UNIVERSITY OF CAMBRIDGE

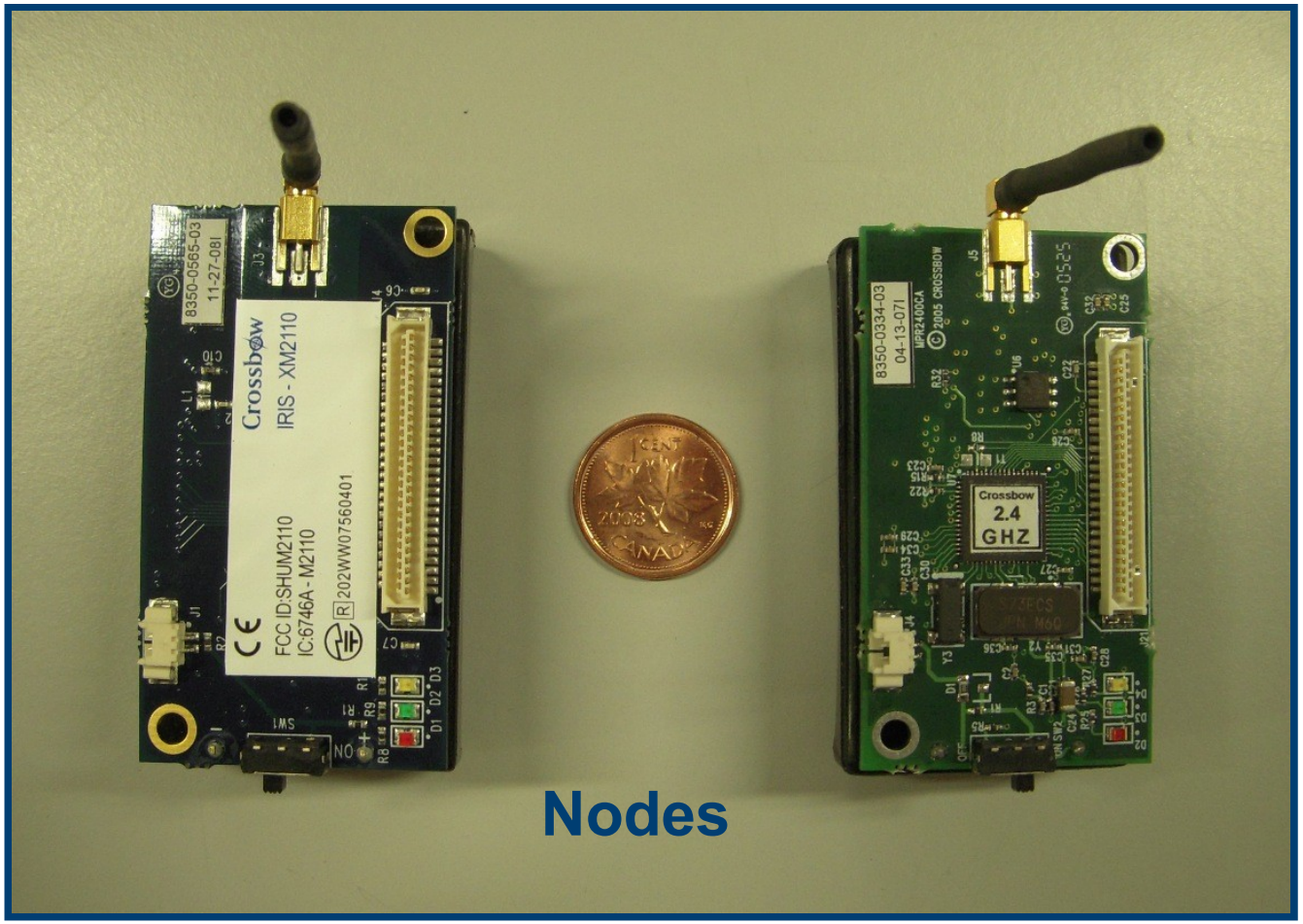
# Sustainable Spanning Structures: Reducing the Impact of Infrastructure

Neil Hoult, Paul Fidler and Cam Middleton

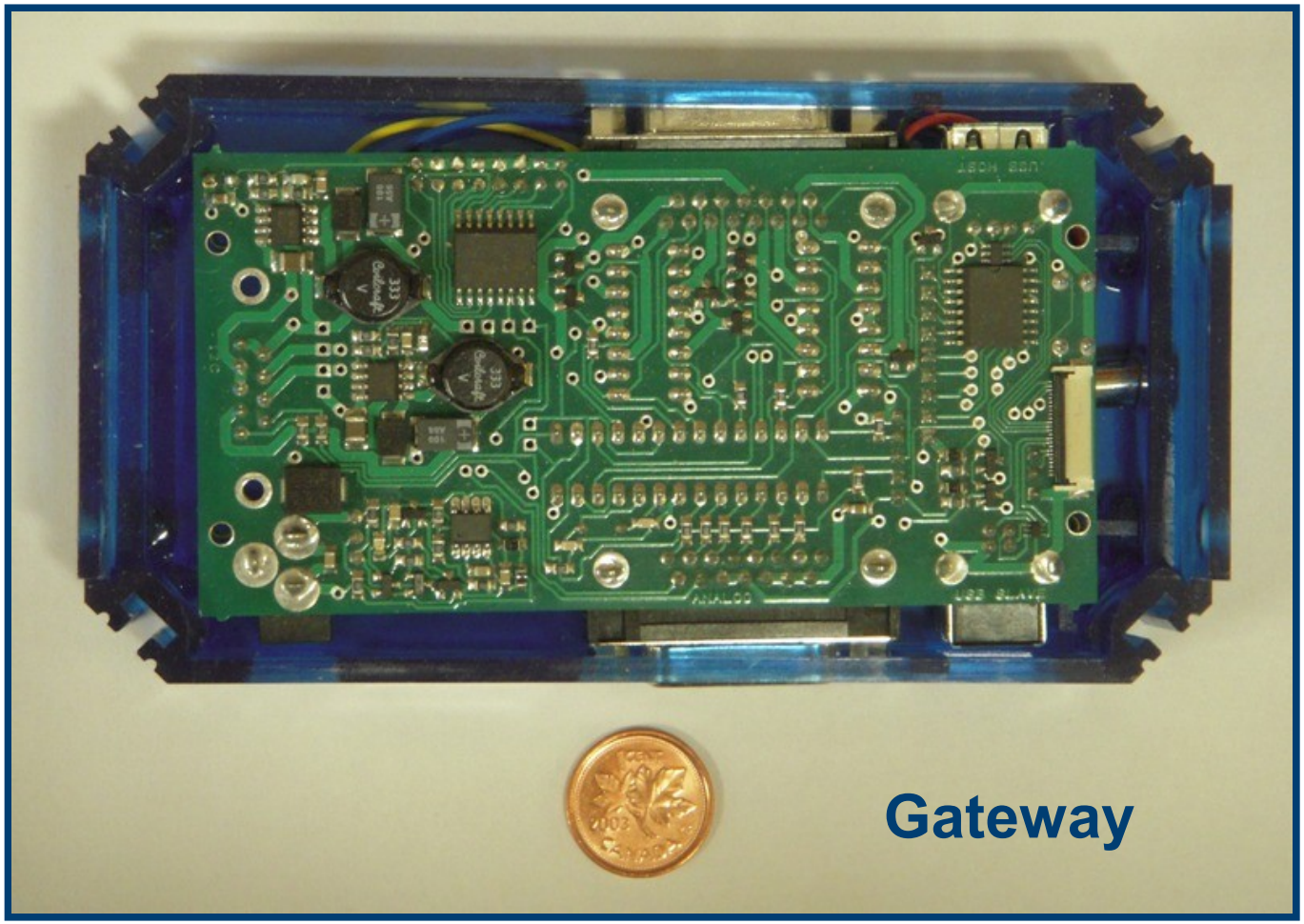
# Overview

- Monitoring
  - Wireless Sensor Networks
- Assessment
  - Fibre optic strain

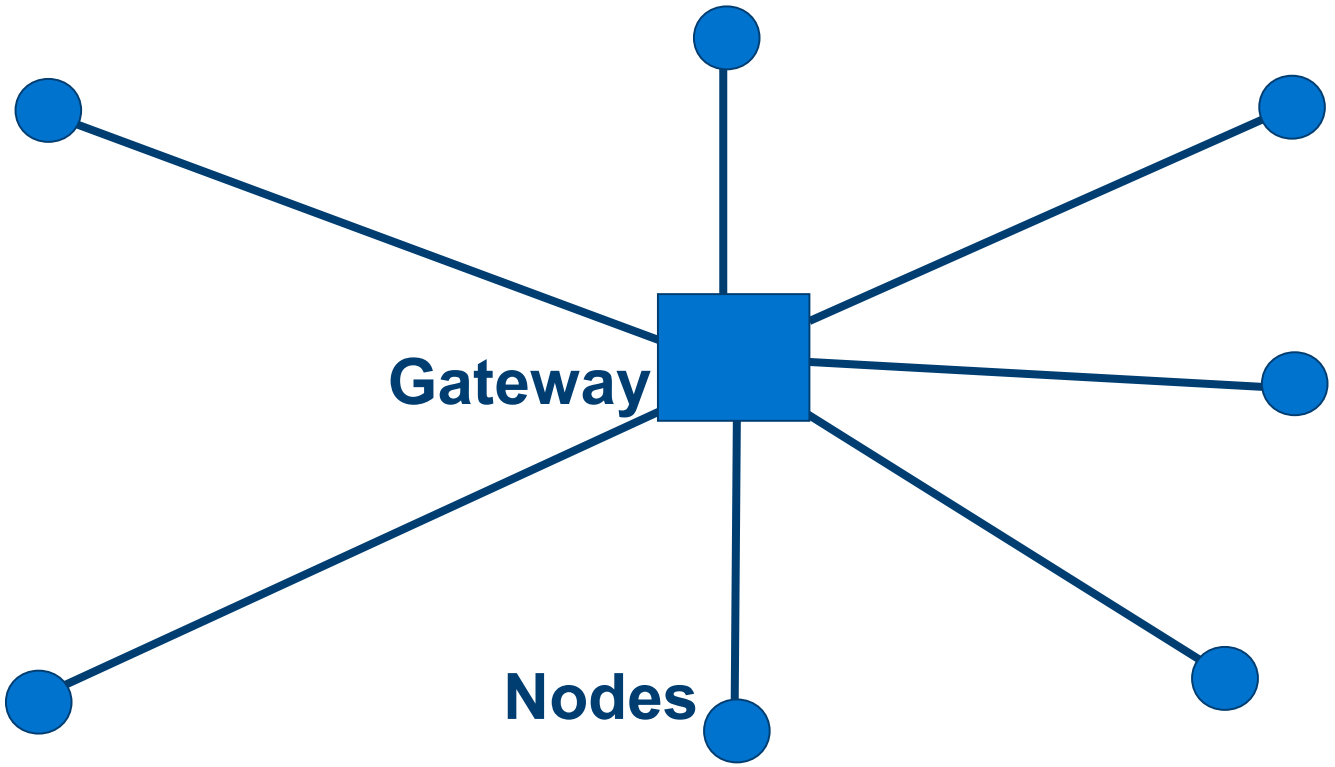
# Wireless Sensor Networks



# Wireless Sensor Networks

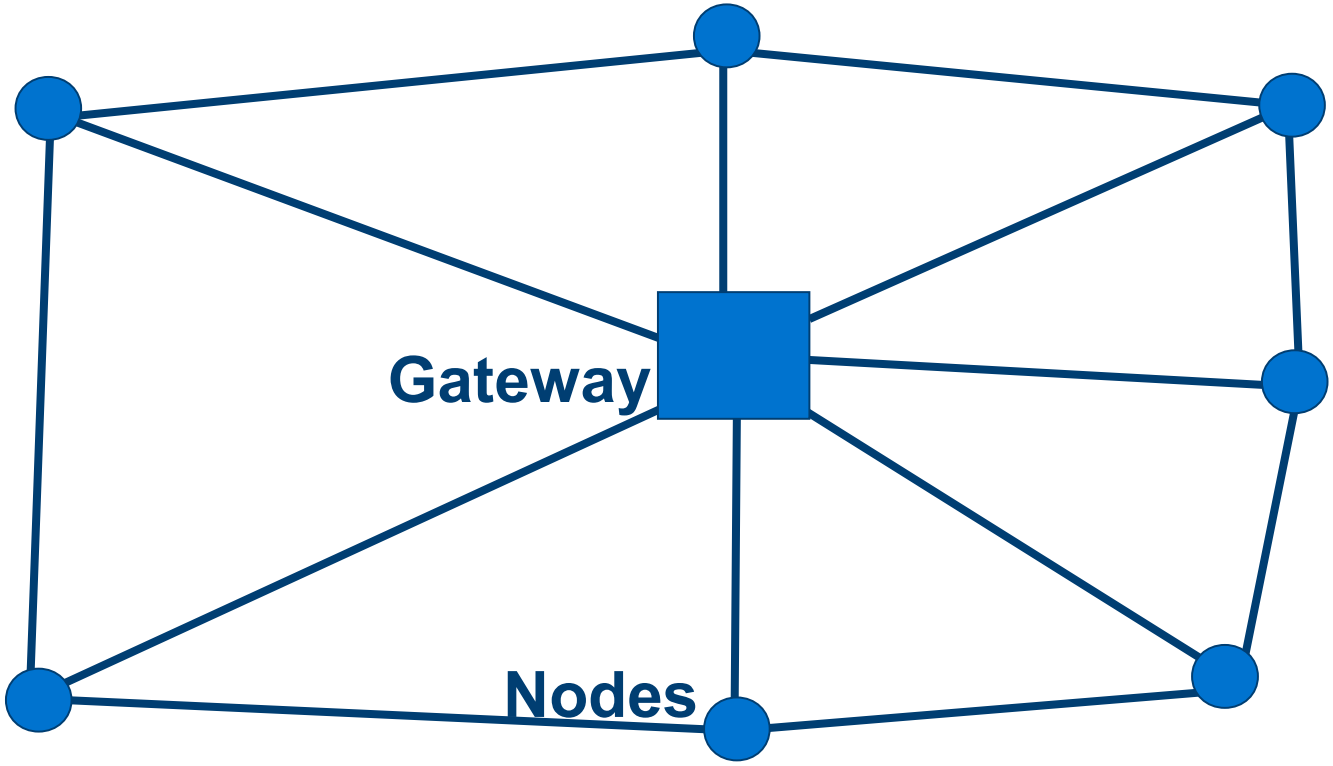


# Wireless Sensor Networks




Star Topology

# Wireless Sensor Networks



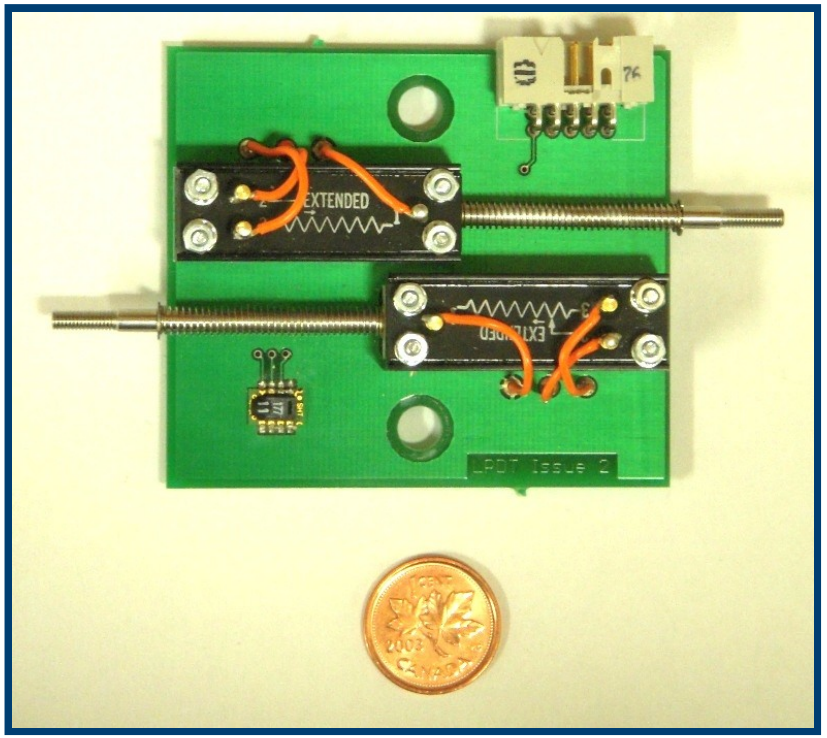

Mesh Topology

# Types of WSNs

| | Sampling Frequency | Applications | Key Considerations |
|---|---|---|---|
| **Low Data Rate** | **Minutes to Days** | **Environmental & Deterioration** | **Battery Life & System Robustness** |
| **High Data Rate** | **Hz to kHz** | **Acceleration & Acoustic Emission** | **Battery Life & Bandwidth** |

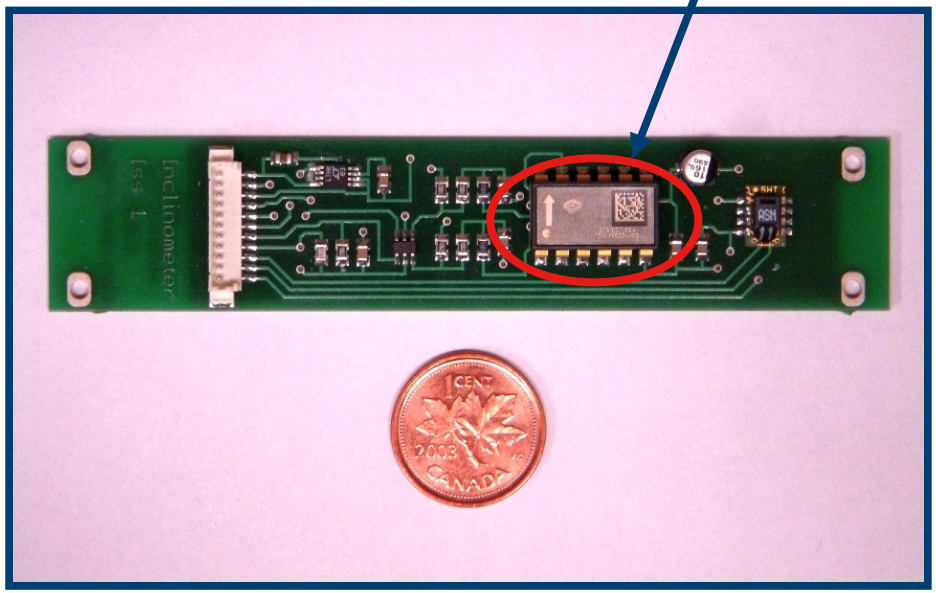
# Sensors

- Conventional transducers:
  - Displacement Transducers & Vibrating Wire Strain Gauges
- Limitations: Power & Processing



# Sensors

- Microelectromechanical Systems (MEMS) based sensors
  - RH & Temperature, Acceleration, Pressure & Inclination

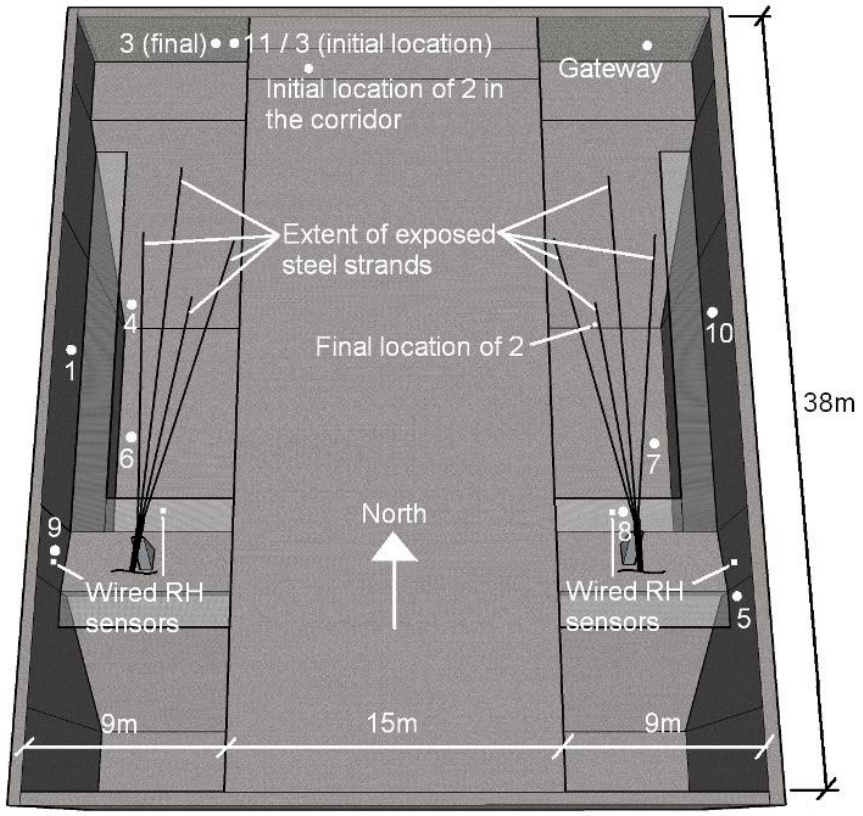


# Field Deployment – Anchorage Chambers

# Field Deployment – Anchorage Chambers

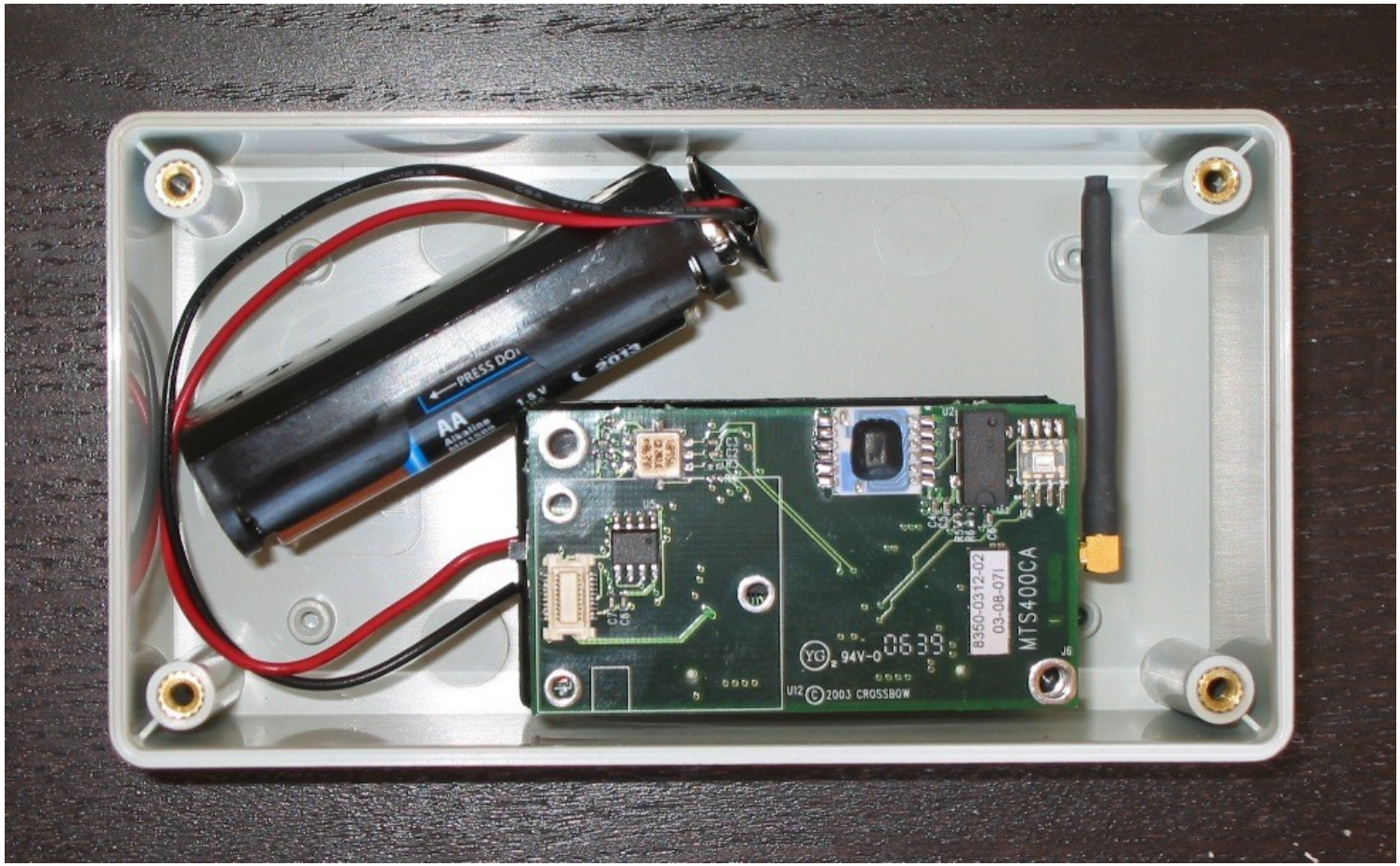
# Field Deployment – Anchorage Chambers

# Anchorage Deployment – RH and temperature monitoring

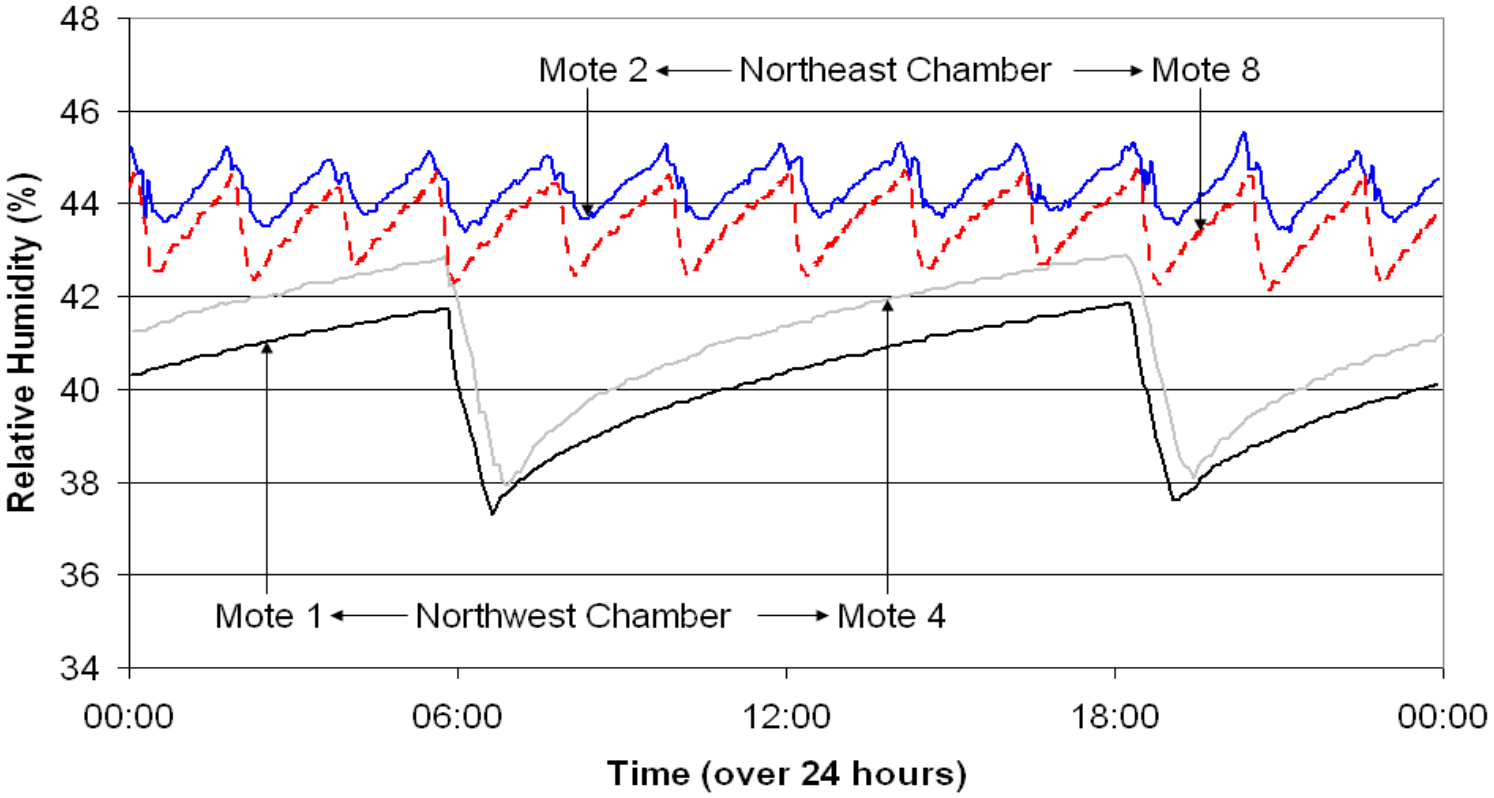



- 12 node network
- 10 nodes measure RH and temperature using off-the-shelf hardware
- 1 node acts as a relay
- 1 node measures inclination of the splay saddle
- Gateway is connected to the Internet via ADSL

# RH and temperature node



# Anchorage Deployment



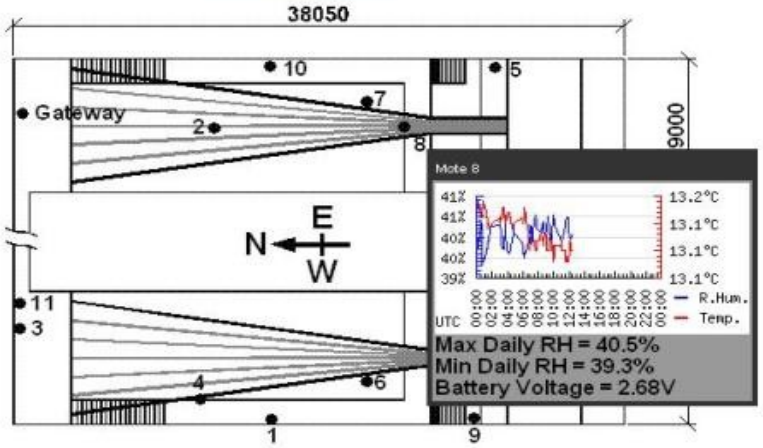
# Data Visualization - Webpage

Smart Humber

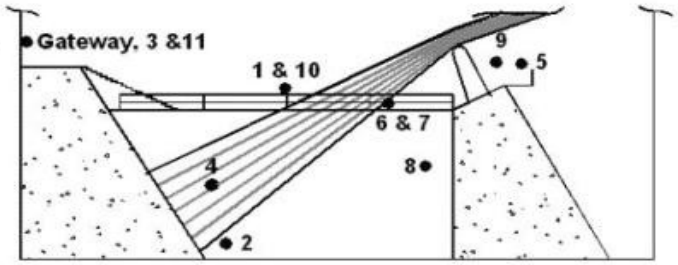
**The Hessle Anchorage of the Humber Bridge has been instrumented with a wireless environmental sensor network.**

We are working on a web interface to allow the sensor data to be viewed for arbitrary time periods. In the interim you may view:

- data from yesterday: humidity and temperature, or
- all data collected to date: humidity and temperature, or
- all data collected to date in raw unprocessed form.




Plan view of mote network

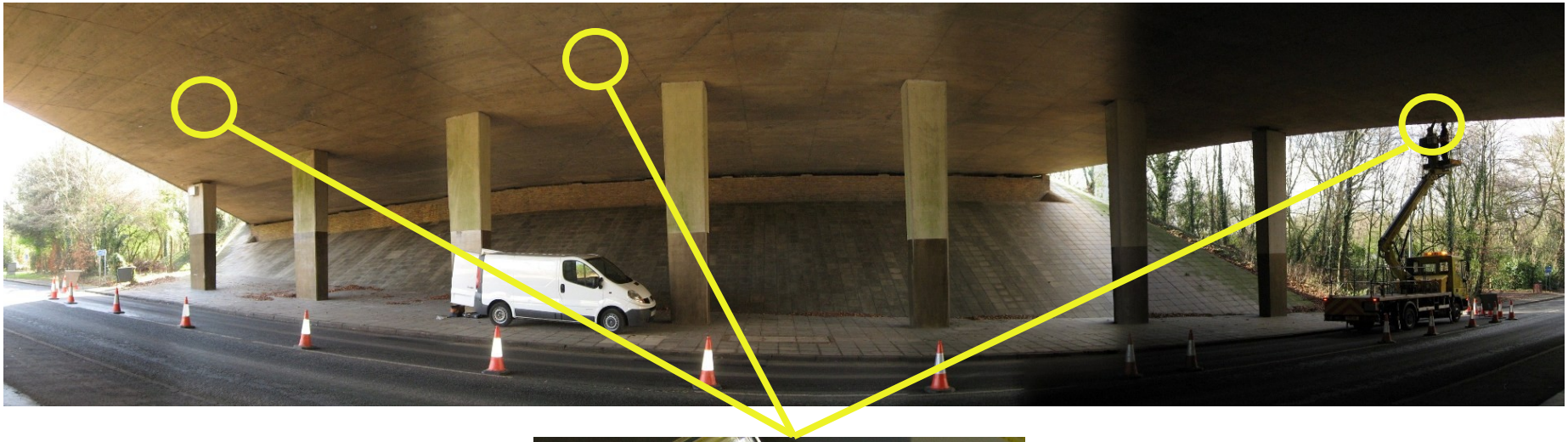


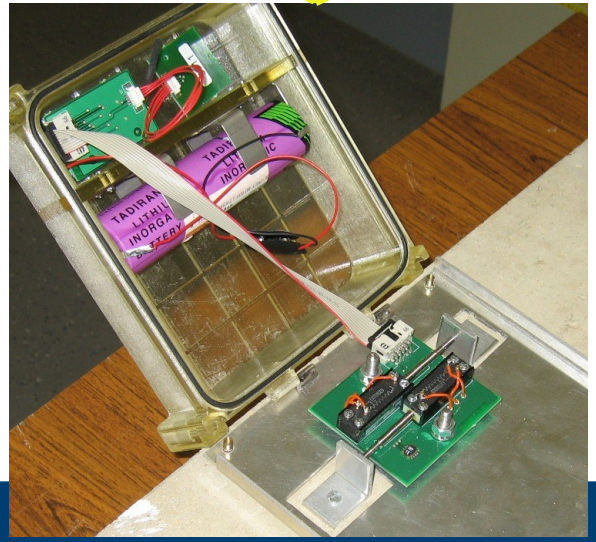

Elevation view of mote network

# Field Deployment – Ferriby Road Bridge

# Field Deployment – Ferriby Road Bridge

# WSN Layout

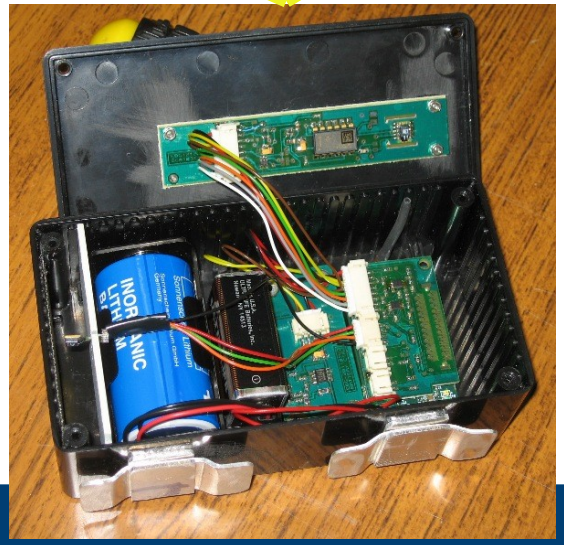




Crack Width Transducers

# WSN Layout

Inclinometers on Bearings



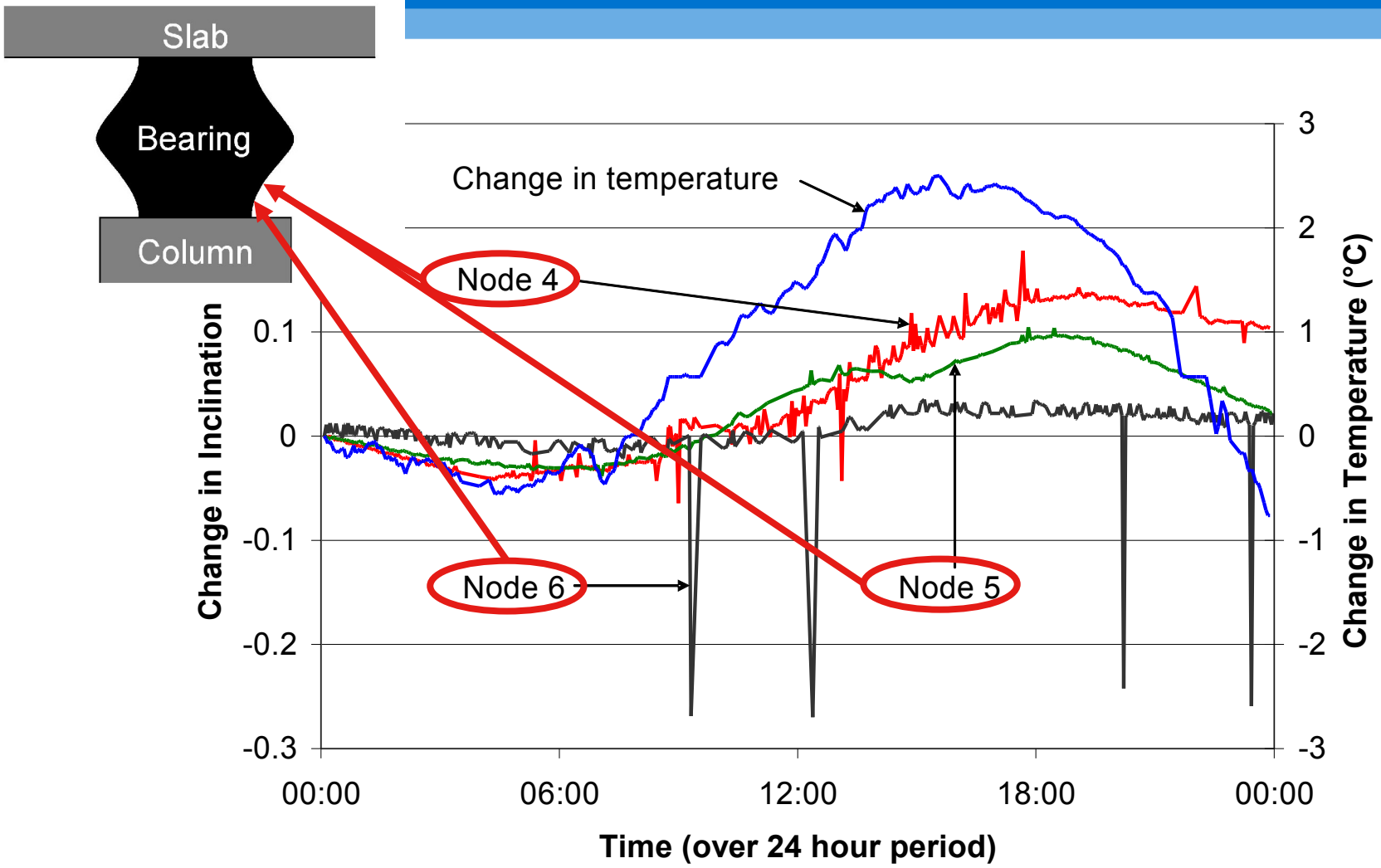
# WSN Layout


Gateway with 12V 100Ah battery & Mobile Phone Modem

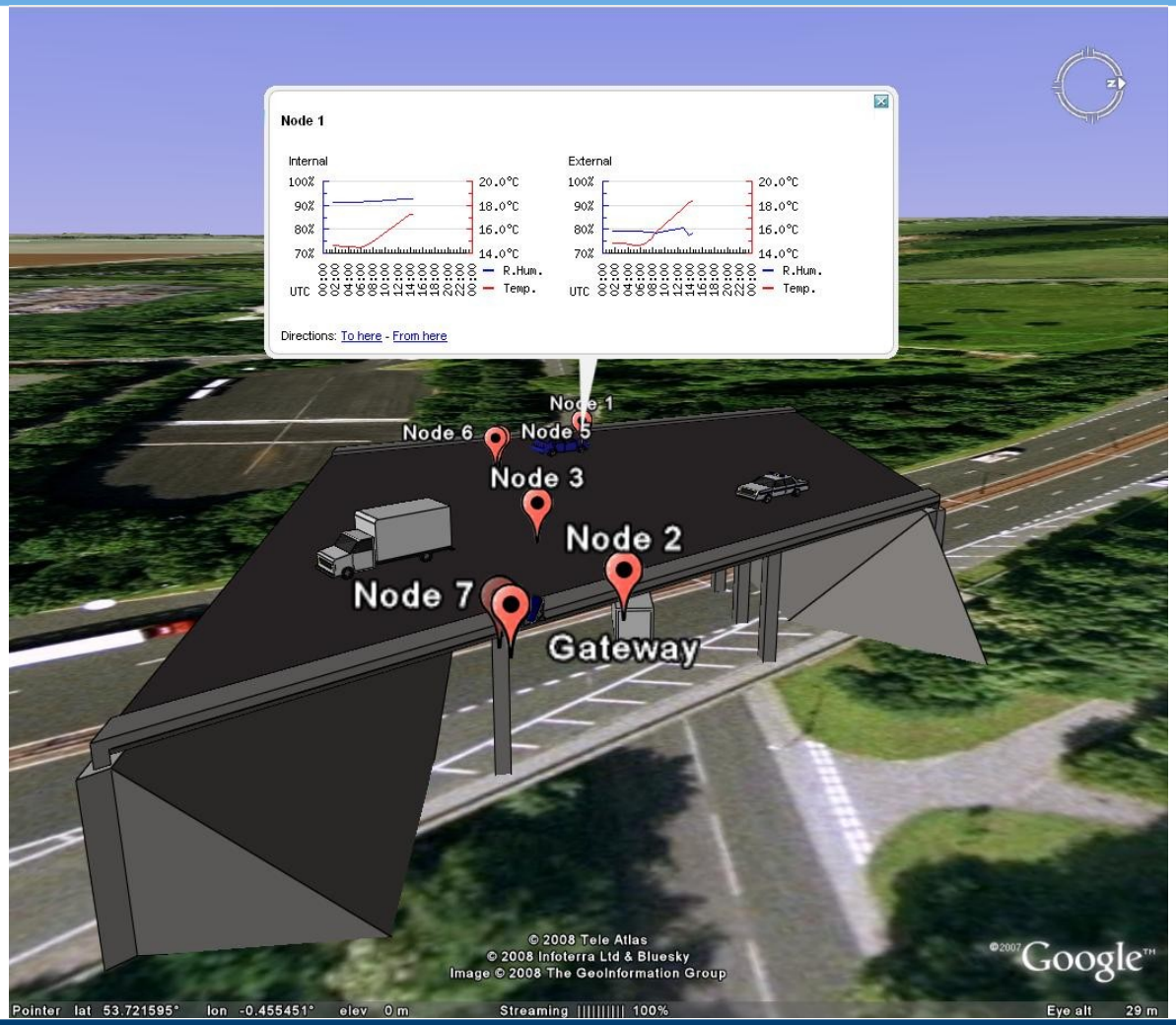
# WSN Layout


Gateway with 12V 100Ah battery & Mobile Phone Modem

# Bearing Movement - Diurnal

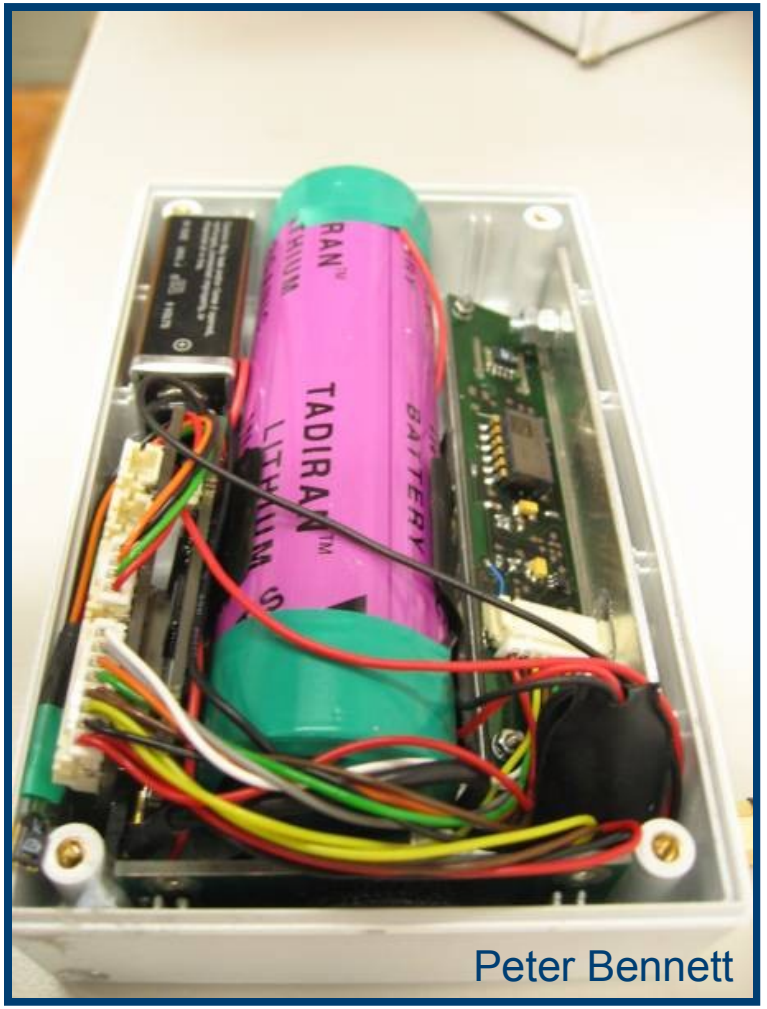


# Network Location & Data Visualization



# Challenge: Power

- 6 to 24 months between battery changes
- Long-life batteries are expensive ($30 to $50)
- Batteries control size
- Gateway requires continuous power
- Power harvesting?

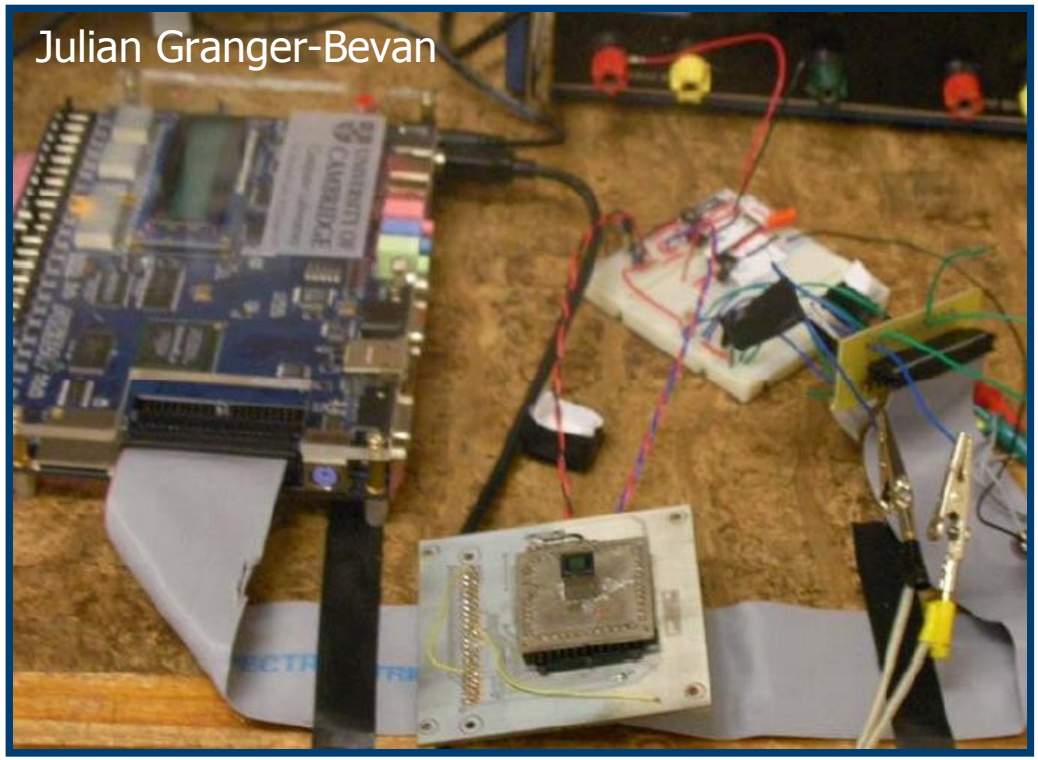


# Challenge: Cost

| Cost: | Installation per Node | Sensor | Data Acquisition per Node | Total per Node |
|---|---|---|---|---|
| Wired System | $2000 | $1000 | $1000 | $4000 |
| Wireless System | $50 | $100 | $230 | $380 |

We're not ready for pervasive use yet!

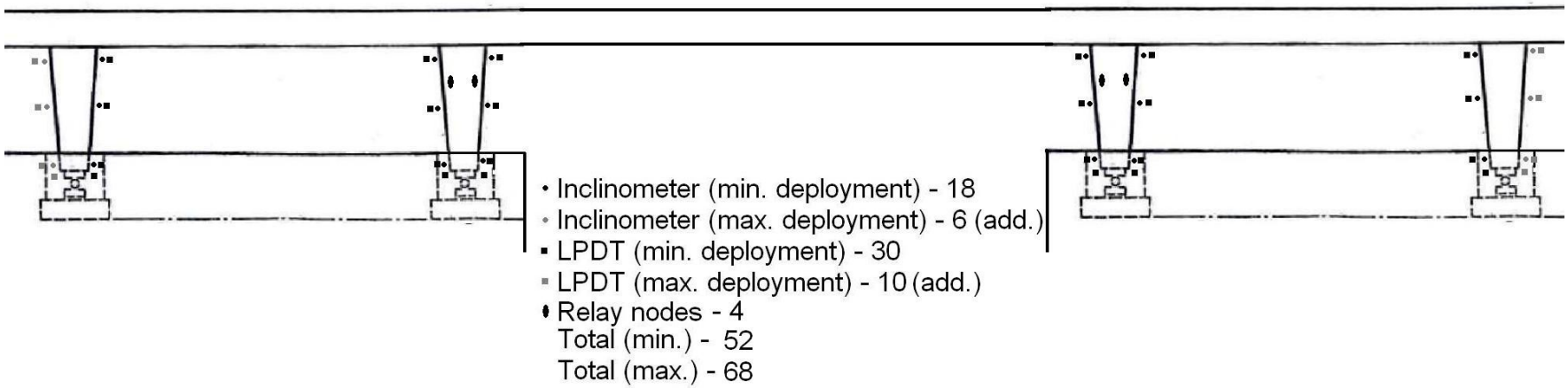
# Innovation: Sensors




- Cameras
  - Crack widths
  - Displacements
  - Strain fields
  - General surveillance
- MEMS strain gauges
  - Cost, Robustness, Gauge length

# Large-scale Deployment

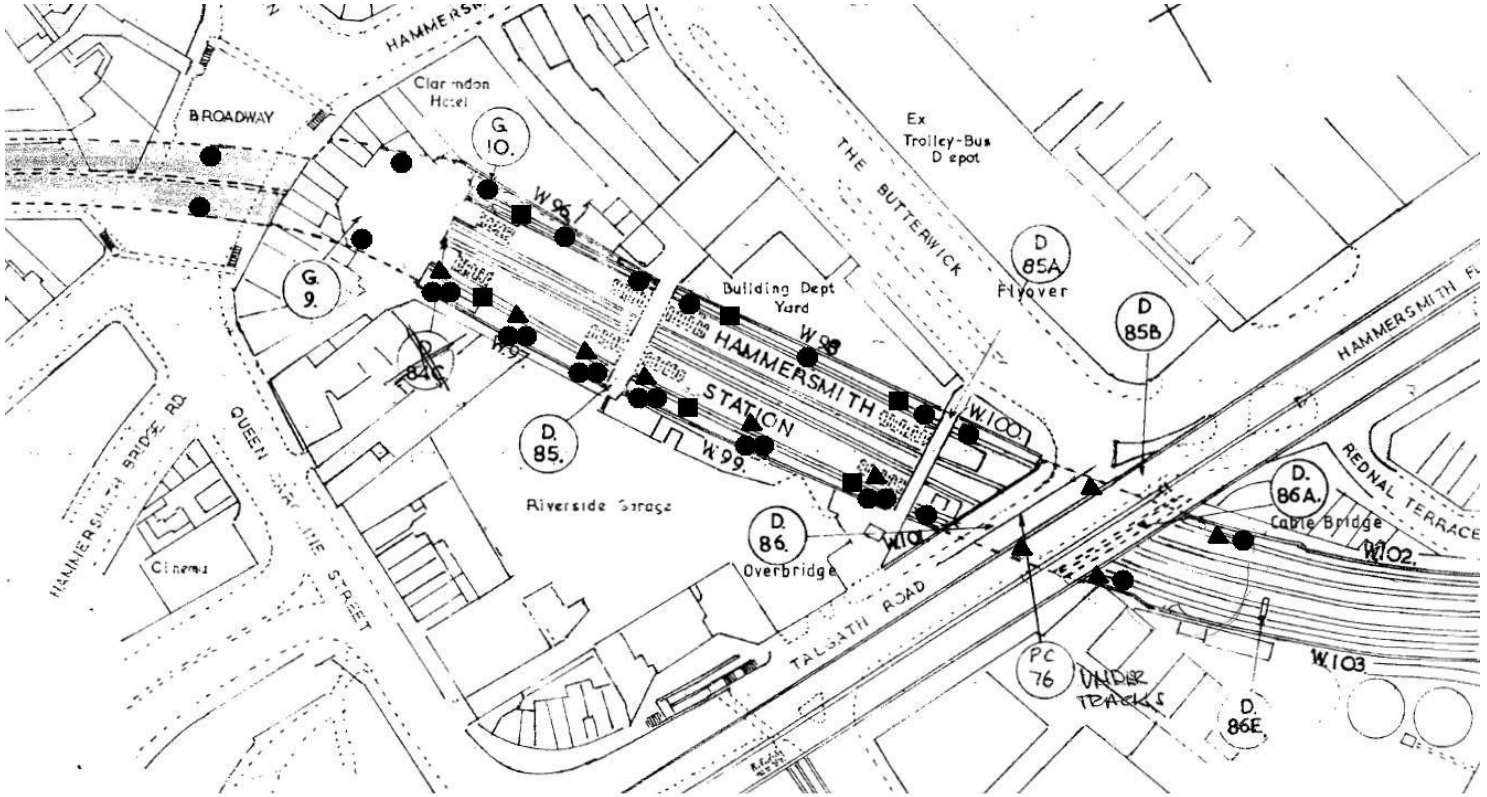
# Large-scale Deployment



# Large-scale Deployment

# Large-scale Deployment

# Large-scale Deployment




- Retaining Wall Inclinometer - 14 Total
- Double Retaining Wall Inclinometer - 6 (12 Total)
- Platform Face Inclinometer - 6 Total
- Relay Node - 10 Total

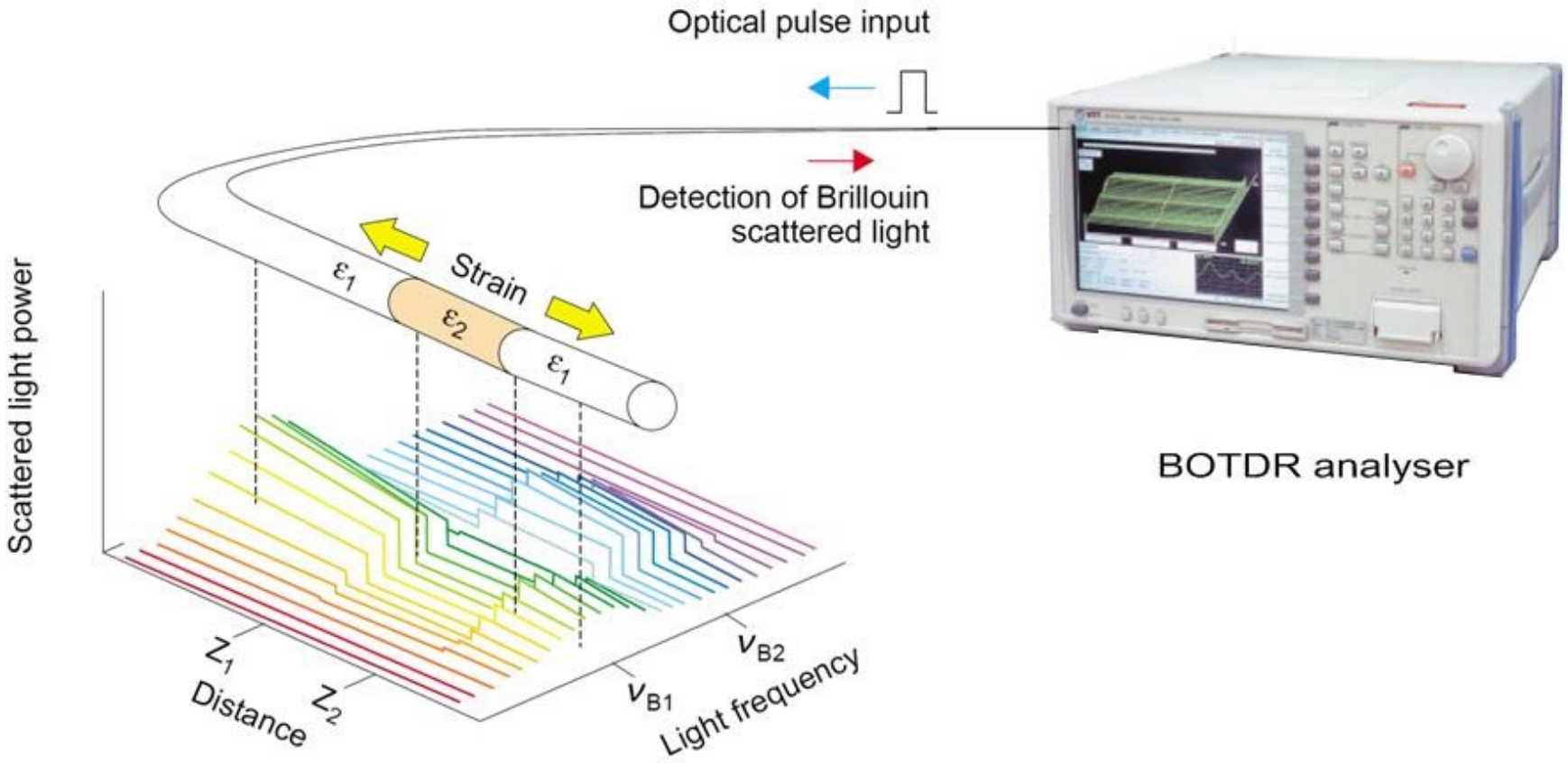
42 Nodes Total

# Assessment using Fibre Optics


# New build monitoring

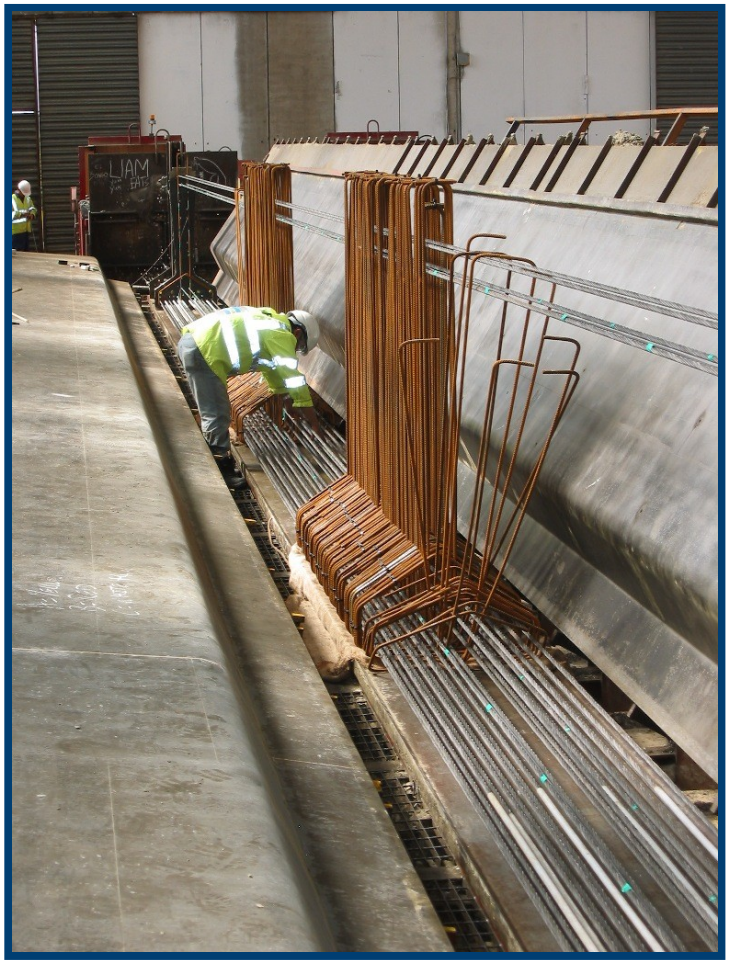
- Monitor new bridge right from construction
- Designer would like to measure redistribution due to creep
- Key questions:
  - Can the system be cost effective?
  - What can it tell us about the structure?

# Brillouin Optical Time-Domain Reflectometry (BOTDR)




The frequency shift of the Brillouin scattered light is proportional to the strain.

# Inexpensive distributed strain measurement?



- Fibre optic cable from $0.35/m - $18/m
- Resolution:18 microstrain (?)
- CAVEAT: the strain analyser costs ~$82,000

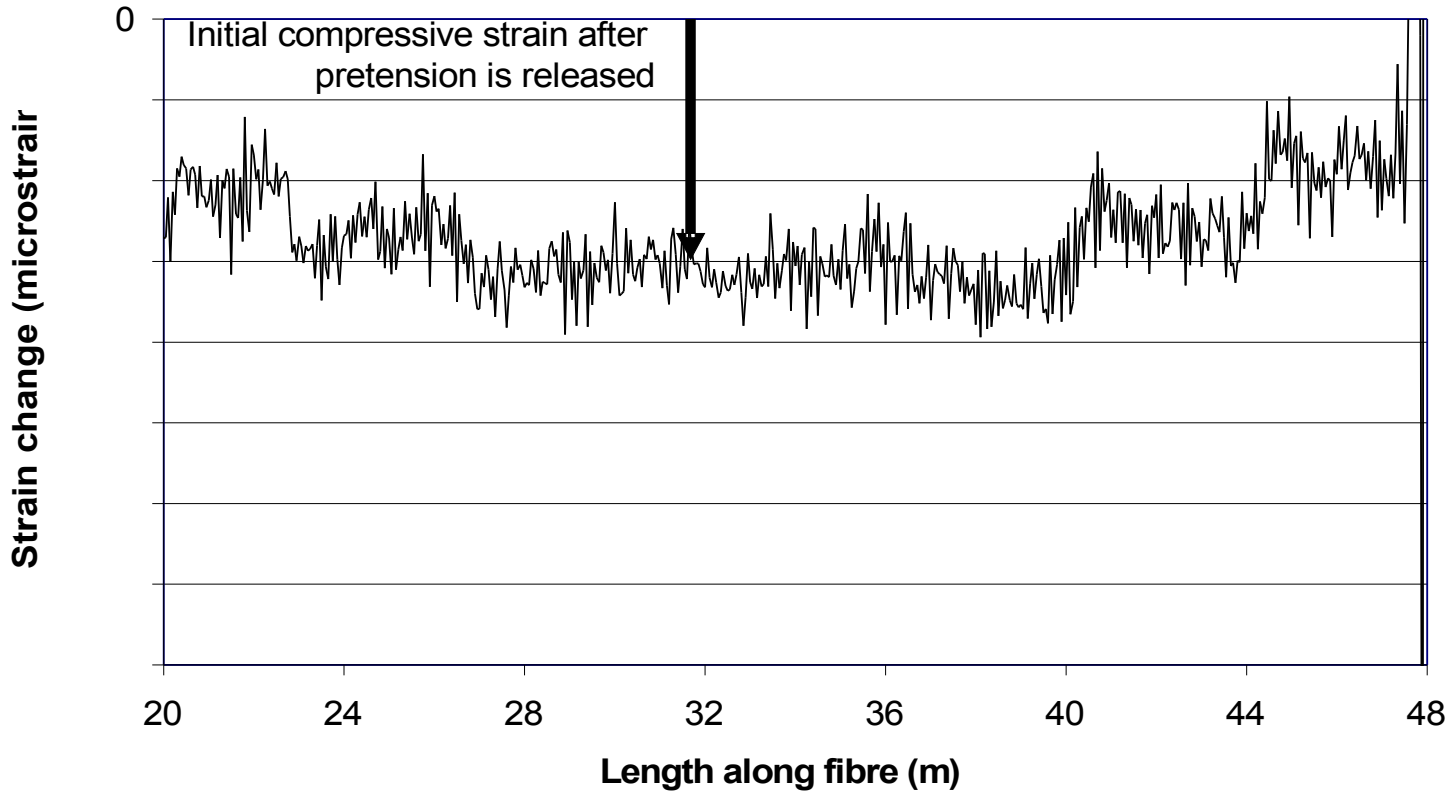
# Addenbrooke's Access Road Bridge

2 (formerly 5 formerly 6) Instrumented Beams

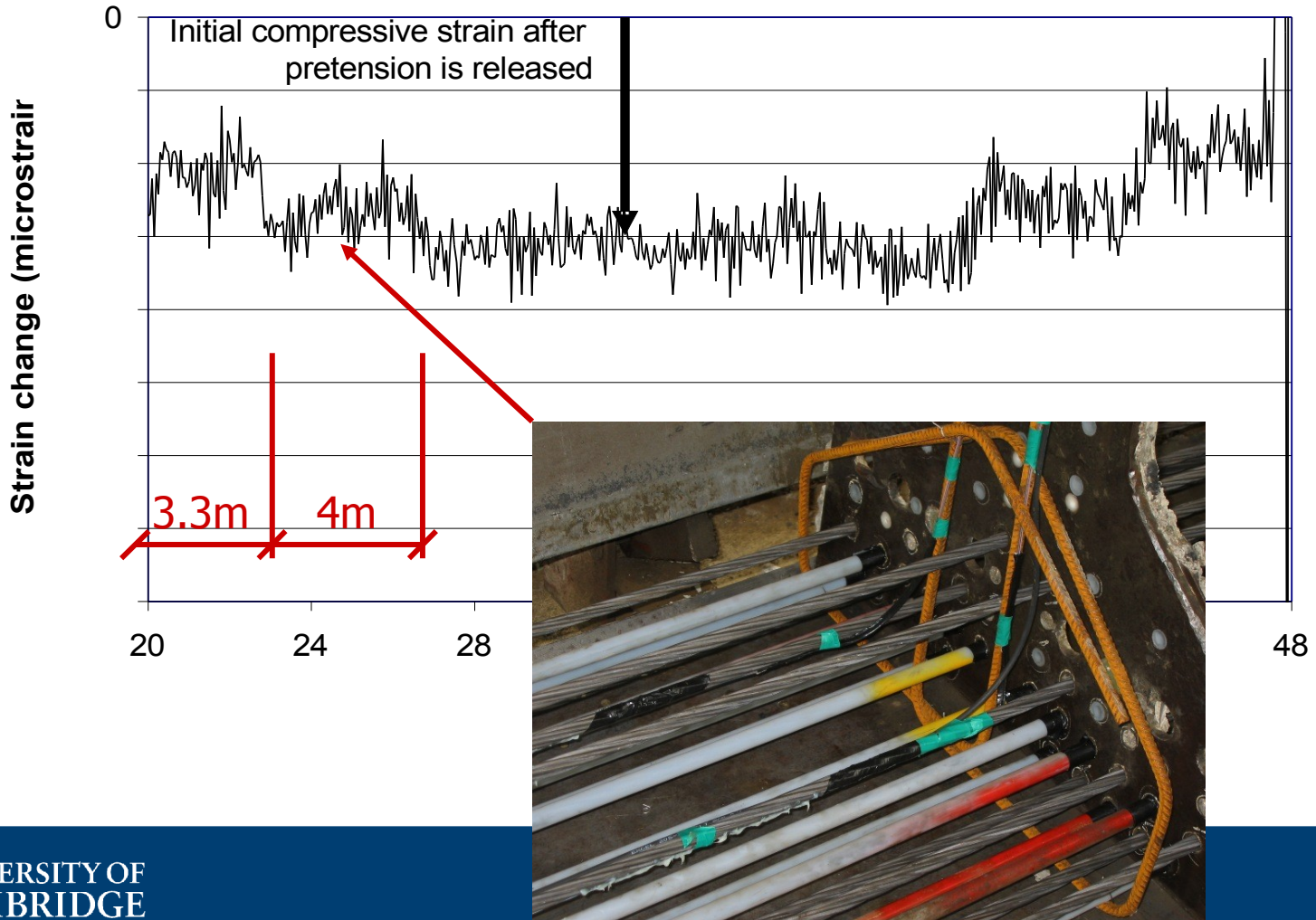
# Inexpensive cable robustness

| | At Precast Plant | | | At construction site after placement | | |
|---|---|---|---|---|---|---|
| Beam No. | Function. Bot. Cables | Function. Top Cables | % of Total | Function. Bot. Cables | Function. Top Cables | % of Total |
| 1 | 2 | 0 | 50 | 1 | 0 | 25 |
| 2 | 1 | 1 | 50 | 1 | 0 | 25 |
| 3 | 1 | 0 | 50 | 1 | 0 | 50 |
| 4 | 2 | 1* | 100 | 0 | 1* | 33 |
| 5 | 0.5 | 0 | 12.5 | 0 | 0 | 0 |
| 6 | 1 | 1 | 50 | 1 | 1 | 50 |
| | | % for all beams | 50 | | % for all beams | 28.5 |

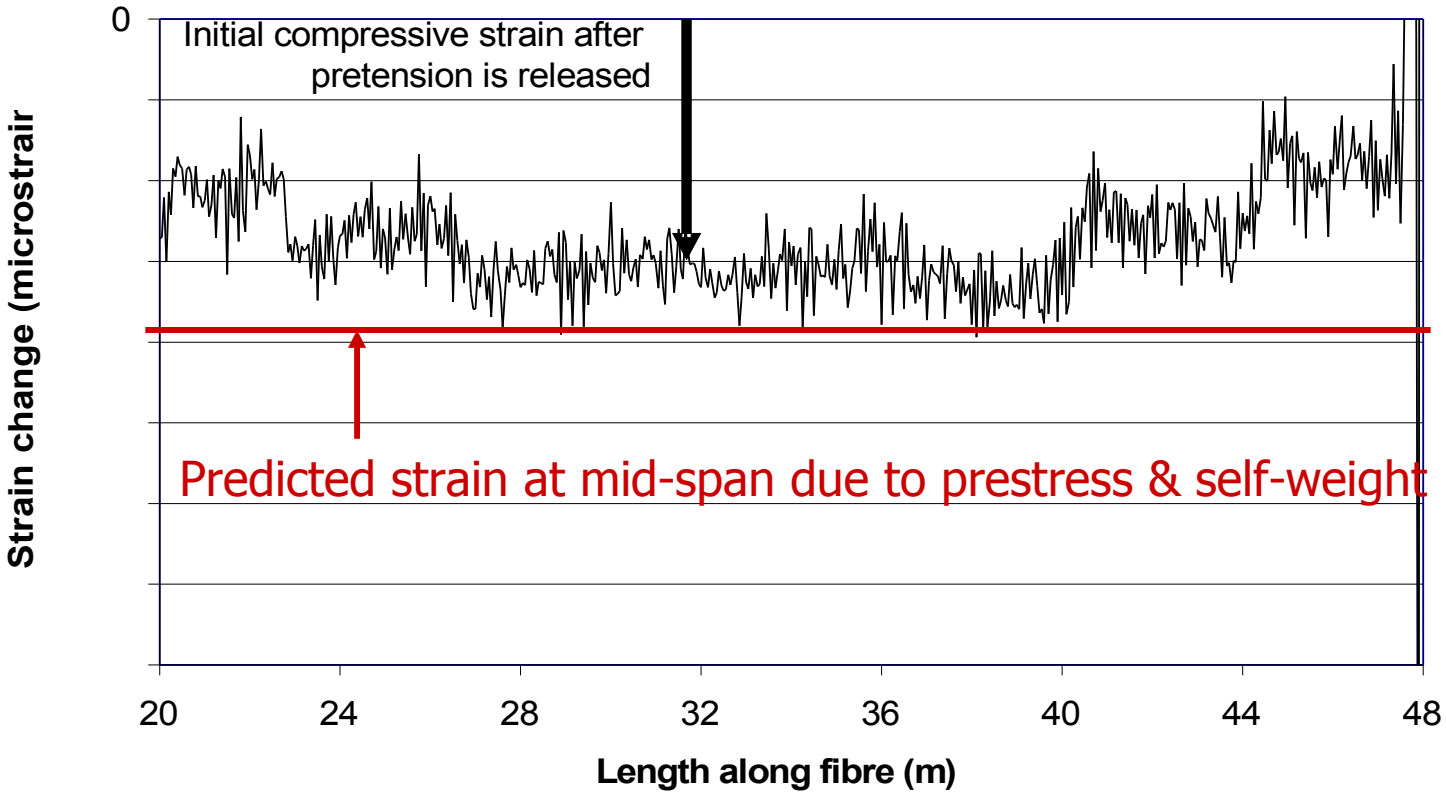
# Testing of Cables



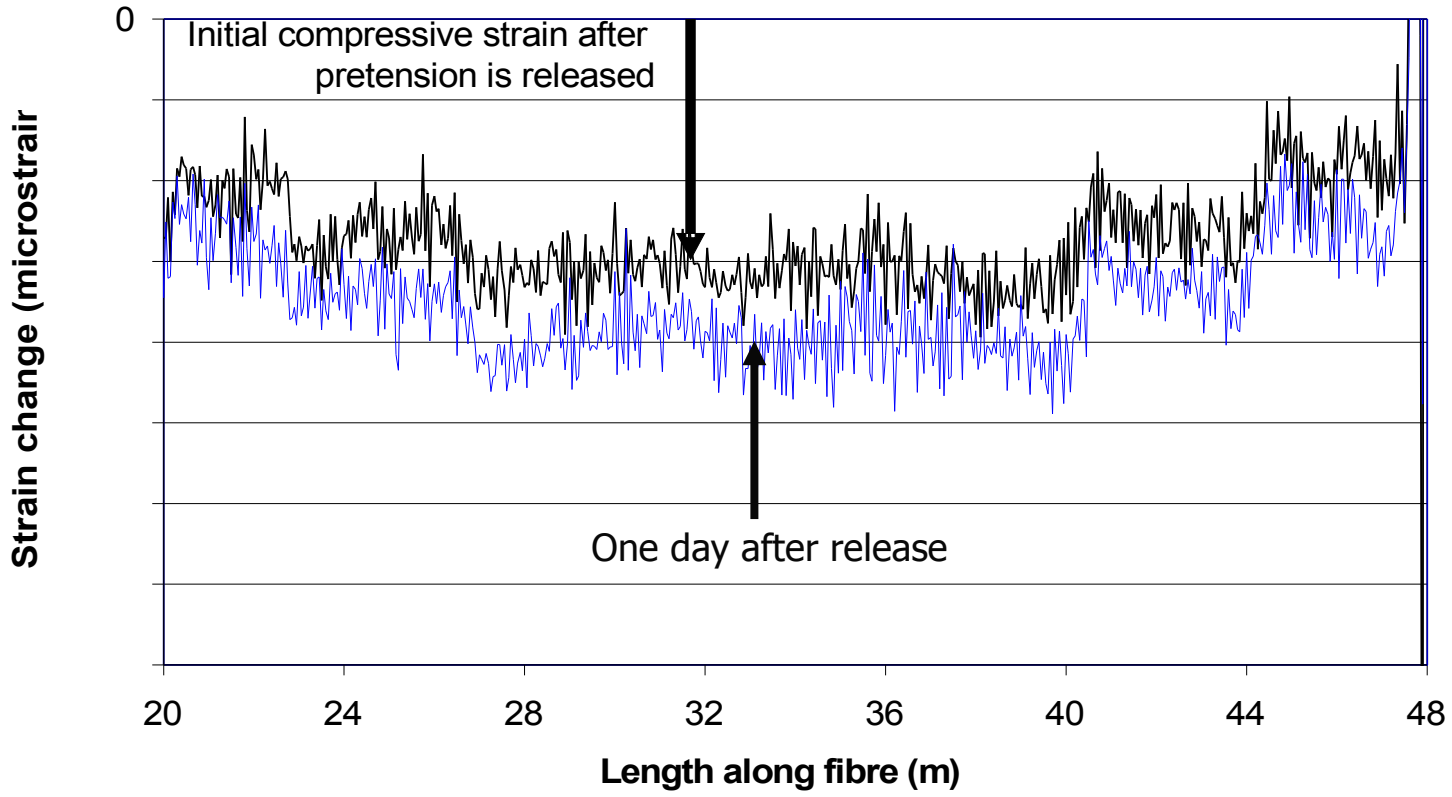
# Testing of Cables



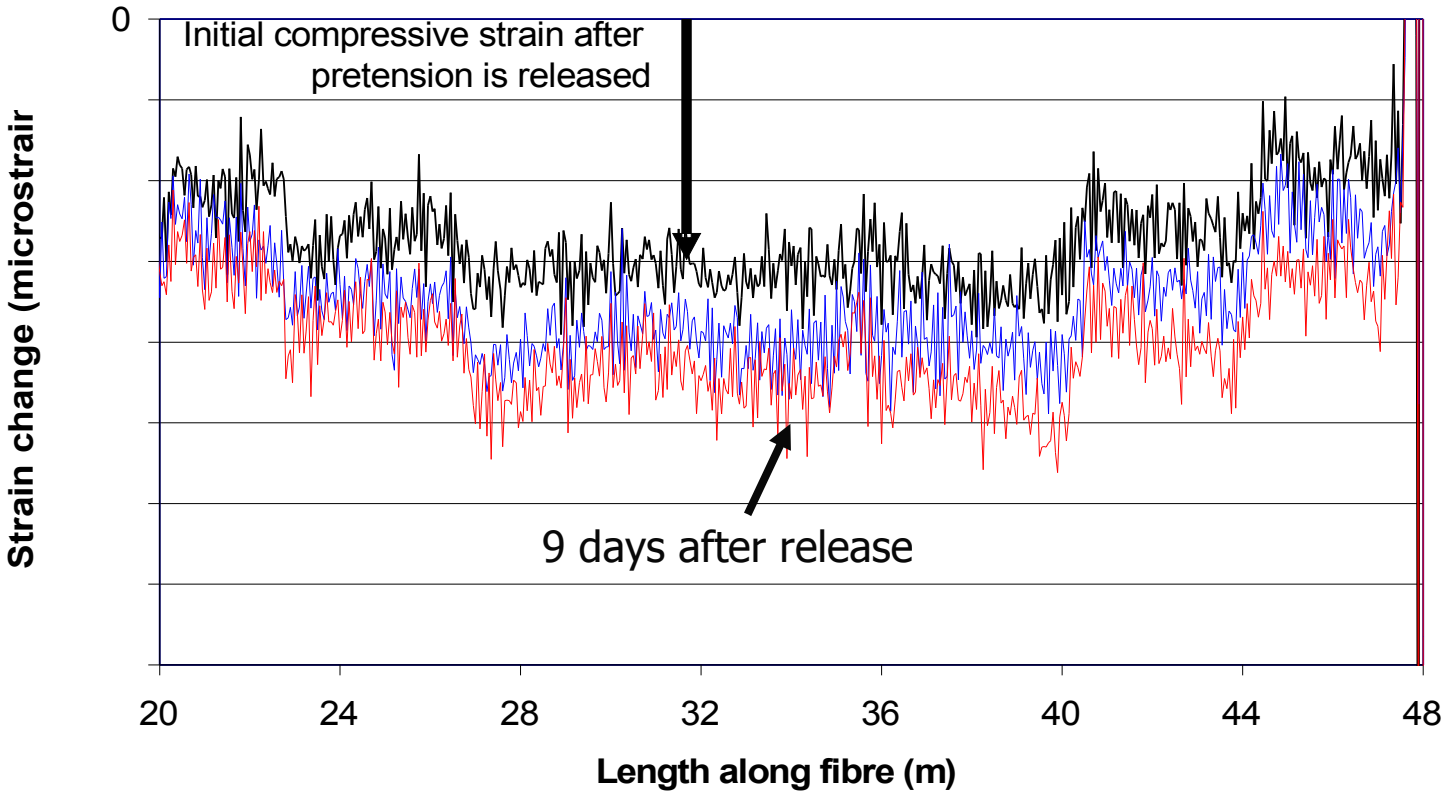
# Testing of Cables



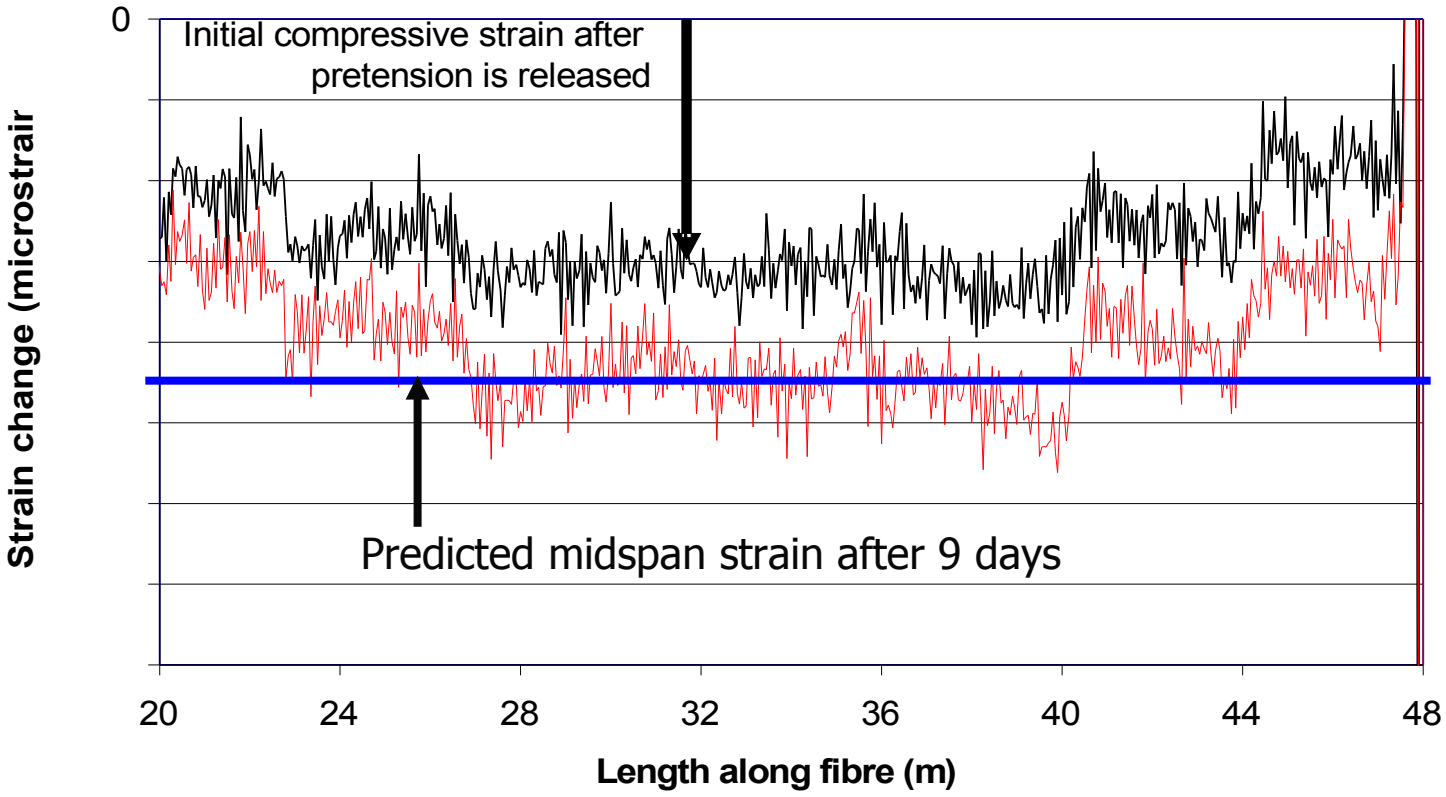
# Testing of Cables



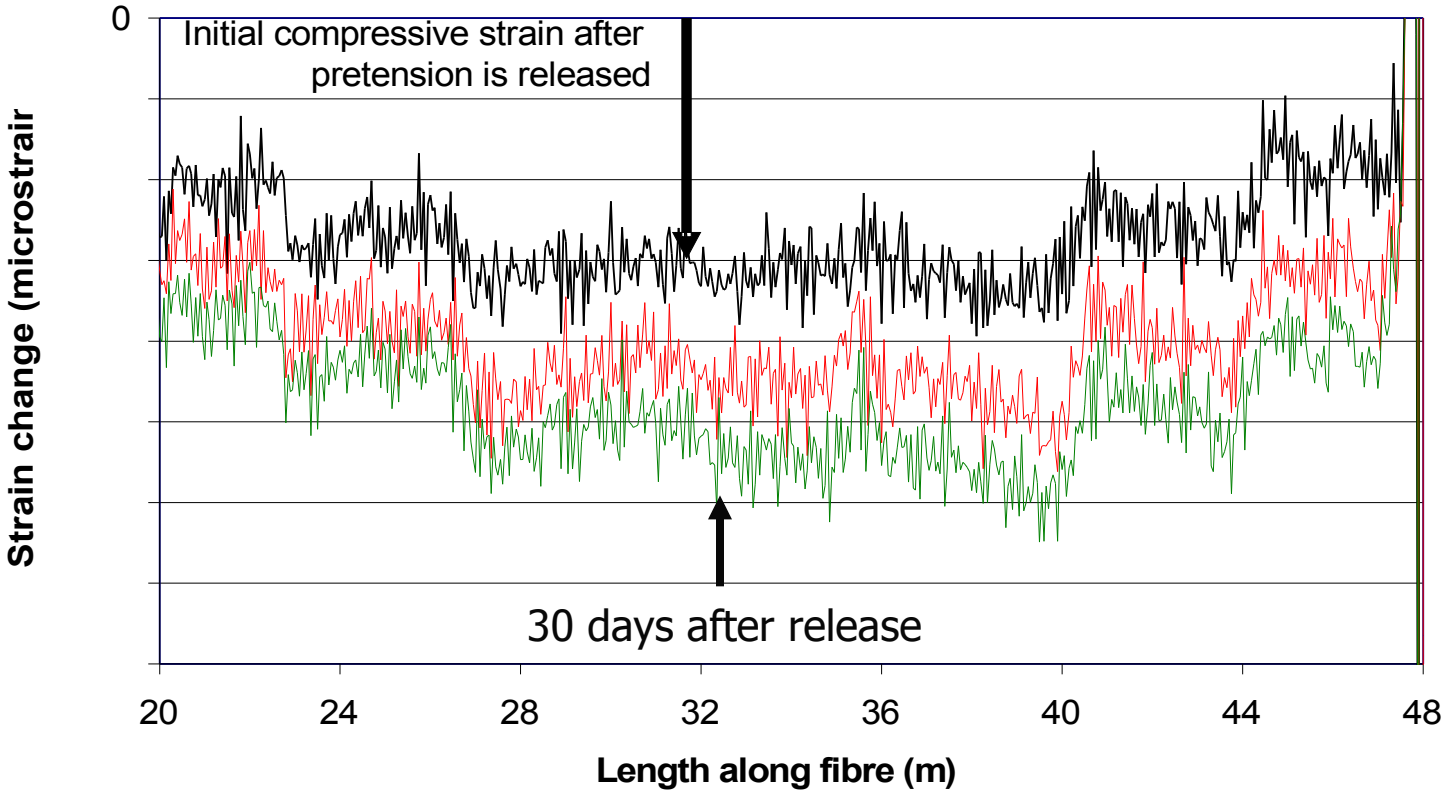
# Testing of Cables



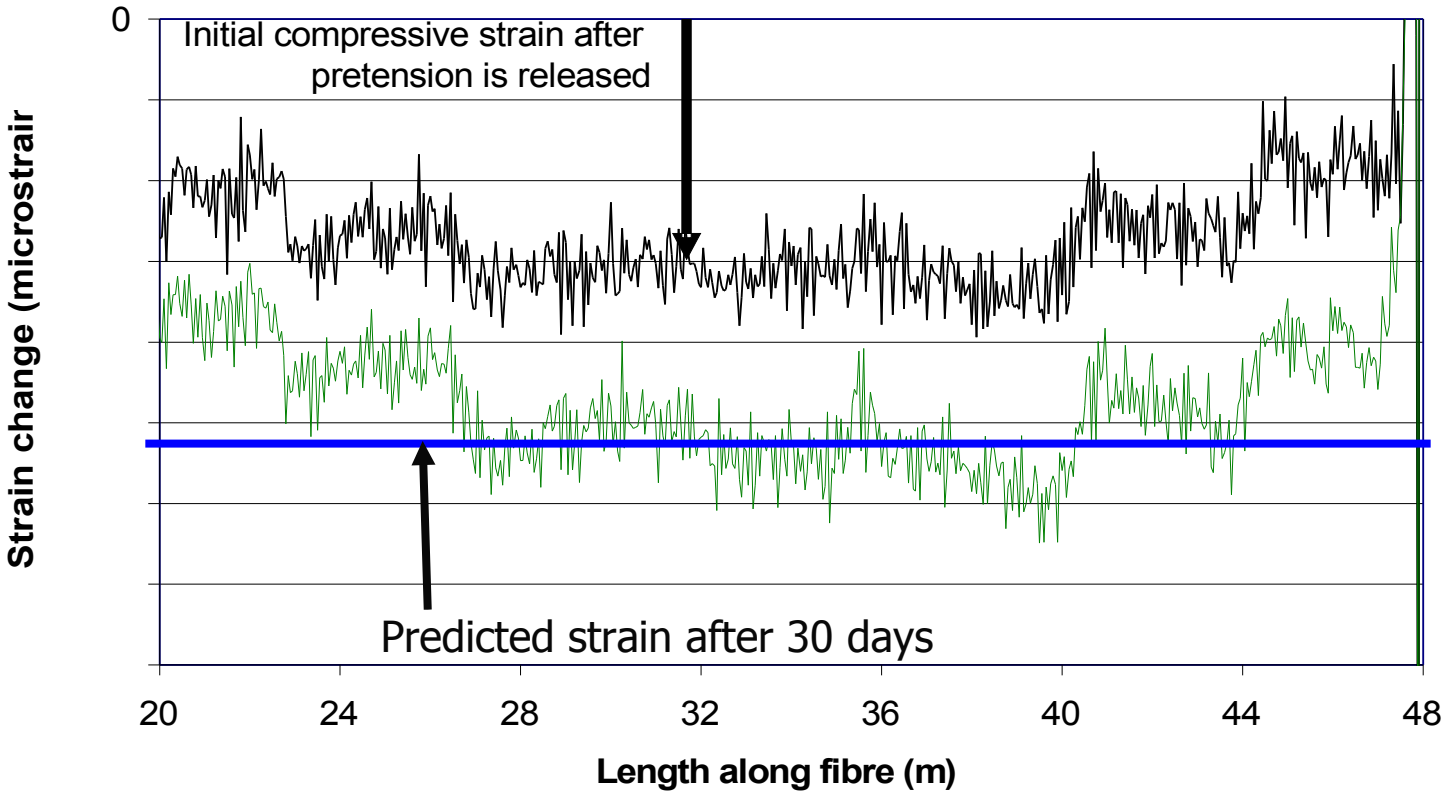
# Testing of Cables



# Testing of Cables



# Testing of Cables



# What can the system tell us?

- Creep: required resolution ~100 microstrain
- Corrosion (rupture of a prestressing strand):
  - Tension: ~100 microstrain
  - Compression: ~10 microstrain
- Residual capacity: possibly
  - However fibre Bragg gratings maybe more appropriate (higher resolution, faster response)

# Cost implications?

- Inexpensive fibres (materials + labour): ~$7,100
- Expensive fibres: ~ $75,000
- Cost of bridge: ~ $7,000,000
- Even expensive cables only amount to 1% of the overall cost

# Thank You, Questions?