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Structural Health Monitoring System Considering Challenges in Managing Port Assets

Sam Mazaheri

Dalrymple Bay Terminal

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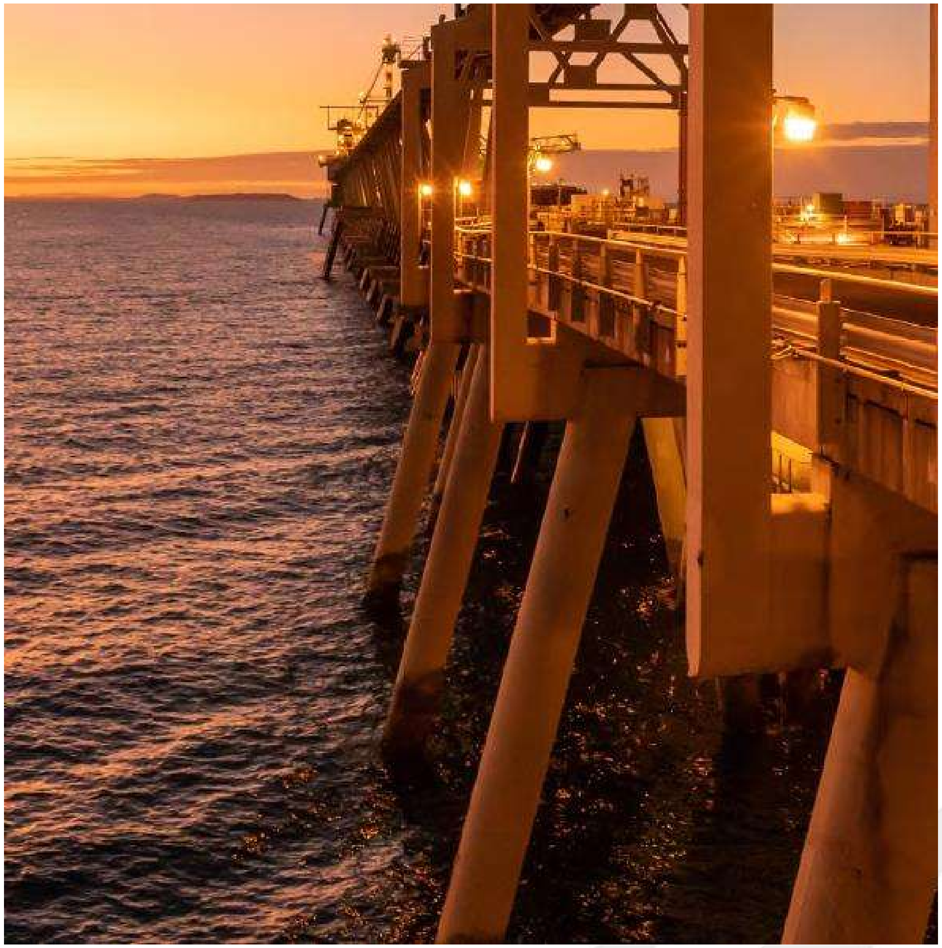

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Challenges in Port Asset Management

Challenges

- Inspection and Maintenance
  - Remote and inaccessible locations
  - Proper infrastructure for access
  - Divers for underwater inspections

- Irregular Inspections
  - Scope
  - Interruption to operation / business
  - High Costs and Economic Impact

Condition Inspection Framework

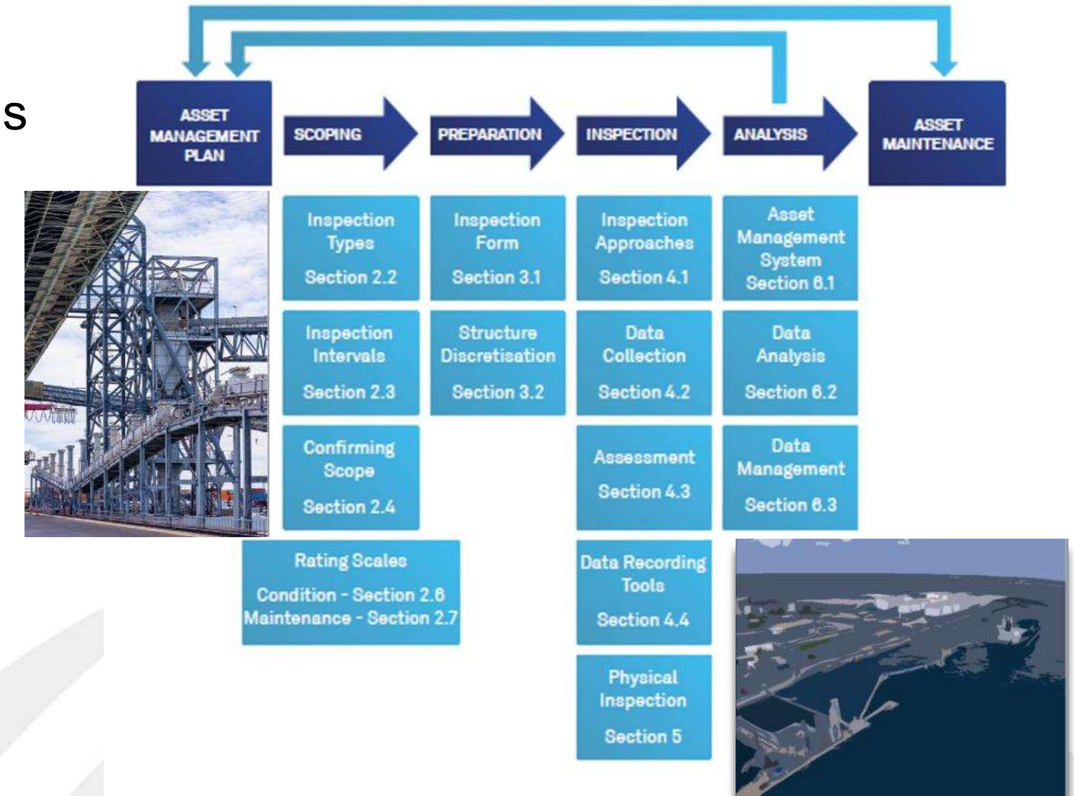

Figure 2-1: Condition Inspection framework of the Wharf Structures Condition Assessment Manual

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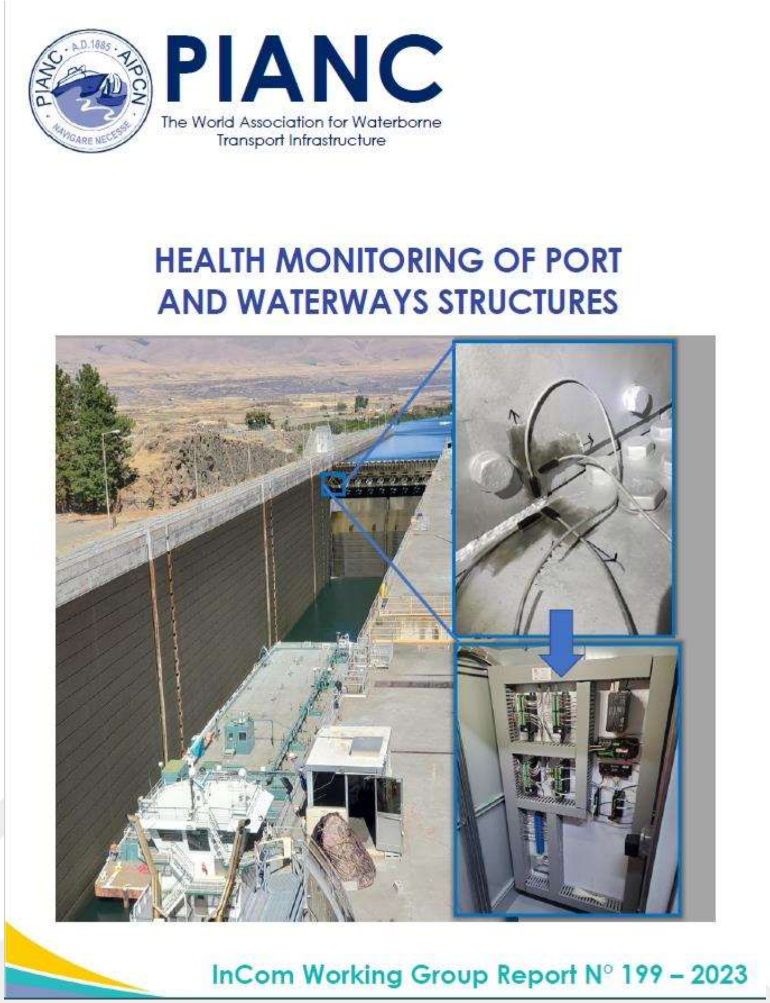
Photo Courtesy: WSCAM, Ports Australia

Structural Health Monitoring (SHM) of Ports and Waterway Infrastructure

- The report has been produced by an international working group governed by the Inland Navigational Commission (InCom).
- Objective is to provide information and recommendations on good practice
- It is an expert guide and state-of-the-art in respect to SHM of Port and Waterways Facilities
- Published in 2023



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SHM System Overview and Key Components

Key Components

- Damage Detection (Is there damage?)
- Localization (where is the damage?)
- Quantification (Damage type, detail, condition, …?)
- Predicting remaining service life (how much longer can the structure be used safely?)

Overview of an SHM System

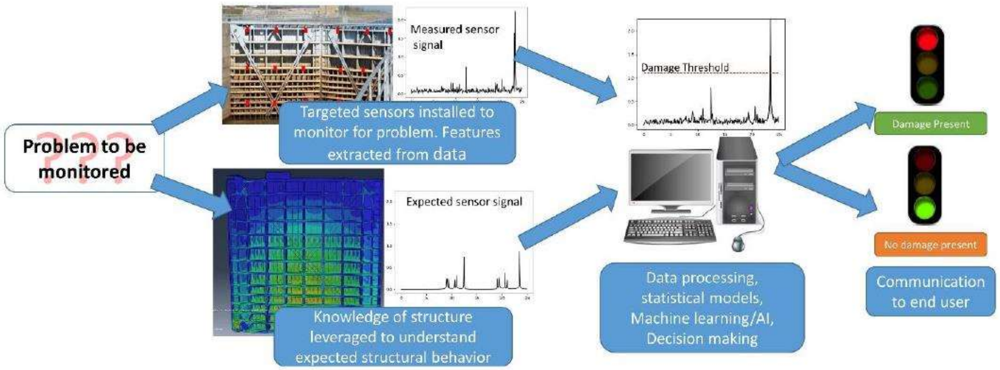

Figure 1.2: Overview of an SHM system

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Sensing Technologies

- What to monitor
- Traditional sensing technologies
  - Accelerometers
  - Strain gages
  - Displacement transducers
- Novel technologies
  - PZT patches
  - Commercial off-the-shelf cameras
  - Automated drones

Quantity	Sensor, Measurement method, measuring range, precision	Common Applications
Tilt/Rotation	Pendulum (vertical) (Wire alignment, horizontal)	Dam displacements.
Relative vertical displacement	Water level tube/Hydrostatic Levelling Sensor	
Relative displacement	String potentiometer	Localised displacement measurement, relative to a stationary measurement point. Requires accessibility for direct contact between structure and nearby stationary reference point.
Relative displacement	Linearly variable differential transformer (LVDT)	Localised displacement measurement, relative to a stationary measurement point. Requires accessibility for direct contact between structure and nearby stationary reference point.
Displacement	Extensometer	Localised displacement measurement. Used perhaps for a component or location of a larger structure where displacement measurements are particularly informative.
Relative Displacement	Distometer/laser distance meter	Non-contact displacement measurement (requires clear line-of-site and a static reference point).
Tilt/rotation	Inclinometer/Tiltmeter and Shape Array Inclinometer	Used to infer angle of a component. Used on dam walls, lock gates, etc.
Dense strain	Fibre Optic sensors	Can be chained together to obtain high resolution displacement measurements across long distances, such as bas deflection of an earthen dam.
Position	Total-station	Highly accurate position measurement for large infrastructure.
Position/ Displacement	Laser-Scanning/LiDAR	Provides precise geotagged point clouds for structure geometry.
Position/ Displacement	Global Navigation Satellite System (GNSS)	Used for displacements of very large civil infrastructure, such as mass concrete dams, levees, etc.
Positions/ Displacement	Ground survey Aperture Radar (GBInSAR)	Used for displacements of very large civil infrastructure, such as mass concrete dams, levees, etc.
Position/ Displacement	Satellite Synthetic Aperture Radar (Satellite SAR)	Used for displacements of very large civil infrastructure, such as mass concrete dams, levees, etc.
Displacement	Multi-beam bathymetry	
Strain	Strain Gage	Very common sensor used to measure single point strain. Provides highly localised data. Useful for measurement of known of suspected 'hot spots' or in locations where the structural response is not expected to vary significantly over a small domain. Can be used to infer displacement and state of stress.
Force	Load Cell	Used at a location where load is applied to a structure, or where load is transferred between components
		such as: A pin holding a cable to a steel plate.
Stress	Pressure Sensor	Commonly used to infer height of water, in a dam reservoir or lock chamber for instance.
Strain/Stress/ Displacement	Visible Spectrum Camera	Use of digital image correlation and computer vision techniques such as optical flow have been found to be successful in measuring strain from successive static images.
Acceleration/ Vibration	Accelerometer	Common SHM sensor used for dynamic, high frequency measurements. Allows for modal analysis of the structure.
Acoustics	Acoustic emissions sensors	These are effectively microphones that listen for the sounds of cracks propagating or corrosion initiating, etc.
Corrosion	Corrosion ladder, linear polarisation resistance measurement, half-cell potential measurement	These techniques can be used to provide an indication of the likely rate of corrosion

Practical Applications

Table 4-1 Summary of typical sensors for structural parameters

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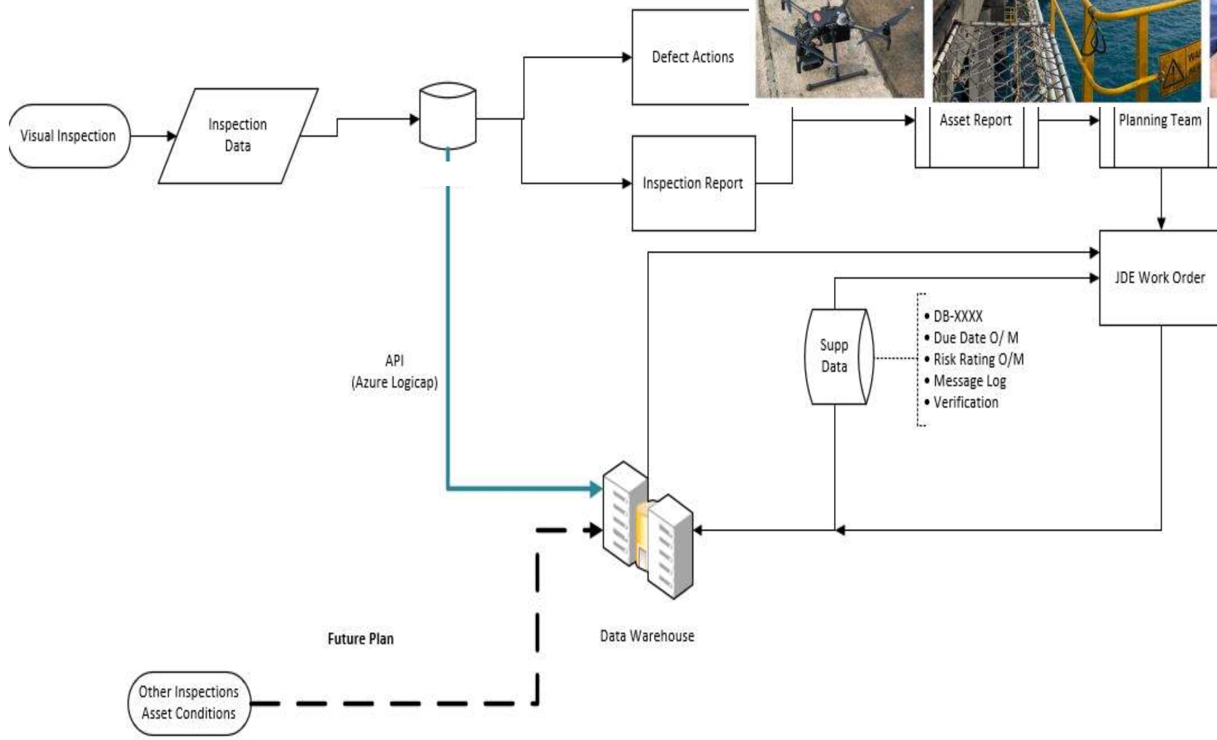
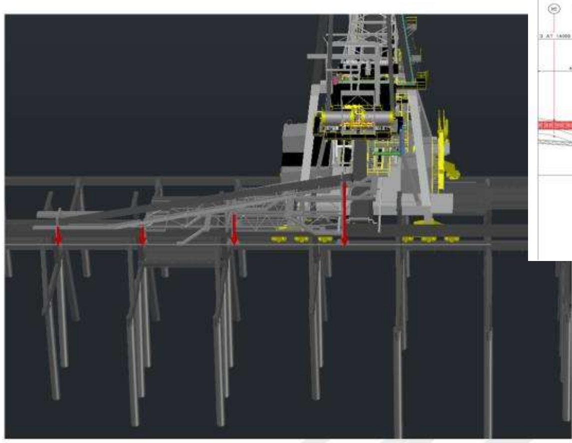
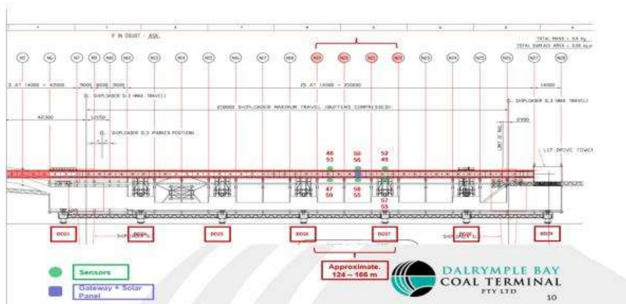
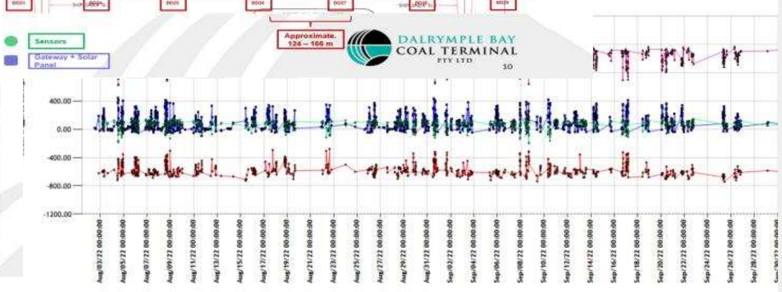
Data Acquisition and Managem

- Sampling rates
- Power
- Communication
  - Equipment – Data Acquisition
    Equipment – Data Processing And Analysis Platform
- Data storage
- Cybersecurity









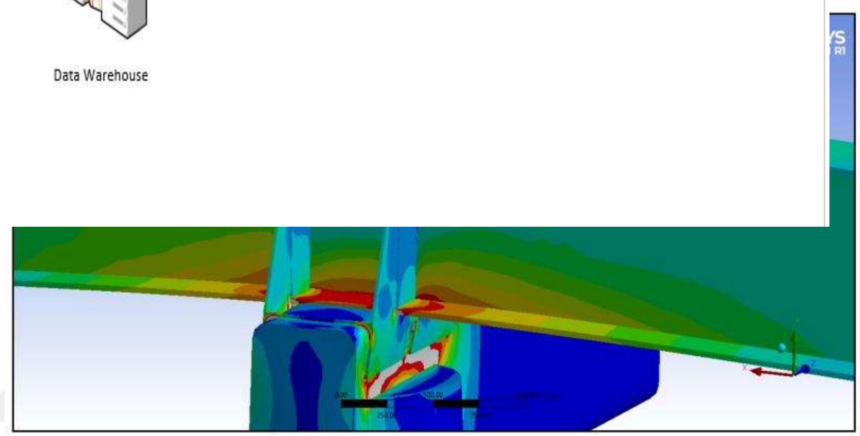


Figure 10 Typical von Mises stress plot for wheels at mid-span (central web)

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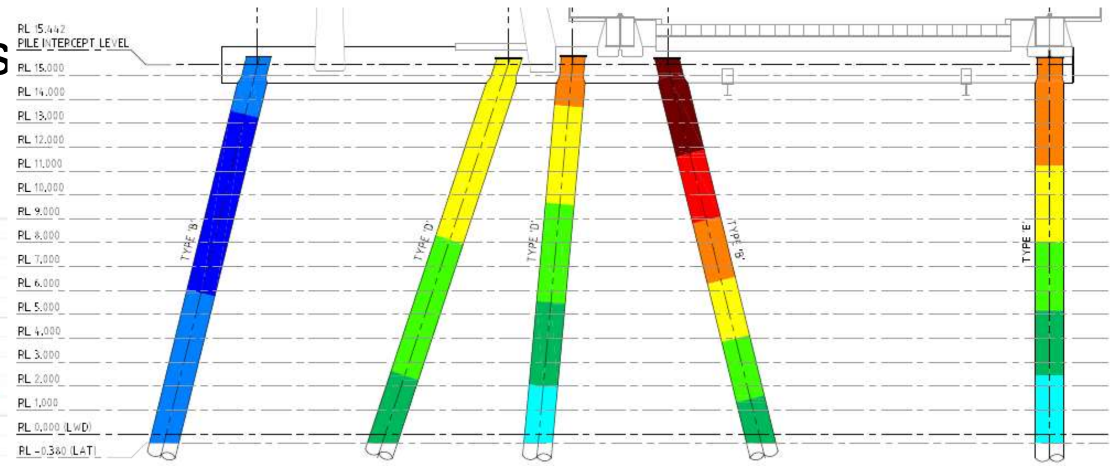
Data Interpretation

- Extracting meaningful features
- Comparing with acceptable values
- Considering environmental factors



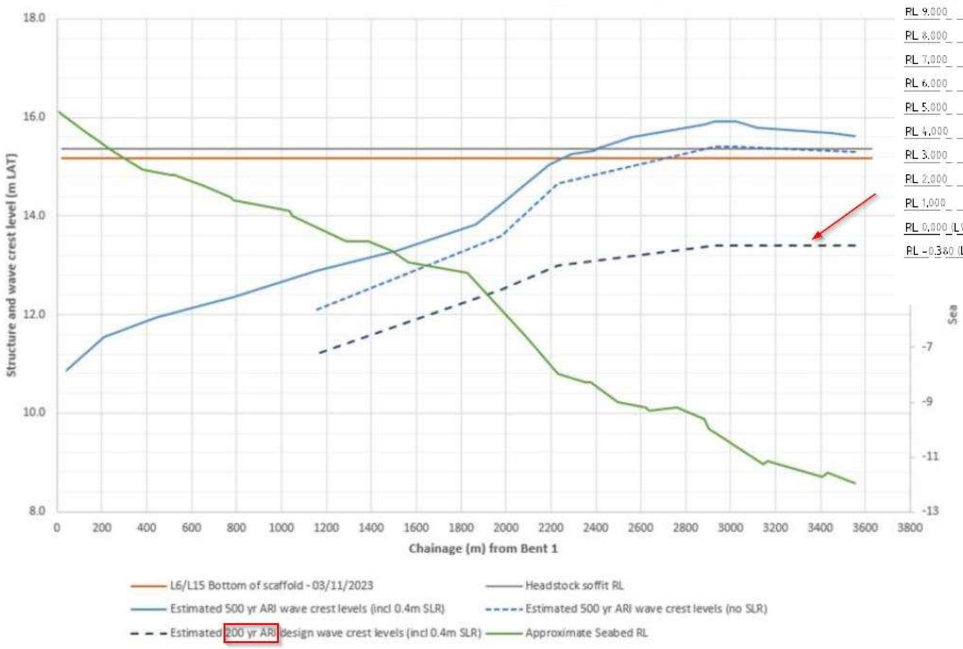


Figure 3: Graph showing estimated wave crest levels along the length of Jetty 1

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Practical Applications

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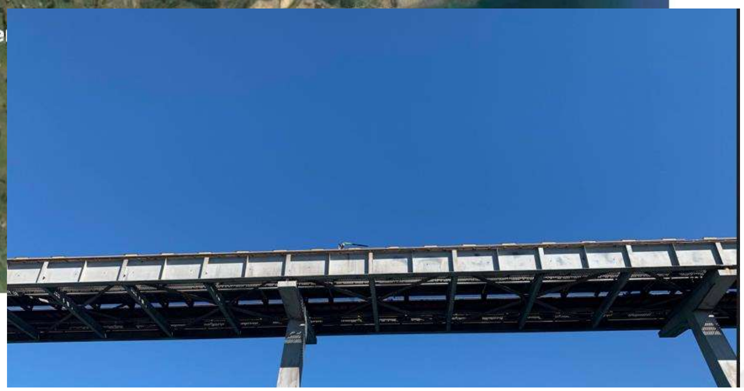
LT Rail Girder on Wharf Structure



L17 SECTION

								Axial		Moment		Shear
	Ag	Ix	Zx	Sx	Fyf	Fyw	Zex	Tens (phiNt) KN	Comp (PhiNs) KN	PhiMsx KN.M	PhiMsy KN.M	PhiVx KN.M
900WB175	22300	2960	6580	7500	300	310	7500	6030	4480	2020	243	1730

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Load Case Analysis

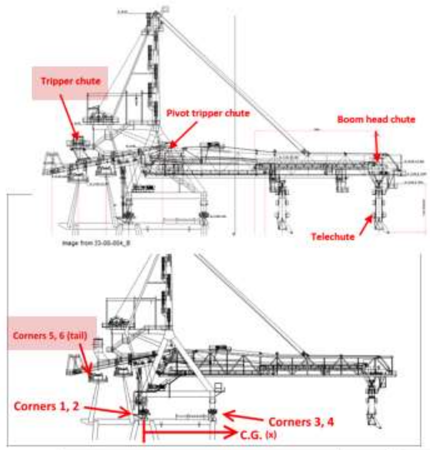
Load Combination –Type III/6 based on SL2 machine parameters

Table 3.7(B) (modified) - Load combinations, Ultimate limit state (ULS) design method

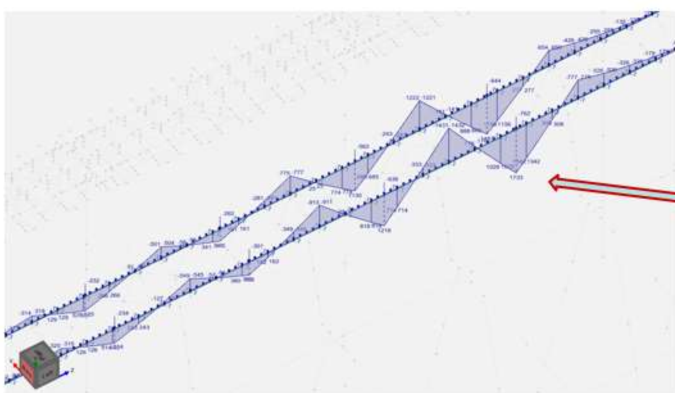
AS4324.1 Clause Ref.	Load Combination / Load Case		Main Loads I	Main and additional Loads II	Main, additional and special loads III				
	Load combination number		I	II/1	III/ 6	III/ 7	III/ 10	III/ 11	III/ 16
3.3	Main Loads								
3.3.2	E	Dead loads	1.35	1.2	1.2	1.2	1.2	1.2	1.2
3.3.3	V	Encrustation	1.35	1.5	1.5	1.5	1.5	1.5	1.5
3.3.4	N	Inclination (see Note 1)	-		-	-		-	-
3.3.5	F	Live loads	1.35	1.2		1.2			1.2
3.3.7	U	Normal digging	N/A		N/A	N/A			
3.3.8	S	Normal lateral digging	N/A		N/A	N/A			
3.3.9	D	Permanent dynamic effects	1.35	1.2	1.2	1.2			1.2
3.3.10	G	Conveyor elements	1.35	1.2	1.2	1.2	1.2	1.2	1.2
3.3.11	R	Friction	-	-	-	-	-	-	-
3.3.12	L	Travel	-	-	-	-		-	
3.4	Additional Loads								
3.4.2	Wo,r	Wind during operation or relocation		1.2	1.2	1.2		1.2	1.2
3.4.3	T	Temperature (see Note 2)		-	-	-	-	-	-
3.4.6	LS	Travel skew		1.2	1.2			1.2	
3.4.7	DD	Non-permanent dynamic effects		1.2					
3.4.9	P	Access ways (see Note 3)		-	-	-	-	-	-
3.4.12	NN	Abnormal inclination (see Note 1)		-			-		
3.5	Special Loads								
3.5.5	VV	Blocked chutes and hoppers			1				
3.5.6	FF	Excess material on conveyors			1				
3.5.7	LL	Travelling device obstructed				1			
3.5.10	WW_u	Wind while idle (ultimate)					1		
3.5.11	OO	Buffers						1	
3.5.16	EL	Extra loads							1.2

Type III/6 combination

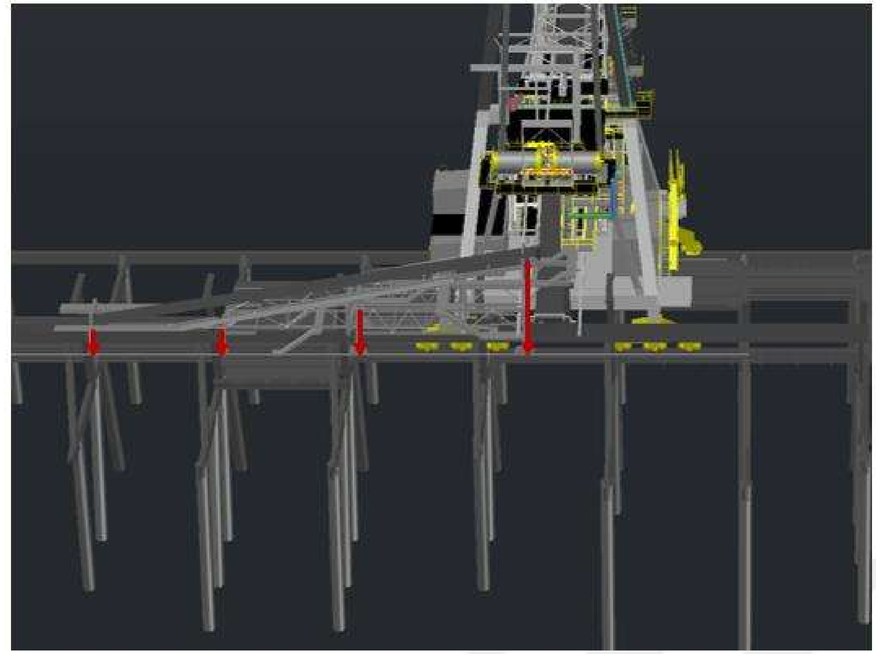
The main, additional and special Type III/6 load combination corresponds to a worst case scenario chute blockage (VV), and simultaneou conveyor belt with excess material (FF). Travel skew loads (LS) are also included in the combination.



	Corner load (kN)					Total mass (t)	C.G. (m)
	1 (NW)	2 (SW)	3 (NE)	4 (SE)	5,6 (Tail)		
Boom vertical (E)	3,927	3,927	2,445	2,445	277	1,327	6.5
Boom horizontal (E)	1,686	1,686	4,686	4,686	277	1,327	12.6
Boom horizontal (E,V,F)	1,507	1,507	5,265	5,265	329	1,414	13.3
Boom horizontal (E,V,VV,FF)	881	881	6,493	6,493	592	1,564	14.7
Boom vertical (E,V)	3,944	3,944	2,481	2,481	294	1,340	6.5
Boom horizontal (E,V)	1,642	1,642	4,783	4,783	294	1,340	12.8



- Max factored wheel load under the head ends: 762 KN
- Max factored moment :1733 KN.M
- Section utilisation at mid span is around 96%



- Details of the comprehensive load case analysis
- Development of FEA (Finite Element Analysis) model
- Visualization of stress distributions using color-coded patterns
- Changes in load case management post-AS4324.1

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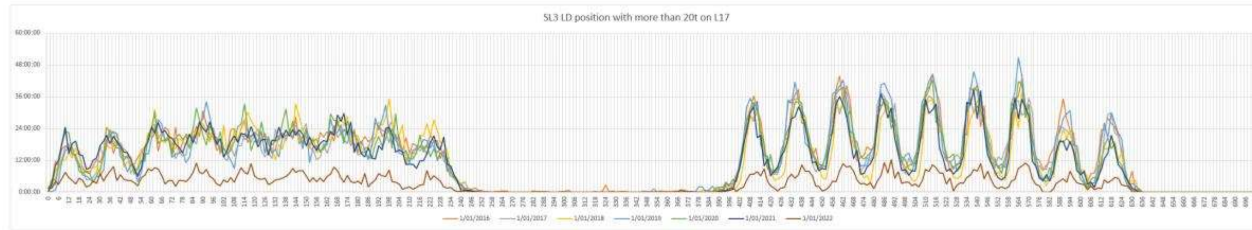
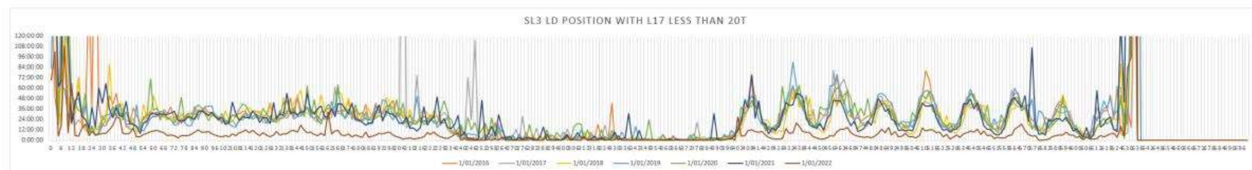
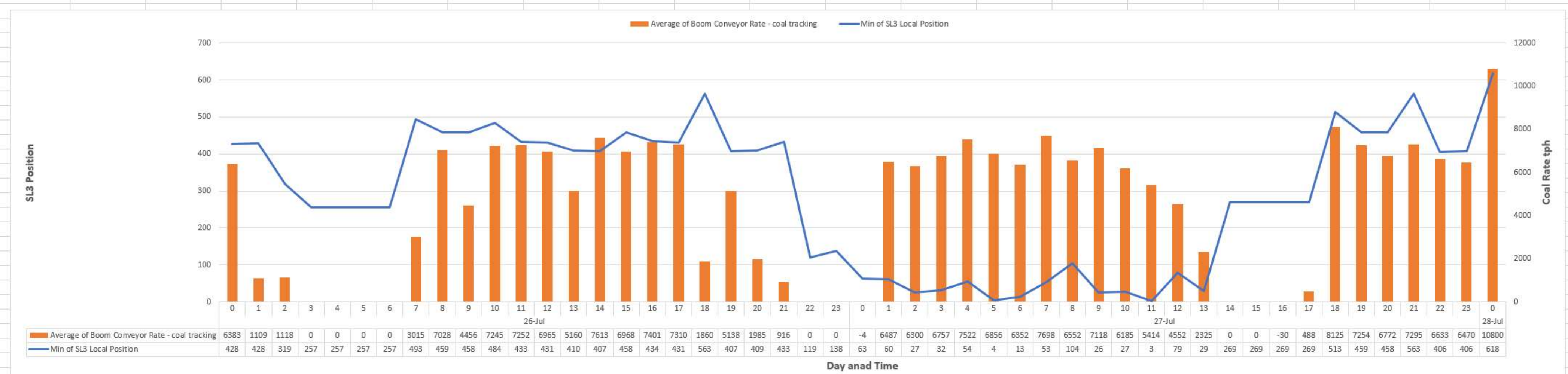
SCADA Data Analysis

- Utilization of five years of SCADA data
- Gathering and analysis of loading data, including material types and frequencies
- Identification of spans subjected to more frequent loading







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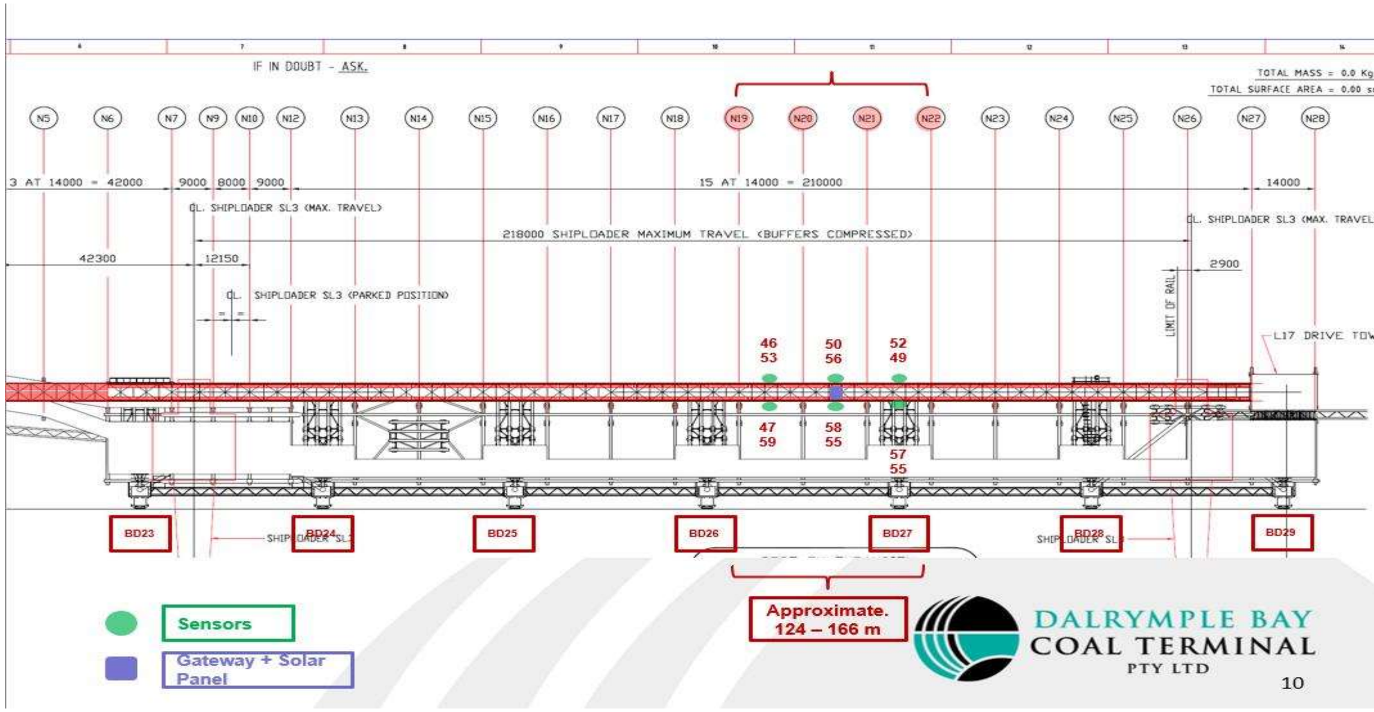
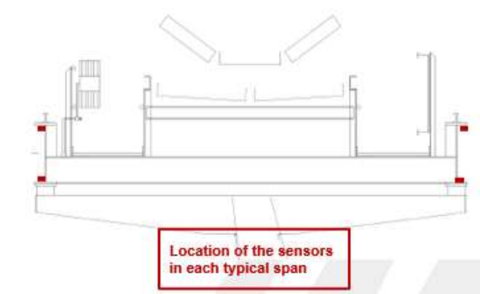
Monitoring Strategy

- Selection of three consecutive spans for closer monitoring
- Installation of 12 wireless strain gauges on designated spans
- Purpose of strain gauges: monitoring structural behaviour under extreme loads





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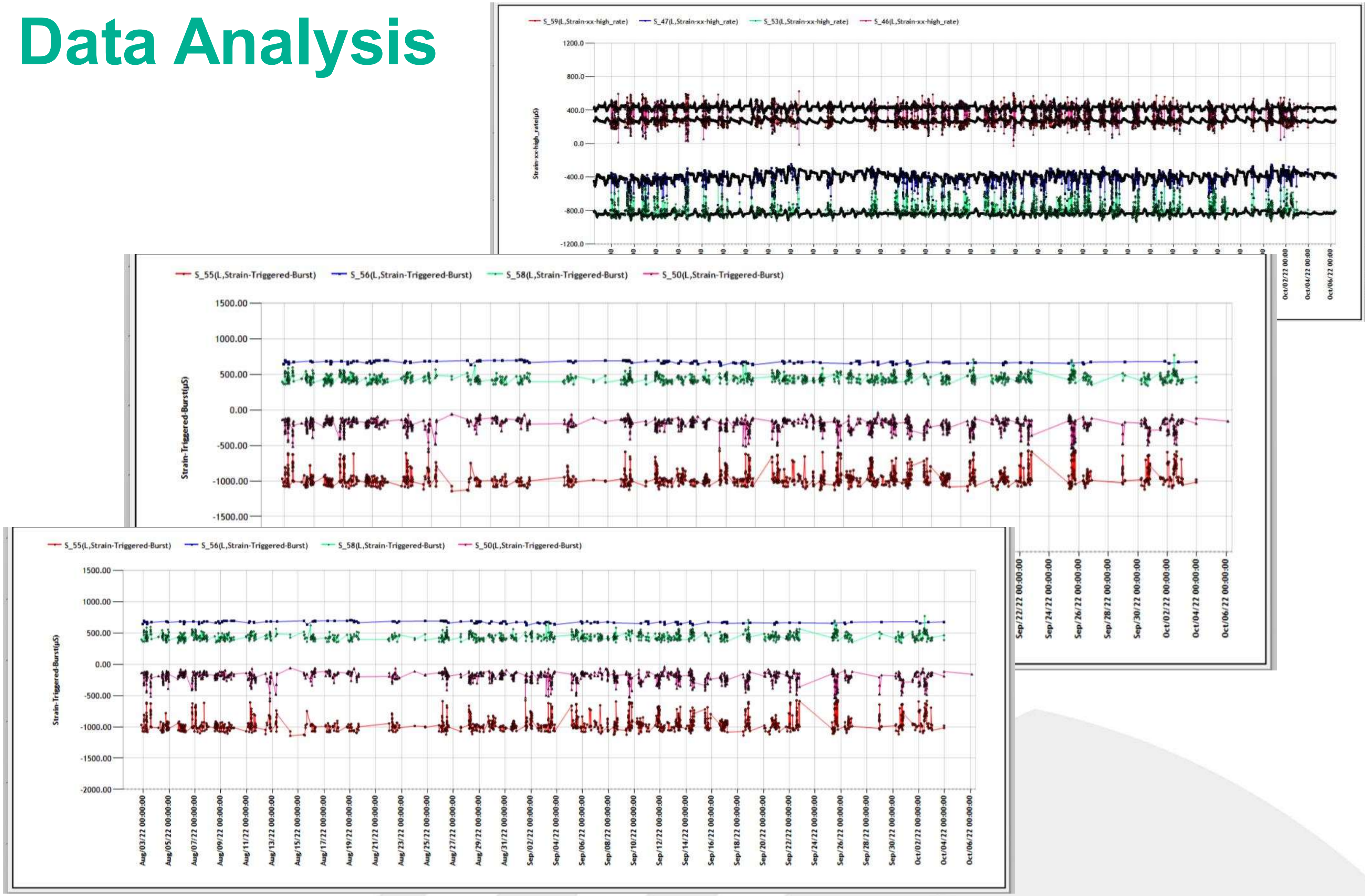
Data Analysis



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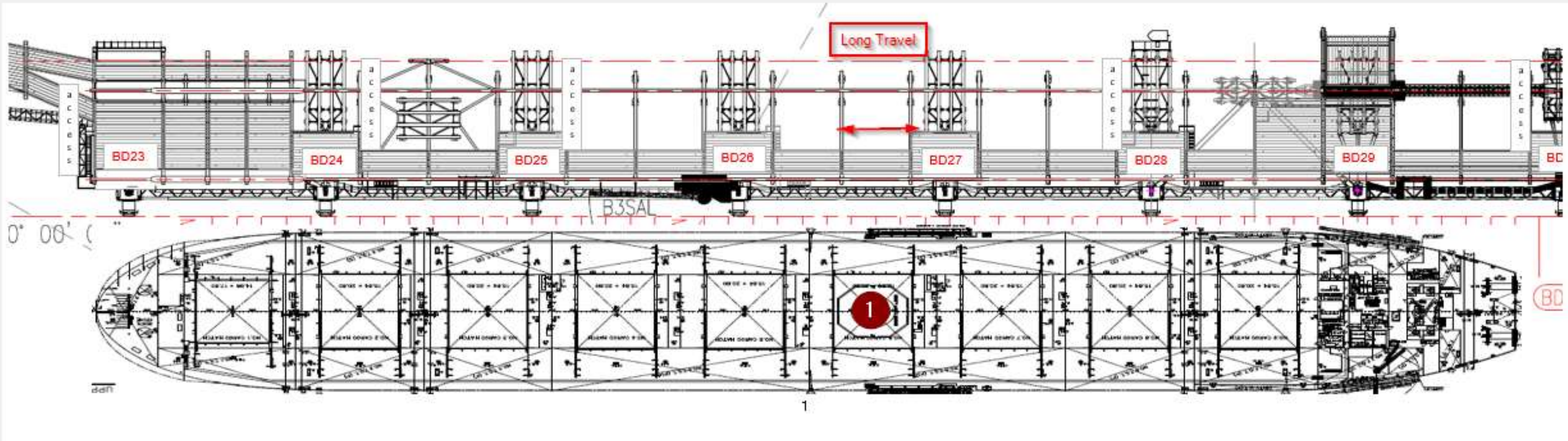

MANUAL BLOCK CHUTE EVENT

Wed 22 Feb 2023
@14:41

Plant	Start Date-Time	Mins	Event Type	Equip	Reason	Category	Comment	Work Order
L15_O/L	22/02/2023 14:41	19:57	Breakdown	L17	TST - TEST & COMMISSIC	Maintenance	block chute event test	
L15_O/L	22/02/2023 13:44	43:02	Stopped	SB3	SBL-AP - SBL - AWAITING	Operations		
L15_O/L	22/02/2023 13:30	14:0	Stopped	SL3	APTL - AWAIT PERM TO L	Ship	ptl 1345	
L15_O/L	21/02/2023 22:15	12:36	Stopped	SL3	CSYS - RUN OFF SYSTEM	Operations		
L15_O/L	21/02/2023 22:03	8:37	Stopped	SB3	PURG - PURGE	Operations		
L15_O/L	21/02/2023 21:49	4:46	Stopped	SL3	HCGP - HATCH CHANGE	Ship		

Operations | Maintenance

Event No.	Start Time	End Time	Task ID	Work Order	Finalised By
8005484	22/02/2023 14:41	22/02/2023 15:00	1518722		CS\CS-BRITTANYM

Event Type	Equipment	Reason	Category
Breakdown	L17 - Conveyor belt L17	TST - TEST & COMMISSION	Maintenance

Reset

Comment: block chute event test

Fault: 2

Report Error
Scheduled
Done

Delete Event | Split Event | Save Event

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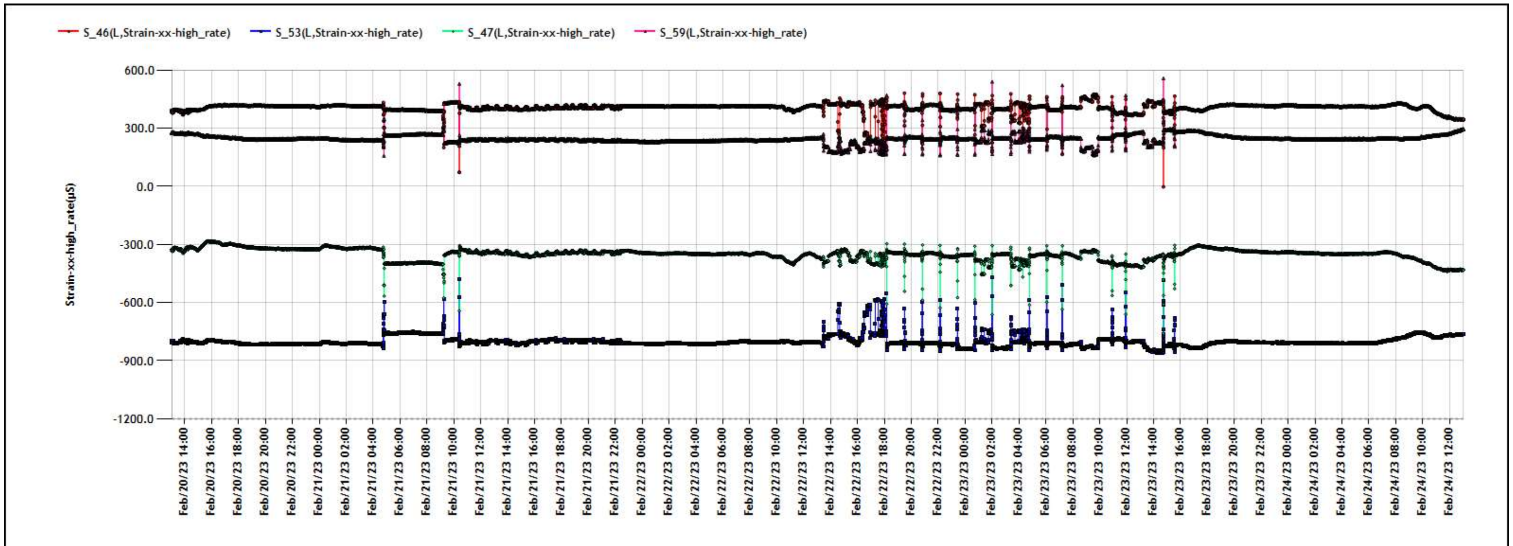
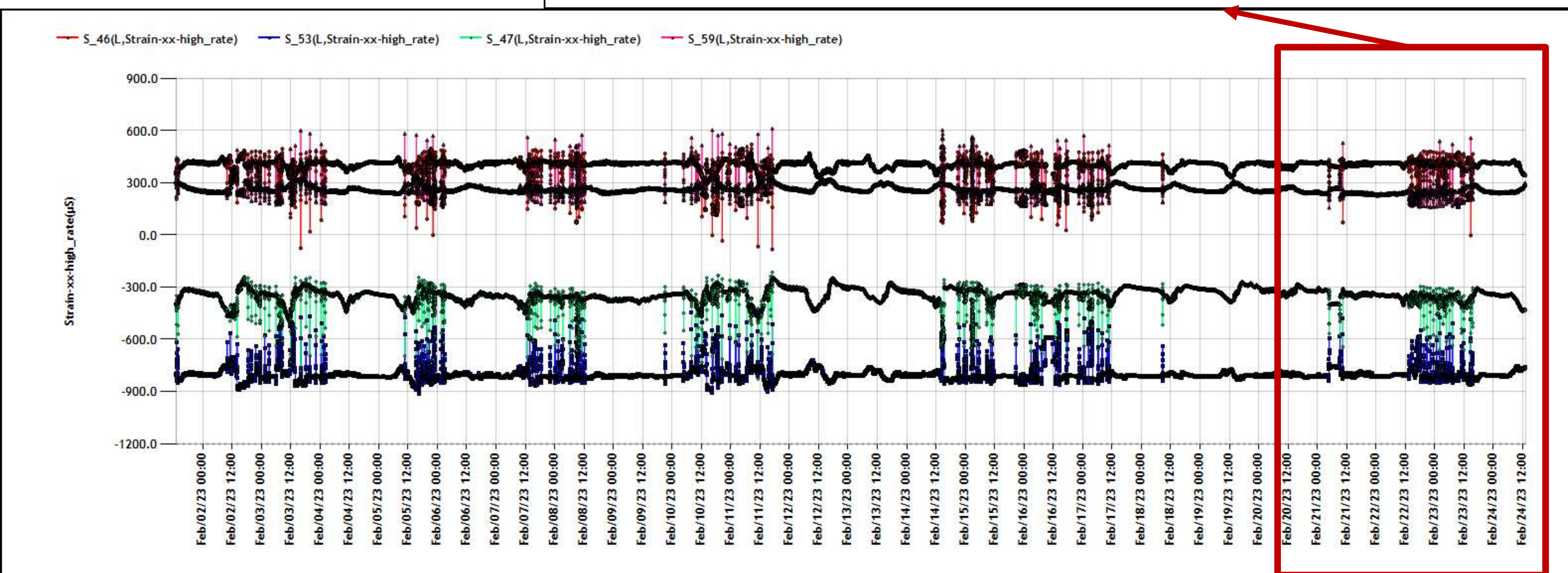
Sec A





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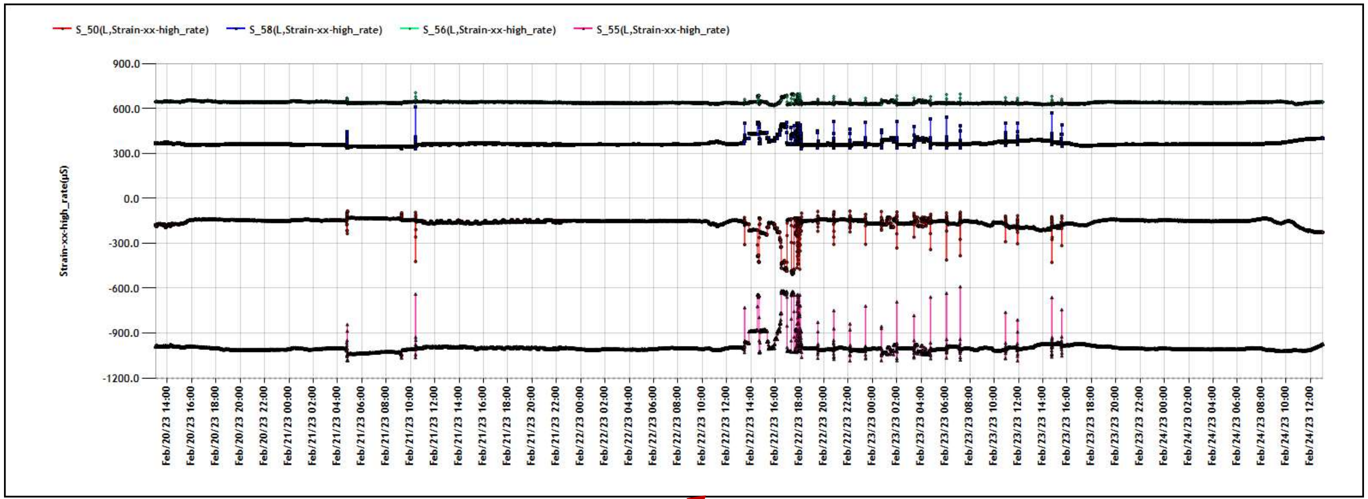
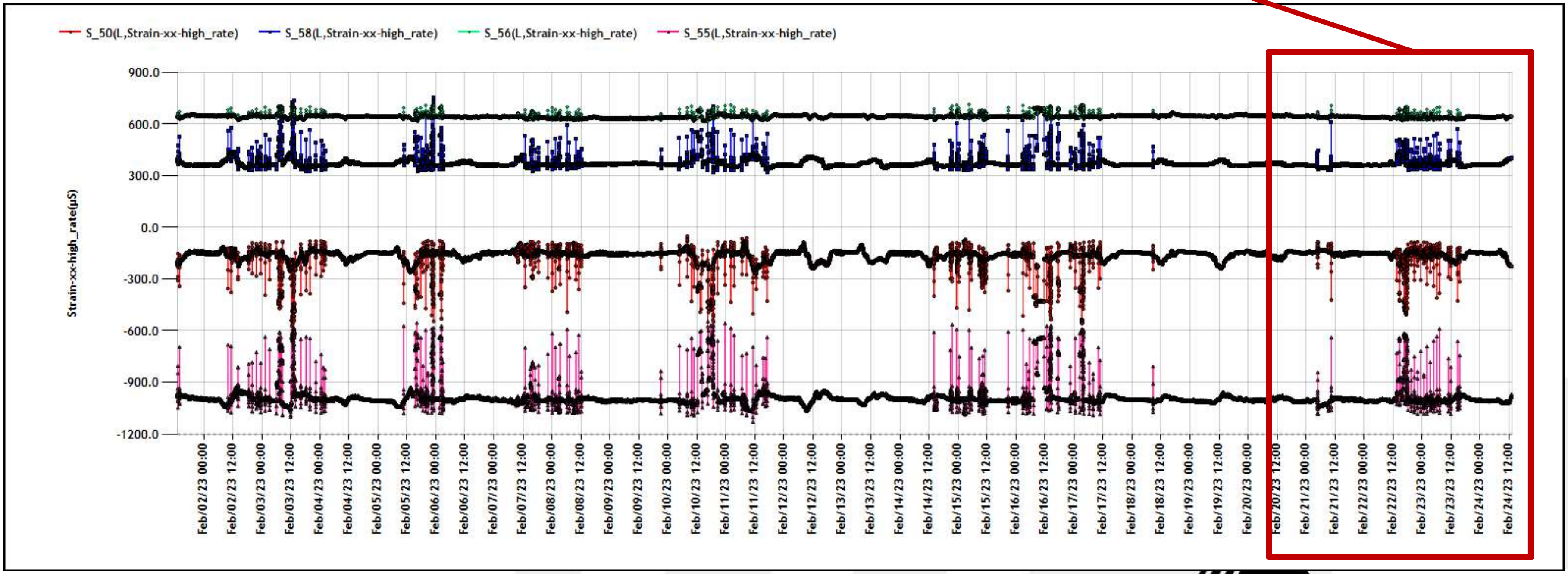
Sec B





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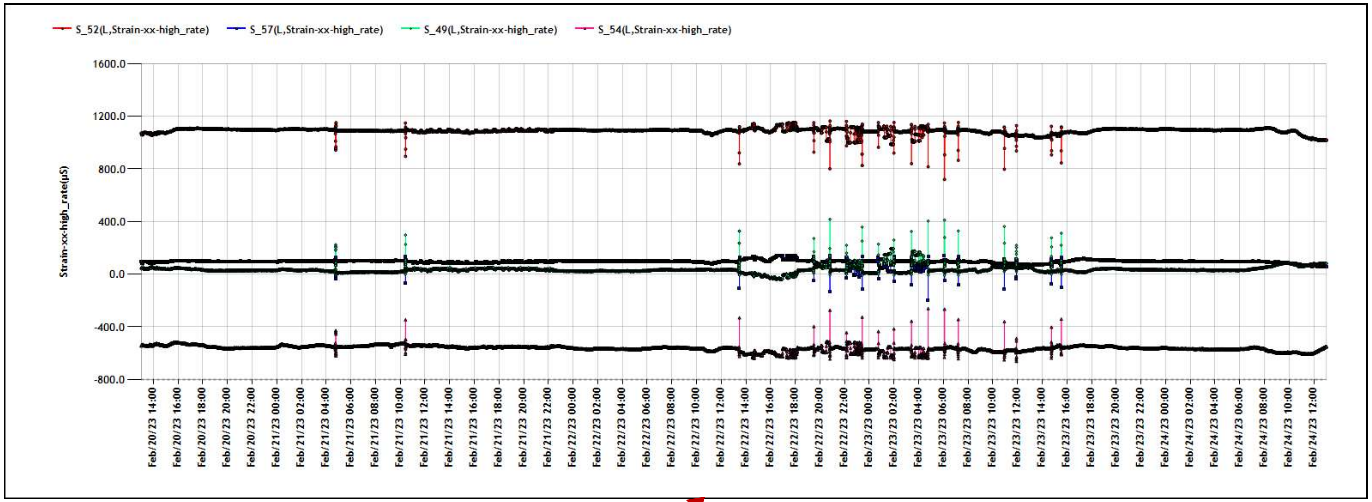
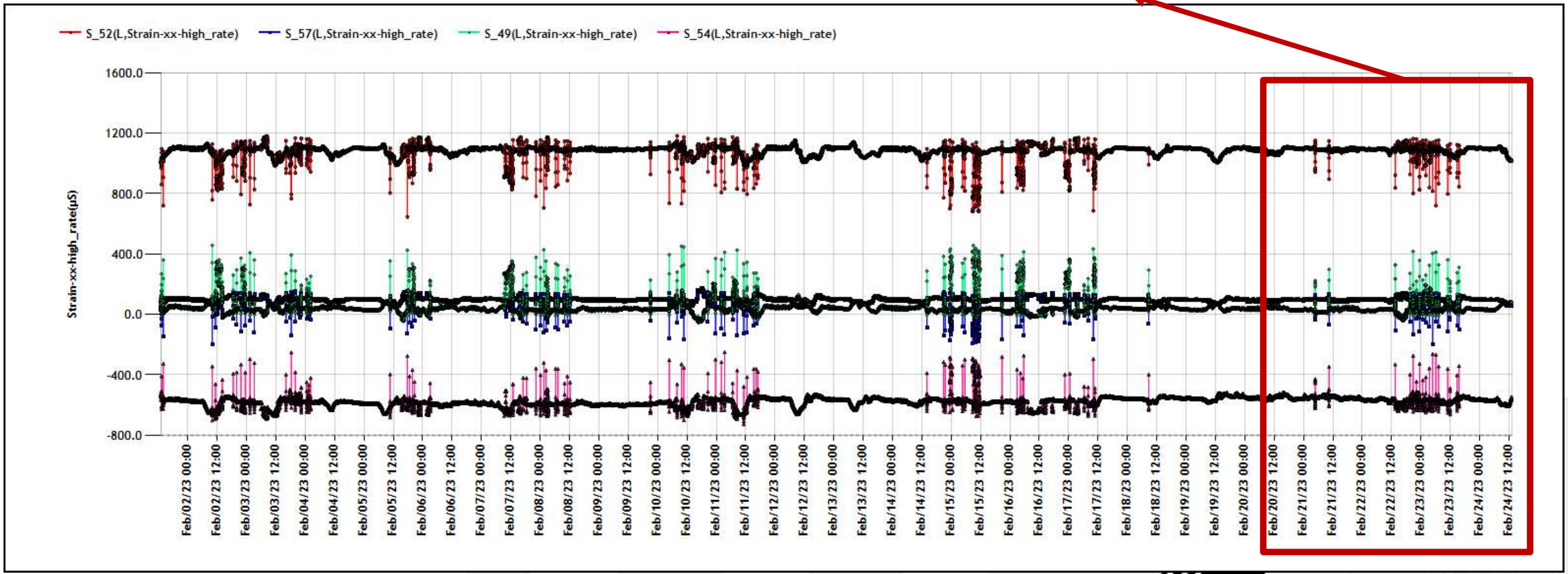
Sec C





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Concluding Remarks

Empowered Asset Management

- Successful Integration of sensor data with operational load cases
- Development of a robust strategy for asset management and maintenance
- Complying with risk assessment process according to AS4324.1
- The importance of data-driven asset management
- Ensuring the effective management of critical offshore assets

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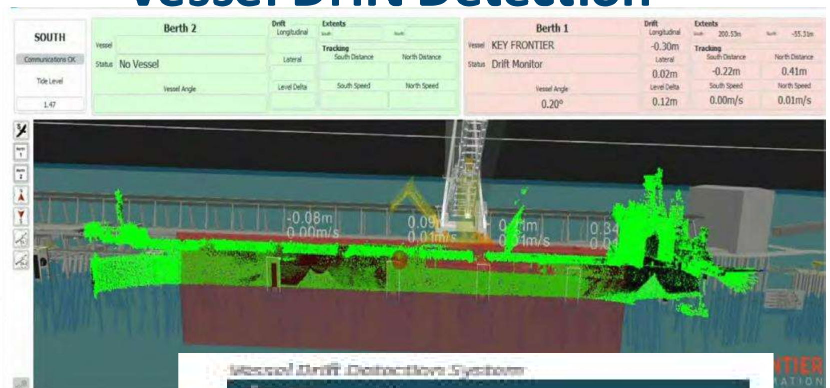
Other Examples

- Jetties
  - Impact from the berthing vessels
  - Loss of piles
  - Scouring at base of piles / over –dredging
  - Failure of fenders
- Quays / Wharves
  - Mooring vessel impacts
  - Loss of backfill material
  - Scour of walls / over-dredging

Operational and Environmental Parameters

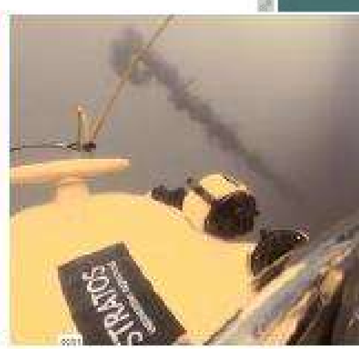
- Berthing Forces / Energy / Velocity
- Temperature
- Moisture
- Wind
- Solar Radiation

Vessel Drift Detection



Underwater Drone

Using underwater drones to complete cathodic protection and structural pile inspections has optimised maintenance time. This technology allows work to continue on the berths and the loading of vessels while the drone operates.



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Concluding Remarks

- Challenges
- SHM in Port and Maritime Infrastructure
  - Has the potential to be considered as an alternative method for structural inspection and assessment
- Best practice and lessons learned
- Data analysis and interpretation is critical aspect of successful SHM
  - Sensors alone do not detect damage.
- Outlook
  - Remote asset management
    - Moving away from a prescribed structural inspection and assessment
    - Being able to detect any impending failure before their occurrence
  - Improving safety and maintainability

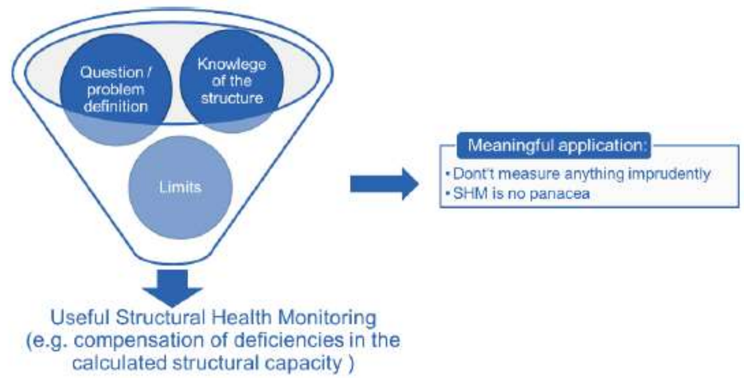

Figure 2.1: High-level overview of SHM

Updating Report No. 199

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Q&A

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Thank you for your attention

Open the floor for questions and discussion

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