Distributed Fibre Optic Sensors

Applications and commercial viability for monitoring civil infrastructure

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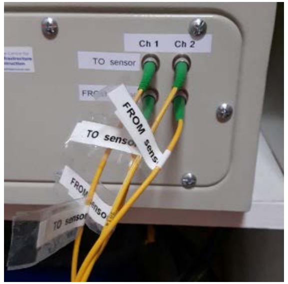
Director – Epsimon Ltd.







Instrumentation and Monitoring conference
London
30th March 2017

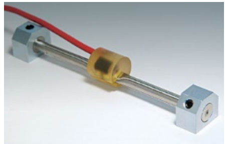
Point sensing vs Distributed sensing

SPATIAL COVERAGE

Point sensors | Pseudo-distributed sensors | Distributed sensors | 2-D / 3-D sensing

Strain, pressure

Metal foil strain gauge



Vibrating wire strain gauge (VWSG)

Pressure cell

Fibre Bragg grating

Acceleration, velocity, inclination

Geophone

Accelerometer

Tilt meter / inclinometer

Displacement

Linear potentiometer displacement transducer (LPDT)

Linear variable differential transformer (LVDT)

Laser distance meter

Temperature

Thermistor / thermocouple sensors

Etc.

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Point sensing vs Distributed sensing

SPATIAL COVERAGE →

Point sensors | **Pseudo-distributed sensors** | Distributed sensors | 2-D / 3-D sensing

Image source: National Driller

Thermal Integrity Profiling thermistor array

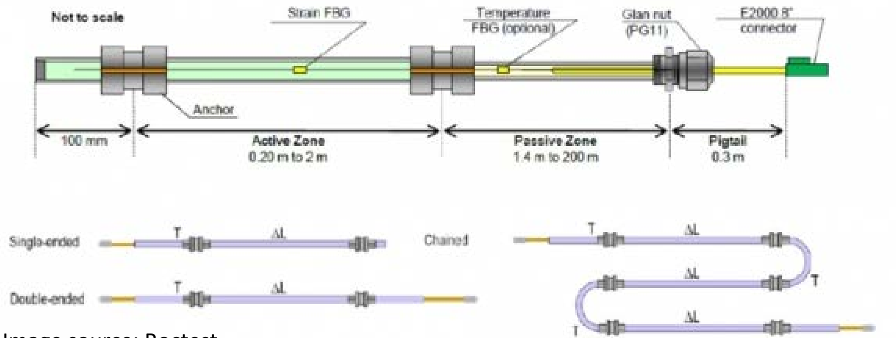


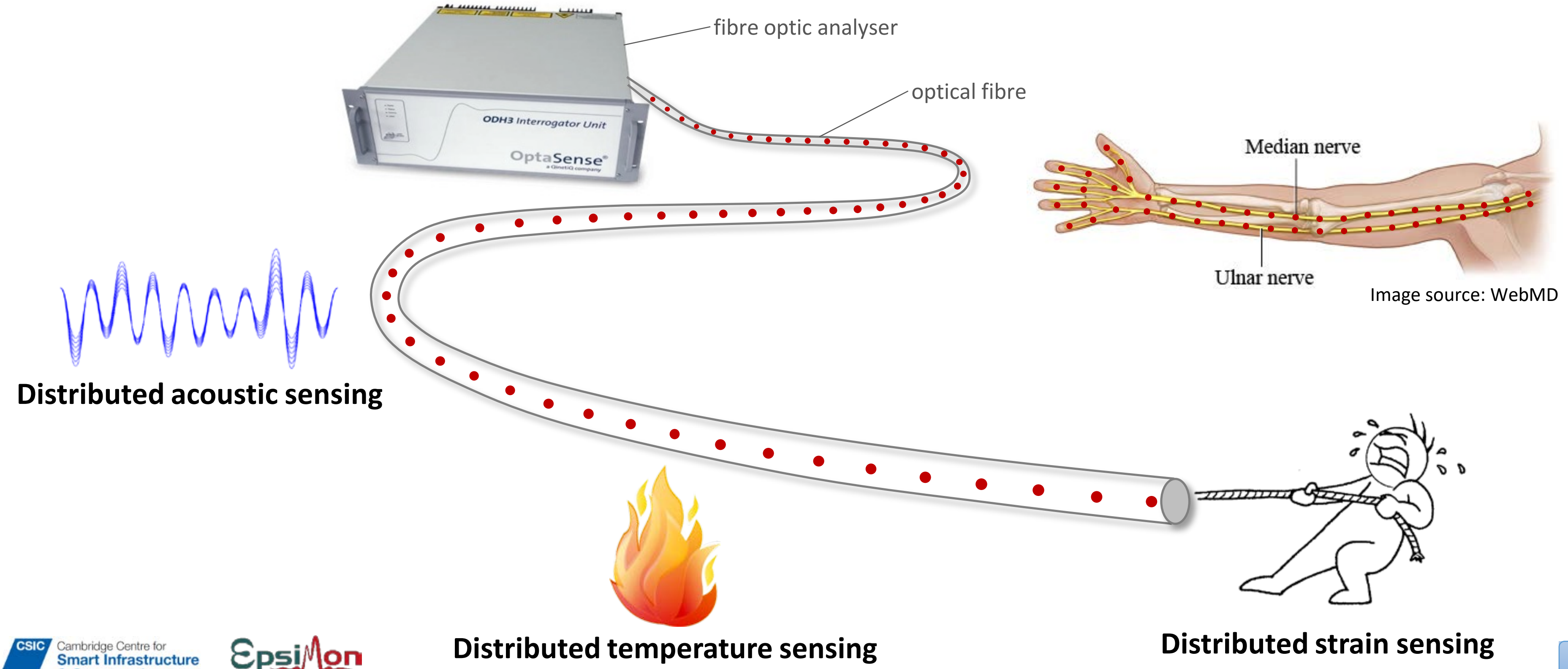
Image source: Roctest

Long-gauge FBG deformation sensor array

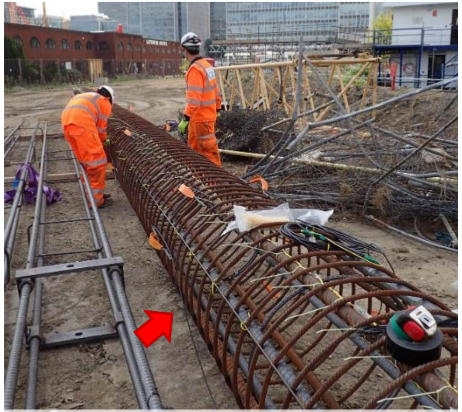
Point sensing vs Distributed sensing

SPATIAL COVERAGE →

Point sensors | Pseudo-distributed sensors | **Distributed sensors** | 2-D / 3-D sensing

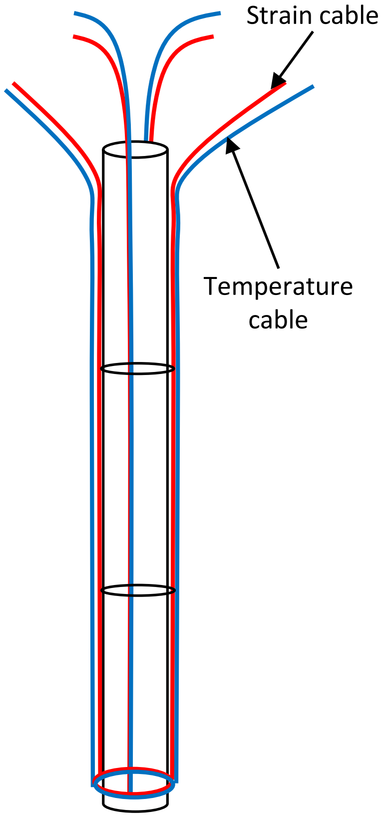


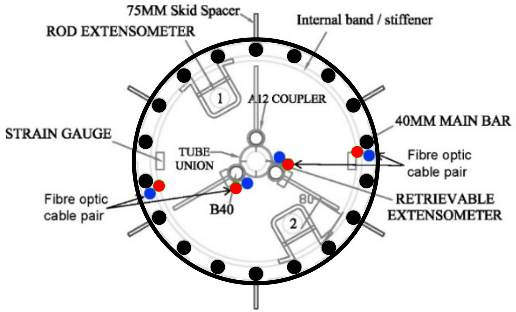
Example application 1: **Concrete piles**

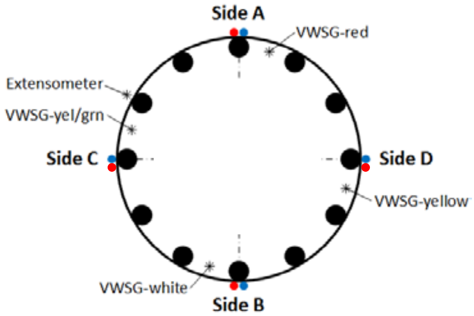


FO cables attached to pile cage

FO cables existing pile head

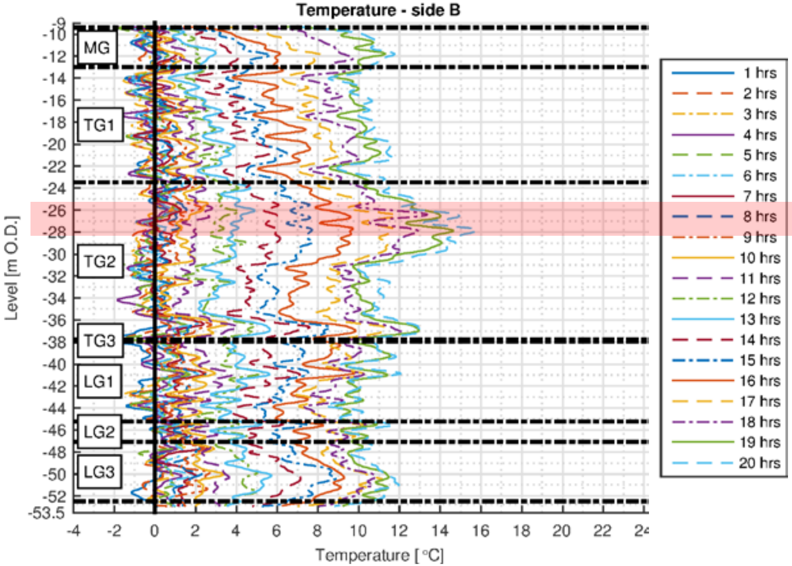


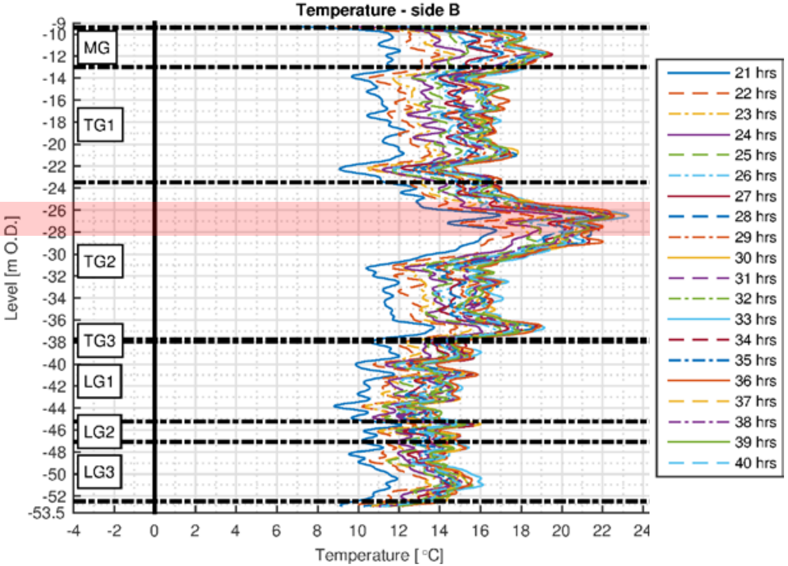


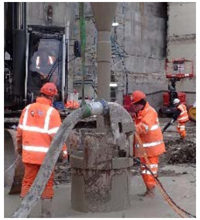


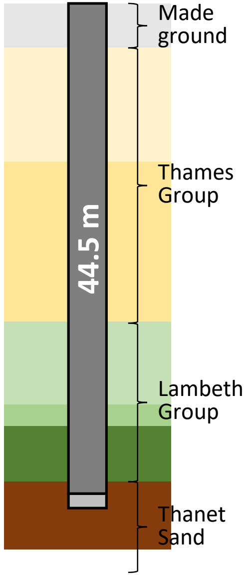
Example application 1: **Concrete piles**

Monitoring data: **Temperature profile during concrete curing**









Zone with higher curing temperature indicating anomaly in concrete

Presence of anomaly was confirmed by cross-hole sonic logging of pile carried out by independent contractor

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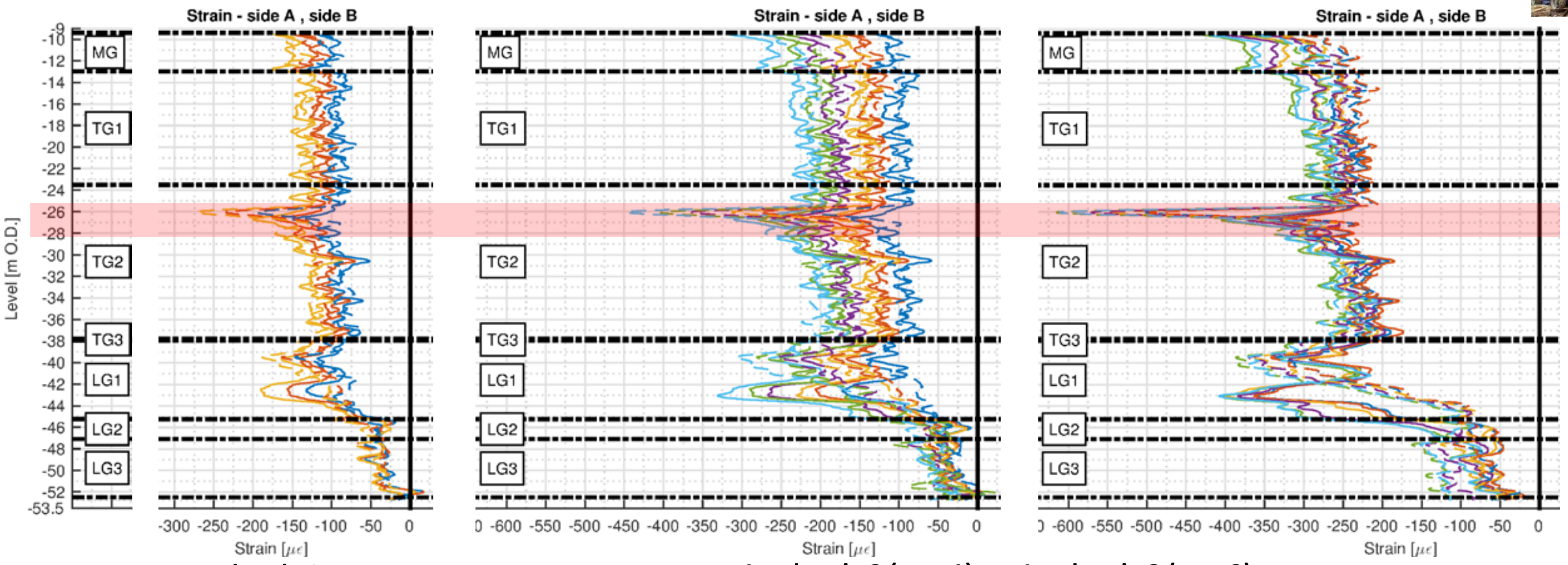
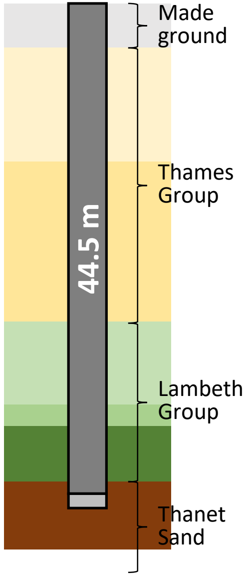
Example application 1: **Concrete piles**

Monitoring data: **Strain profile during static compression load test**





Load cycle 2

- 3250 kN - side A
- 3863 kN - side A
- 4475 kN - side A
- 3250 kN - side B
- 3863 kN - side B
- 4475 kN - side B

Load cycle 3 (part 1)

- 3250 kN - side A
- 4475 kN - side A
- 5088 kN - side A
- 5700 kN - side A
- 6313 kN - side A
- 6925 kN - side A
- 3250 kN - side B
- 4475 kN - side B
- 5088 kN - side B
- 5700 kN - side B
- 6313 kN - side B
- 6925 kN - side B

Load cycle 3 (part 2)

- 7538 kN - side A
- 7538 kN - side A
- 8150 kN - side A
- 8763 kN - side A
- 9375 kN - side A
- 9375 kN - side A
- 7538 kN - side B
- 7538 kN - side B
- 8150 kN - side B
- 8763 kN - side B
- 9375 kN - side B
- 9375 kN - side B

Higher strain (compressive)

Confirmation of anomaly: lower stiffness or smaller area (void, inclusion, segregation, etc.)

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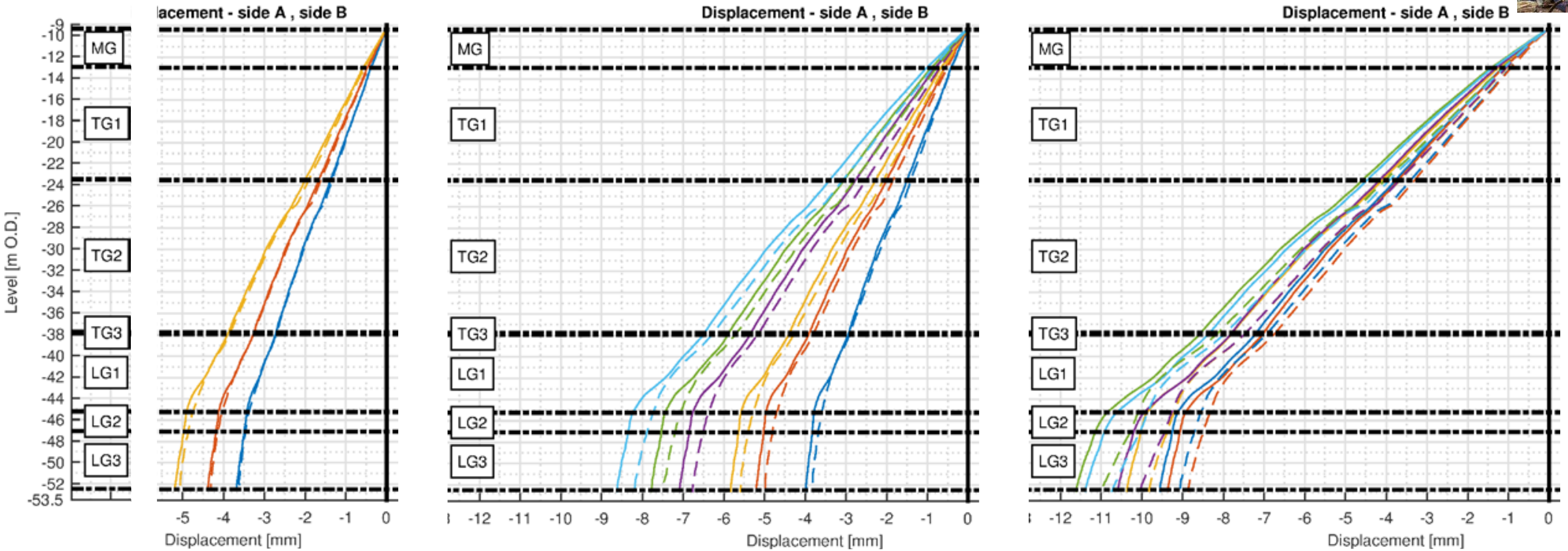
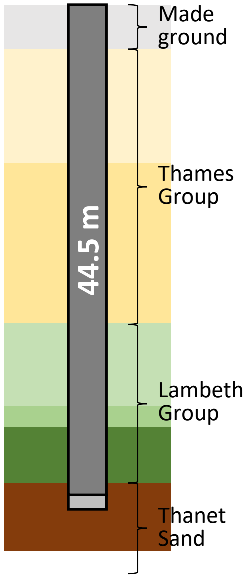
Example application 1: **Concrete piles**

Monitoring data: **Displacement profile during static compression load test**





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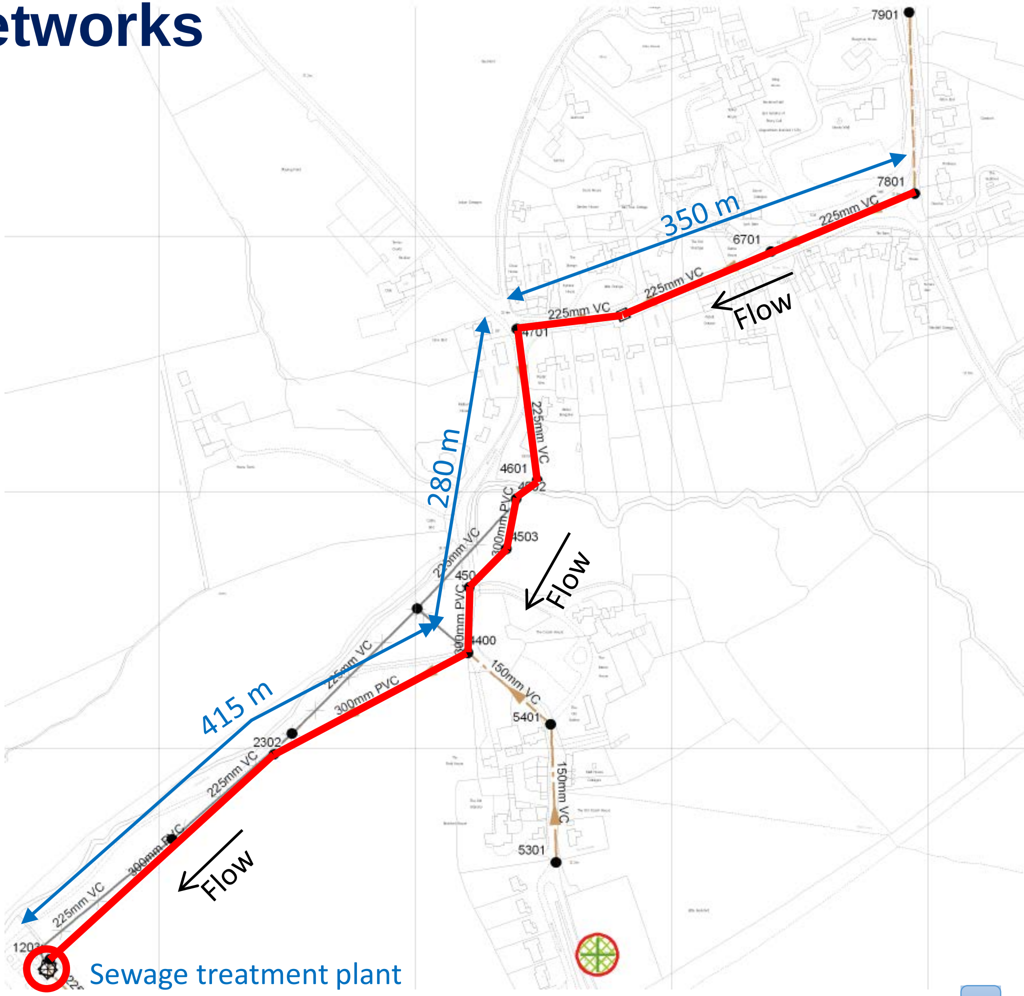
Example application 2: **Sewer networks**

Monitoring of 1045 m domestic foul sewer network leading to sewage treatment plant

- To identify:
  - locations of **rainwater ingress**
  - locations of **restricted flow**

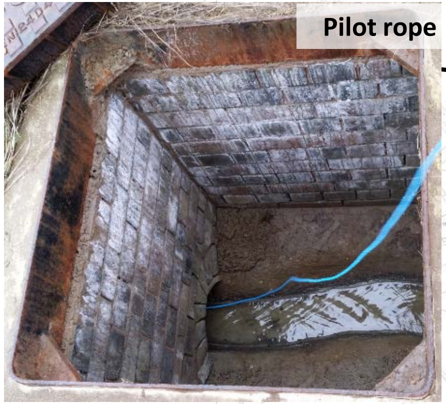
- Continuous measurement (every 2 min.) of **temperature profile** during 80 days

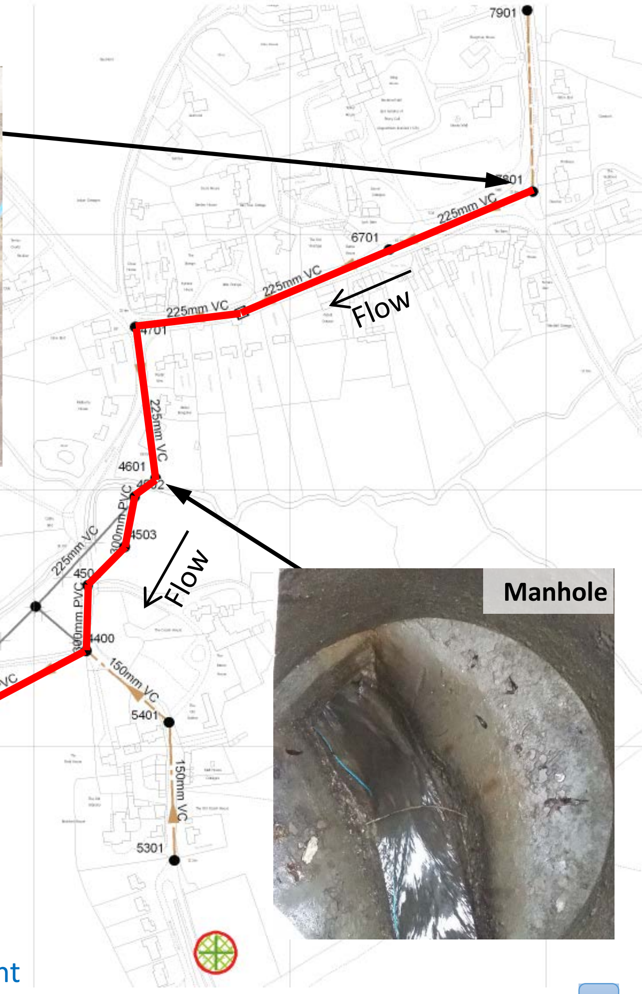
- Detect **temperature change** during rainfall (rain water has a different temperature from sewage)



Example application 2: **Sewer networks**

Rainfall gauge





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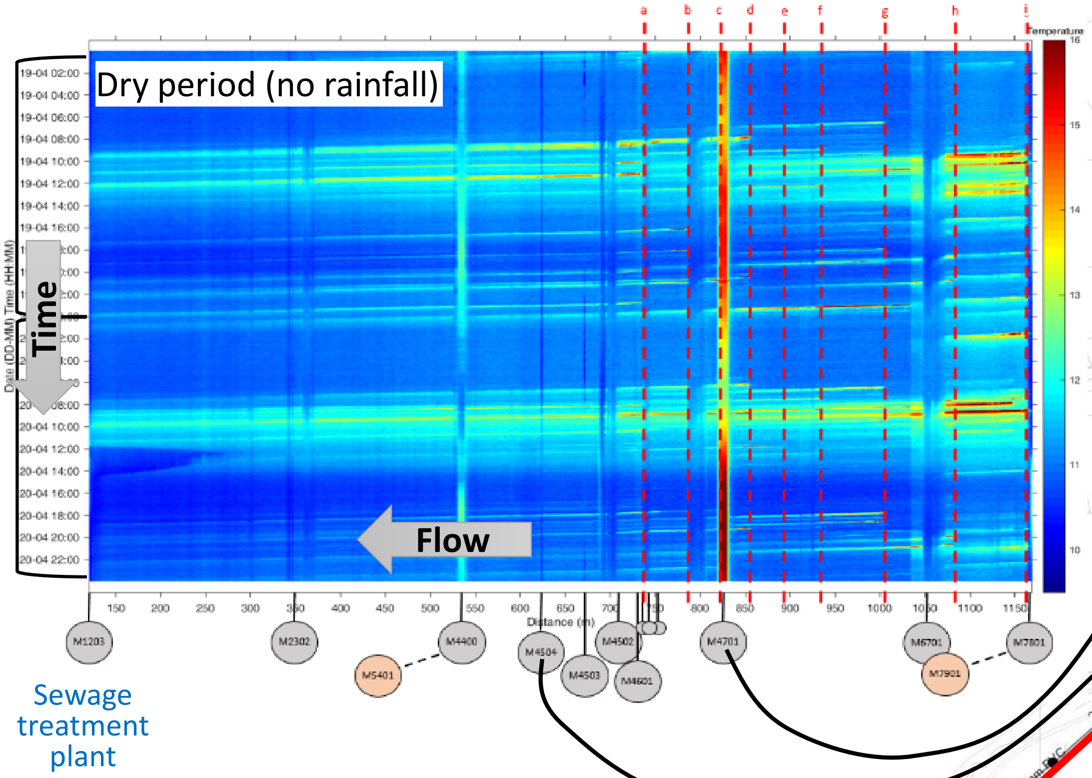

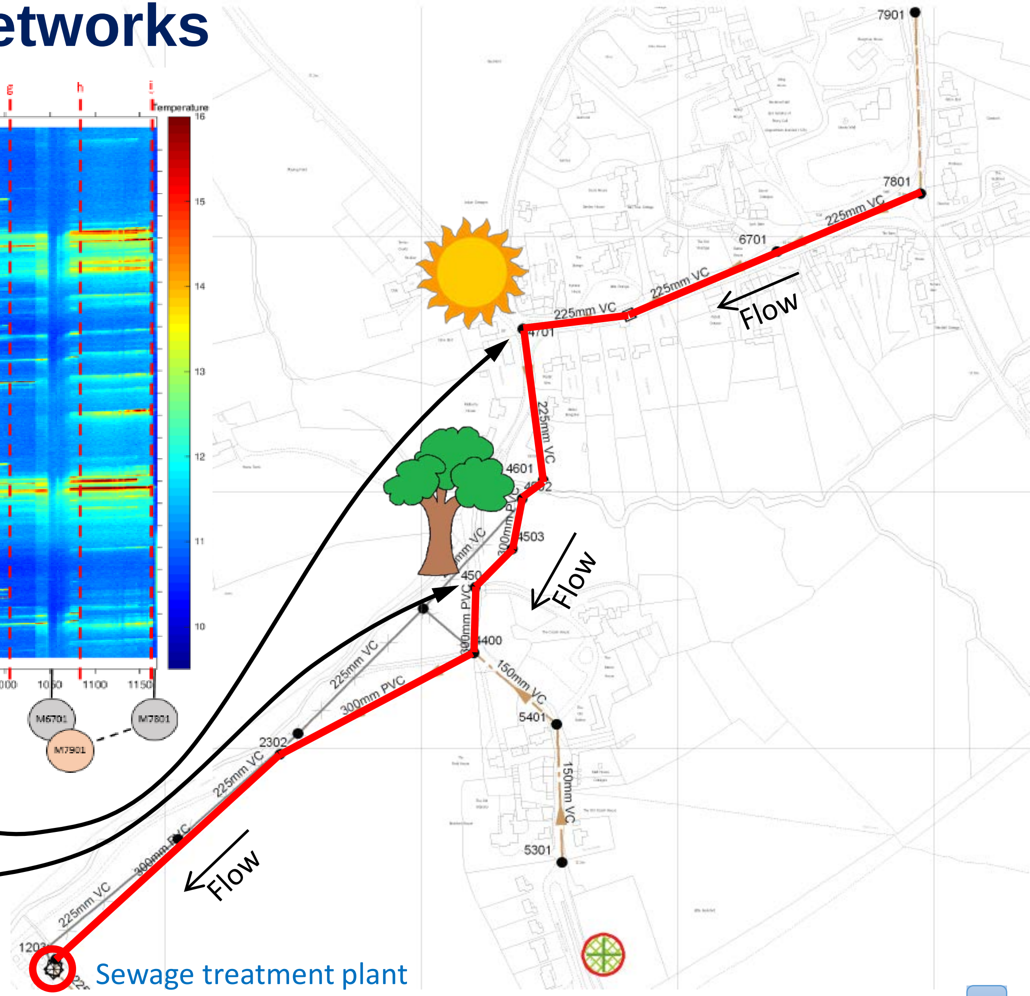

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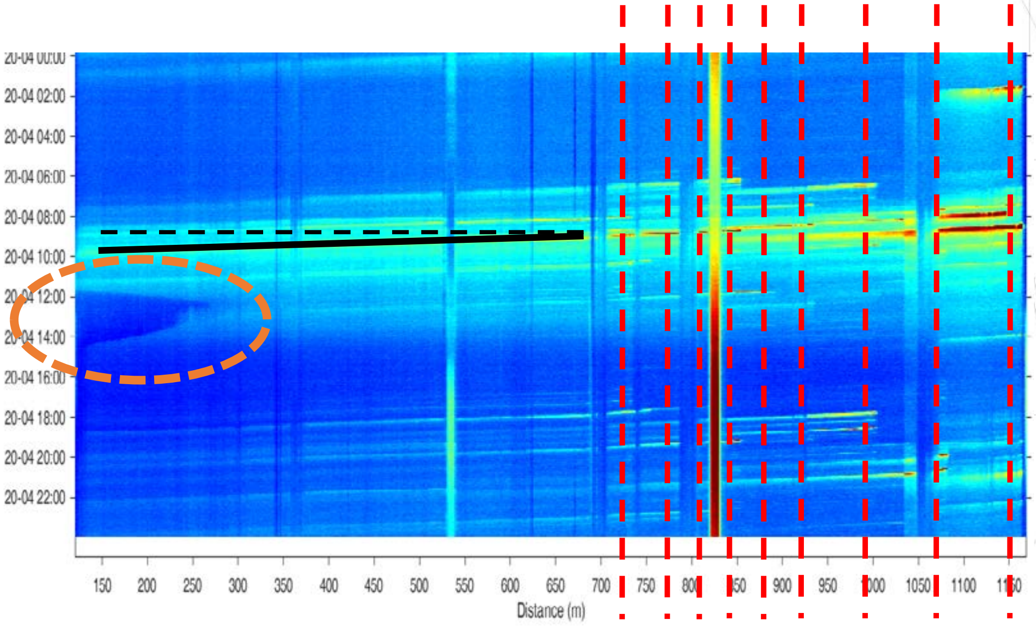
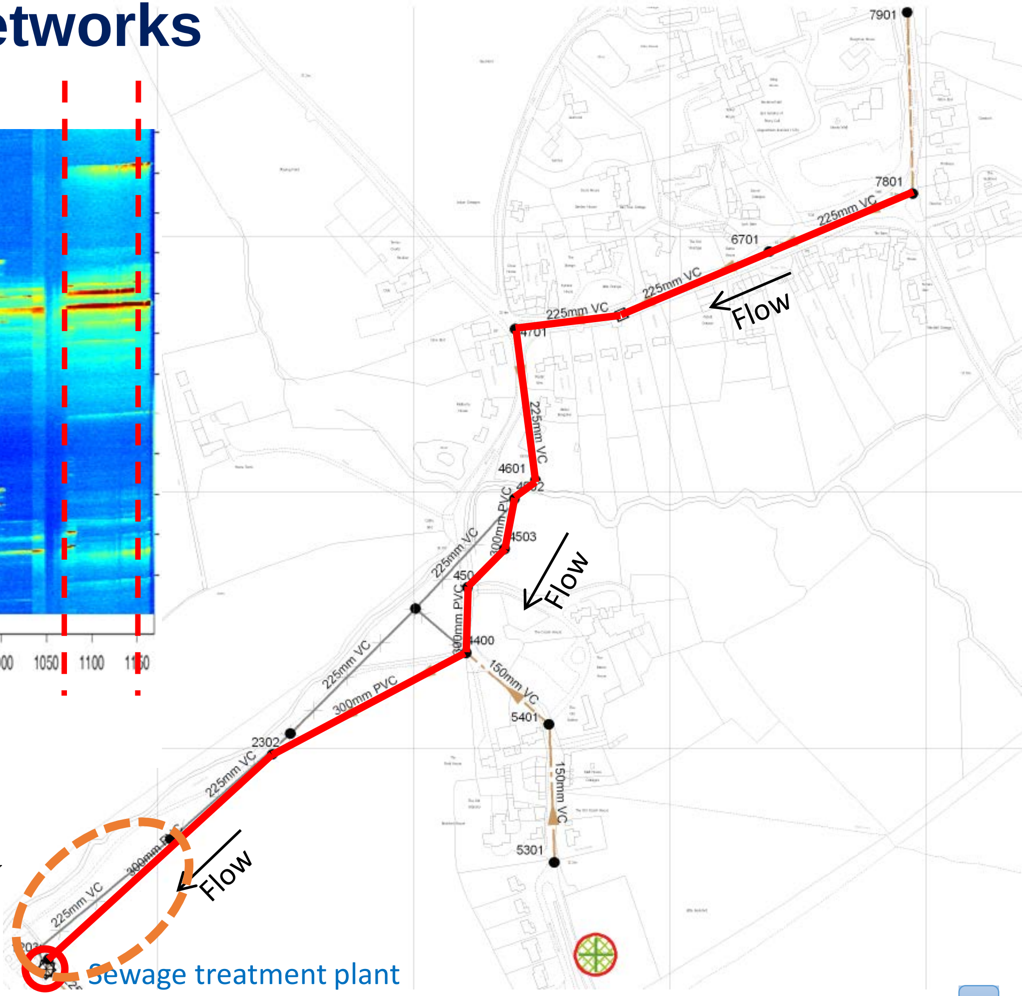
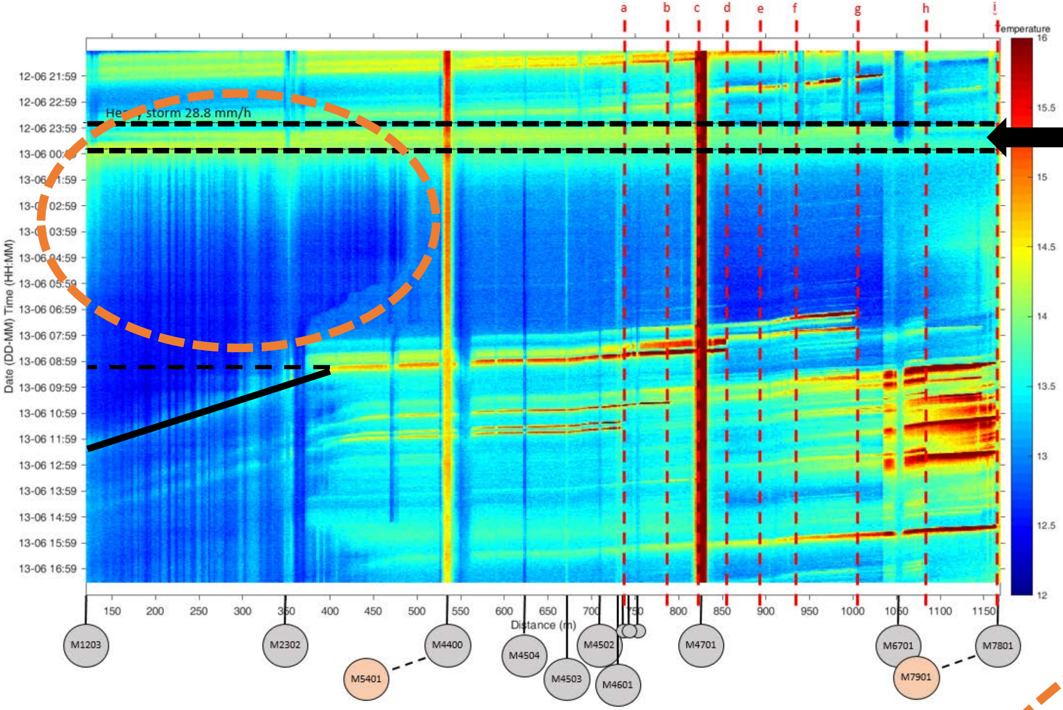
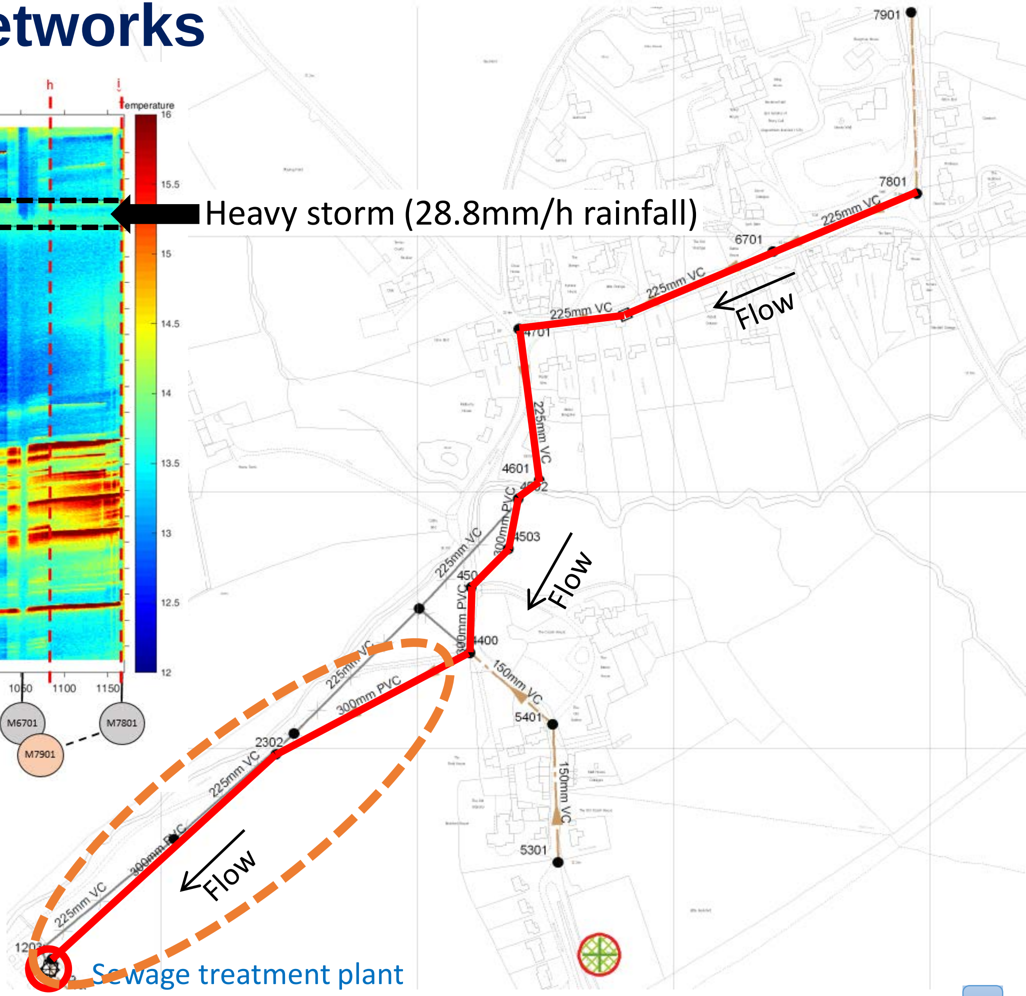




- Backup from treatment plant
- Slope of discharge line $= \frac{\text{distance}}{\text{time}} =$ flow velocity

Example application 2: **Sewer networks**





- Rapid rain water (warmer) infiltration throughout
- Backup from treatment plant over longer distance
- Large reduction in flow velocity at backup

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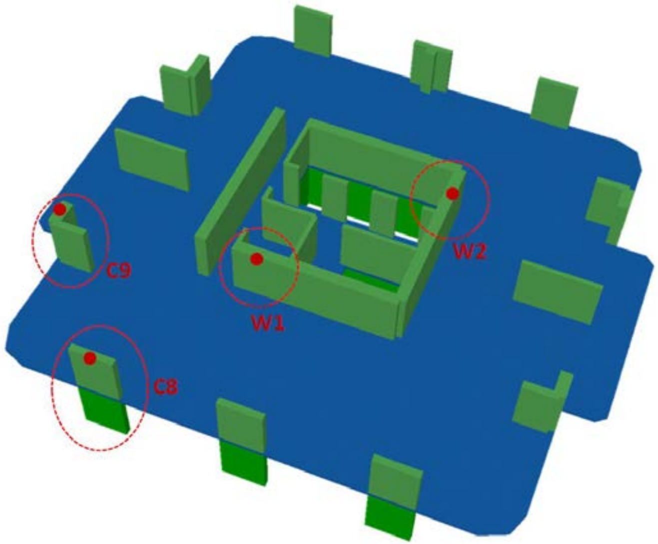
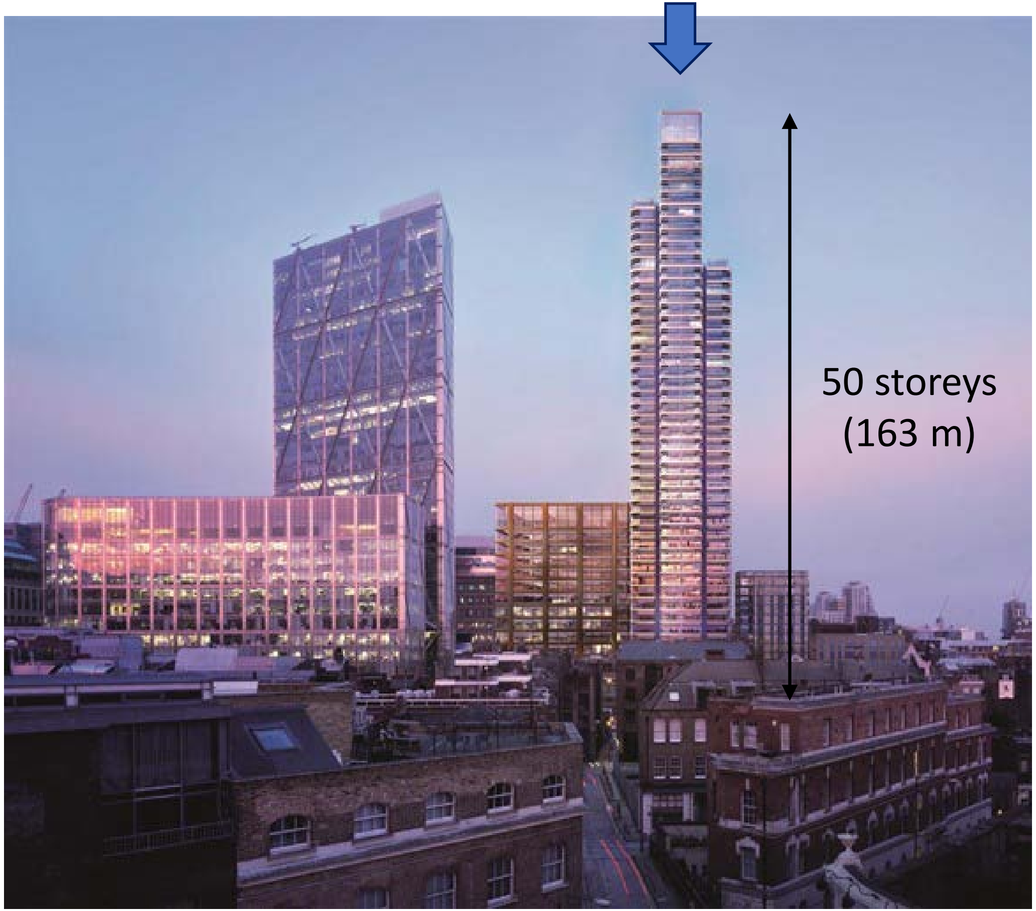
Example application 3: **High-rise building**

Monitoring of 2 RC columns and 2 RC walls over full height of the building

- To measure **progressive axial shortening** due to elastic & inelastic effects



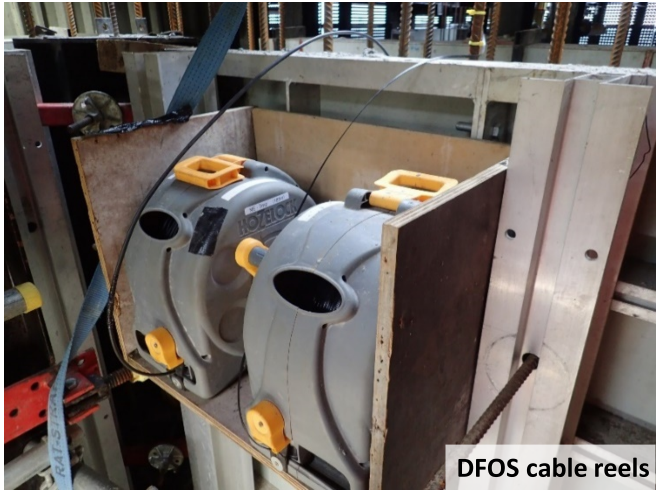


Example application 3: **High-rise building**

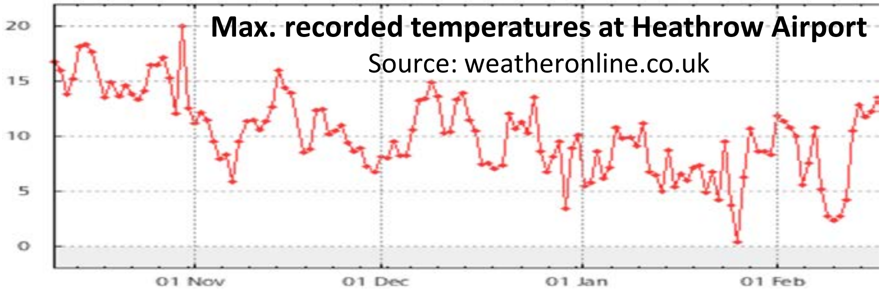
- Tower constructed using **automated jumpform**
- DFOS cables installed by contractor as tower is constructed
- Continuous measurement (every 30 min.) of **strain and temperature profile** throughout construction (est. 17 months)


Image courtesy of Multiplex

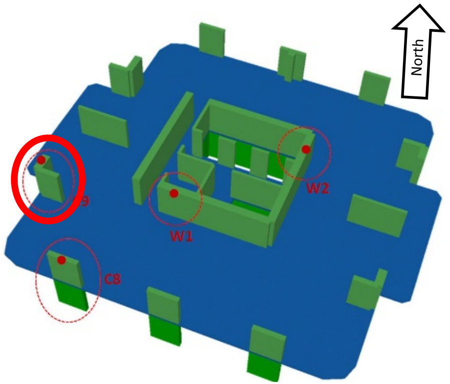

DFOS cables installed in column

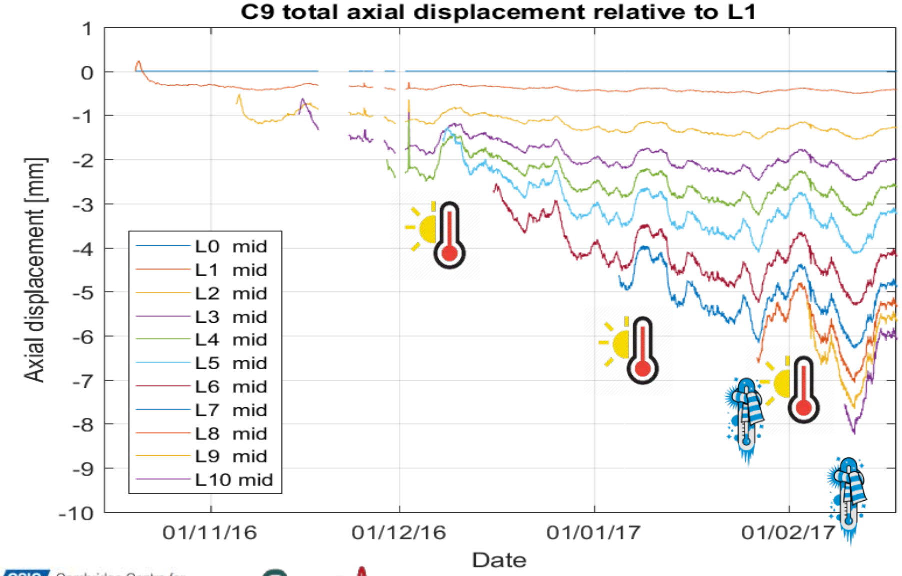

DFOS cable reels

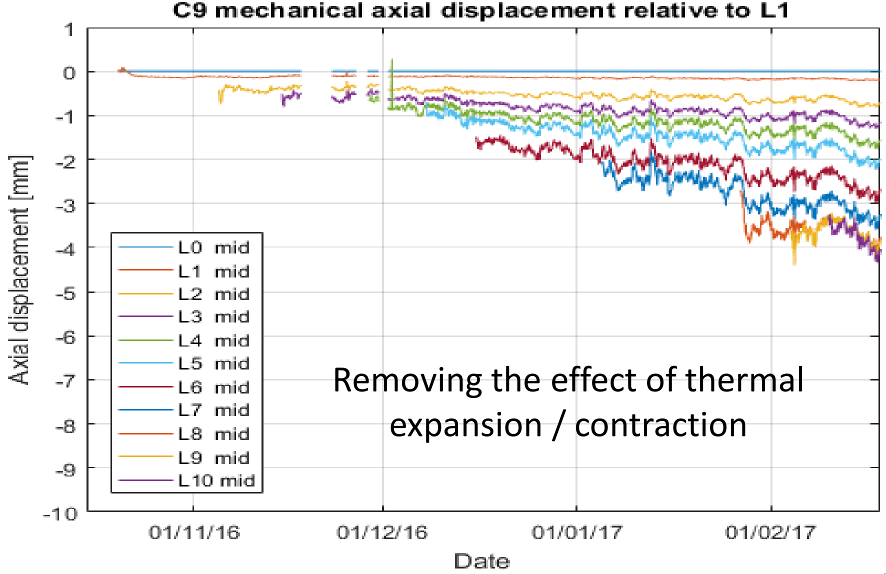
Example application 3: **High-rise building**



Axial shortening of Column C9



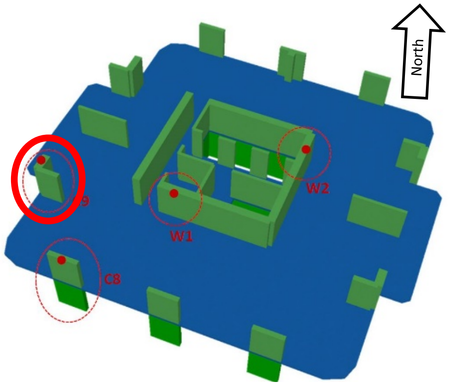


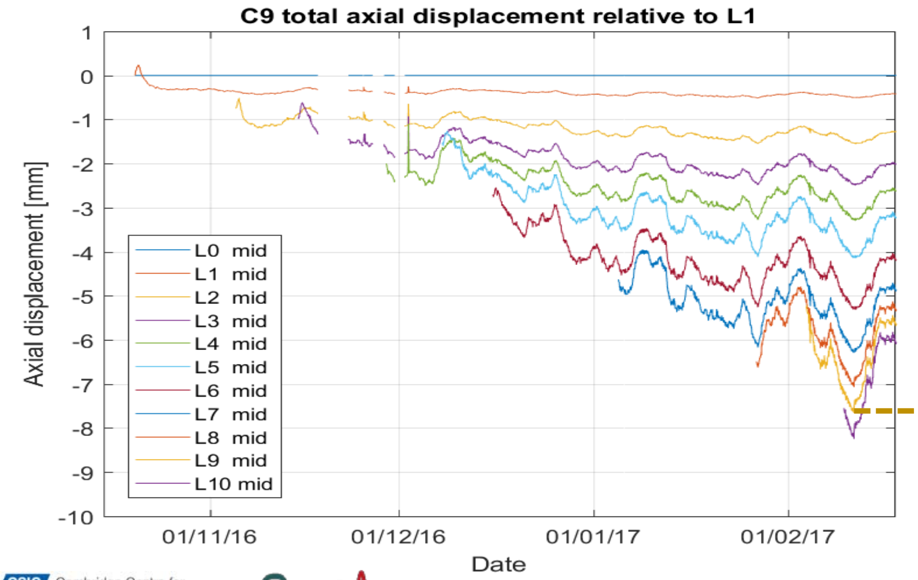


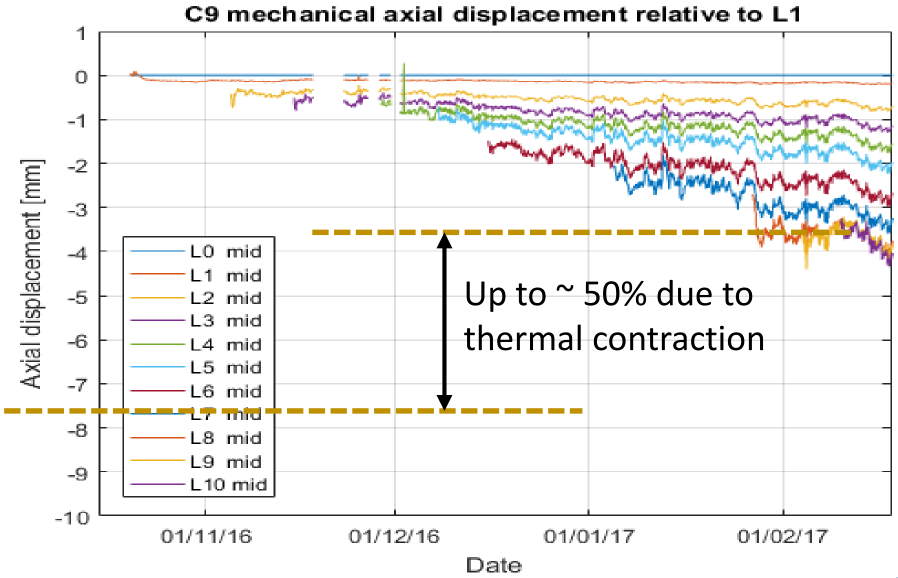
Example application 3: **High-rise building**

- Significant effect from thermal movement

Axial shortening of Column C9



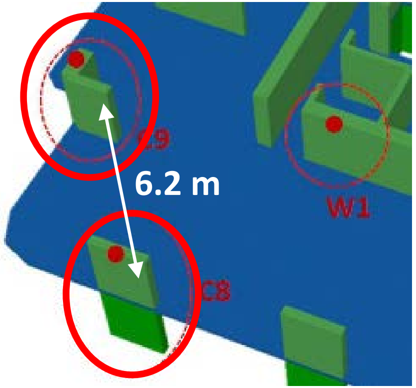


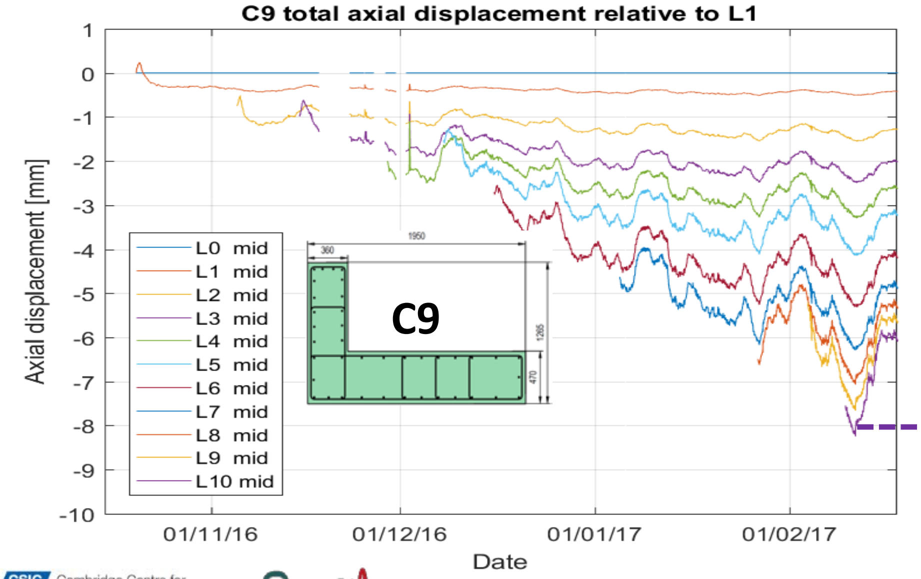


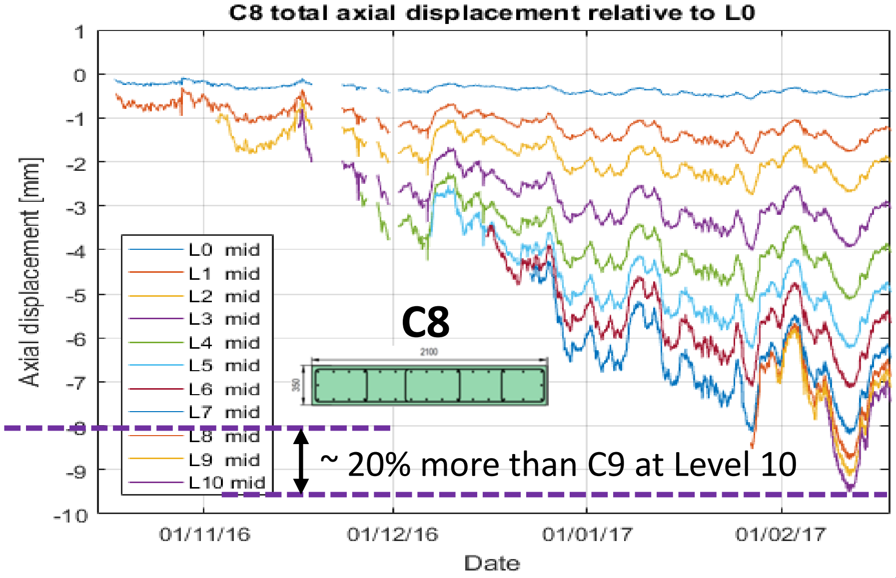
Example application 3: **High-rise building**

- Significant effect from thermal movement
- Differential shortening (different column sizes)

Axial shortening of Column C9 vs C8







Performance and cost effectiveness

Readout unit / analyser property	Distributed fibre optic sensors	Vibrating wire strain gauge
MEASUREMENT PERFORMANCE		
Strain repeatability	± 10 με to ± 30 με *	± 1 με
Strain range	Up to ± 10000 με	Up to ± 3000 με
Temperature repeatability	± 0.1°C to ± 2°C *	N/A
Maximum measurement rate	One measurement every 3 min.	Several measurements per second
SPATIAL PERFORMANCE		
Distance measurement range	> 70 km on a single continuous cable	Single point
Minimum sampling interval	One measurement every 5 cm	Single point
TYPICAL COST		
Cost of sensor / FO cable	£ 5 to £ 20 per meter **	£ x0 to £ x00 each
Cost of data logger / analyser	£ 80,000 to £ 160,000 ***	£ x,000

* Depends on the FO technology used
** Depends on robustness
*** Depends on functionality, distance range, etc.

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Equivalent to:
- up to 20 strain gauges per meter
- < £1 per strain gauge

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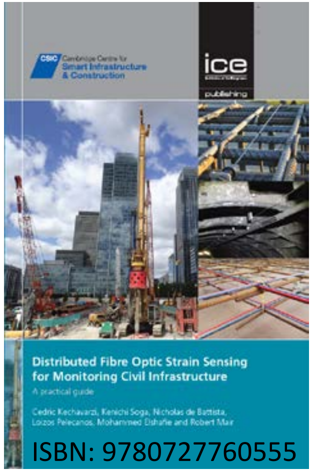
When is distributed fibre optic sensing useful?



- Important to ***choose the right instrumentation***

- Some examples when DFOS could be the ideal monitoring technology:
  - ✓ Need to monitor strain / temperature over **distance** (1D) or **area** (2D)
  - ✓ Looking to detect **events with unknown location** (future cracks, water infiltration, embedded anomalies,…)
  - ✓ Acceptable to sacrifice some measurement precision (± 10 με at best) to gain **spatial coverage**
  - ✓ Detecting changes in strain / temperature over a **period of time**
  - ✓ Require **non-electrical, intrinsically safe sensors** (e.g. in hazardous environments such as sewers, nuclear facilities,…)

How can DFOS provide added value to your monitoring applications?

UNIVERSITY OF CAMBRIDGE

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Epsimon INFRASTRUCTURE MONITORING

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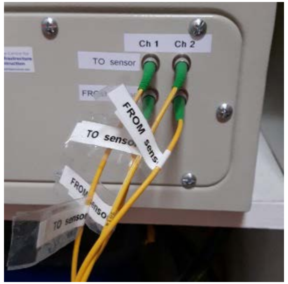

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