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Bridge Monitoring in the United Kingdom

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Senskin 2cd Workshop, İstanbul, 24-25.May.2018

Project co-funded
by the EU under H2020

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Introduction

- Peter Jones
  - Chartered Civil Engineer
  - 8 years’ experience working with highway structures – 7 years working in London
  - Experience of several bridges that have been monitored in some form

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Bridge stock in the United Kingdom

- 422,000km of public highway
  - From Roman times to modern construction
  - Motorway construction 1960s and 1970s
  - Mostly owned by local authorities
  - Strategic Road Network (7,000km) mainly owned by national road authorities (of England, Wales, Scotland and Northern Ireland)
  - Many old bridges in urban areas
  - Bridges on main roads often 1960s/1970s
  - Concrete deterioration a common defect

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Bridge stock in the United Kingdom

- 16,000km of railway
  - Much built in Victorian era (1850-1900)
  - Vast majority owned by the national infrastructure owner (Network Rail)
  - Many old, brick arch bridges

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Bridge stock in the United Kingdom

Challenges for UK highway bridges

- Highly congested road network
  - 10th most congested country in the world
  - 3rd most congested country in Europe
- Network occupation for maintenance to be avoided where possible (particularly peak times)
- Budgets for maintenance and capital investment are severely limited
- **Keep existing infrastructure operational under ever increasing demand and ever limited budget!**

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Bridge inspection (highway bridges)

- General inspection: every 2 years
  - Visual inspection
- Principal inspection: typically every 6 years
  - Visual inspection from within touching distance
- Special inspection: as required by defects
  - Specific inspection and testing to further understand the defect, its cause, its likely progression
  - Recommend next steps
- Similar routine for railway bridges

Role of bridge monitoring

- Defect identified and investigated (Special Inspection):
  - Do nothing (revisit at next inspection)
  - Repair immediately
  - Plan to repair at a future time
  - Monitor
    - Range of techniques available:
      - From periodic visual inspections / measurements
      - To complex automated continuous monitoring

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Requirements for monitoring

- Monitoring Specification (defined by Standard BD79/06) requires for any monitoring regime:
  - Summary of findings from inspection and assessment
  - Detailed monitoring plan; monitoring related to predicted mode(s) of failure
  - Accuracy required
  - Frequency required
  - Trigger levels defined
  - Actions required if trigger levels are exceeded;
  - Recording and reporting requirements
  - A plan for periodic review

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Case study: Hammersmith Flyover

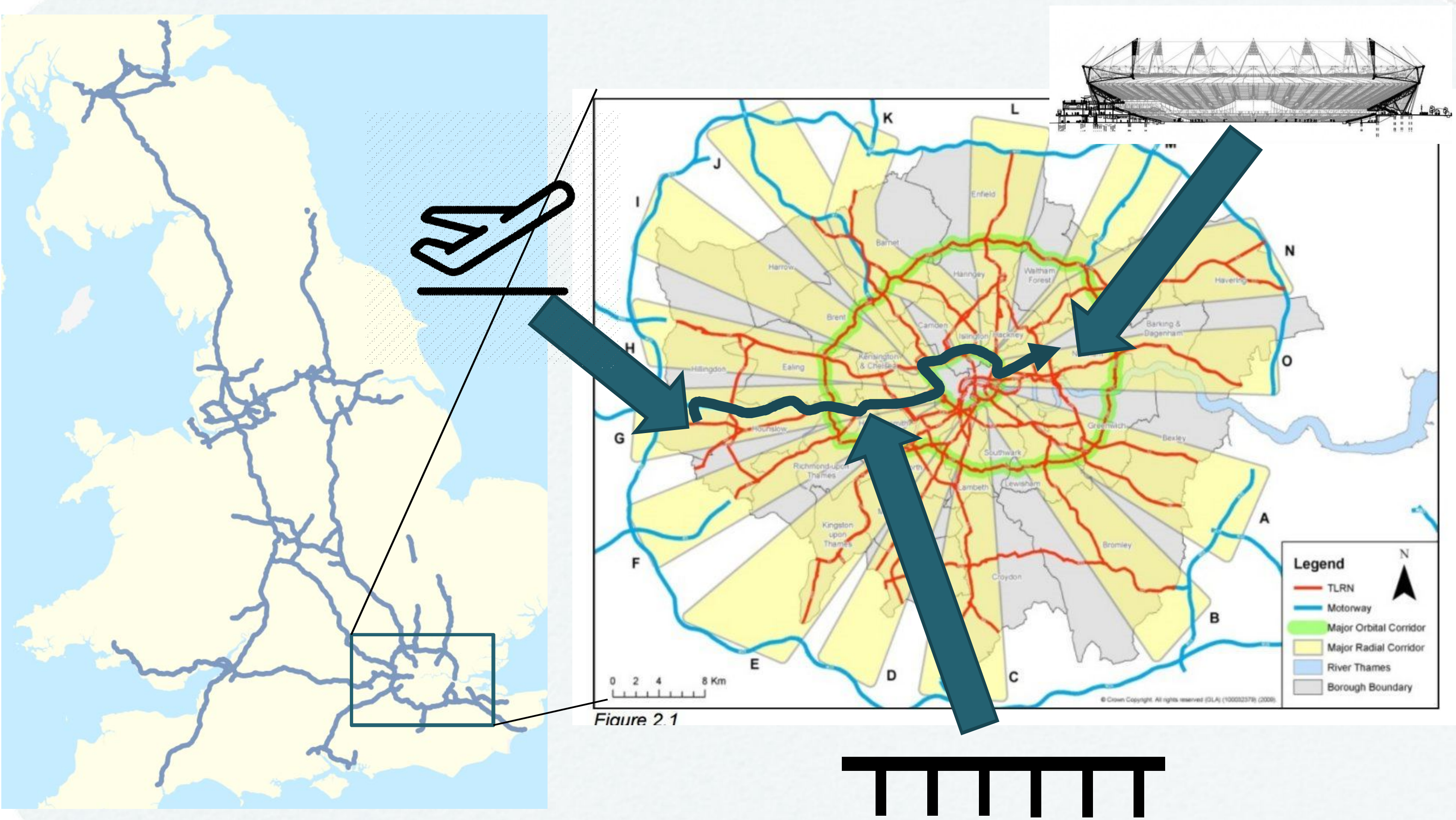

Figure 2.1

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Hammersmith Flyover: Overview

- 622m elevated length
- 16 spans
- 4 lanes

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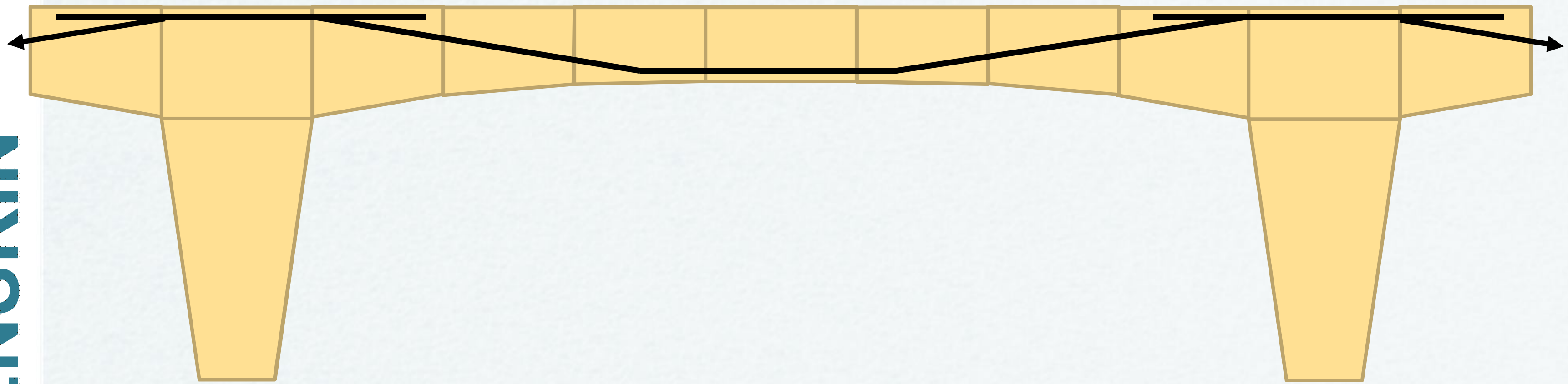
Hammersmith Flyover: Structure

- Post-tensioned pre-cast concrete 4 lane viaduct
- Steel tendons under tension compress the concrete segments to provide load carrying capacity



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Hammersmith Flyover: History

- Constructed in 1960s
- Pioneering post-tension design – one of the first in the United Kingdom
- Electric heated road to avoid use of de-icing salts
  - Used for one winter
  - Costs were enormous: no-one could decide who should pay
  - Decommissioned, and de-icing salts used ever since

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Hammersmith Flyover: Problem

- Water ingress (with salt) through the deck has been a problem
- Tendons are n
  - Steel tendons
  - Each tendon
  - Some wires h

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Hammersmith Flyover: Problem

- Tendons are encased in grout: impossible to see
- Wire breaks are impossible to locate retrospectively
- Number of wires broken is critical to understanding capacity of structure = safety
- Interim solution: Structural health monitoring

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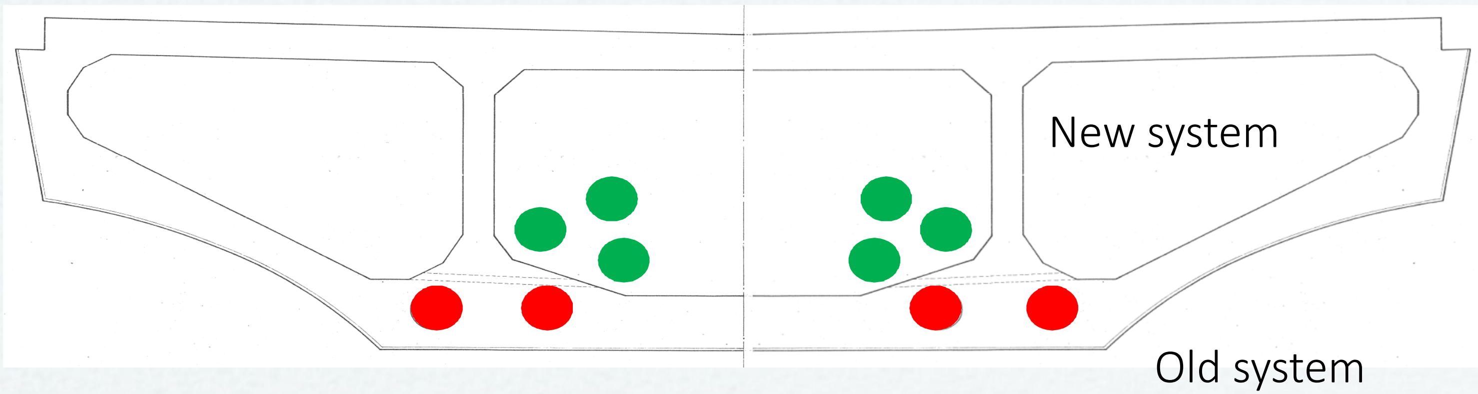
Hammersmith Flyover: Solution

- Long term solution:
  - Installation of new, independent post-tension system in parallel with existing
  - Minimum disruption to traffic permitted
  - To be constructed before load restrictions required



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Hammersmith Flyover: Monitoring

- Pre-construction phase:
  - Monitor rate of deterioration
    - Timescale to need for weight restriction/propping
    - Input to design and construction programme
  - Early warning of catastrophic event
    - Detect a loss of compression at segment joints
  - Understand structural behaviour
  - Monitoring provided by Mistras Group (UK)

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Hammersmith Flyover: Monitoring

- Construction phase:
  - Monitor rate of deterioration
    - Timescale to need for weight restriction/propping
    - Input to design and construction programme
  - Early warning of catastrophic event
    - Detect a loss of compression at segment joints
  - Monitor impact of construction work
    - Stressing of new tendons
    - Jacking of columns
    - Decommissioning of existing tendons

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Hammersmith Flyover: Monitoring

- Post-construction phase:
  - Monitor long-term performance of the works
  - Validate the technical design
    - Design was non-Standard
    - Cutting edge finite element modelling
  - Monitoring also provided by Mistras Group (UK)

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Hammersmith Flyover

- Different monitoring requirements required different techniques to achieve the output:

Monitoring system	Monitoring element	Monitoring output
Acoustic emission	Post-tensioning wires	Wire breaks detected
Displacement/strain	Pre-cast segment joints	Strain across joint (to detect loss of compression)
Deflection	Mid-span deflection	Excessive deflection (to detect loss of compression)
Displacement	Bearings	Movement of columns
Displacement	Expansion joint	Expansion gap
Strain	Bridge superstructure	Strain due to stressing Strain due to bridge jacking

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Acoustic emission monitoring

- Wires under such tension have a high potential energy
- When wire breaks, energy is released
- Energy is dispersed through the concrete structure
- Sensors detect sound "finger print" of a wire break
- Currently being used by TRL to monitor:
  - Post tension bridges (eg. Huntingdon viaduct)
  - Cable stay bridges (Forth Road Bridge)

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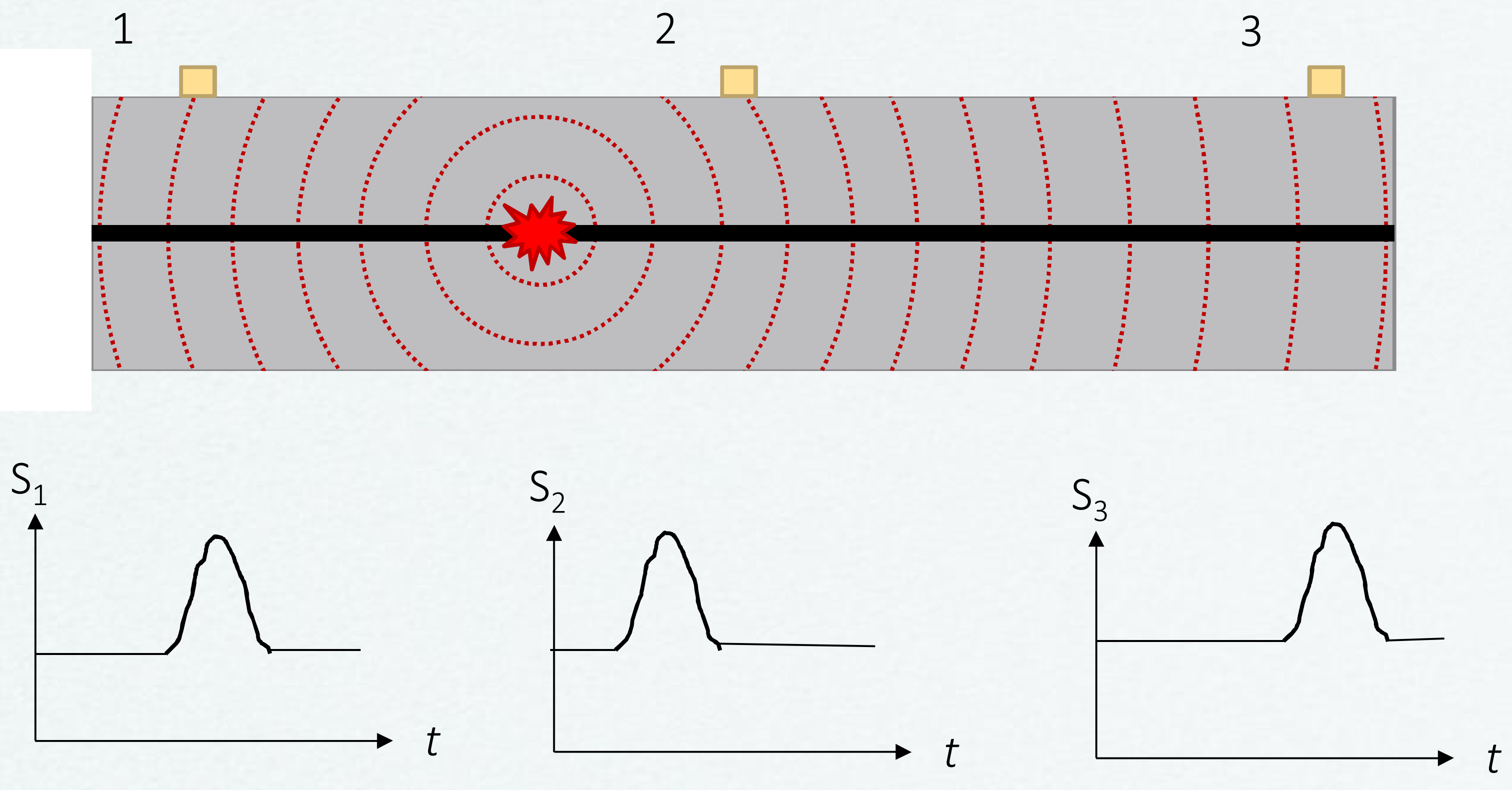
Acoustic emission monitoring



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Acoustic emission monitoring

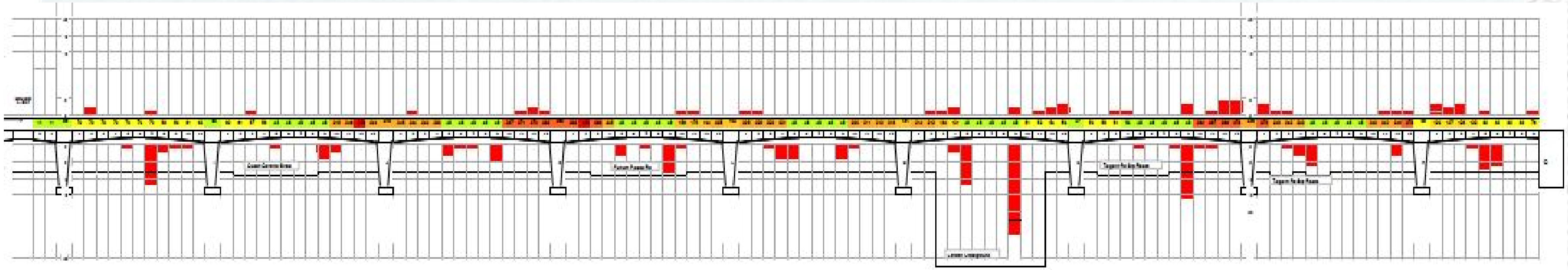
NB. Data is NOT real

	Span A-B	Span B-C	Span C-D	Span D-E
No. of wires	928	1024	1024	1024
Assumed baseline (2006)	890	1012	978	1002
Min required for full load capacity	780	860	860	860
Wire breaks detected	12	16	3	25
Highest no. wire-breaks/month in past year	3	[illegible]	[illegible]	6
Time to zero spare capacity	32 months	34 months	9.5 years	19 months

Input to design and construction programme: span D-E requires strengthening within 19 months

Acoustic emission monitoring

- Plot of wire breaks/segment



Elevation showing estimated numbers of ineffective wires in each segment (from Special Inspection) and wire breaks detected by Acoustic Monitoring since July 2010

- Graphical representation of more critical locations
- Diagram was used to secure funding for major bridge works

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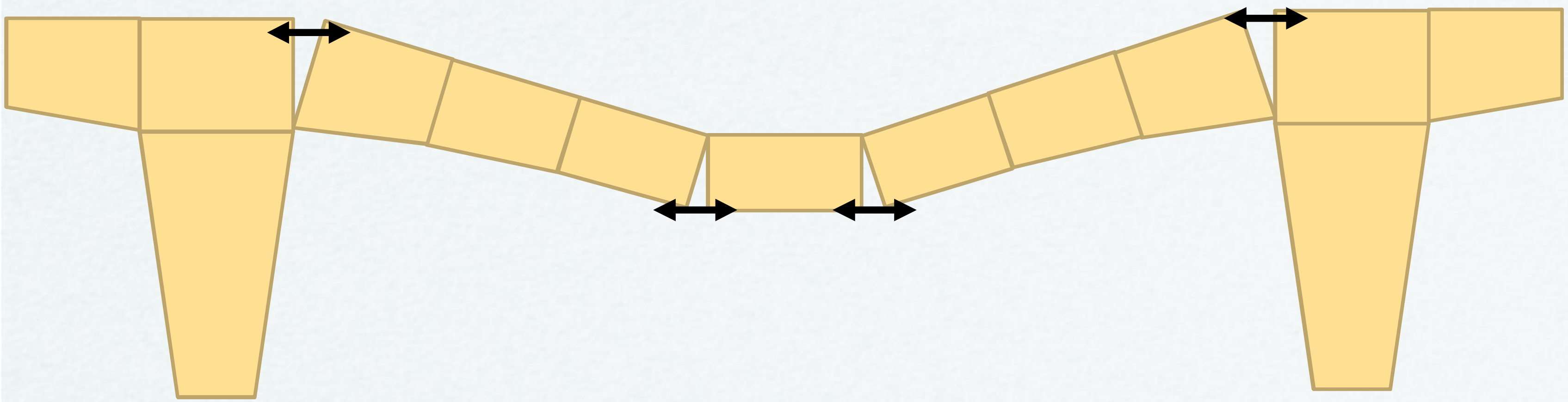
Segment opening monitoring

- Critical pre-cast segment joints monitored to warn of loss of compression
- Collapse mechanism: joints open by piers and at mid-span



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Segment opening monitoring

- LDVT – (linear variable displacement transducer) measures displacement at joints
- During construction new equipment installed to measure at greater frequency and with greater accuracy
- Trigger levels identified with an action plan for each trigger level
- These trigger levels never activated, but provided reassurance throughout

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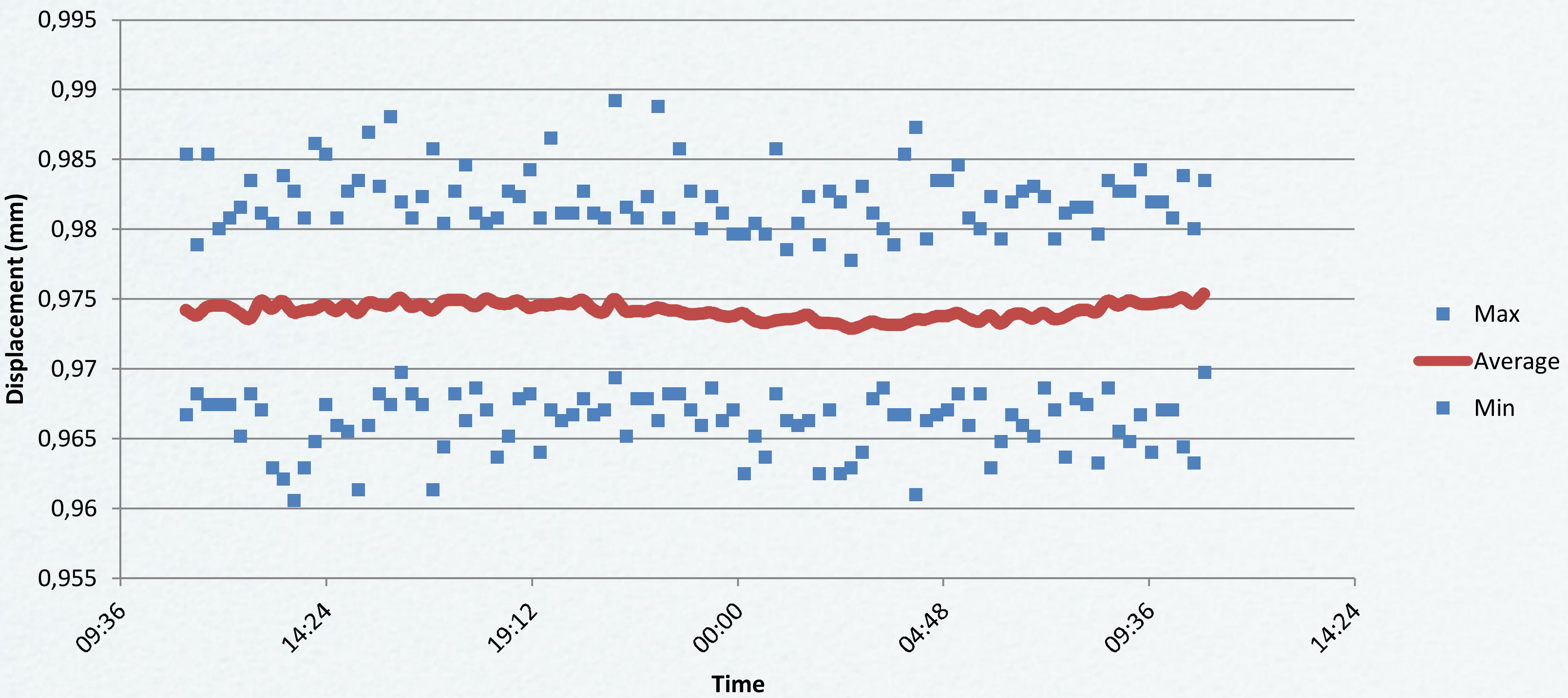
Segment opening monitoring

- Average displacement over a minute period
- Plus max and min within that minute recorded



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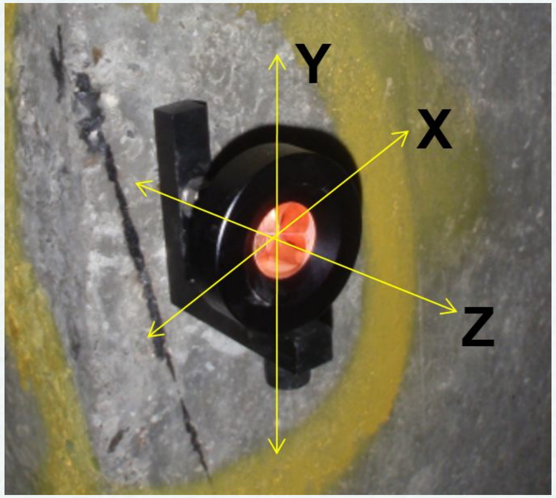
Bridge deflection monitoring

- Additional monitoring of the displacement of the mid-spans
- Use of total stations to detect out-of-range deflections



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Hammersmith Flyover: Bearings

- Bearing monitoring

Bridge pier

Fail-safe stool

Roller bearing

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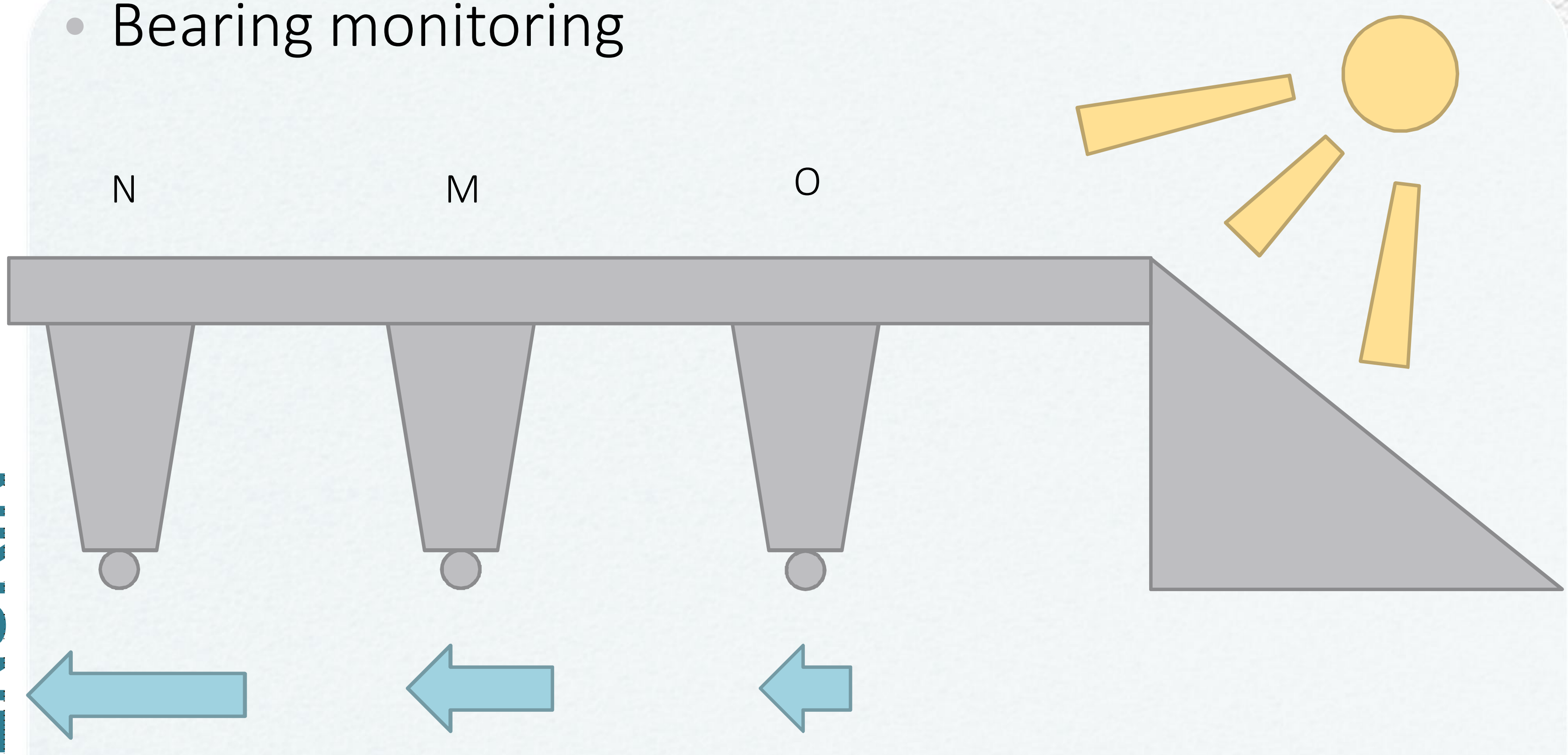
Hammersmith Flyover: Bearings

- Bearing monitoring



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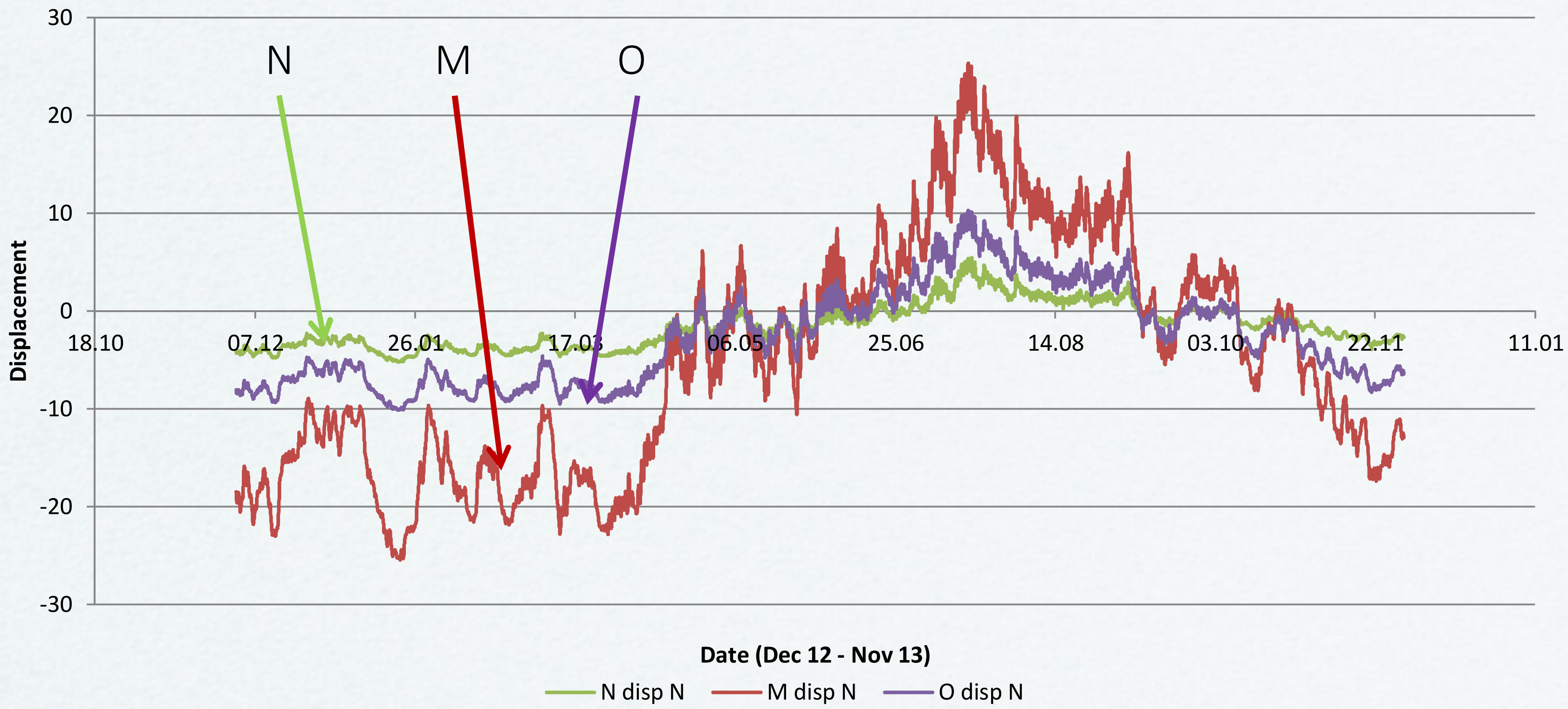
Hammersmith Flyover: Bearings

- Bearing displacement



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Hammersmith Flyover: Bearings

- Pier ‘N’ was stuck on its fail-safe stool due to corrosion caused by flooding of the bearing pit

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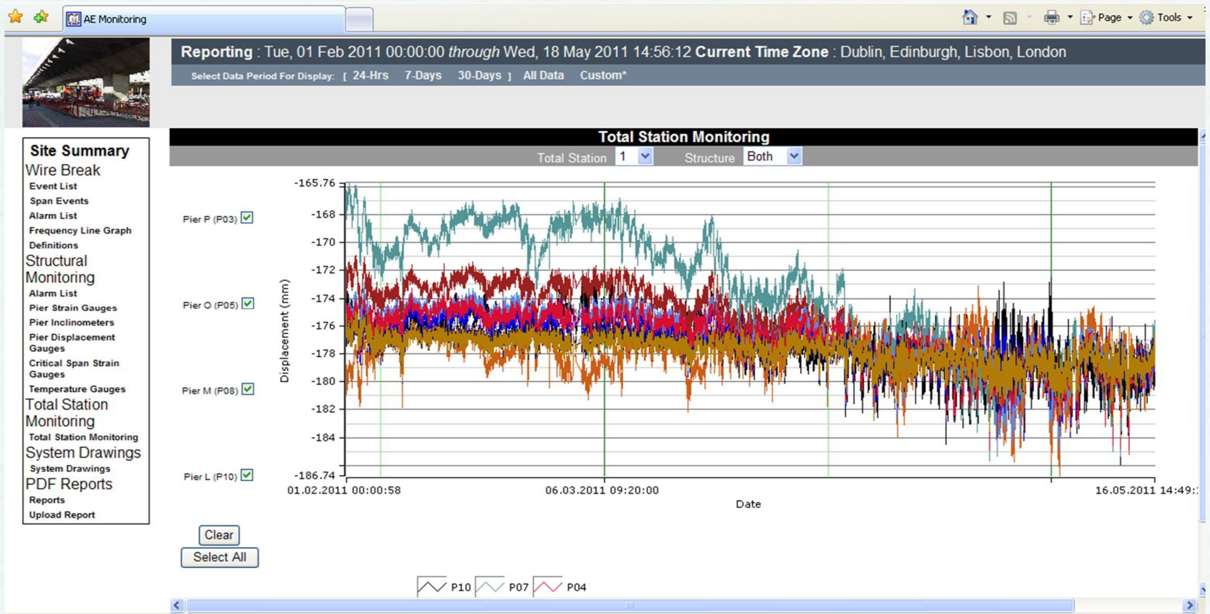
Hammersmith Flyover: Management

- All monitoring data visible remotely via a web portal on the Mistras Group website
- Current and historic data from all sensors available



Hammersmith Flyover: Construction

- Local strain monitoring during construction

37 strands of 7 wires stressed to >1000MPa

Strain gauges measure local effects of force transfer to structure

Bearing monitoring measures global effect of force transfer

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Hammersmith Flyover: Long-term

- Long-term monitoring to validate the design:
  - Bearing movement
  - Periodic natural frequency tests on the new tendons
- Long-term monitoring to inform maintenance:
  - Flood detection in the bearing pits (to protect the bearings)
- Designed and installed by Mistras Group (UK)

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Hammersmith Flyover

- Outcomes of monitoring:
  - Design / construction programme optimised to avoid load / lane restrictions
  - Operational safety assured through monitoring of critical aspects of structure
  - Behaviour of structure during construction understood
  - Design parameters validated through monitoring and comparison with design calculations

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Conclusion

- Bridge monitoring in the UK plays an important role
  - to keep roads available with an assurance of safety
  - to inform design of repairs
    - To minimise cost of repairs
    - To minimise disruption as a result of construction work

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Thank You! Any questions?

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