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CIVIL ENGINEERING

CASE STUDY – HEALTH MONITORING OF 6 BRIDGES

Dr Colin Caprani

Structural Health Monitoring Workshop Program

Vicroads

16 July 2018





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Background



LEVEL CROSSING REMOVAL

FRANKSTON SKYE-OVERTON RD LX

- From 2005-2015
 - 22 safety incidents
 - pedestrian fatality in 2010
 - Traffic delays across Frankston
- **60 days** train line possession



REPLACEMENT SOLUTION

U-TROUGH BRIDGE BEAMS

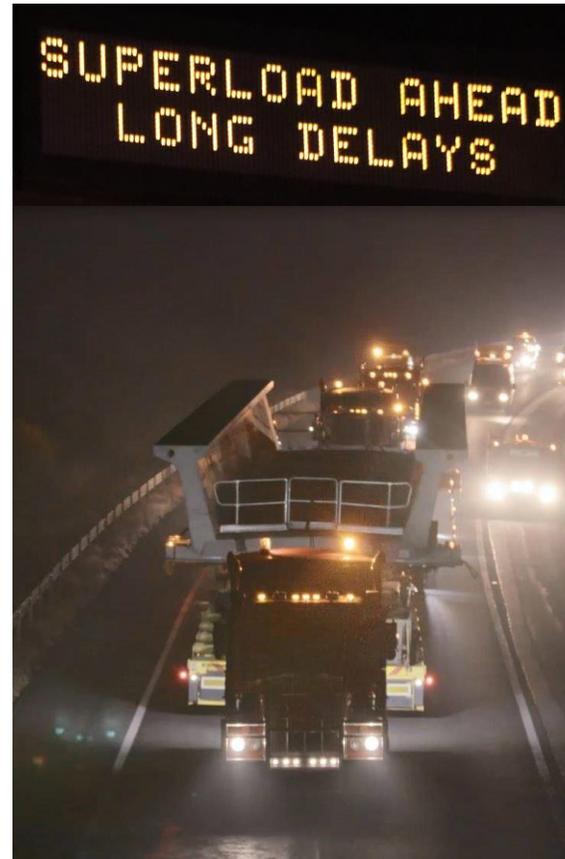
- Pre-cast bridge beams off site and transport
- 24 No. 31 m post-tensioned U-trough beams
 - 270 tonnes



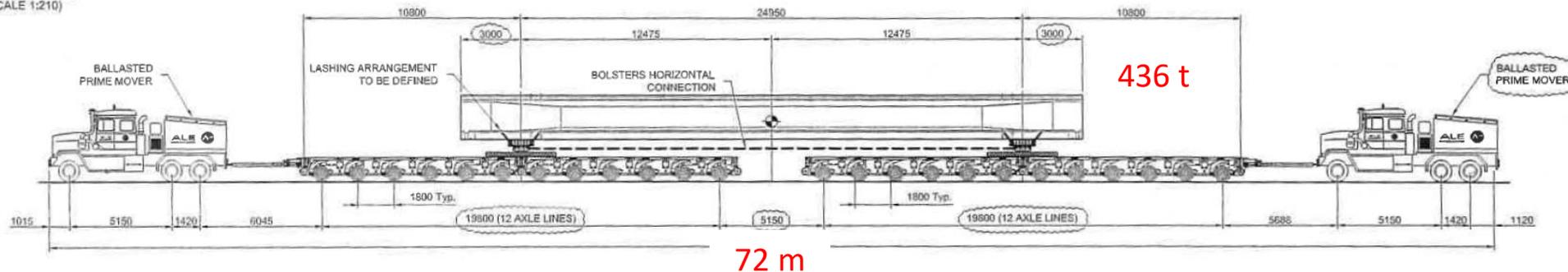
THE SUPERLOAD

WEIGHTS & DIMENSIONS

TRAILER SPECIFICATION		TRAILER SPECIFICATION	
1x2x12 - HTDRAULIC TRAILER (4200) - FRONT		1x2x12 - GOLDHOFER THP-SL (4200) - REAR	
all weights in t (metric tonnes)	Total	all weights in t (metric tonnes)	Total
NUMBER OF AXLE LINES	12	NUMBER OF AXLE LINES	12
NUMBER OF FILES	2	NUMBER OF FILES	2
PAY LOAD	138.1	PAY LOAD	138.1
TRAILER WEIGHT	48.0	TRAILER WEIGHT	48.0
ENGINE WEIGHT	0.0	ENGINE WEIGHT	0.0
AUXILIARY STEEL WEIGHT	10.0	AUXILIARY STEEL WEIGHT	10.0
TOTAL LOAD	196.1	TOTAL LOAD	196.1
LOAD DETAILS		LOAD DETAILS	
LOAD PER AXLE LINE / TRAILER	16.34	LOAD PER AXLE LINE / TRAILER	16.34
LOAD PER SUSPENSION	8.17	LOAD PER SUSPENSION	8.17
HYDRAULIC PRESSURE (bar)	113	HYDRAULIC PRESSURE (bar)	113
GROUND BEARING PRESSURE (t/m ²)	3	GROUND BEARING PRESSURE (t/m ²)	3



ELEVATION VIEW
(SCALE 1:210)



MONITORING

Timeline

- 14 March – first mention
- 28 March – first meeting
- 29 March – go ahead
- 30 March – 3 April – Easter
- 9 April – Planned first move
- 6-17 April – Installation (round the clock)
- 18-19 April – Baseline readings
- 20 April – Movement #1
- 28 May – Movement #20



MONITORING

REQUIREMENTS

- VERY tight timeline
 - No lead-time for new equipment
- Deflections required
 - Up to 12 points per structure
 - 10 Hz sampling rate
- Traffic under/over to be unobstructed
 - For 6 week duration of the movements
- Site challenges:
 - Potential for vandalism
 - No power
 - Difficult/unsafe access
 - Wide geographic area

Note: The solutions adopted reflect these criteria and so may not be the optimum solution in other situations.



THE BRIDGES

LOCATIONS

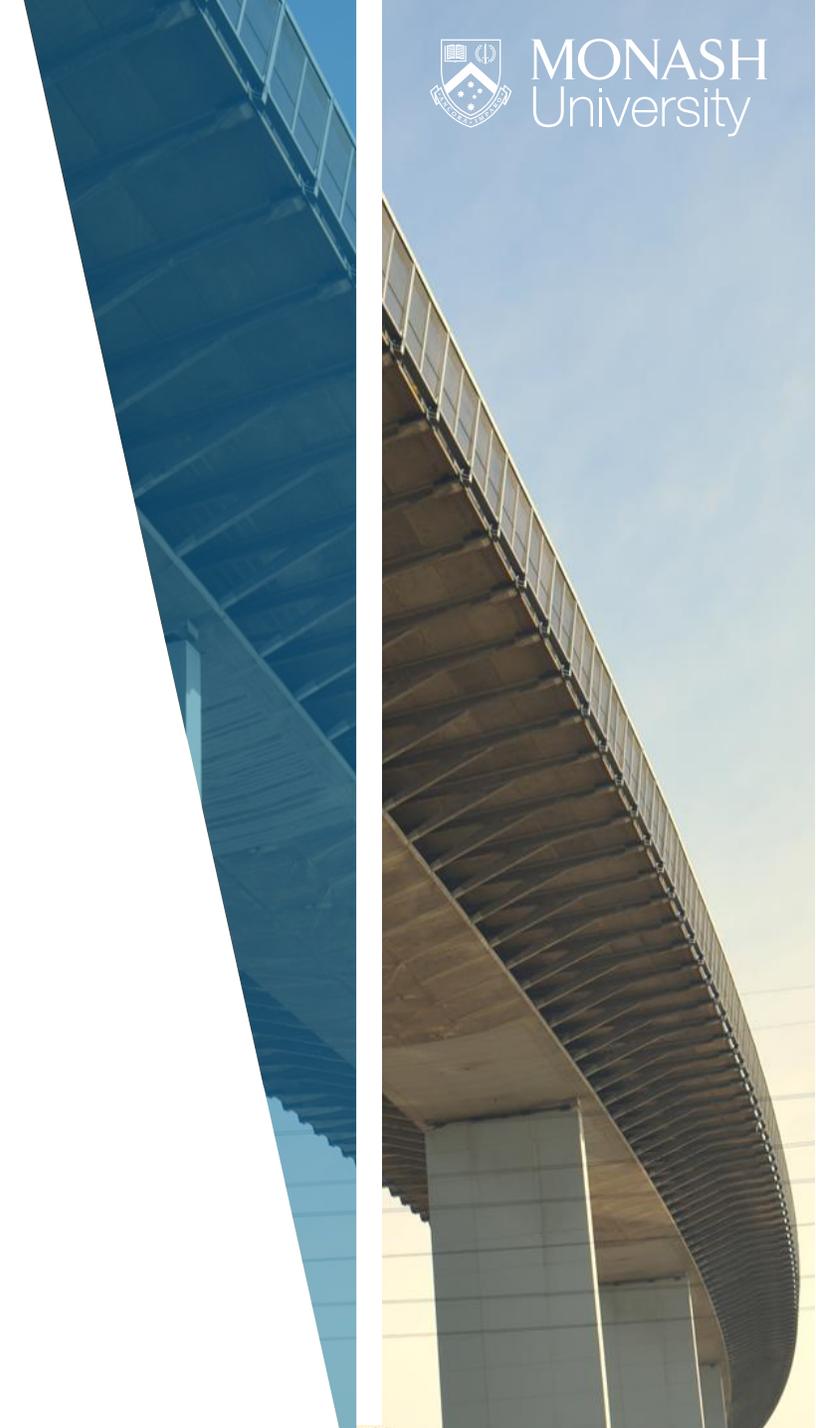


Kilmore
Arch

Kilmore-Epping
(Findon Creek)

Kempston

Banksia
Middleborough





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Kilmore Bridge



KILMORE BRIDGE

ARRANGEMENT

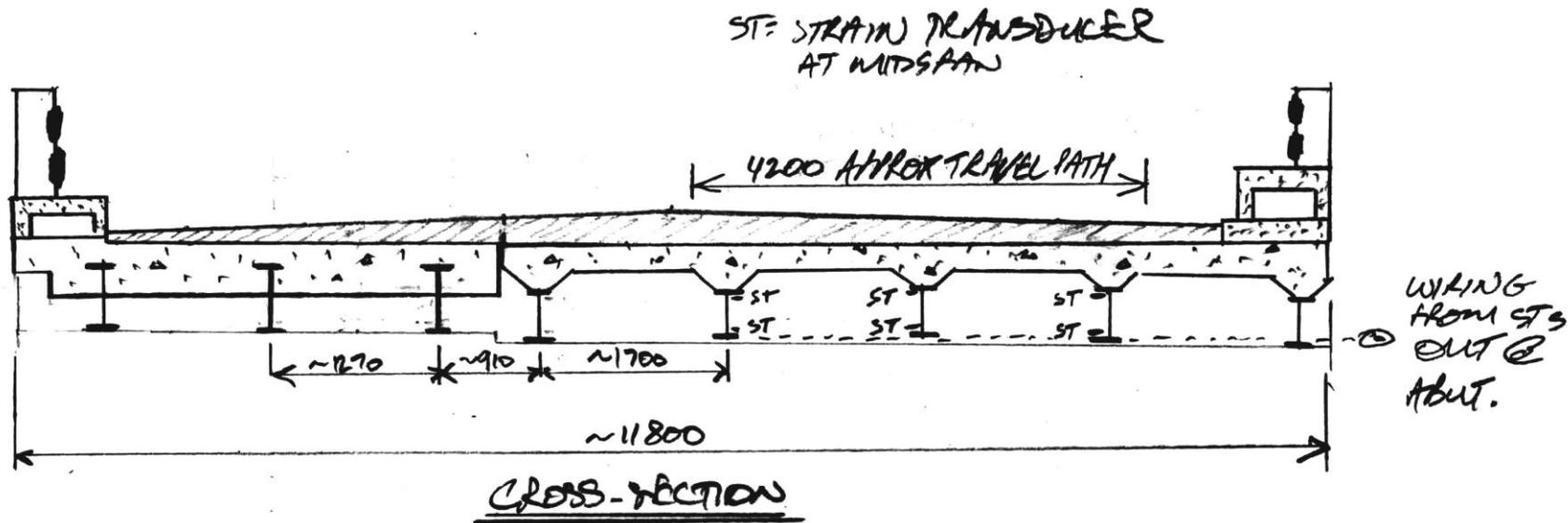
- Widened bridge
- Widening 1930s RSJ-Concrete composite



KILMORE BRIDGE

MONITORING CONCEPT

- Load was initially to straddle joint but agreed to centre on 'new' bridge
 - Off-centre running of load vital to achieve with TSS

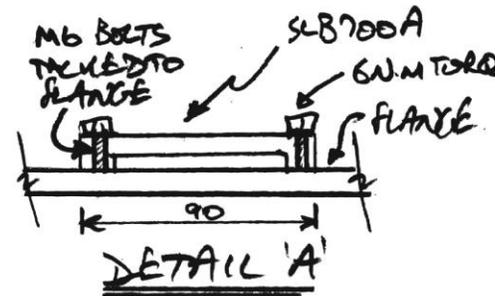
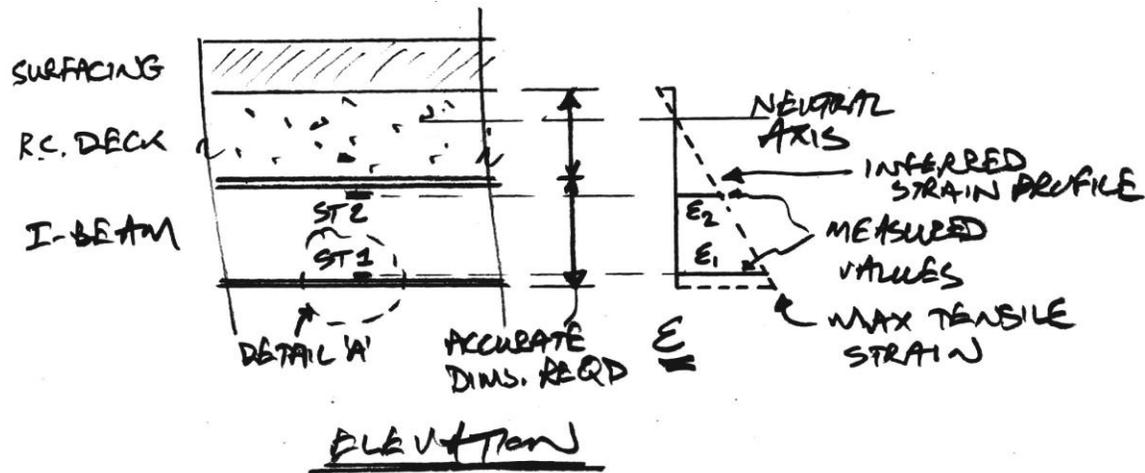


MONITORING

CONCEPT

- Monitoring concept
 - Measure strains to determine mid-span curvature
 - Deflection estimated as:

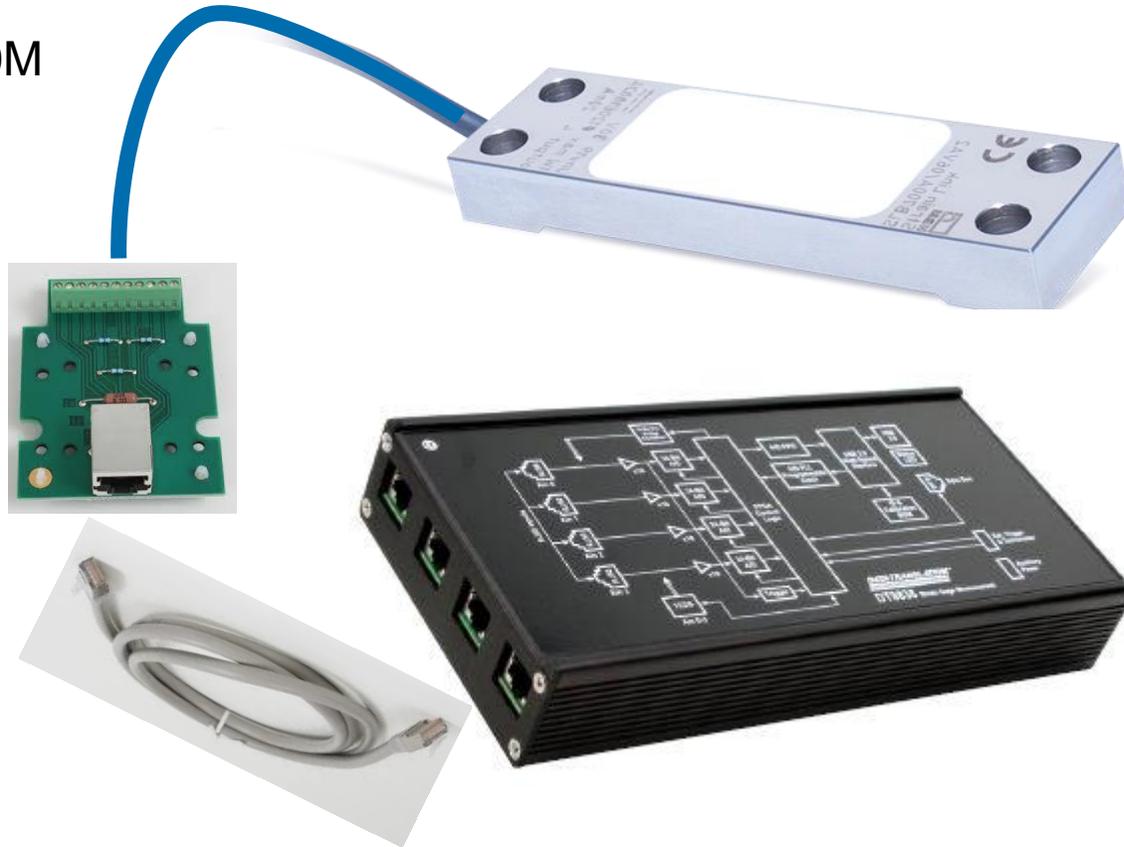
$$K = \frac{\epsilon_{\text{Top}} - \epsilon_{\text{Btm}}}{d_{sg}} \quad \delta_c = \frac{10L^2}{96} K_c$$



MONITORING

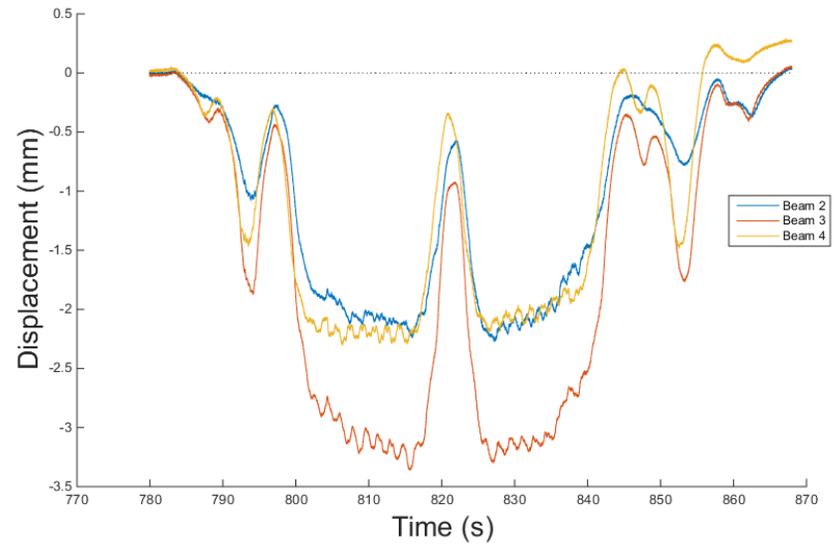
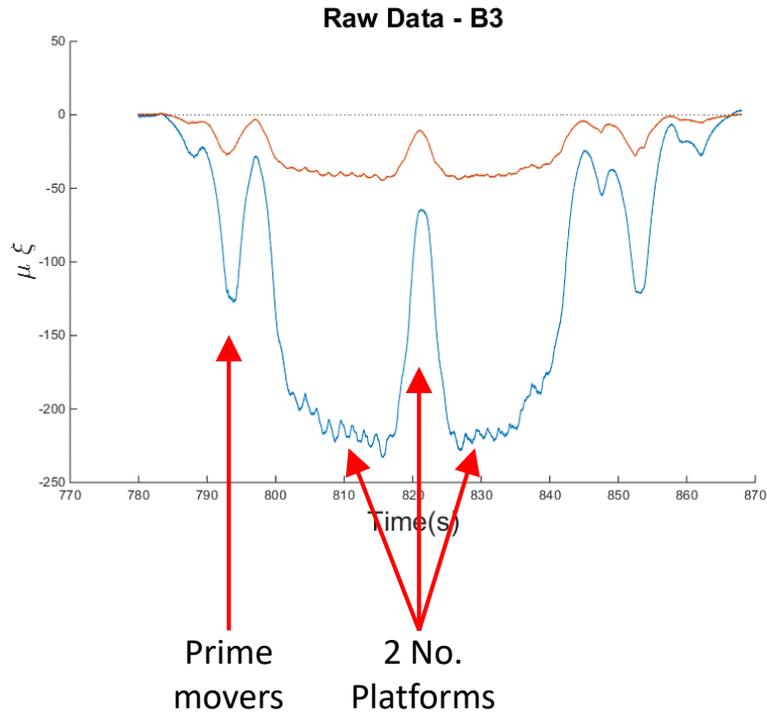
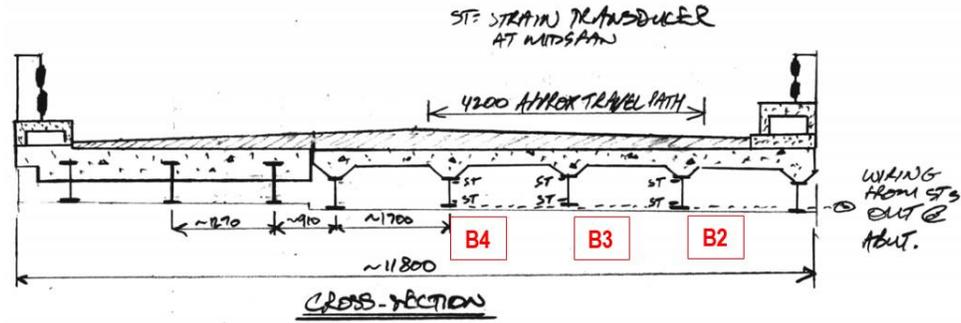
EQUIPMENT

- Strain Transducers
 - 5 No. HBM SLB700A
 - 1 No. Monash CP1990M
- Wiring
 - 72 m 6-core
- DAQ
 - 2 No. DT9838
- Software
 - QuickDAQ



MONITORING

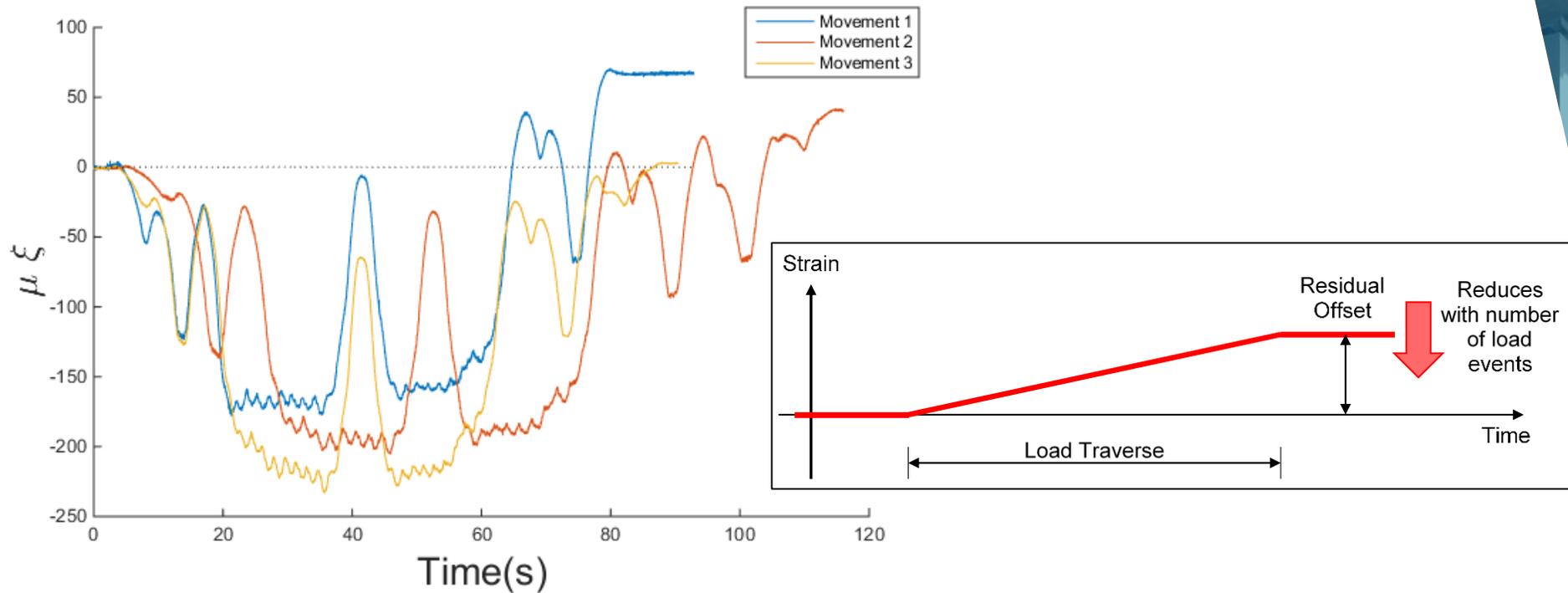
EXAMPLE RESULTS



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ISSUES

- Ratcheting of strain transducer connections
 - Artificial appearance of residual strain
 - Reduces with repeated loading



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Arch Bridge



NORTHERN HWY ARCH BRIDGE

ARRANGEMENT

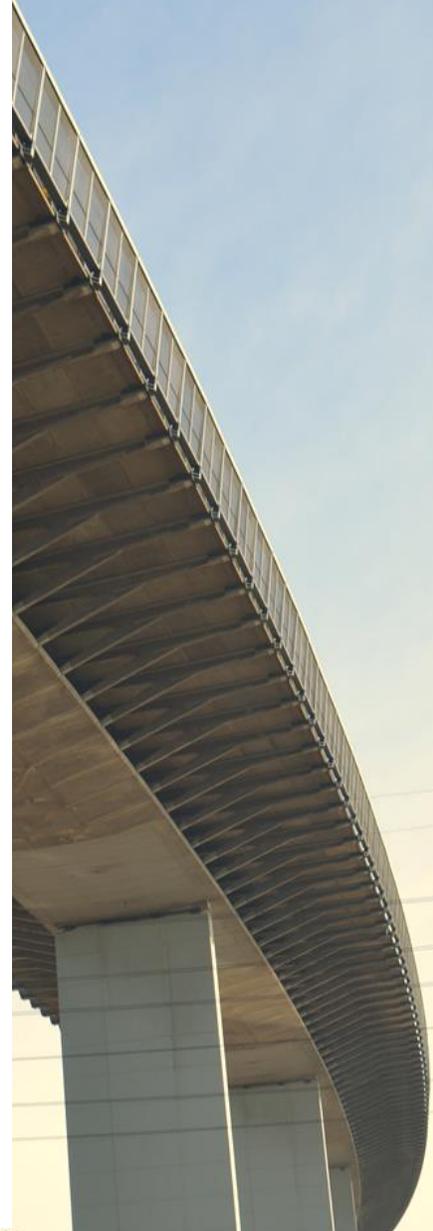
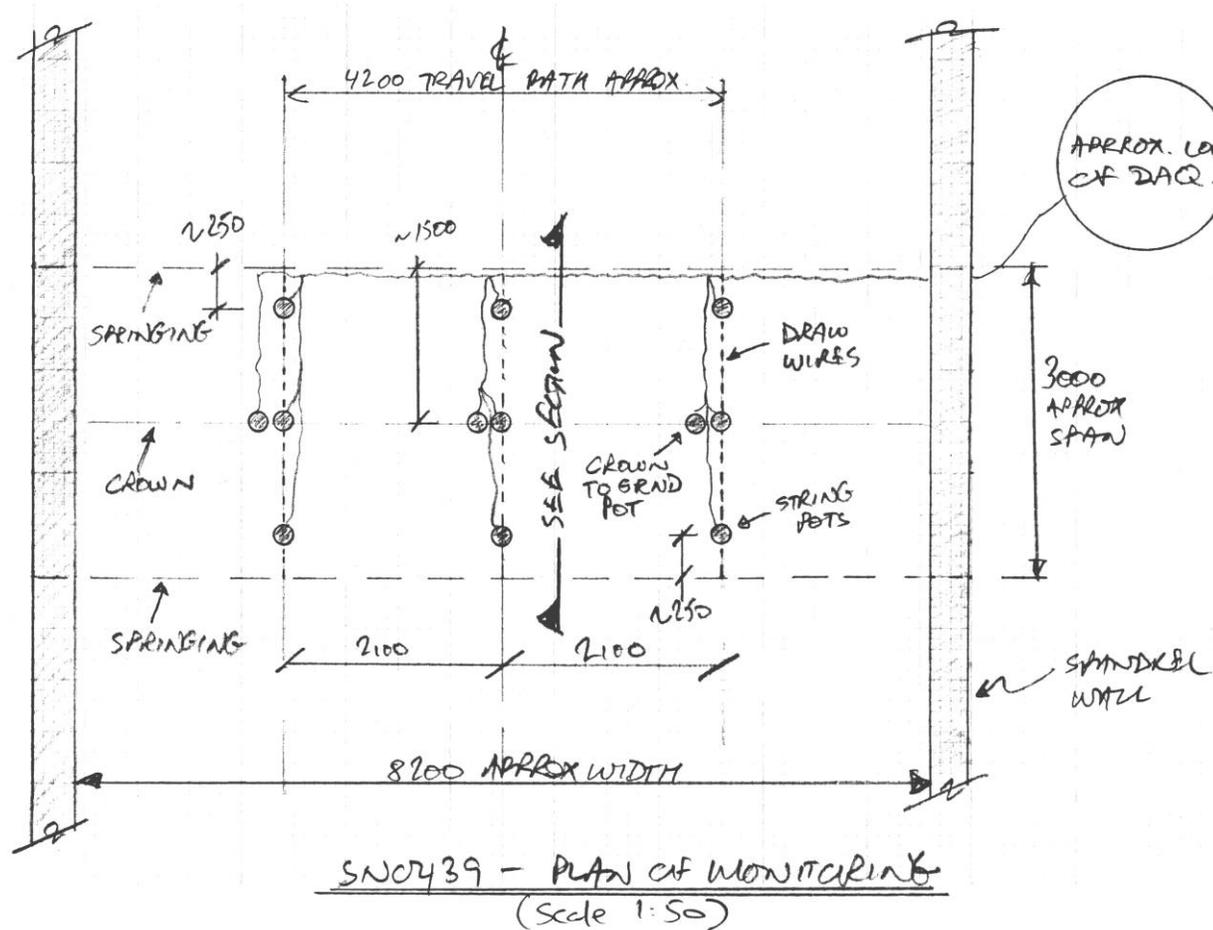
- Bluestone granite arch
- Heritage structure
- No exterior damage



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CONCEPT

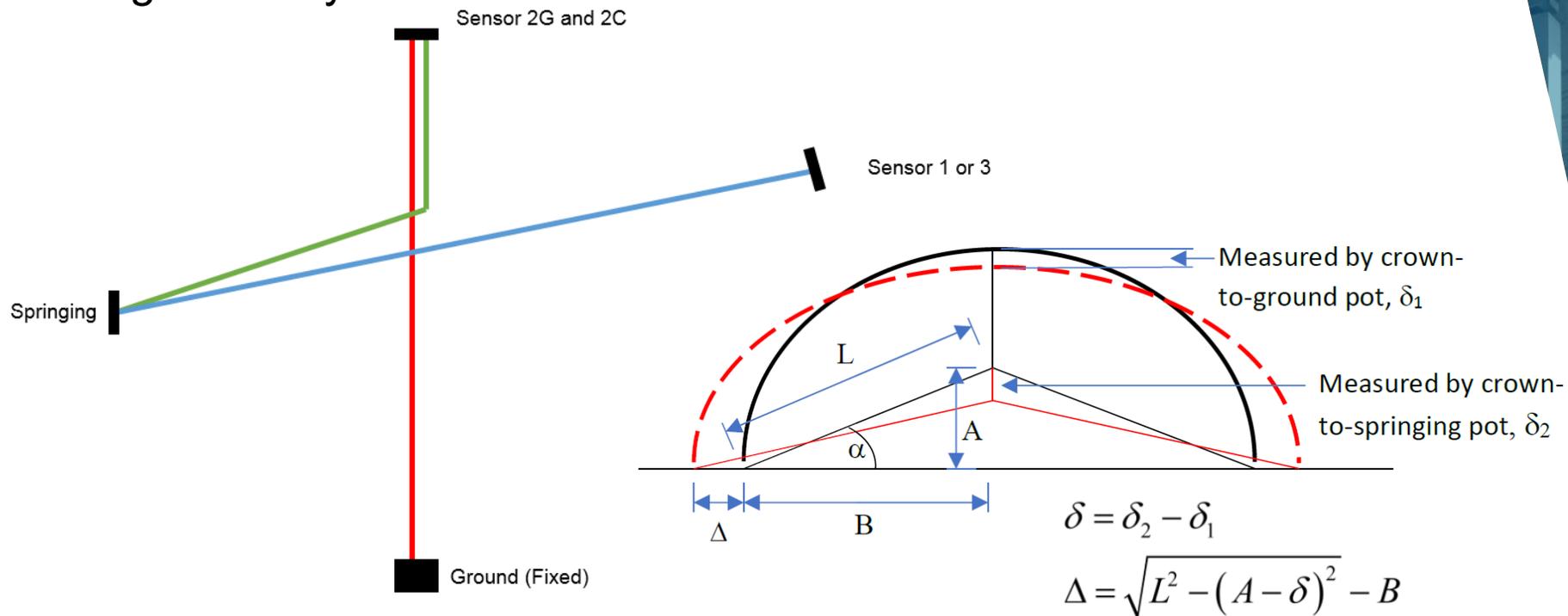
- Spandrel walls
 - Post-move surveying
- Barrel shape
 - Real time deformations



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CONCEPT

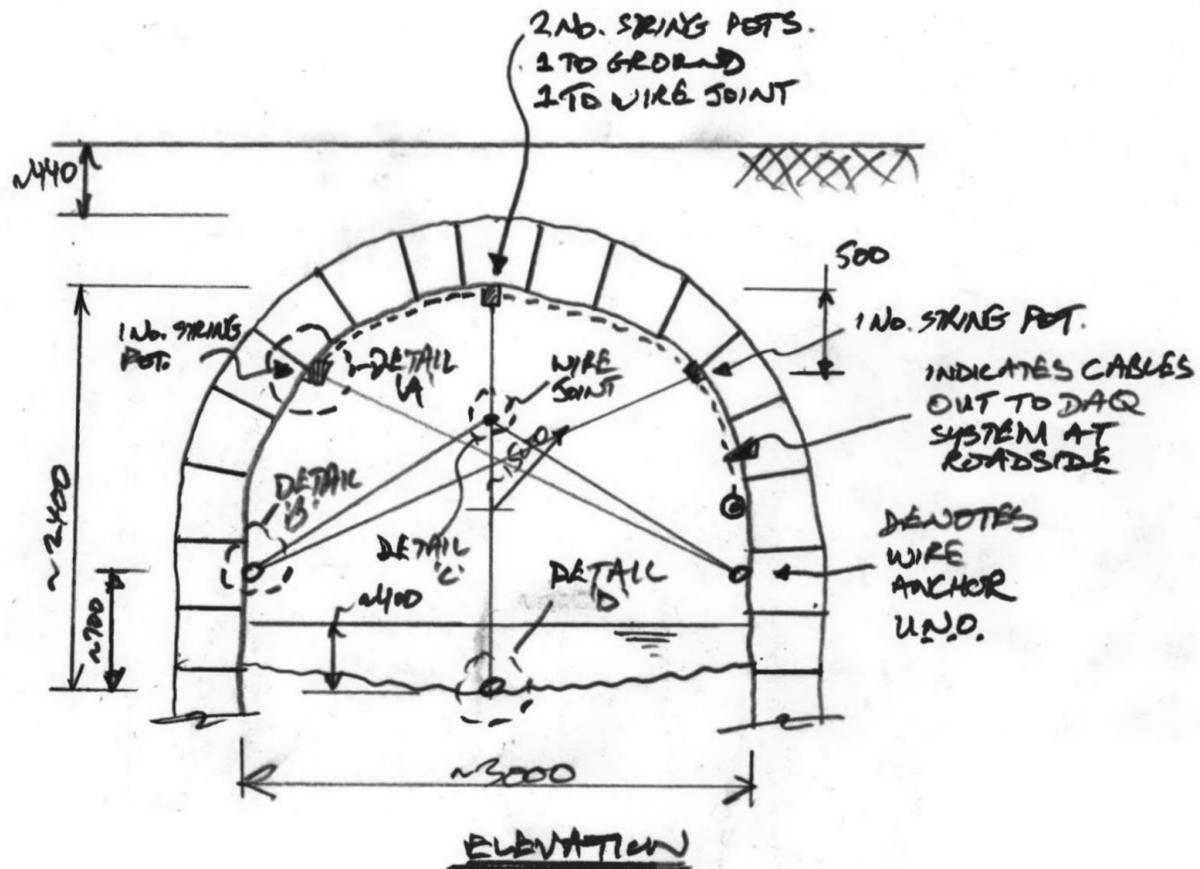
- Considerations:
 - Flooding – keep sensors high
 - Only 12 sensors
- Use trigonometry...



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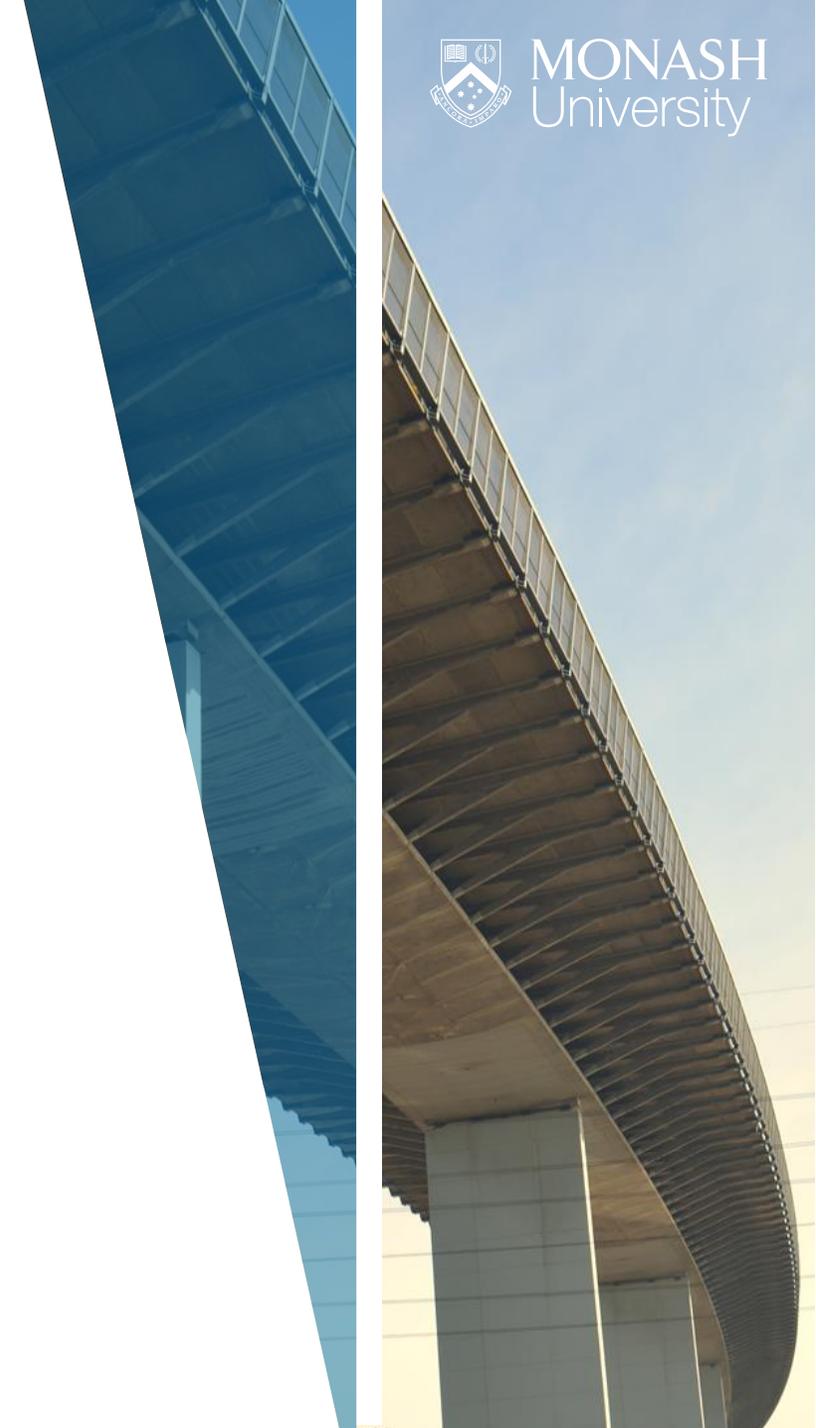
ARRANGEMENT

- 4 string pots at each plane:



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ARRANGEMENT



MONITORING

EQUIPMENT

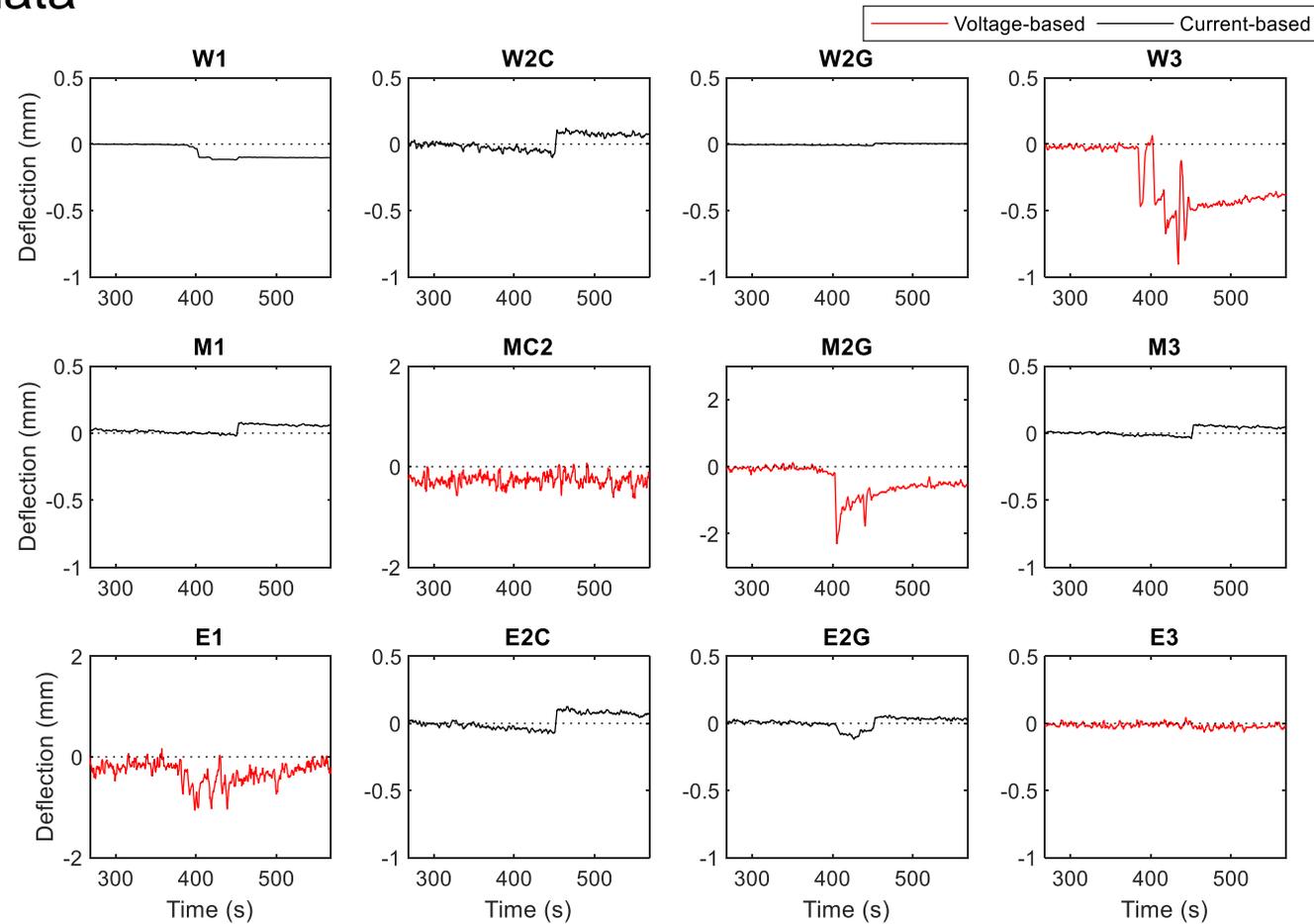
- String pots
 - 7 No. Micro-epsilon WDS-X-P60-SR (Current)
 - 5 No. Micro-epsilon WDS-X-P60-CR (Voltage)
- Wiring
 - 200 m 4-core
- DAQ
 - Datalogger DT85
- Signal conditioning
 - 24V DC power regulator
 - 240V AC line filter
- Software
 - deFriend



MONITORING

RESULTS

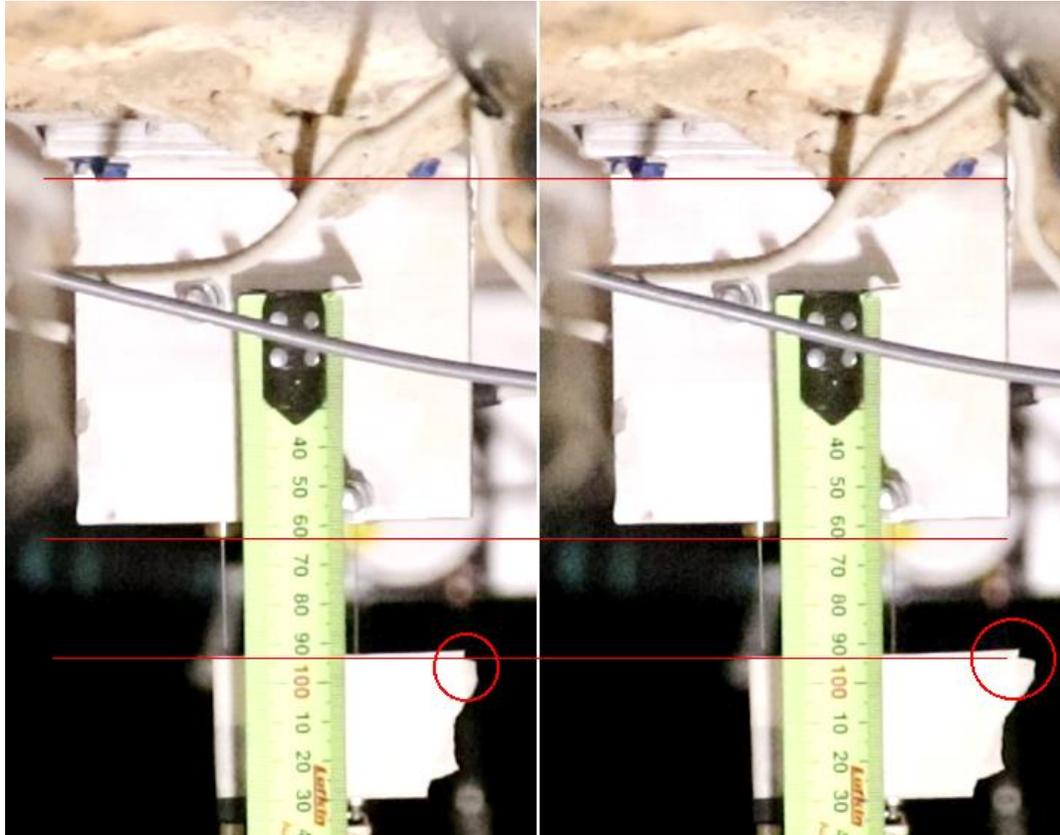
- Raw data



MONITORING

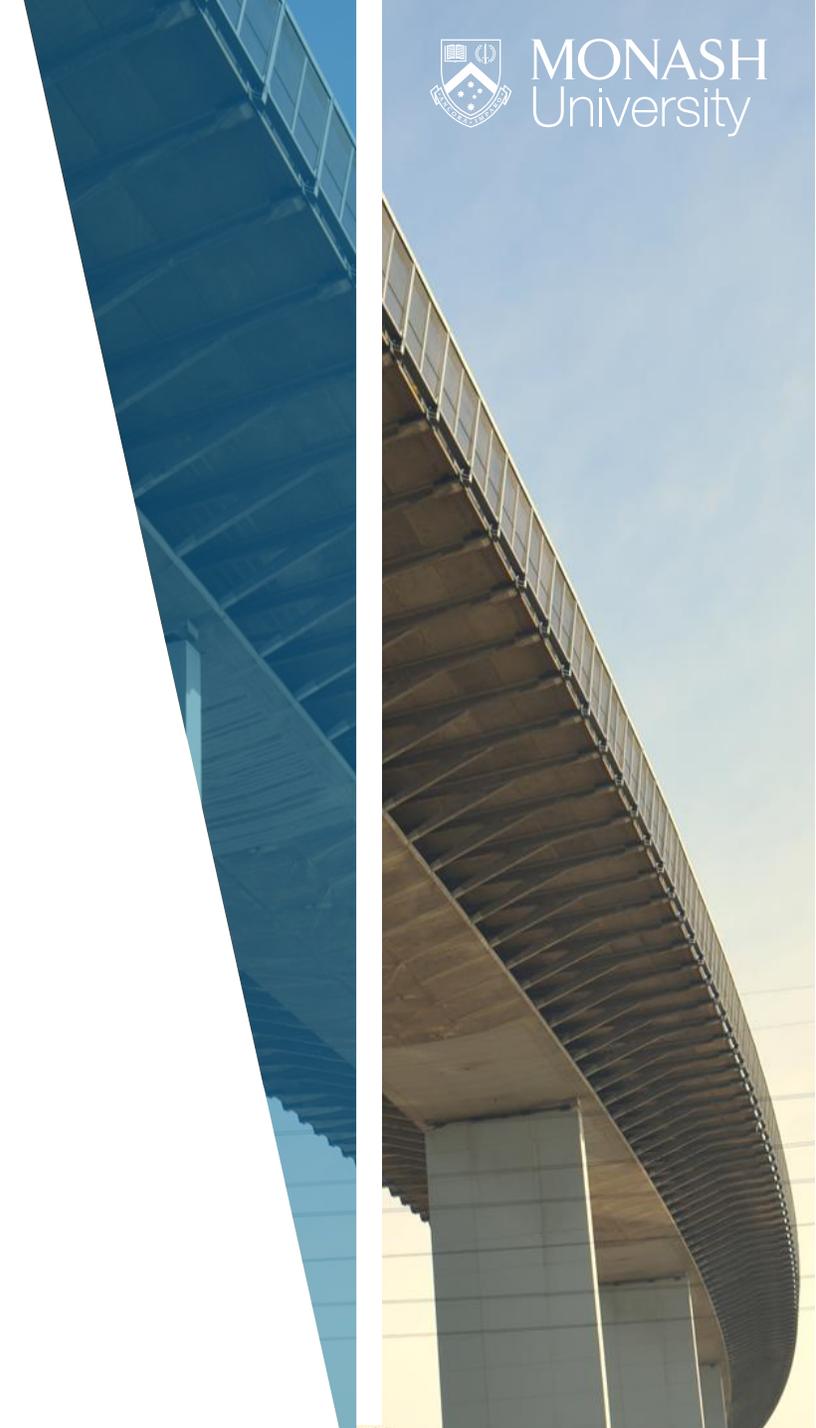
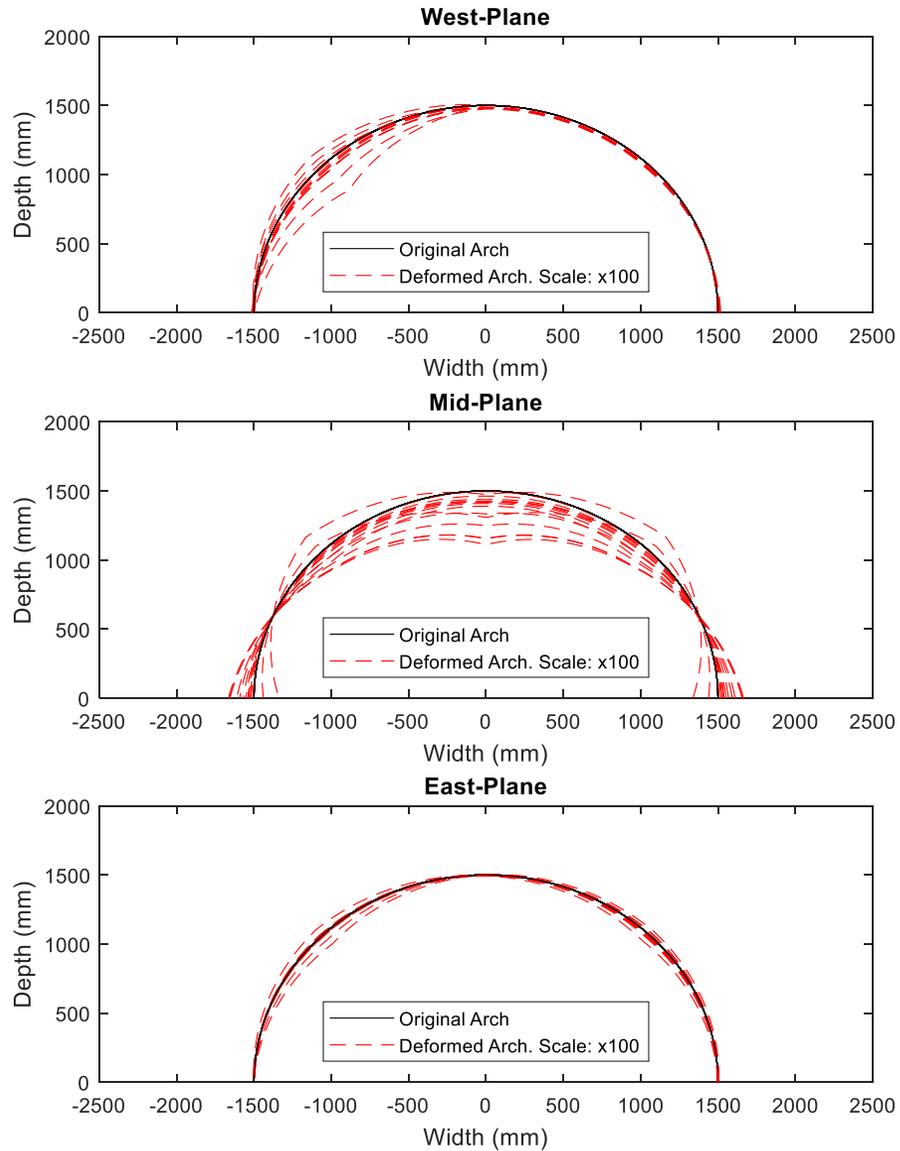
VALIDATION

- Sense-check using high resolution video & zoon lens



MONITORING

RESULTS



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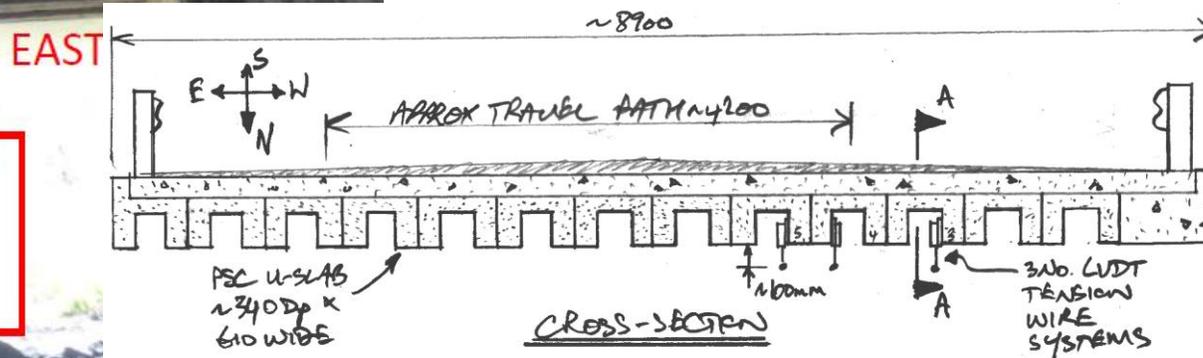
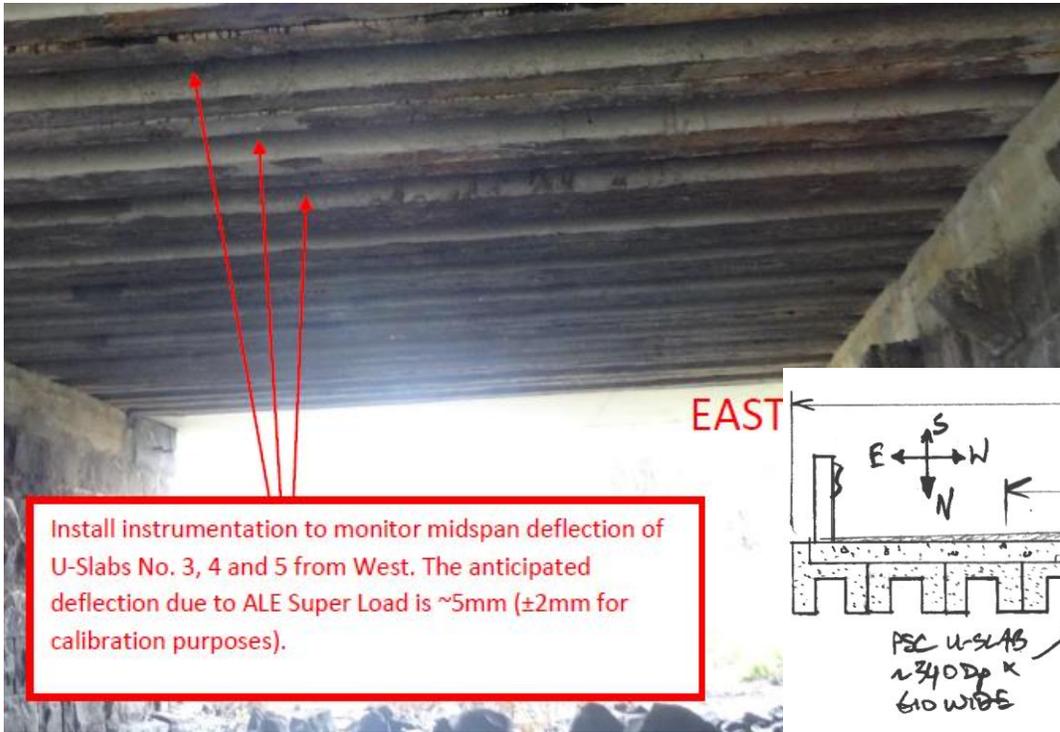
Findon Creek Bridge



FINDON CREEK BRIDGE

ARRANGEMENT

- No drawings
- Approx. 6 m u-slab span
- Unknown if there is a composite overlay slab



MONITORING

CONCEPT

- Platform ruled out on cost
- Tension wire system
 - Inspired by literature
 - LVDTs connected to beam measuring from wire benchmark tensioned between abutments
- More on this later



Available online at www.sciencedirect.com

SCIENCE @ DIRECT®

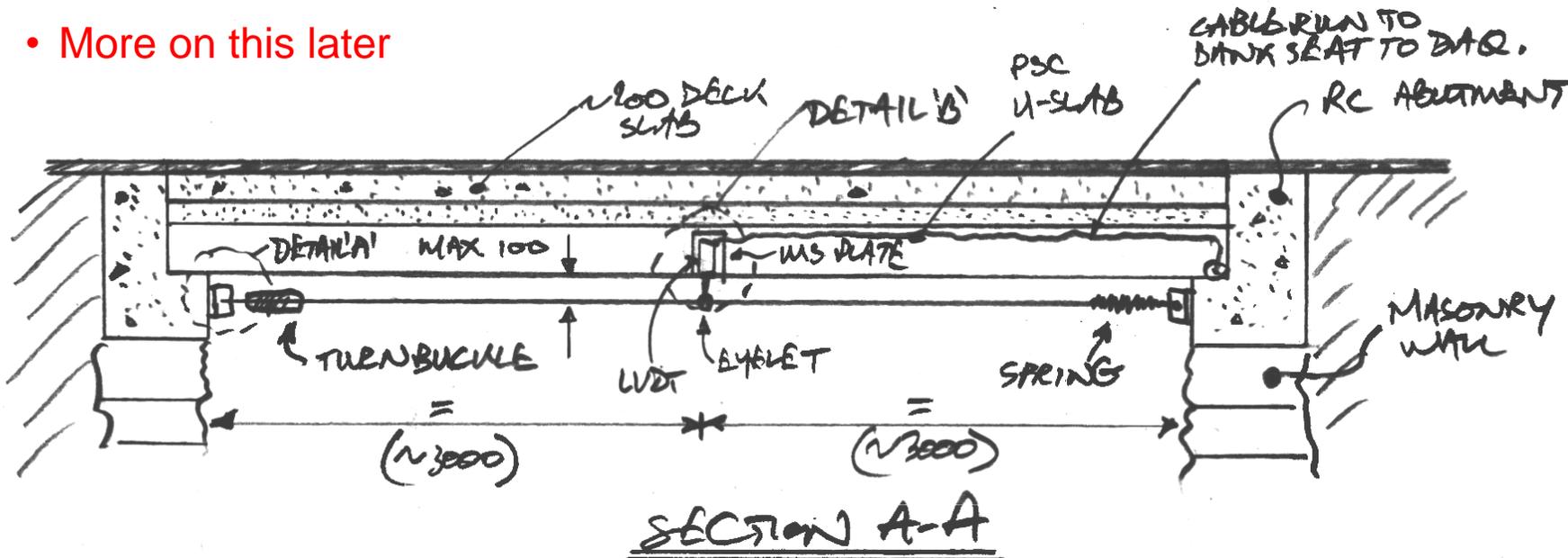
NDT&E International 38 (2005) 213-218

NDT&E
international

www.elsevier.com/locate/ndteint

Comparison of laser Doppler vibrometer with contact sensors
for monitoring bridge deflection and vibration

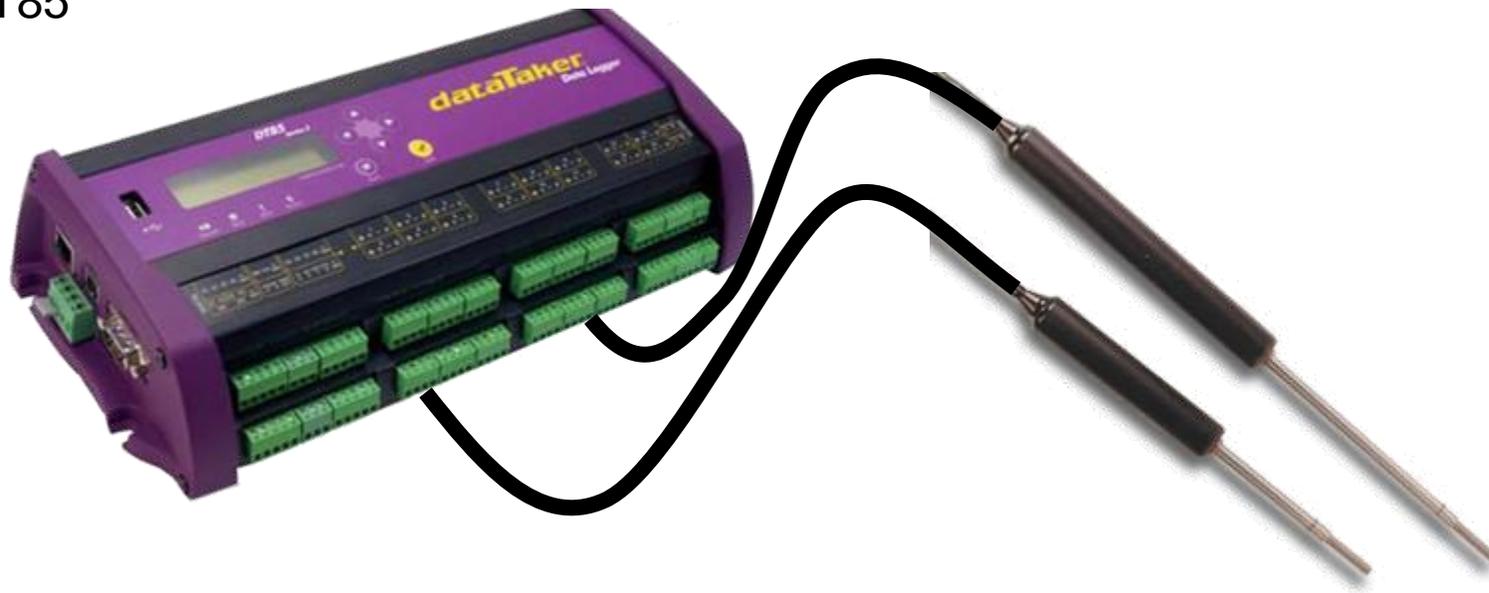
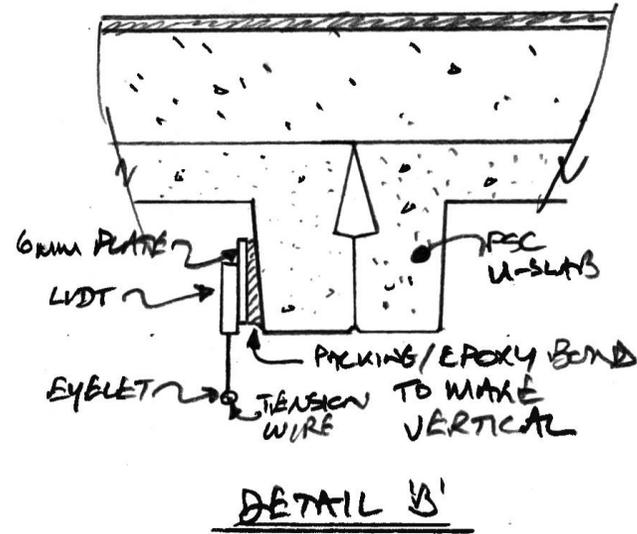
Hani H. Nassif^{a,*}, Mayrai Gindy^{b,1}, Joe Davis^{a,2}



MONITORING

EQUIPMENT

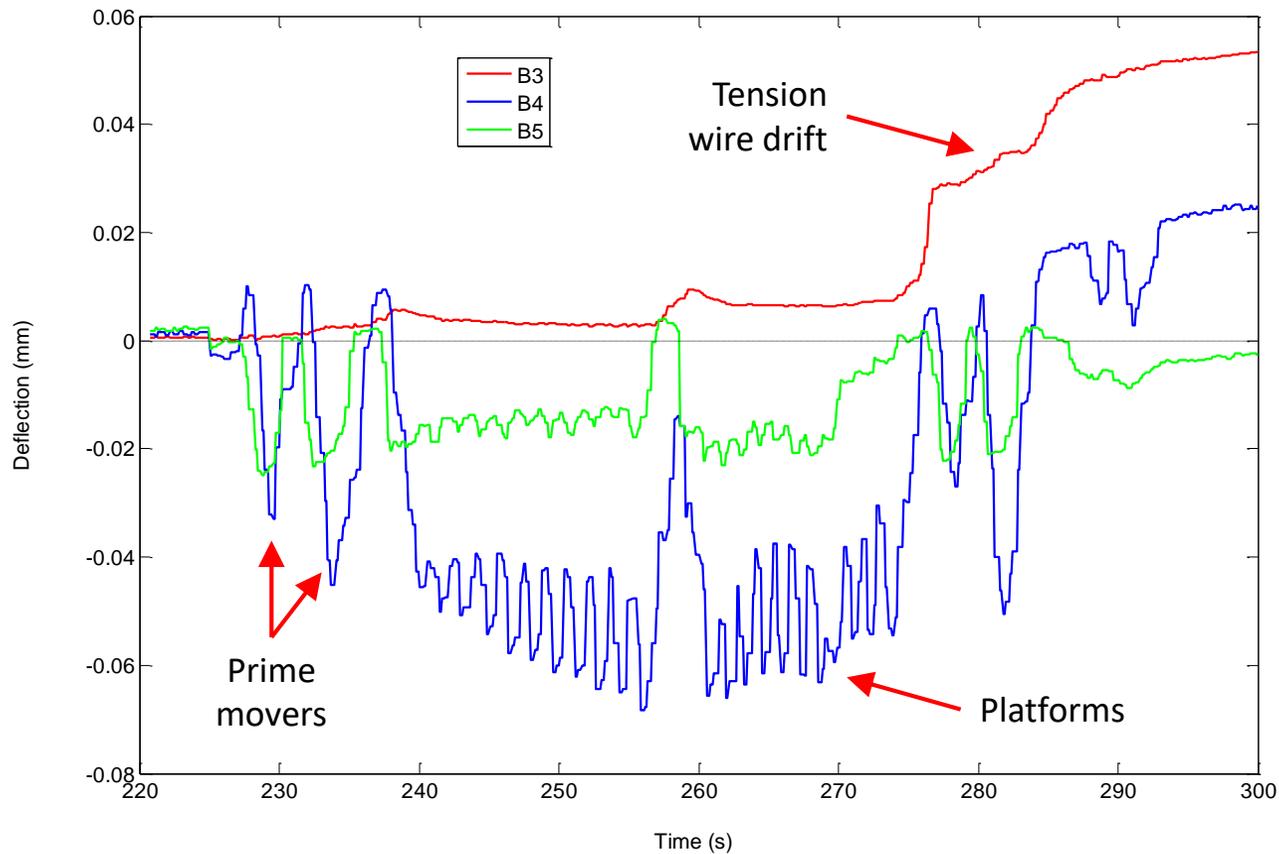
- Linear potentiometers
 - 3 No. 50 mm linear pots
- Wiring
 - 45 m 4-core
- DAQ
 - Datalogger DT85
- Software
 - deFriend



MONITORING

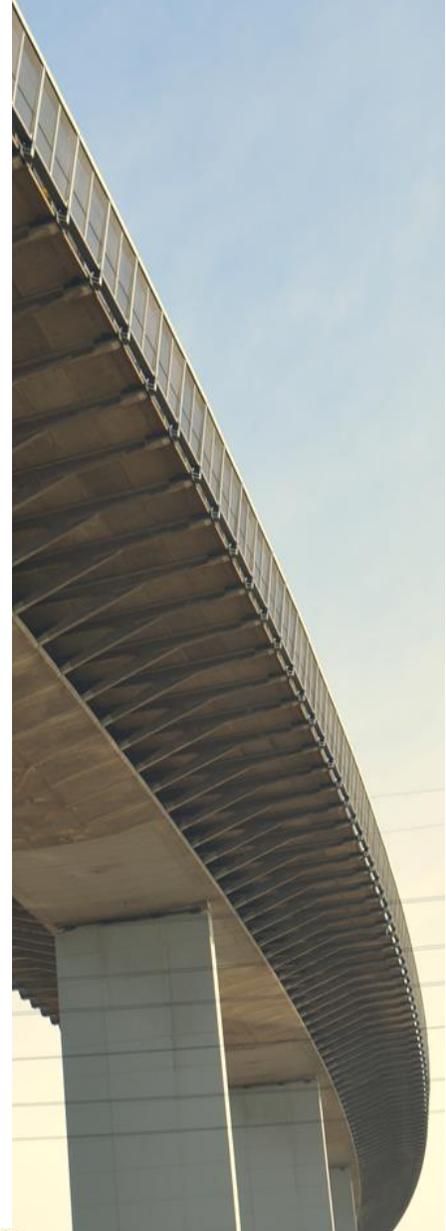
RESULTS

- Very small movements
- Subject to electrical noise
- Some drift



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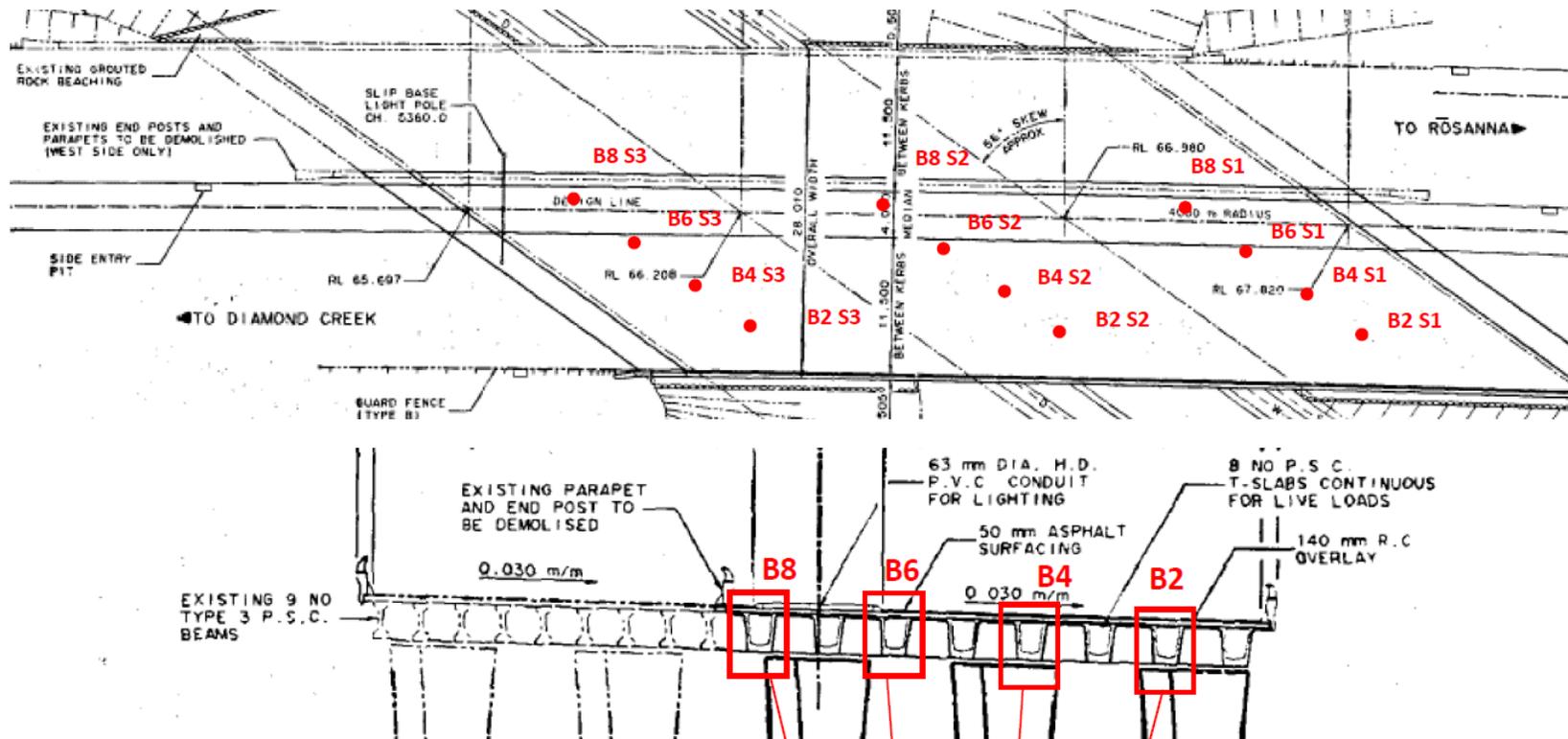
Kempston St Bridge



KEMPSTON ST BRIDGE

ARRANGEMENT

- 3-span ABC Super-T continuous
 - Contra-flow running on widened half of bridge
 - 23 – 27 – 25 m spans



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CONCEPT

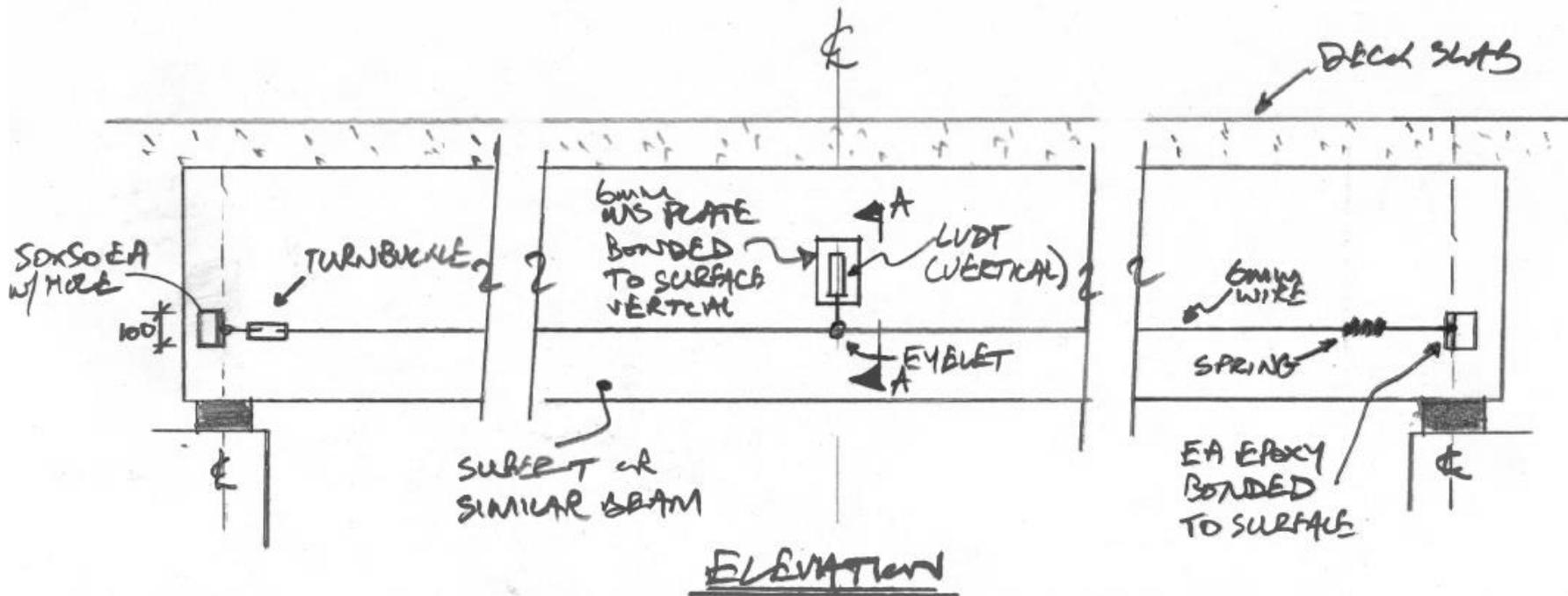
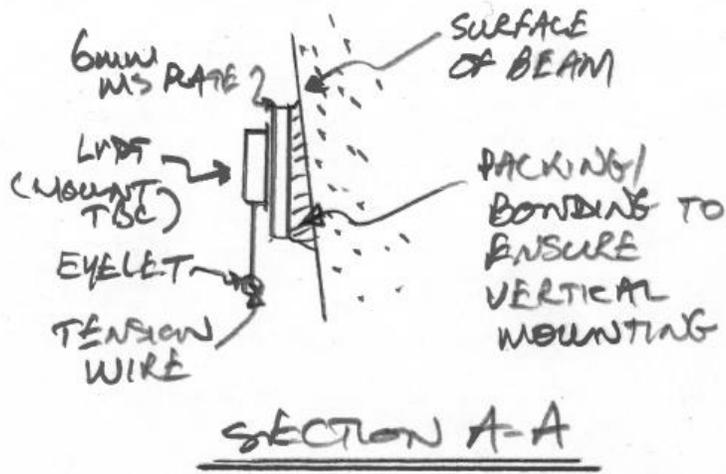
- Deflection measurement using tension-wire system
- Very long cable runs
 - Re-arranged on site
 - Listen to electricians!
- Original plan:



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CONCEPT

- Tension wire system
- Longer spans
 - Difficulty in obtaining sufficient tension
- Transducer applies about 7 N force at mid-span of cable
- Bracket required for sloping face of Super-T



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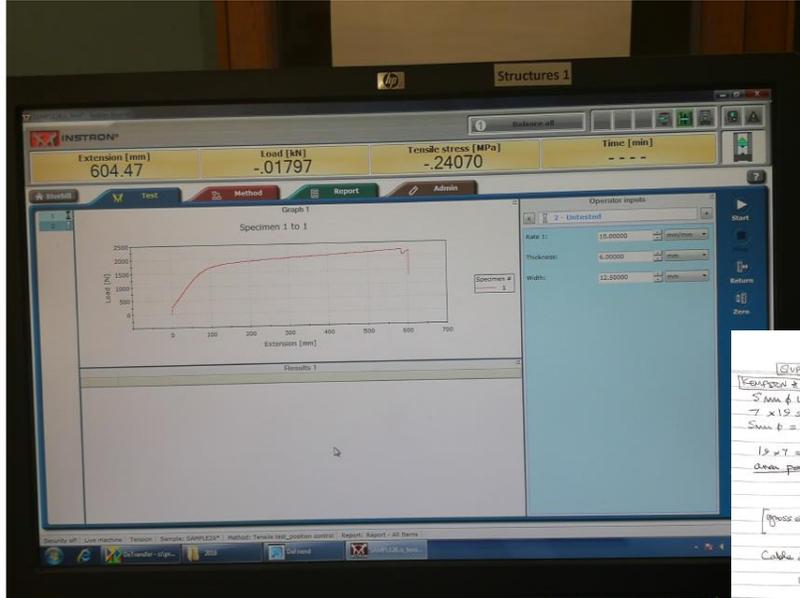
EQUIPMENT

- Linear potentiometers
 - 12 No. 50 & 100 mm pots
- Wiring
 - 650 m 4-core
- DAQ
 - Datalogger DT85
- Software
 - deFriend



MONITORING

CABLE TENSION



OVERLOAD MOVEMENTS 100-1

14th Apr 2018 PB

REASON & MIDDLE BOREHOLE ENLARGEMENTS - CABLE

- 5 mm φ wire rope grade 316 Stainless steel
- x19 stainless wire construction
- Str. φ = 12 wires φ = 2.1166 mm
- 12 x 7 = 137 wires
- area per wire $(\frac{\pi(2.1166)^2}{4}) \times 12 = 0.1363 \text{ cm}^2$
- $A = 1.2 \text{ cm}^2$ ✓

gross overchuck $\text{Stress} \times \text{area} = 19 \text{ kN} \times 1.2 \text{ cm}^2 = 22.8 \text{ kN}$

Cable data sheet → Min breaking load 13.9 kN

12 x 1570 x 10⁻³ = 22.8 kN R 1570 kN

TEST SPRING CAPACITY

- φ PENETRATION SPRINGS 280 mm long
- φ MIDDLE BOREHOLE 170 & 175 mm long
- UNSTRETCHED SPRINGS 127 mm long

1. Extension to Forcepoint 153 mm (280=127)

- φ Middleborehole +3 x 48 mm (210=167)

Lab test of Spring capacity

- Forcepoint 153 mm extension = 1.8 kN
- Middleborehole 45, 143 extension = 1 kN x 2 = 2 kN

Conclusion → wire rope standard Forcepoint to 2 kN

7x19 (12/6/1) - Marine Grade Stainless Steel Wire Rope

DOWNLOAD THE DATA SHEET CONTACT US FOR PRICING

Product Details

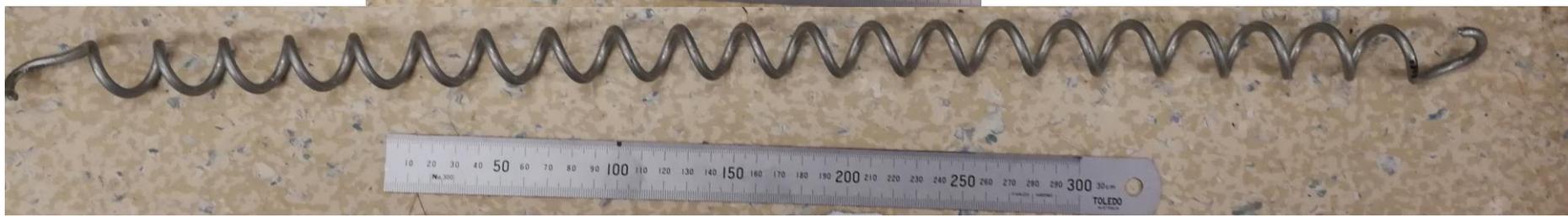
7x19 A19216 stainless steel wire rope is used for a wide range of applications. Extremely flexible when compared to both 1x19 and 7x7, the 7x19 construction is often used where a flexible stainless steel wire rope is particularly required. 7x19 performs well for running applications. Used extensively throughout the marine industry as well as for general engineering applications. 7x19's excellent flexibility makes it a favourite for control cables and a variety of marine rigging applications, examples of which are shown below.

Applications

- Control cables
- Control lines
- Steering rigging
- Flaming rigging
- Steering cable
- Marine/Offshore environment
- General industrial work
- Wire rope slings
- Steel ropes

Breaking Loads

Nominal Diameter [mm]	Approximate Mass [kg/m]	Minimum breaking loads - 1578 Mpa [kN]	[kg]
3	0.033	5.00	500
4	0.059	8.00	800
5	0.093	13.90	1,417



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CABLE ANCHORS



MONITORING

INSTALLATION

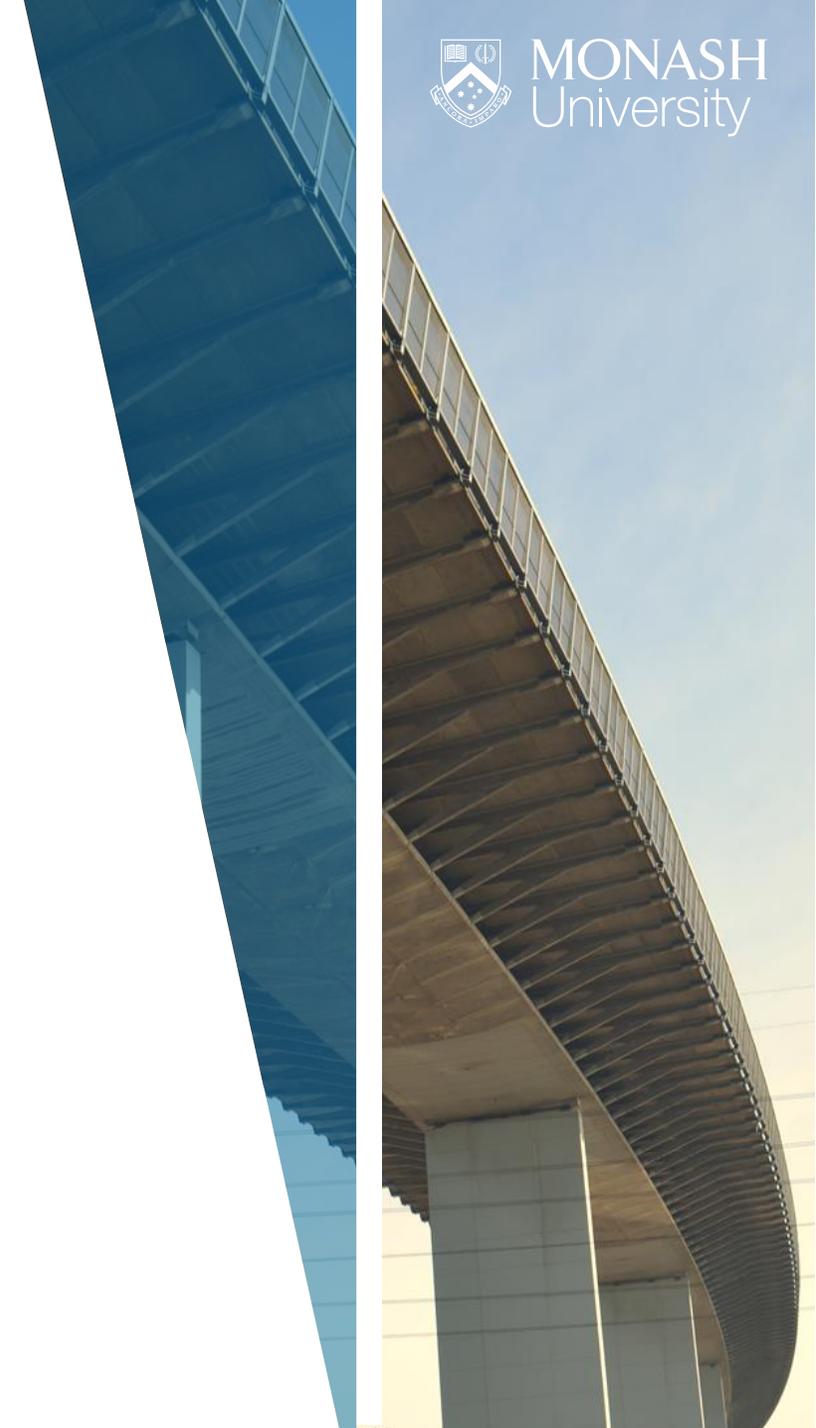


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INSTALLATION

Stressing the tension wire

- Combination of fence tensioner and ratchet



MONITORING

INSTALLATION



Checking elongation of the spring-turnstile system



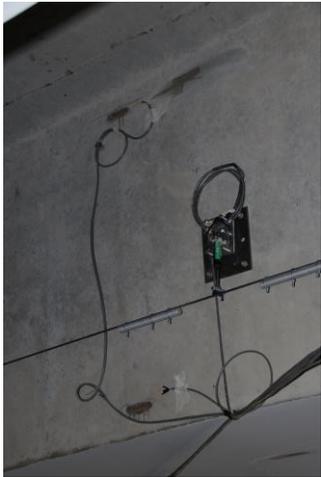
Checking verticality of the displacement sensor

MONITORING

VALIDATION

Cross-checking with

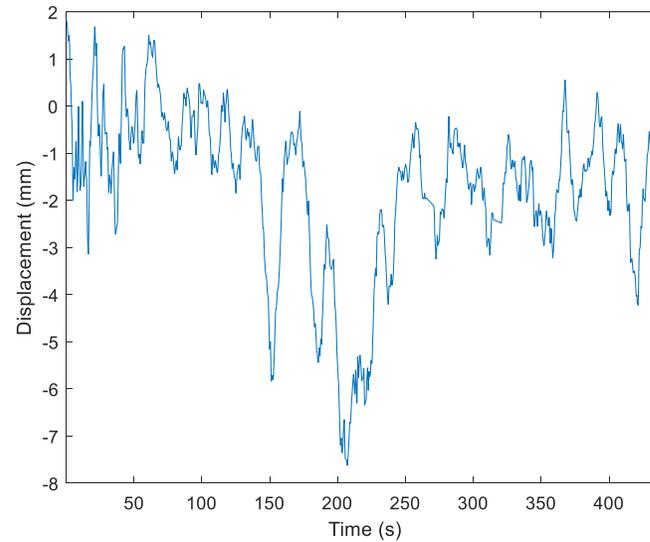
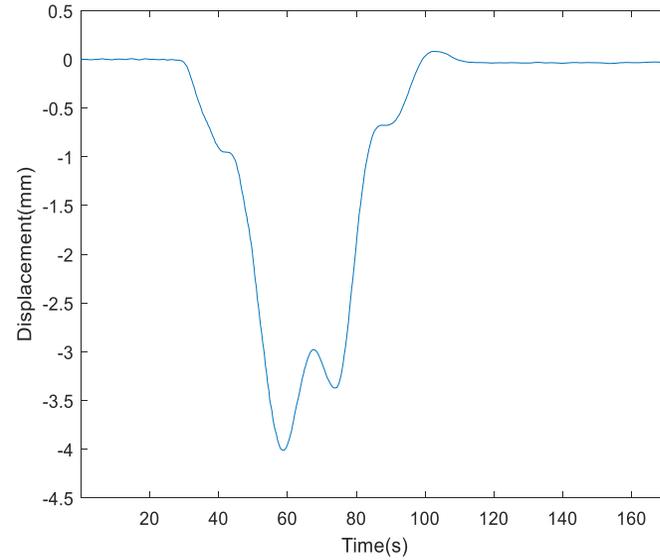
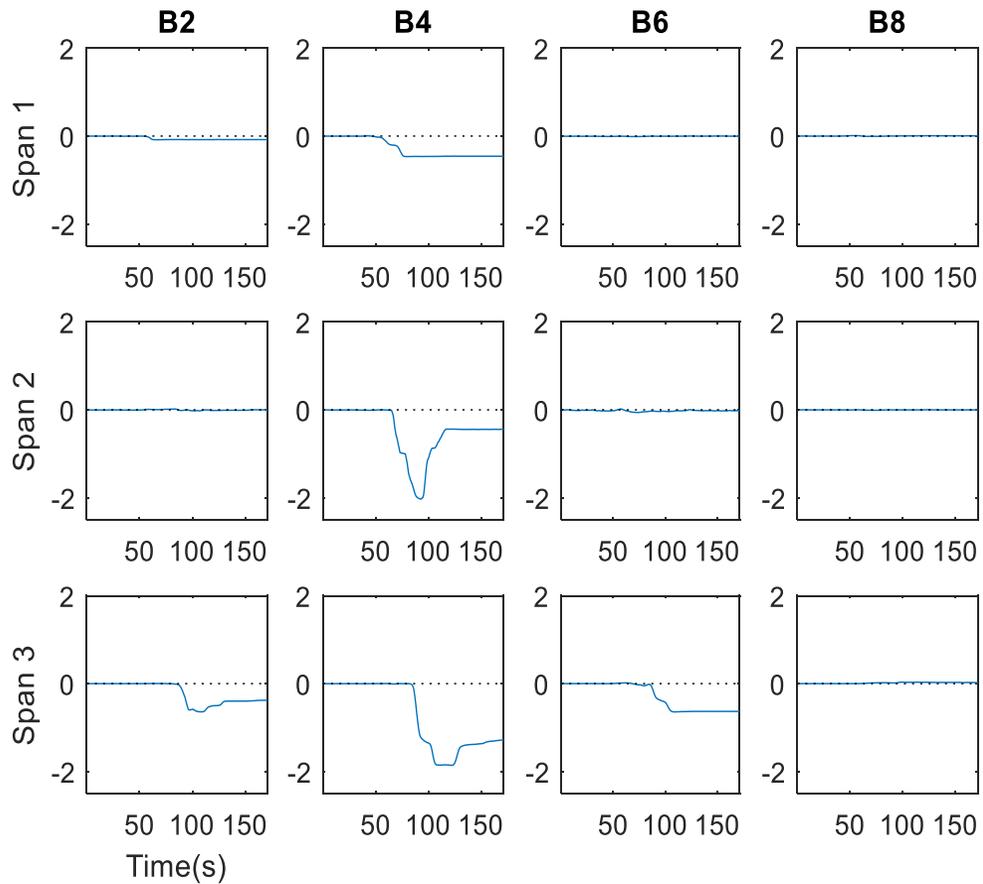
- Strain gauges
 - curvature
- String pot to ground
 - Upper bound
- LDV for baseline
 - Frequency floor issue



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RESULTS

- Good validation essential!



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OTHER MEASURES

RUN-ON PLATES





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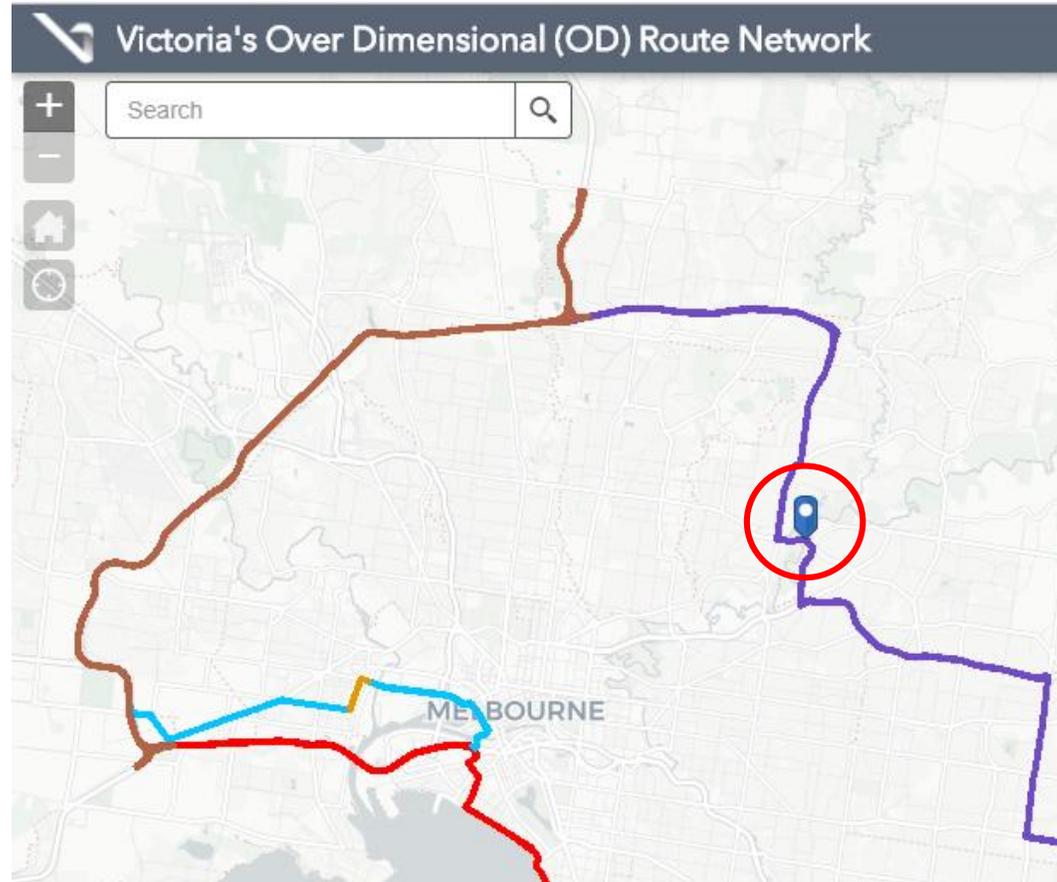
Banksia St Bridge



BANKSIA ST BRIDGE

LOCATION

- Critical capacity bottleneck on OD1
- Vital until North-East Link is built
- Crosses Yarra River in sensitive habitat

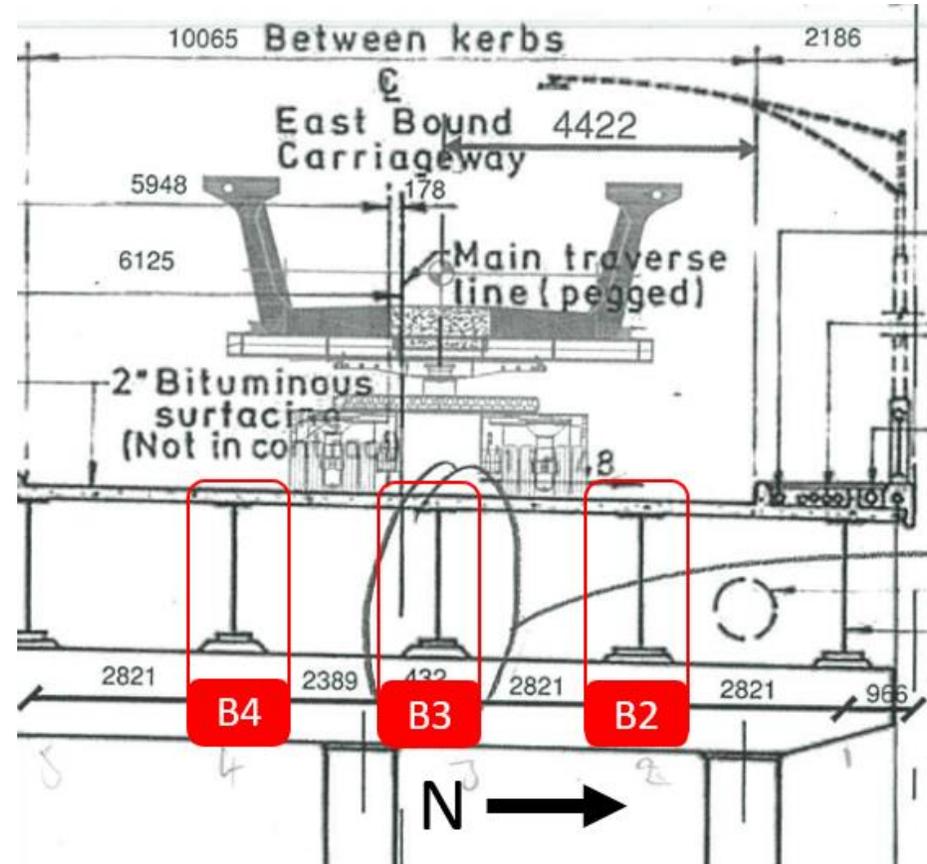


BANKSIA ST BRIDGE

ARRANGEMENT

Critical elements:

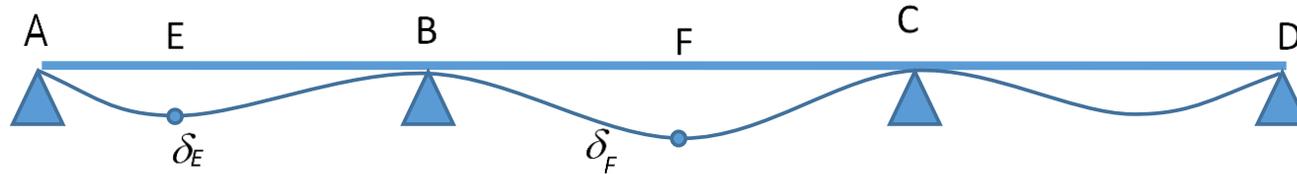
- Deck
- Run-on slabs
- Bracing
- Crosshead
- Girders



MONITORING

CONCEPT

- Long-term wireless solution sought for displacements
 - Recommended acquire strains



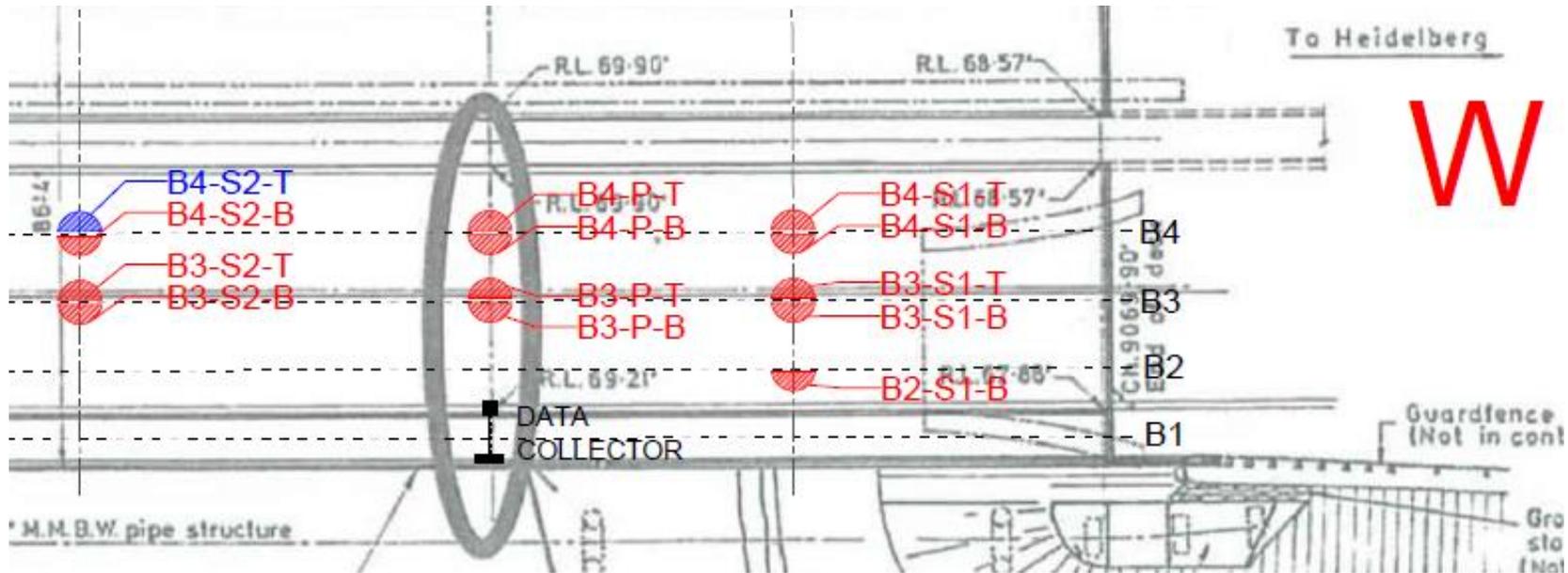
$$\delta_E \approx \frac{L^2}{96}(10\kappa_E + \kappa_B) \quad \delta_F \approx \frac{L^2}{96}(2\kappa_B + 10\kappa_F)$$

- Required 18 wireless node strain gauges
 - 3 girders x (2 mid-spans + 1 hogging support) x 2 gauges
- Only 12 wireless node strain gauges available

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CONCEPT

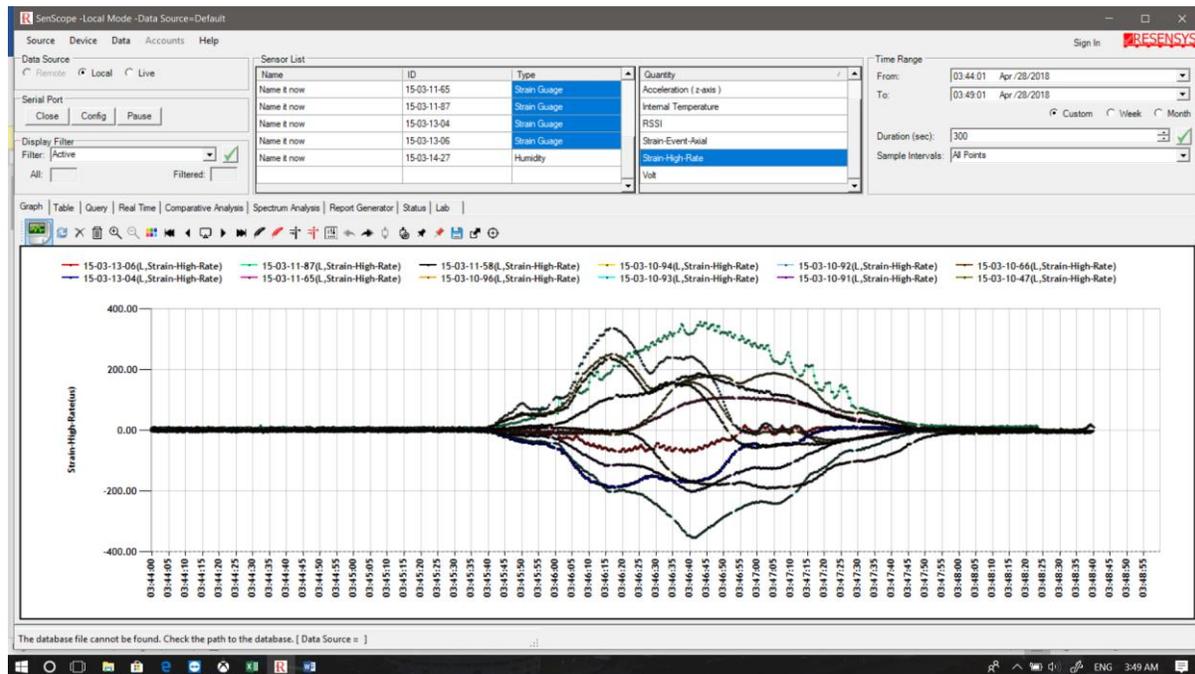
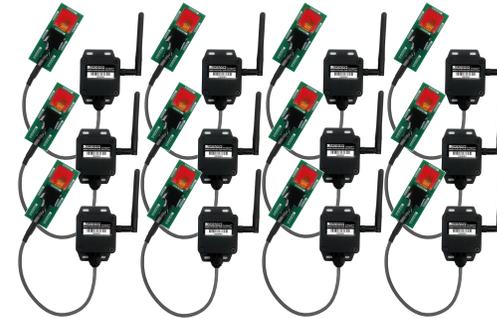
- Solution:
 - use symmetries along and across the girders



MONITORING

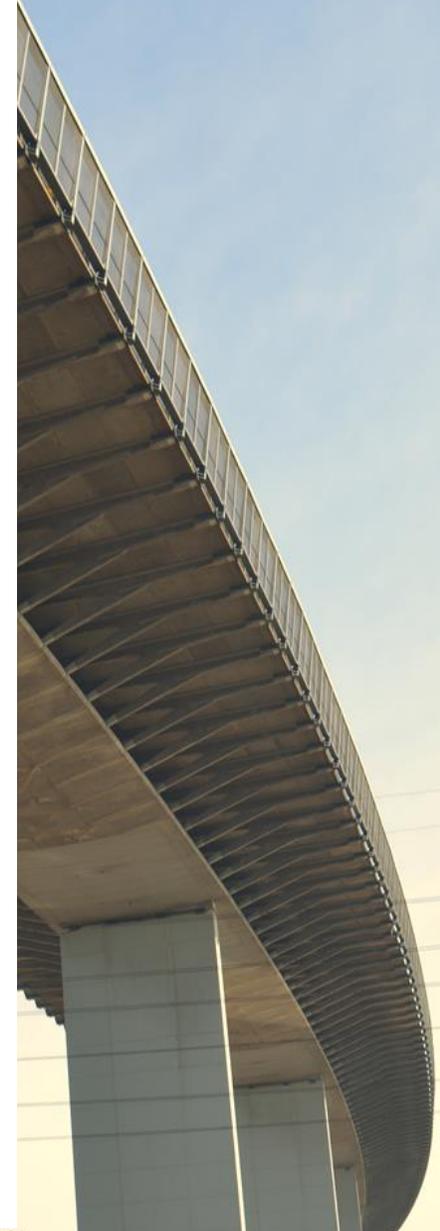
EQUIPMENT

- Resensys
 - Senspot strain gauges & temp probe
 - Senimax 3G & USB gateway
 - Senscope remote access software



MONITORING

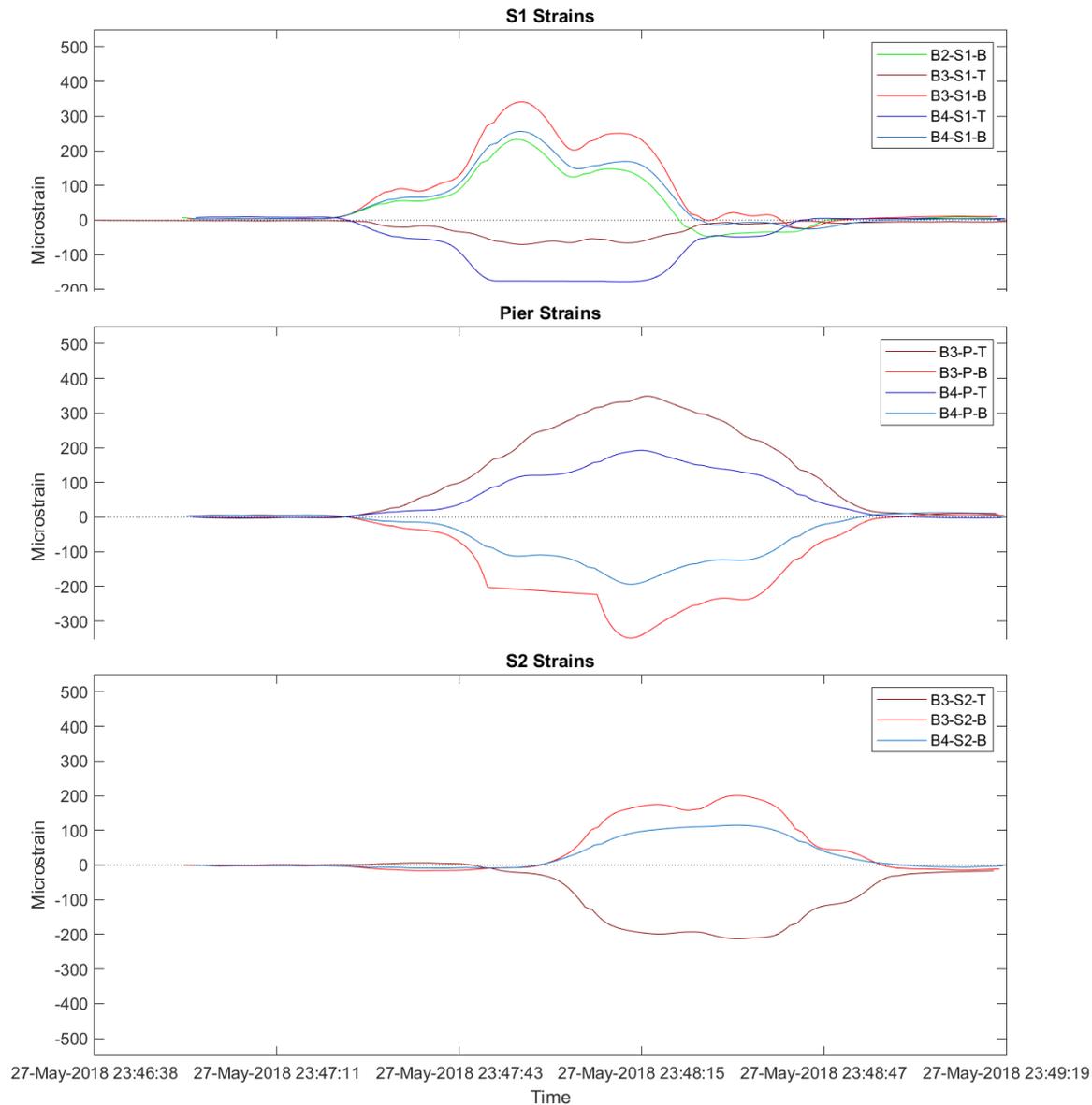
INSTALLATION



MONITORING

RESULTS

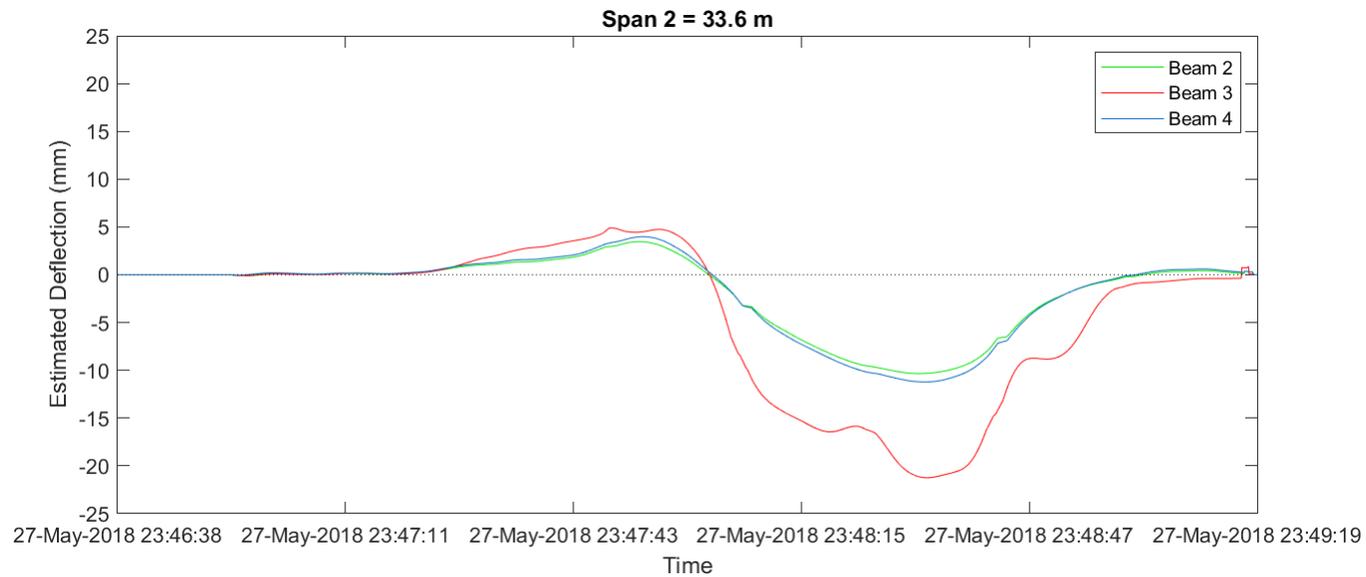
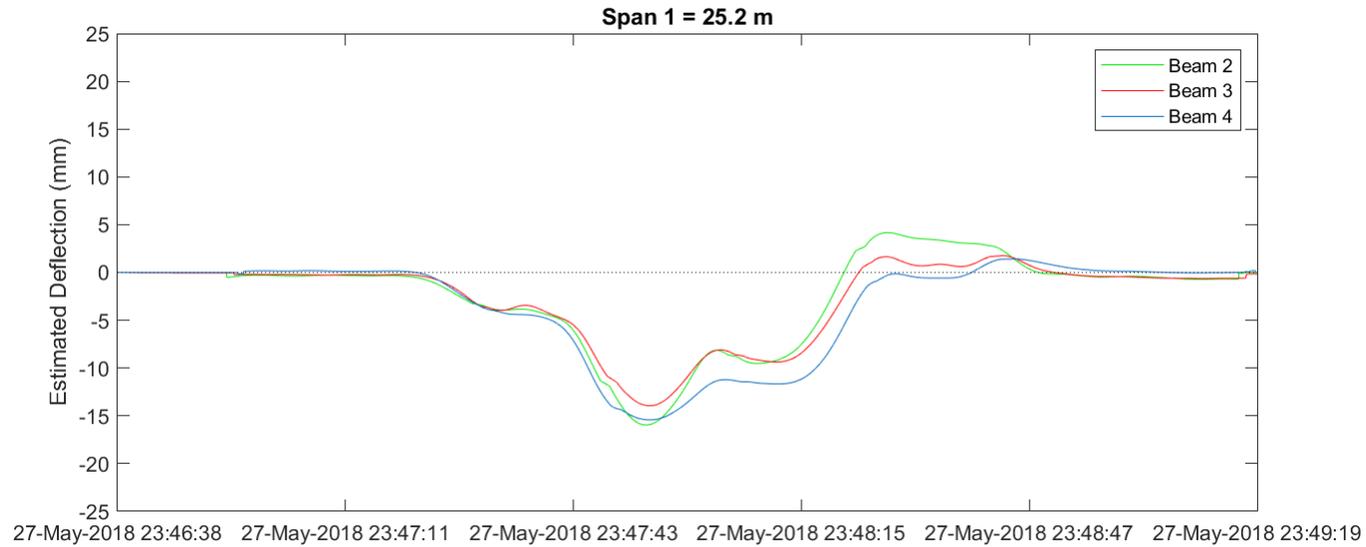
- Raw:



MONITORING

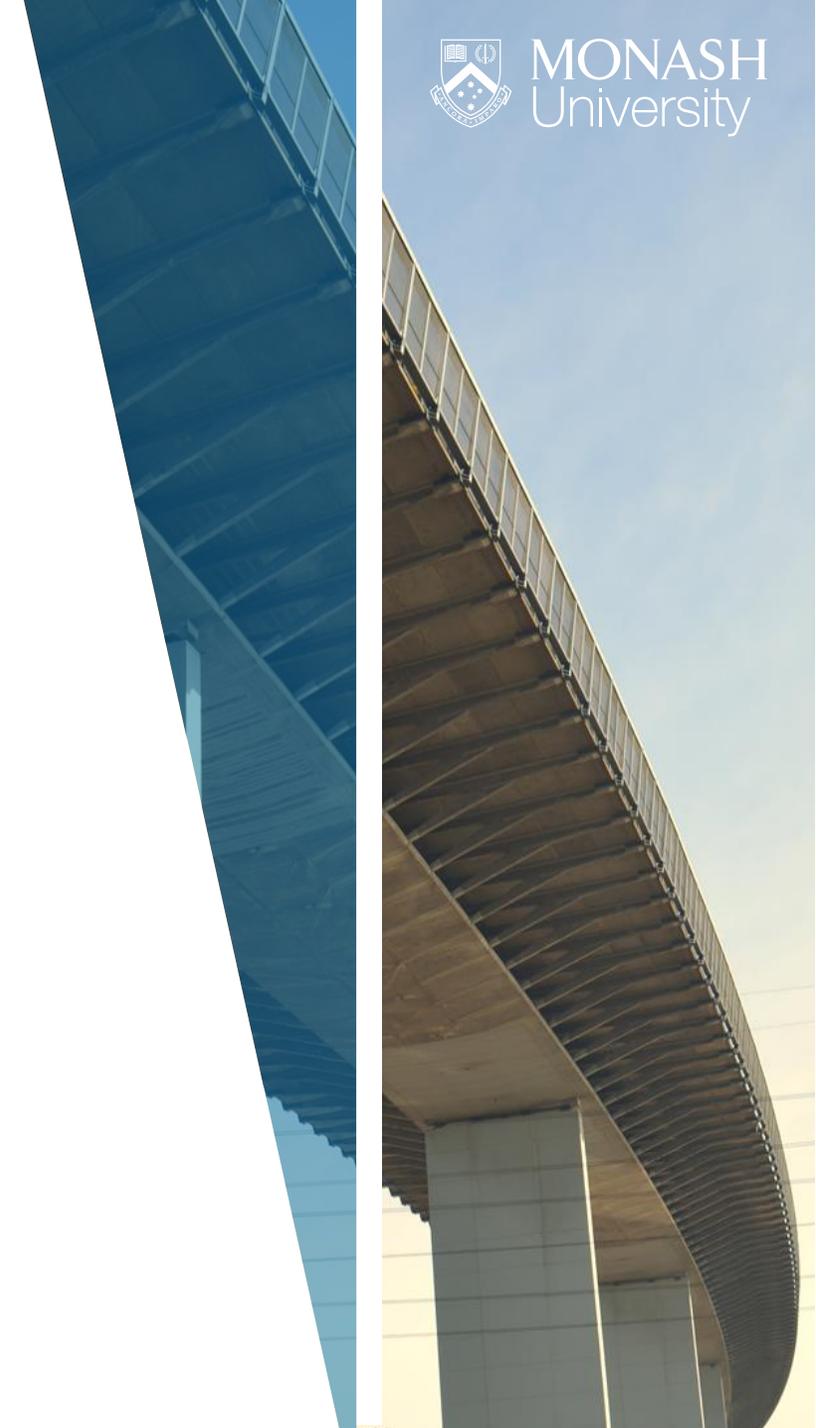
RESULTS

- Processed:



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Middleborough Rd Bridge



MIDDLEBOROUGH RD BRIDGE

LOCATION

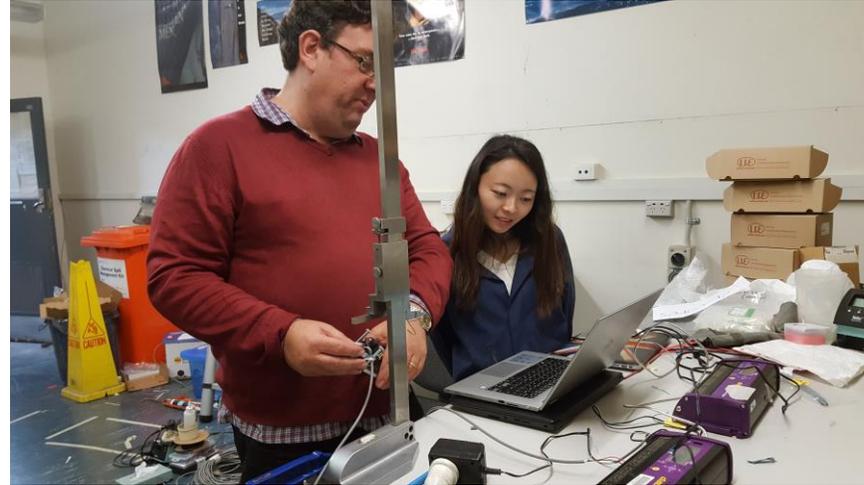
- Crosses the Eastern Freeway
 - Road closure not possible
- Superload to turn onto bridge
 - Potential difficulty in maintaining appropriate wheel path



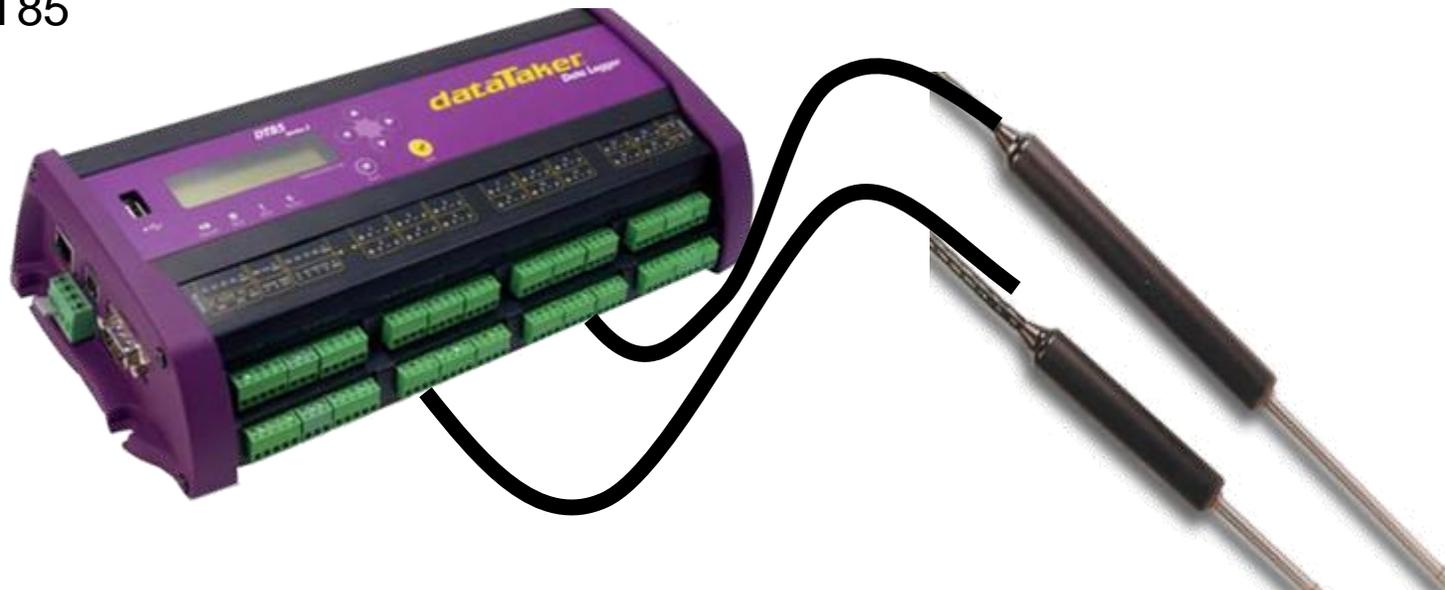
MONITORING

EQUIPMENT

- 8 sensors required
 - 6 transducers
 - 2 string pots
- Wiring
 - 170 m 4-core
- DAQ
 - Datalogger DT85
- Software
 - deFriend



Lab calibration of systems



MONITORING

INSTALLATION

- Interaction between lane closures and tensioning operations
 - Lane closures and traffic management changeovers give about 4 working hours per night
 - Safe temporary coiling of data cable and tension wires during daytime

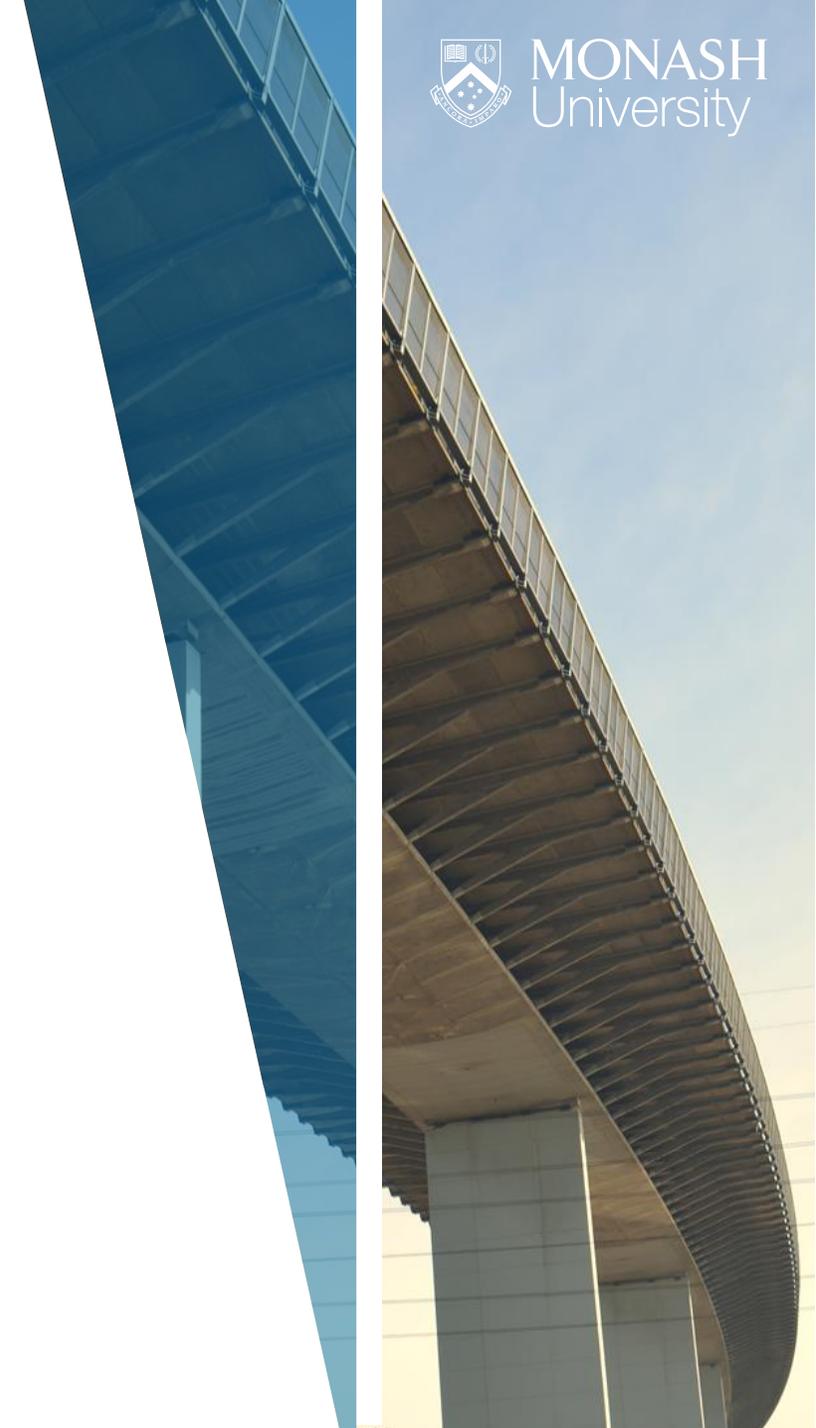


MONITORING

VALIDATION



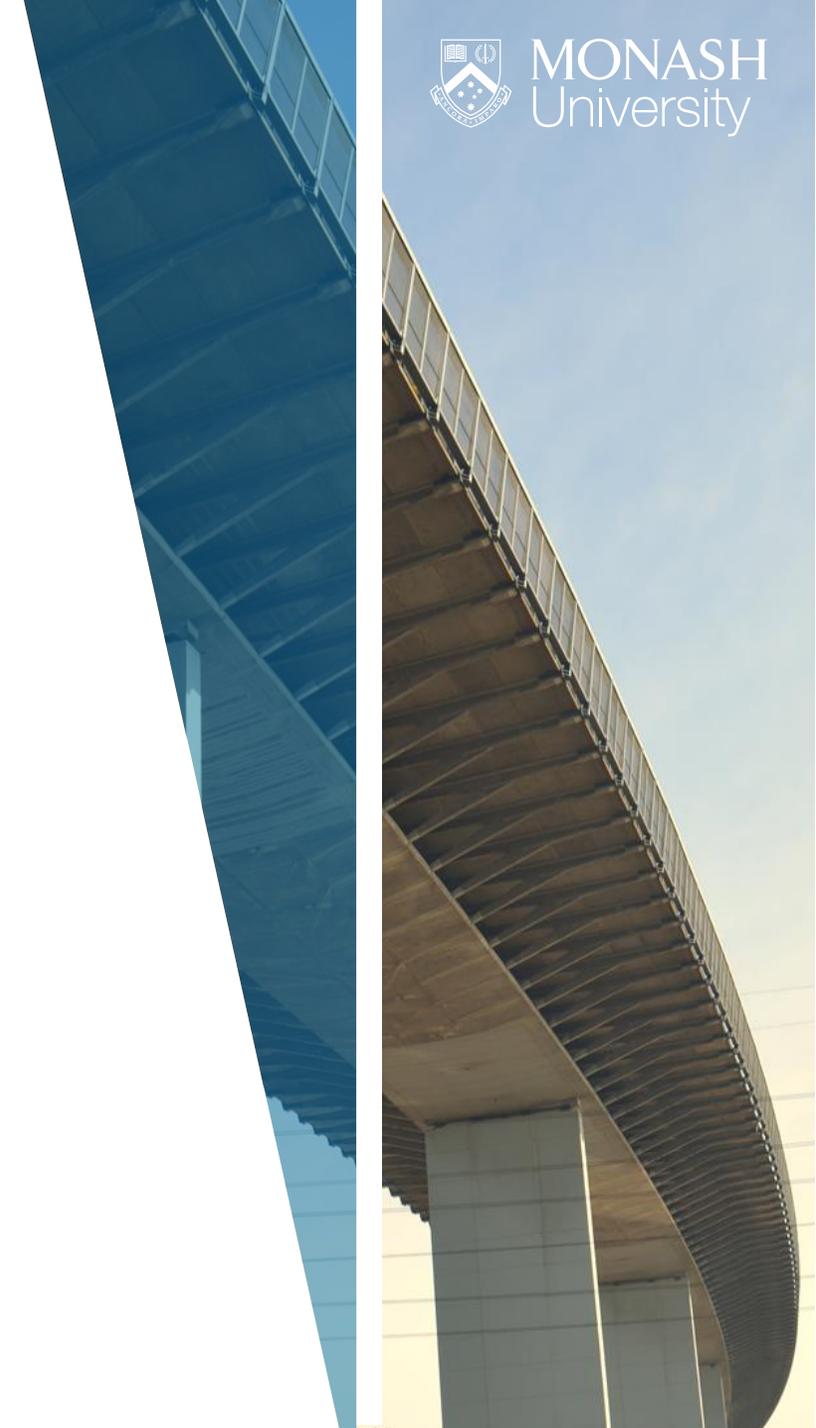
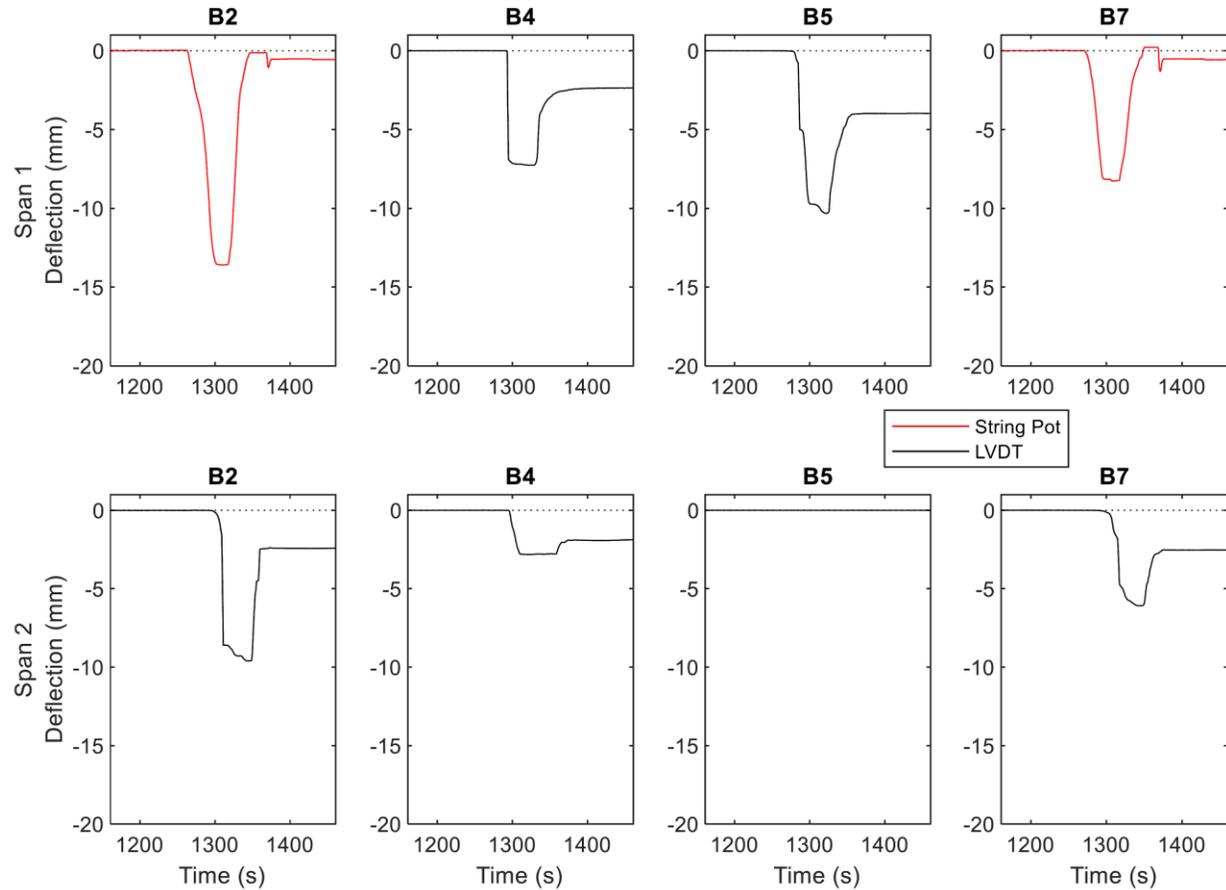
In-situ checking of string-pot calibration



MONITORING

RESULTS

- Some tension wire 'stickiness'



MONITORING

ISSUES

- Vandalism
 - 4 cables cut between moves
 - Fixed in 10 minutes without holding up the load
 - Cables renamed A to D
- Sensor cables remapped using logic table

	Cable A	Cable B	Cable C	Cable D
B2S2?	Too small	Too small	Cable D	Must be
B4S2?	Must be	Cable A		
B5S2?	Too small	Too small	Must be	Too small
B7S2?	Too big	Must be	Cable B	

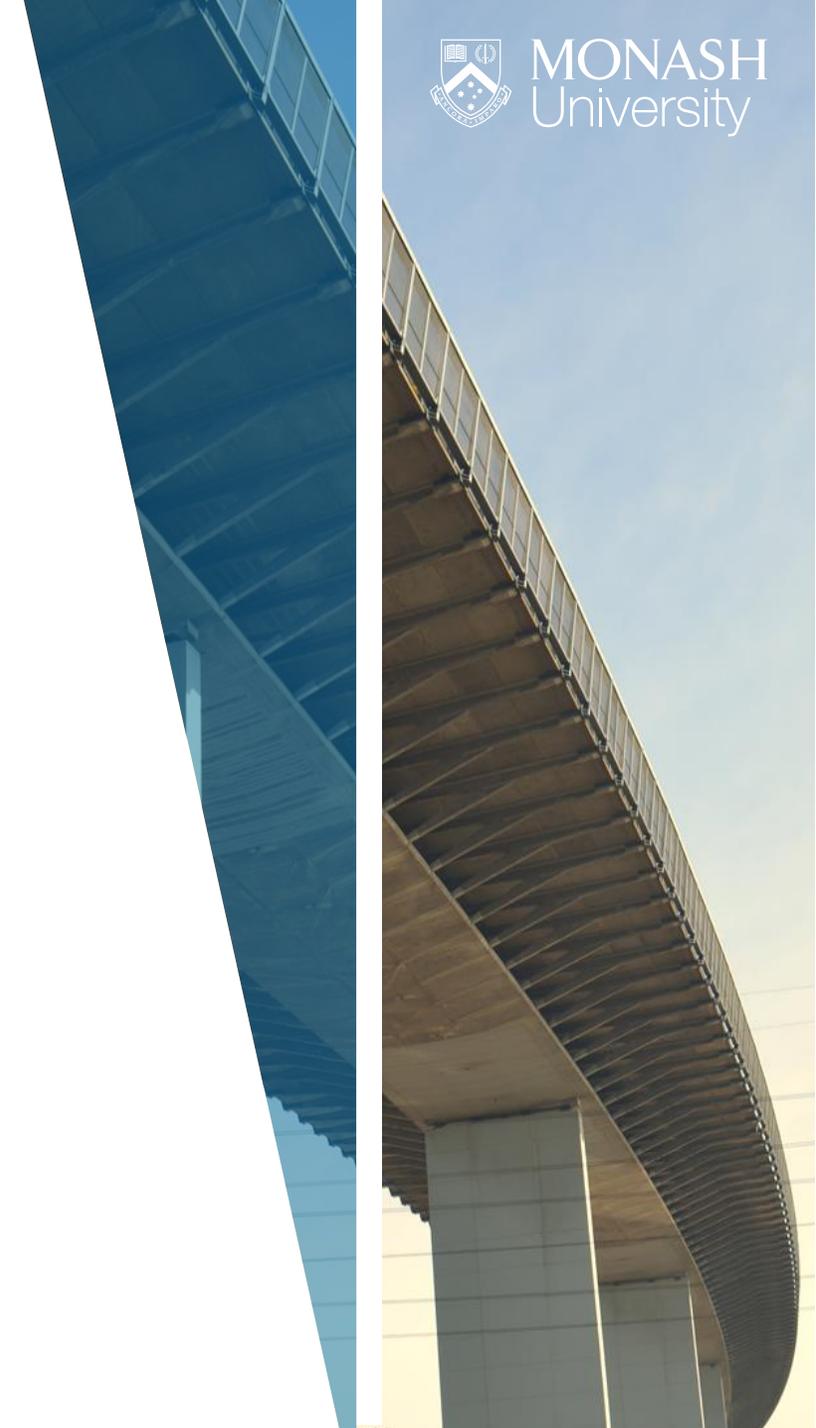
MONITORING

WHEEL PATH CHECKING



MONITORING

STATION





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CONCLUSIONS



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FINALLY...

POSITIVE IMPACT FOR VICTORIA

- LXRA video: <https://youtu.be/T3Ovm2kRwbE>
- Monash video: <https://vimeo.com/276174664/4a1f8b7ad8>





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THANK YOU!

