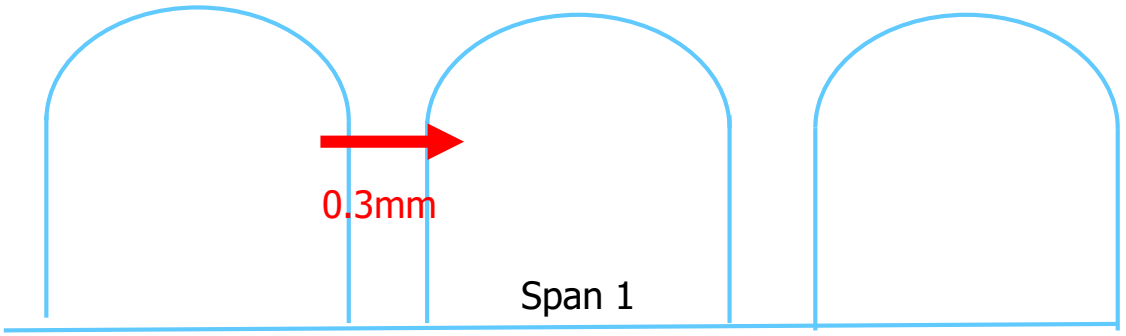
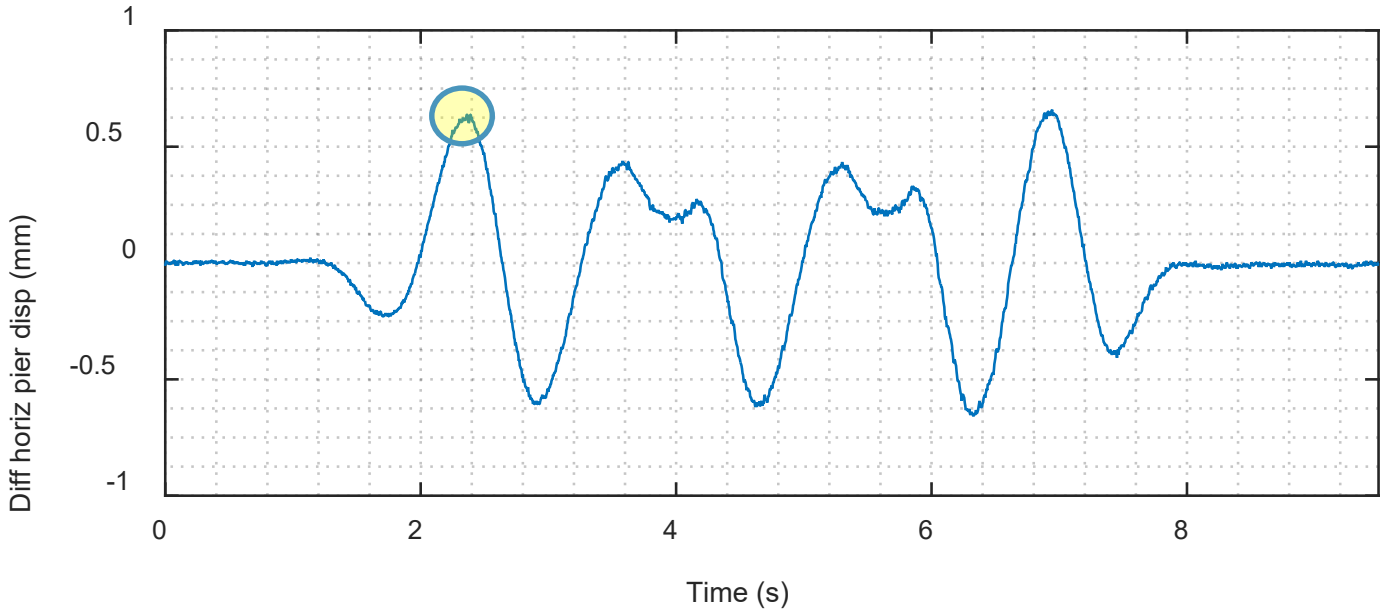
Acikgoz et al (2018) *Structural Control and Health Monitoring*

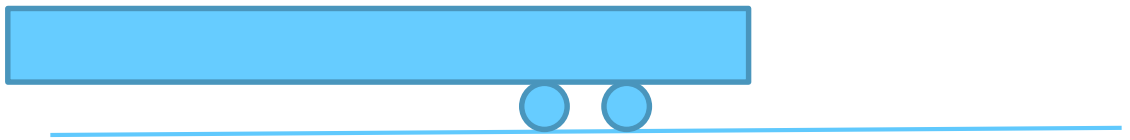
Dynamic results: Span opening and closing

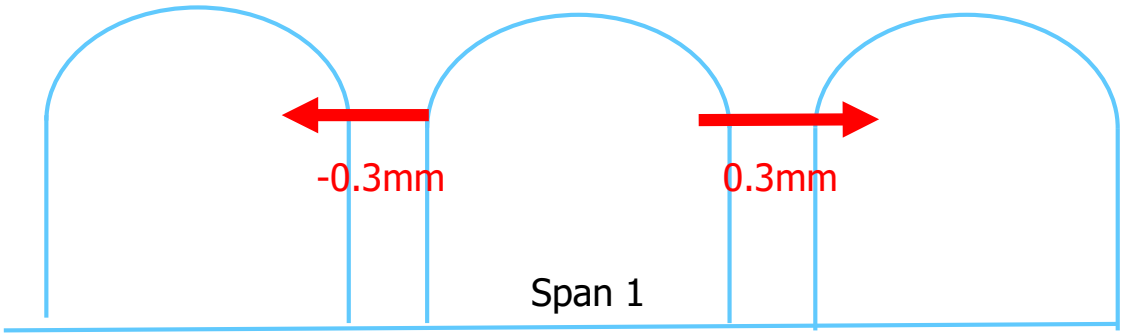




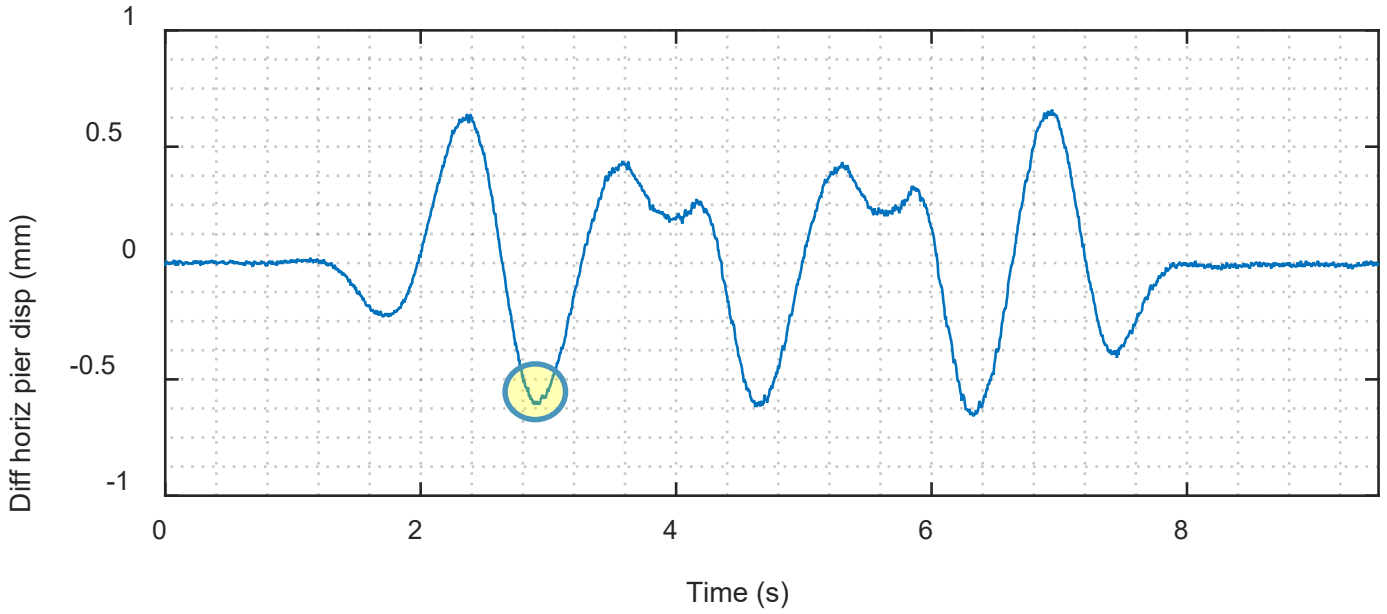
Dynamic results: Span opening and closing

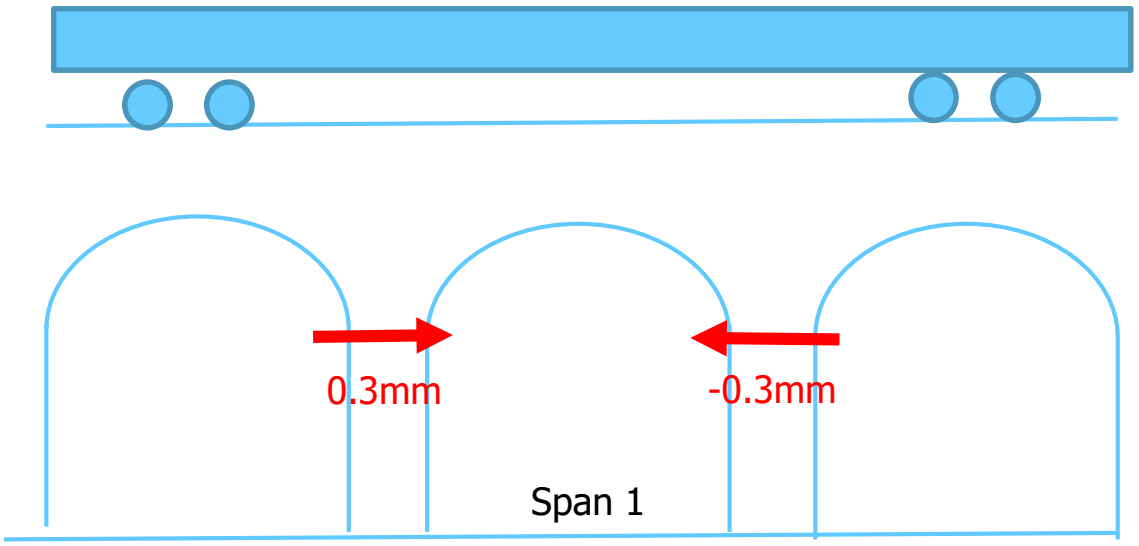




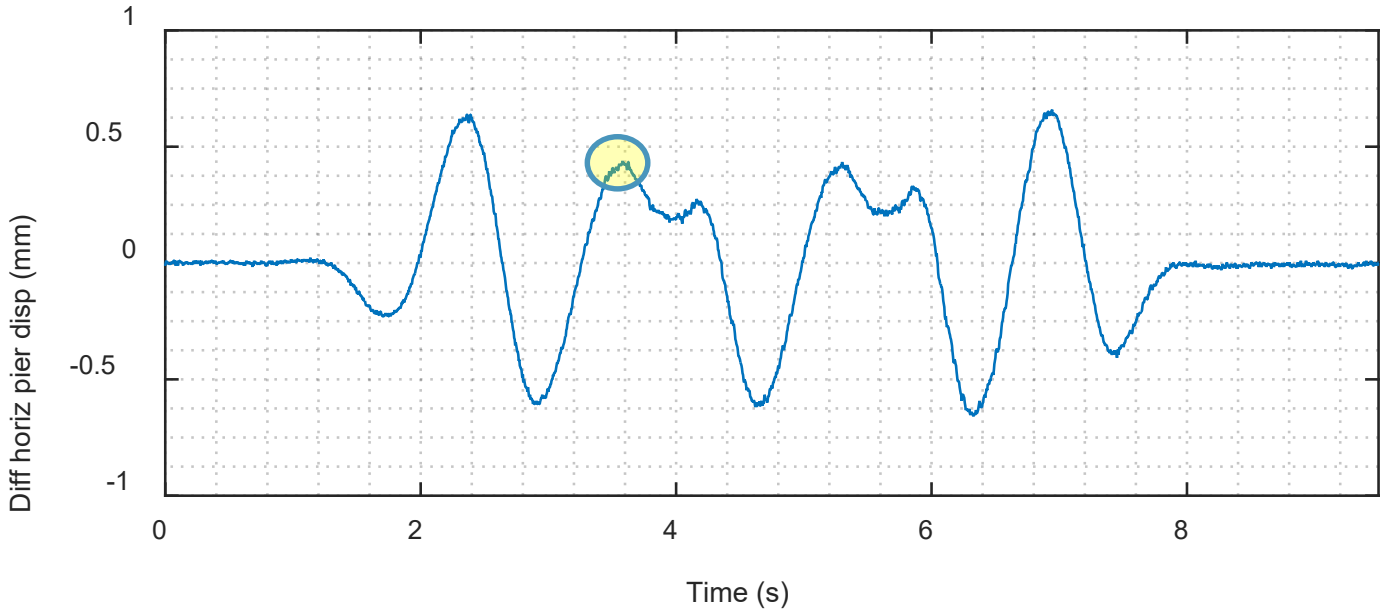


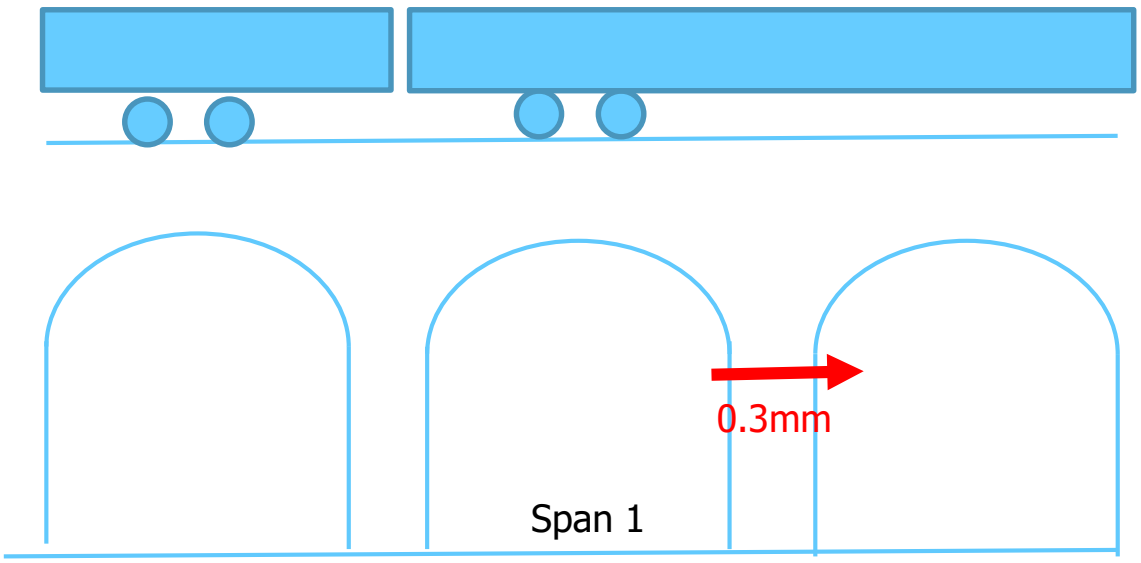
Dynamic results: Span opening and closing



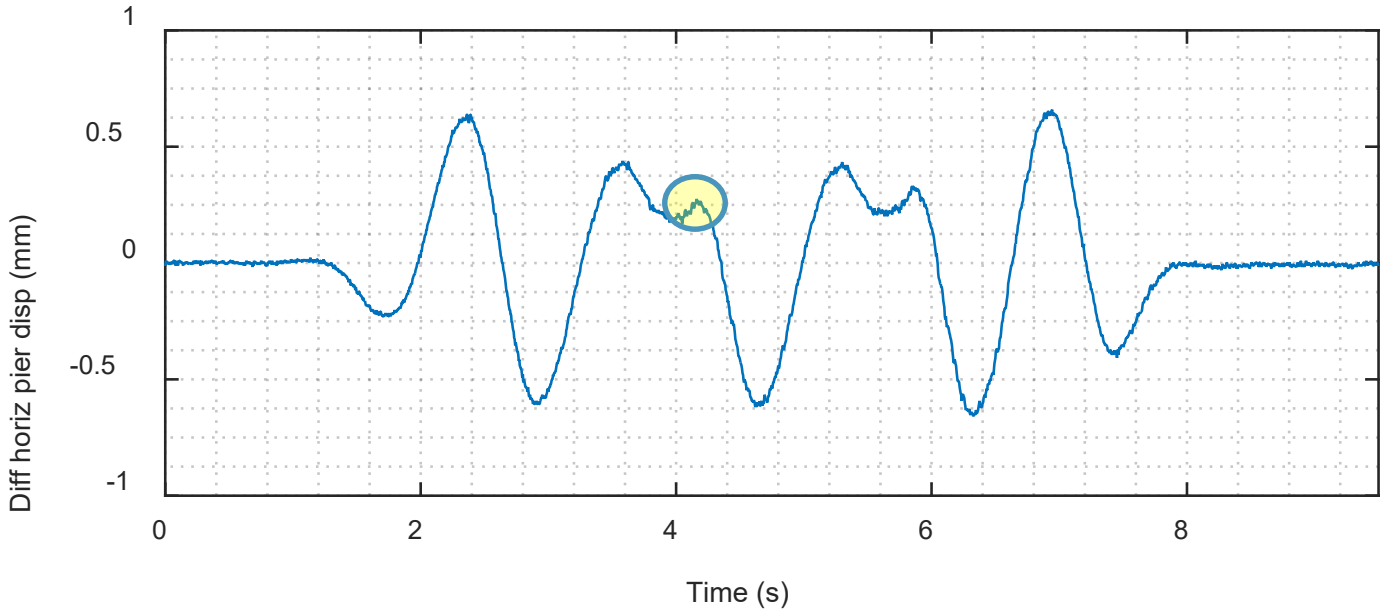


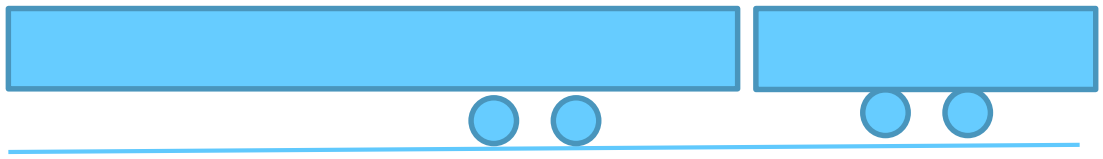
Dynamic results: Span opening and closing

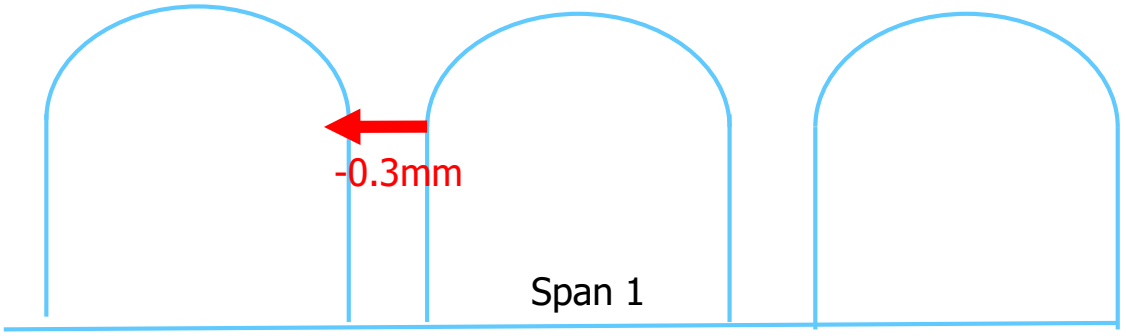




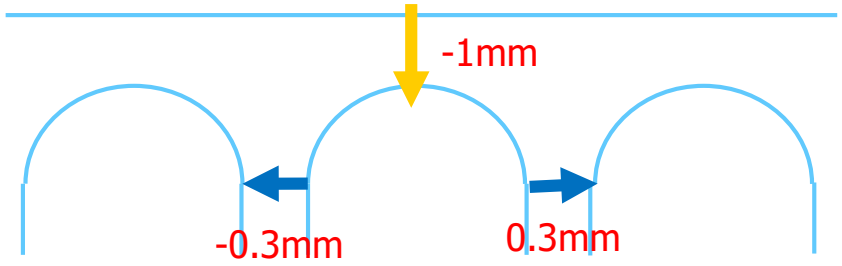
Dynamic results: Span opening and closing

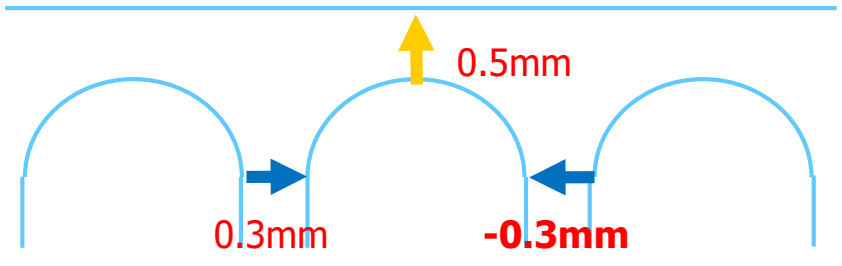






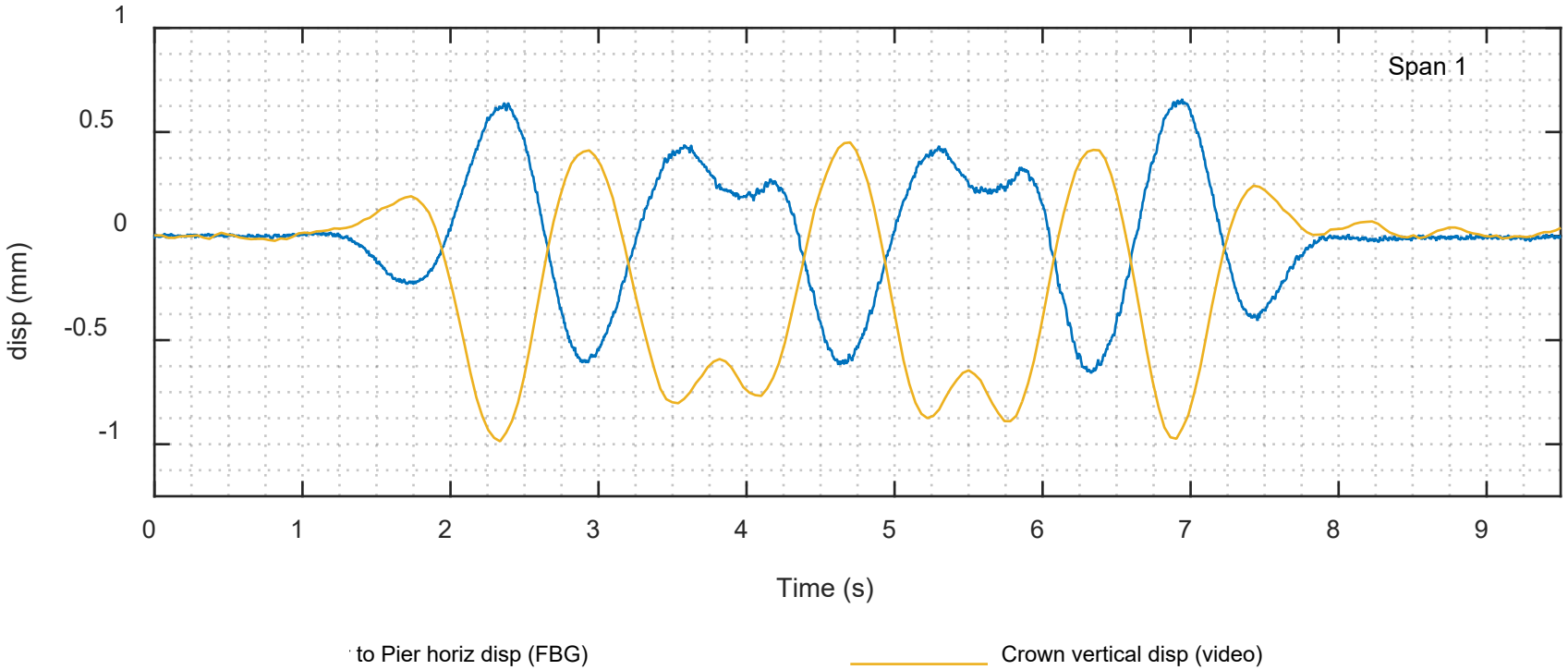
Response of crown



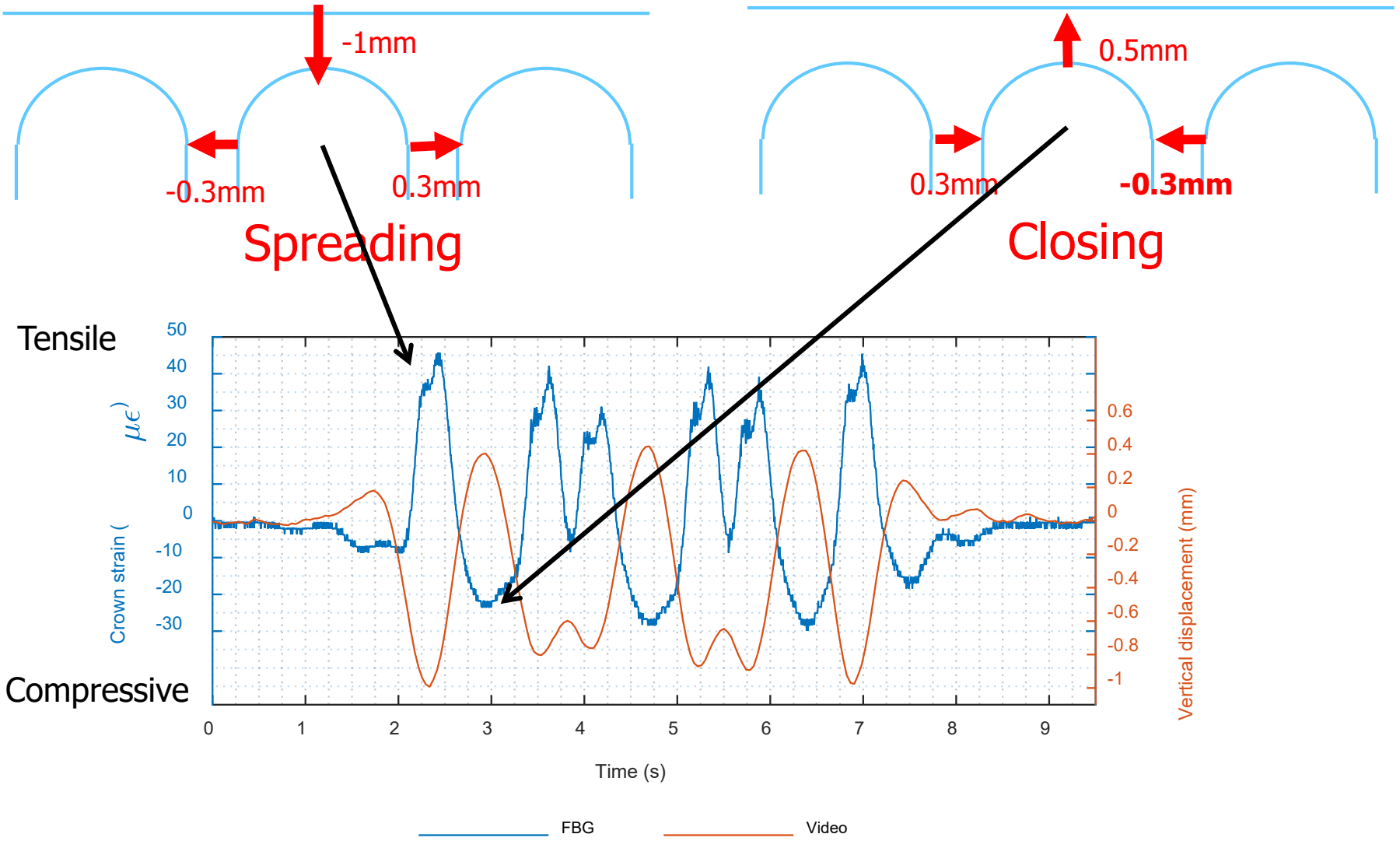


Spreading

Closing



Response of crown



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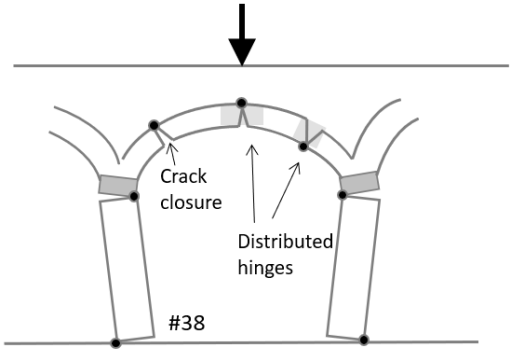
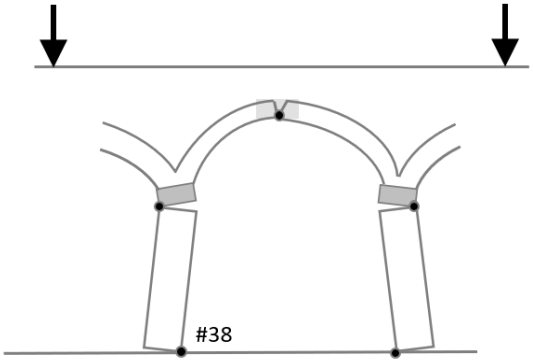
Response:

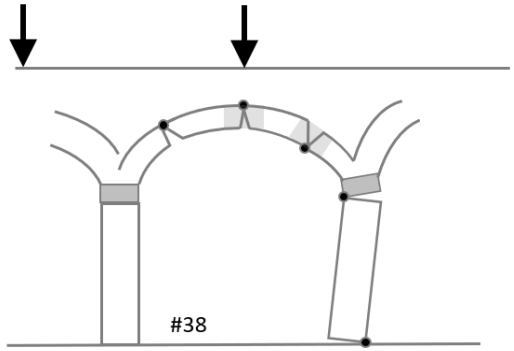
- Span opening and closing induces different mechanisms.
- Different hinge locations allow different crown movements for opening/closing.
- A narrow stiff pier top section rotates as a rigid block.



Response @ τ=3.5

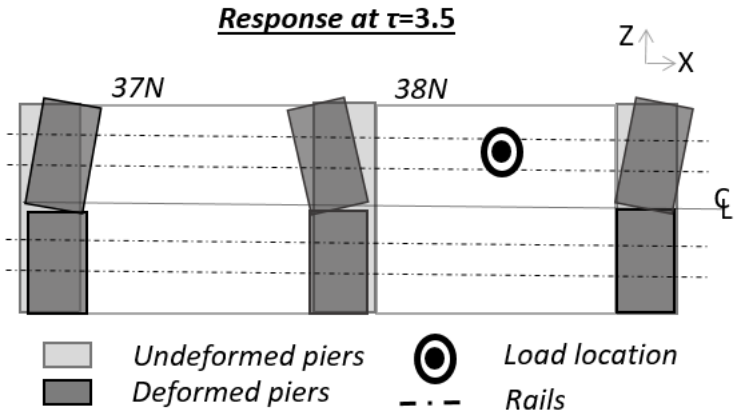


Response @ τ=4.5



Response @ τ=5.35

Plan view:



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Acikgoz et al (2018) *Engineering Structures*

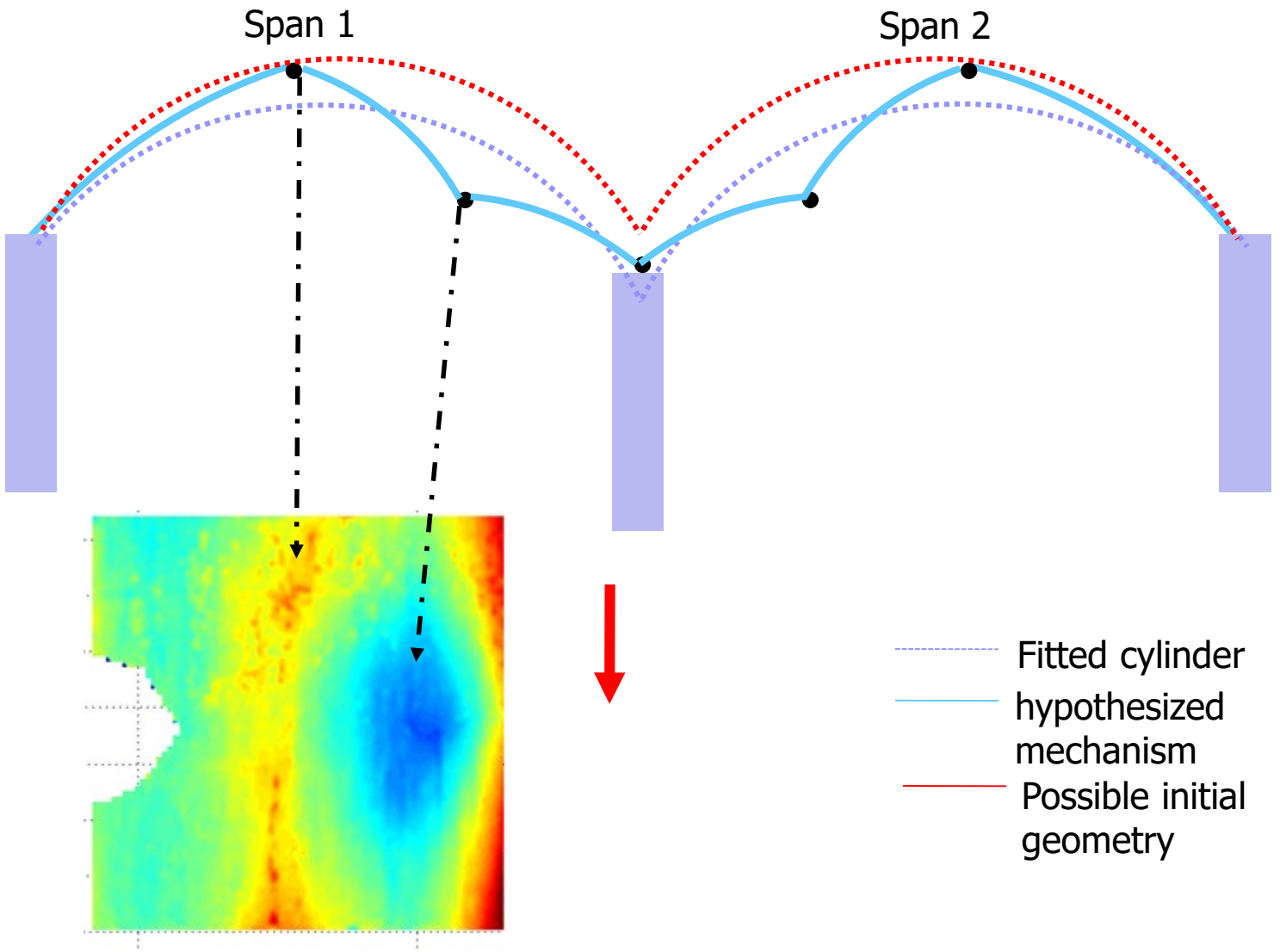
Dynamic Monitoring Explained:

- Dynamic span opening and closing
- Main response mechanism
- Worst case loading
- Pier rotation, bending and torsion
- Crack opening/closing
- Influence of cracks on the dynamic behaviour
- Dynamic amplification due to train speed
- etc …

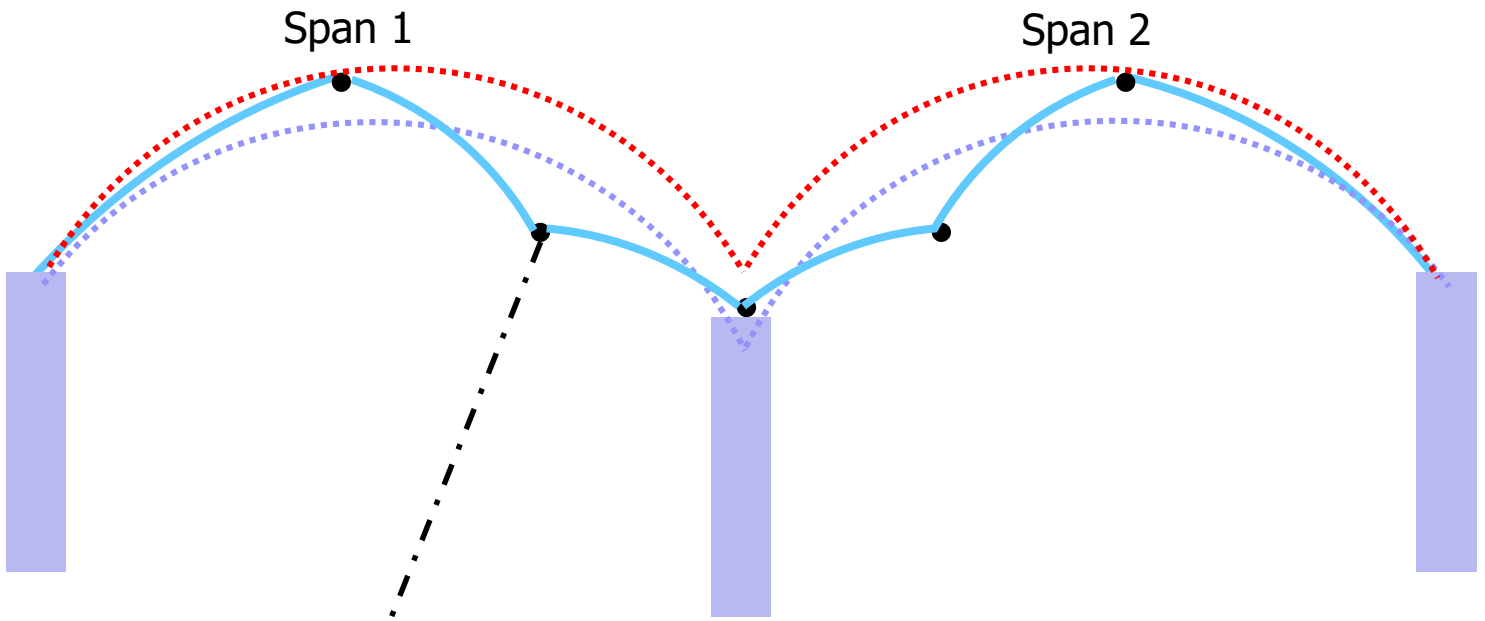
- Effect of existing settlements?…

Settlement due to relieving arch

Cause of Transverse Cracks



Cause of Transverse Cracks

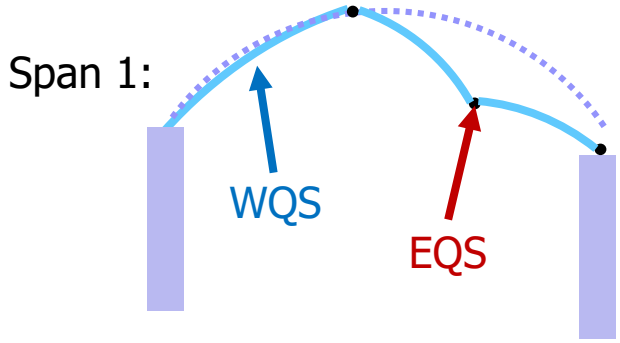


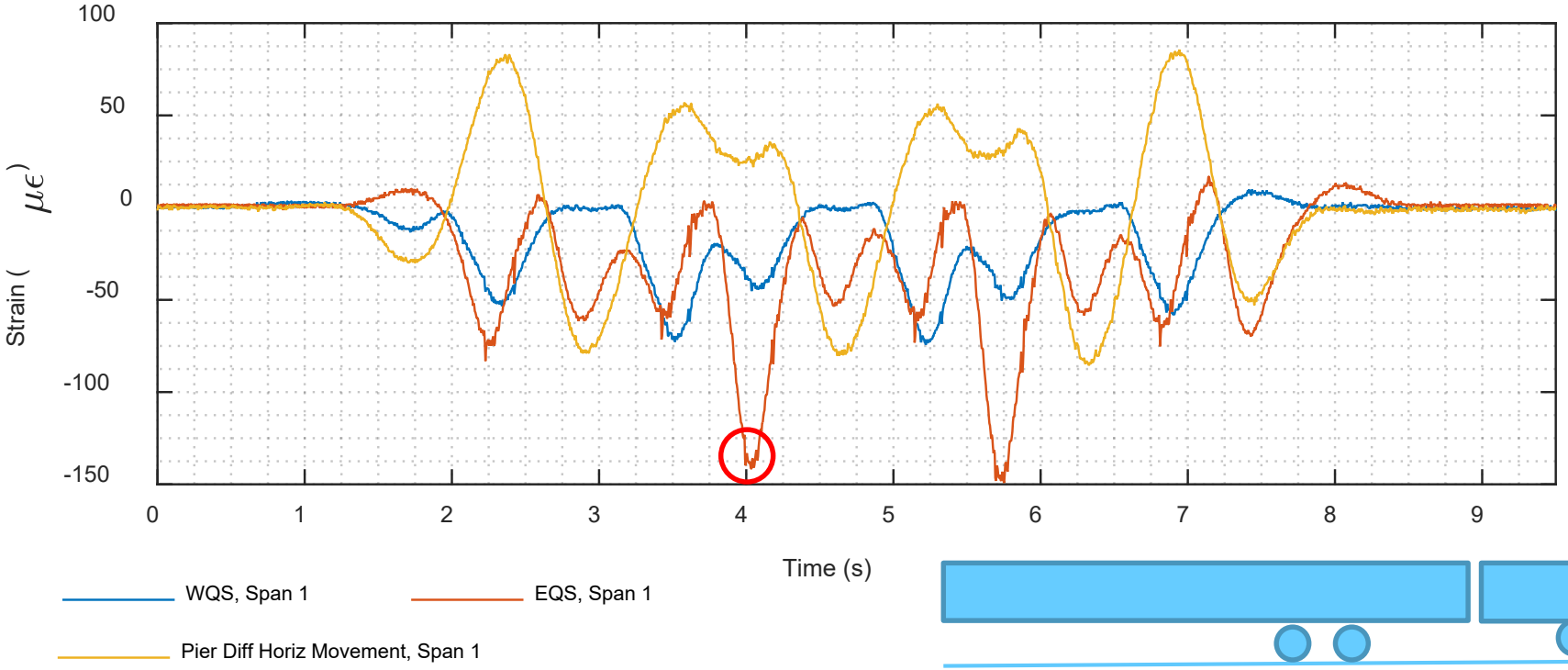
Fitted cylinder

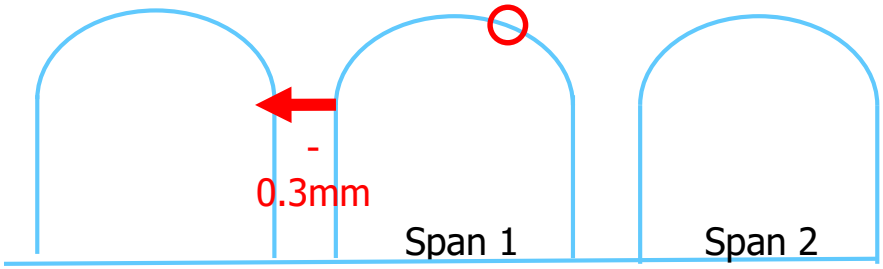
hypothesized mechanism

Possible initial geometry

Transverse Crack – Dynamic response







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General Implications

- Distributed fibre optic data = more comprehensive understanding of the global response
- New laser scan algorithms to identify existing 3D deformation
- Both enable structural understanding needed to inform:
  - long term monitoring
  - intervention and maintenance

Structural Health Monitoring

(tracking degradation)

- Haris Alexakis (post-doc)
- Andrea Franza (post-doc)
- Matt DeJong (PI)

Imperial College London

The Alan Turing Institute

CSIC Cambridge Centre for Smart Infrastructure & Construction

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NetworkRail

EPSRC Engineering and Physical Sciences Research Council

Innovate UK

CSIC

Advance Sensing

CSIC Cambridge Centre for Smart Infrastructure & Construction

+

Big Data Analytics

The Alan Turing Institute

Imperial College London

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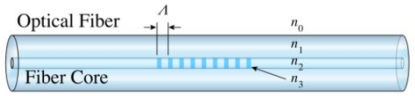
Long-term monitoring plan

FO sensors



High sensitivity accelerometers

Acoustic emission sensors

CSIC Cambridge Centre for Smart Infrastructure & Construction

The Alan Turing Institute

Imperial College London

NetworkRail

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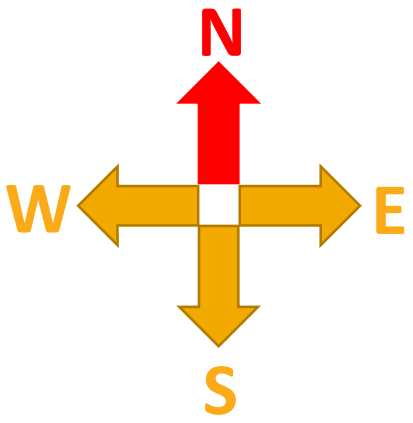
CSIC



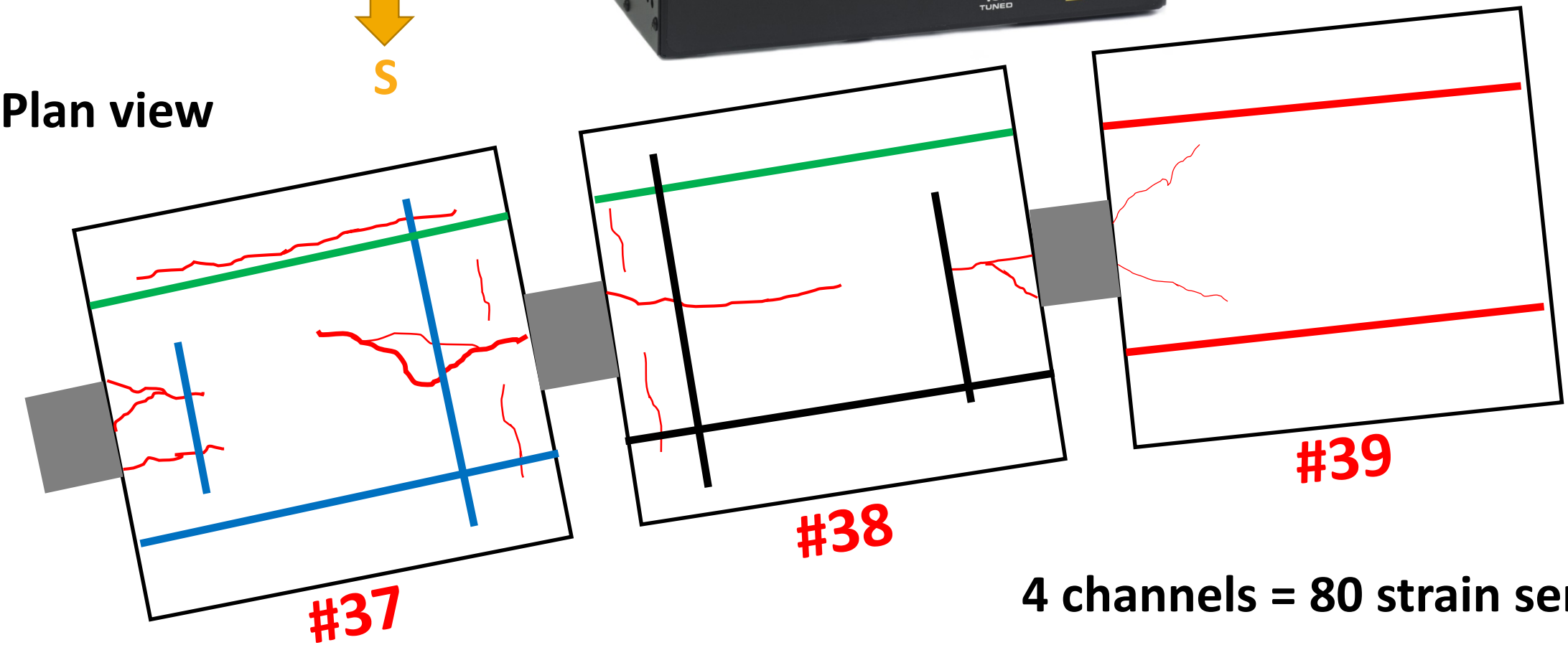
Channel 1

Channel 2

Channel 3

Channel 4

Plan view



4 channels = 80 strain sensors!

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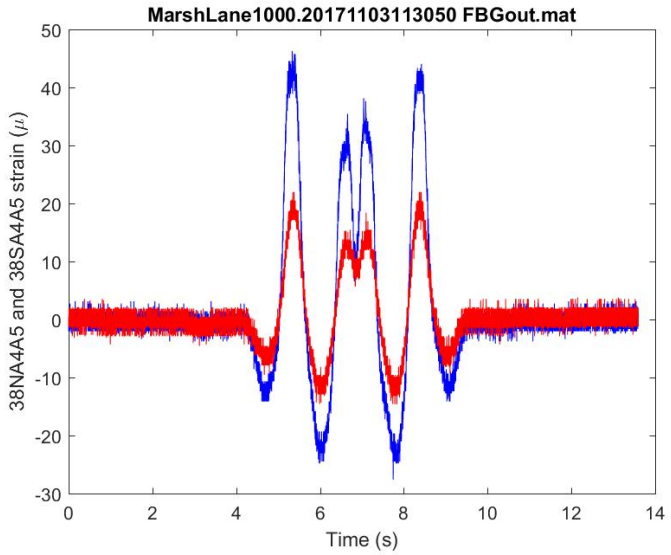
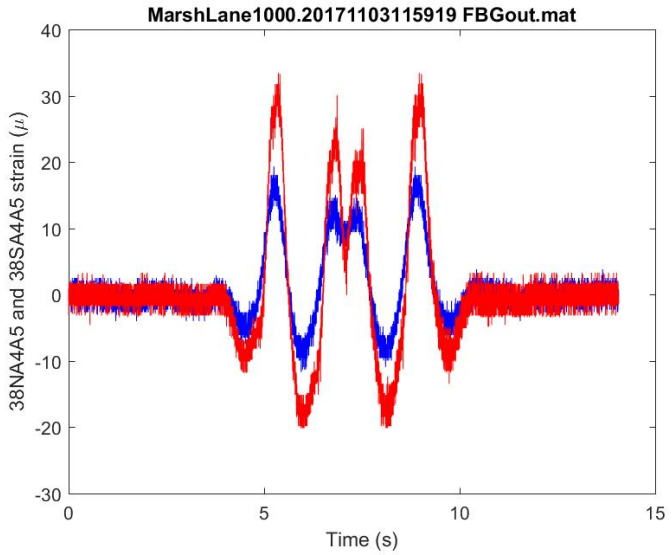
CSIC Cambridge Centre for Smart Infrastructure & Construction

Nov 2017: 62 records in total

Type 1N (8 records, 13%)



Type 1S (6 records, 10%)



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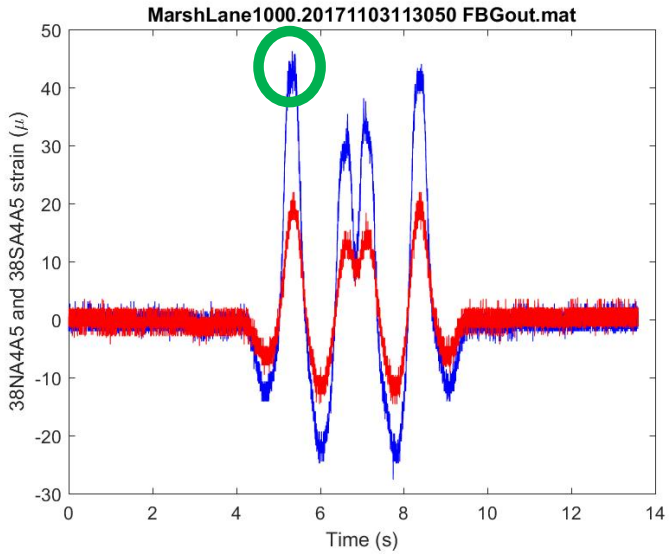
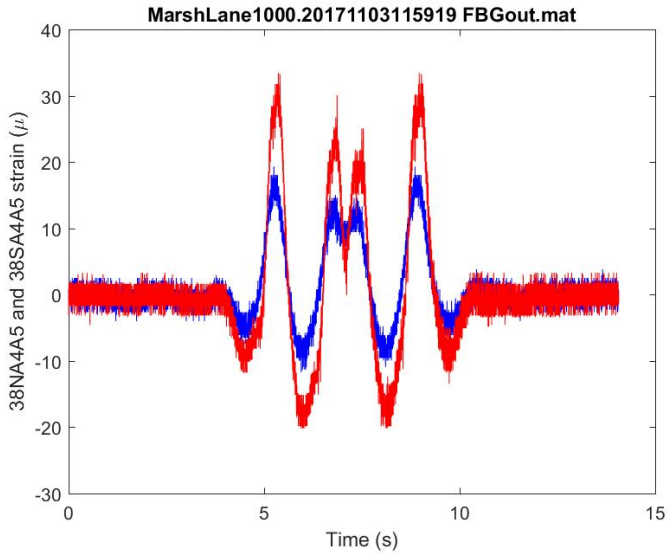
Cambridge Centre for Smart Infrastructure & Construction

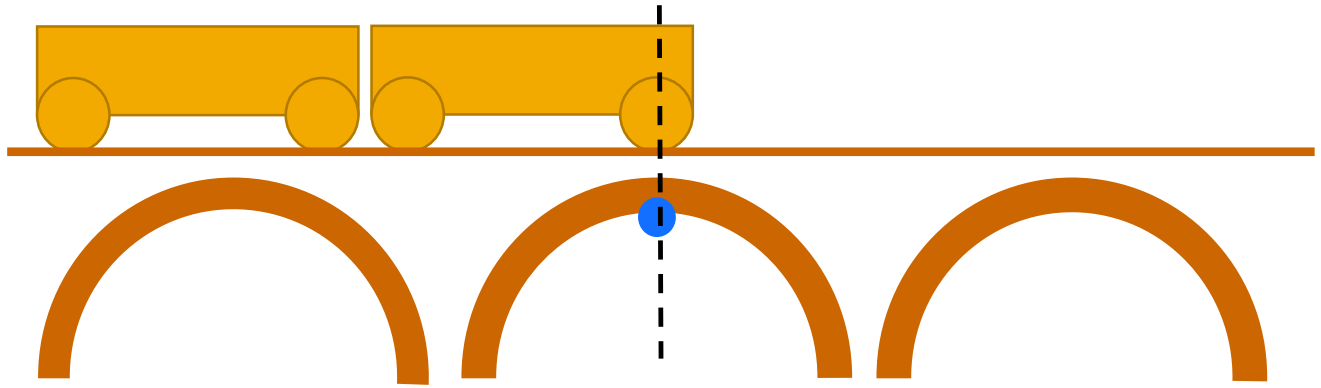
Nov 2017: 62 records in total

Type 1N (8 records, 13%)



Type 1S (6 records, 10%)





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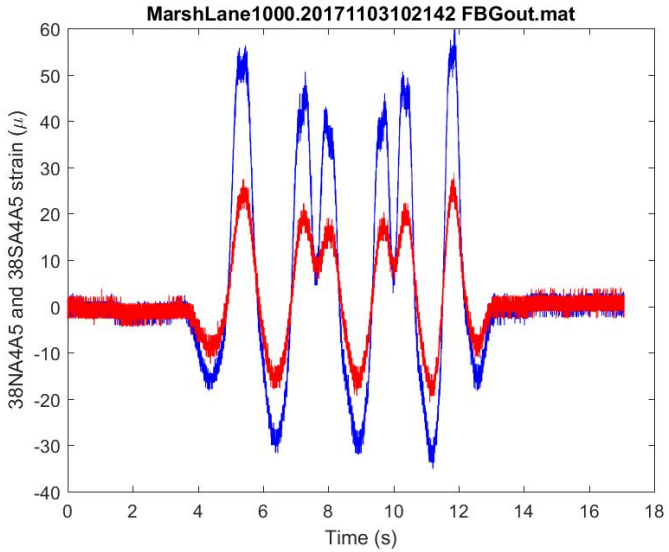
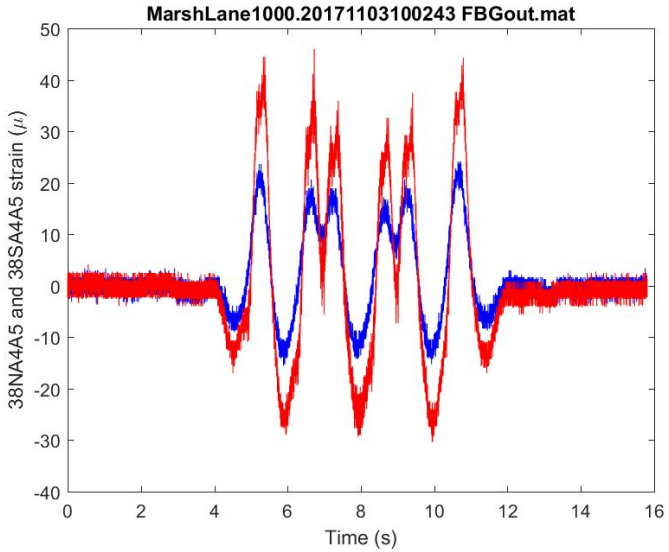
CSIC Cambridge Centre for Smart Infrastructure & Construction

Nov 2017: 62 records in total

Type 2N (19 records, 30%)



Type 2S (14 records, 23%)



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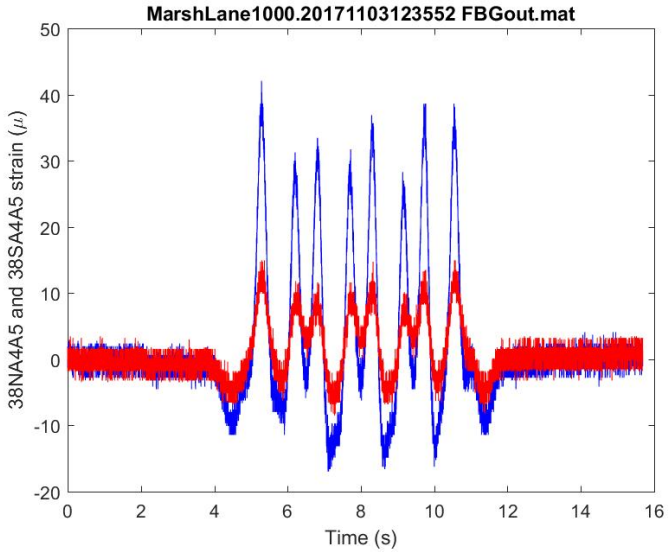
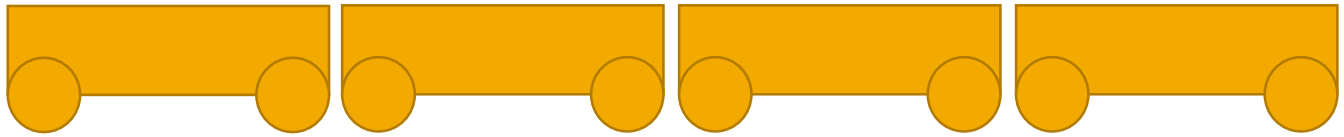
Nov 2017: 62 records in total

Type 3N (3 records, 5%)

Type 3S (no records)





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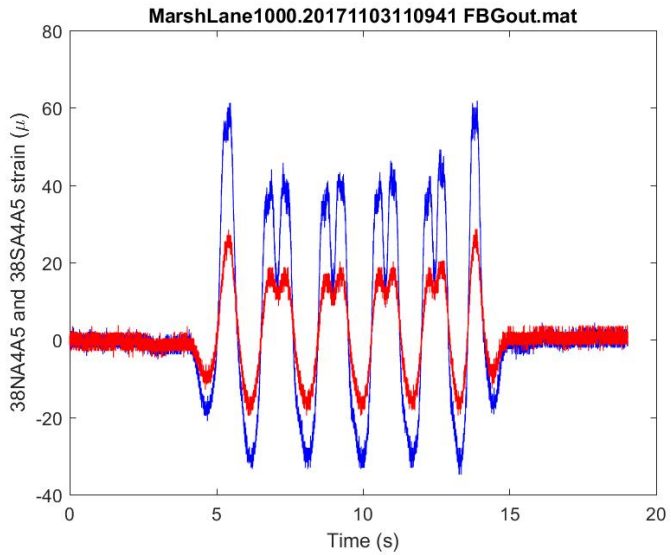
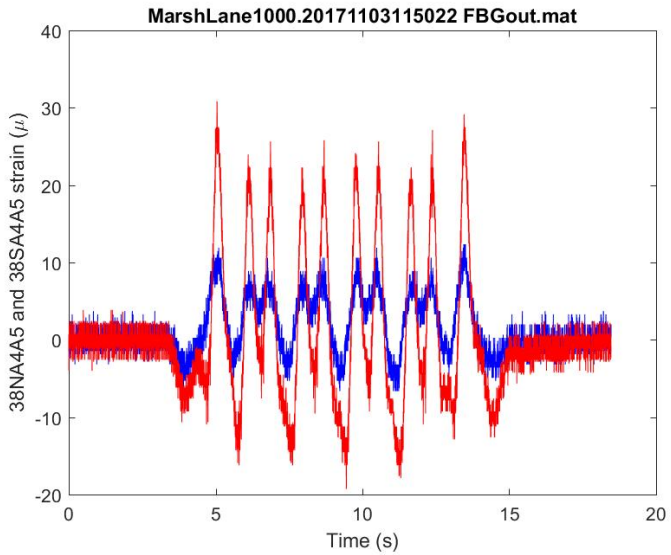
Nov 2017: 62 records in total

Type 4N (2 records, 3%)

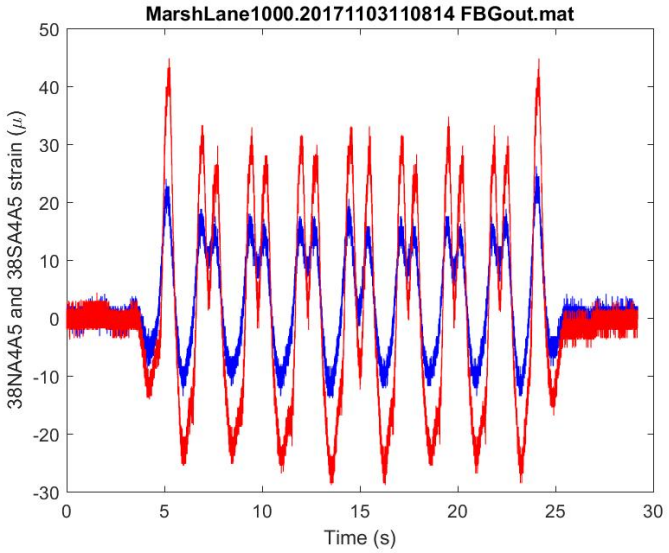


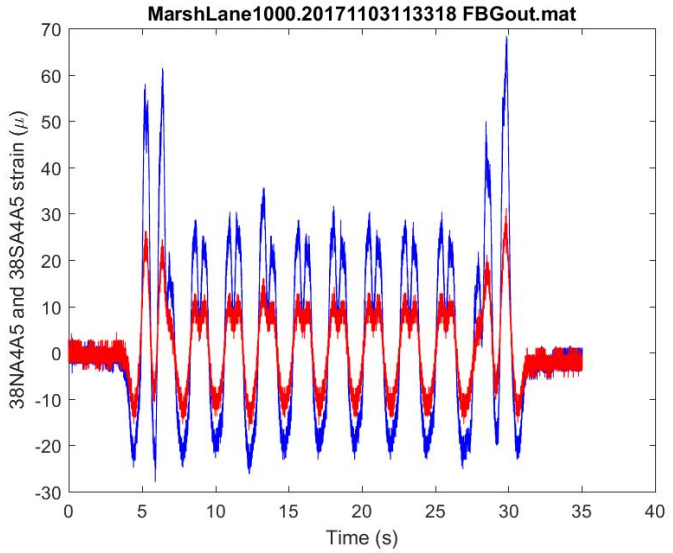
Type 4S (1 records, 1.5%)

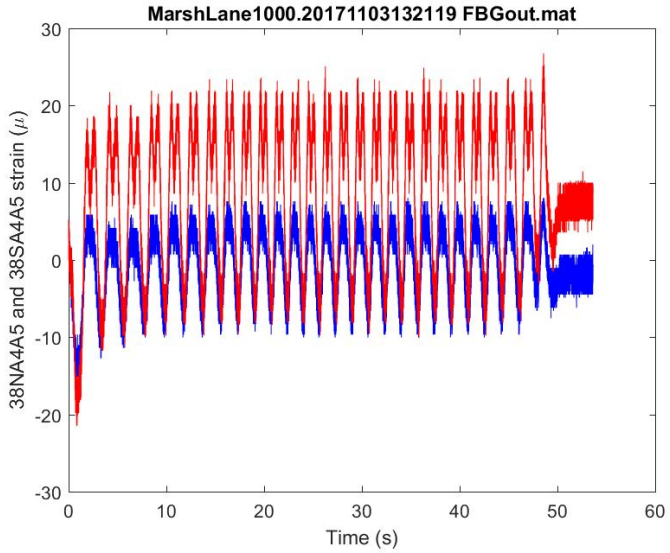


Nov 2017: 62 records in total

Multiple coaches (3 records, 5%)







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Categorize data based on

Direction

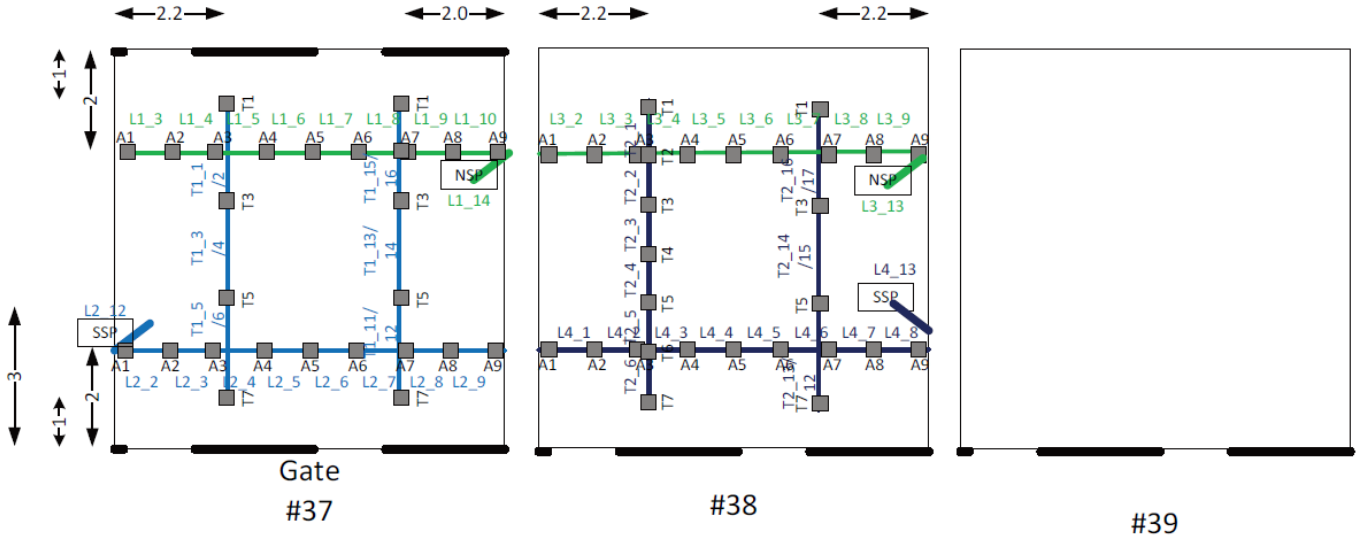
Coaches

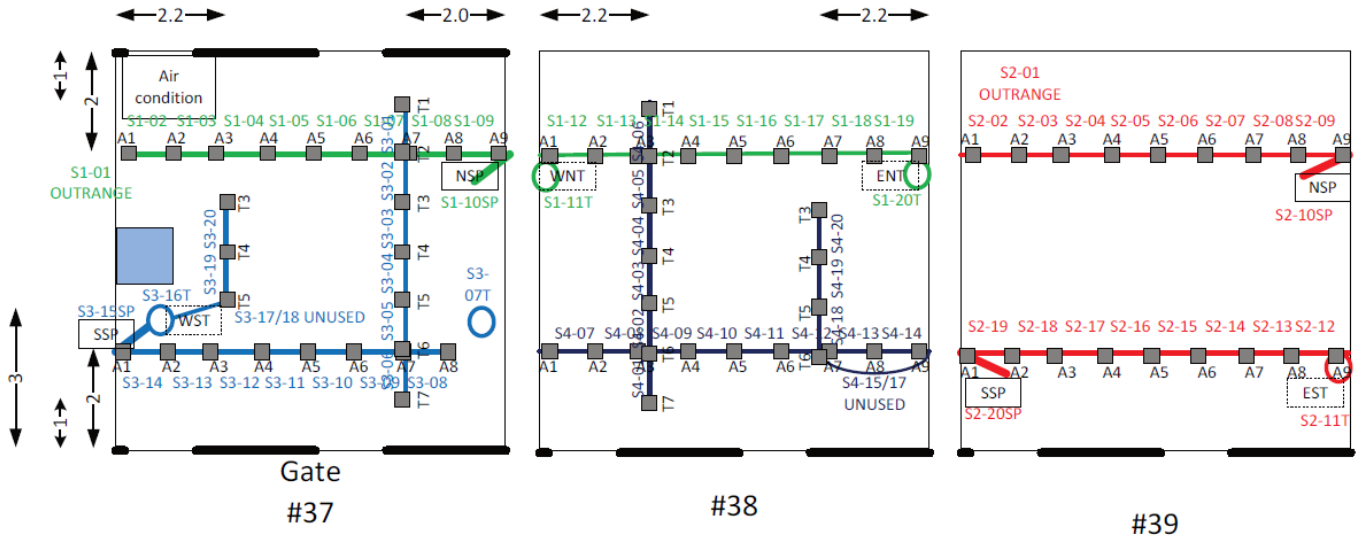
Relative axle distance

Velocity

Weight level (signal amplitude)

Temperature





July 2016

15 months

Nov 2017

4 months

Mar 2018

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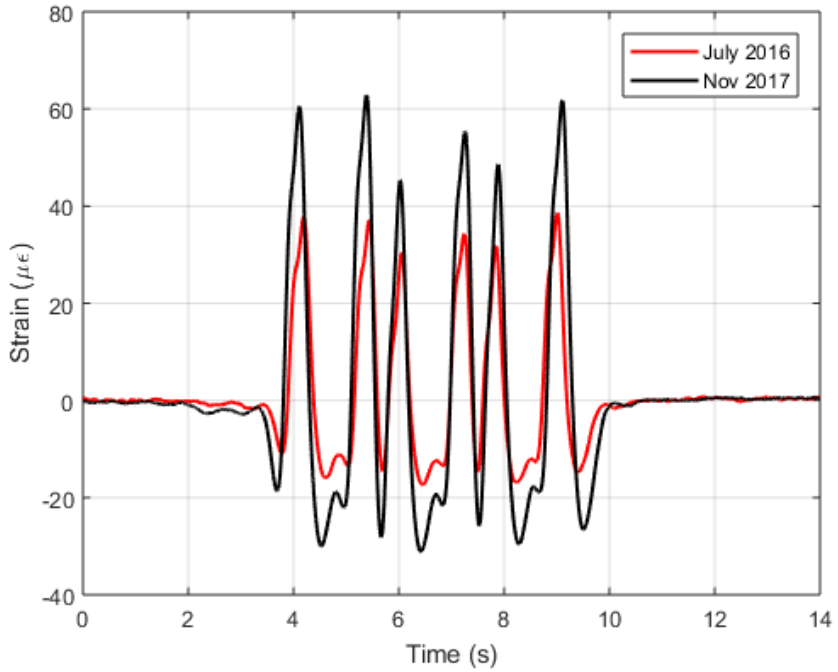

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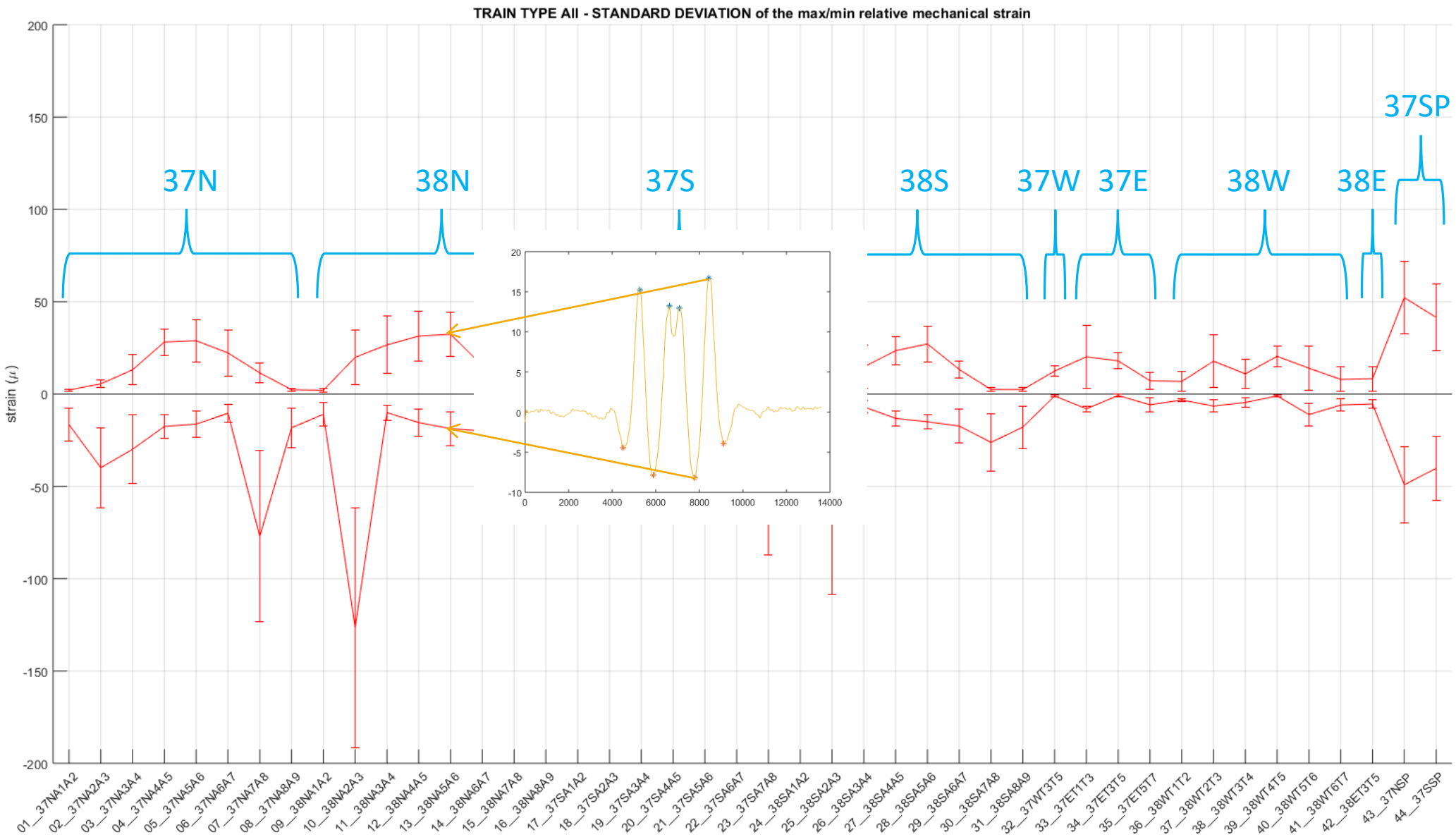
July 2016
(95 trains)



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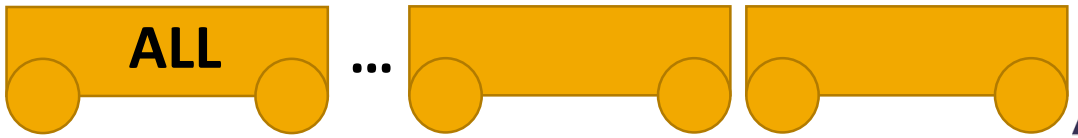

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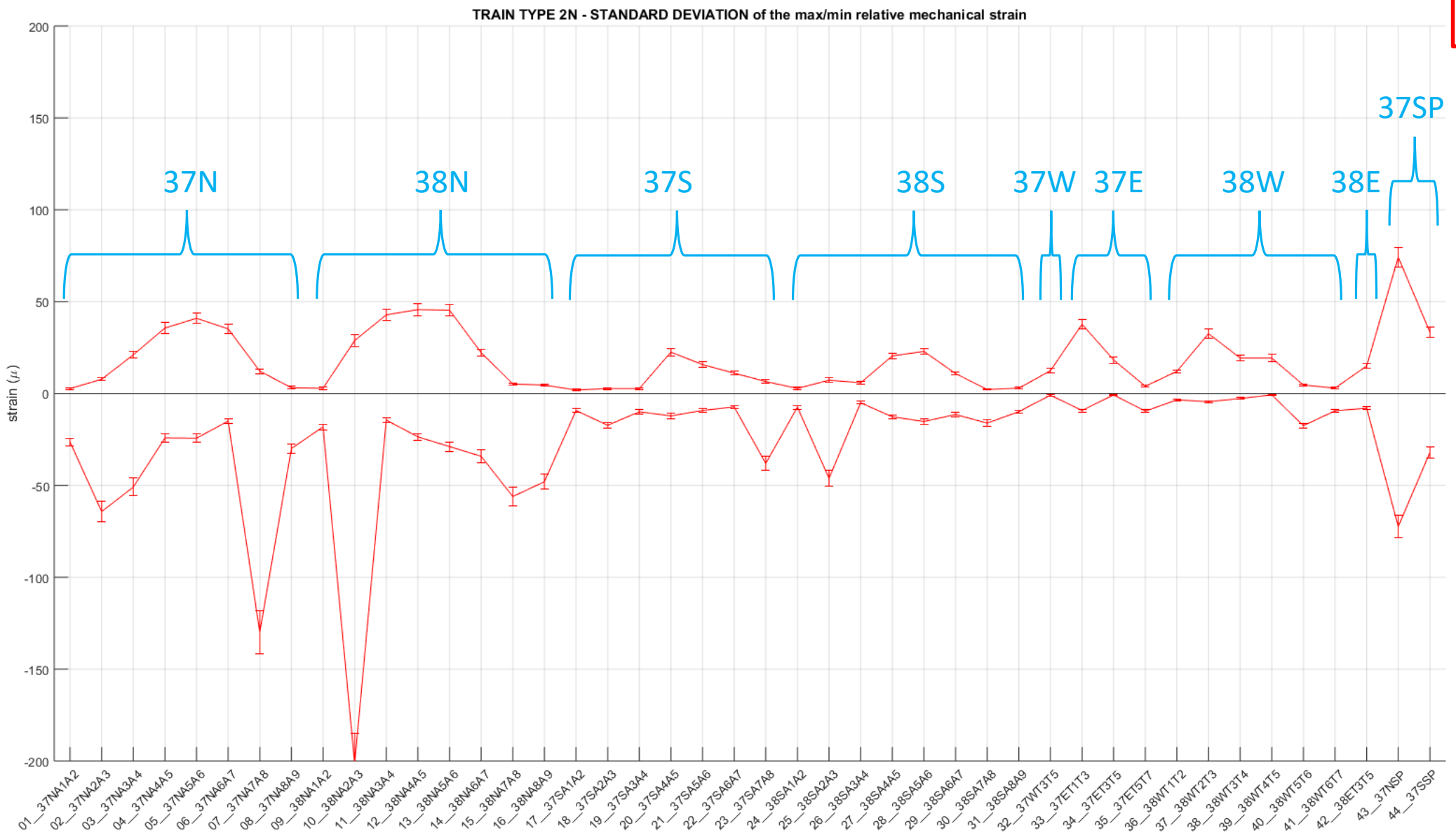
July 2016
(31 trains)



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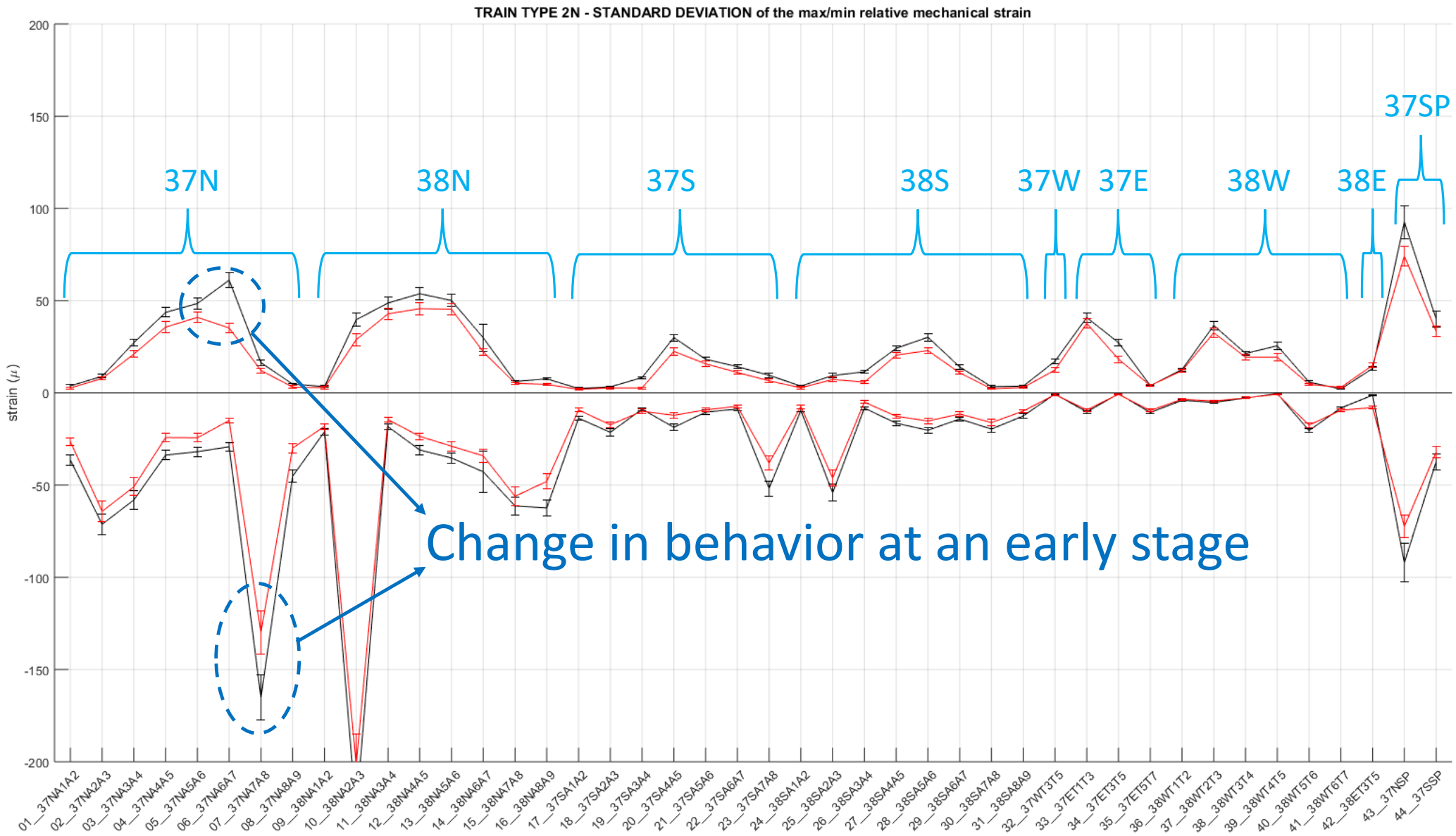
CSIC Cambridge Centre for Smart Infrastructure & Construction

July 2016
(31 trains)

Nov 2017
(19 trains)



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North

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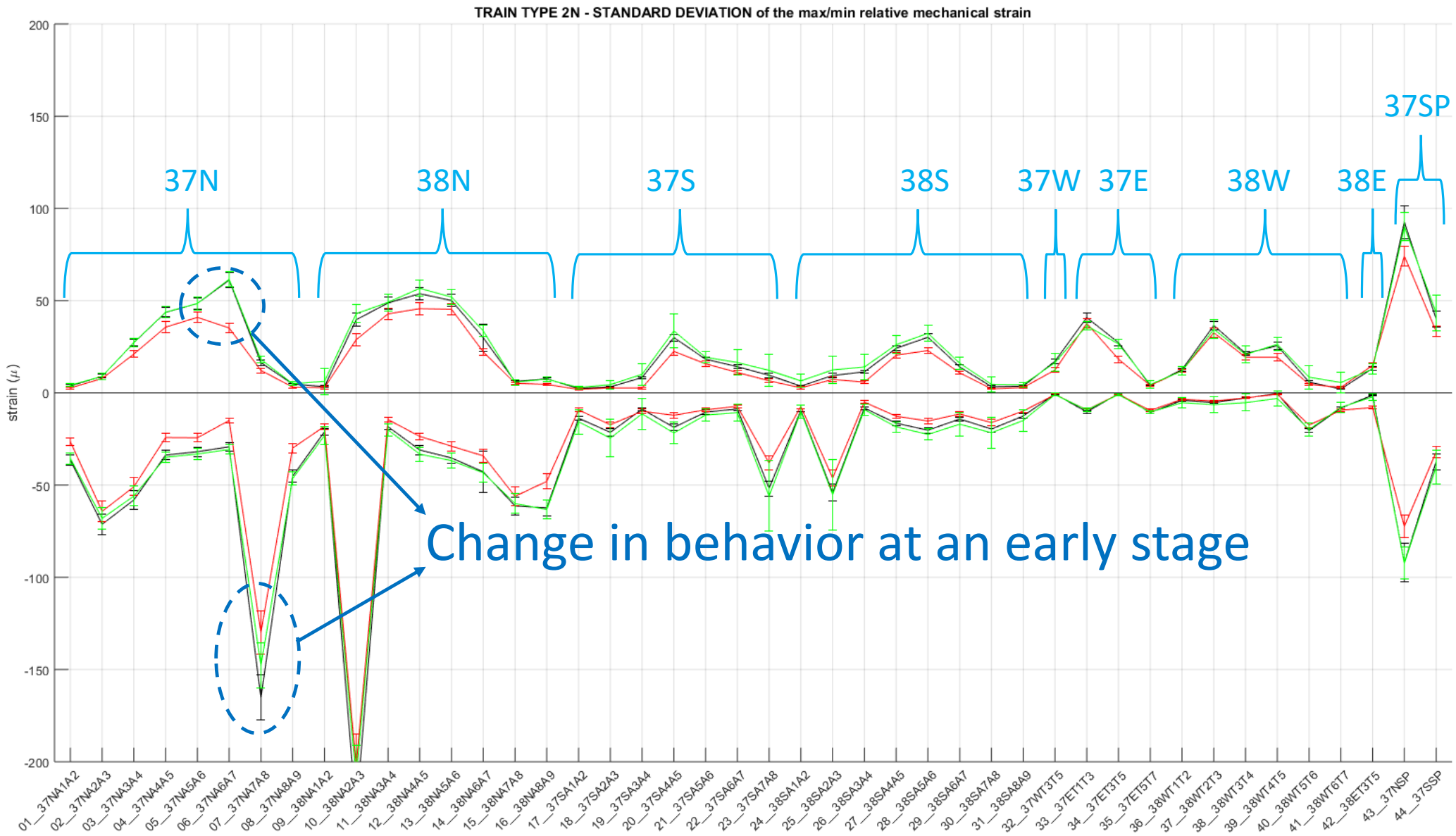

July 2016 (31 trains)

Nov 2017 (19 trains)

Mar 2018 (42 trains)

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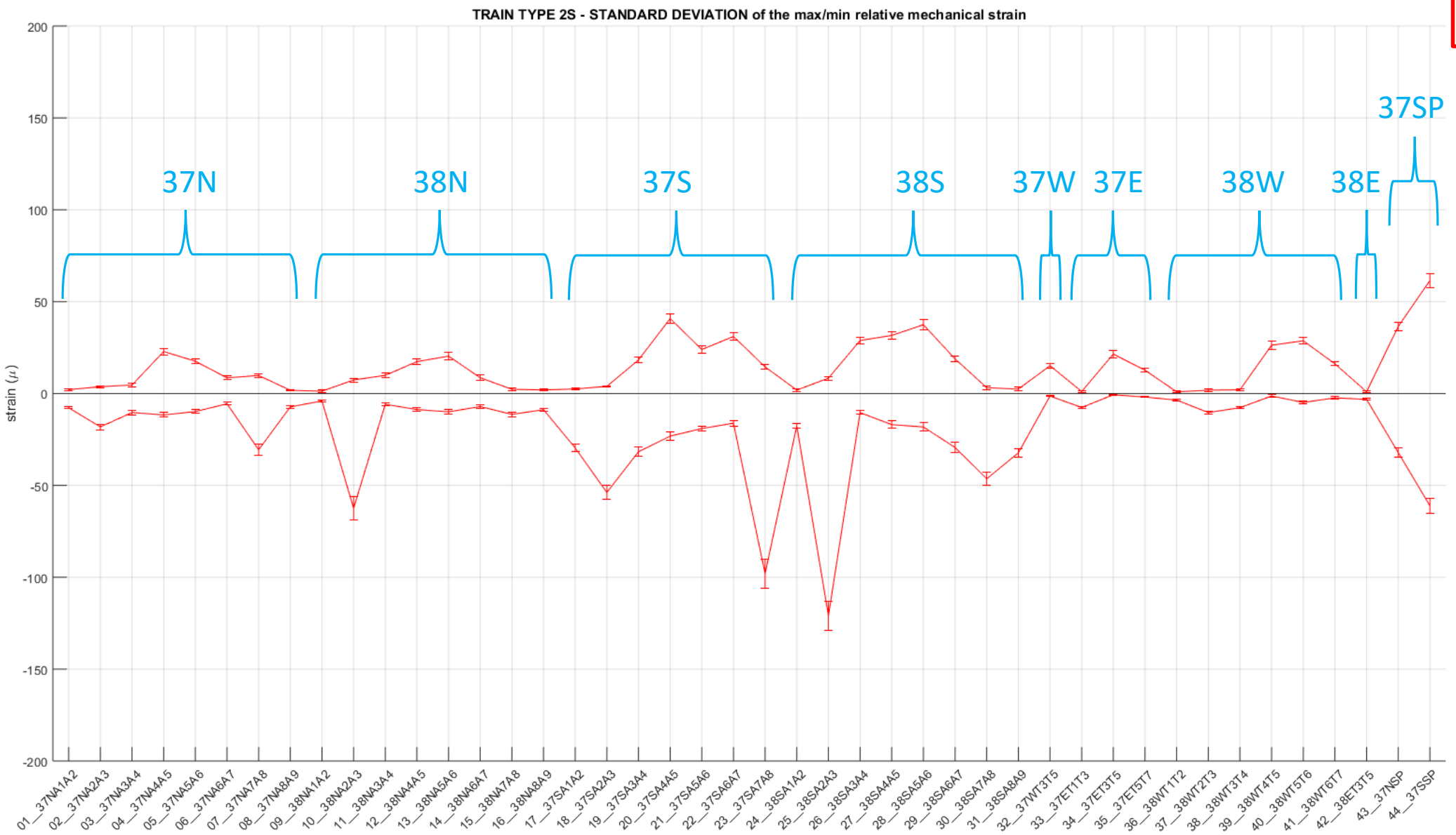
July 2016
(22 trains)



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South

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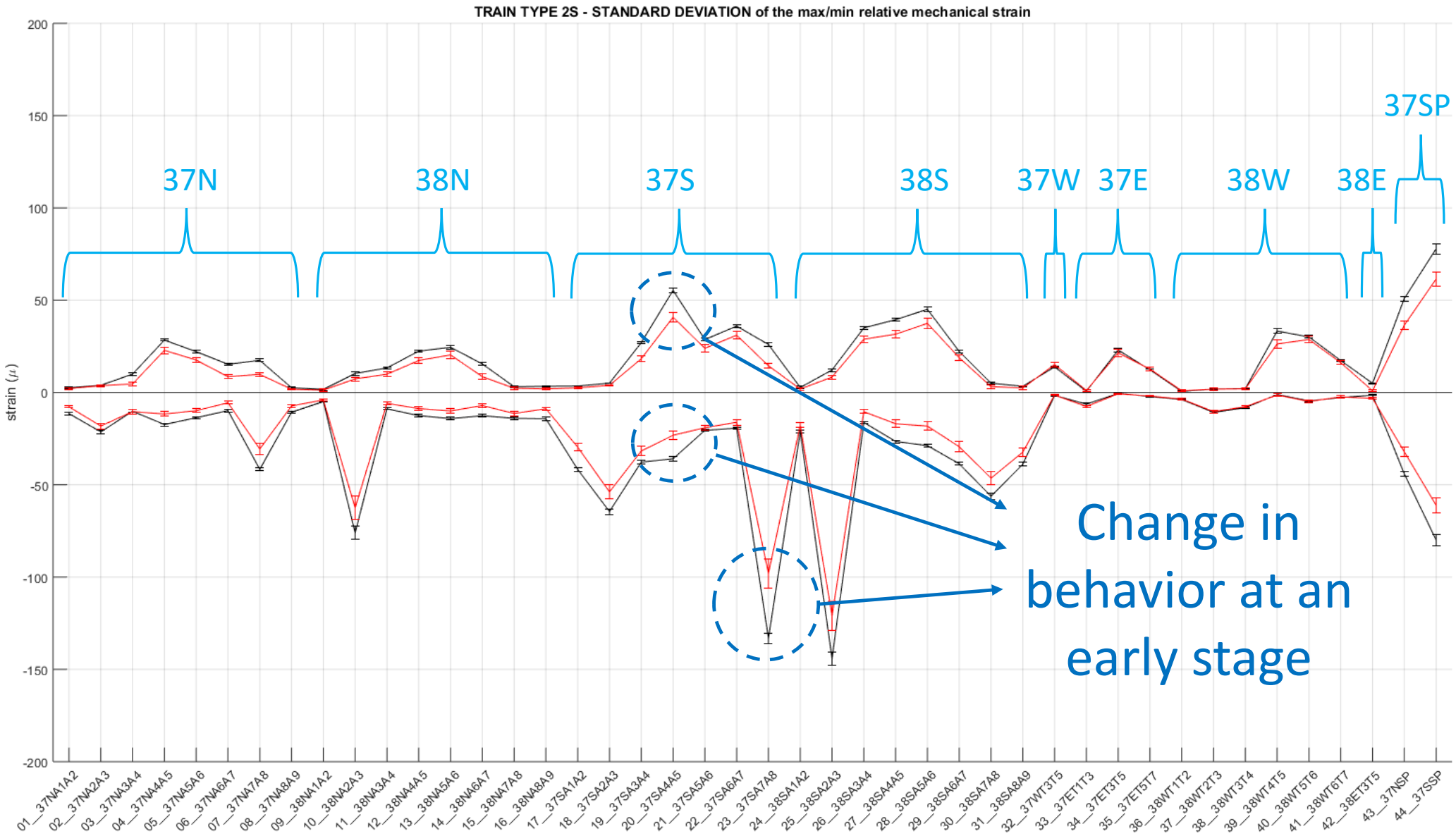
July 2016
(22 trains)

Nov 2017
(13 trains)



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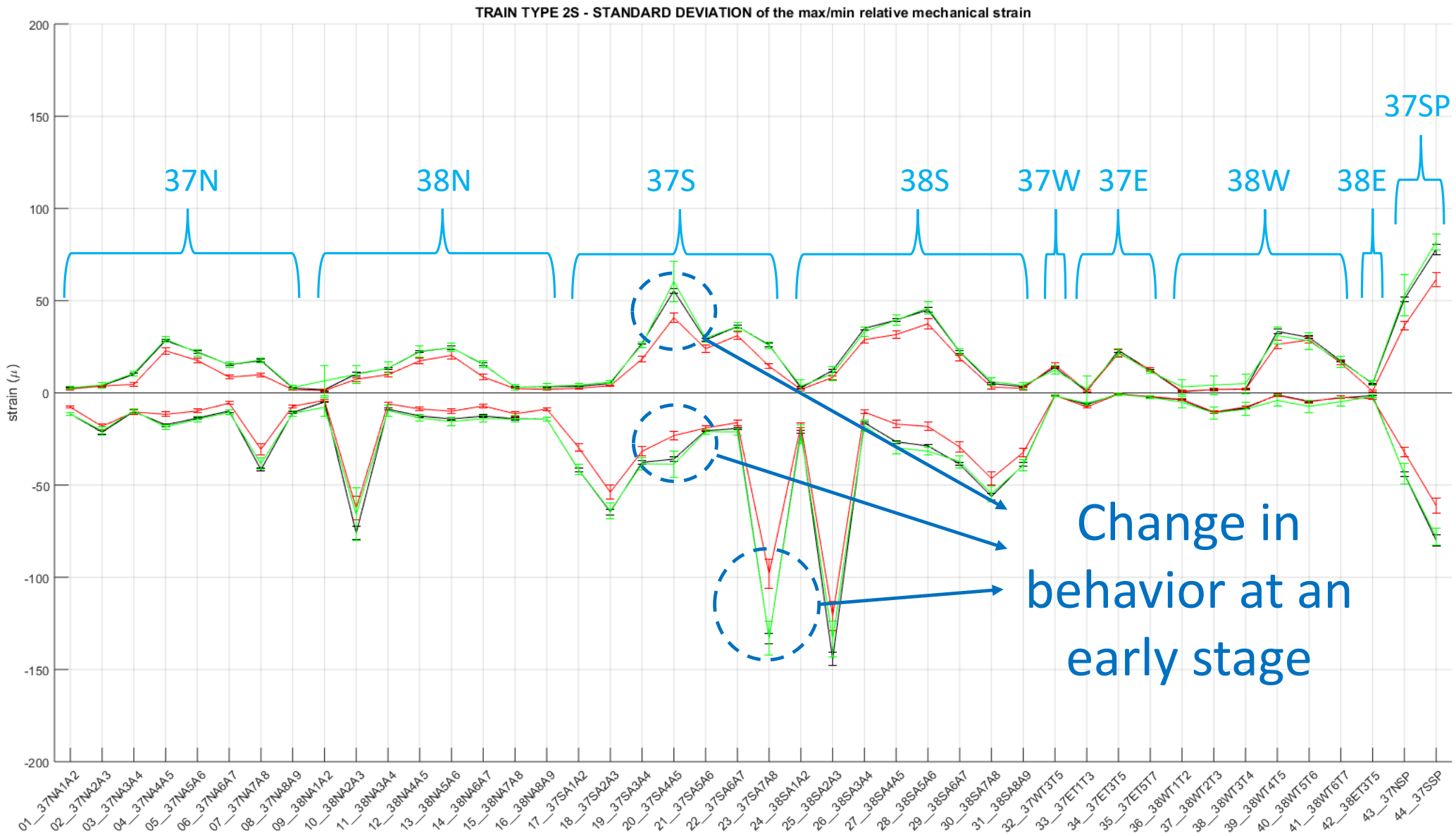

July 2016 (22 trains)

Nov 2017 (13 trains)

Mar 2018 (34 trains)

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South

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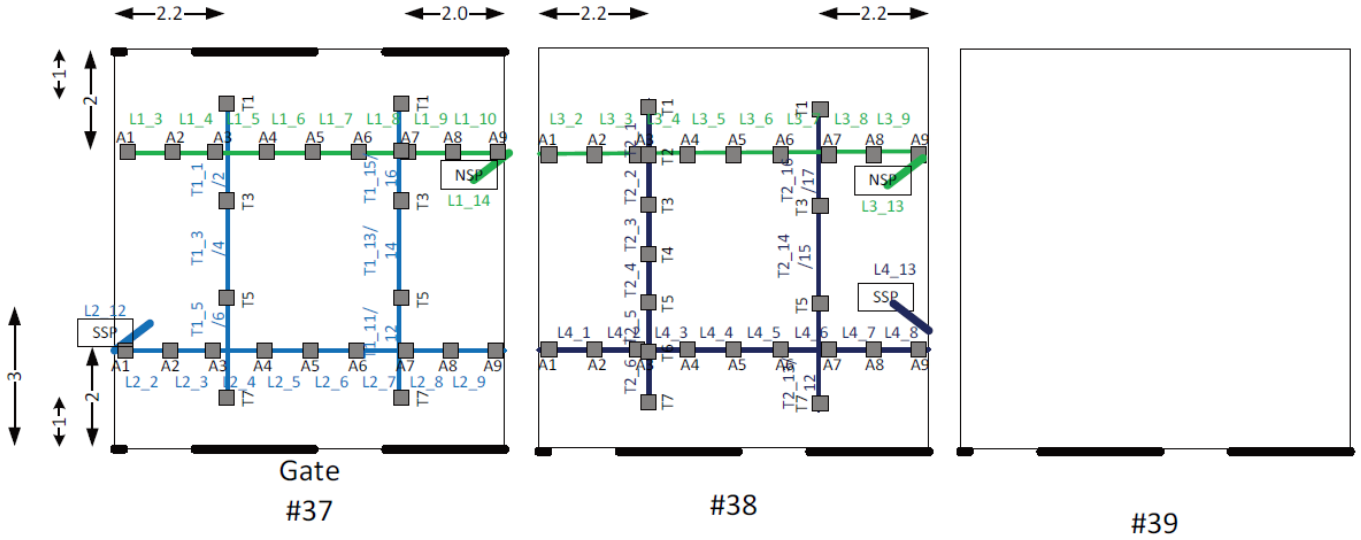
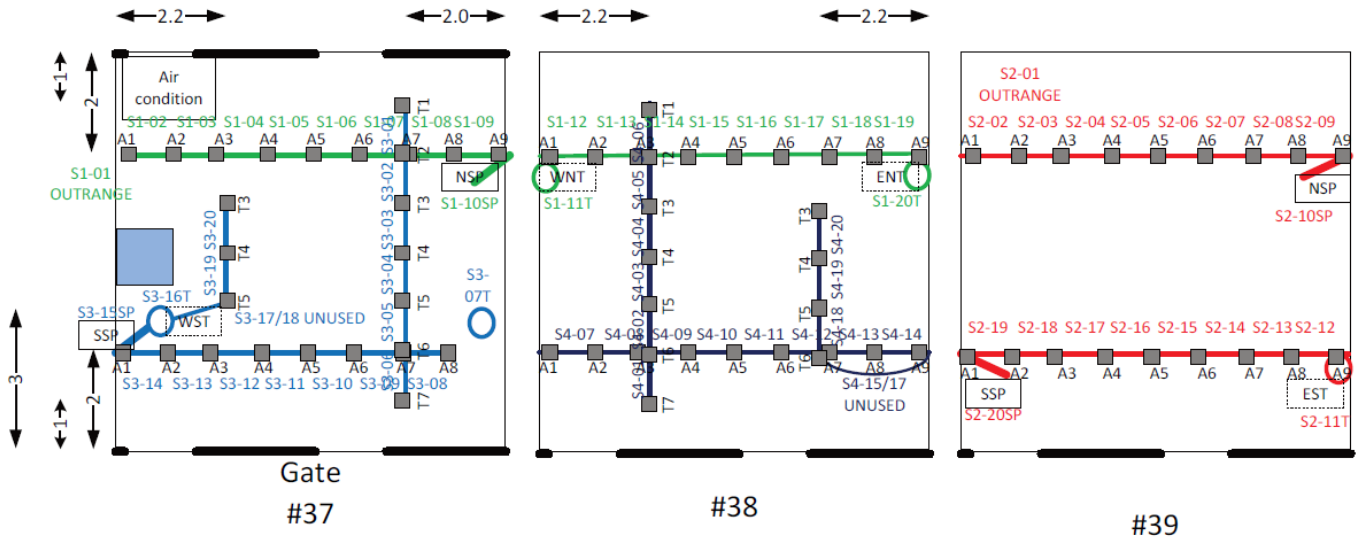


July 2016



Nov 2017

Similar weather conditions

Mar 2018

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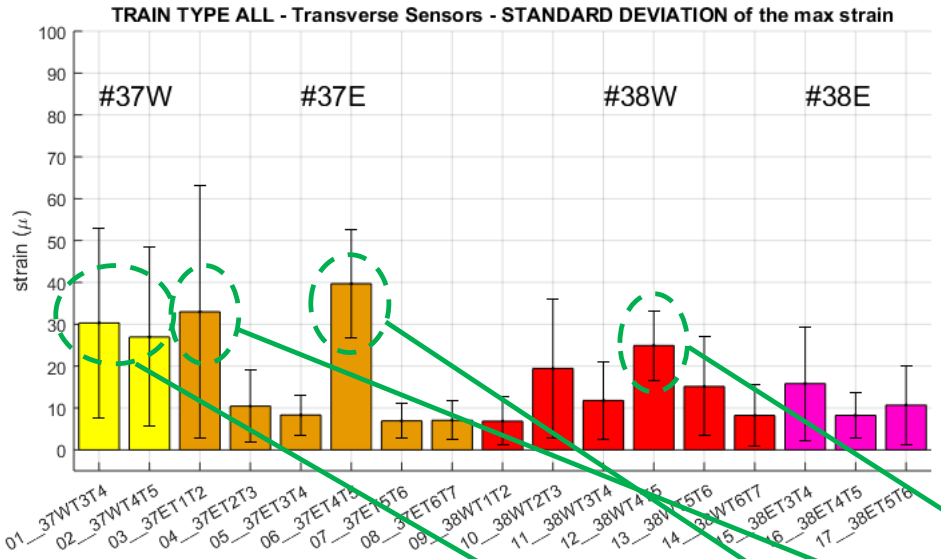
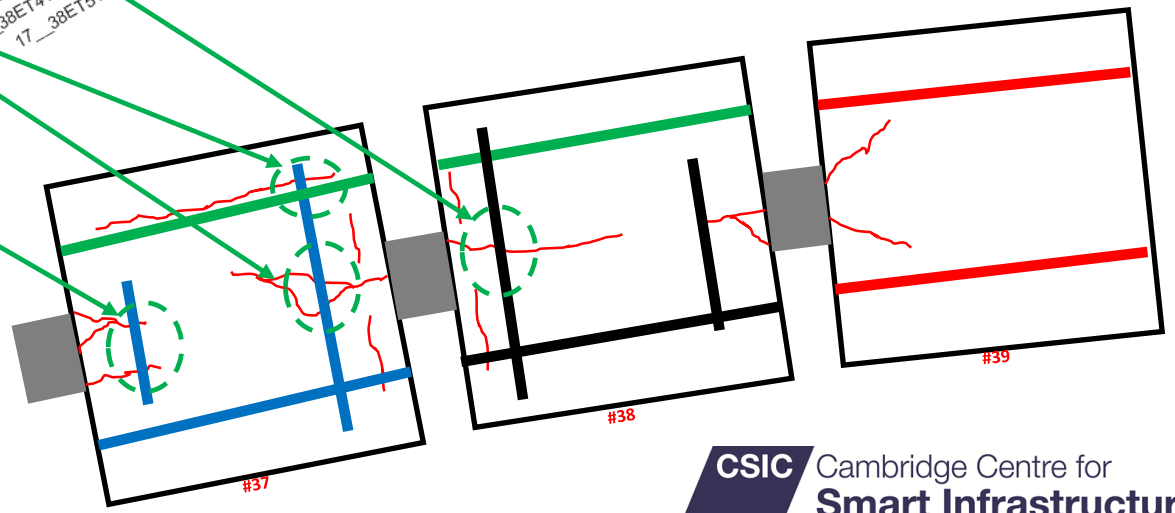
Signal Processing and Statistical Analysis



Damage detection



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Acoustic Emission Sensors: Identify and monitor cracks

Operating Frequency Range
35 - 100 kHz

Resonant Frequency
55 kHz

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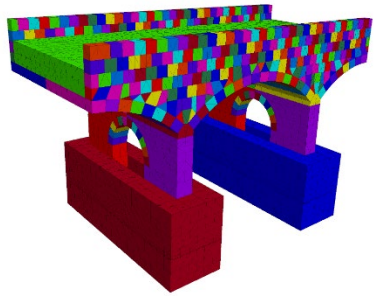
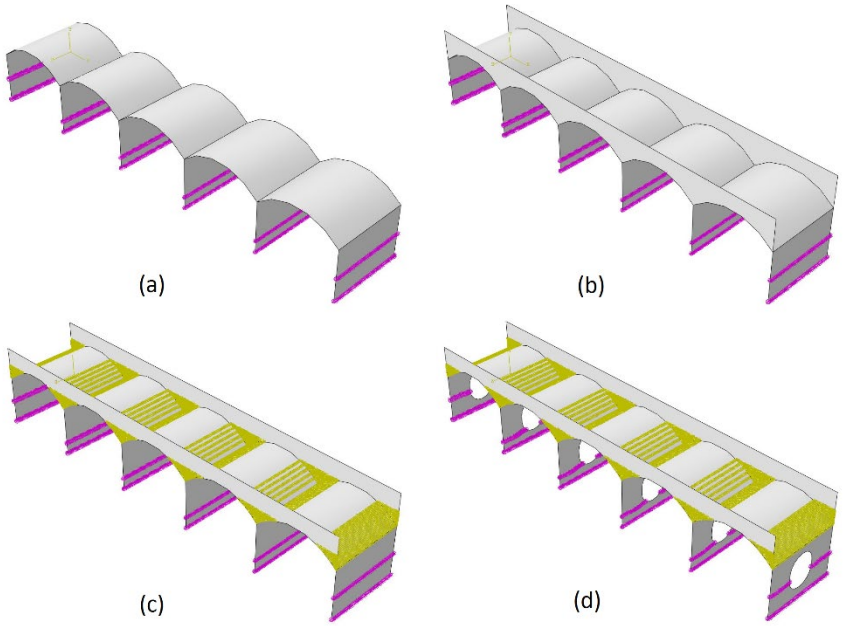
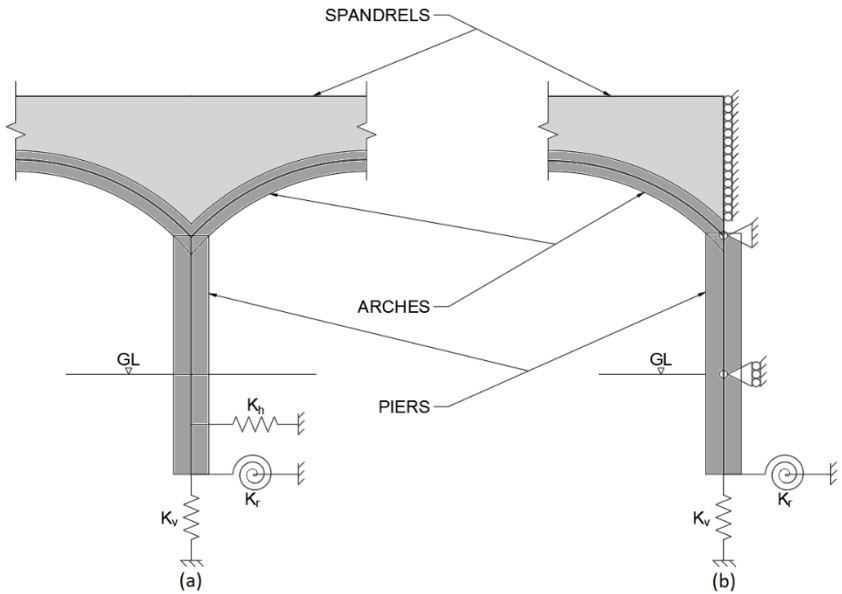
Next steps

FEM and DEM modelling







Data-Centric Engineering

The Alan Turing Institute

Imperial College London

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Better asset management

- Locate and quantify through long-term monitoring progressive damage at an early stage
- Assess the effectiveness of previous intervention
- Avoid unnecessary limitations in bridge operation (e.g. speed limits)

Acknowledgments

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- Dr Ioannis Brilakis, Cambridge

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- Dr Andrea Franza, Cambridge

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Thank you!

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The Alan Turing Institute

Imperial College London

NetworkRail

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