#CCSA 2023 @ WORK

Be inspired – be energised

CONDITION MONITORING: PRACTICAL IMPLEMENTATION – LESSONS LEARNT

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CEMENT & CONCRETE SA

"When you can measure what you are speaking about, and express it in numbers, you know something about it. But when you cannot measure it, your knowledge is of a meager and unsatisfactory kind. You have scarcely advanced to the stage of science"

Lord Kelvin (1891)

STRUCTURAL HEALTH MONITORING

Structural health monitoring (SHM) uses sensors that are permanently placed on a structure to monitor the structural behaviour over time. These sensors should be affordable, lightweight, and unobtrusive so as not to interfere with the structural strength or behaviour.

- Why monitor a structure?
- What can be measured?
- Different sensors
- Material properties
- Restrained vs free behavior
- Environmental conditions
- Installation on site
- Logging
- How much will it cost?
- What can go wrong?
- Data management
- Examples of monitoring projects

WHY MONITOR A STRUCTURE?

Structural Health Monitoring is used to detect and quantify changes to the material and geometry of a structure over time. Careful analysis of specific measurement points can be used to:

- Detect damage
- Facilitate performance based design
- Assess the condition of the structure
- Predict remaining service life

- What is the cost of not monitoring a structure? (consequences of damage to structure?)
- Could structural health monitoring lead to a CO_2 saving? (i.e. not having to build a new structure)

WHAT CAN BE MEASURED?

- Temperature
- Strain
- Pressure
- Acceleration
- Displacement
- Tilt (relative displacement)

SENSORS - TEMPERATURE

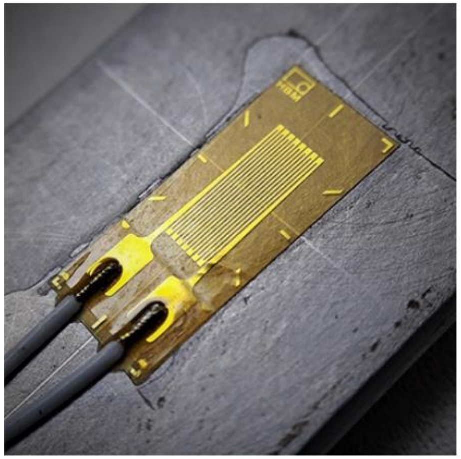
Thermistors

- a type of resistor whose resistance is strongly dependent on temperature. The resistance difference is measured and temperature can be calculated.
- Fairly accurate ±0.2 °C from 0°C to 70°C
- good long-term stability

Thermocouples

- an electrical device made up of two wire of different materials that form a junction. The voltage that can be measured between the wires is temperature dependent.

SENSORS - STRAIN



Electrical resistance strain gauges

- Measure the change in electrical resistance across a thin conductive foil. A gauge factor is used to converts the change in resistance to the change in length
- Short term loading – readings can drift with time
- Configuration is important
- Static / dynamic loads

Vibrating wire strain gauges

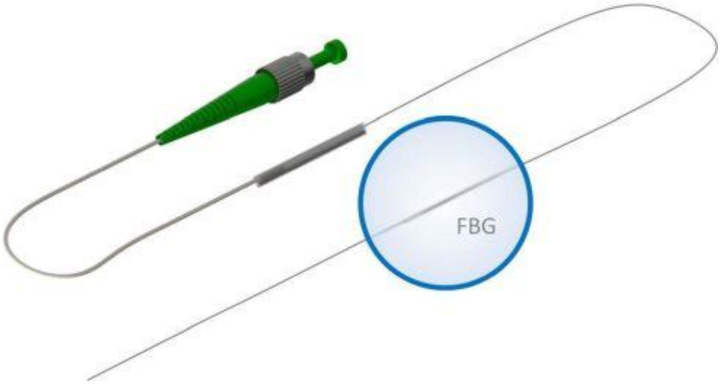
- A tensioned wire, when plucked, vibrates at a frequency that is proportional to the strain in the wire
- Long term loading
- Static / dynamic loads
- Temperature also measured

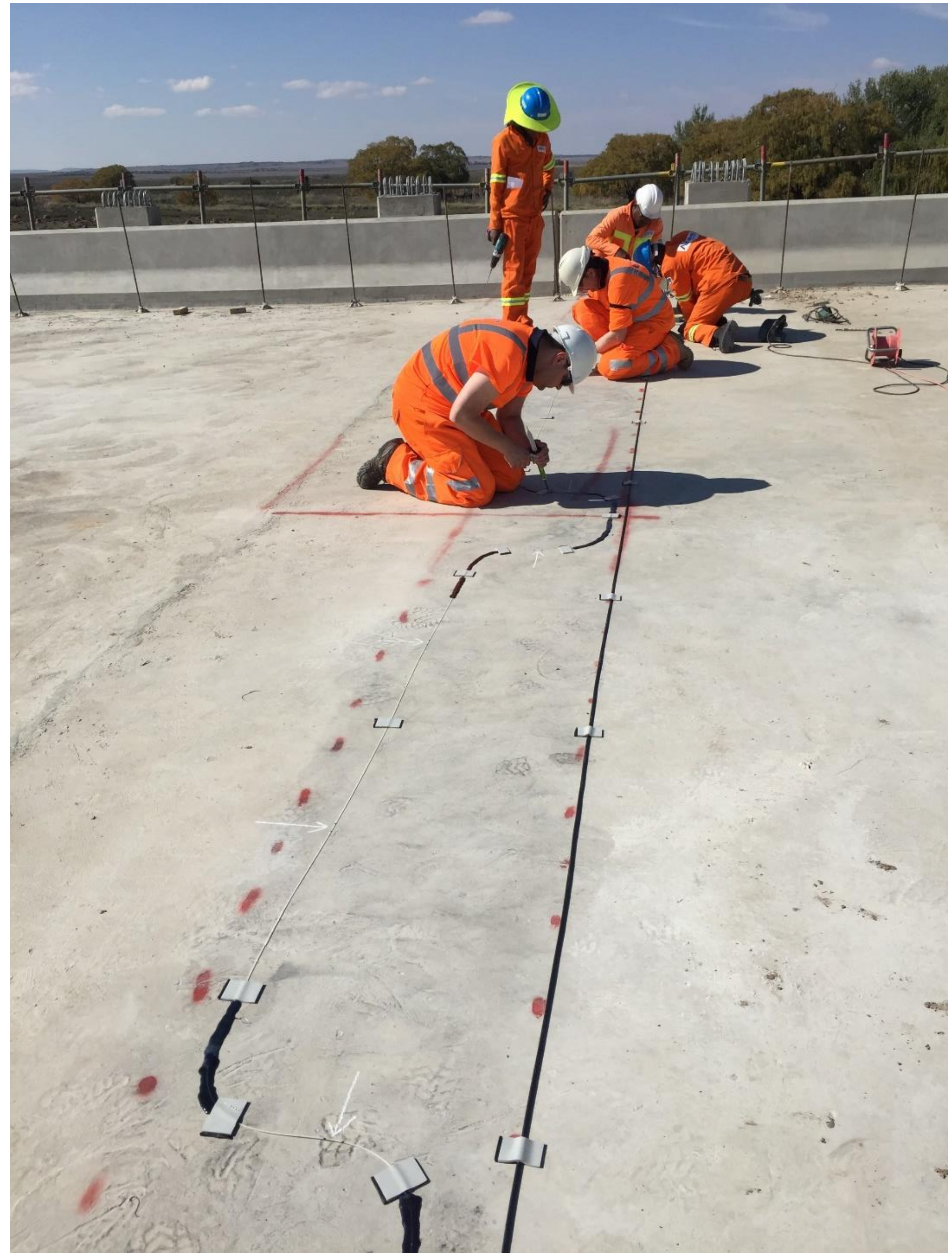

No9 13.53
No10

SENSORS - STRAIN

Fibre bragg gratings (FBG's)

- Normal fibers have uniform refractive index along their length
- In FBG's the refractive index of the core changes at specific points
- The change in light wave length measured at these specific points, and strain can be calculated from this.
- Non-destructive testing; multiple sensors on a string; light weight; can measure dynamic loading (> 50Hz for dynamic measurements)



SENSORS – EARTH PRESSURE

Pressure cells

- The vibrating wire pressure cells are based on vibrating wire technology.
- A type of sensor that converts stress or pressure into a measurable and readable electrical unit.
- Used to measure total stress in various geotechnical construction fields.

SENSORS – TILT

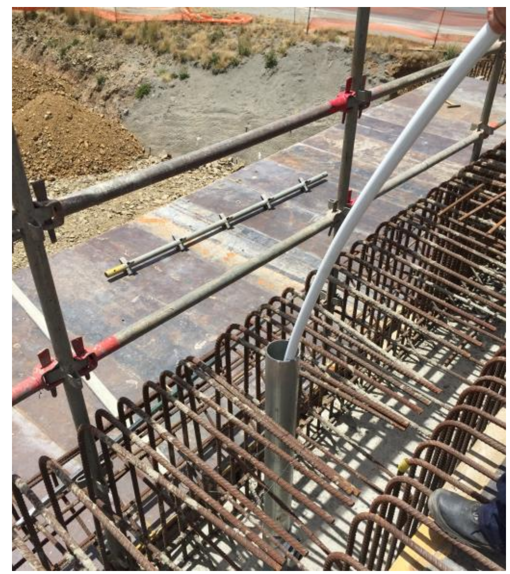
Tilt meter

- Sensitive inclinometer designed to measure very small changes from the vertical level, either on the ground or in structures

SENSORS – TILT

Shape Accel Array

- Chain of rigid segments connected by flexible joints.
- Joints are designed to resist twist but allow the segments to tilt in x, y and z directions
- Relative displacement can be calculated



SENSORS – ACCELERATION

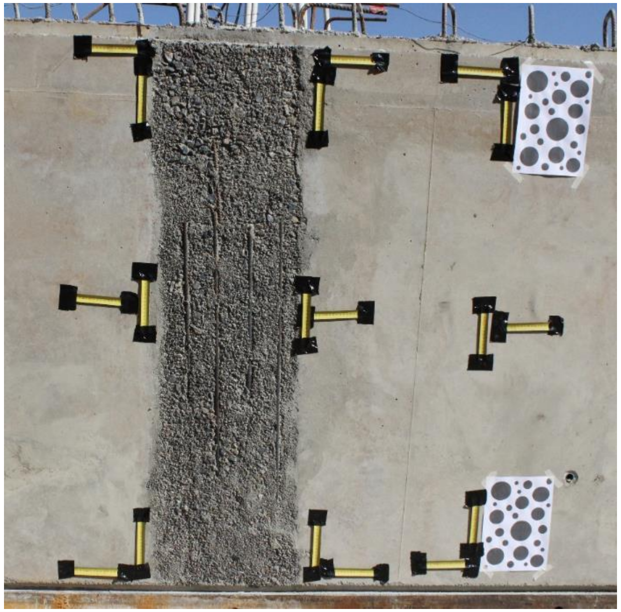
Accelerometers

- Measures the acceleration of any body or object.
- Natural frequency - modal reactions change if there is damage
- Mobile apps can offer good accelerometers – just as good as bought ones.
- Smart phone app used (e.g. pothole detection)
- Fast Fourier transformation can be used to calculate deflection.
- In the future we might be able to use a phone to do a simple model vibration analysis on slabs.

SENSORS – VISUAL TECHNIQUES

Particle image velocimetry (PIV)

- Measurement displacement taking a series of photos during loading and then using software to post-process the photo image data.

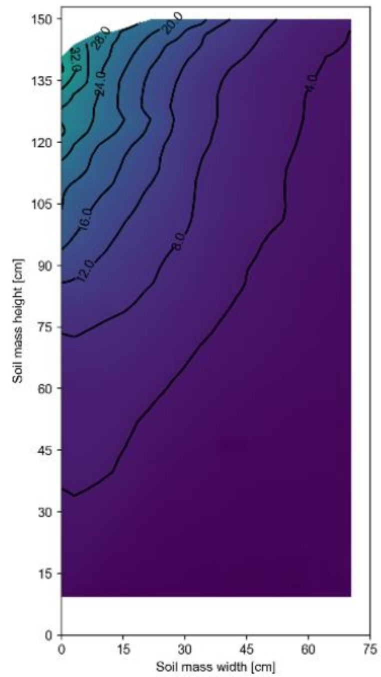


PIV measurements done on a prestressed beam while pre-stressing cables were cut

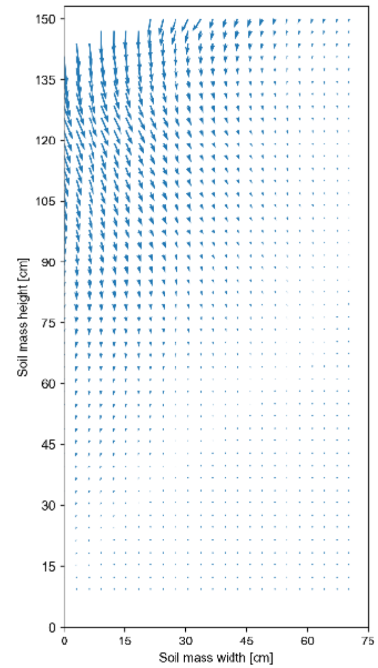
SENSORS – VISUAL TECHNIQUES

Particle image velocimetry (PIV)

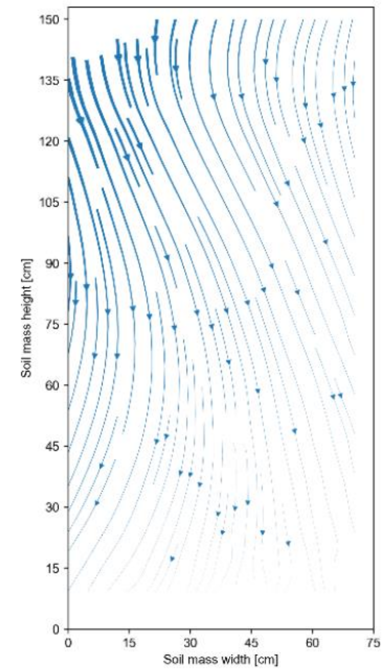
Scaled model of bridge abutment



Sand displacement



Field vectors



Streamlines

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MATERIAL PROPERTIES

Material testing

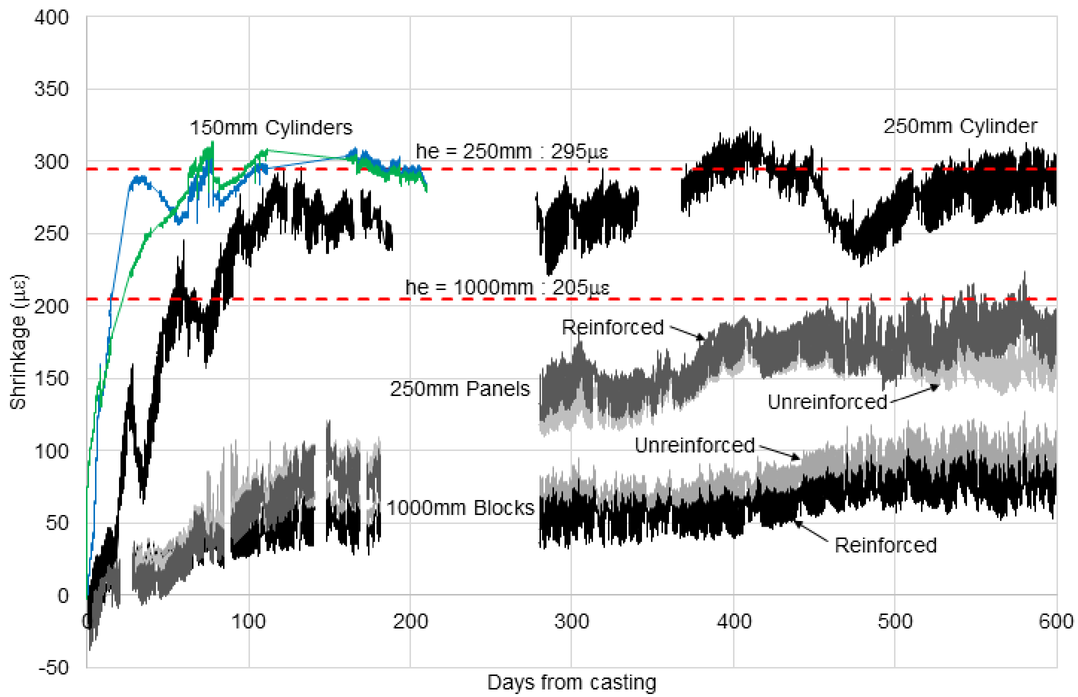
Concrete – E value, coefficient of thermal expansion, MOR, drying shrinkage

Steel – E value, coefficient of thermal expansion

Timber – E value, coefficient of thermal expansion

RESTRAINED VS FREE BEHAVIOUR

What strain are you measuring? Mechanical, thermal, shrinkage, creep?



Reference structures shrinkage strain

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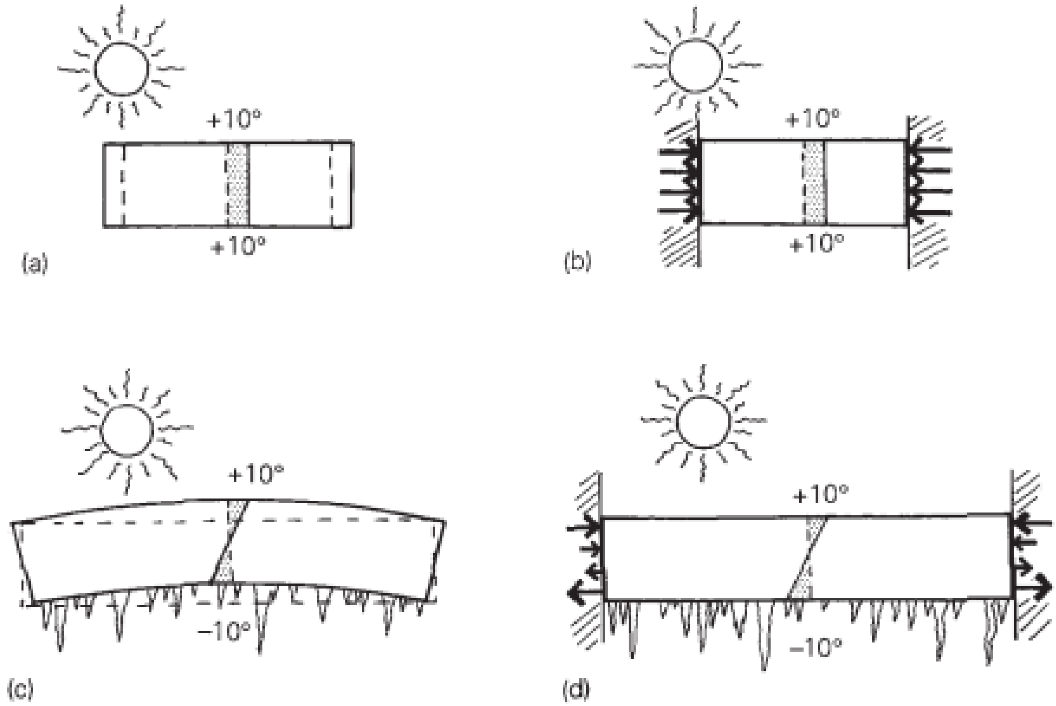
RESTRAINED VS FREE BEHAVIOUR



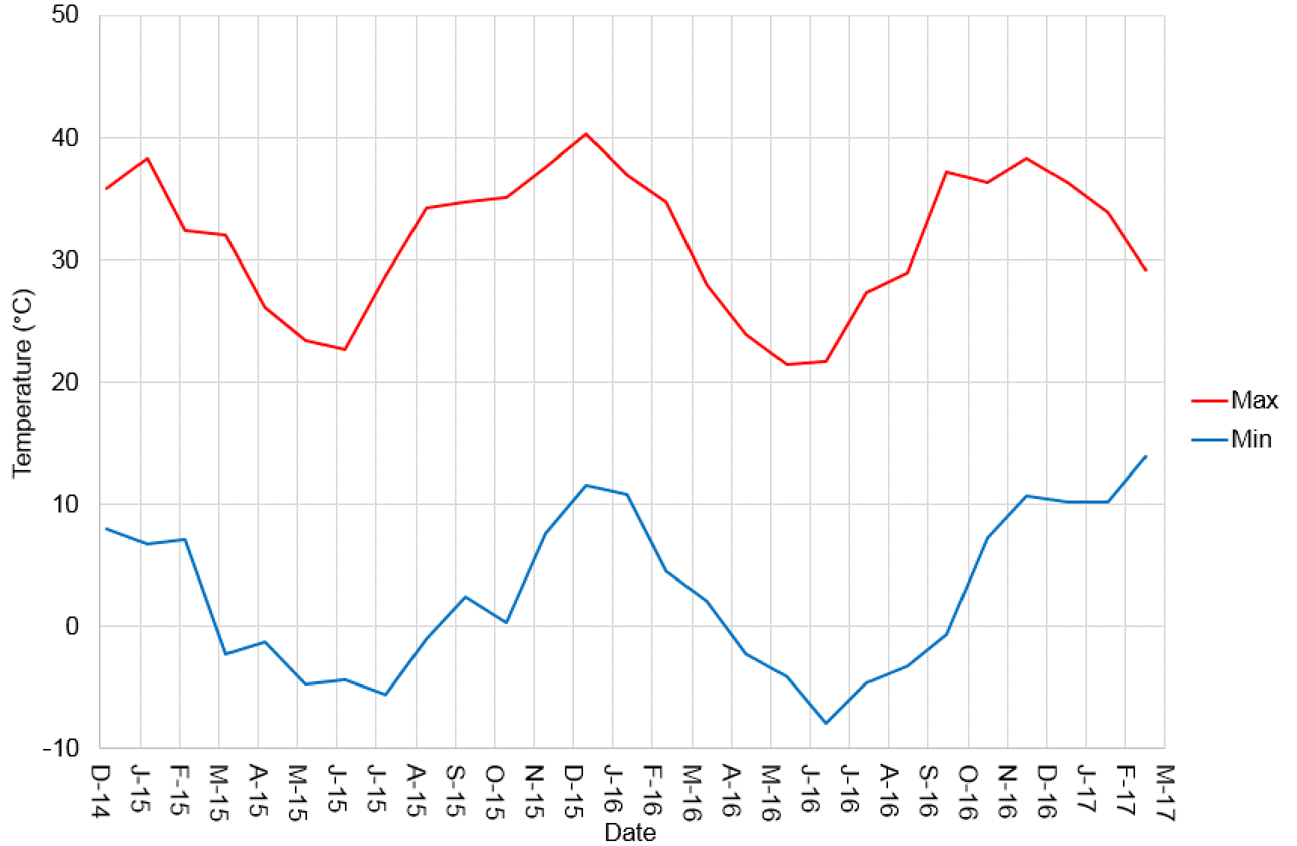
Effects of temperature distribution and restraint conditions on movement and stress in bridge deck elements (Hambly, 1991)

ENVIRONMENTAL CONDITIONS

Weather station

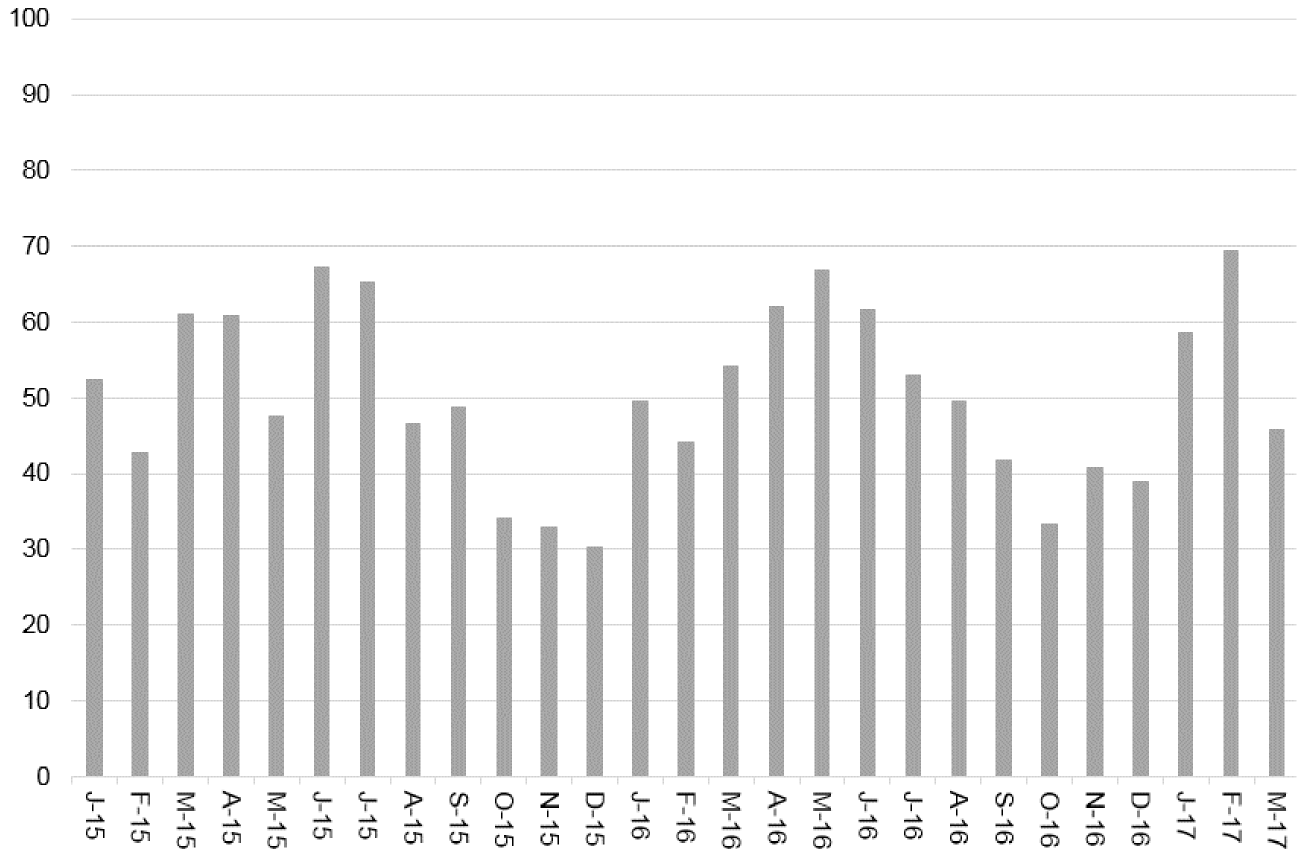
- Ambient temperature
- Rainfall
- Humidity
- Wind speed and direction

ENVIRONMENTAL CONDITIONS



Van Zylspruit - Max and min ambient temperatures from Jan 2015 to Mar 2017

ENVIRONMENTAL CONDITIONS



Van Zylspruit - Average monthly humidity measured from Jan 2015 to Mar 2017

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SENSOR INSTALLATION

Van Zylspruit - Cabling and ducts

LOGGING

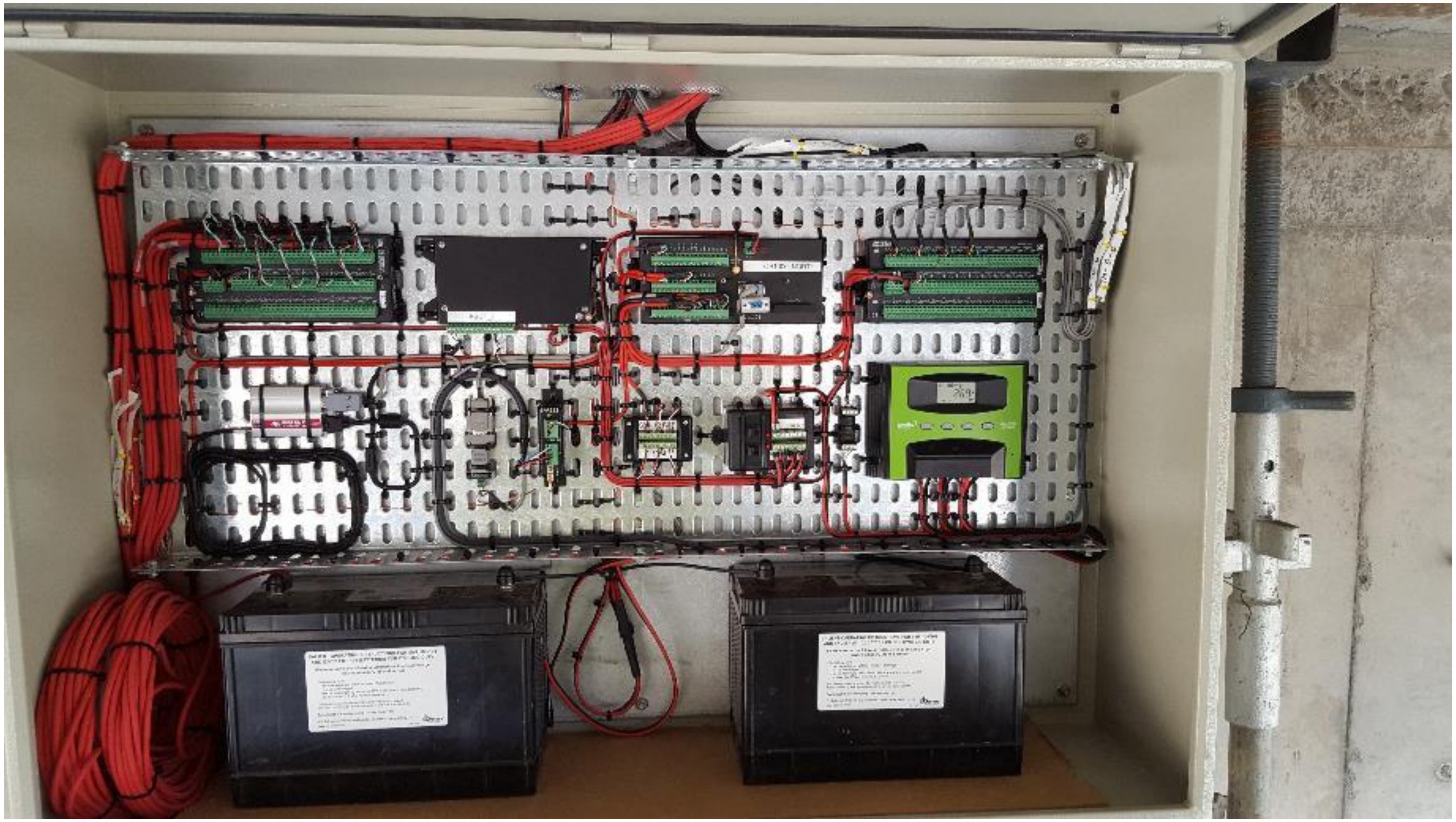
Static logging

- Environmental effects.
- Permanent loads.
- Most sensors can be used for this.

Dynamic logging

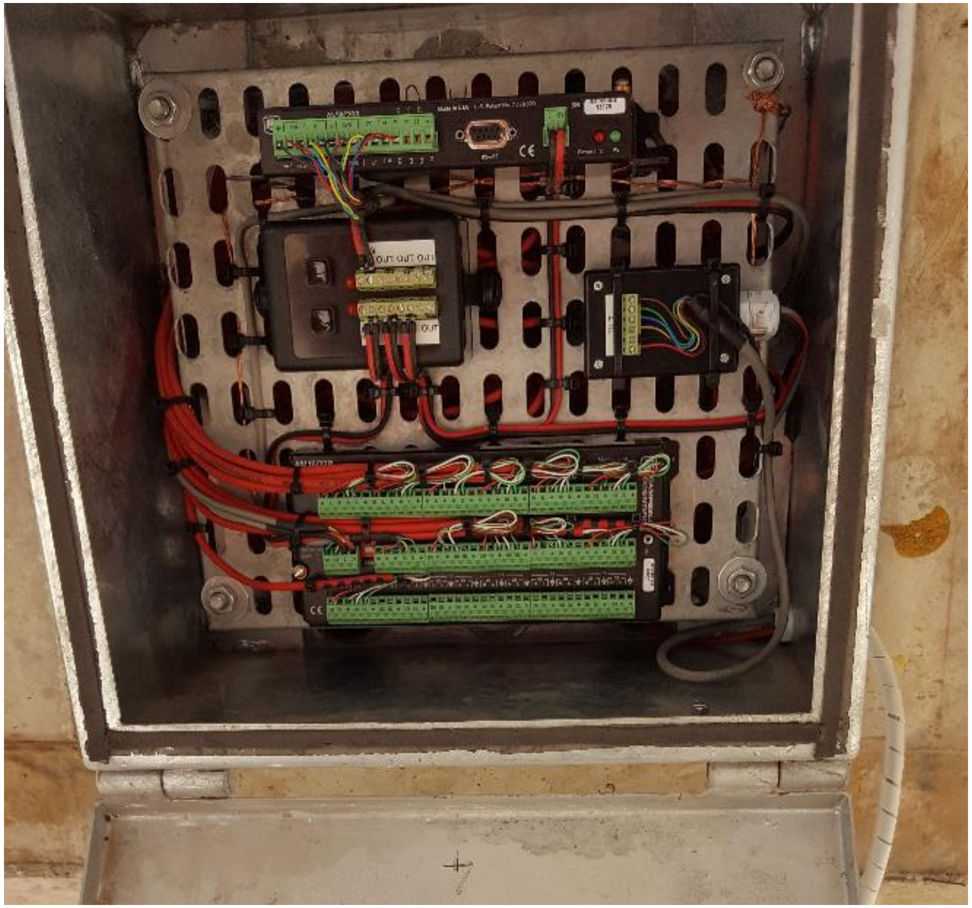
- Rapid, repeated measurements.
- Sampling rates of up to 50Hz.

LOGGING



Van Zylspruit – Logger and batteries

LOGGING



Van Zylspruit - Multiplexers

LOGGING

Van Zylspruit - Multiplexers

POWER SUPPLY

Van Zylspruit – Solar panels

HOW MUCH WILL IT COST?

- Sensors
- Installation – site location
- Cabling
- Power supply
- Logging
- Data analysis

WHAT CAN GO WRONG

- Leaving sensors or ducting out of concrete cast

  Design and detailing of SHM system – drawings, fixing details etc
- Strange readings!

  Build in redundancy to the SHM system
- Program delays

  This affects the price
- Sensors in the incorrect position / orientation or covered incorrectly

  Don't just leave it to the Contractor to sort out
- Damage to cables

  Log during concrete placement
- Theft / vandalism

  Place storage boxes, solar panels etc. out of the general view

DATA MANAGEMENT

- Big data
- Data analysis and management
- Warning systems
- How does restraint effect the readings?

EXAMPLES OF MONITORING PROJECTS

- Van Zylspruit bridge (fully integral bridge)
- Javett Centre bridge
- Multiple Ply Timber trusses
- Wind turbine foundations

VAN ZYLSPRUIT BRIDGE MONITORING

Reinforced Concrete

Length: 90m

Width: 14.5m

5 Spans: 20.7m

Height: 5m

VAN ZYLSPRUIT BRIDGE MONITORING

Sensors installed:

- 110 VW strain gauges
- 20 rebar strain gauges
- 41 thermistors
- 2 Shape Accel Arrays (22 links each)
- 8 tilt meters
- 20 earth pressure cells
- 10 temperature and humidity sensors
- 11 concrete reference samples

Over **550** channels logging every 15 minutes

MEASUREMENTS

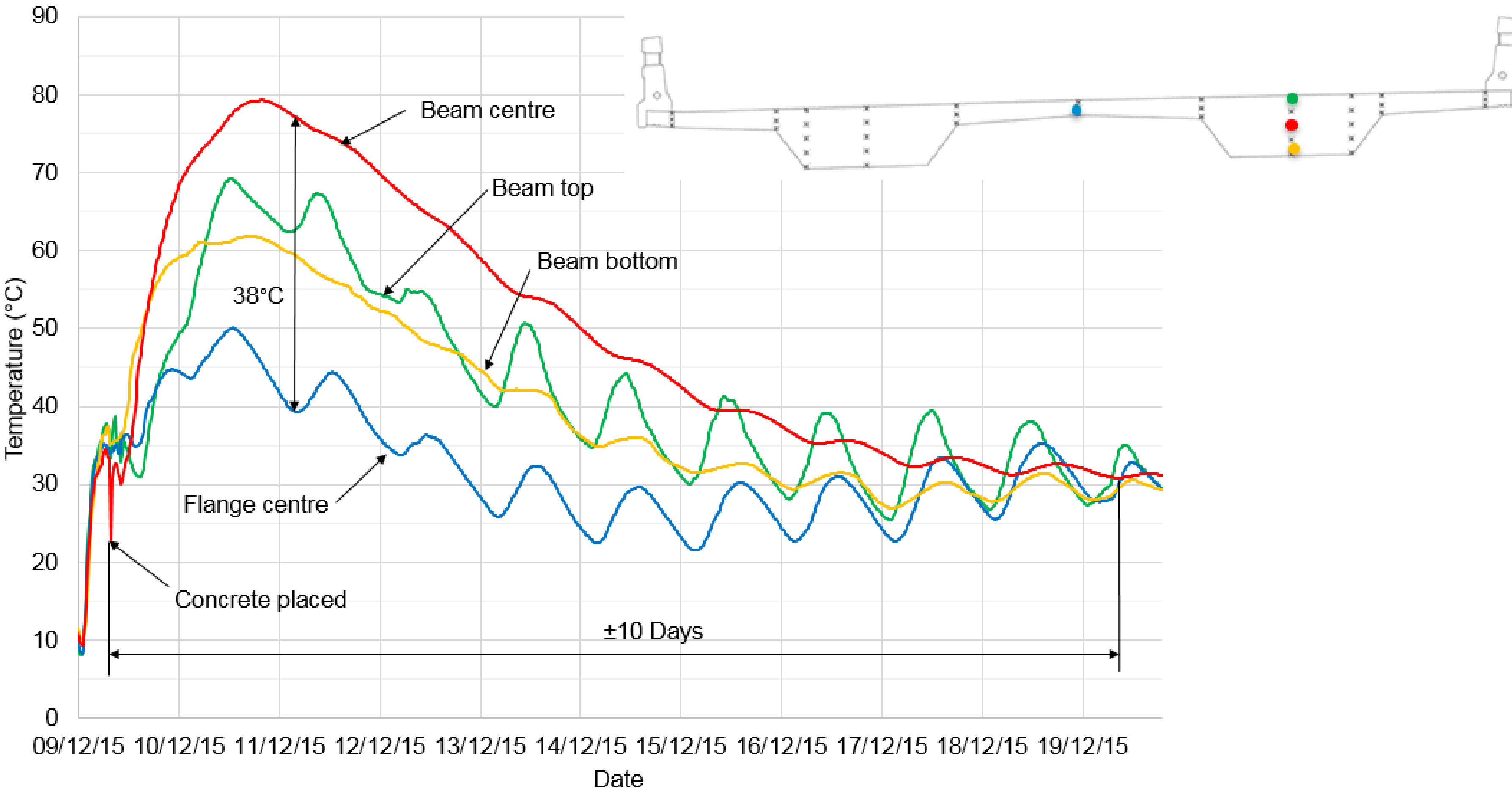
- Heat of Hydration
- Deck temperature
- Change in effective bridge temperature
- Vertical temperature gradient through the deck
- Abutment movement
- Lateral earth pressure

CONCRETE MATERIAL PROPERTIES

W40 Concrete: 19mm Dolerite stone and CEM II/A-M (V-L) 42.5R

- 28 day compressive cube strength: **60MPa**
- 28 day split cylinder strength: **3.6MPa**
- 28 day Modulus of Elasticity: **37GPa**
- Coefficient of thermal expansion: **8.5 to 9.5x10^{-6}/°C**
- Shrinkage of reference cylinder: **300μm**

HEAT OF HYDRATION



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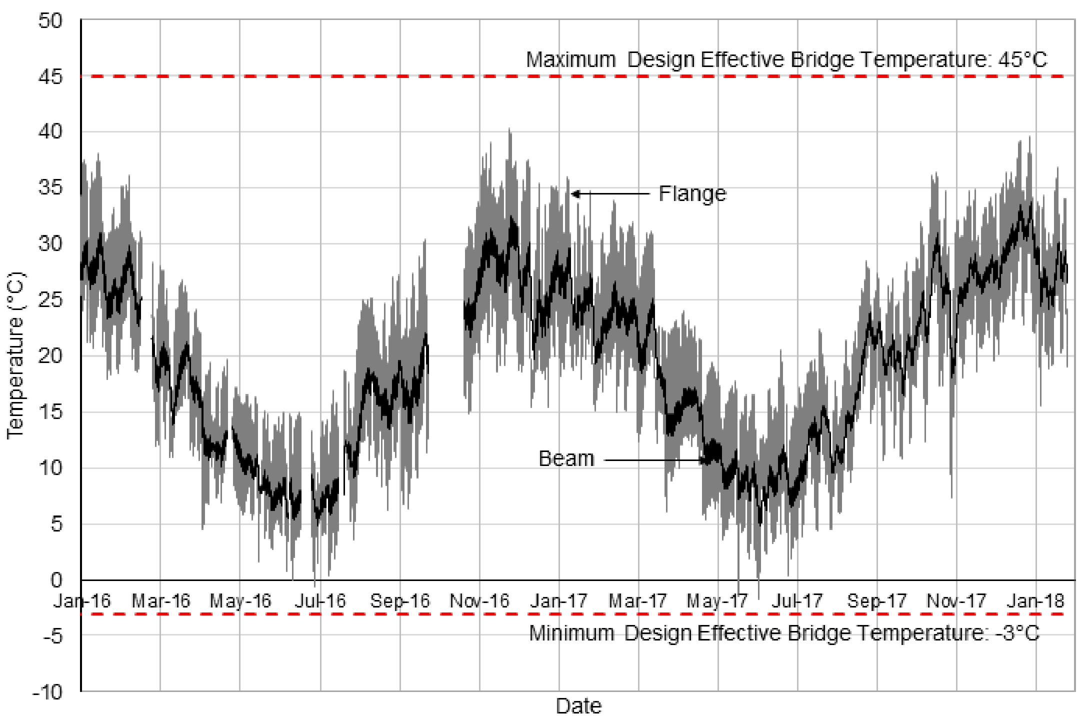
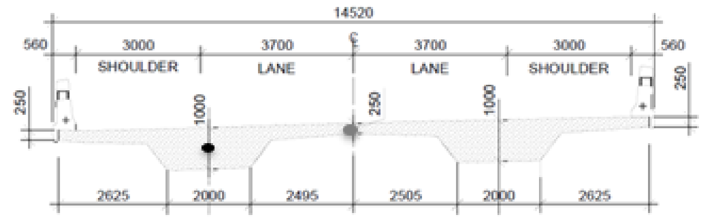
BRIDGE TEMPERATURES





Measured Temperatures

Flange	Beam
Max: 40°C	Max: 32°C
Min: -0.5°C	Min: 5°C

Centre of beam and centre of flange temperature from Jan 2016 to Mar 2018

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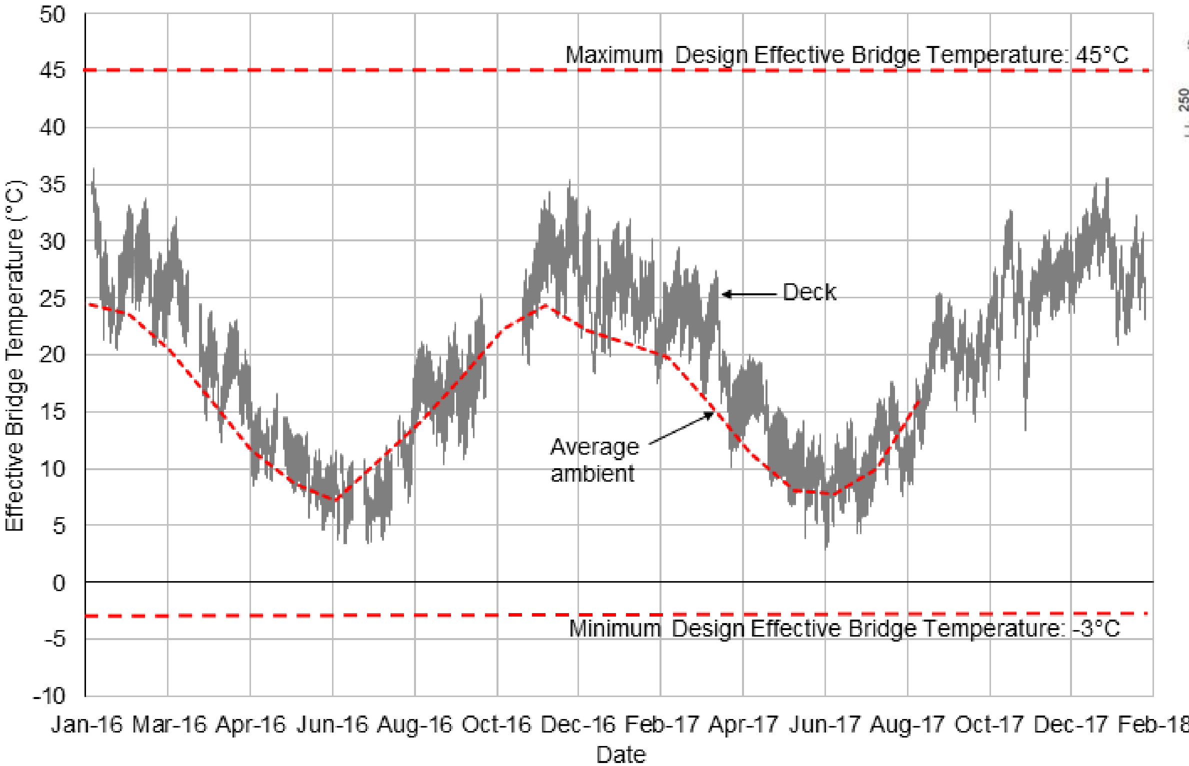
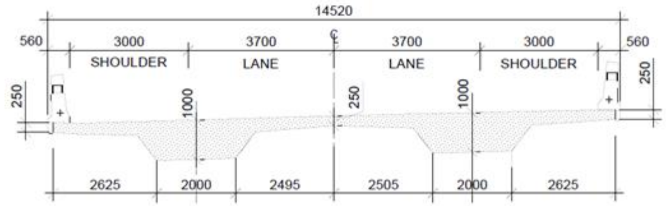
EFFECTIVE BRIDGE TEMPERATURE





Effective bridge deck temperature:
(Emerson 1976)

Max: 35.33°C

Min: 3.24°C

Effective bridge temperatures from Jan 2016 to Feb 2018

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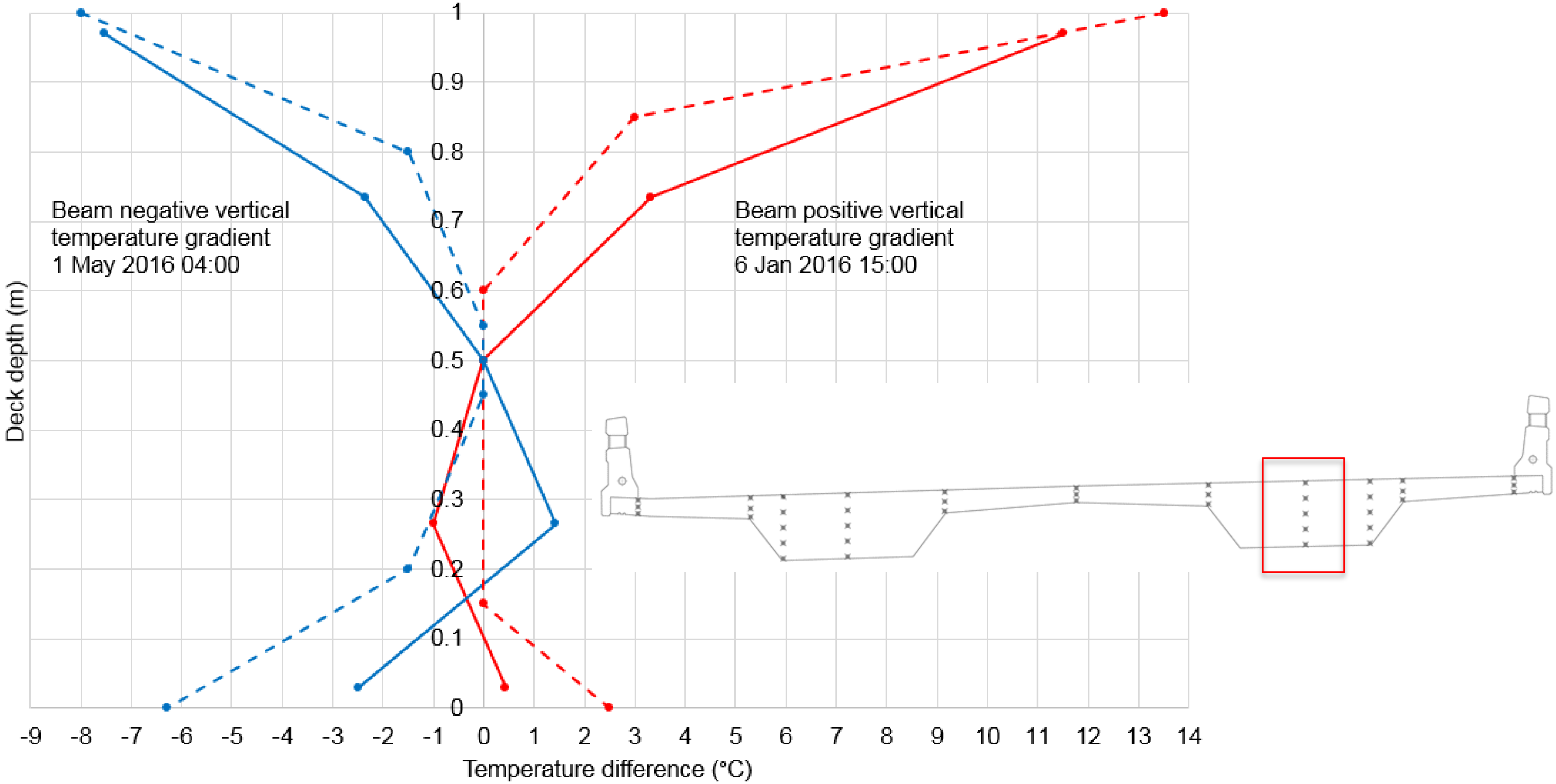
VERTICAL TEMPERATURE GRADIENT - BEAM



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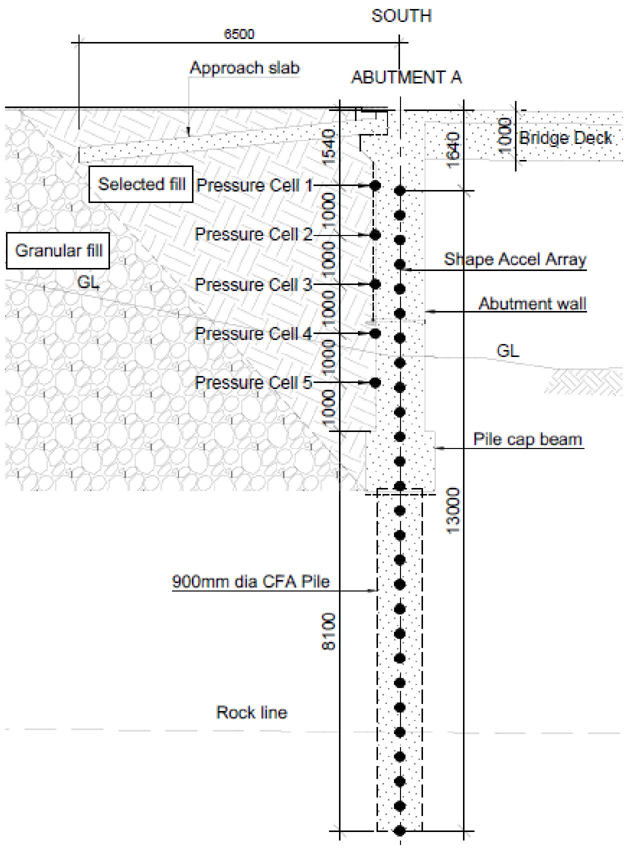
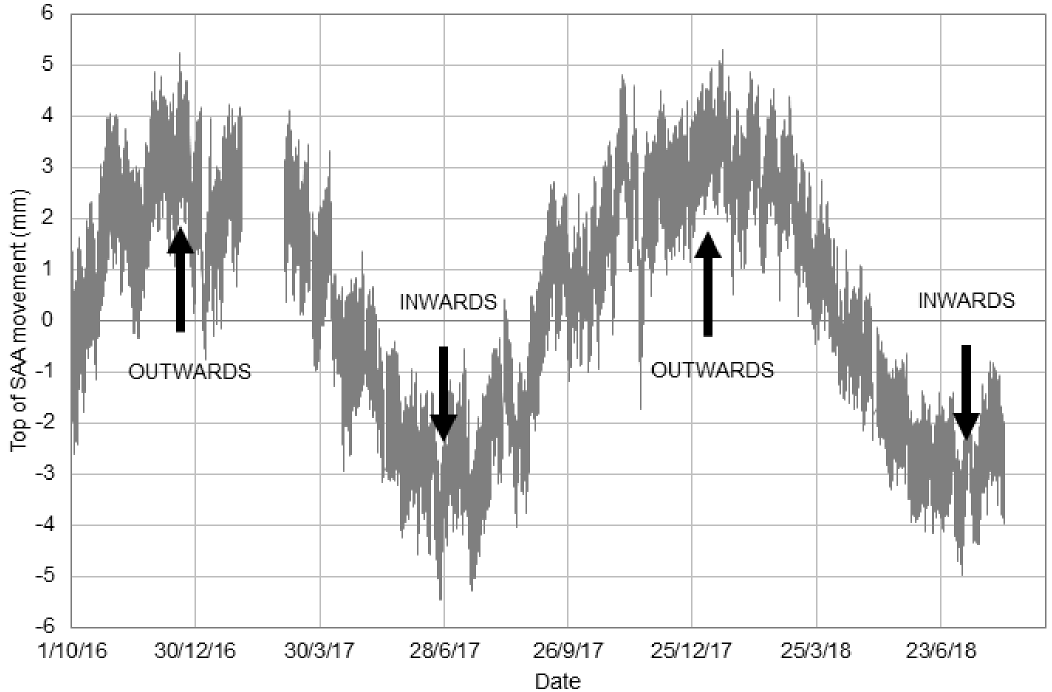
ABUTMENT MOVEMENT



Section through the southern abutment wall showing the pressure cell and SAA positions



Relative top of abutment movement from October 2016 to August 2018

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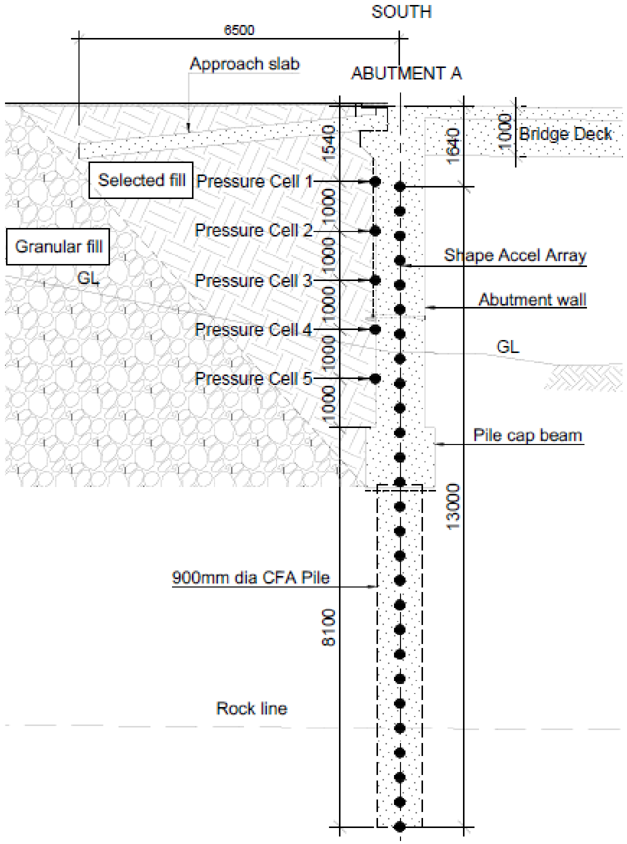
LATERAL EARTH PRESSURE



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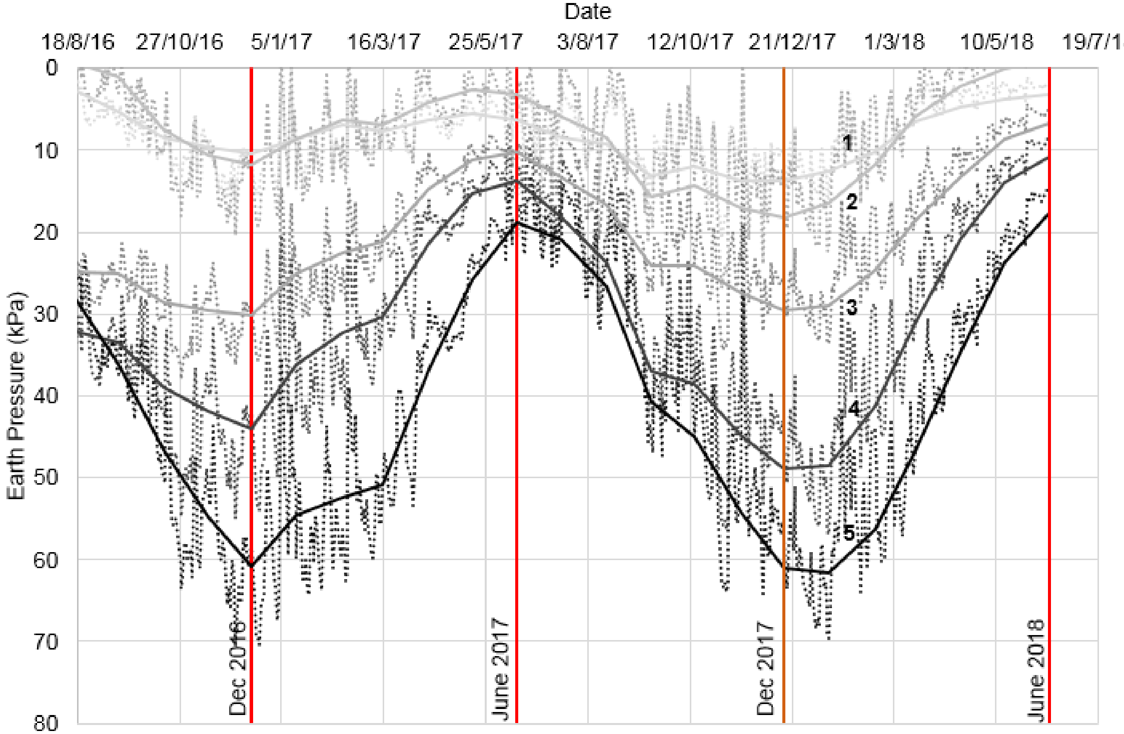

Lateral earth pressure from August 2016 to August 2018

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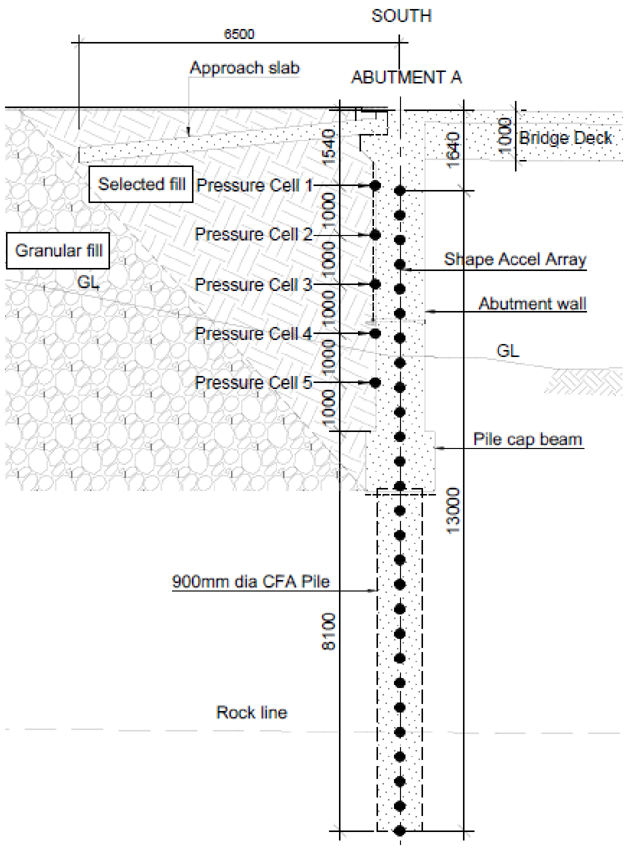
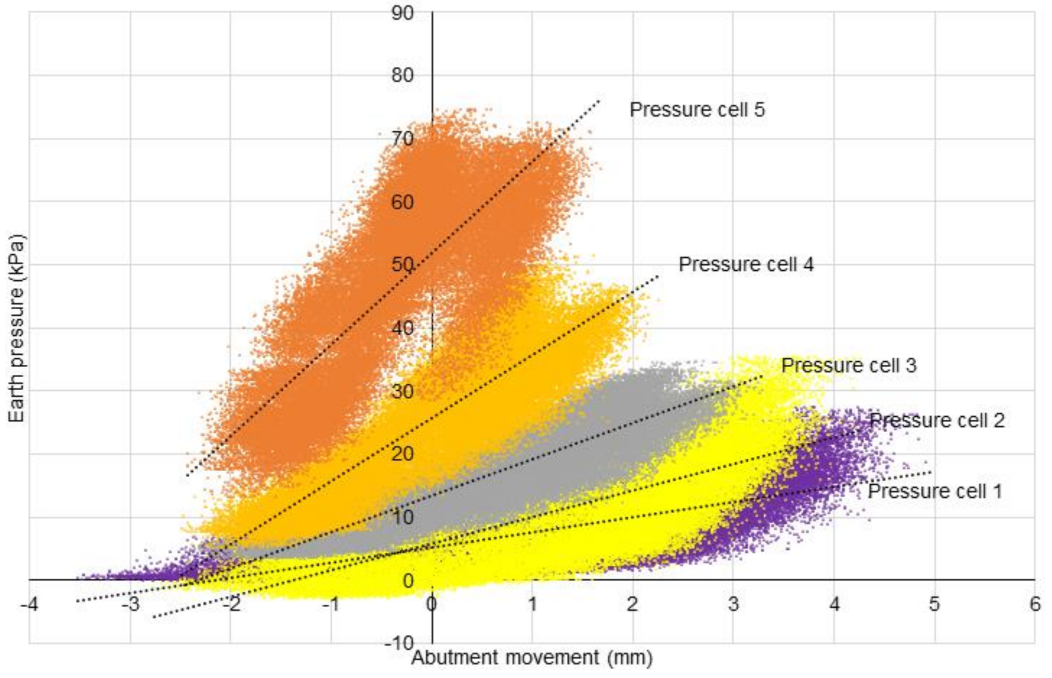


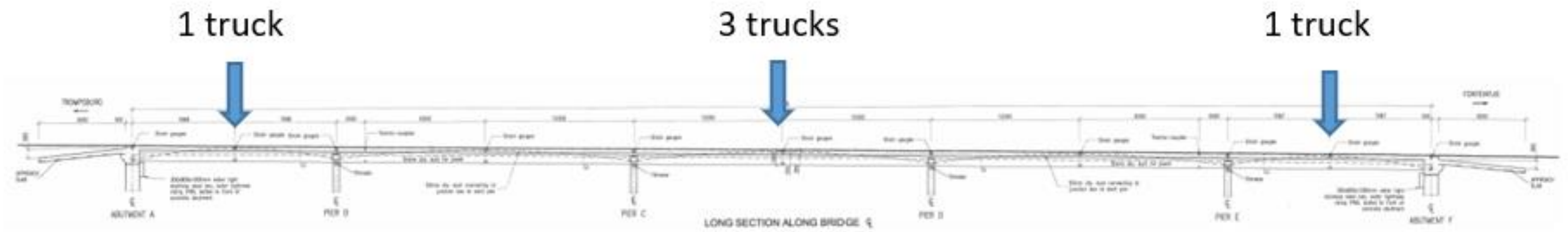


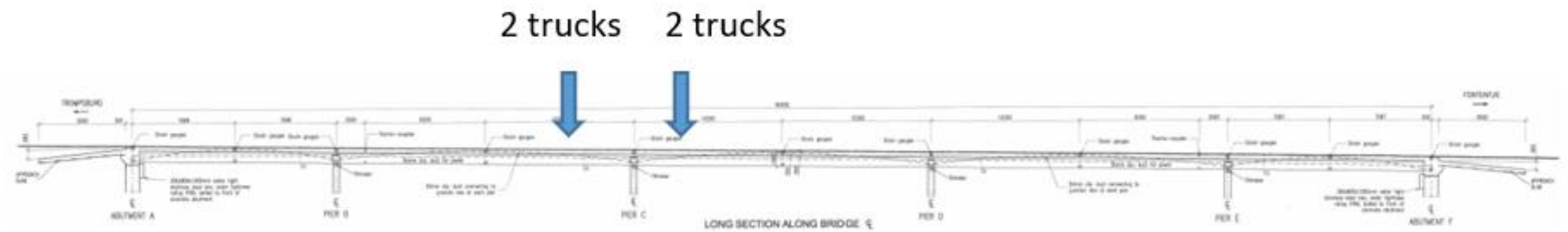
Section through the southern abutment wall showing the pressure cell and SAA positions

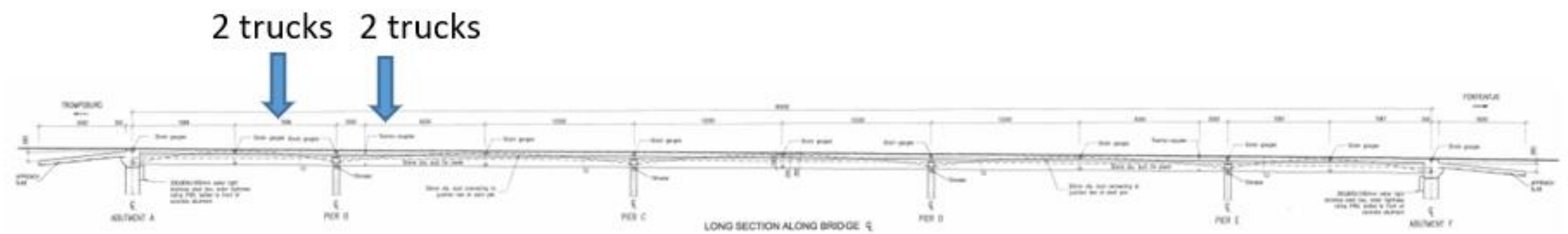
Abutment movement plotted against the North abutment earth pressure (October 2016 to August 2018)

LOAD TEST

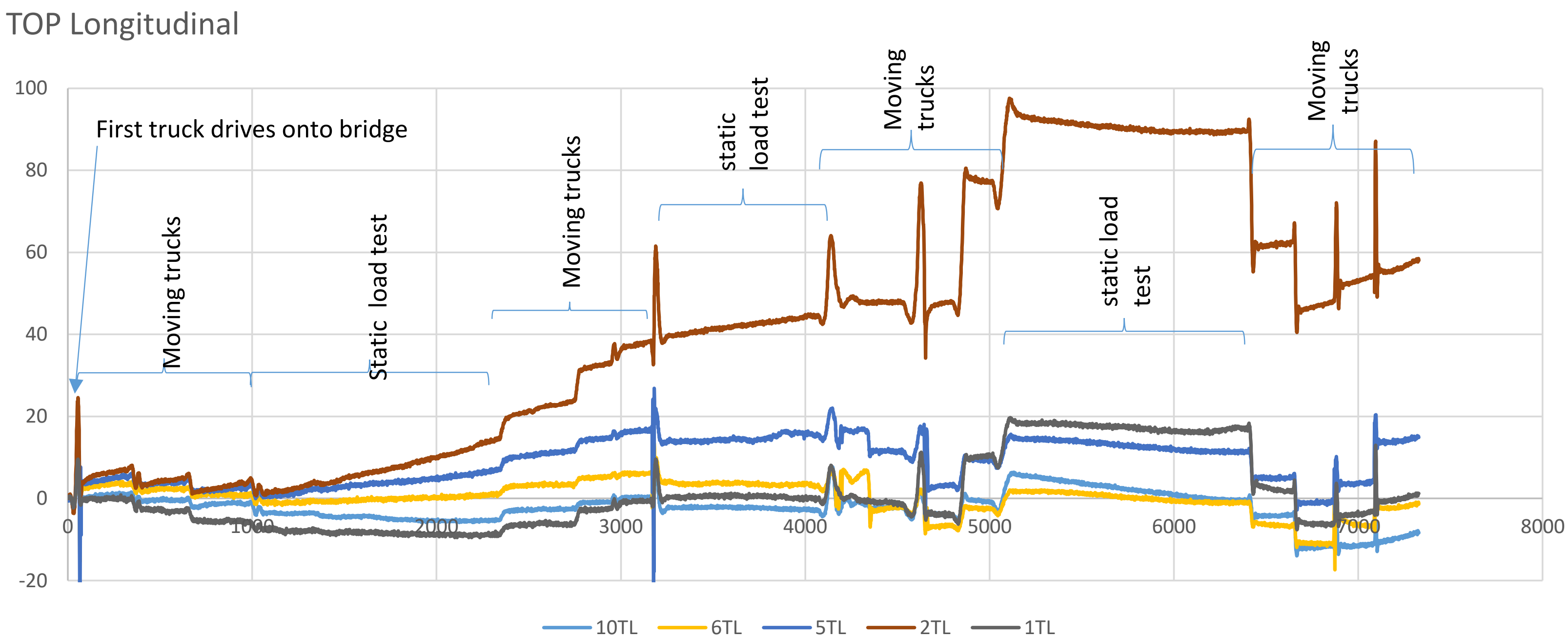
Five fully loaded trucks weighing 34 tons each were used to load the bridge deck in three configurations:

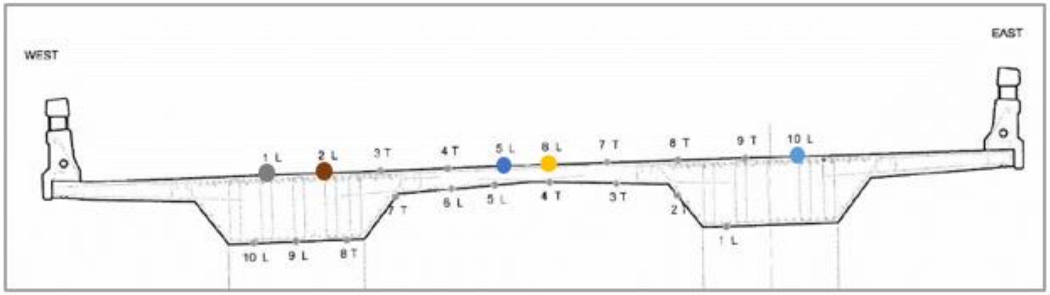






LOAD TEST





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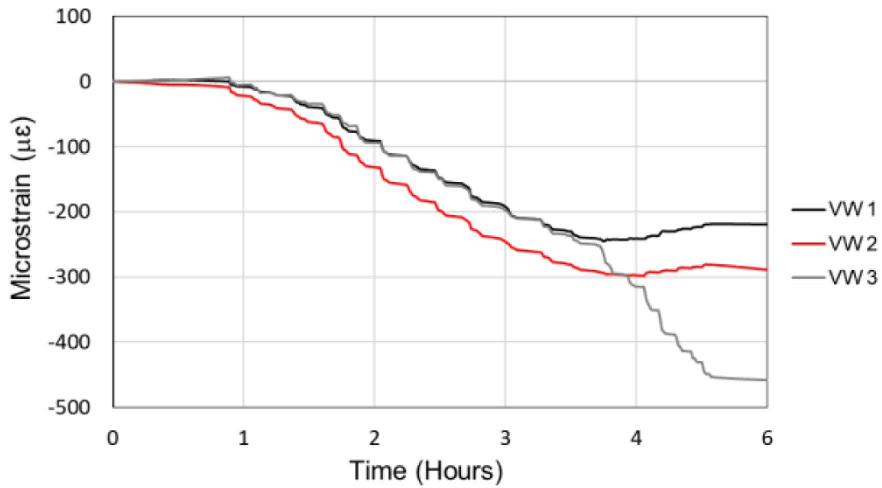
JAVETT CENTRE BRIDGE INSTRUMENTATION

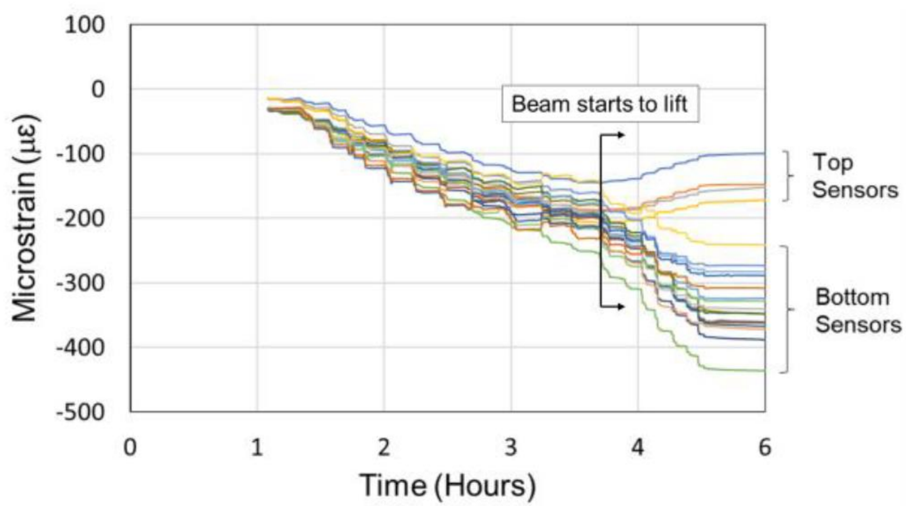
Prestressed Concrete U beams

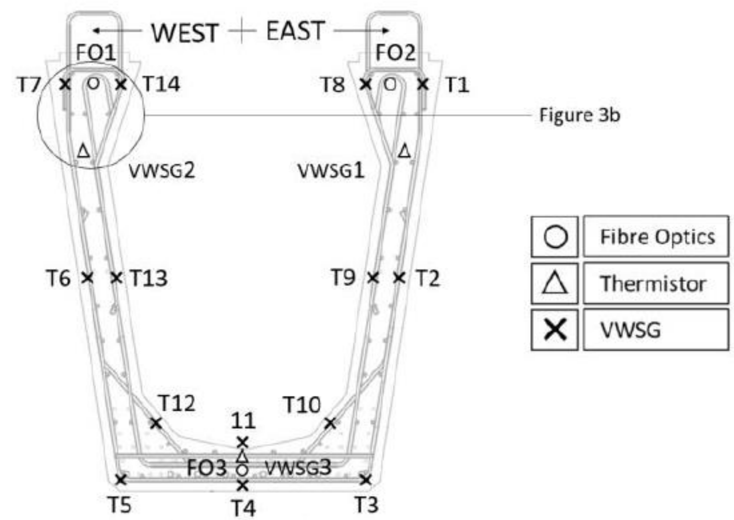
Span: 33m

Width: 18.1m

PRESTRESSED BEAMS - STRESSING







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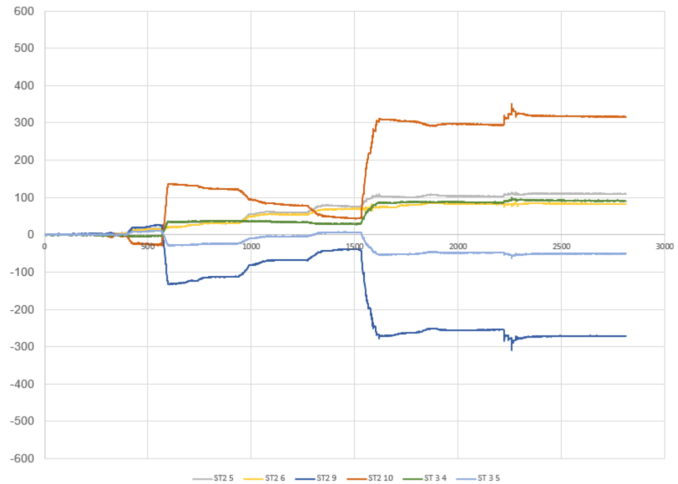
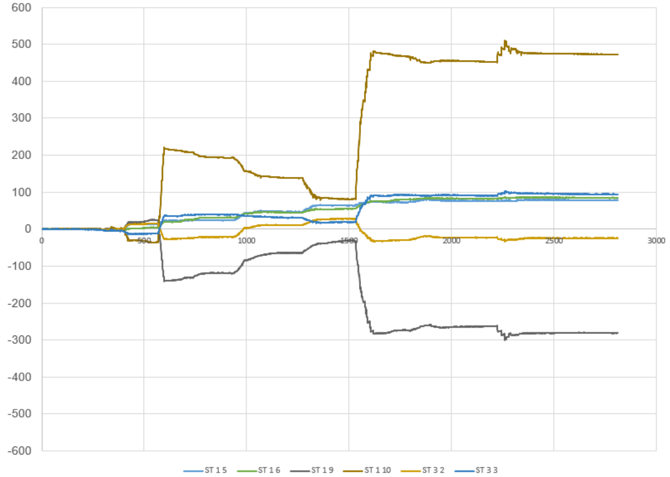
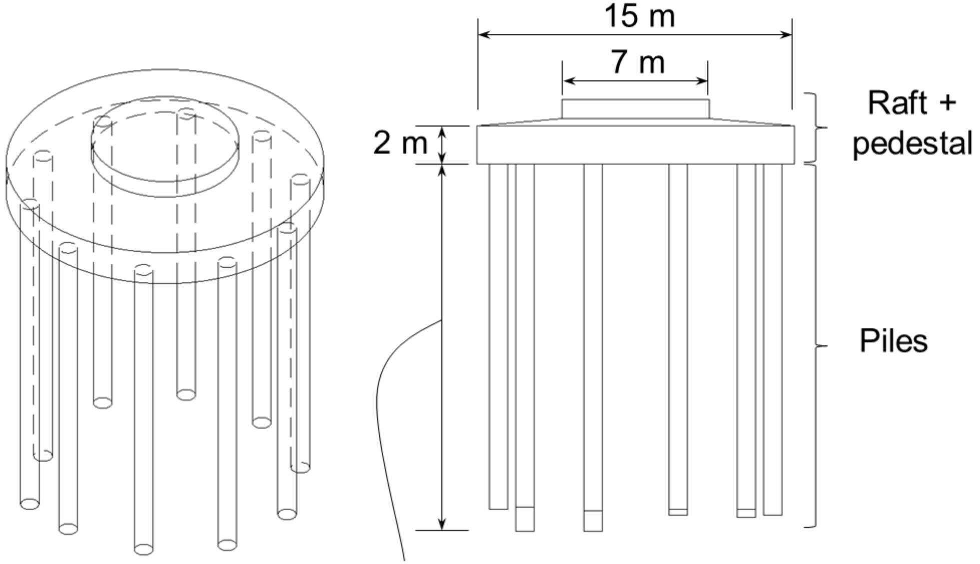
MULTIPLE PLY GIRDER TRUSSES





WIND TURBINE FOUNDATIONS



Instrumentation and monitoring of an onshore wind turbine piled-raft foundation

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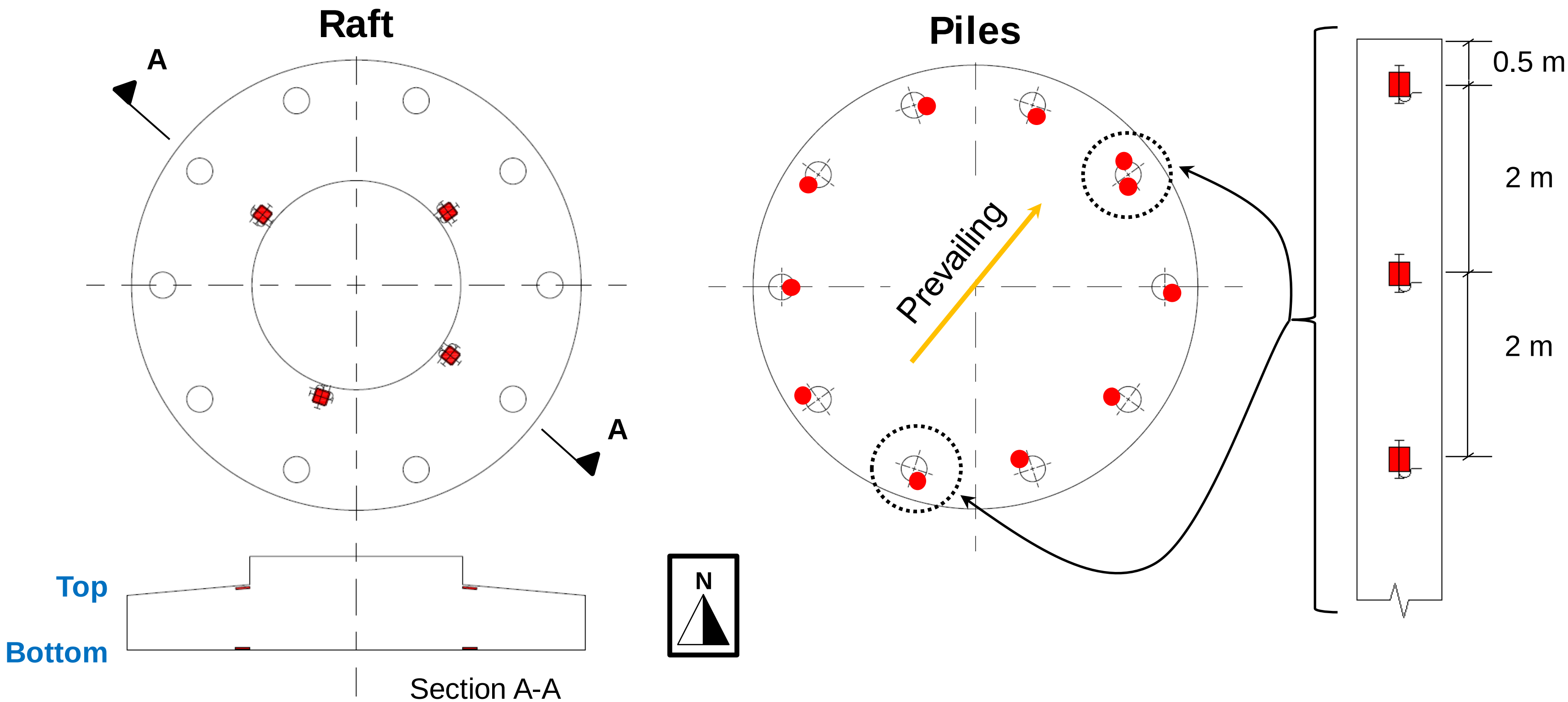
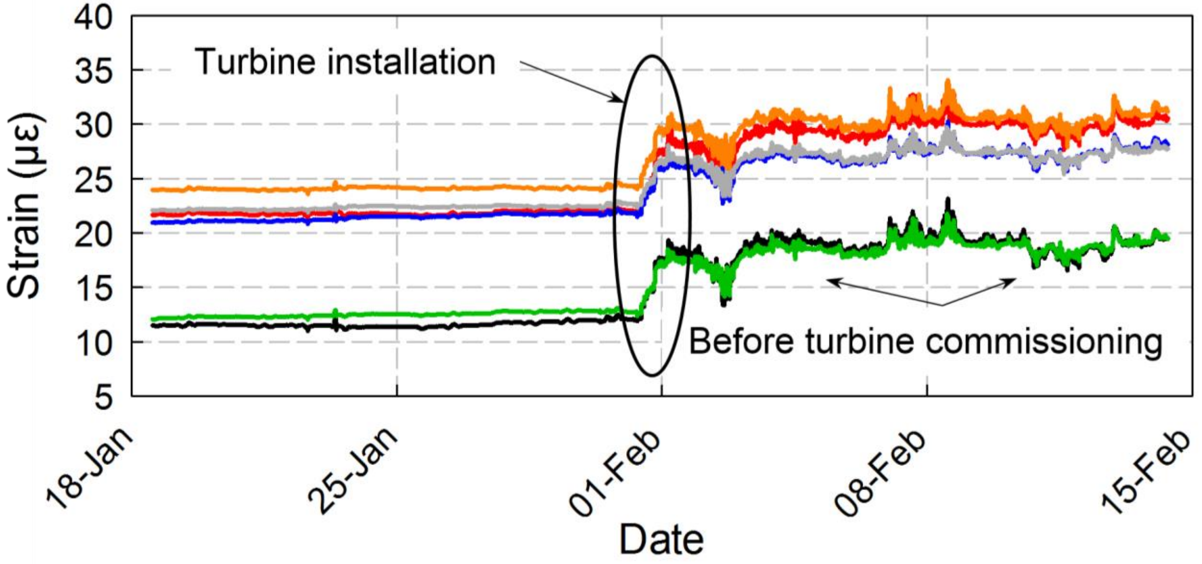
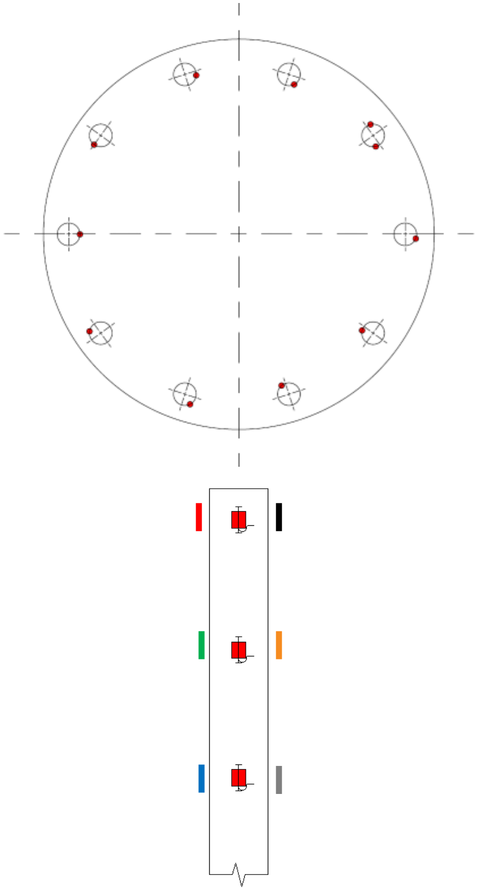


Instrumentation and monitoring of an onshore wind turbine piled-raft foundation

WIND TURBINE FOUNDATIONS





Pile strain measurements

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YUNIBESITHI YA PRETORIA

Faculty of Engineering, Built Environment and Information Technology
Fakulteit Ingenieurswese, Bou-omgewing en Inligtingtegnologie / Lefapha la Boetšenere, Tikologo ya Kago le Theknolotši ya Tshedimošo

CEMENT & CONCRETE SA

CONCLUSION

"When you can measure what you are speaking about, and express it in numbers, you know something about it…" Lord Kelvin 1891

- We are modelling structures with very sophisticated software more "accurately" but what is really happening in the structure?
- Extrapolated designs – taller, longer spans, more slender, but when should we stop?
- If we don't measure, we don't know!

THANK YOU!