# Fiber Optic (+) Monitoring of Building Settlement and Bridge Degradation

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Structural Engineering

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# Outline – 4 projects

1. Tunneling-induced building settlement: Building scale (Bank Station - London, UK)
2. Tunneling-induced building settlement: City scale (Crossrail - London, UK)
3. Rail bridge diagnostics (CFM-5 Bridge – Yorkshire, UK)
4. Rail bridge degradation (Marsh Lane Viaduct – Leeds, UK)

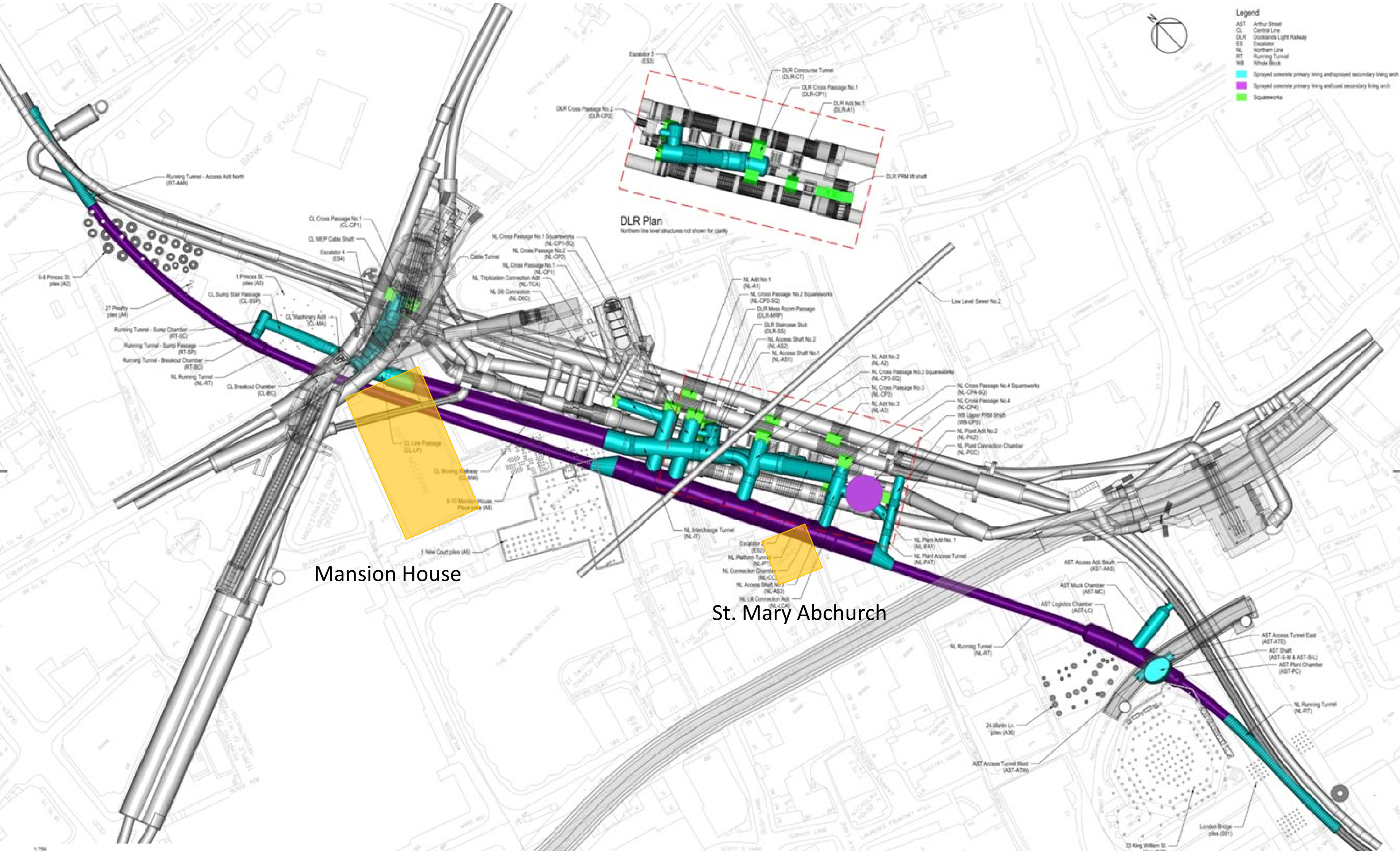
# 1. Tunneling-induced settlement: Building scale (Bank Station Subway Upgrade)

- Sinan Acikgoz (post-doc)
- Andrea Franza (post-doc)

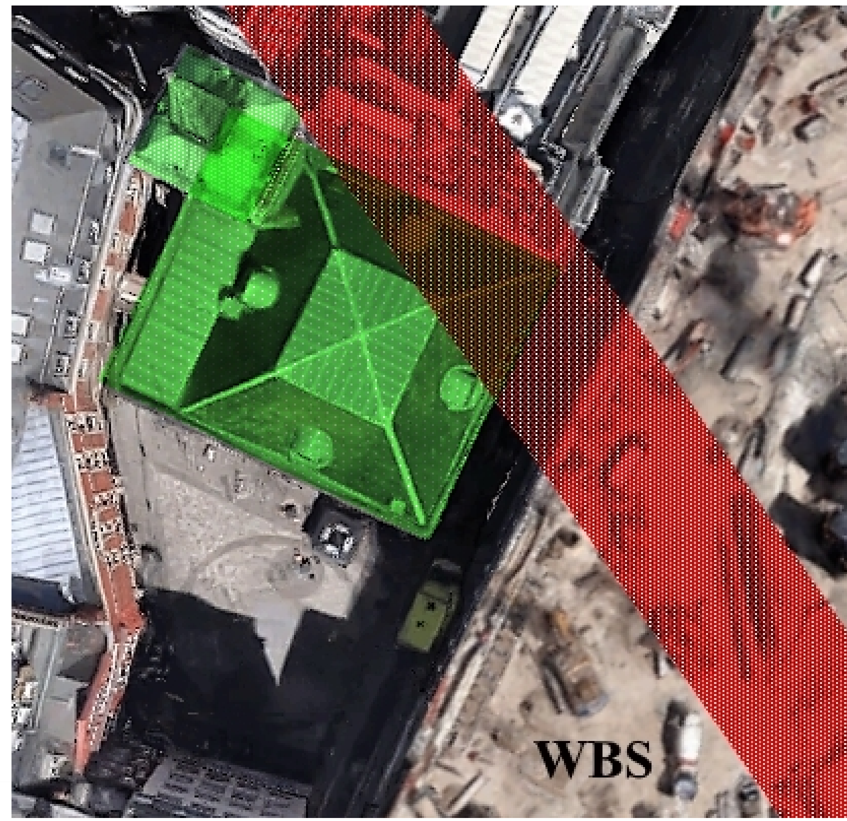
- *New Civil Engineer TechFest Award for: 'Innovation in Instrumentation & Monitoring'*

Cambridge Centre for Smart Infrastructure & Construction

# Bank Station Subway Upgrade



# St Mary Abchurch, London



# Background: Fundamental behavior - Soil-structure interaction experiments

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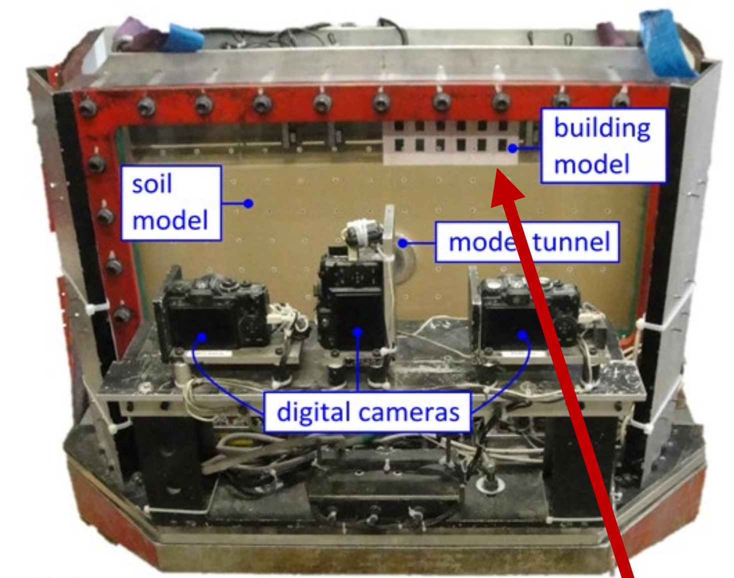
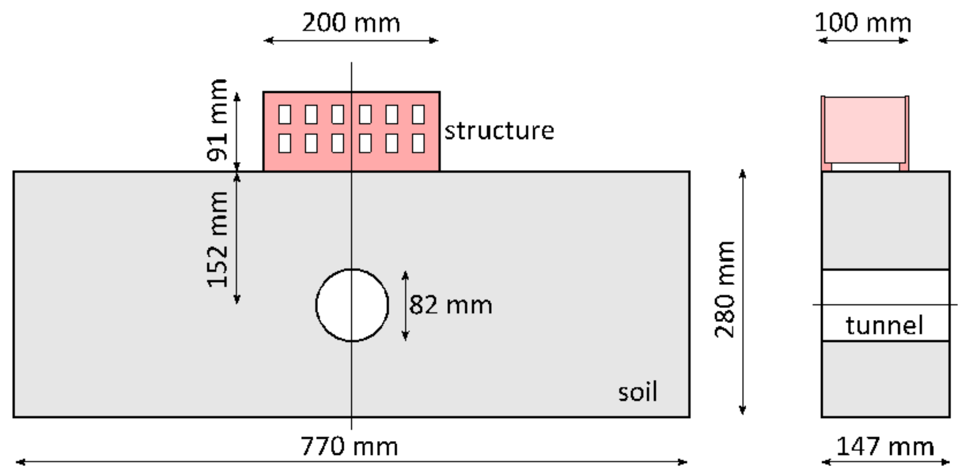
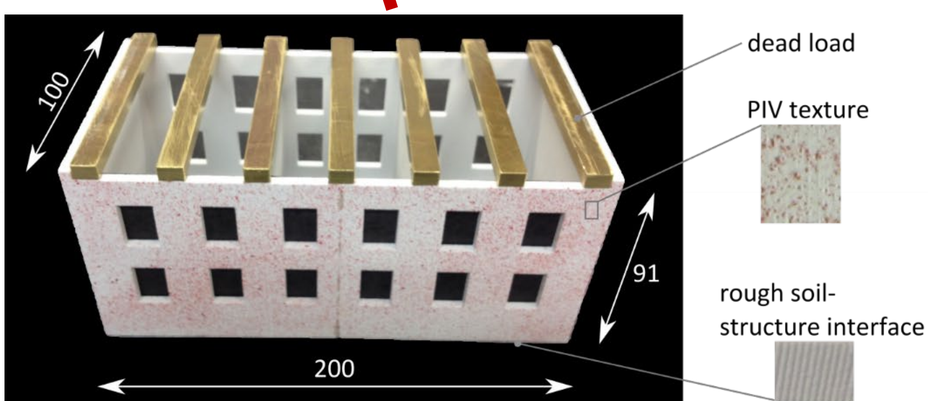
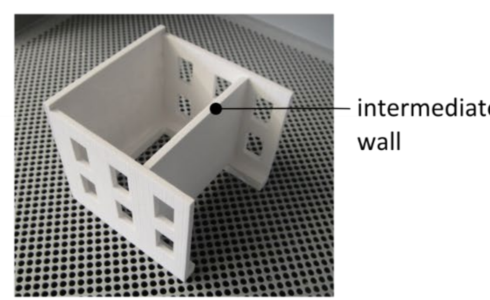
# Fundamental behavior:
# Soil-structure interaction experiments




Half of the model after 3D printing

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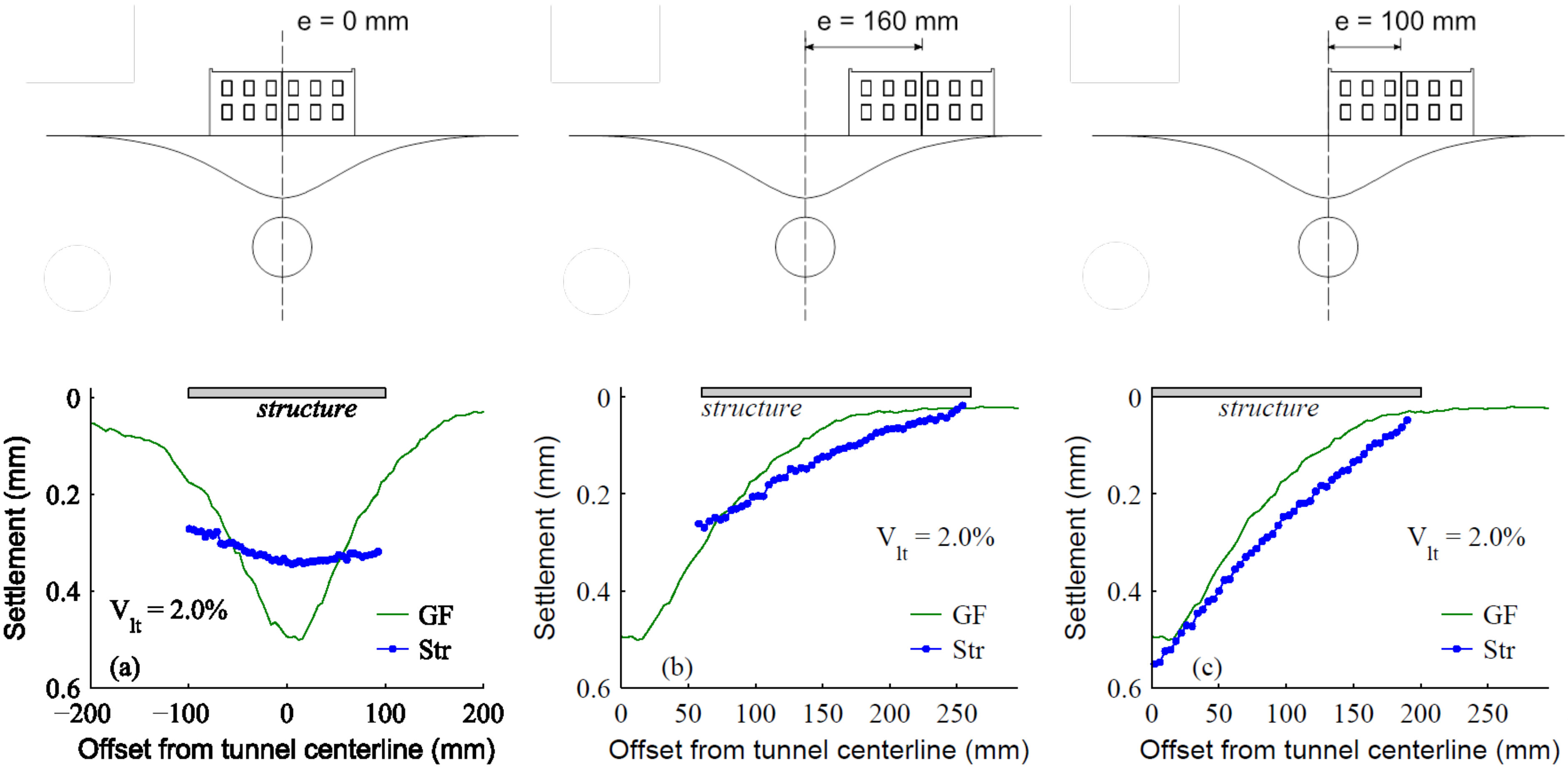
# Fundamental behavior:
# Soil-structure interaction experiments




(a) T1 - Structure in sagging. (b) T2 - Structure in hogging. (c) T3 - Structure in transition.

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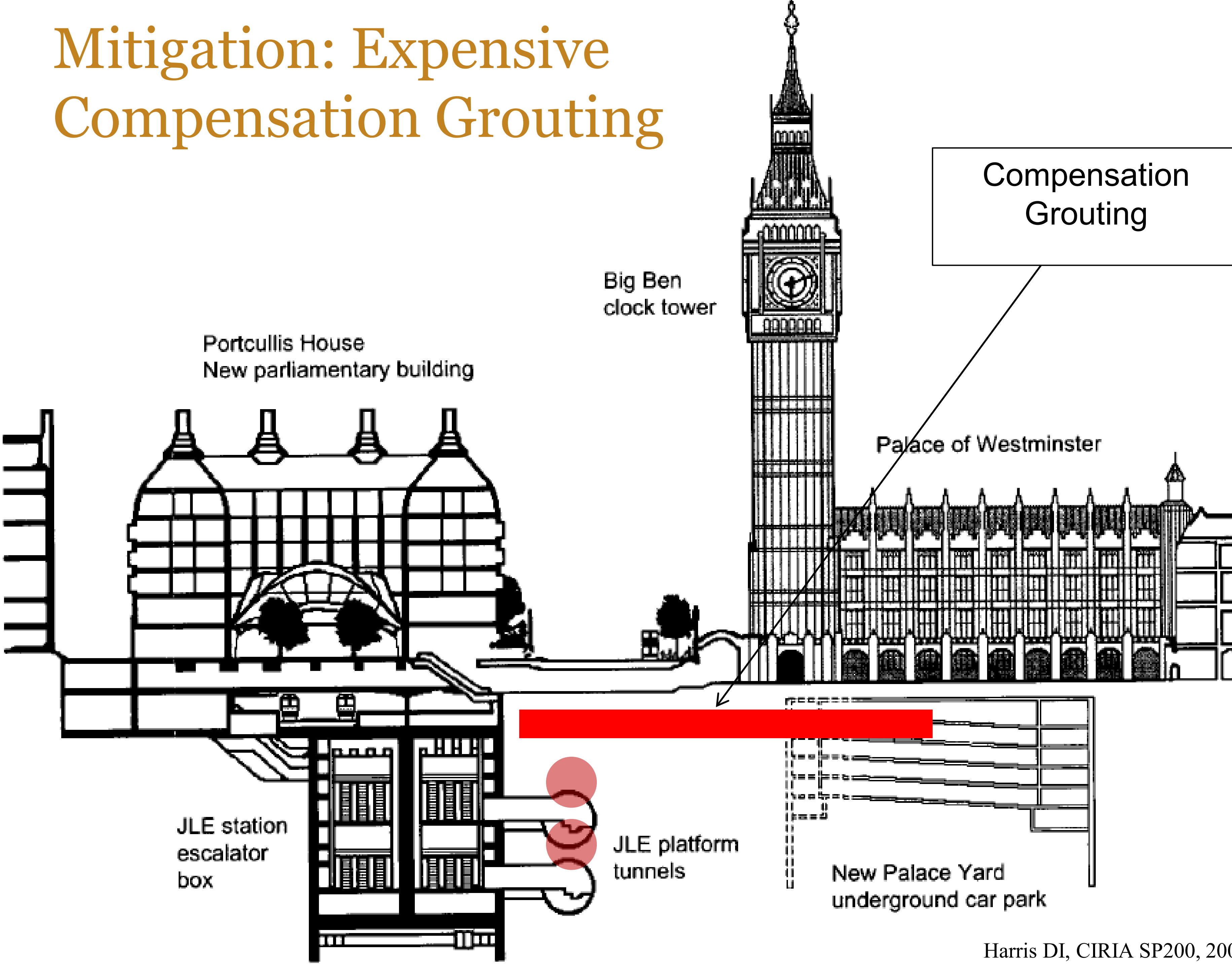
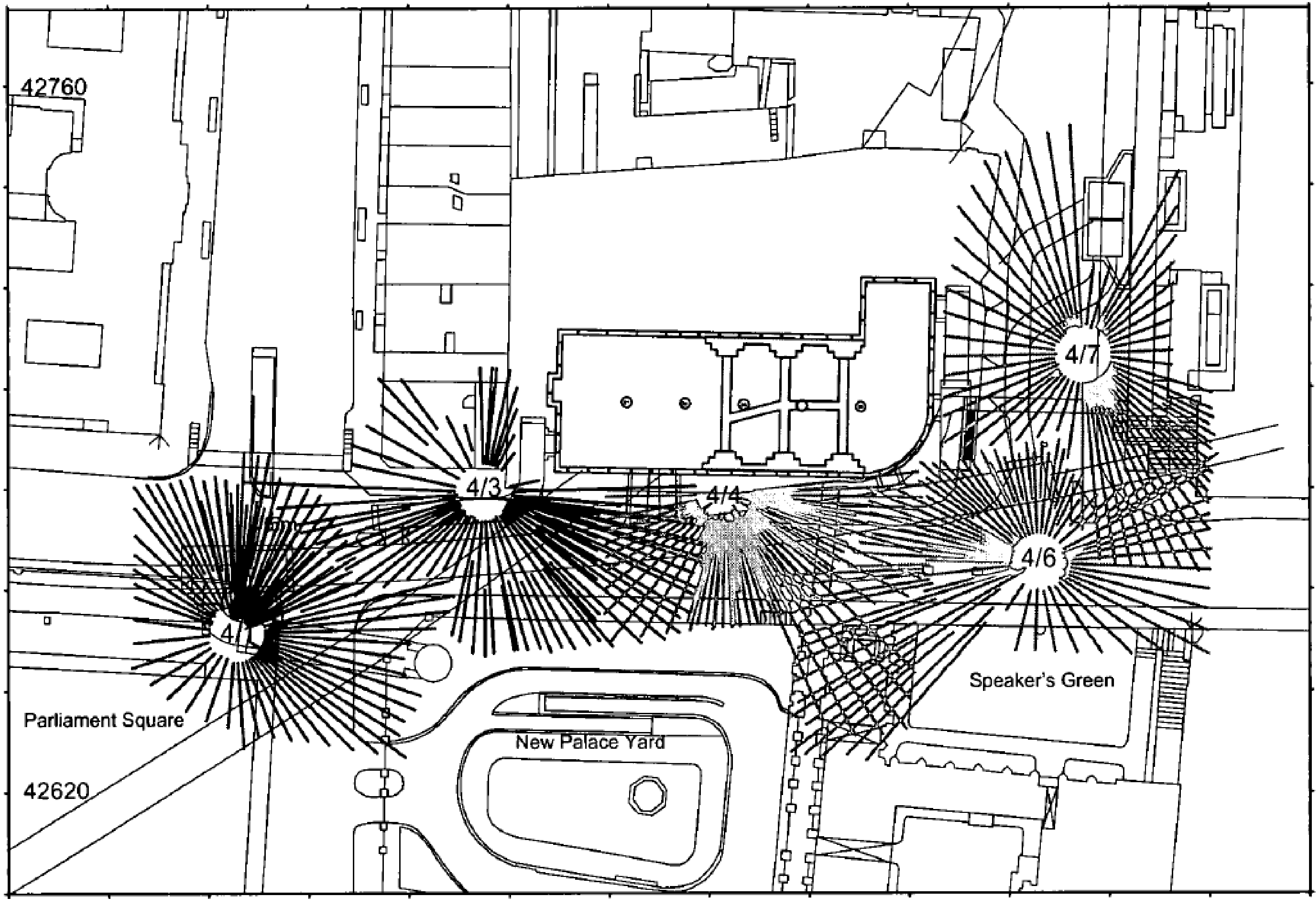
# Mitigation: Expensive Compensation Grouting



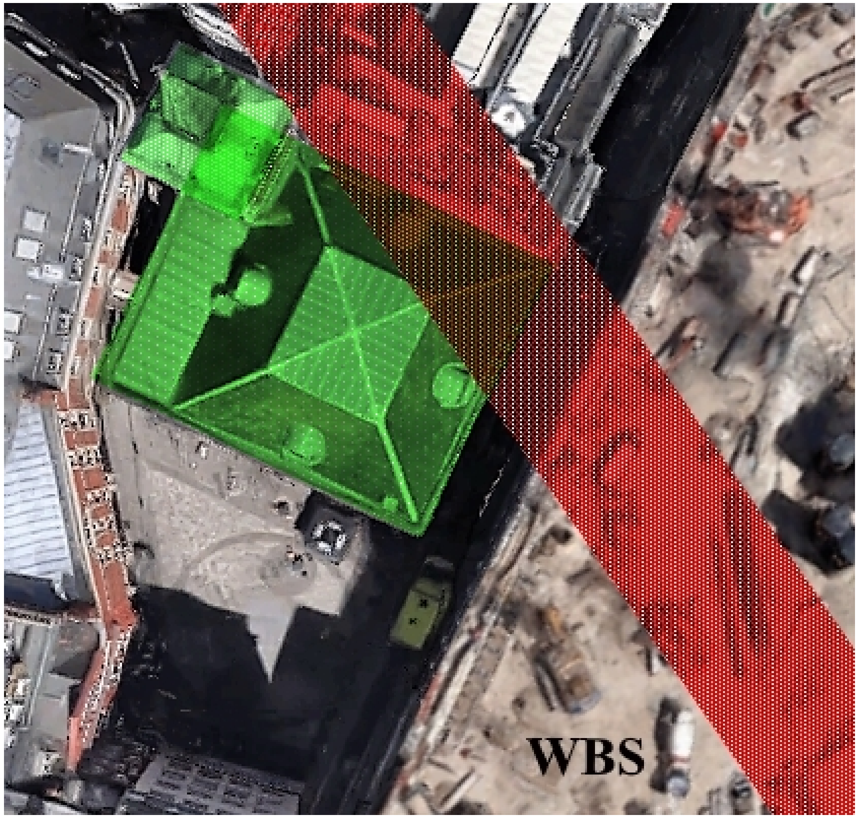

Harris DI, CIRIA SP200, 2001.



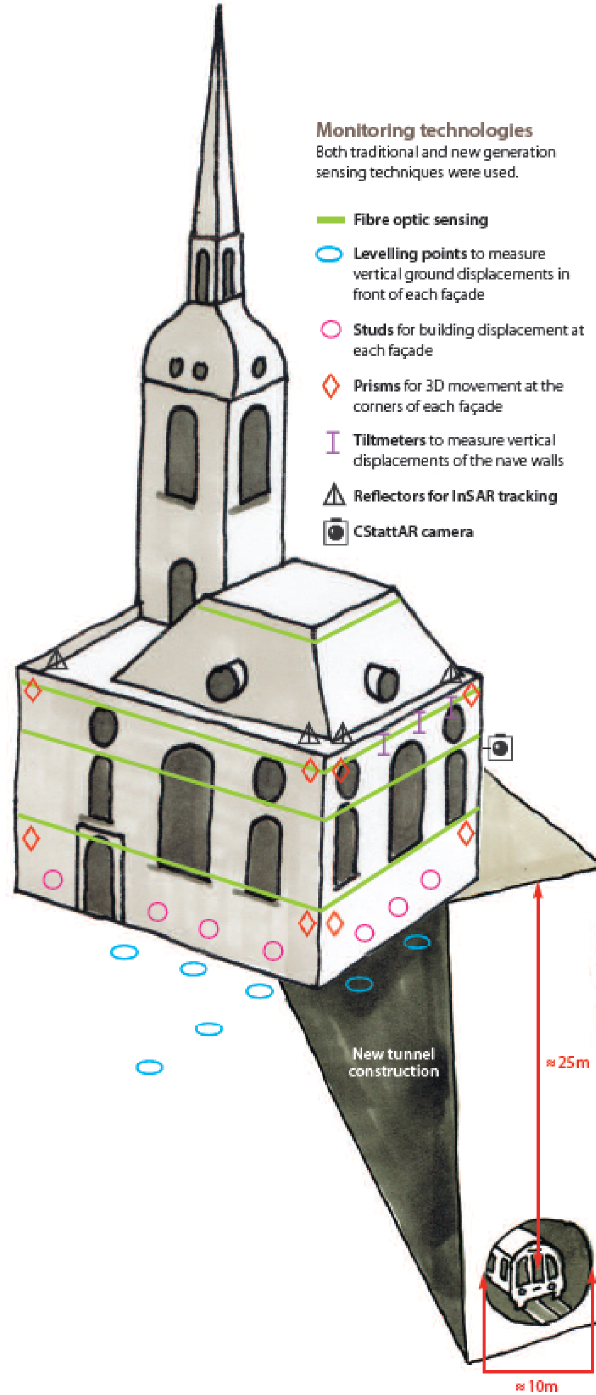

Harris DI, CIRIA SP200, 2001.

# How can we measure real behavior in the field?

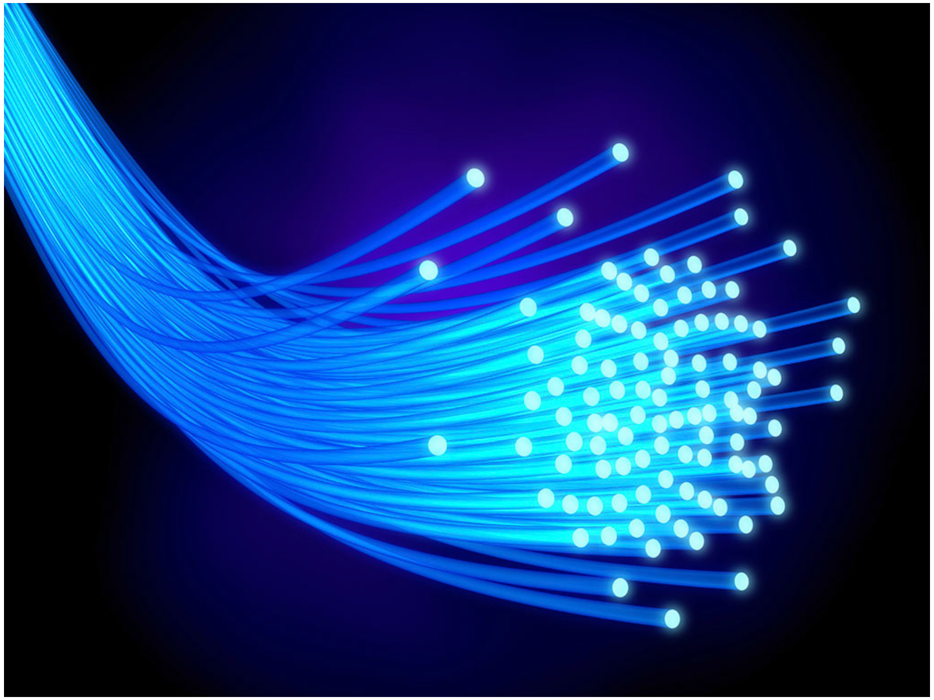
# St Mary Abchurch, London

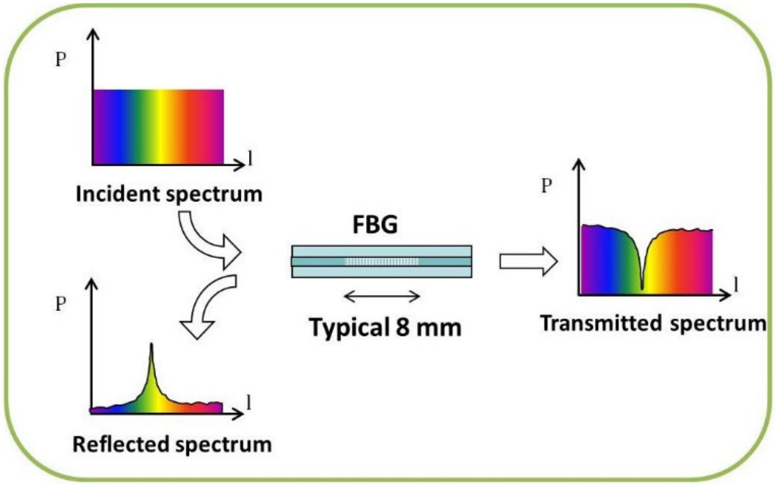


# St Mary Abchurch, London



# Fiber Bragg Grating (FBG) Sensing





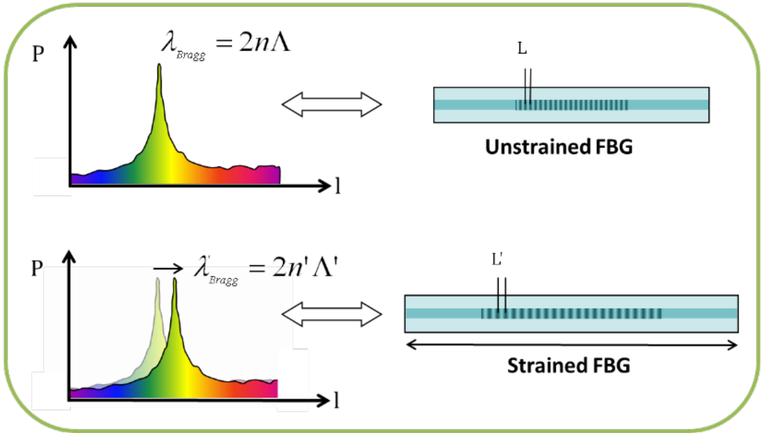




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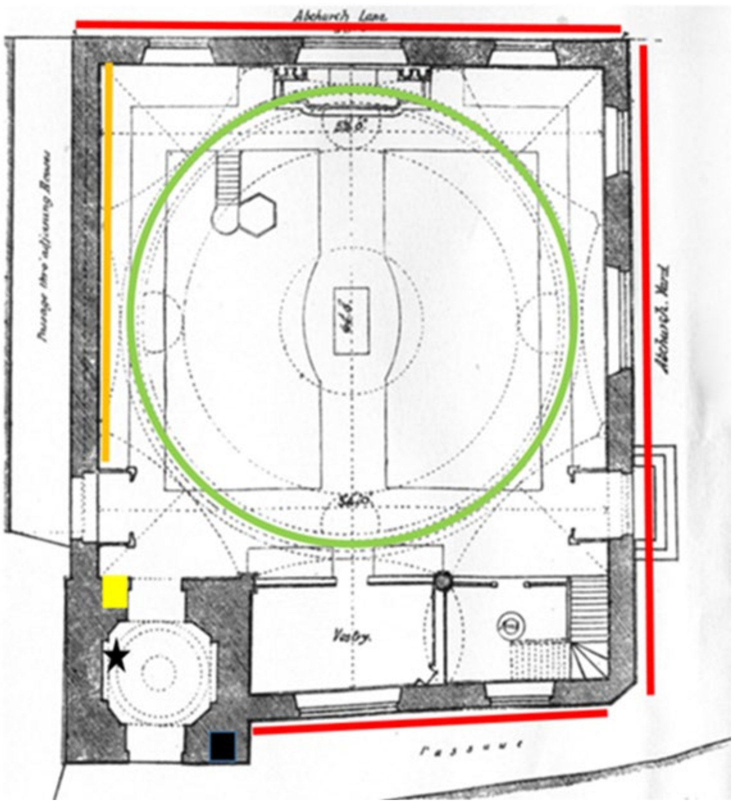
Image credit: www.fbgs.com

# Fiber Optic Sensor Installation





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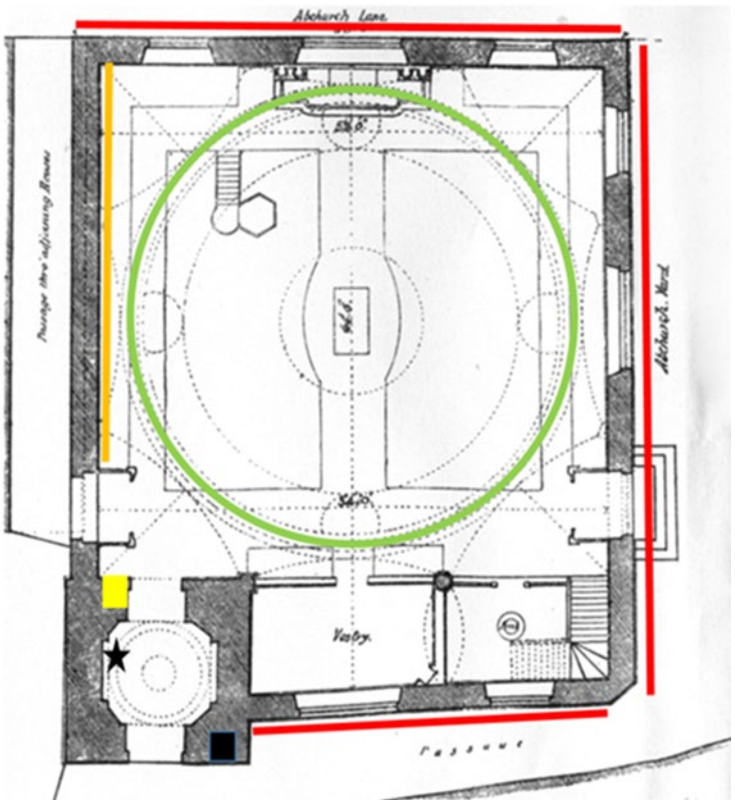
# Fiber Optic Sensor Installation





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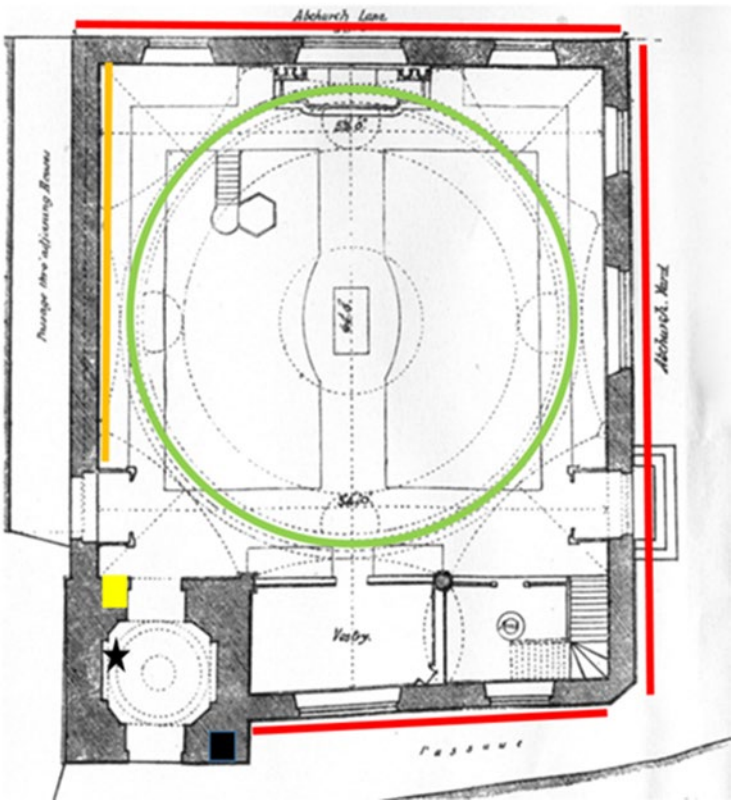
# Fiber Optic Sensor Installation





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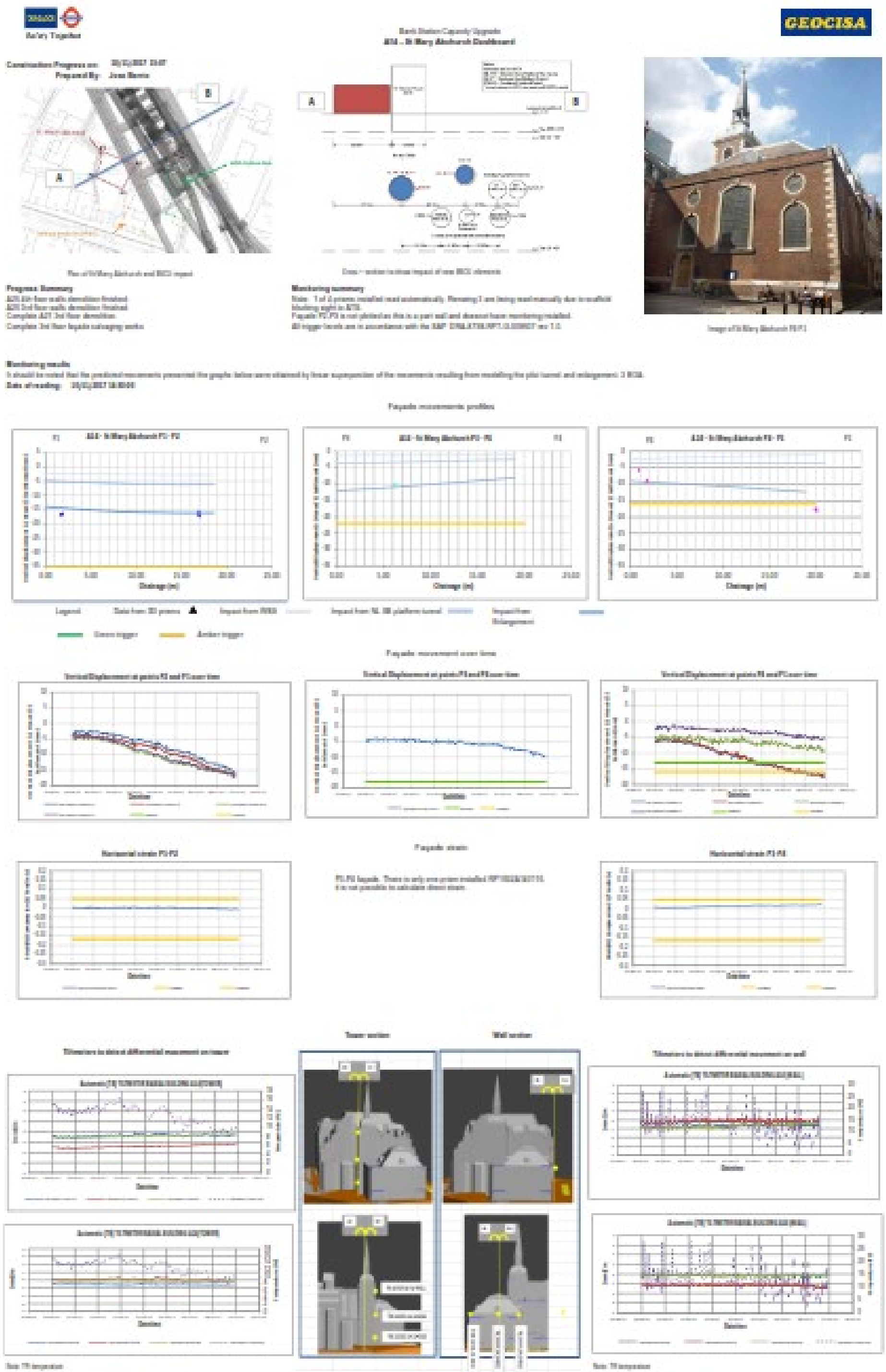
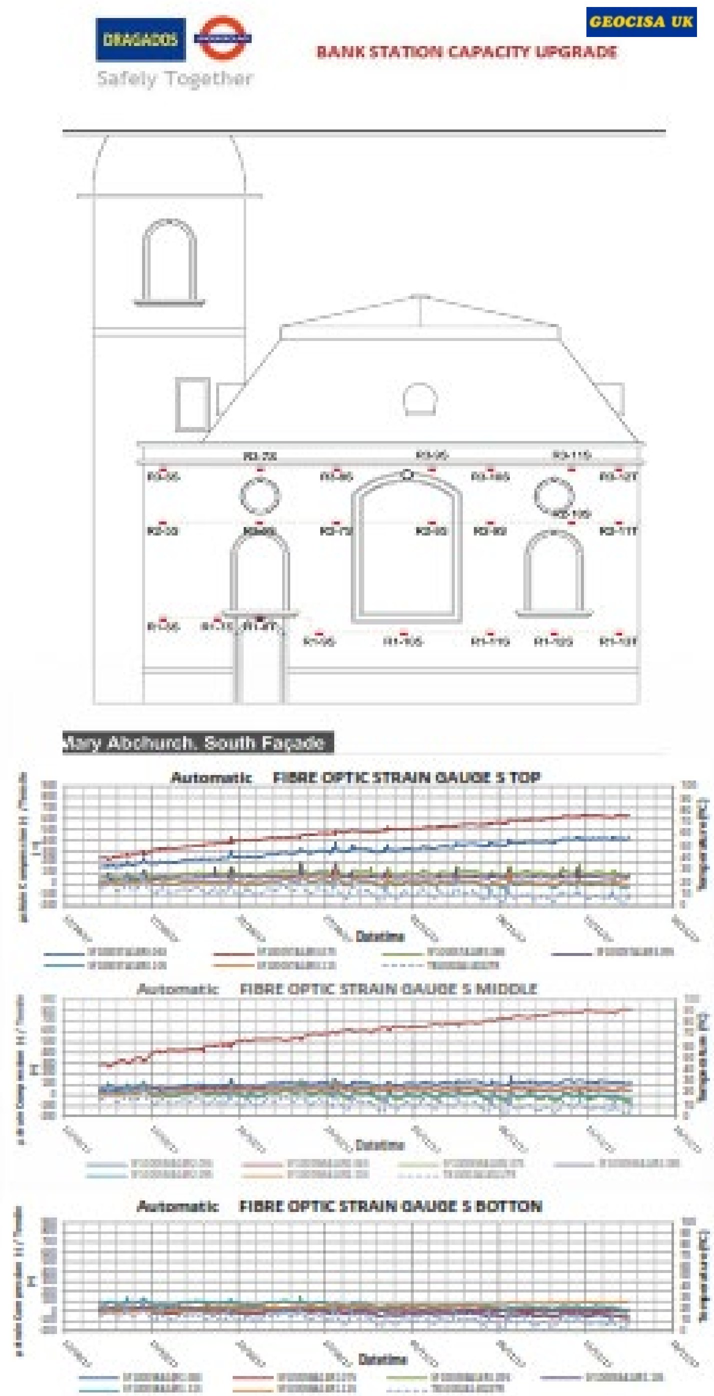
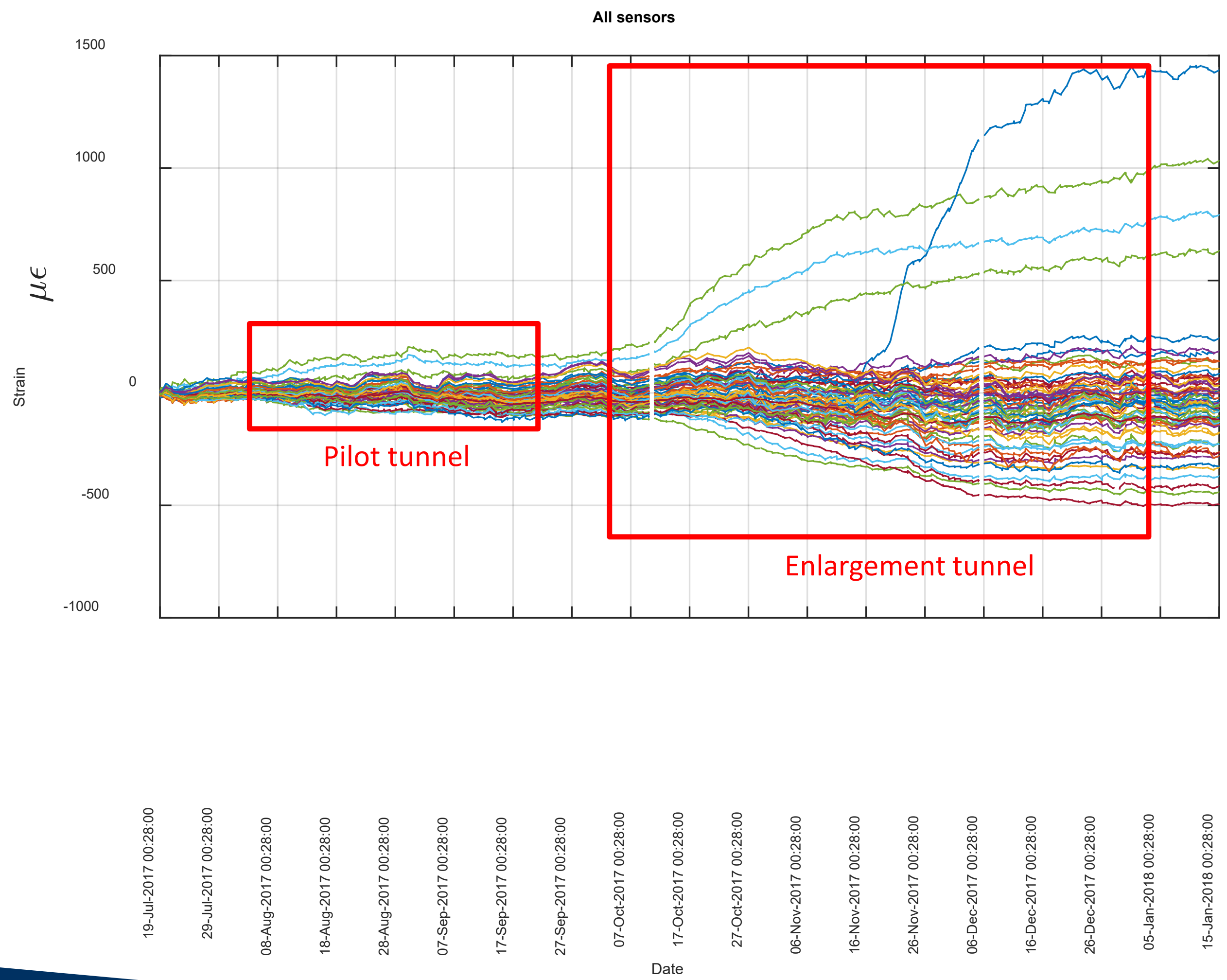

GEOCISA
Safely Together
Bank Station Capacity Upgrade
Progress Summary
Monitoring summary
Monitoring results
Façade movements profiles
Façade movement over time
Façade strain
Tower section
Wall section


GEOCISA UK
DRAGADOS
Safely Together
BANK STATION CAPACITY UPGRADE
Mary Abchurch. South Façade
Automatic FIBRE OPTIC STRAIN GAUGE S TOP
Datetime
Automatic FIBRE OPTIC STRAIN GAUGE S MIDDLE
Datetime
Automatic FIBRE OPTIC STRAIN GAUGE S BOTTON
Datetime

# Strain data from all sensors

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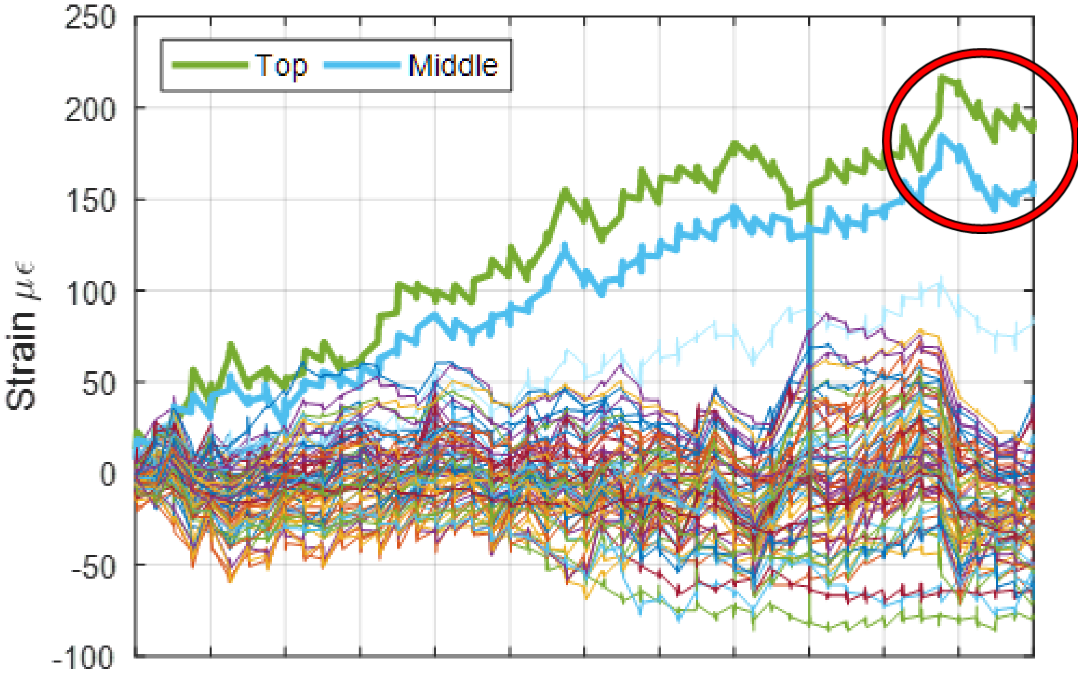
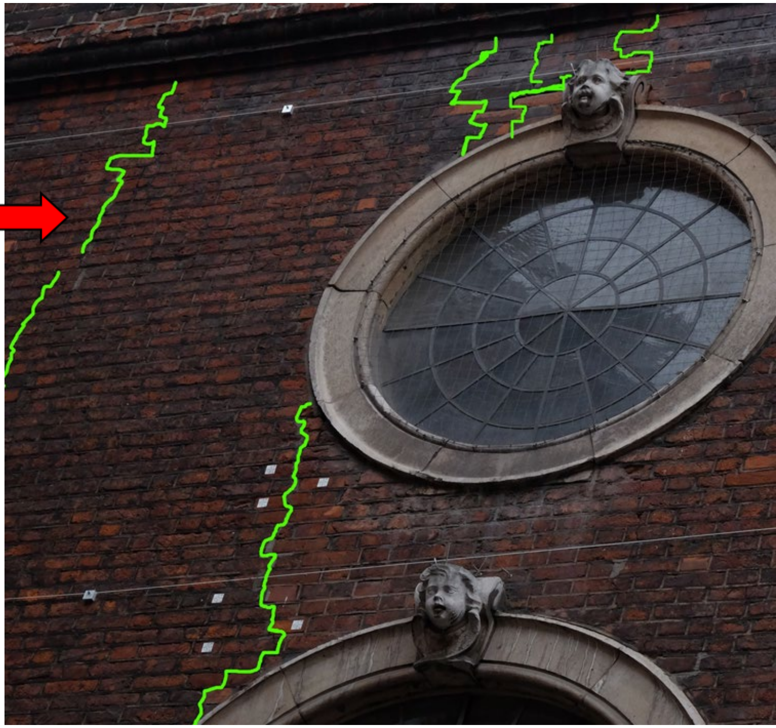
# Fiber Optic Sensor Results

## Measure damage directly

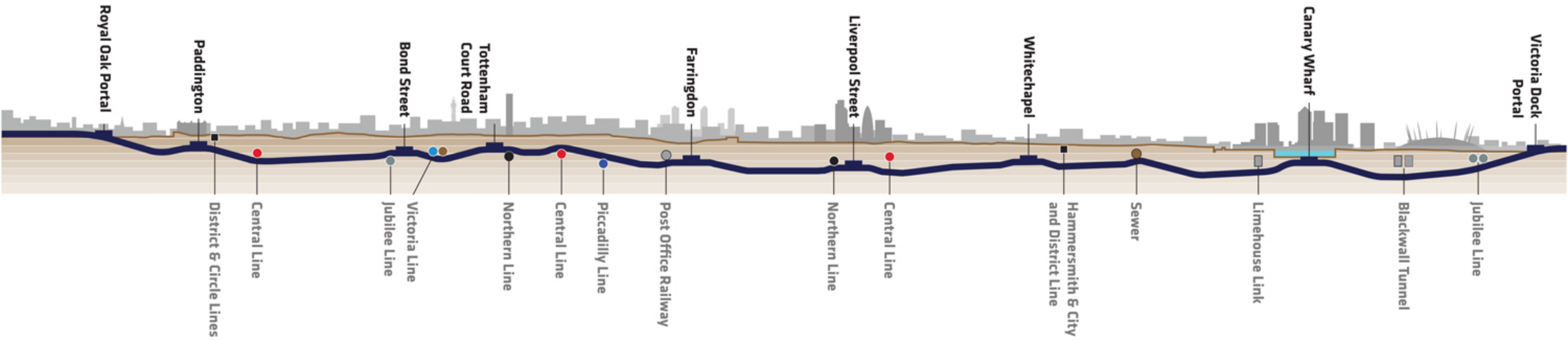


# 2. Tunneling-induced settlement: City scale (Crossrail - London, UK)

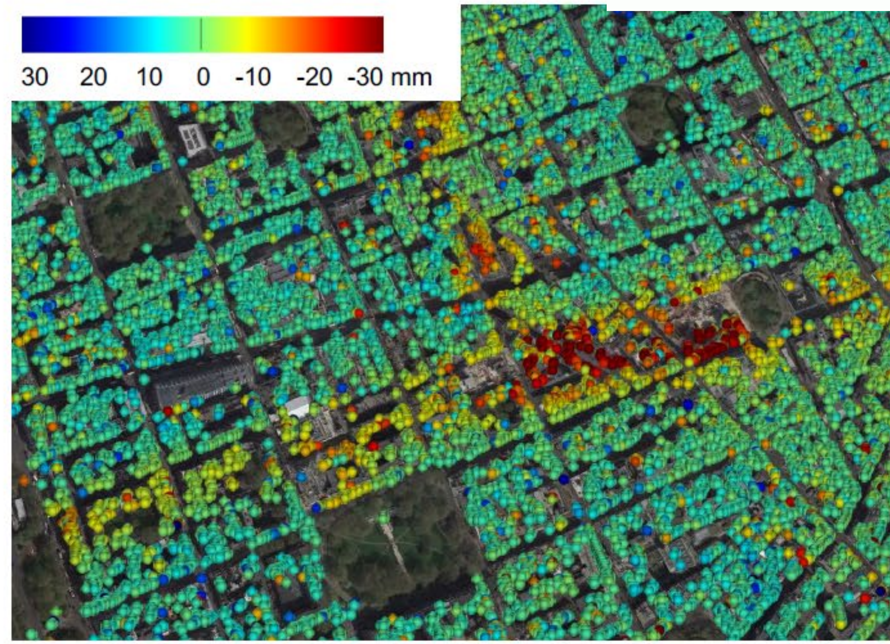
- Giorgia Giardina (former post-doc, now Bath Univ.)
- Pietro Melillo (JPL, Pasadena)

# Crossrail Twin Tunnels




# Field behavior: Crossrail, London
# InSAR (satellite) Monitoring of Settlements


**(a)** Displacement map



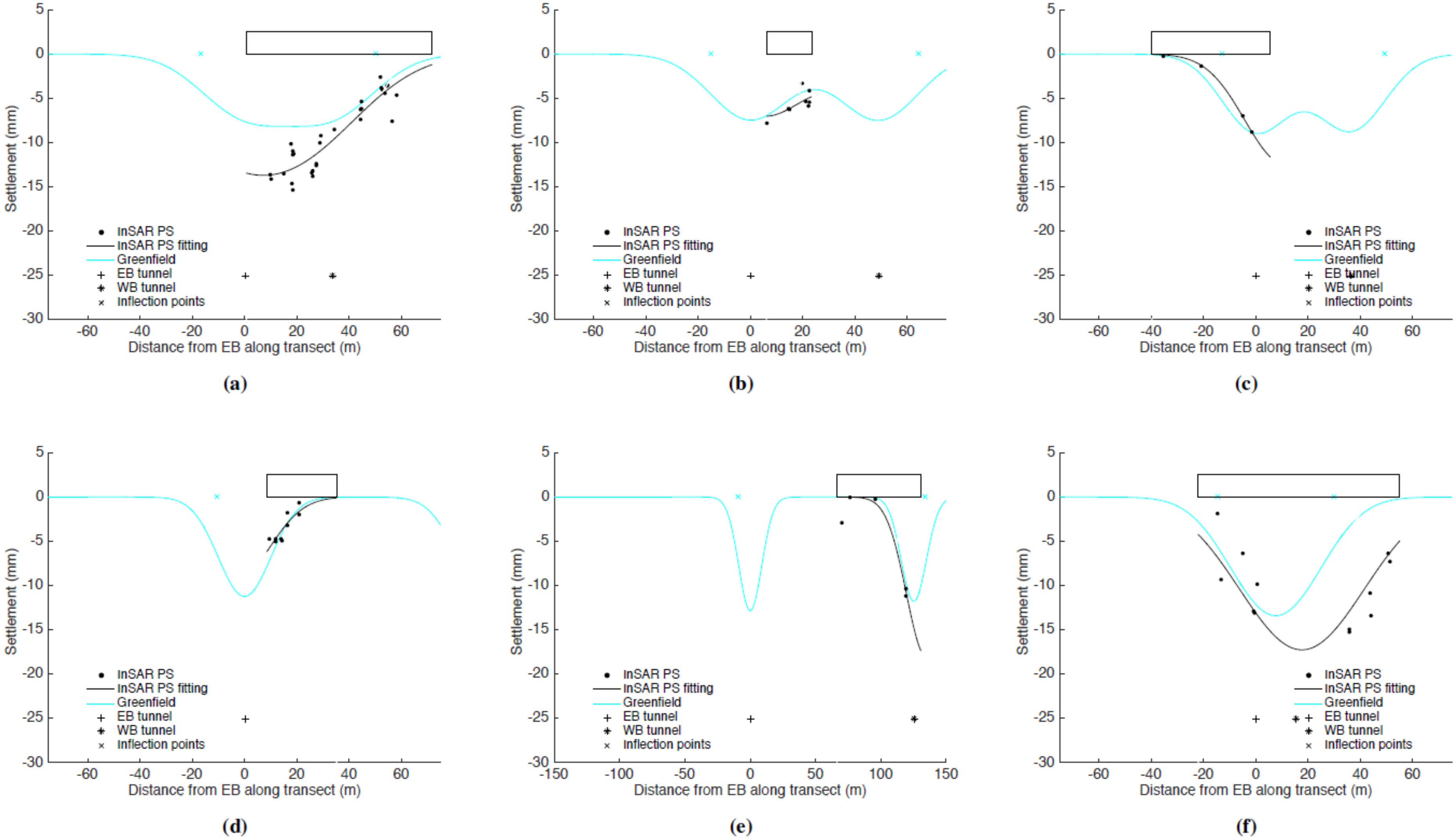

**(b)** Displacement map zoom-in

<u>Giardina</u> G, Milillo P, **DeJong** MJ, Perissin D, Milillo G (2018). Evaluation of InSAR monitoring data for post-tunnelling settlement damage assessment, *Structural Control and Health Monitoring*.

# InSAR Results: Six example buildings

Jet Propulsion Laboratory
California Institute of Technology

UNIVERSITY OF BATH



Collaborators:

## 3. Bridge Diagnostics (CFM-5 Bridge – Yorkshire, UK)

- Sam Cocking (PhD Student)
- Haris Alexakis (Postdoc)

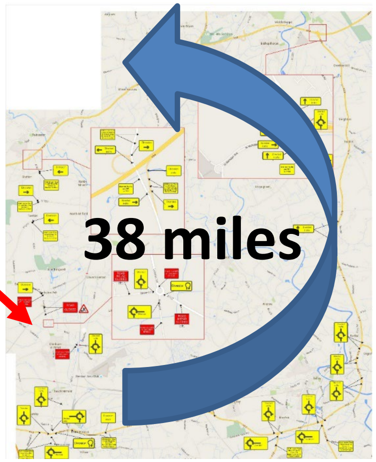
Funding:

- New Civil Engineer TechFest 2019: Rail Visionary Award
  *"Innovative Structural Health Monitoring of Ageing Infrastructure"*

# CFM-5 Rail Bridge

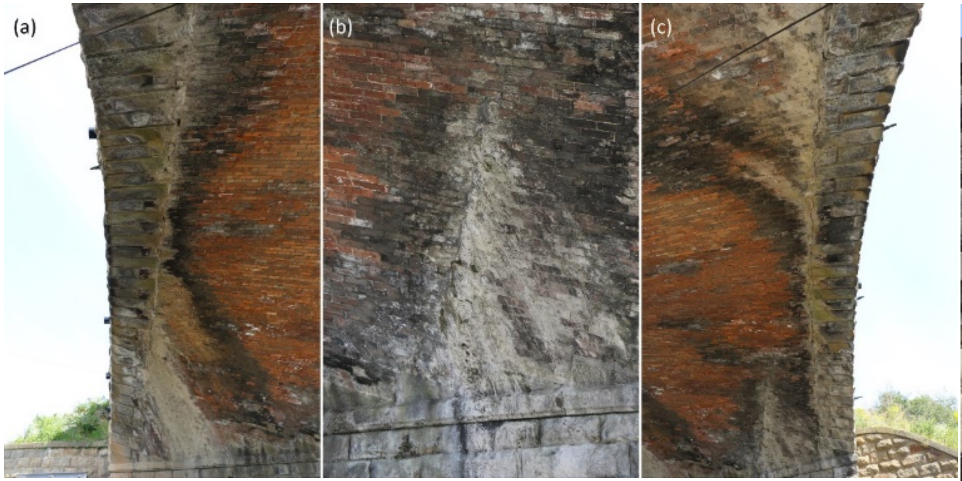
# Motivation

1. Understanding of field behavior
2. Condition monitoring to ensure safety
3. Compare SHM technologies (AECOM)



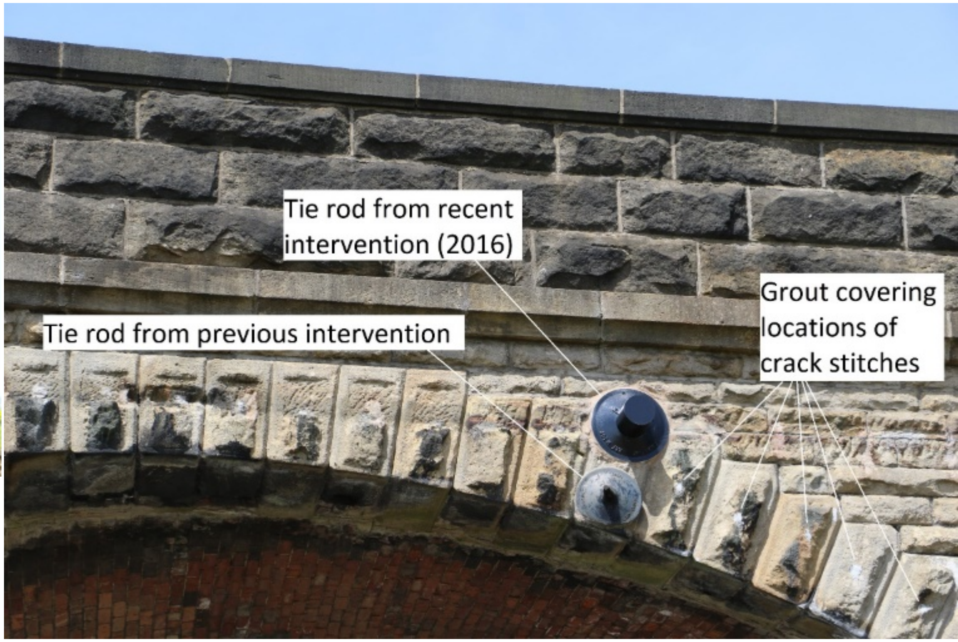

# Key damage and intervention

## Notable cracks:

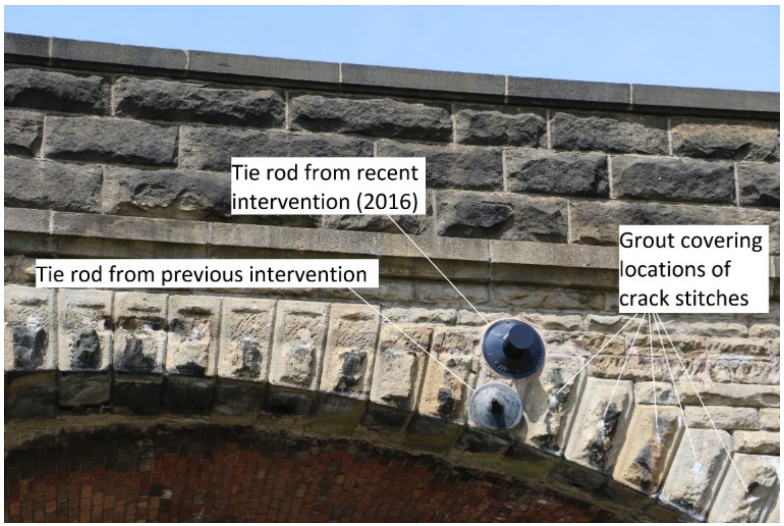


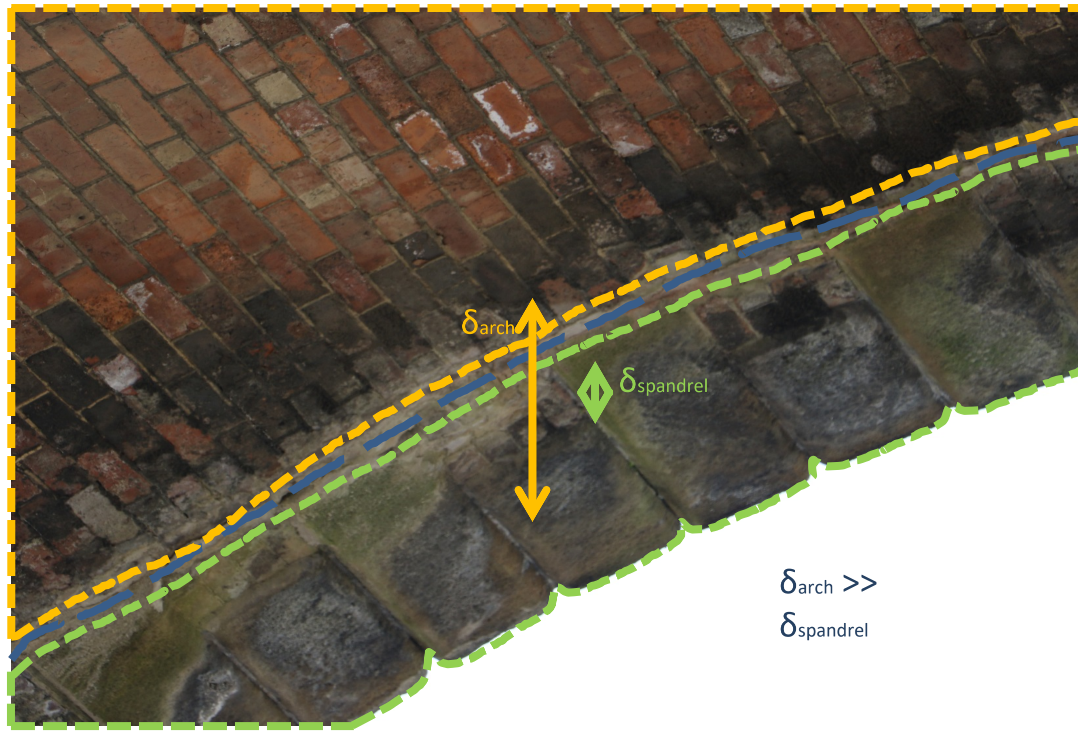

(a,c) Spandrel separation crack
(b) Longitudinal crack in SE corner

## Intervention:



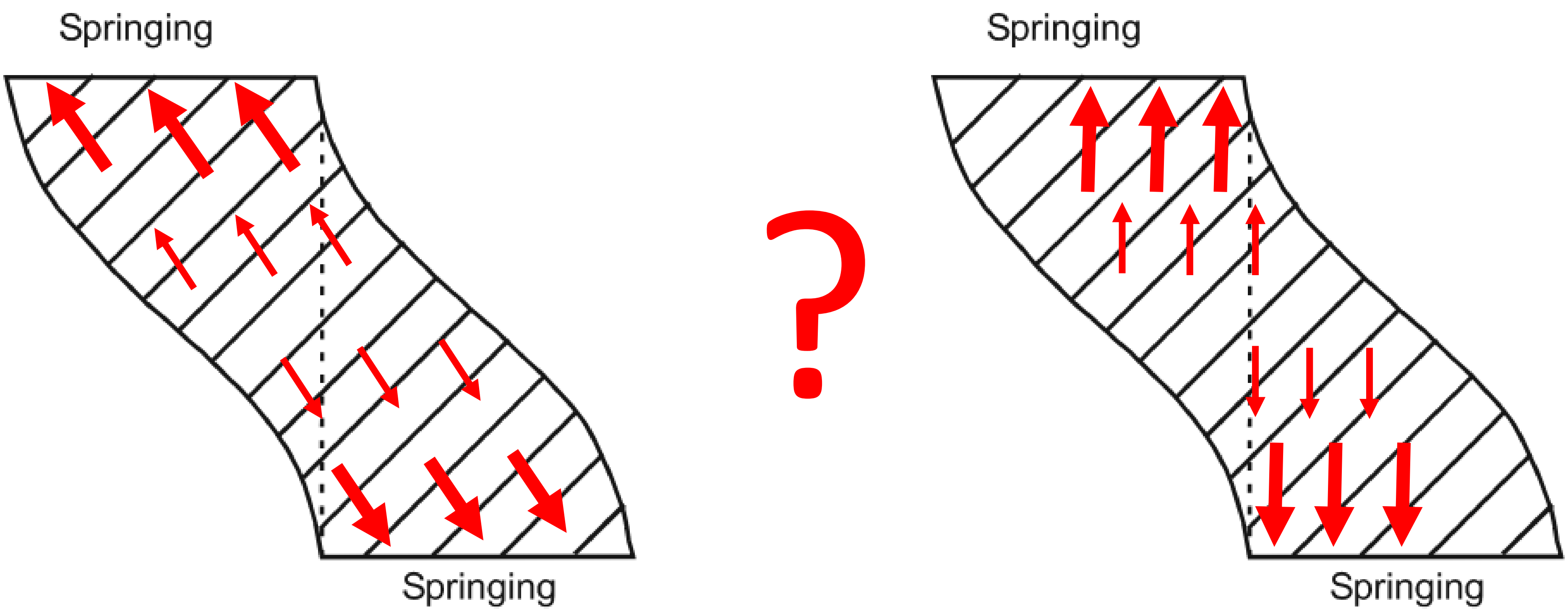
# Arch pumping is a key concern



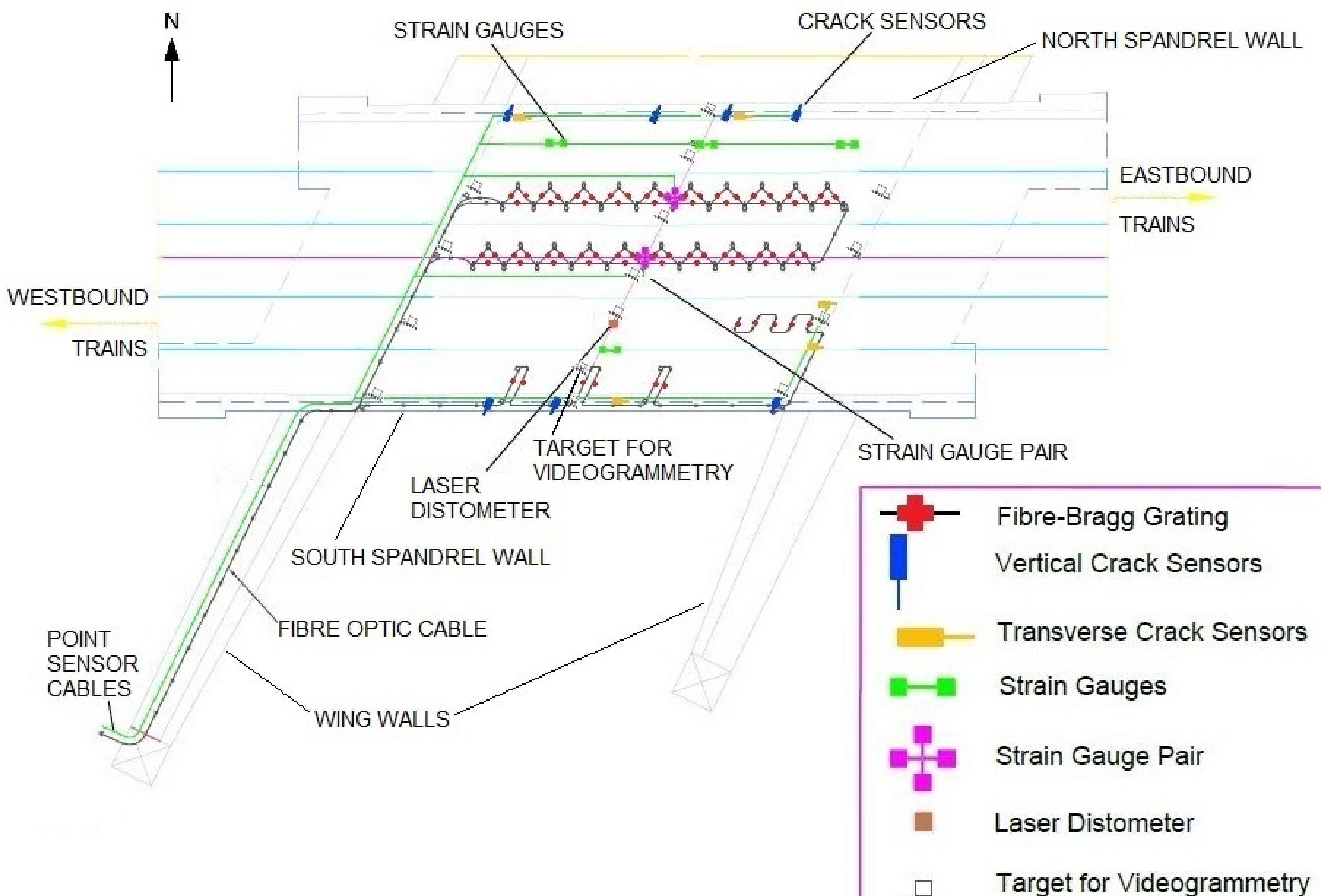




$\delta_{arch} >> \delta_{spandrel}$

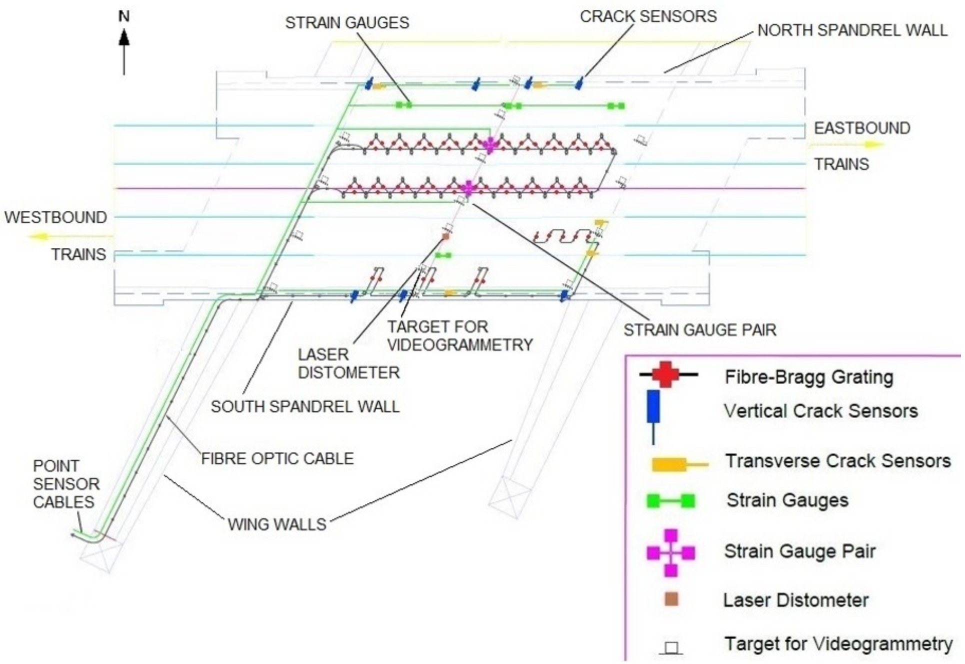
# Structural Behavior

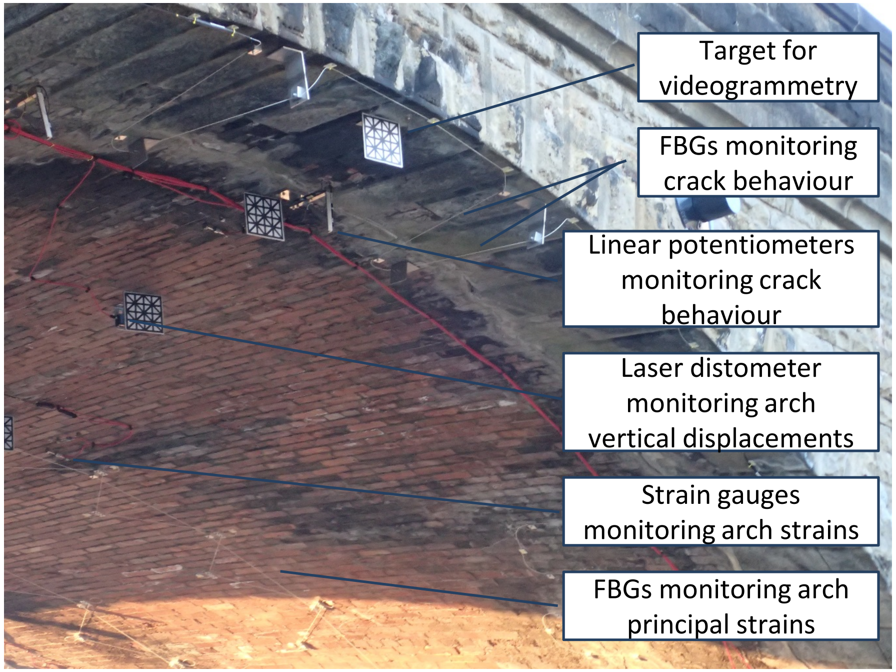


# Monitoring Installation - Overview



# Monitoring Installation - Overview

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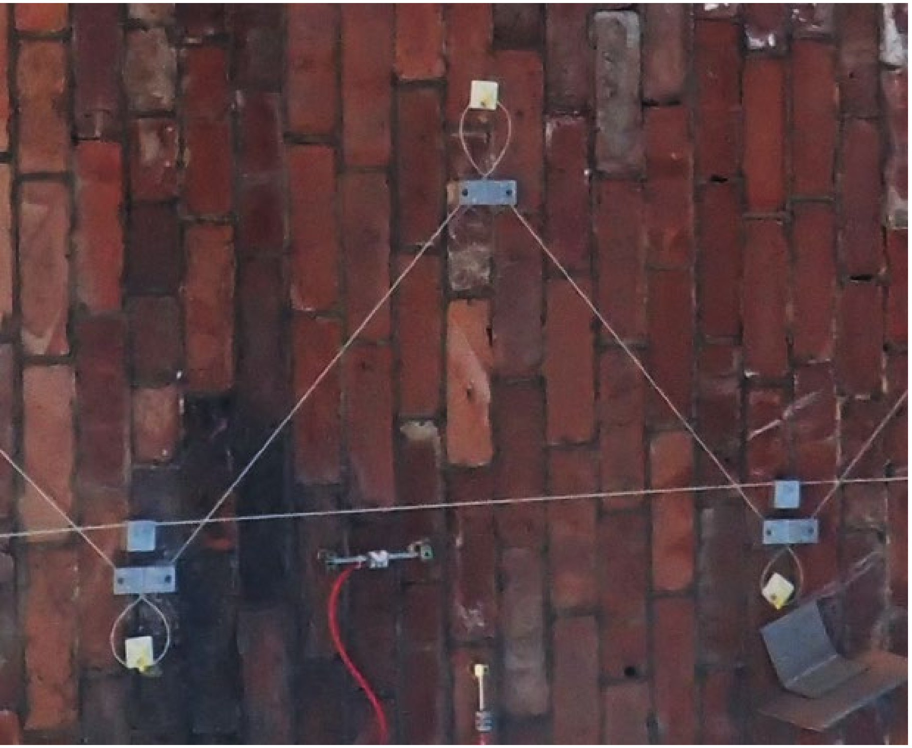
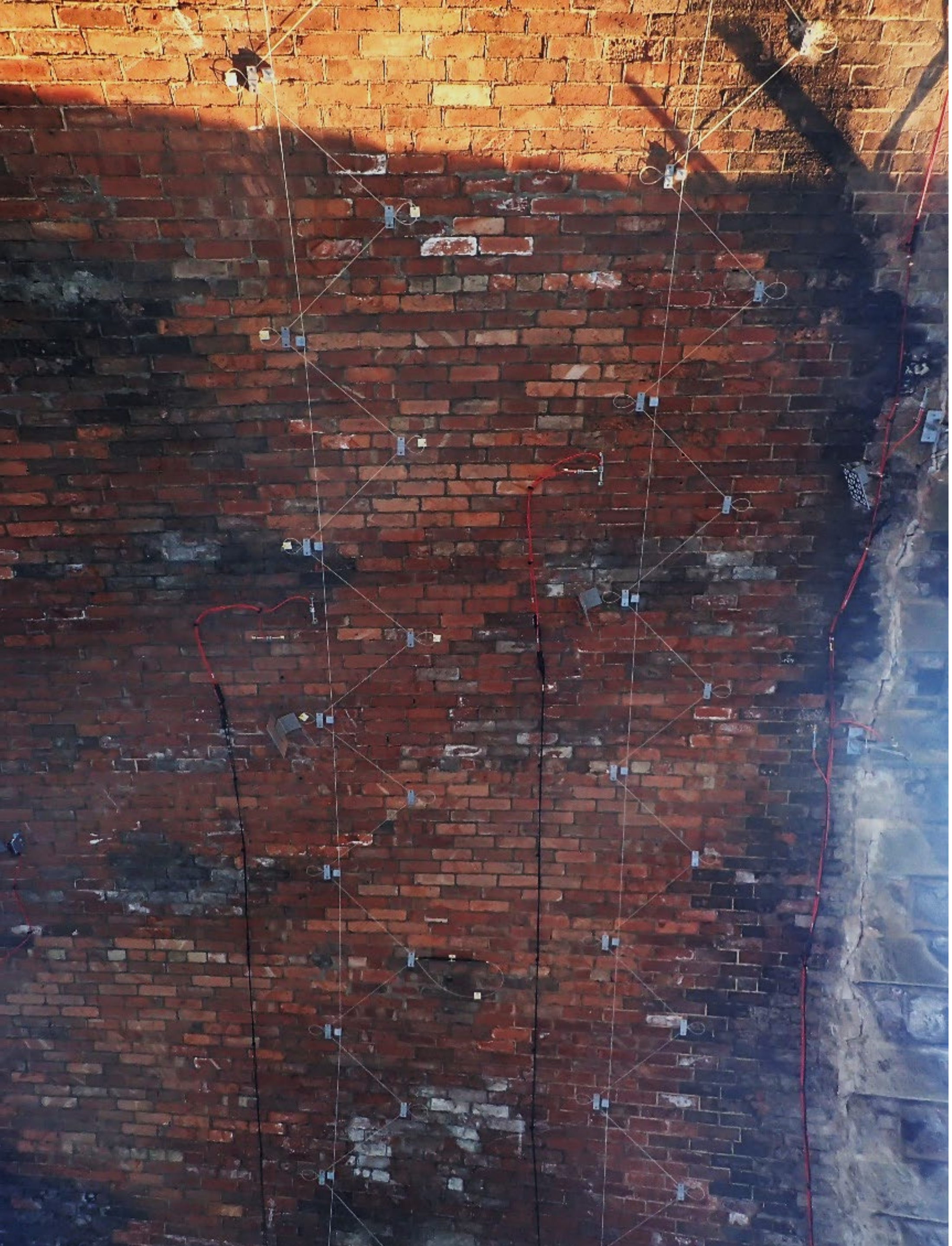
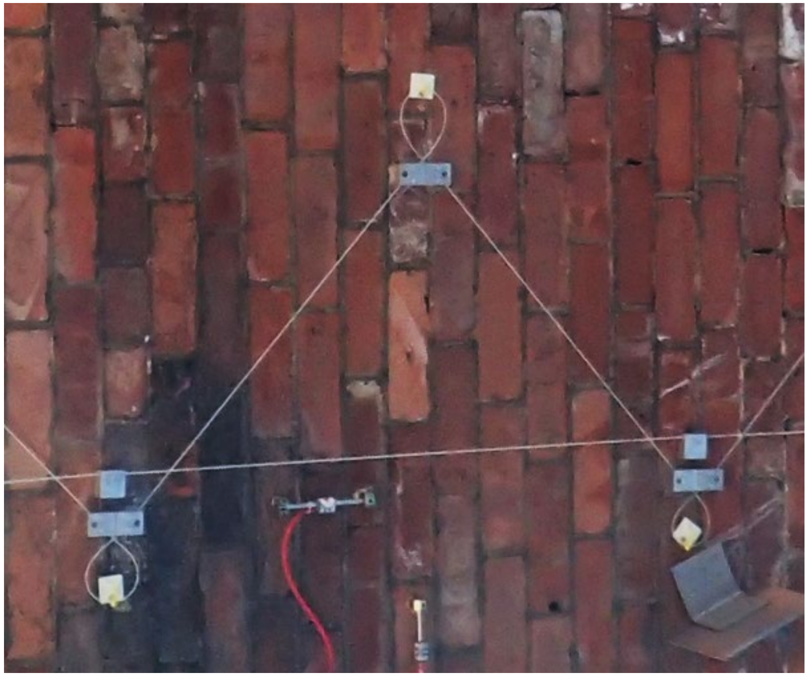
# Monitoring Installation - FBG

FBG rosettes:

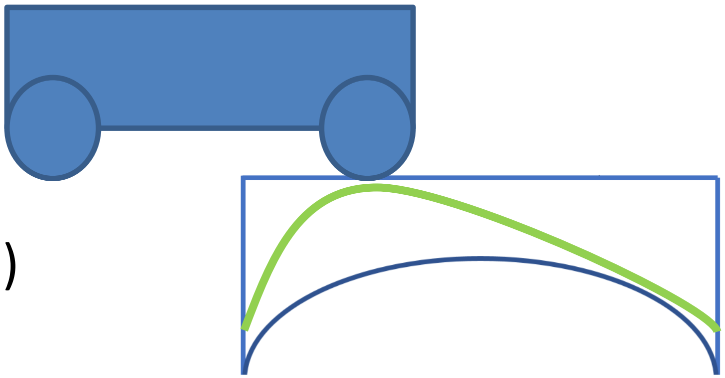


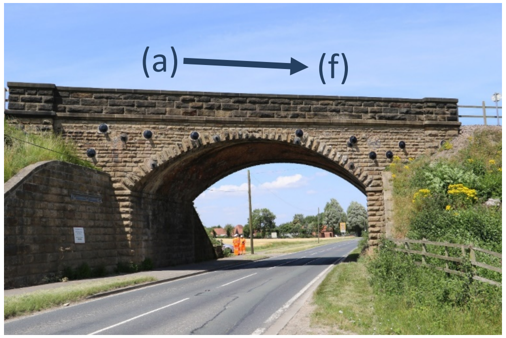
FBG pairs:

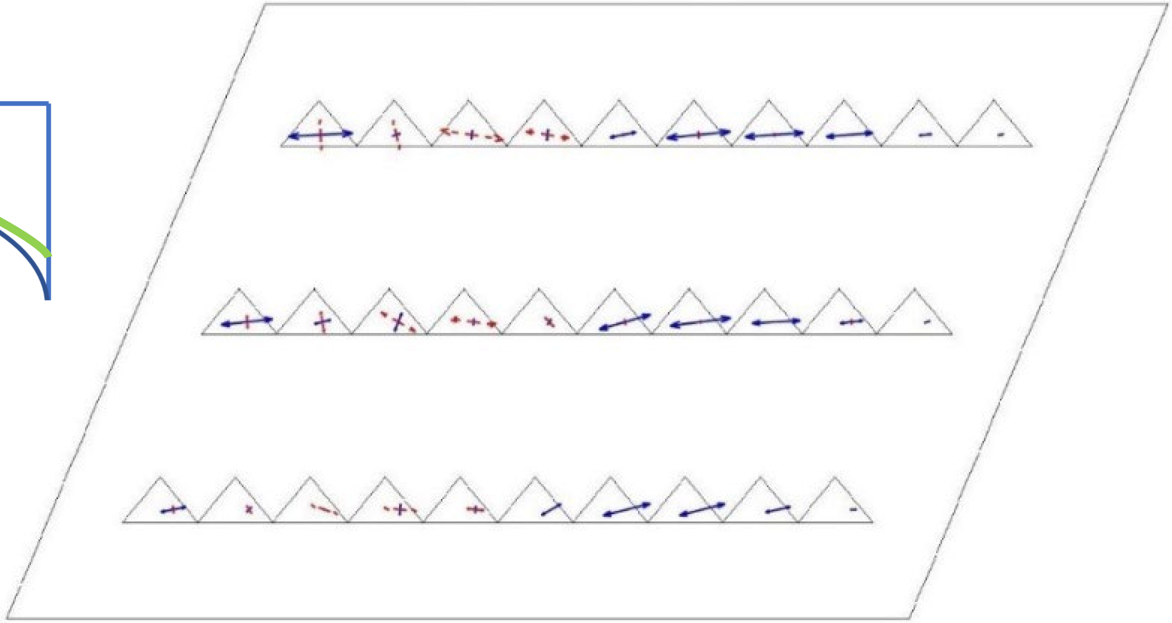



# Mapping Principal Strains

(a)





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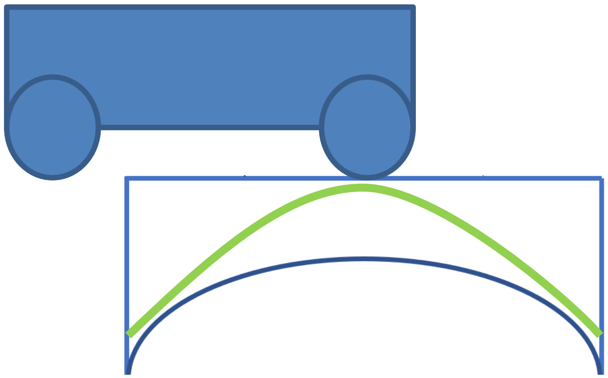
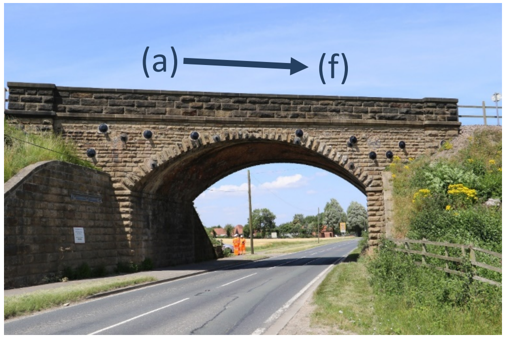
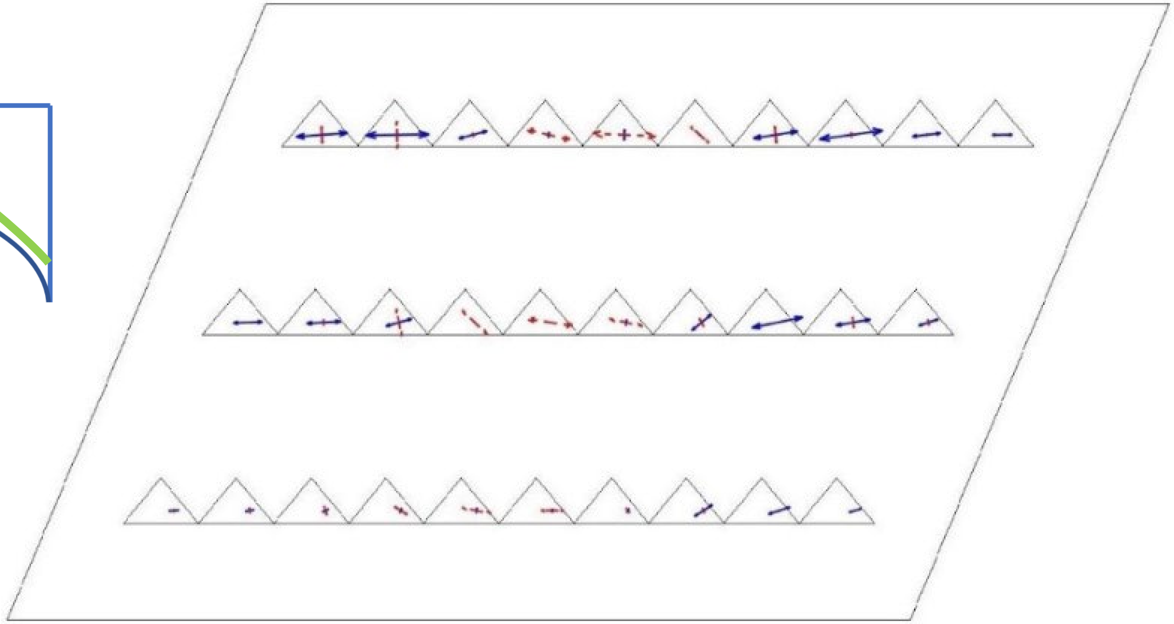
# Mapping Principal Strains

(c)





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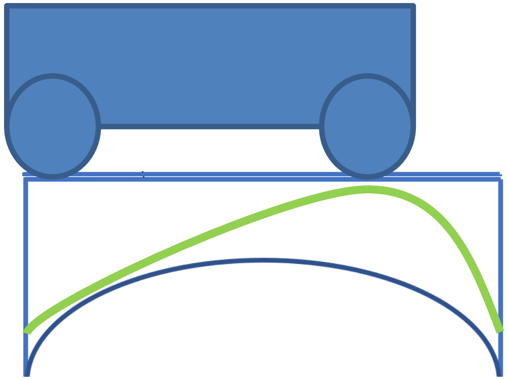
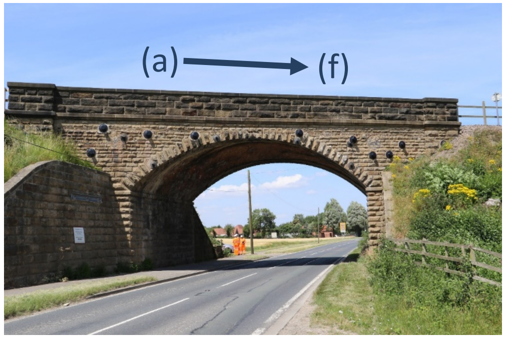
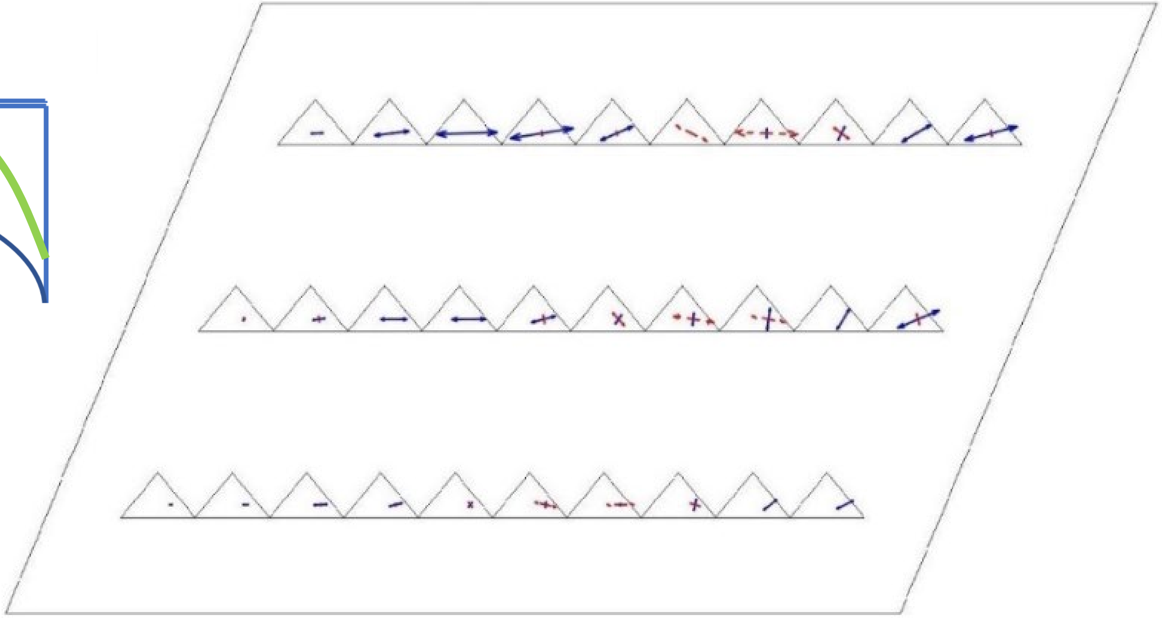
# Mapping Principal Strains

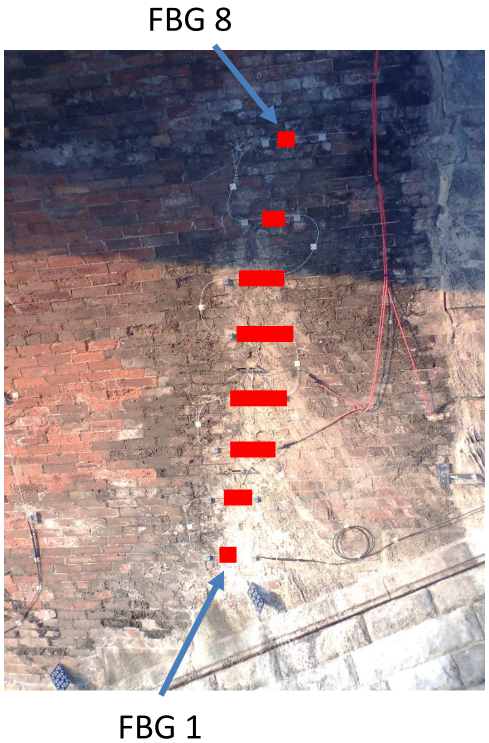
(e)

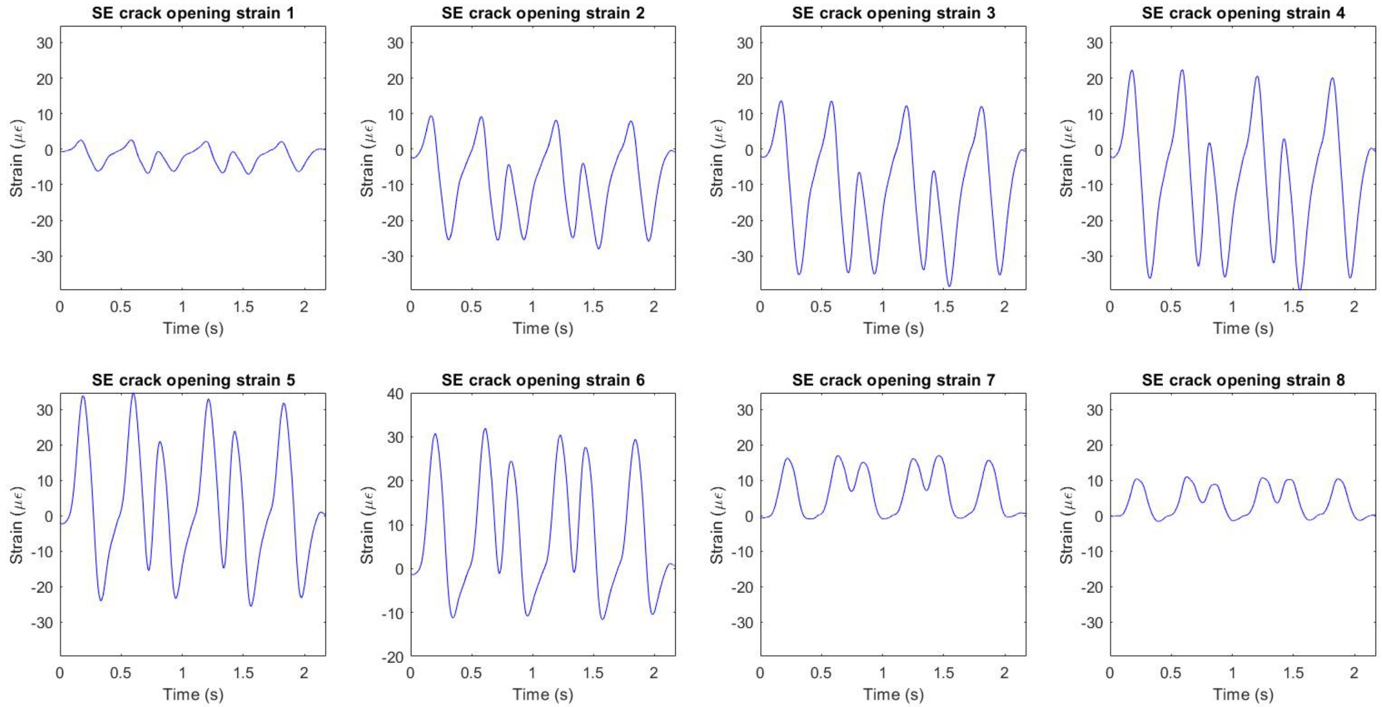




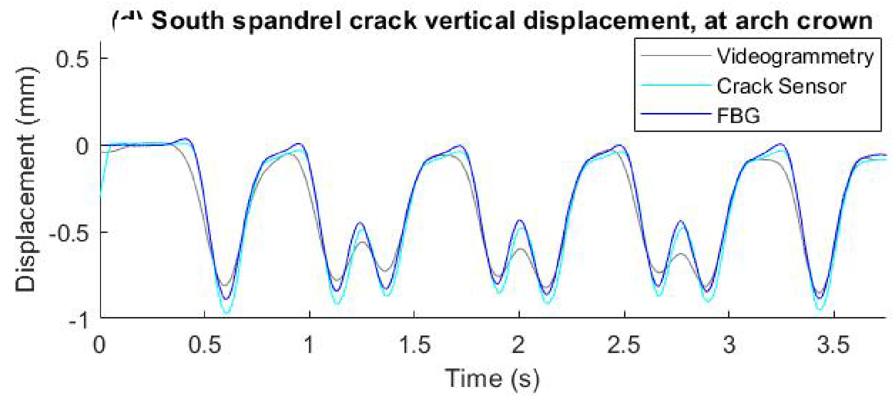



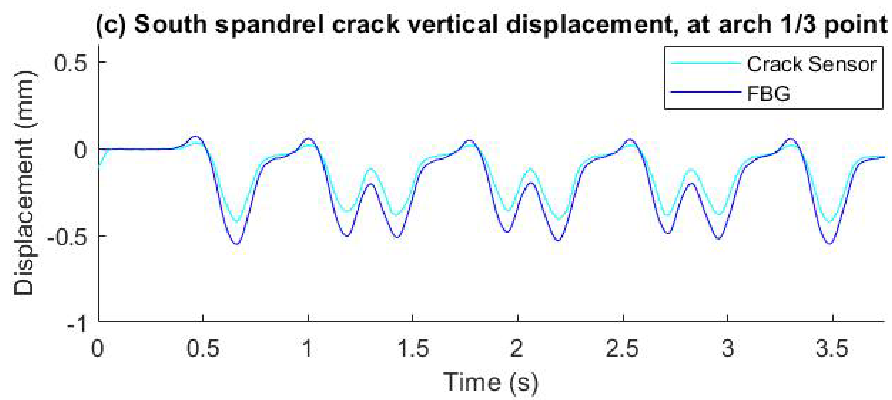
# Monitoring Crack Opening



# Monitoring Arch Pumping



# Collaboration

NetworkRail

Network Rail

CFM-5 monitoring collaboration

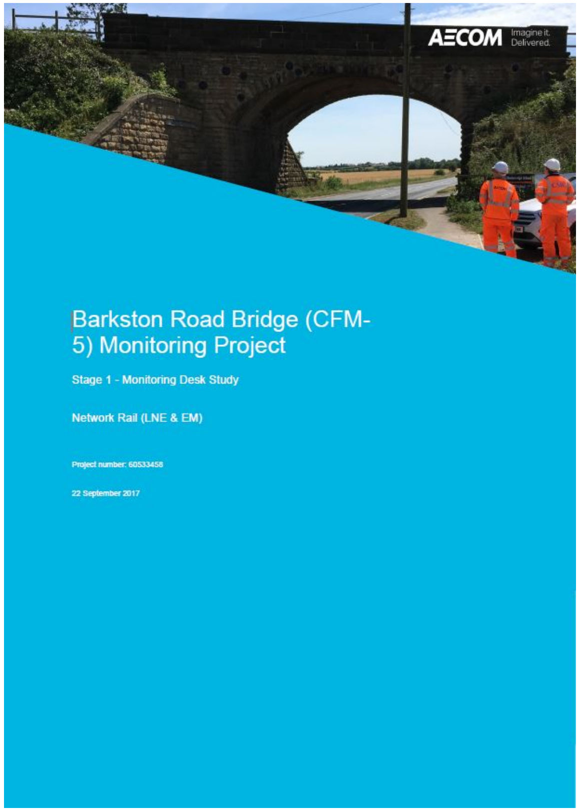
CSIC

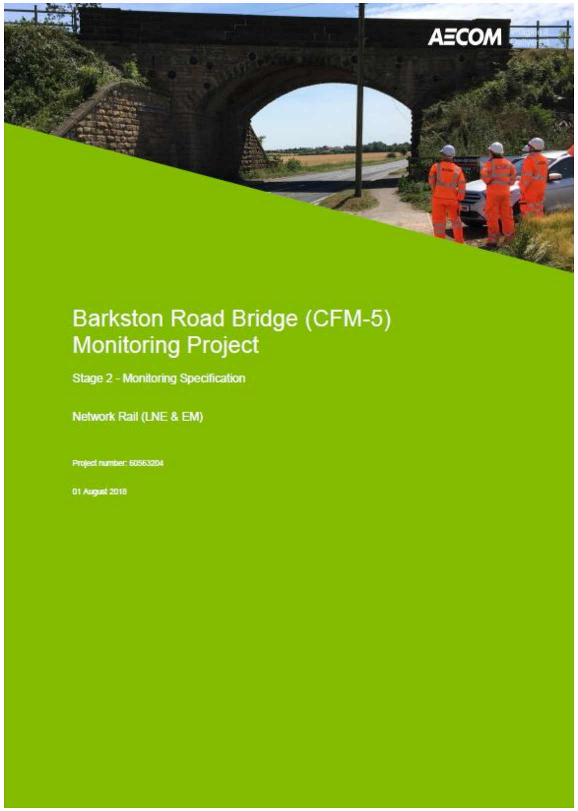
AECOM

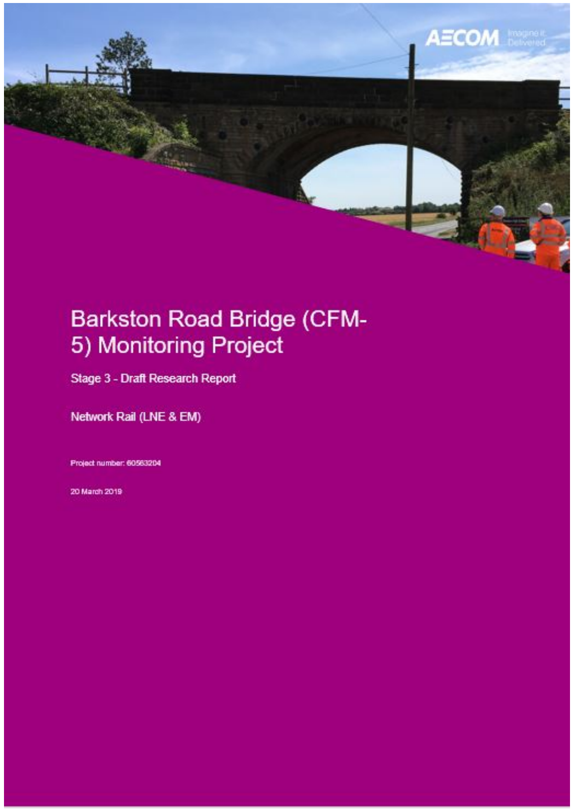
CSIC Cambridge Centre for Smart Infrastructure & Construction

AECOM

# Practical Dissemination

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Collaborators:

# 4. Monitoring Bridge Degradation (Rail Viaduct – Leeds, UK)

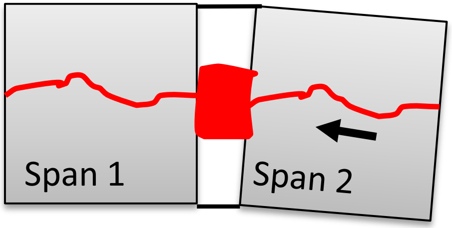
- Sinan Acikgoz (now faculty at Oxford)
- Haris Alexakis (postdoc)

Funding:

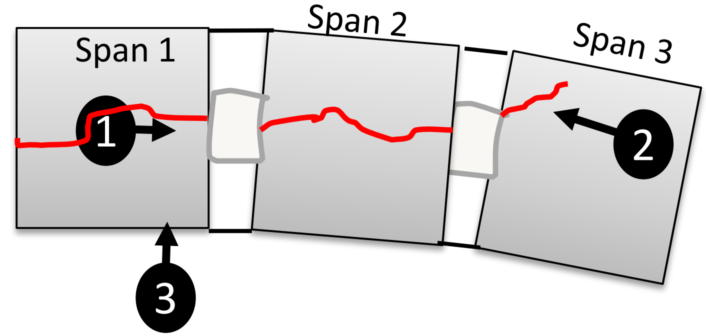
- New Civil Engineer TechFest 2019:
  Rail Visionary Award
  *"Innovative Structural Health Monitoring of Ageing Infrastructure"*

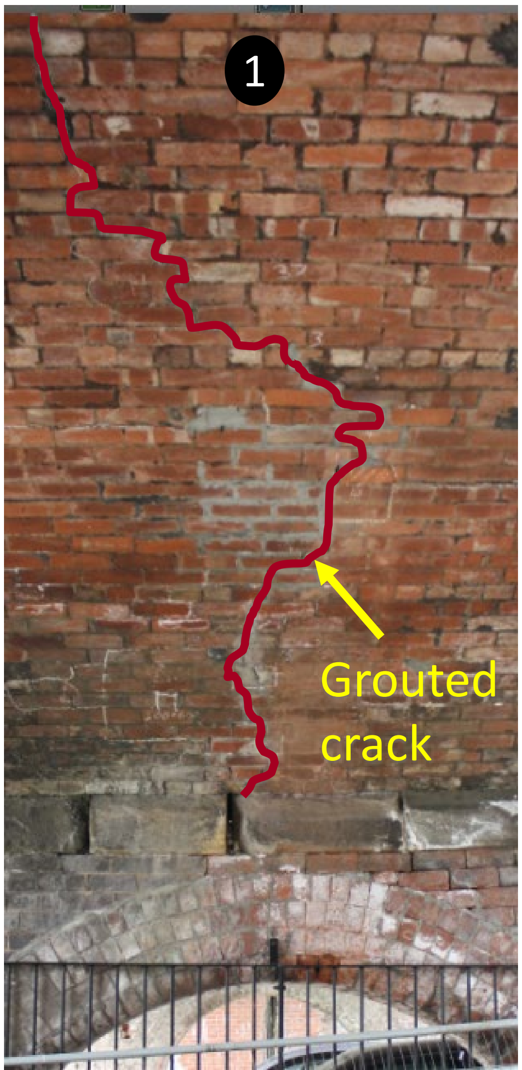
# Marsh Lane Viaduct – Leeds, UK

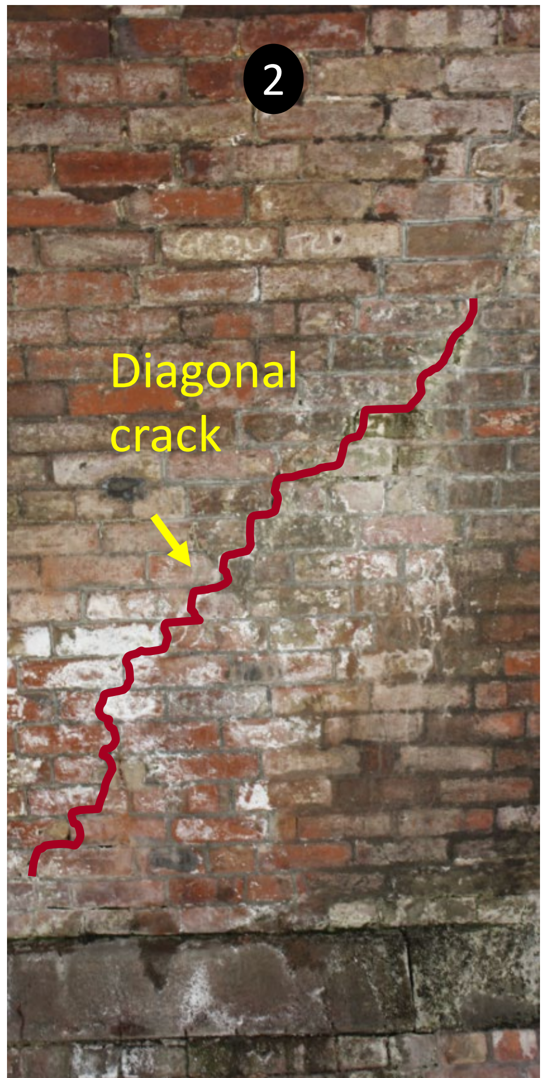
# Marsh Lane Viaduct




# Marsh Lane Viaduct




# Sensing Deployment

Fibre optic cables

Acoustic emission sensors

High-sensitivity accelerometers

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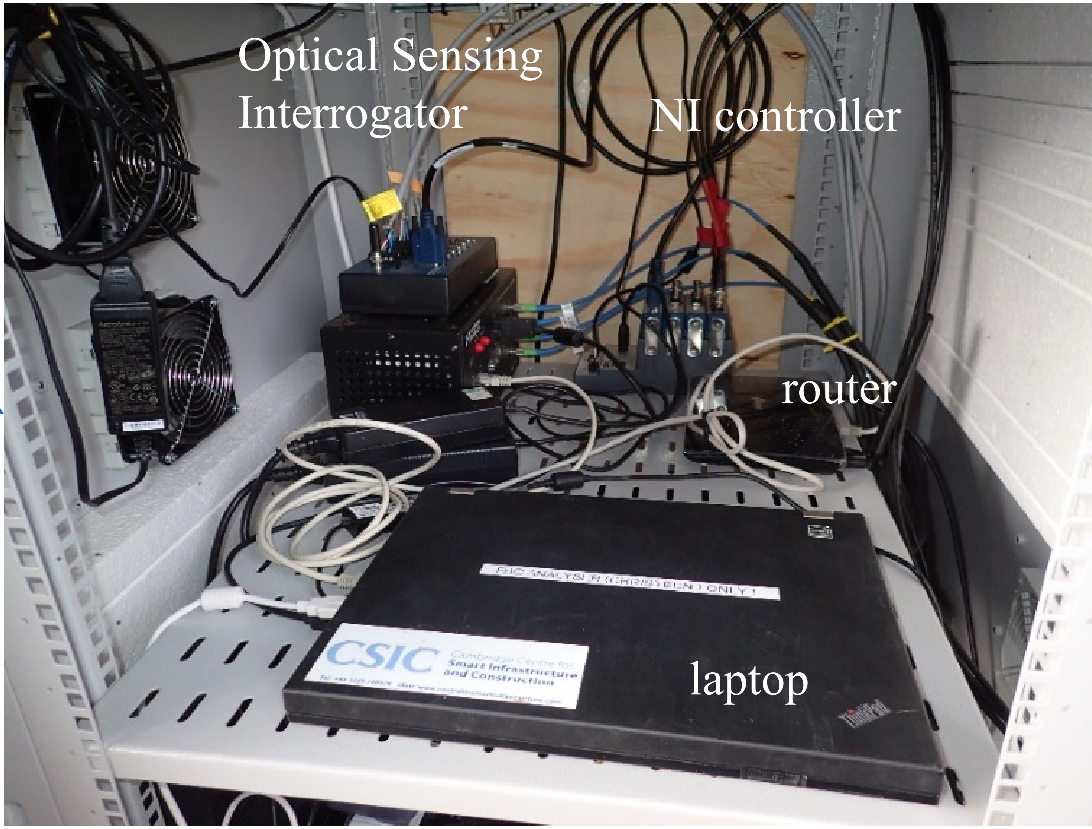
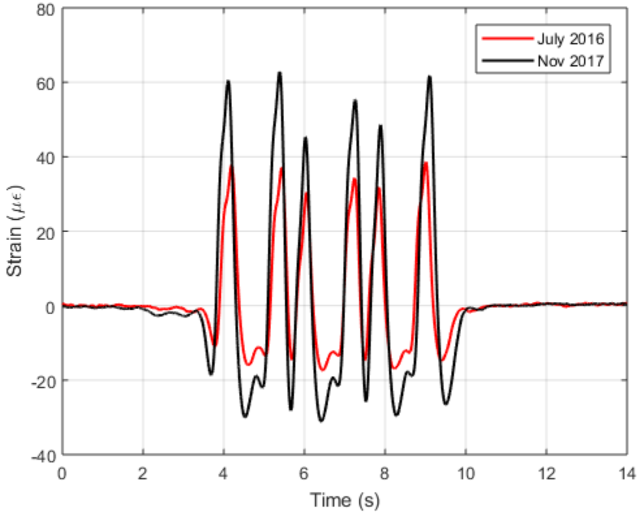
The Alan Turing Institute
NetworkRail
Air condition
S1-01 OUTRANGE
S1-02 S1-03 S1-04 S1-05 S1-06 S1-07 S1-08 S1-09
A1 A2 A3 A4 A5 A6 A7 A8 A9
NSP
S1-10SP
S3-01 S3-02 S3-03 S3-04 S3-05 S3-06
T1 T2 T3 T4 T5 T6 T7
S3-07T
S3-19 S3-20
S3-16T
S3-15SP
SSP
WST
S3-17/18 UNUSED
S3-14 S3-13 S3-12 S3-11 S3-10 S3-09 S3-08
S1-12 S1-13 S1-14 S1-15 S1-16 S1-17 S1-18 S1-19
WNT
S1-11T
ENT
S1-20T
S4-01 S4-02 S4-03 S4-04 S4-05 S4-06
S4-18 S4-19 S4-20
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
S2-19 S2-18 S2-17 S2-16 S2-15 S2-14 S2-13 S2-12
S2-20SP
EST
S2-11T
1 2 3

# Data Acquisition System

# Remote Damage Identification

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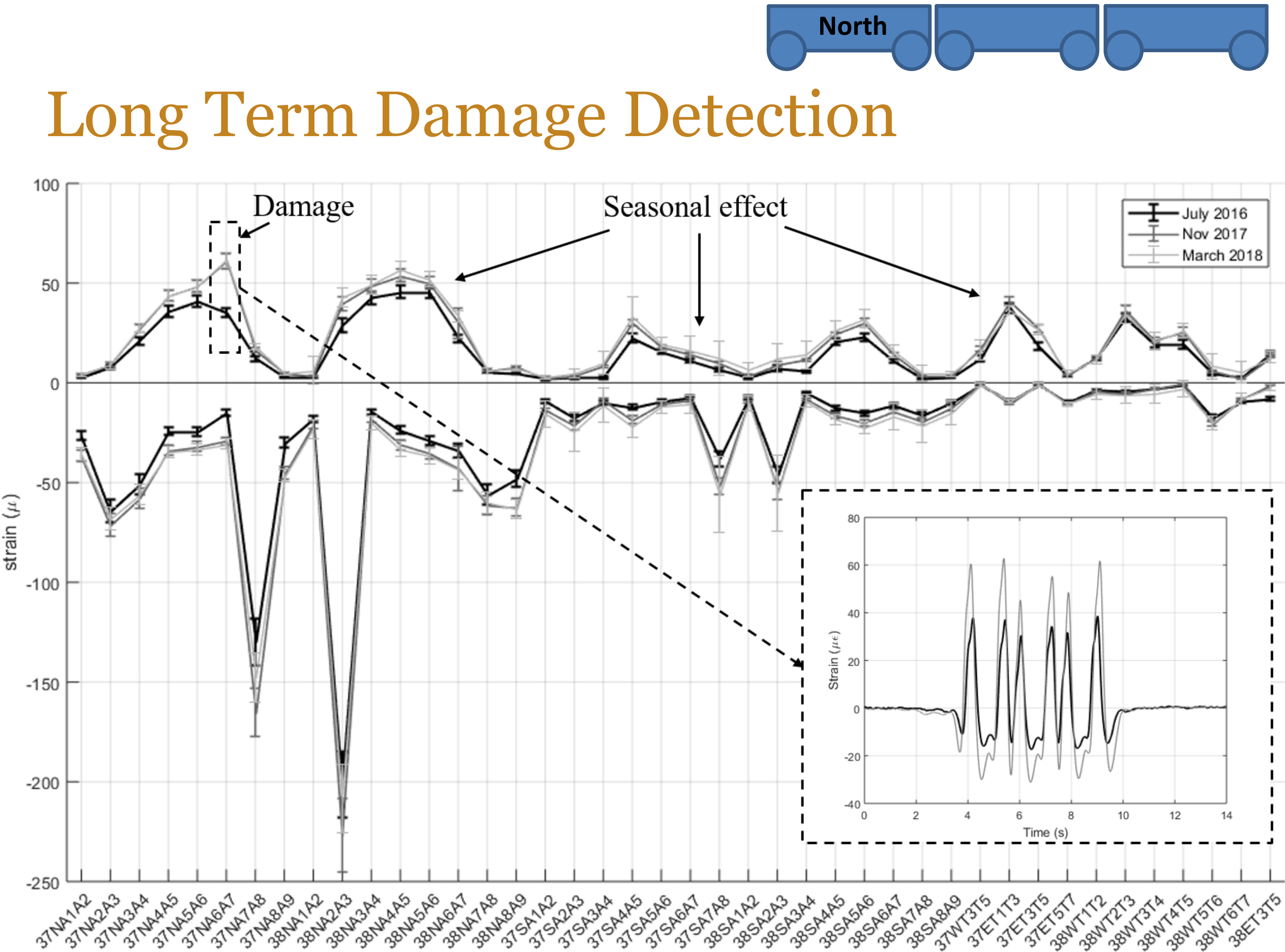
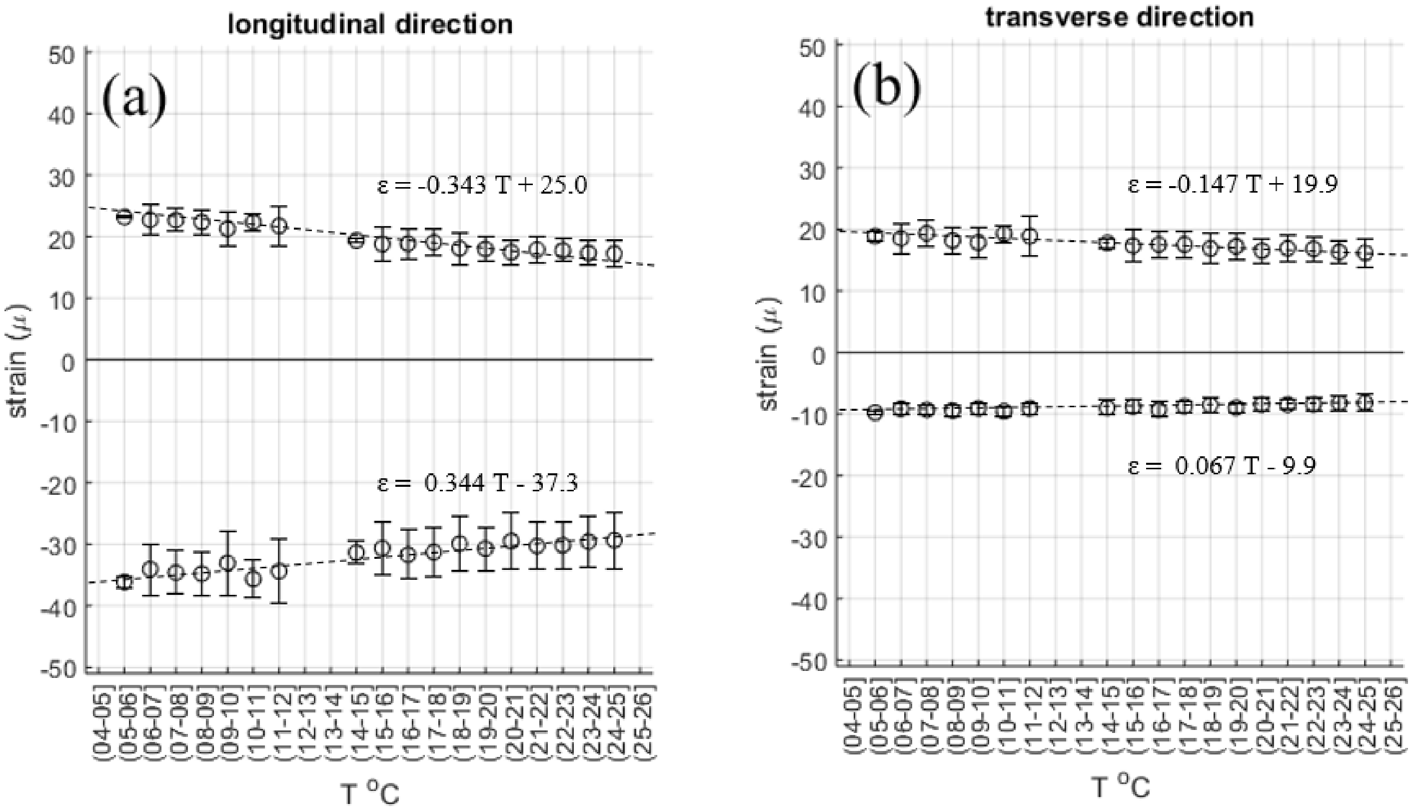
# Long Term Damage Detection

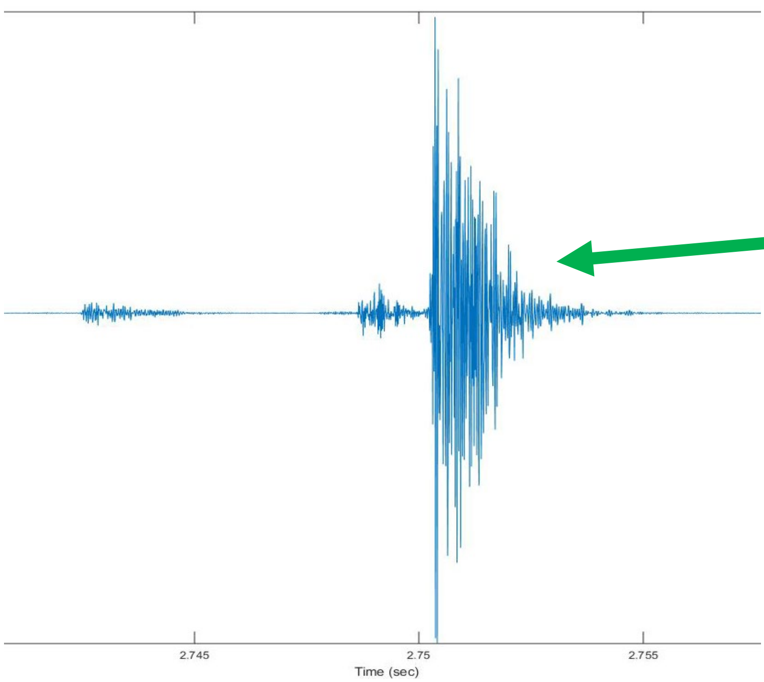


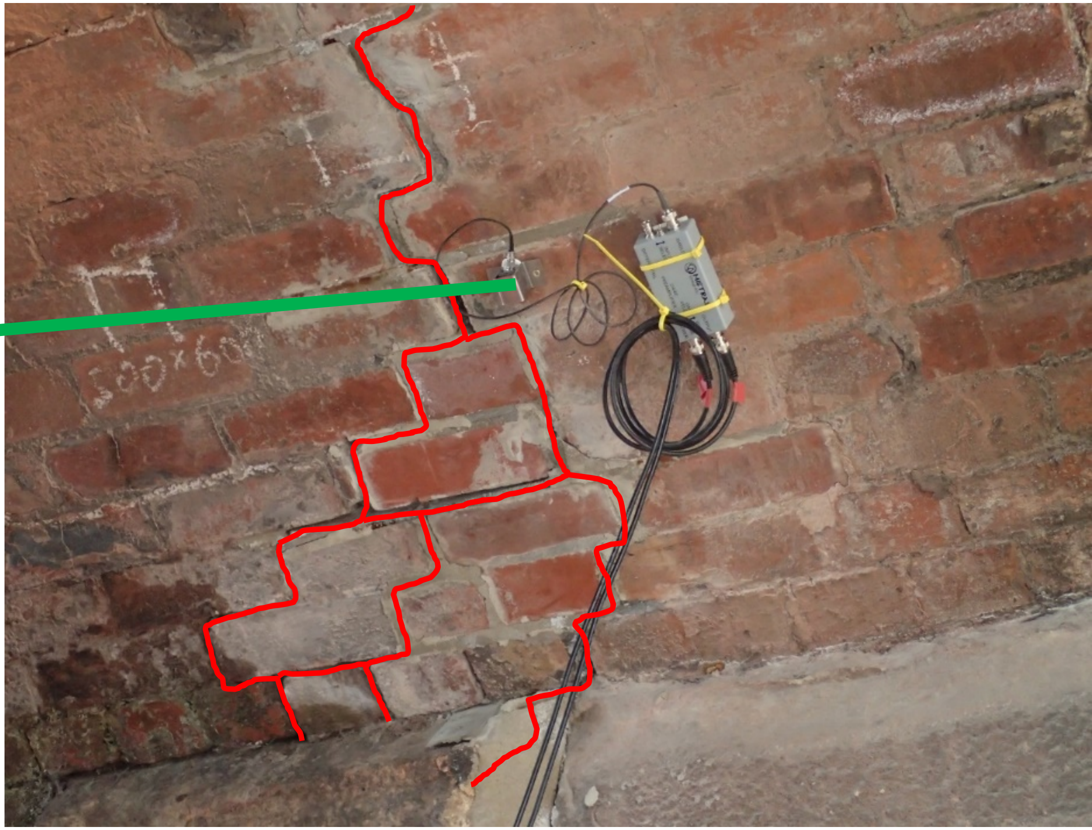

# Long Term Damage Detection

## Combining FO with environmental data



# Acoustic Emission Sensing



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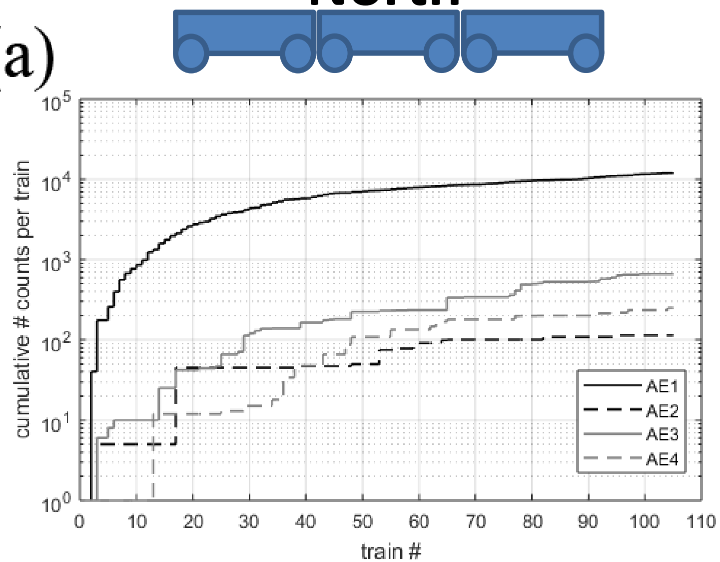
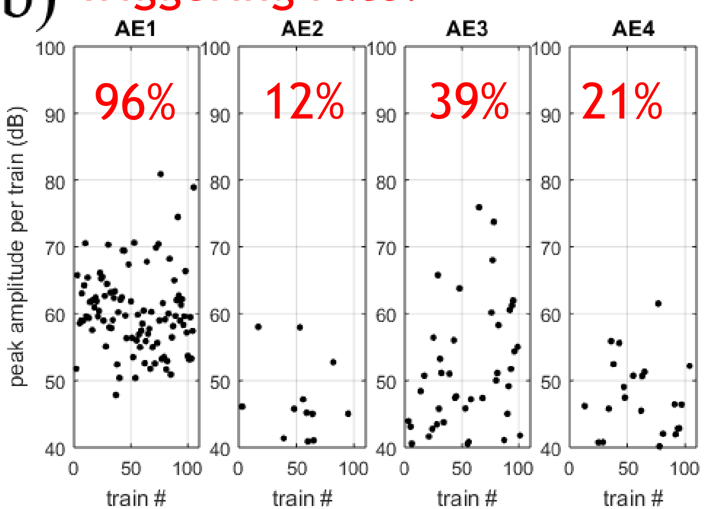
# AE results – Active cracking

**North**

(a)

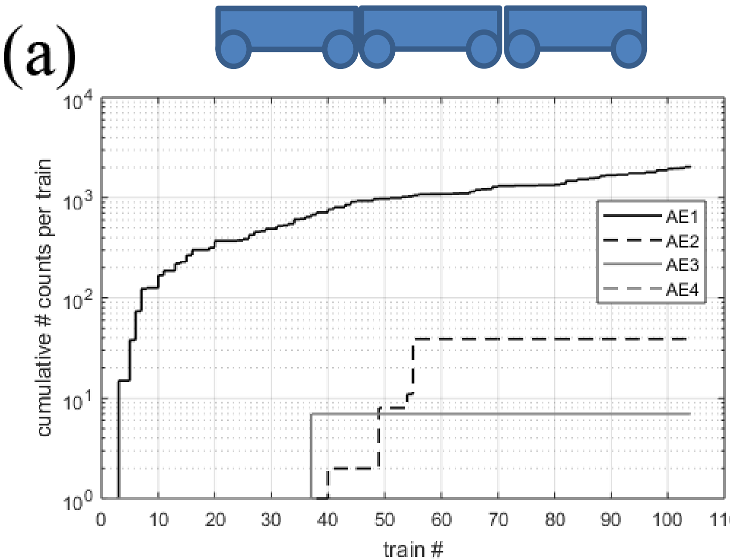



(b) Triggering rate:

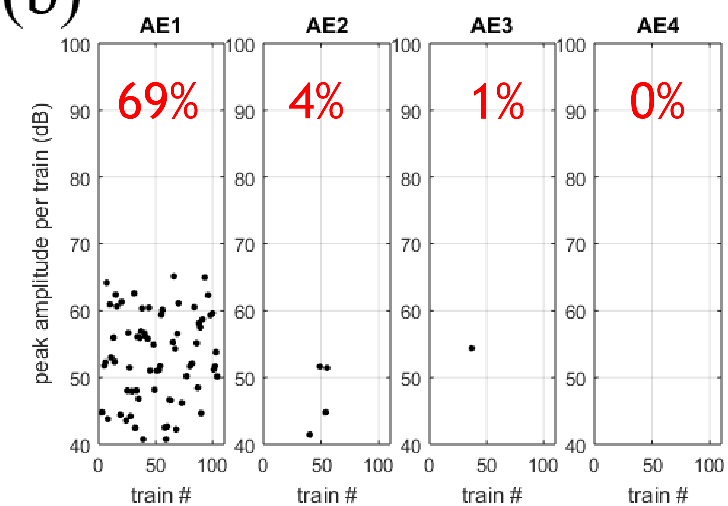



**South**

(a)




(b)



# Concluding remarks

- Benefits of Fiber Optic Monitoring
  - Distributed monitoring
    - Distributed damage
    - Unknown damage location
    - Detailed deformation information for model evaluation
  - Reliable
  - Durable
  - High Frequency (FBG)
  - Installation
    - Single fiber… less cables
    - External or embedded

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