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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



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

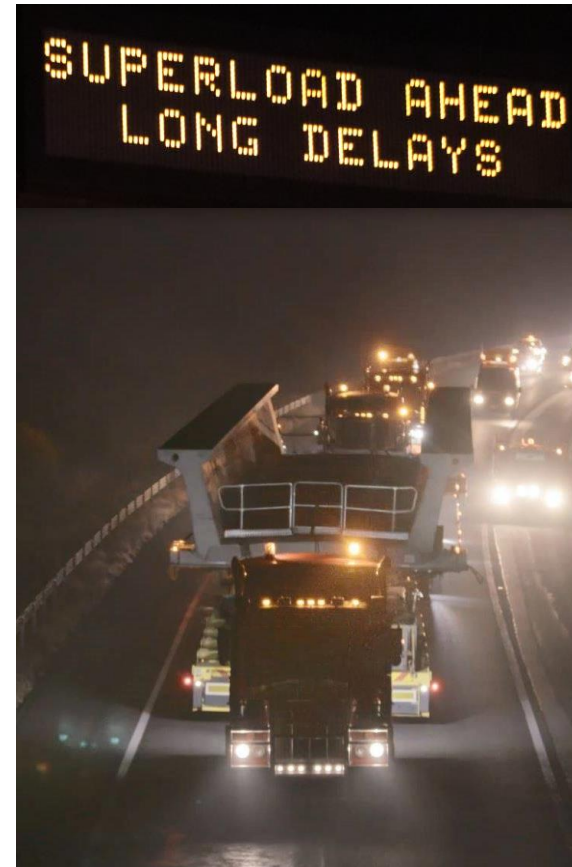
- Pre-cast bridge beams off site and transport
- 24 No. 31 m post-tensioned U-trough beams
 - 270 tonnes



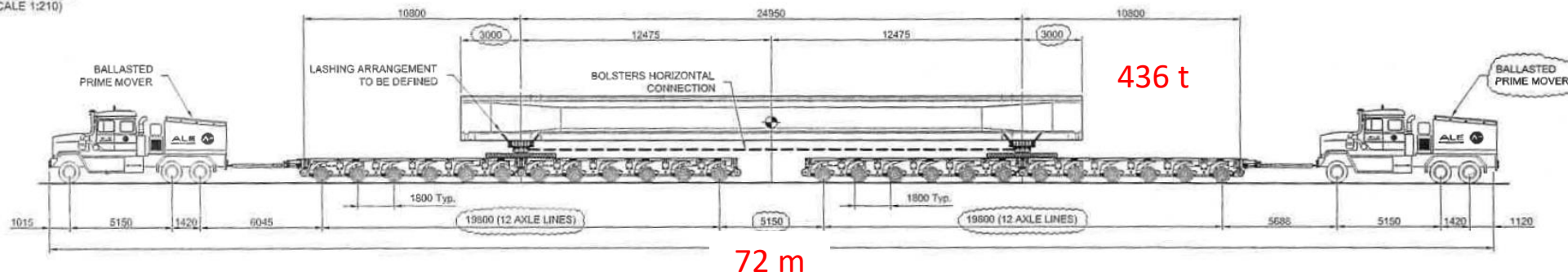
THE SUPERLOAD

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

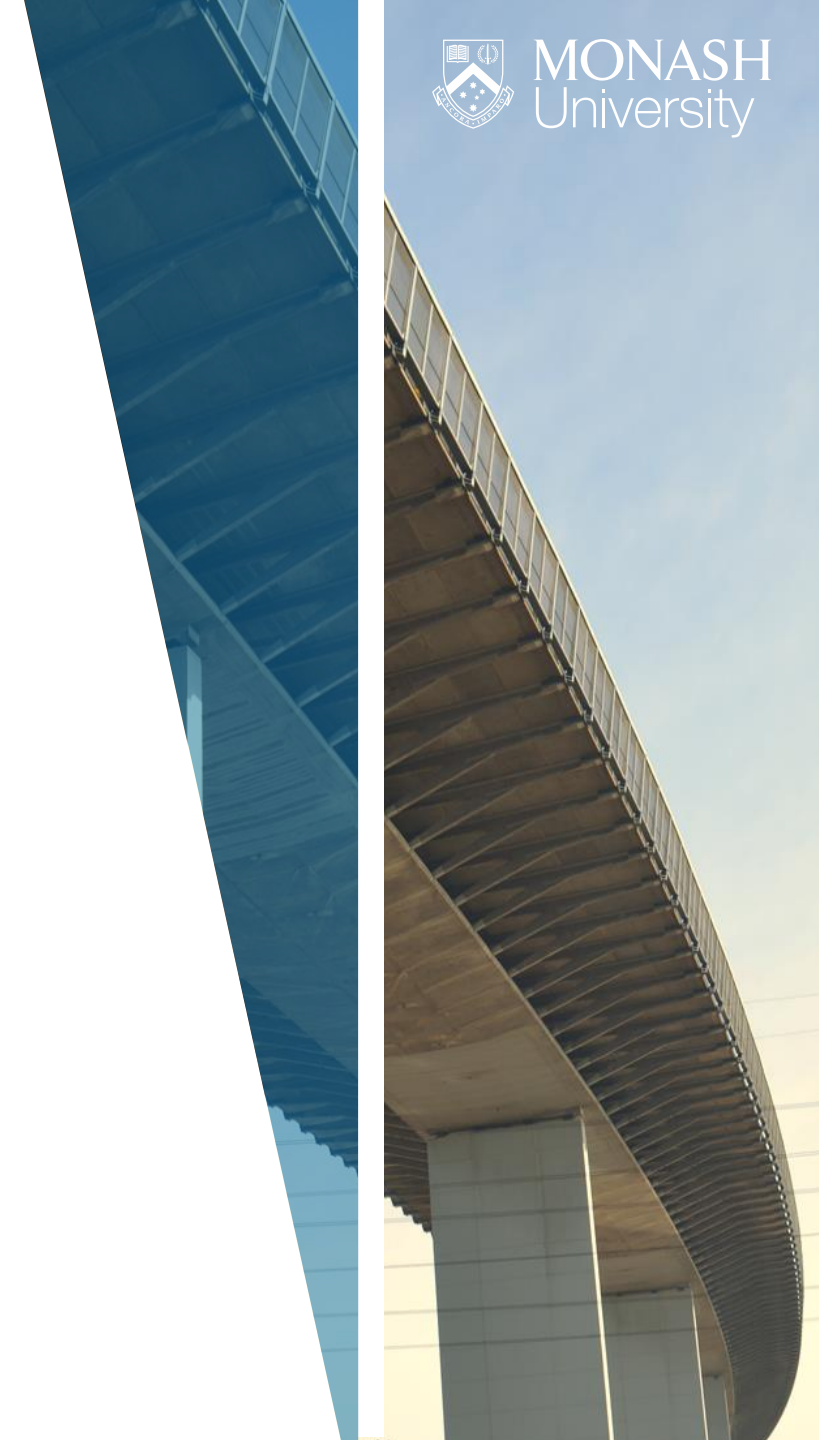


Kilmore
Arch

Kilmore-Epping
(Findon Creek)

Kempston

Banksia
Middleborough





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Kilmore Bridge



KILMORE BRIDGE

ARRANGEMENT

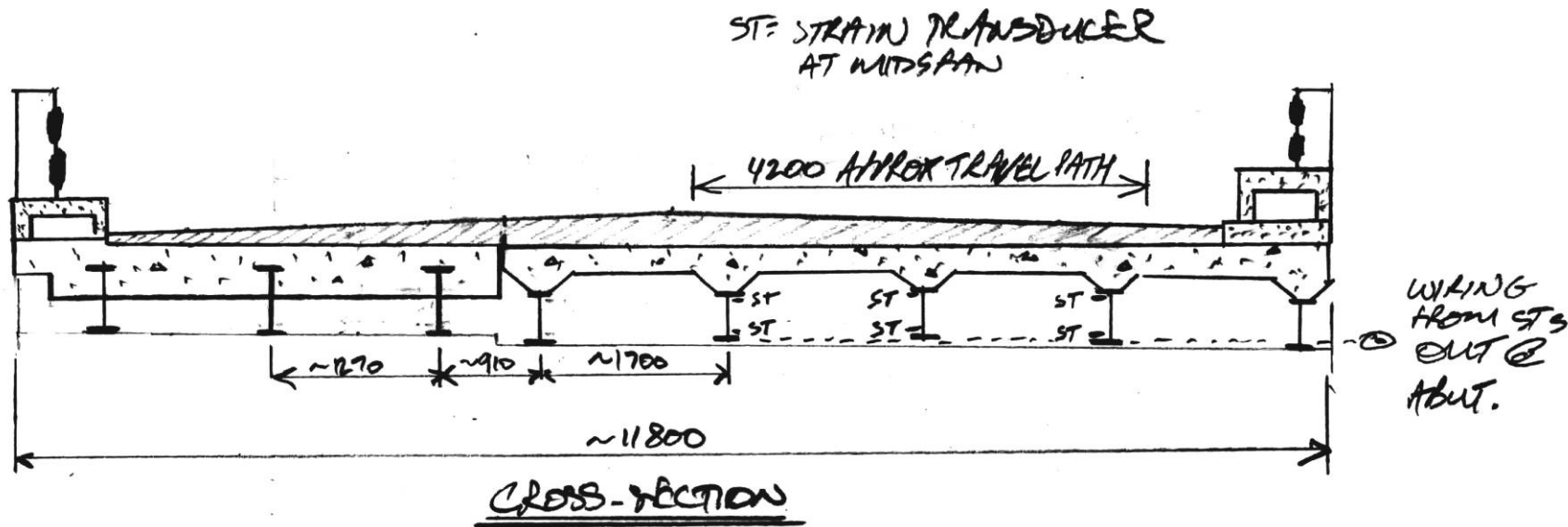
- Widened bridge
- Widening 1930s RSJ-Concrete composite



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

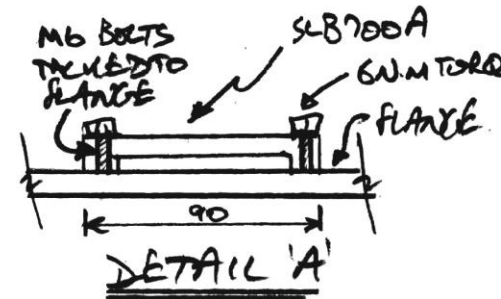
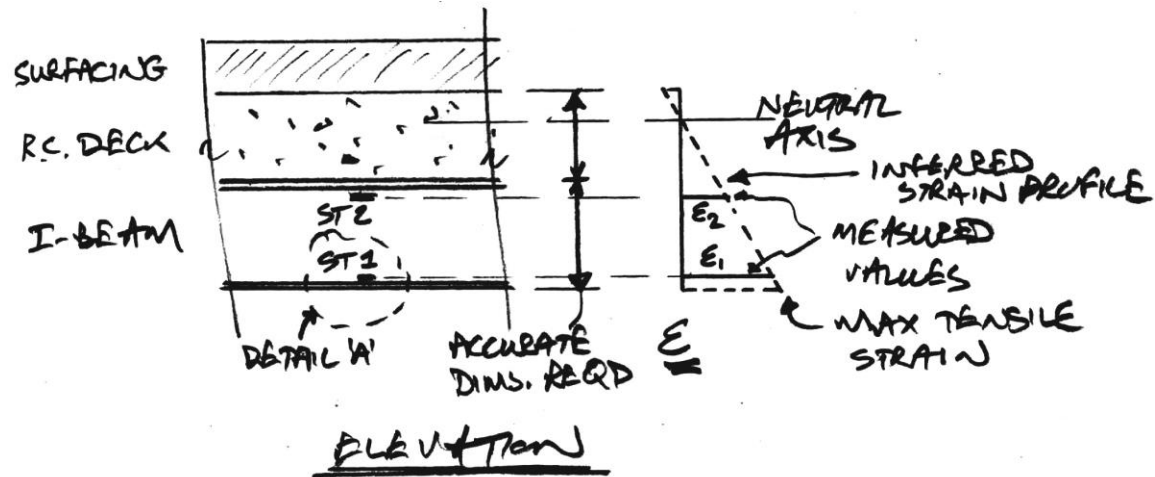


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CONCEPT

- 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

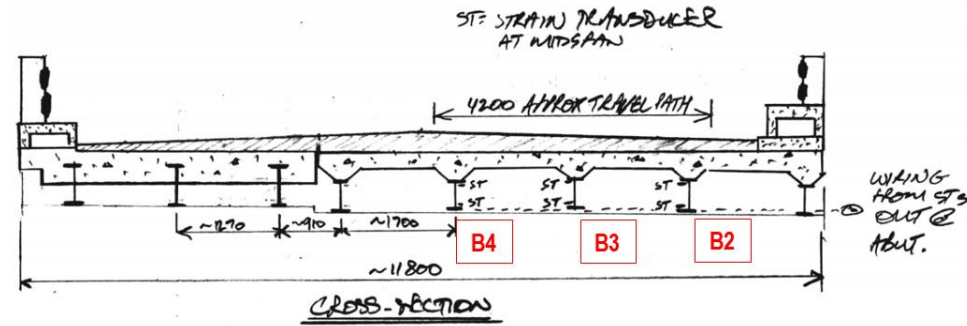
EQUIPMENT

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

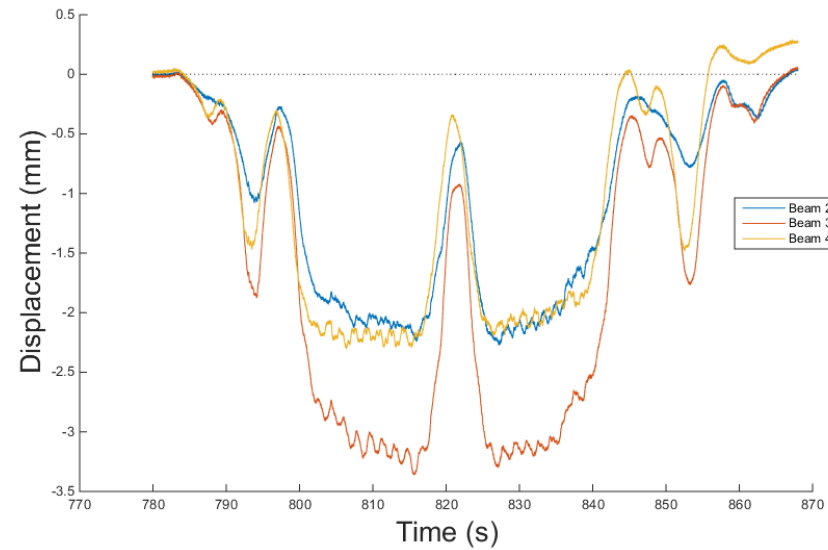
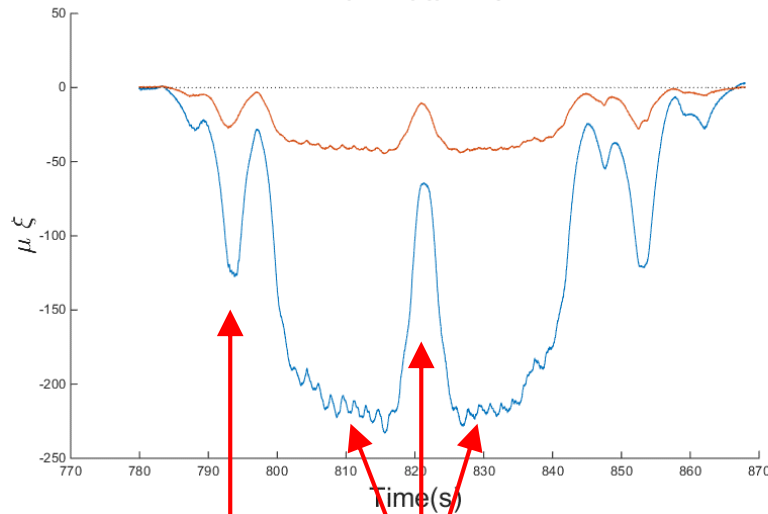


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EXAMPLE RESULTS



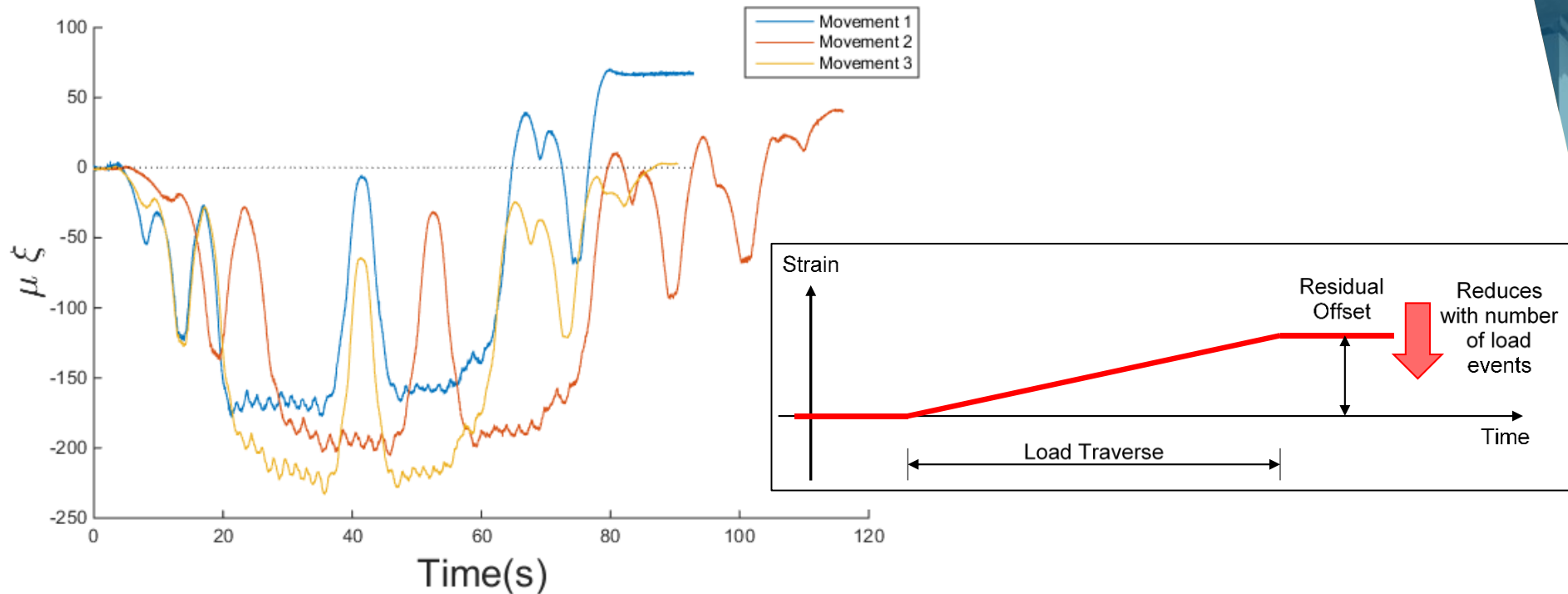
Raw Data - B3



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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



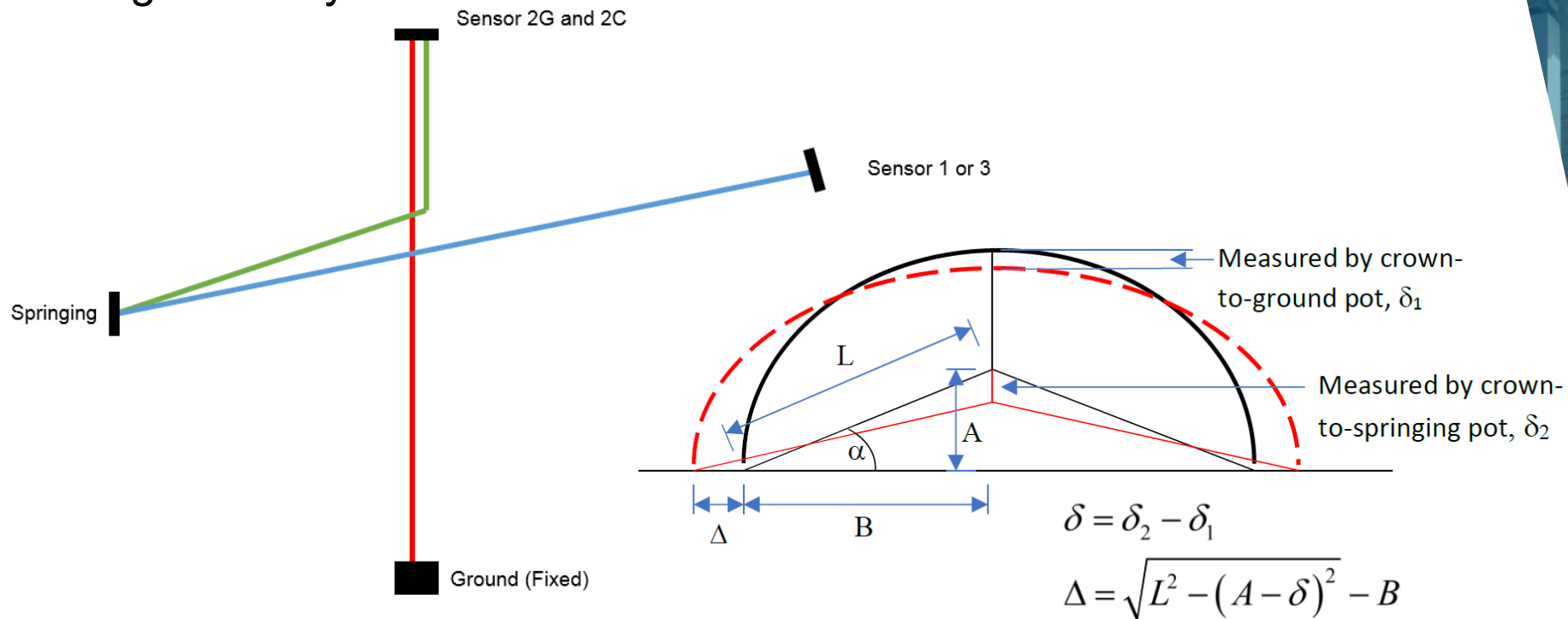
CONCEPT

-
- 4200 TRAVEL PATH APPROX
- 2250
- SPRINGING
- ~1500
- CROWN
- SEA SEAM
- DRAW WIRES
- 3000 APPROX SPAN
- CROWN TO BRID POT
- STRING POTS
- 2100
- 2100
- 2250
- SPRINGING
- 8200 APPROX WIDTH
- SANDWICH WALL
- APPROX. LOC OF DAQ.
- SN0439 - PLAN OF MONITORING
(Scale 1:50)

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CONCEPT

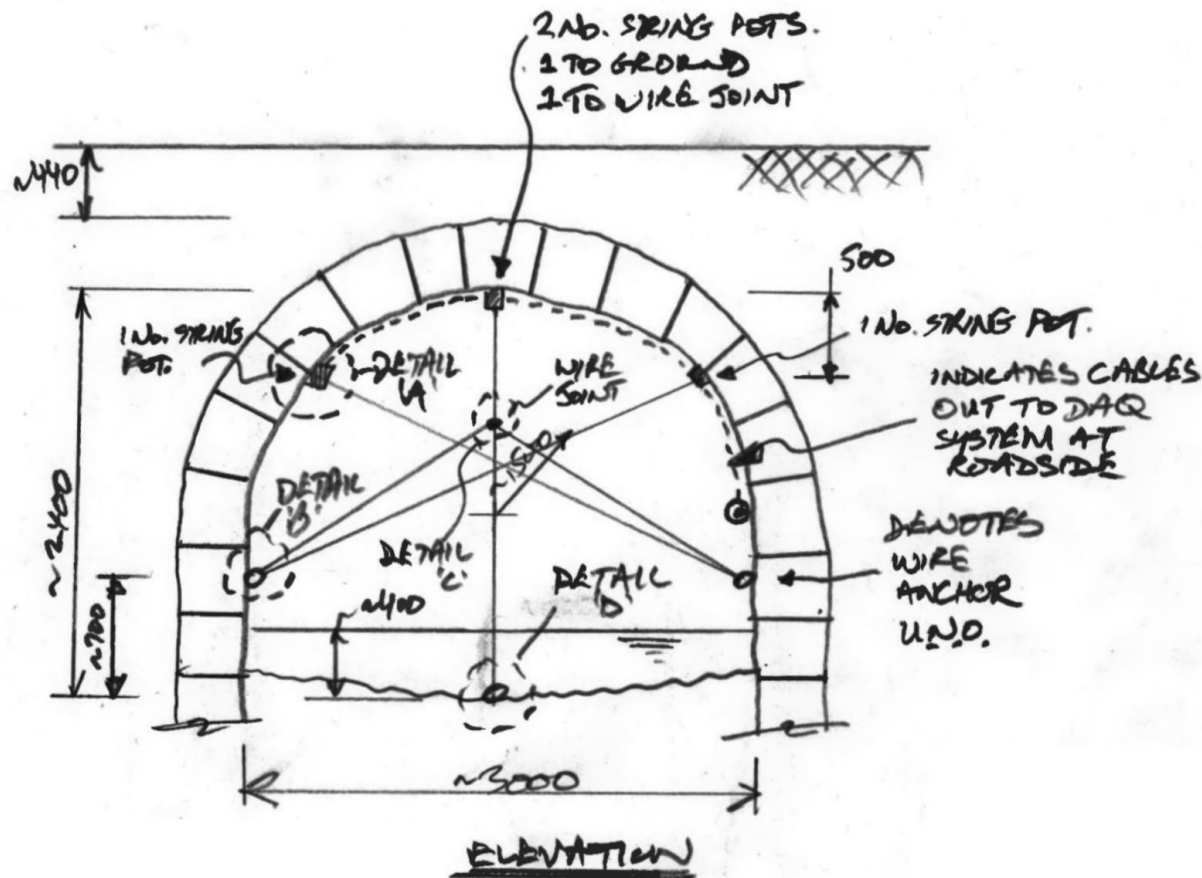
- Considerations:
 - Flooding – keep sensors high
 - Only 12 sensors
- Use trigonometry...



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ARRANGEMENT

- 4 string pots at each plane:



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ARRANGEMENT



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EQUIPMENT

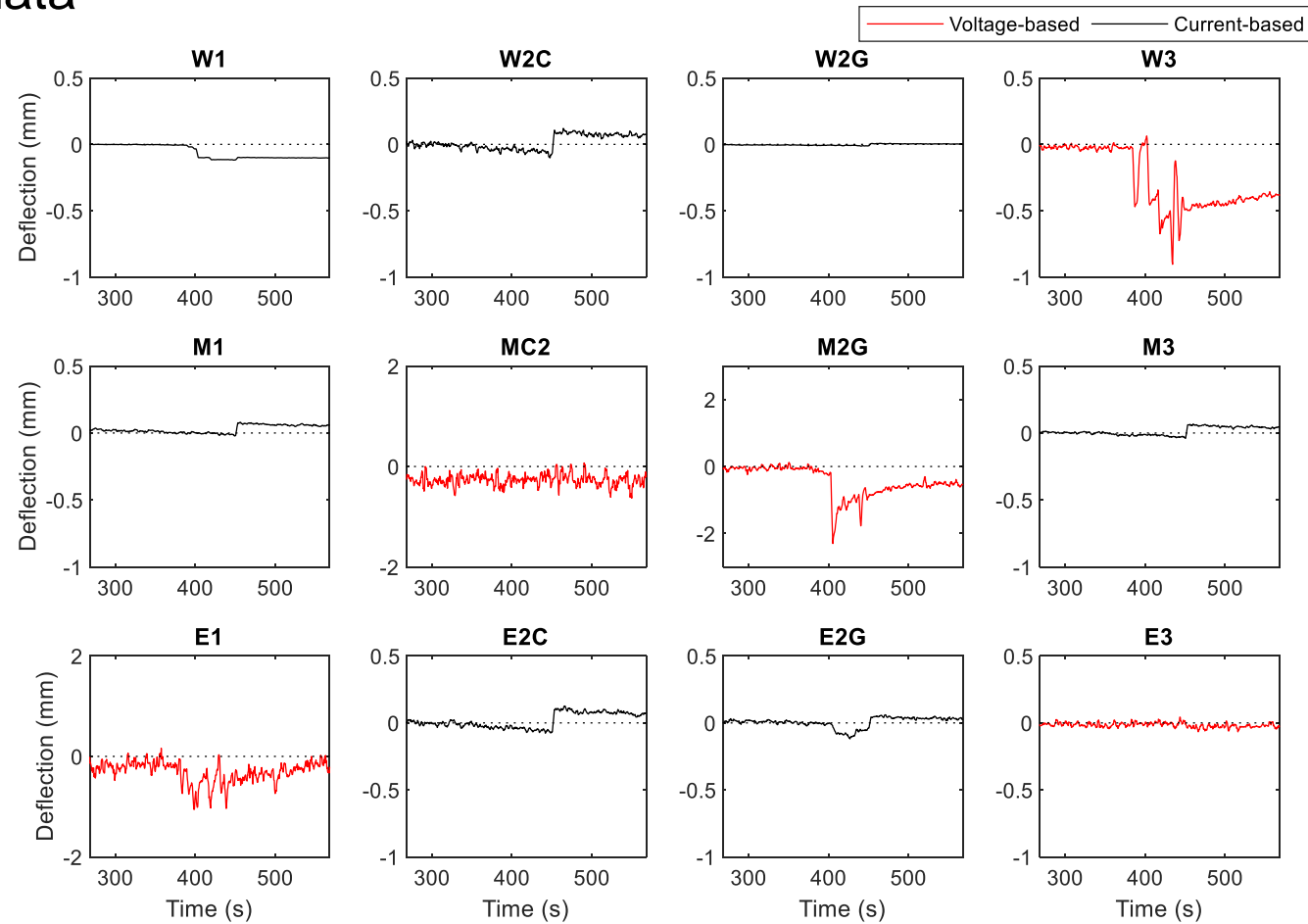
- String pots
 - 7 No. Micro-epsilon WDS-X-P60-SR (Current)
 - 5 No. Micro-epsilon WDS-X-P60-CR (Voltage)
- Wiring
 - 200 m 4-core
- DAQ
 - Datalogger DT85
- Signal conditioning
 - 24V DC power regulator
 - 240V AC line filter
- Software
 - deFriend



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RESULTS

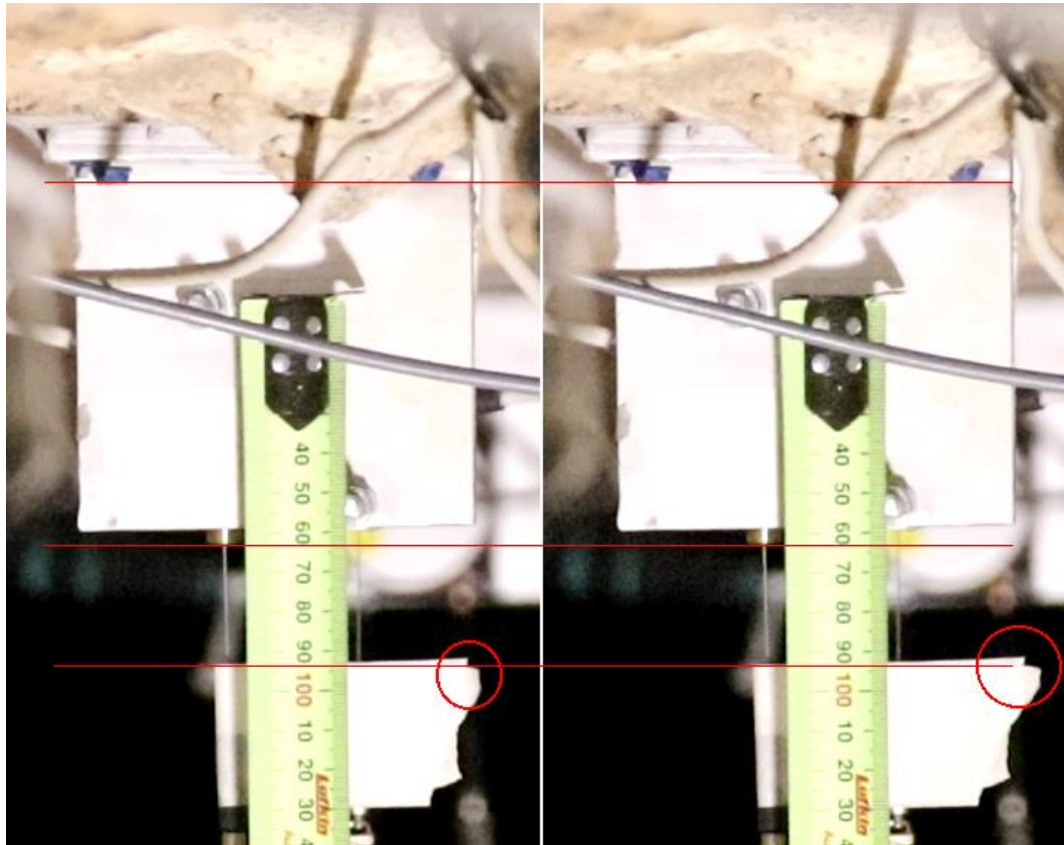
- Raw data



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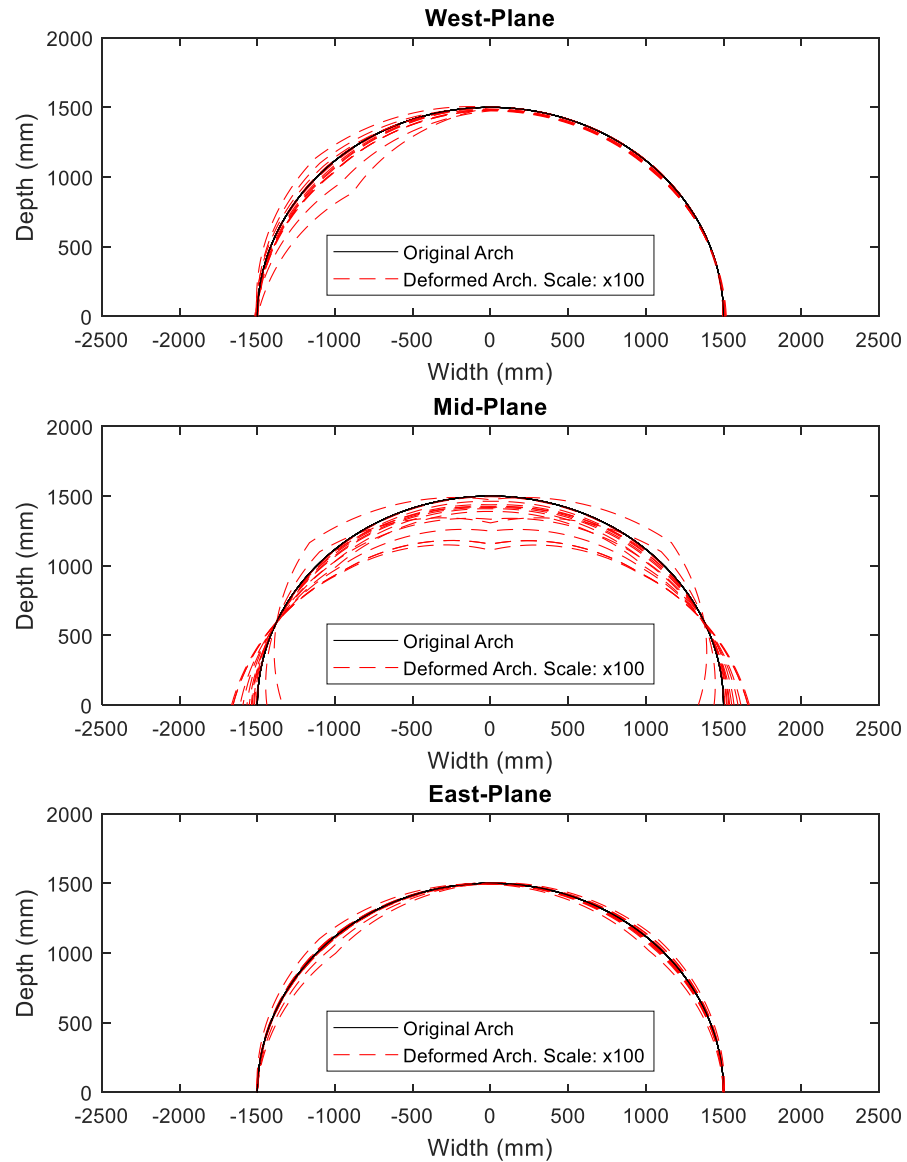
VALIDATION

- Sense-check using high resolution video & zoon lens



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RESULTS



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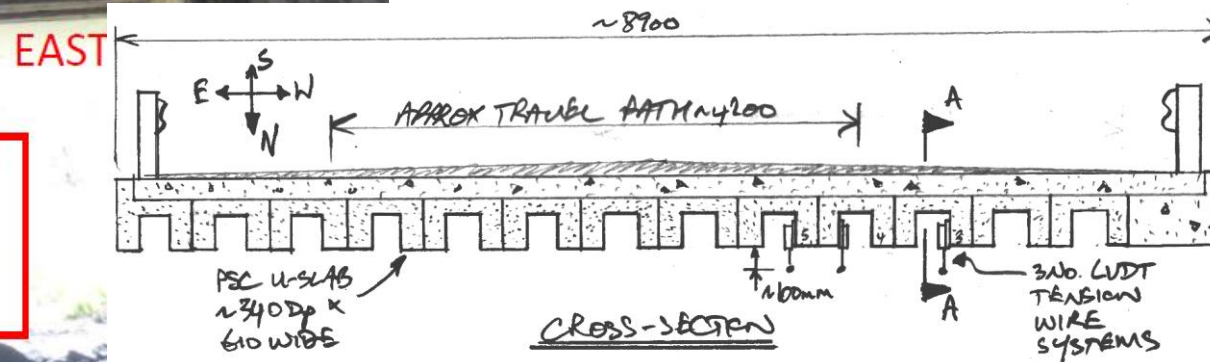
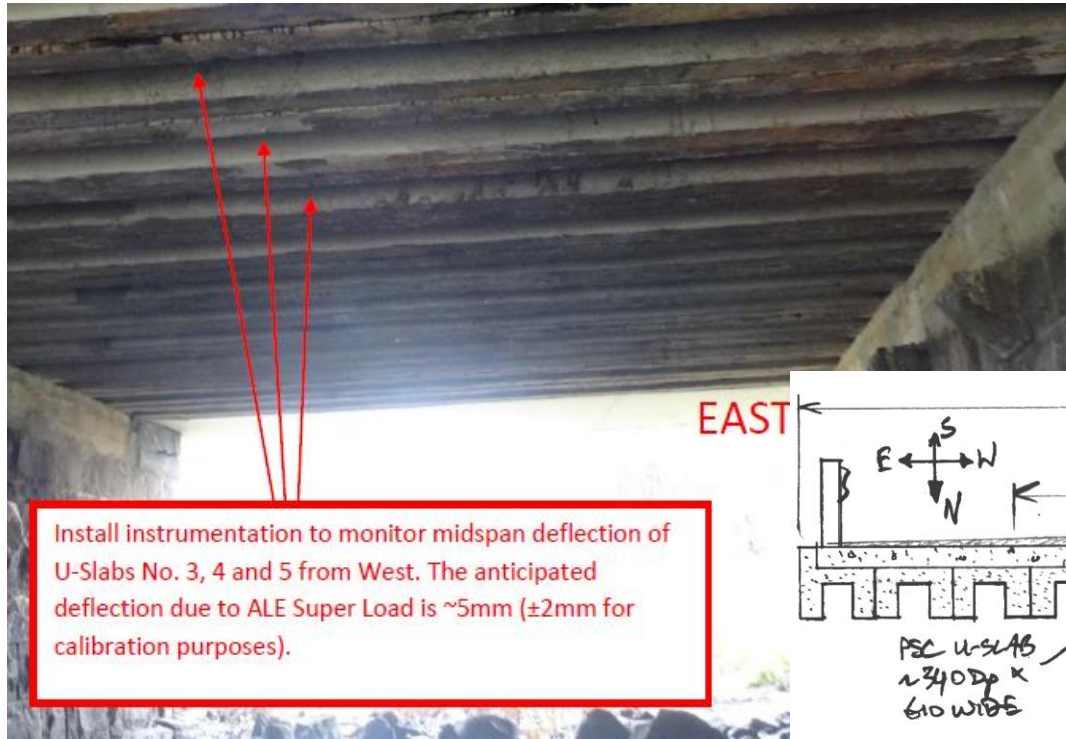
Findon Creek Bridge



FINDON CREEK BRIDGE

ARRANGEMENT

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



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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®

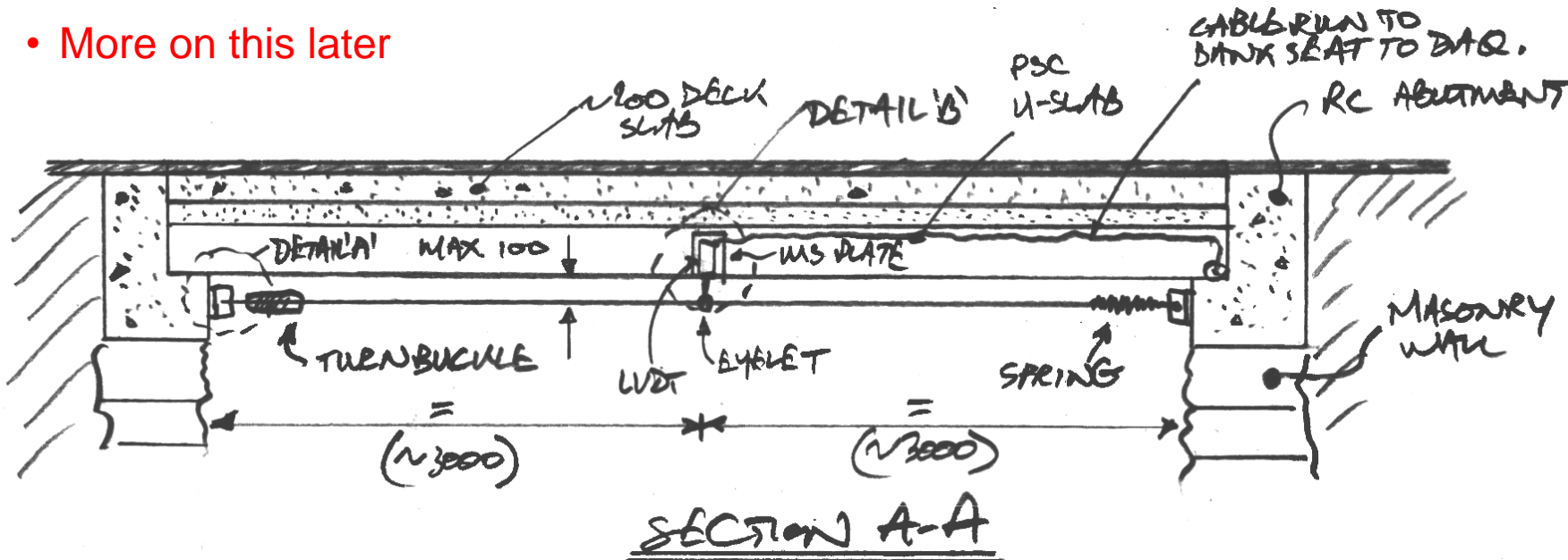
NDT&E International 38 (2005) 213–218

NDT&E
international

www.elsevier.com/locate/ndteint

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

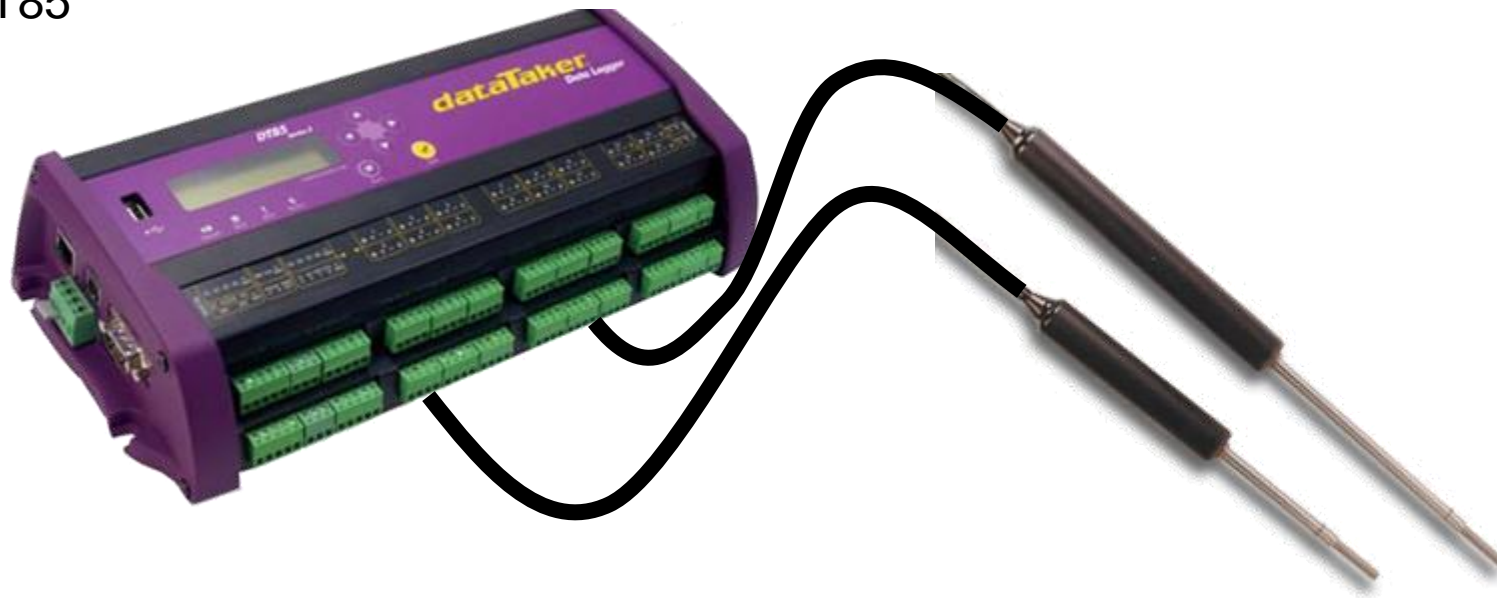
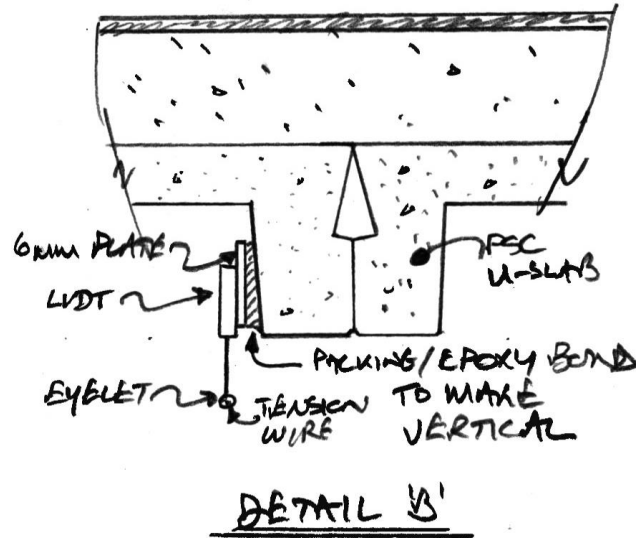
Hani H. Nassif^{a,*}, Mayrai Gindy^{b,1}, Joe Davis^{a,2}



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EQUIPMENT

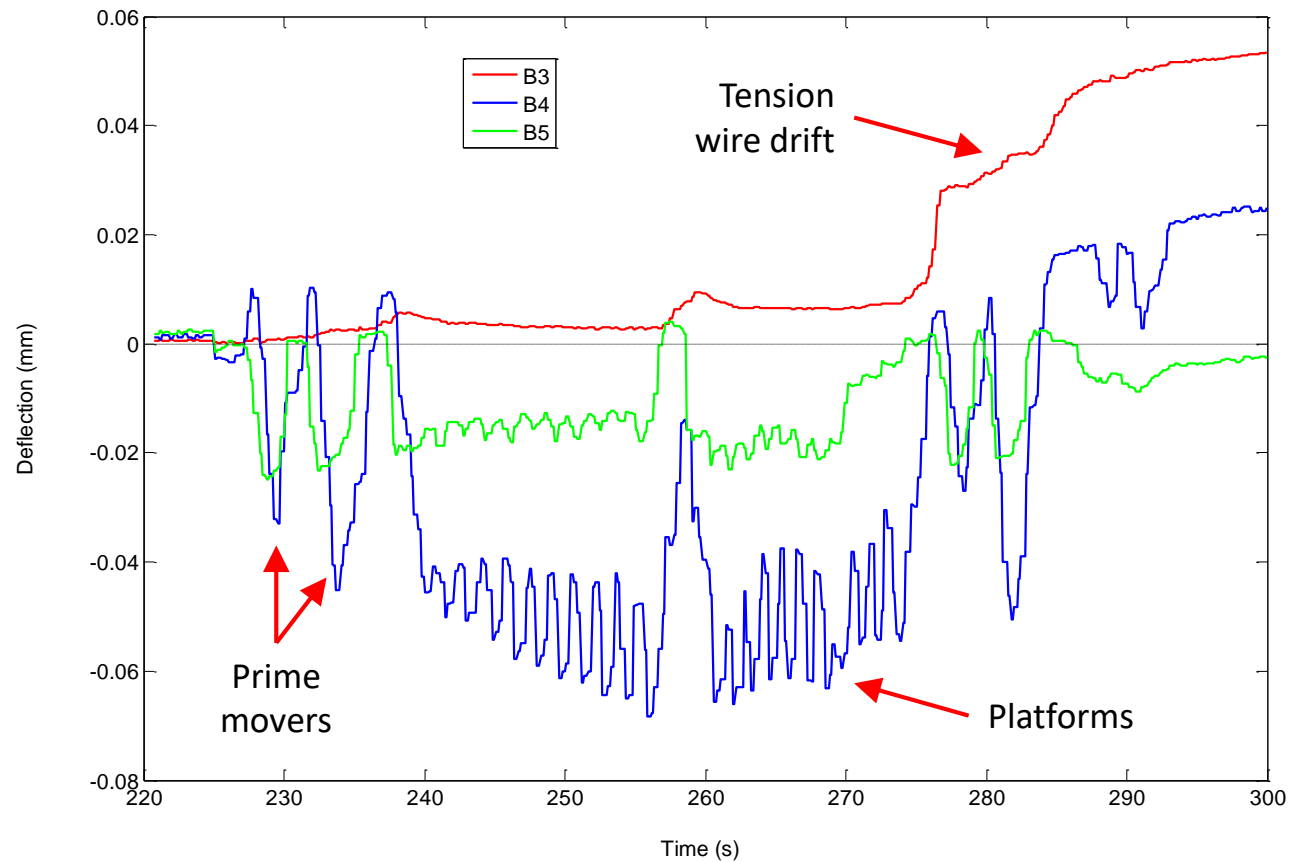
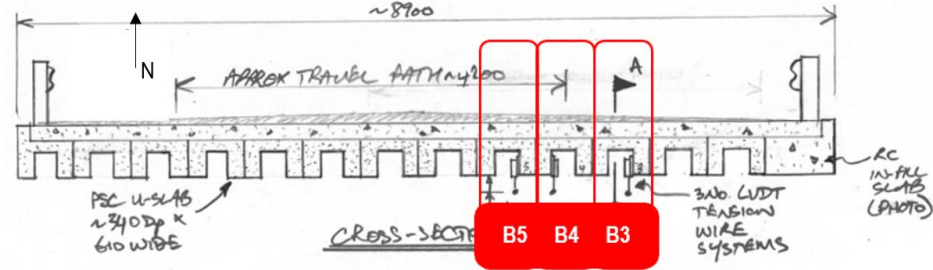
- Linear potentiometers
 - 3 No. 50 mm linear pots
- Wiring
 - 45 m 4-core
- DAQ
 - Datalogger DT85
- Software
 - deFriend



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RESULTS

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



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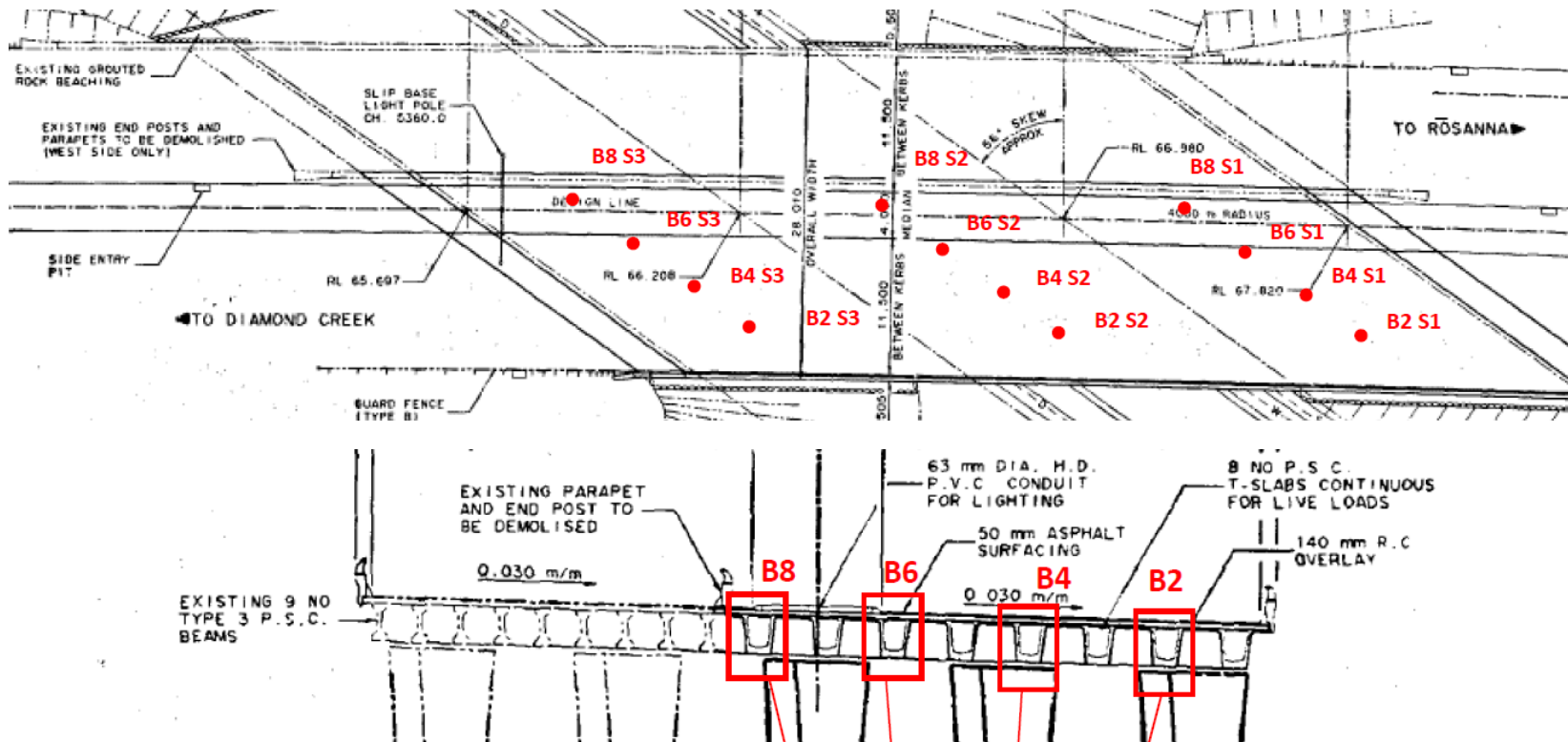
Kempston St Bridge



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

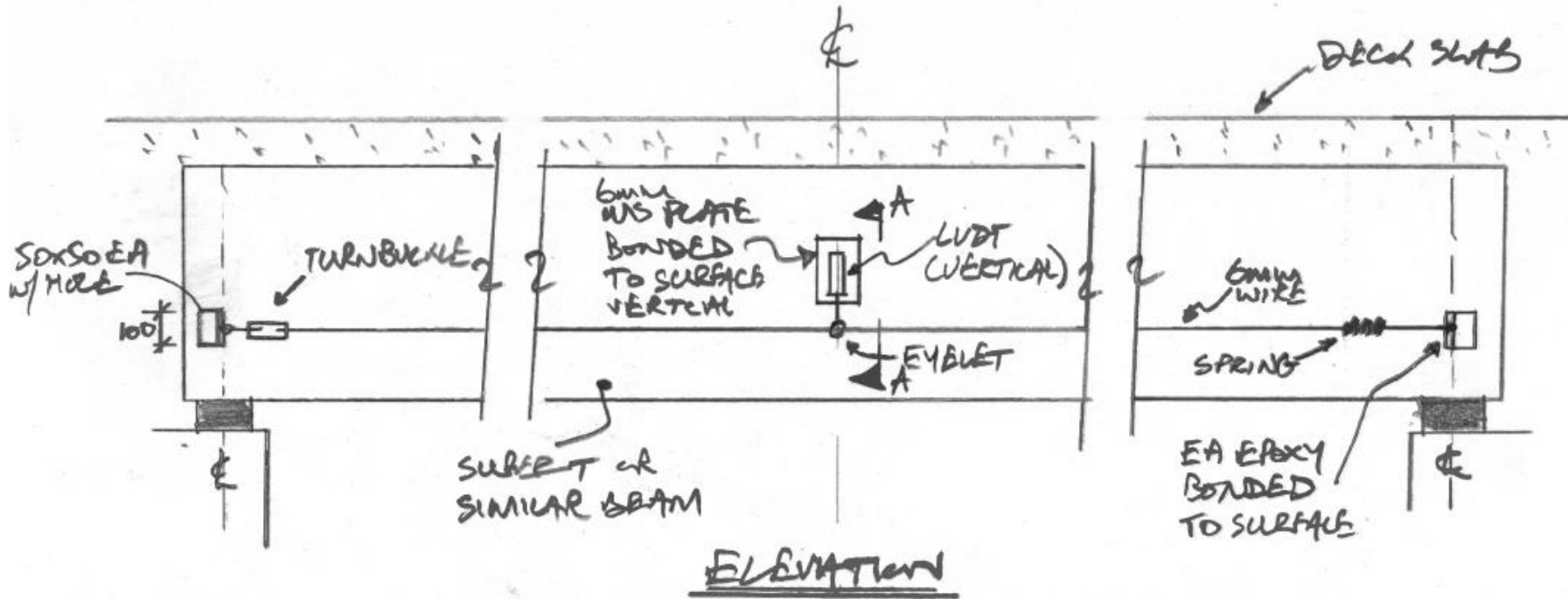
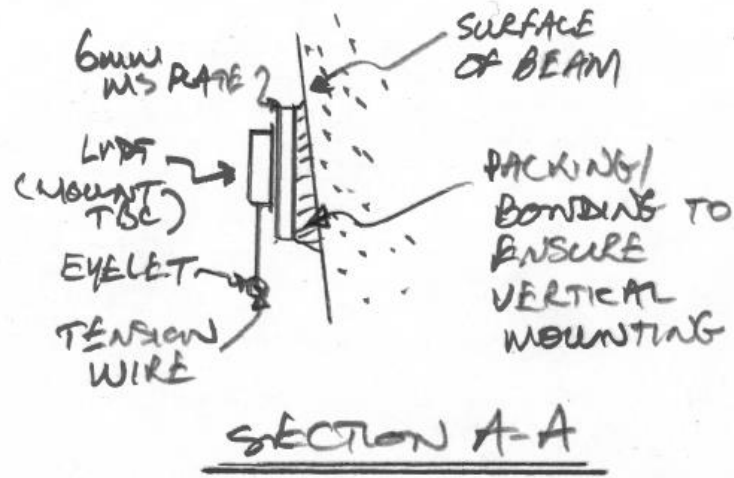
- Deflection measurement using tension-wire system
- Very long cable runs
 - Re-arranged on site
 - Listen to electricians!
- Original plan:



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CONCEPT

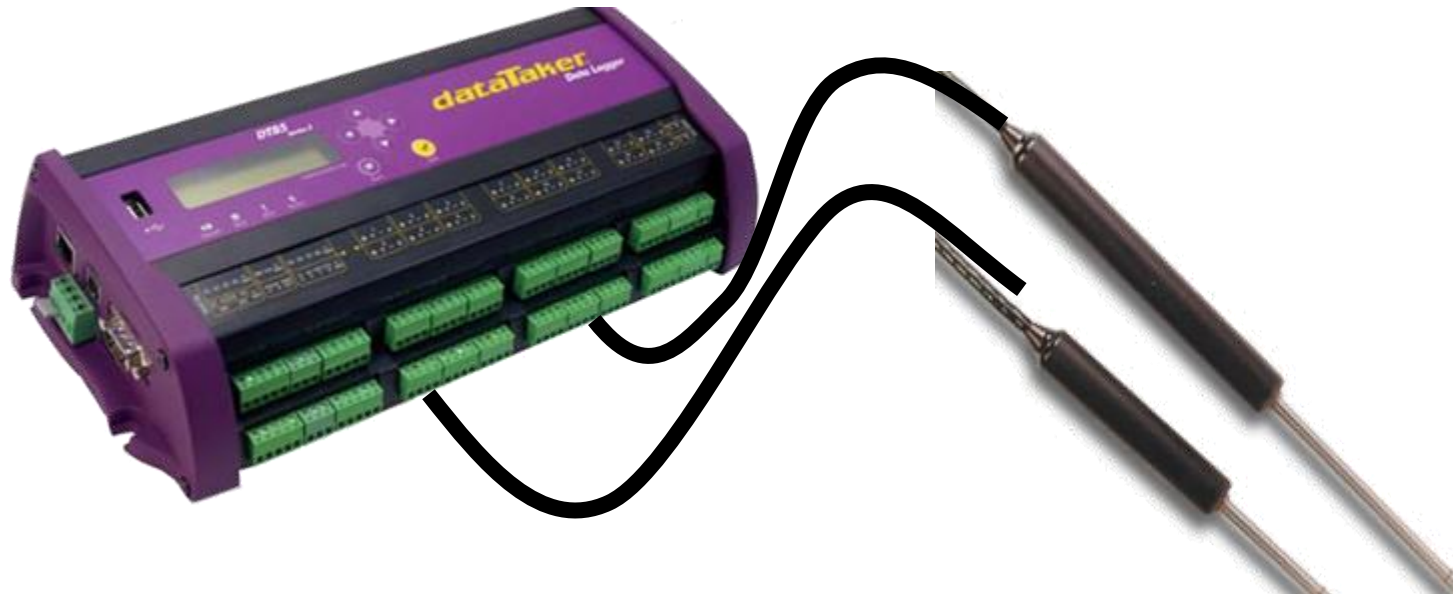
- Tension wire system
- Longer spans
 - Difficulty in obtaining sufficient tension
- Transducer applies about 7 N force at mid-span of cable
- Bracket required for sloping face of Super-T



MONITORING

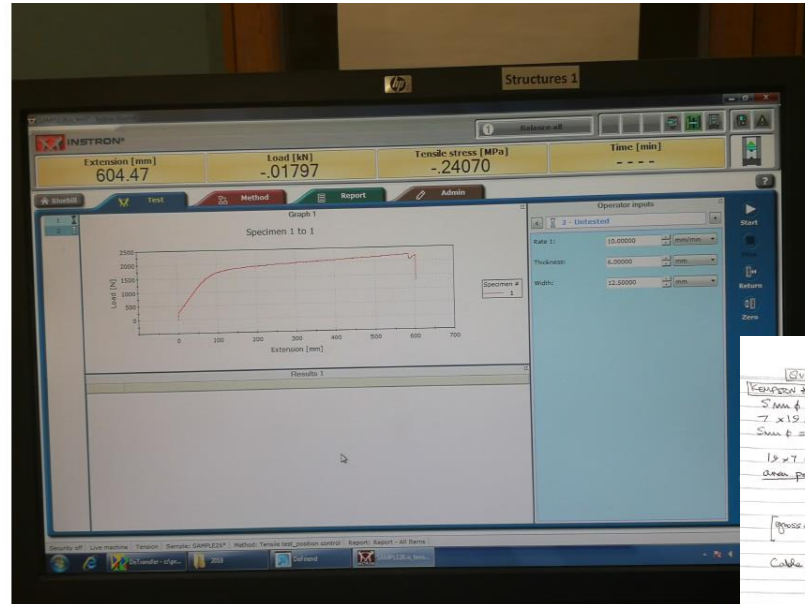
EQUIPMENT

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




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CABLE TENSION



OVERLOAD MONITORING
 KEMRON & MIDDLEBOROUGH BRIDGES - CABLE
 5 mm ϕ wire rope grade 316 Stainless Steel
 7 x 19 stainless wire rope construction
 Size $\phi = 12$ wires $\phi = 0.4166$ in
 $12 \times \pi \times 13^2 = 133$ wires
 Area per wire $\phi = 0.1666$ in $\times \pi = 0.1363$ in²
 $A = 12 \times 0.1363 = 1.636$ in²
 Gross overchuck Stainless solid $\pi \times 12^2 = 19$ in²
 $12 \times 1570 \times 10^3 = 28.26$ kN
 $R = 1570$ MPa
TEST SPRING CAPABILITIES
 1. KEMRON SPRING 280mm long
 2. MIDDLEBOROUGH 170 x 175 mm long
 UNKNOWN SPRING 127mm long
 3. Extension to Kemron 153 mm (280=127)
 Middleborough $\pm 3 \times 48$ mm (210=161)
 Lab test of Spring graph
 Kemron 153 mm extension = 1.8 kN
 Middleborough 45, 143 extension = 1 kN $\times 2 = 2$ kN
 Conclusion \rightarrow Wisconsin standards Kemron to 2 kN
 Middleborough to 2 kN

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



[DOWNLOAD THIS DATA SHEET](#) [CONTACT US FOR PRICING](#)

Product Details

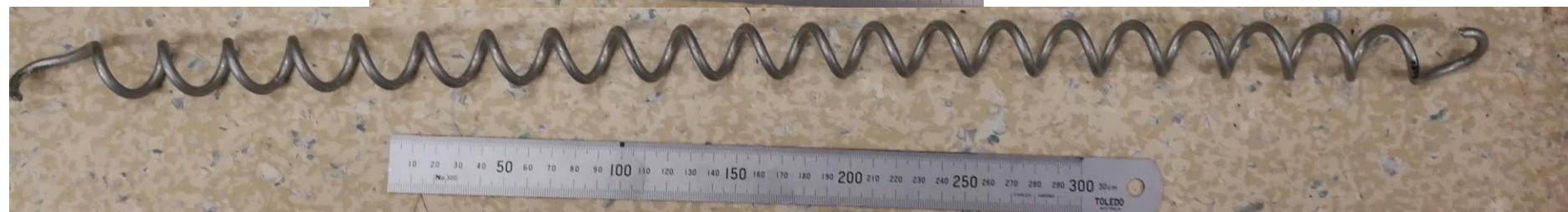
7x19 AISI316 stainless steel wire rope is used for a wide range of applications. Extremely flexible when compared to both 7x19 and 7x21, the 7x19 construction is often used where a flexible stainless steel wire rope is particularly required. 7x19 performs well for running applications. Used extensively throughout the marine industry as well as for general engineering applications, 7x19's excellent flexibility makes it a favourite for control cable and a variety of marine rigging applications, examples of which are shown below.

Applications

- Control cables
- Control
- Standing rigging
- Running rigging
- Control cable
- Marine/Golfcart equipment
- Swing bracket work
- Wire rope slings
- Steel ropes

Breaking Loads

Nominal Diameter	Approximate Mass	Minimum breaking loads - 1578 Mpa
[mm]	[kg/m]	[kN] [kG]
3	0.033	5.80 500
4	0.039	8.80 800
5	0.063	13.90 1,417



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CABLE ANCHORS



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INSTALLATION



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INSTALLATION

Stressing the tension wire

- Combination of fence tensioner and ratchet



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INSTALLATION



Checking elongation of the spring-turnstile system



Checking verticality of the displacement sensor

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VALIDATION

Cross-checking with

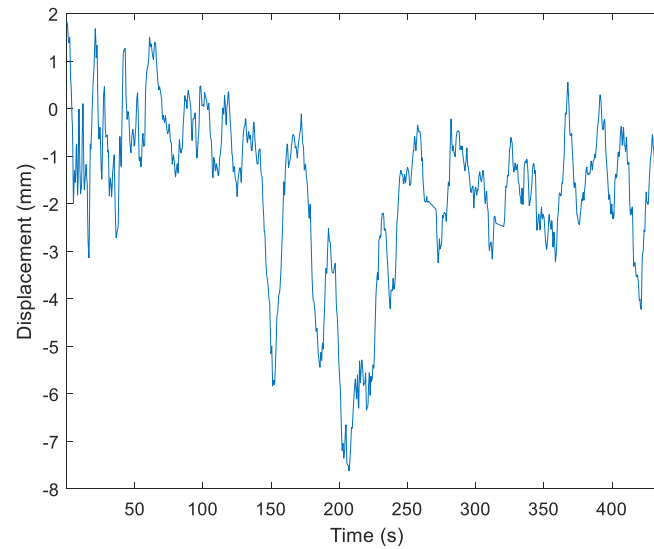
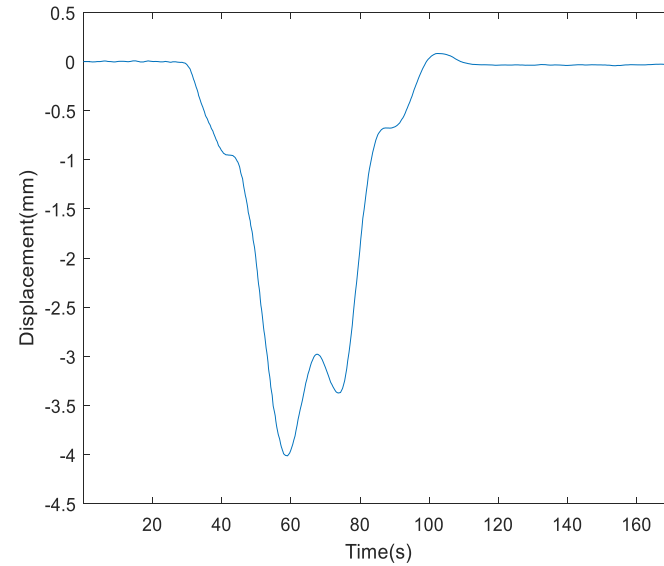
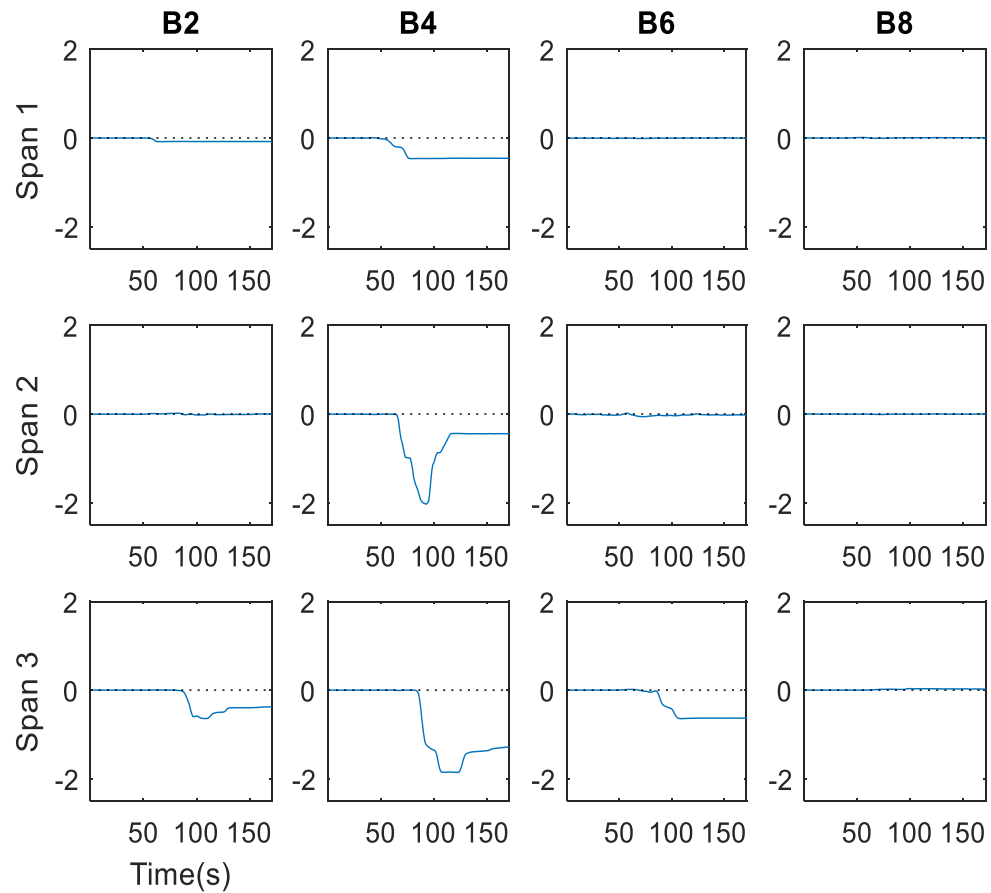
- Strain gauges
 - curvature
- String pot to ground
 - Upper bound
- LDV for baseline
 - Frequency floor issue



MONITORING

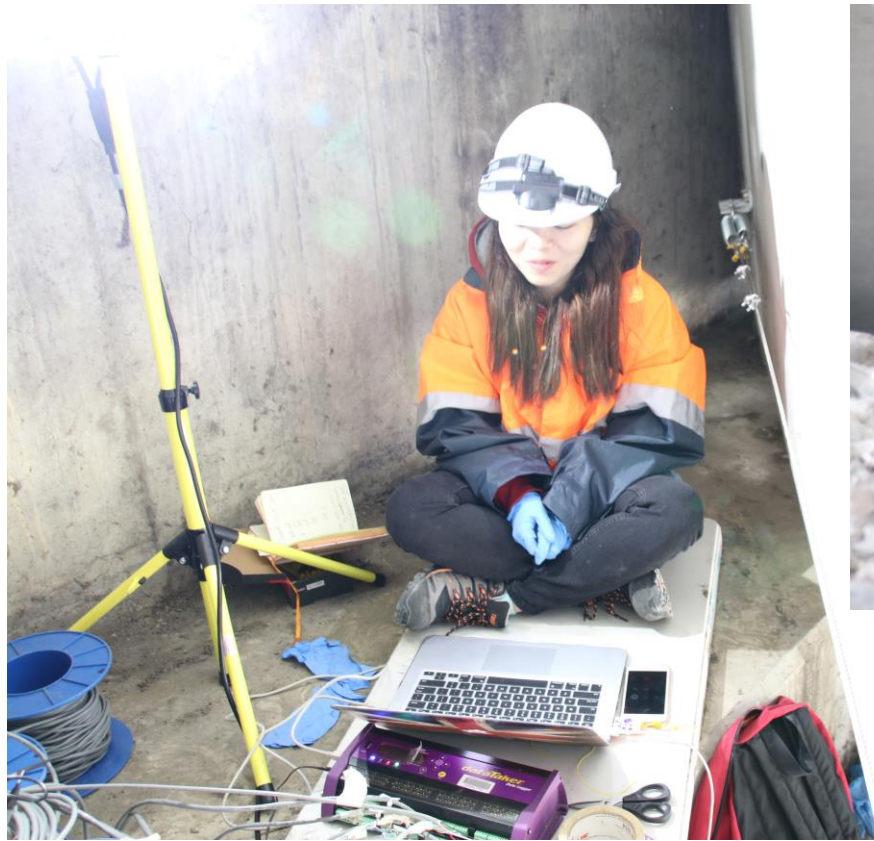
RESULTS

- Good validation essential!



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OTHER MEASURES

RUN-ON PLATES





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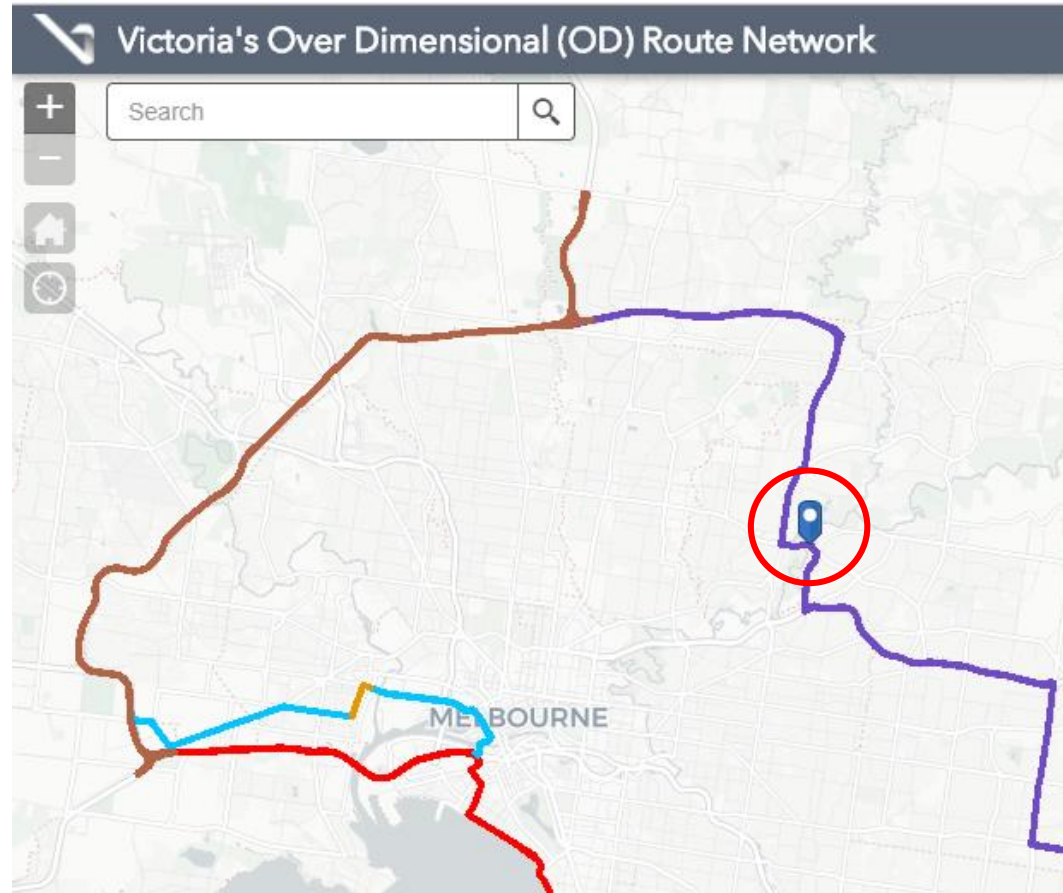
Banksia St Bridge



BANKSIA ST BRIDGE

LOCATION

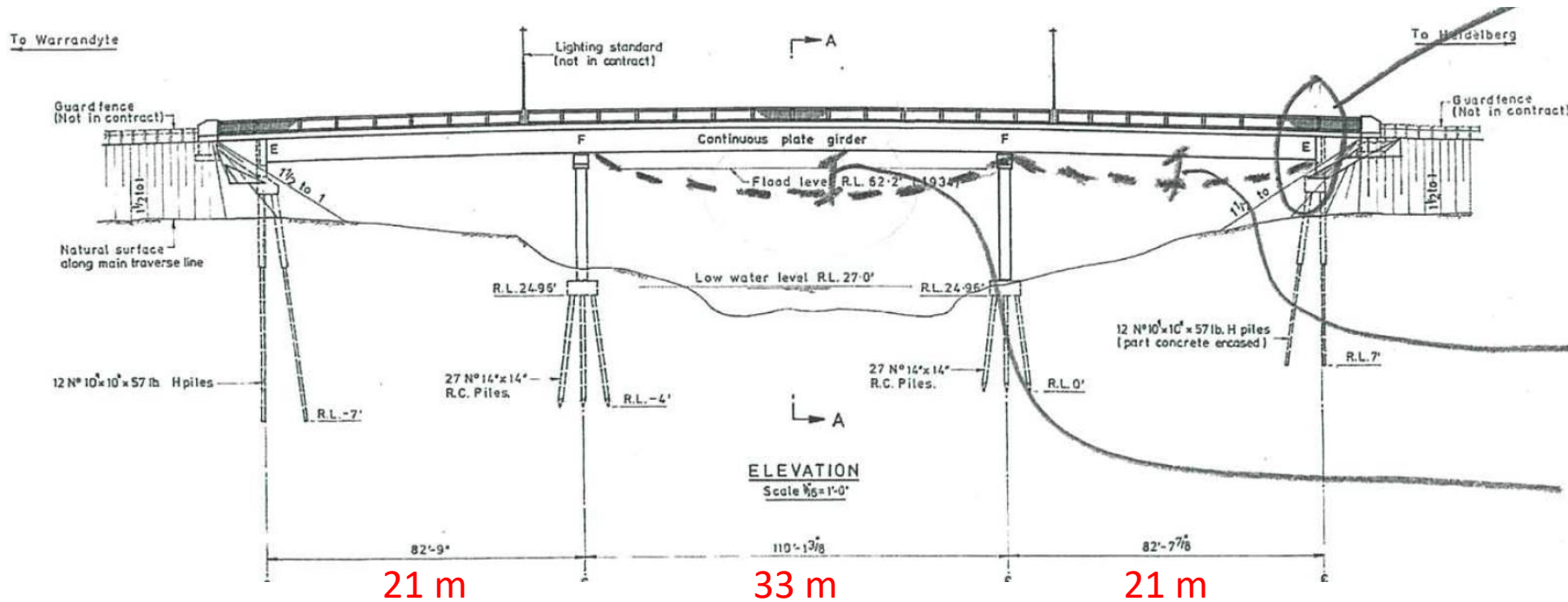
- Critical capacity bottleneck on OD1
- Vital until North-East Link is built
- Crosses Yarra River in sensitive habitat



BANKSIA ST BRIDGE

ARRANGEMENT

- 3-span continuous steel plate girder bridge
- Monitoring required:
 - 3 No. plate girders
 - Spans 1 & 2 (symmetry accepted for span 3)

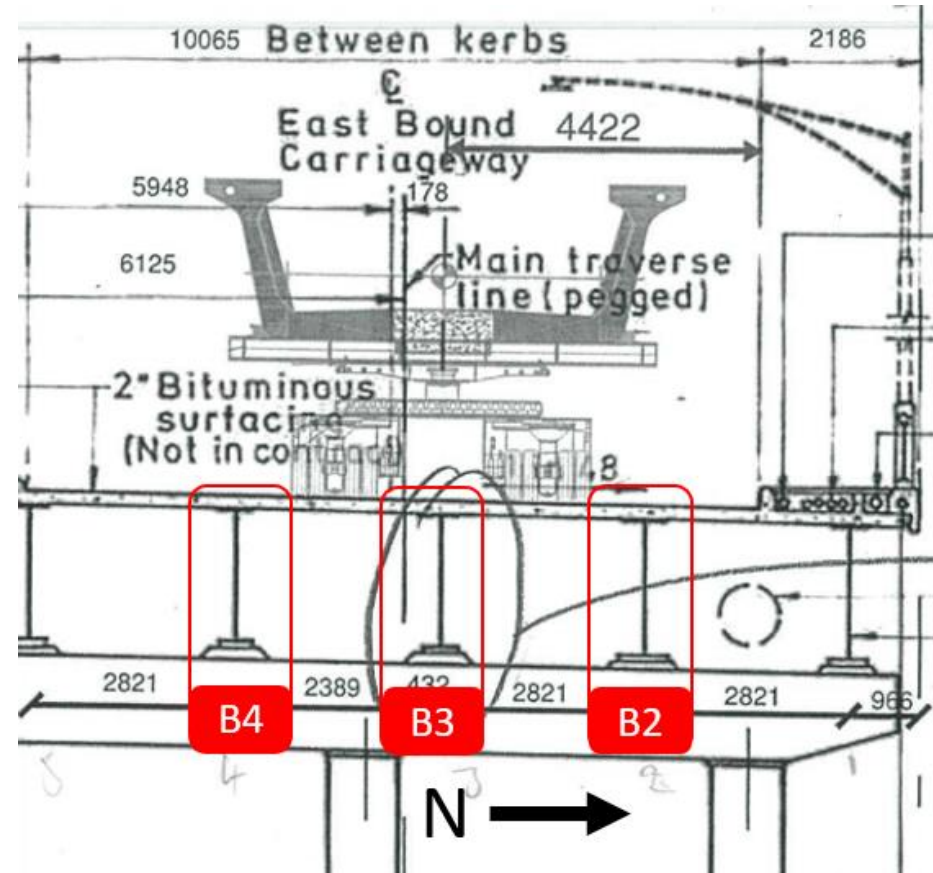


BANKSIA ST BRIDGE

ARRANGEMENT

Critical elements:

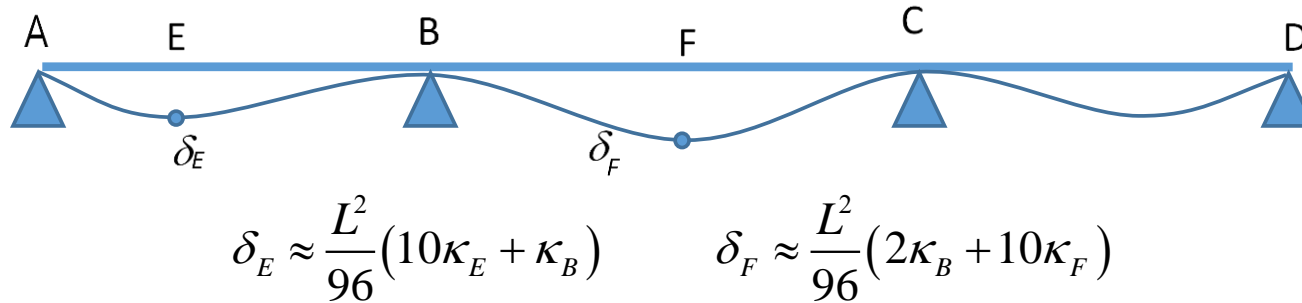
- Deck
- Run-on slabs
- Bracing
- Crosshead
- Girders



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CONCEPT

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

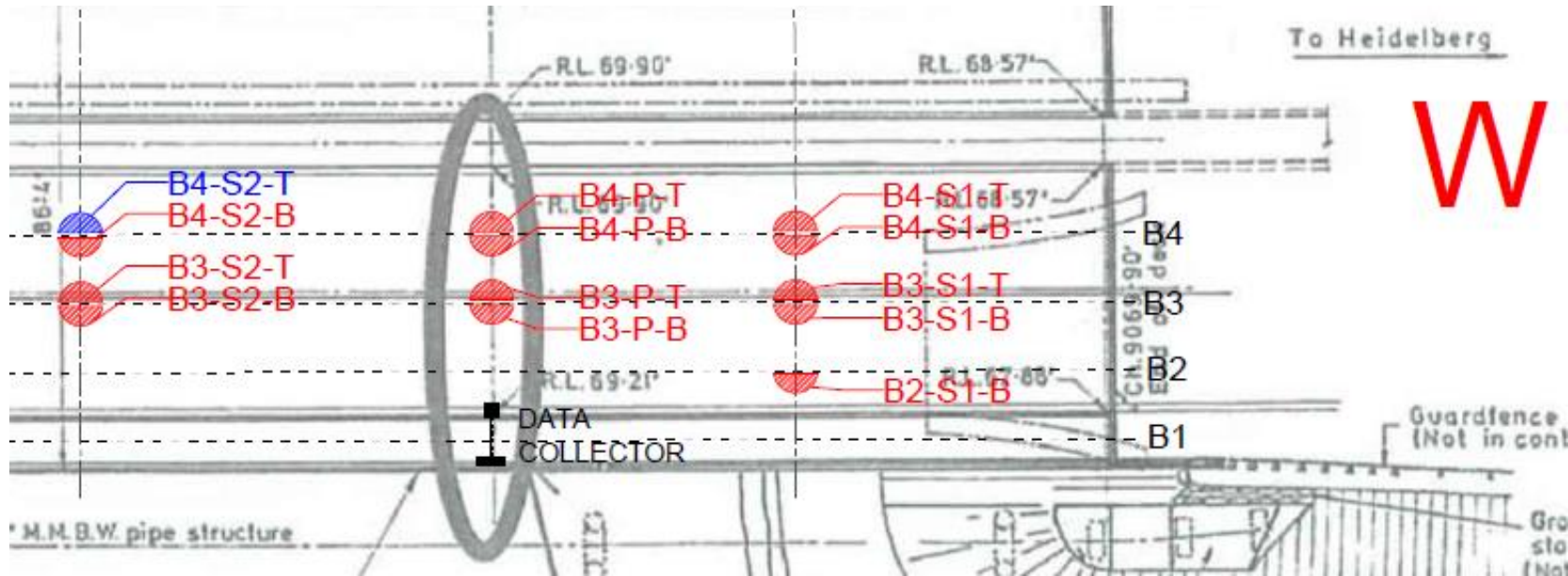


- Required 18 wireless node strain gauges
 - 3 girders x (2 mid-spans + 1 hogging support) x 2 gauges
- Only 12 wireless node strain gauges available

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CONCEPT

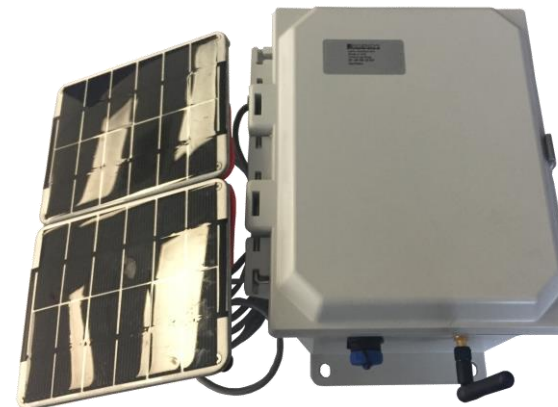
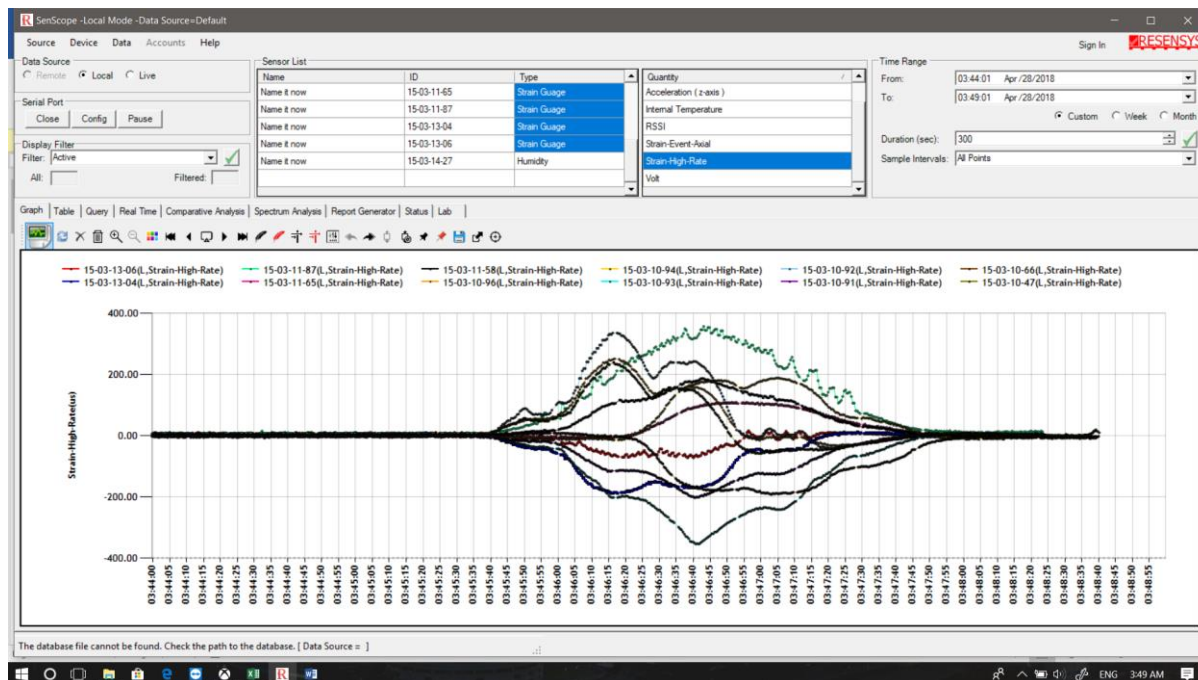
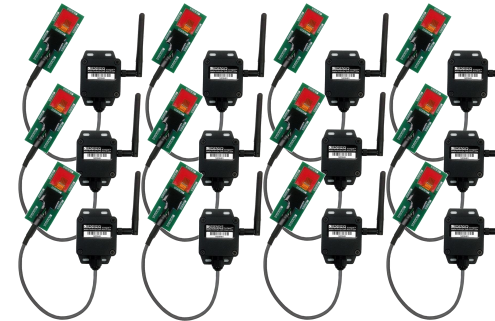
- Solution:
 - use symmetries along and across the girders



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EQUIPMENT

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



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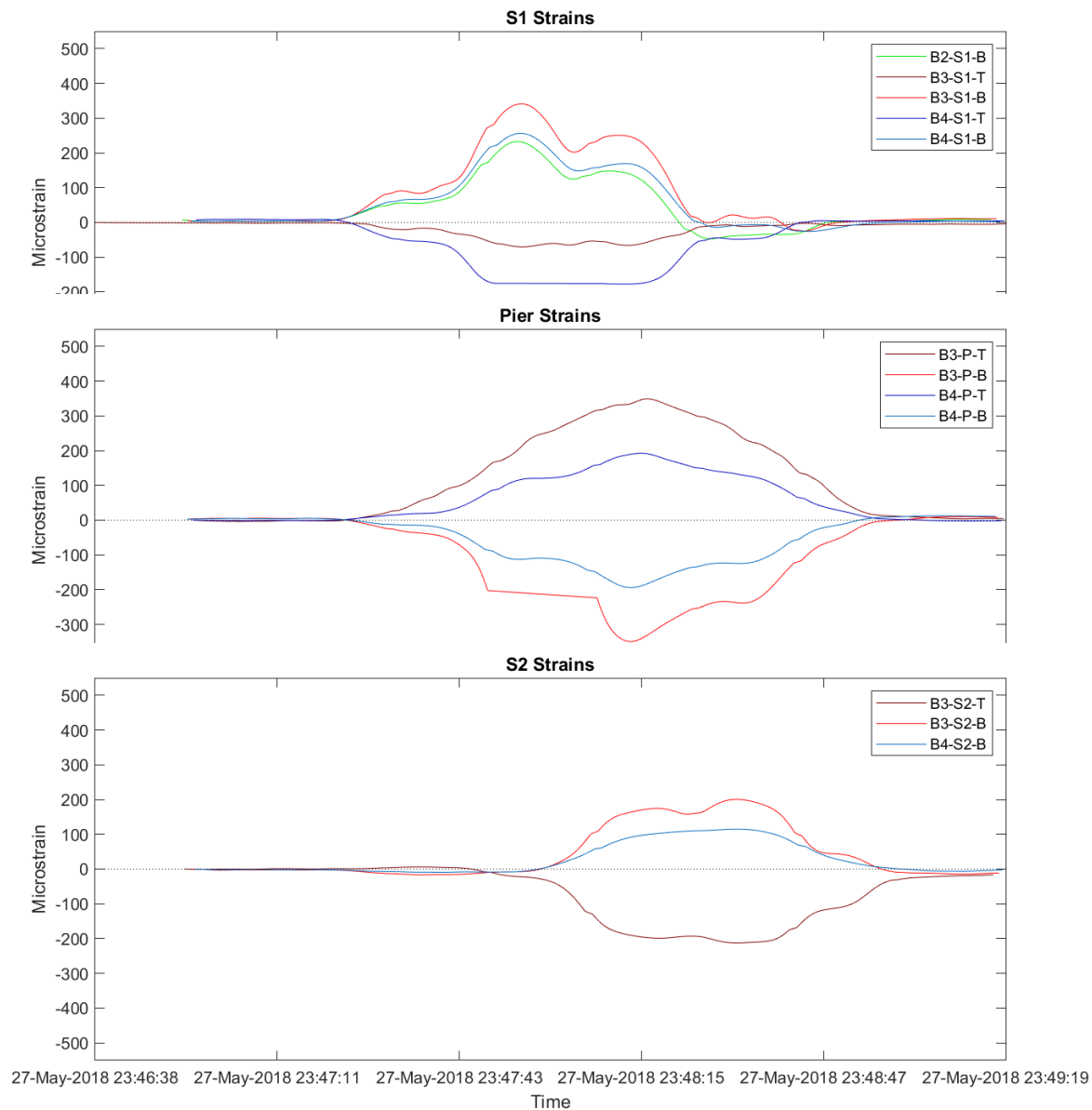
INSTALLATION



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RESULTS

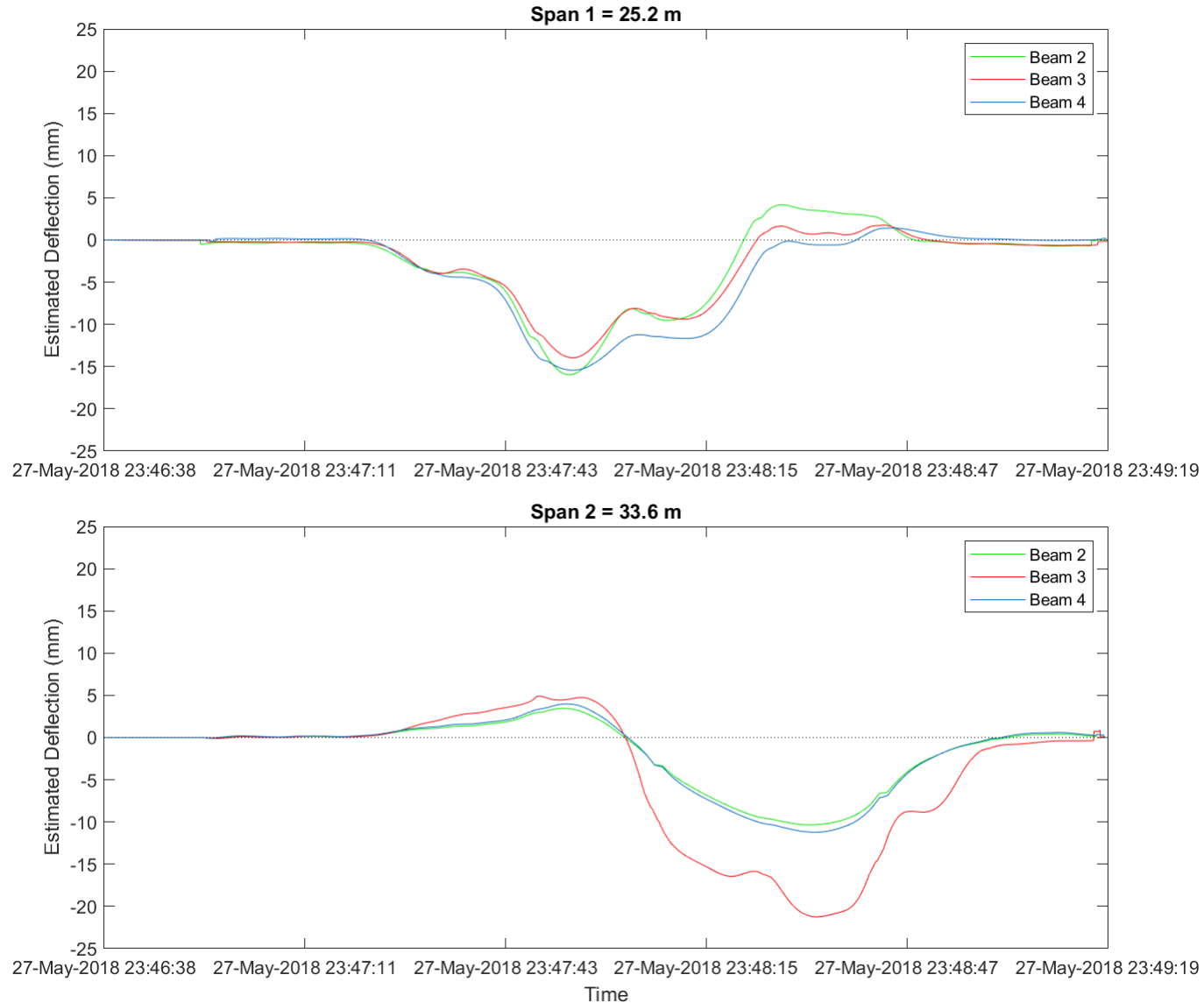
- Raw:



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RESULTS

- Processed:



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Middleborough Rd Bridge



MIDDLEBOROUGH RD BRIDGE

LOCATION

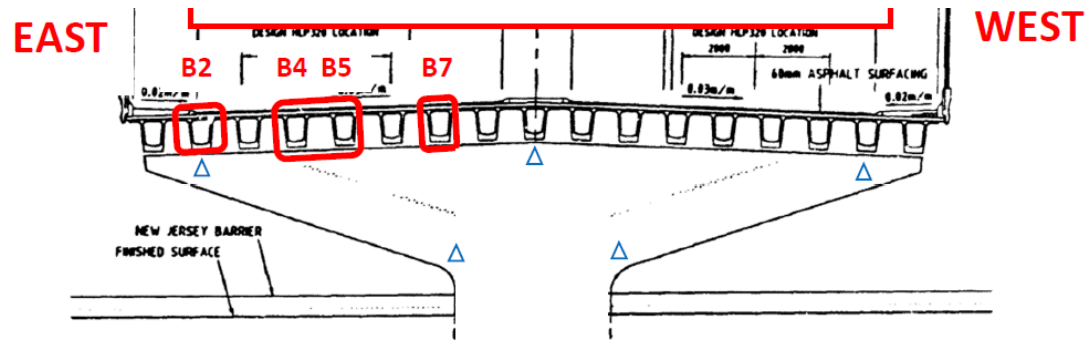
- Crosses the Eastern Freeway
 - Road closure not possible
- Superload to turn onto bridge
 - Potential difficulty in maintaining appropriate wheel path



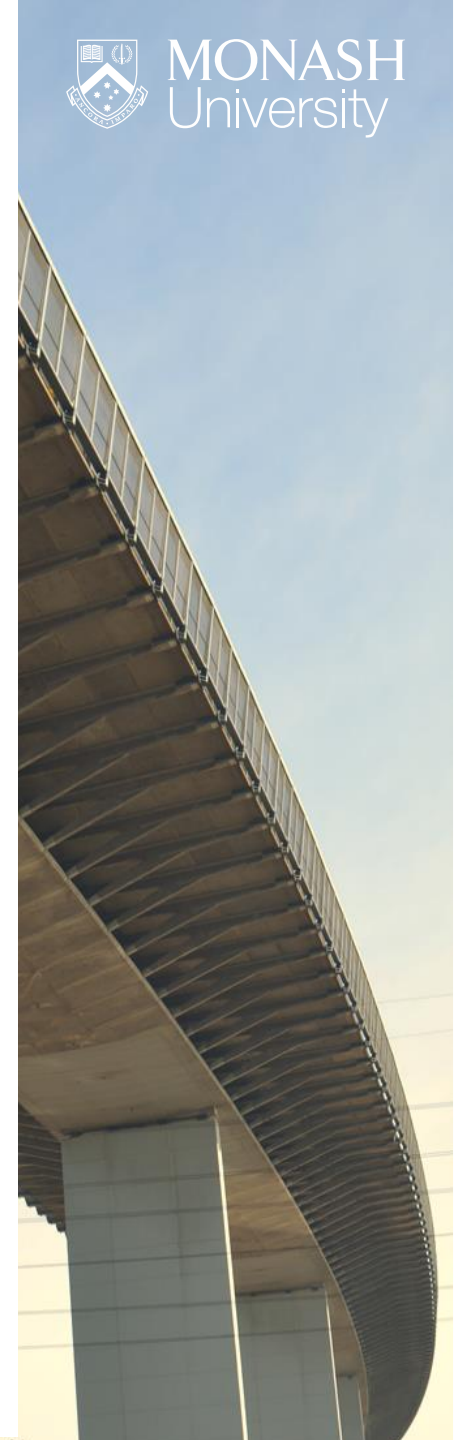
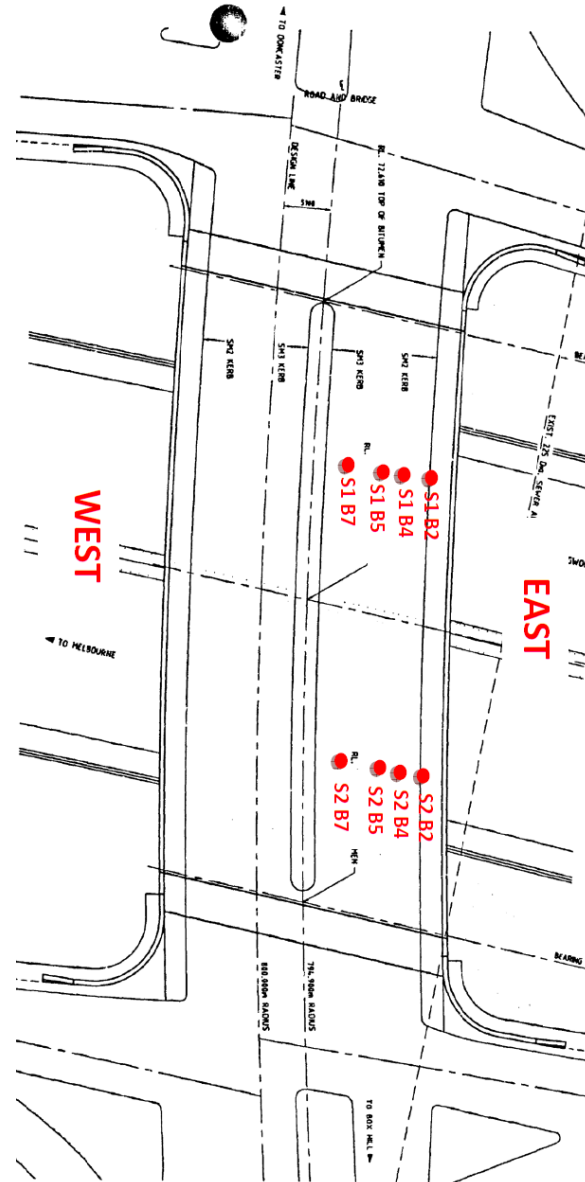


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- 2-span ABC Super-T
 - Simply-supported
- 33 m spans
- 4 beams per span



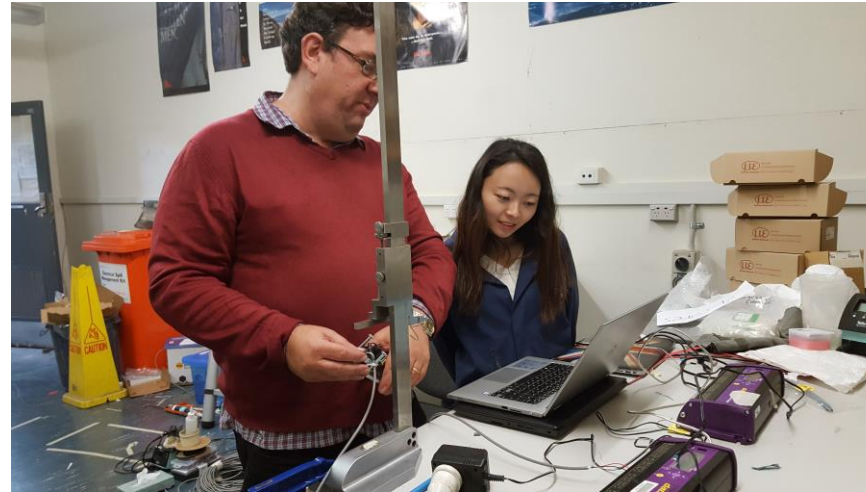
- Use tension wire system



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EQUIPMENT

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



Lab calibration of systems



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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



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VALIDATION

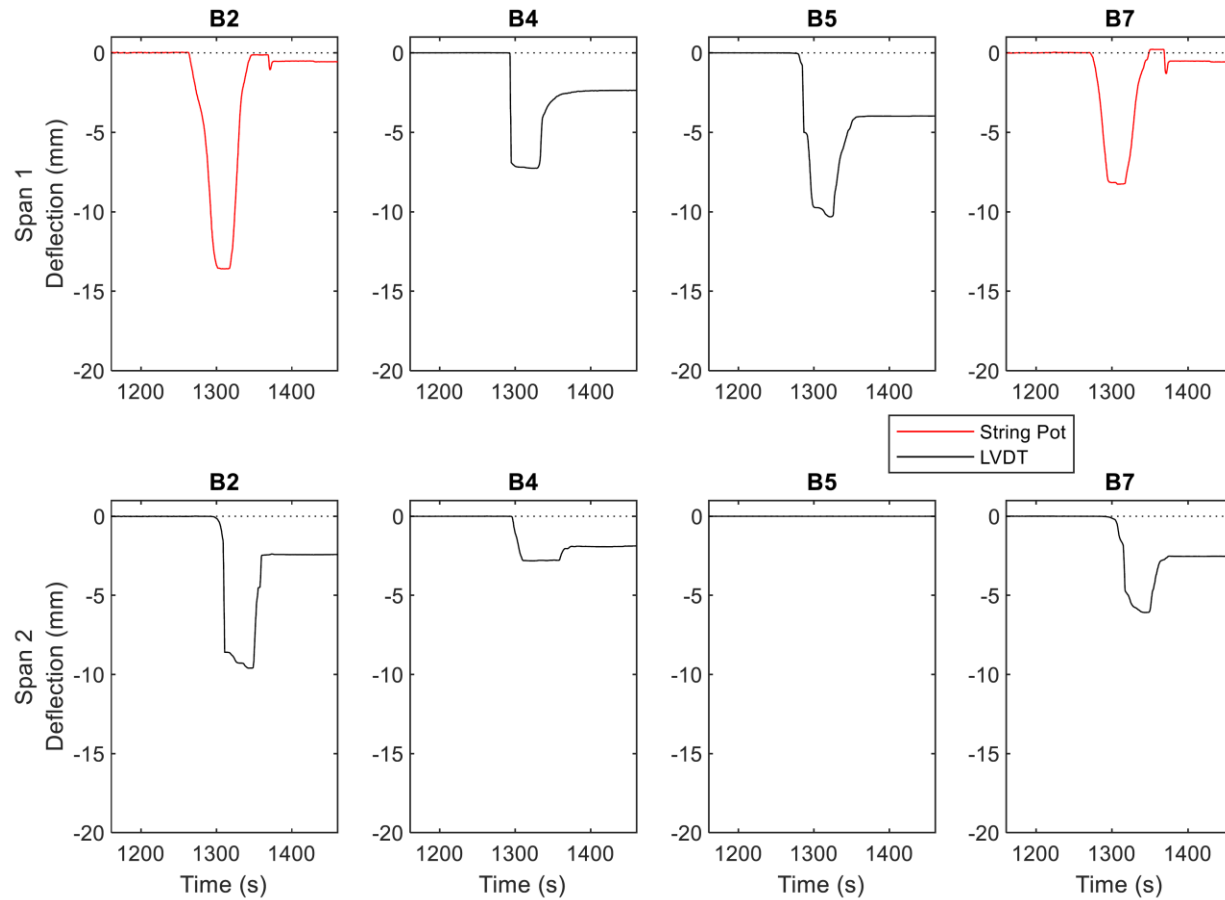


In-situ checking of string-pot calibration

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RESULTS

- Some tension wire 'stickiness'



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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	

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WHEEL PATH CHECKING



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CONCLUSIONS



ACKNOWLEDGEMENTS

KEY TO SUCCESS

- **John Holland**

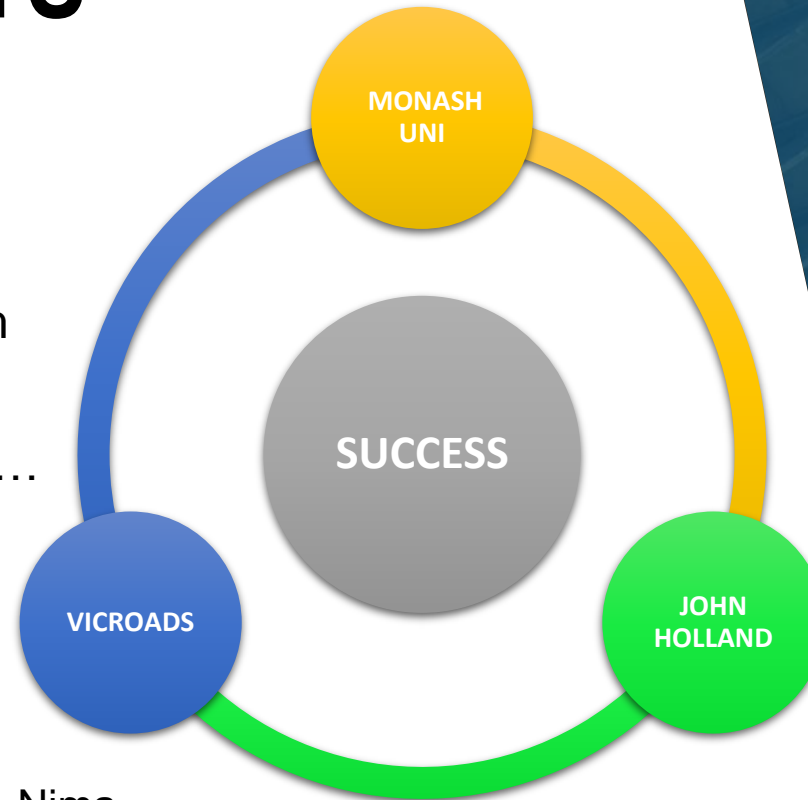
- Amanda, Jim, Scott, Dave, Sean and team

- **Vicroads**

- Andy, Yew-chin, Nick, Andrew, Suki, Hong...
- TSS Officers

- **Monash Uni**

- Pippa, Long, Mark, Rachel, Noi, Pauline
- 25 postgraduate students:
 - Mayer Melhem, Jianghua Deng, Solomon Lin, Nima Sadeghi, Armin, Yu Fung Lee, Timothy Lui, Mario Melhem, Ehsan Ahmadi, Yunlong Tang, Ahmed Murgab Mohammed Mahil, Amir Eslamikhousani, Justin Ngan, Ayal Wanniarachchi, Radhika De Silva, Pabita Sijapati, Sobhan, Manoj, Seyyed Sobhan, Mohammed Al-Ameri, Shaohua Zhang, Sajjad Hosseini, Manoj Samarakoon, Joseph Lee
- Jinghan Lu from Melbourne Uni



FINALLY...

POSITIVE IMPACT FOR VICTORIA

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





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THANK YOU!

