CORROSION UNDER STRESS:

The Development & Application of Corrosion Control Solutions for Prestressed Concrete Structures

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OUTLINE

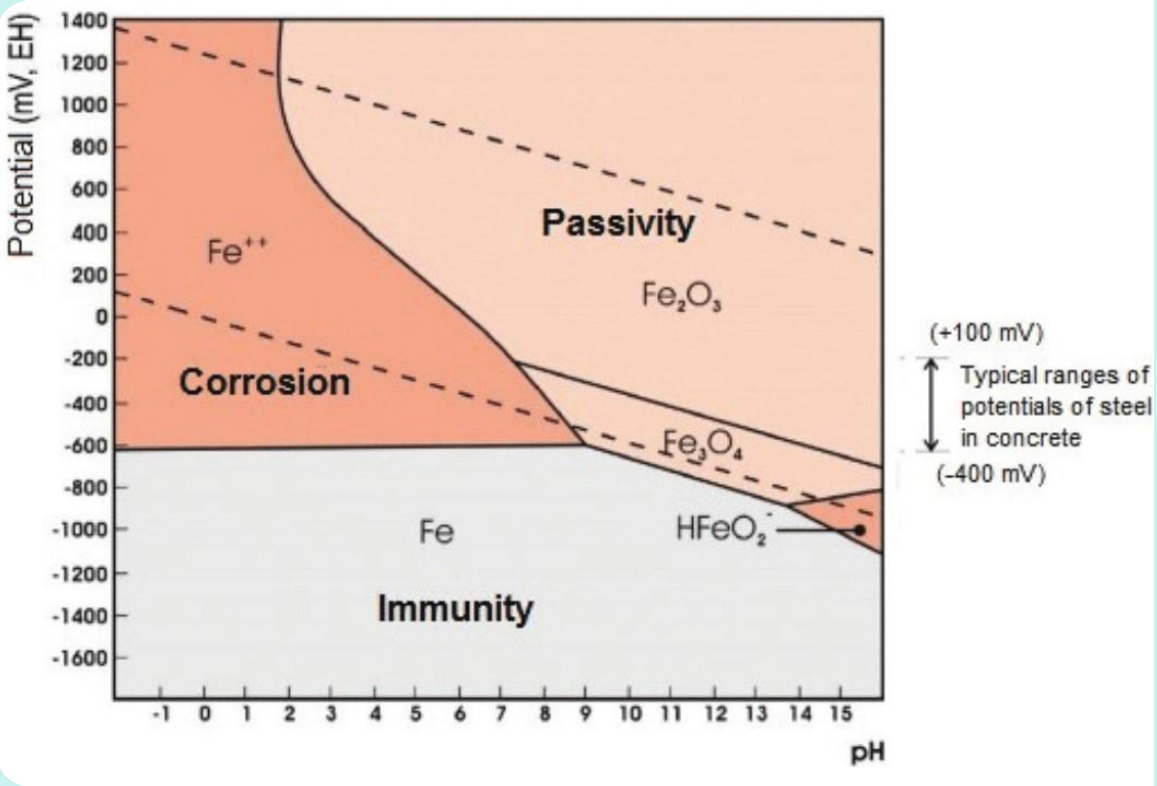
The Application of Corrosion Control Systems for Prestressed Concrete Structures

1. Corrosion of Prestressed Concrete: **Mechanisms** & **Implications**
2. Available Mitigation Strategies: **Pros** & **Cons**
3. Bulk Liquids Berth 1 – A Case Study:

    1. Diagnosis & Optioneering
    2. Mitigation Design
    3. Repair & Protect

Corrosion of Prestressed Concrete: Mechanism & Implications

- Steel will **Freely Corrode** when exposed to **Most Electrolytes**
- Steel in Concrete however is mostly protected due to **Highly Alkaline Environment (pH 13-14)**
- The introduction of Cl- will **Break Down** the passive layer introducing pitting corrosion and lateral corrosion.
- **Corrosion Rate** will depend upon drop in resistivity, surface area ratio (anode/cathode) and water saturation level
- Prestressed Concrete is understood to have higher **Corrosion Resisting Properties** than RC Concrete



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Corrosion of Prestressed Concrete: Mechanism & Implications

- Whilst it is more resistant to corrosion, when it does occur, the implications are substantial.
- Corrosion of Prestressed Tendons can result in catastrophic failure of the element:
  - **Brittle Fracture** – Exceeding the load capacity
  - **Stress Corrosion Cracking** – Caused by anodic stress corrosion and hydrogen induced stress corrosion cracking.
  - **Fatigue and Corrosion Influences –** corrosion fatigue cracking & fretting corrosion
- In all instances, failure is caused by substantial loss of ductility and therefore, early identification is **imperative**.

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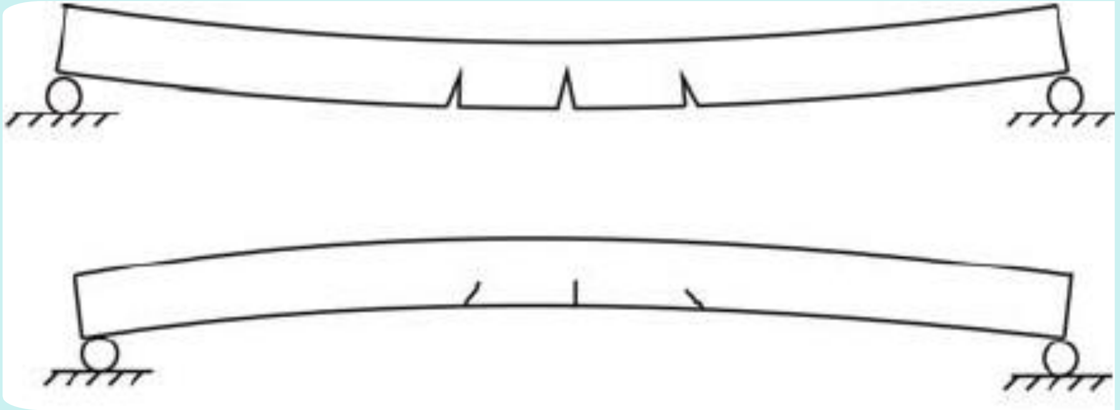
Corrosion of Prestressed Concrete: Mechanism & Implications

- Traditional RC corrosion is visually identifiable through cracking/spalling/delamination – **Easy to Identify**

- Prestressed elements corrosion is often more **difficult to identify**:

  - Corrosion Product Buildup within the voids between the strands, resulting in less volumetric expansion.
  - Hogging bending effects from prestressed steel – compressive forces at the bottom of the element, reducing the visibility of cracking



Mitigation Strategies: Augmentation, Mechanical, Electrochemical

- Generally, traditional remediation techniques do not apply to prestressed concrete
- Risk of Destressing or Damaging Very brittle strands
- Augmentation of Strand is not possible
- Supplementation of Structural Strength is required through external methods

- Carbon Fibre - Passive
- External PT – Active

- External Repair Methods have their own limitations and challenges and often will not be able to 100% “augment’ existing condition.

Mitigation & Control is Best Addressed through Preventative Measures

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Mitigation Strategies: Augmentation, Mechanical, Electrochemical

- "Mechanical Protection" systems refer to Physical Barriers that prevent or delay the ingress of Cl-, O2, H2O.

- Penetrative Sealers – Silane/Siloxane
- Barrier Coatings – Epoxies, PU

- Effective at the early stages of contamination but are less effective once critical thresholds have been achieved.
- 10-15 year service life

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Mitigation Strategies: Augmentation, Mechanical, Electrochemical

- Application of Cathodic Protection will serve two key purposes:

1. Draw the Cl- away from the steel ∴ **maintain alkalinity**
2. Lower the electro potential of the steel to within the **immunity zone**

- Most Effective Strategy once Cl- is at steel

- Complex/Expensive/Risky (Hydrogen Embrittlement)

An Effective Solution – Requires Lots of Consideration

Case Study:

BLB 1

A Hybrid Solution

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Project Background

- **Bulk Liquids Berth – Constructed in the 1970's**
- Supply of Essential liquid products handling and distribution for NSW (Gas, Fuel, Bitumen etc)
- Traditional RC Wharf Structure with various pre-cast, prestressed concrete bridge elements – walkways, pipe bridges, catwalks etc.
- Aggressive Environment over 40 years since time of construction
- Considered a "Hazardous Area" due to volatility of the products being stored/handled on site.

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Problem Diagnosis & Developing the Business Case

- **The asset owner uses an asset management framework that includes a Marine Structures Inspection Program.**

- Two Yearly Structural Condition Assessments for different elements, including:

  - Visual Inspection & Crack Mapping
  - Ferric Covermeter & GPR Scanning
  - Potential Mapping
  - Surface-Mounted Resistivity Analysis
  - Chloride Profiling & Diffusion Modelling
  - Carbonation Testing, and
  - Alkali Silica Reaction (ASR) Testing

- **Ongoing/Worsening Corrosion Activity was identified to the majority of the precast, prestressed elements.**

To Maintain Use of the Structure A Life Extension Strategy Was Required

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The Decision Making & Optioneering Process

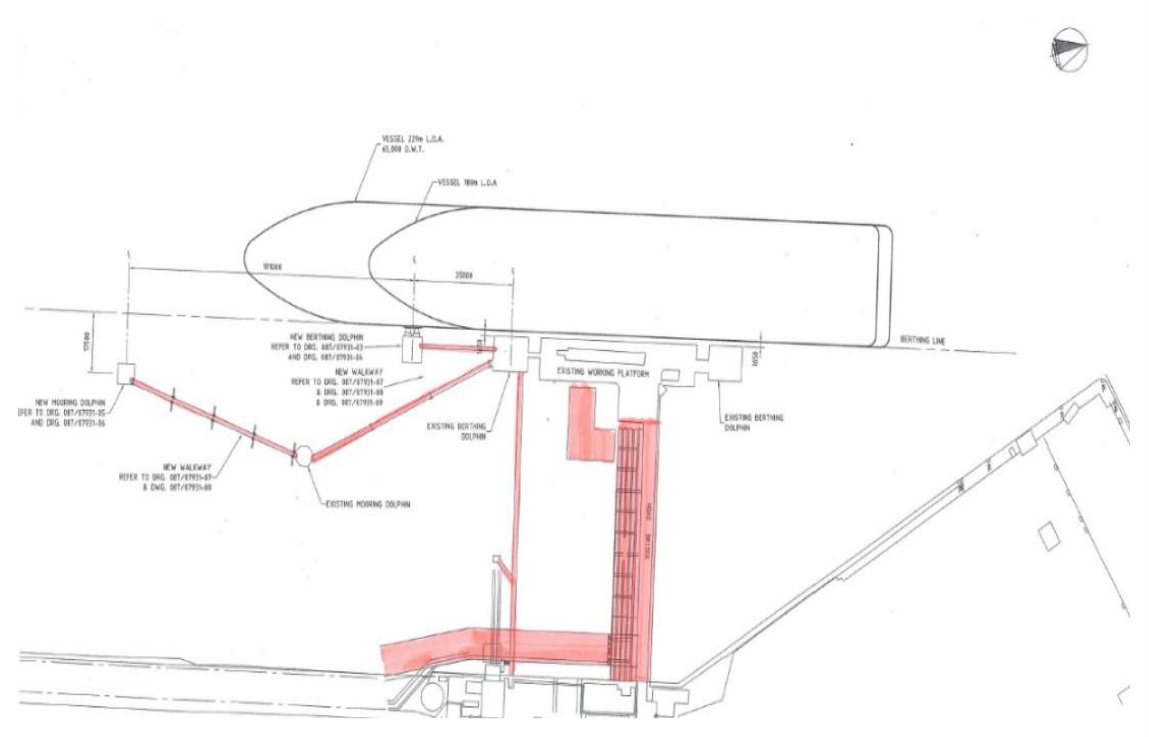
- To ensure informed decision making, a detailed optioneering process was undertaken – Assessing Technical, Financial, Environmental, Operational and Reputational impact to the facility and its stakeholders.

  - Option 1 – **Do Nothing** : 10 to 20 years

  - Option 2 – **Concrete Repair & CP** : 30+ years

  - Option 3 – **Replace Structures** : 30+ years

- Each Option was assessed via a **Quantitative Risk Assessment** and a **Net Present Value (NPV)** lifecycle Cost assessment



The Decision Making & Optioneering Process

- **Option 2** (Electrochemical Treatment with Concrete Repair) **–** Highest Value solution
- Lowest Risk Outcome over the life of the asset
- **Acceptable $$$ (Capex & Opex)**
- **Minimal Disruption** to the Operation of the Facility
- **Business Case** was Prepared and submitted to the board of the port authority **for Approval**

The Design Process – A Challenging Environment

- **Further Optioneering was undertaken, and a Hybrid Corrosion Protection Solution was adopted:**

- Stage 1 – Energisation (Extract Cl- away & Repassivate Steel)
- Stage 2 – Galvanic Stage (Maintain low Corrosion Rates through Galvanic *Zinc* Anode Arrangement)

- Reduced Risk to the structure – Minimal Chance of Hydrogen Embrittlement
- Simplified Maintenance & Monitoring Requirements

- Design included provision of 35,000 + Hybrid Anodes, 188 Zones - across the total structure

The Design Process – 50 Year Design Life

- **Hybrid Corrosion Protection – Relatively New** (~12 Years at the time this project was underway)
- Risk of further chloride ingress & redistribution of Cl- : depassivation of steel over design life.
- Design Calculations were carried out to verify sufficient capacity for **additional impressed current treatments** over the design life:
- Impressed Current Energisations at:
  - Year 0
  - Year 15
  - Year 30
- System Zoned & Wired in such a way as to allow for ad-hoc monitoring/energisation over this period

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The Design Process – Avoiding Embrittlement of Prestressing

- The **Energisation Phase** of Hybrid Corrosion Protection is when the structure is at the **Highest Risk of Embrittlement.**

- For RC Structures – Energisation is typically applied at a constant voltage ~ 8V dc (7-28 days)
- For Prestressed Concrete – This must be much lower.

Design Considerations were made to reduce this risk through:

  - Limiting the size of zoning - more control/resolution
  - Increasing qtty of permanent reference electrodes
  - Adopting a conservative potential limit -800mVssc
  - Specifying an alarmed, monitoring system

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Repair & Installation Challenges: Working With Prestressing

- As with all CP systems, **extreme care** is required during installation to eliminate risks of short-circuits, discontinuity, poor quality backfilling or electrical works
- With Prestressed Concrete, the risks associated with these considerations are amplified.
- Robust Quality Control systems are required, Routine inspections, hold points, verification
- **Test, Test, Test… Then Proceed.**
- Working with prestressed concrete presents some unique challenges.

Repair & Installation Challenges: Staging & Managing Repairs

- If not completed correctly, repairs to prestressed concrete can risk **Destressing** the tendons.
- **Staging is key** to minimize any temporary reduction in structural capacity and limit the quantity of concrete material for removal at any one time.

- During the BLB 1 project consultation from structural engineers was sought to develop standard repair guidelines to inform the works.

- **Additionally,** Use of cutting grinders & Percussive jackhammers can risk damaging the tendons
- Ultra-High Pressure Water jetting **(Hydrodemolition)** was used .
- **Whilst Highly Effective; expensive for small repairs, safety considerations and high noise levels.**

Planning is Key

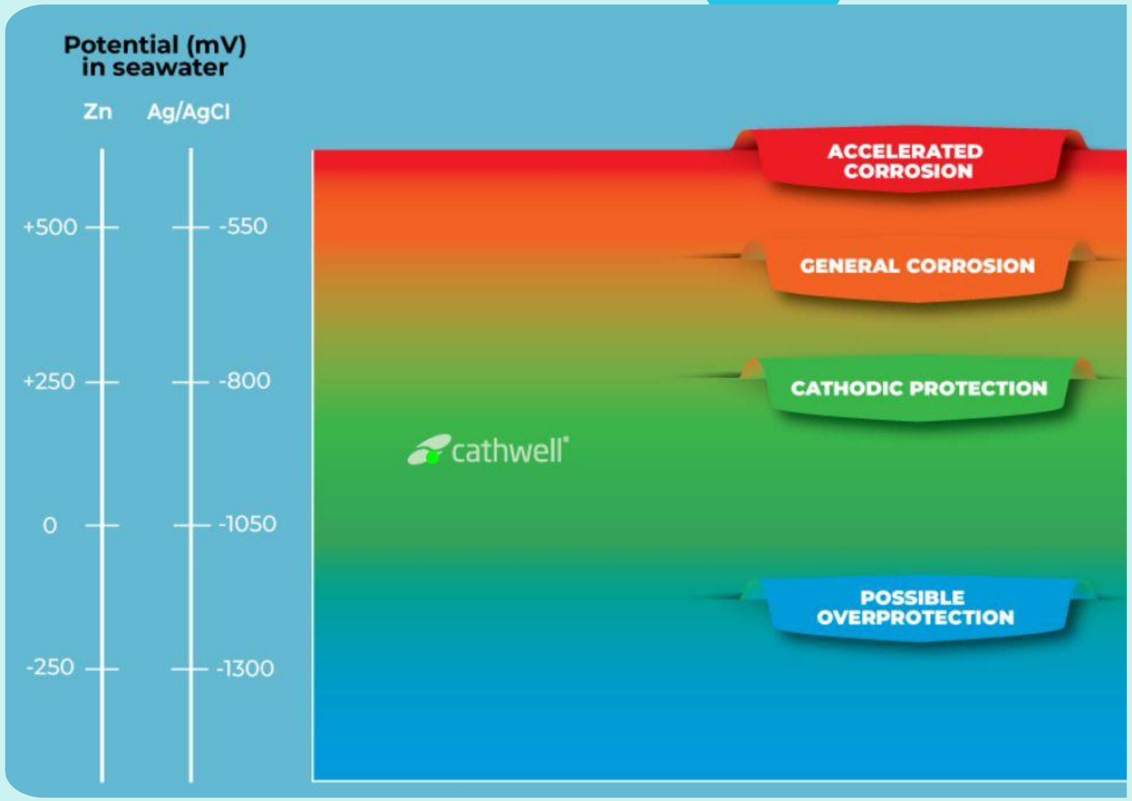
Repair & Installation Challenges: Preventing “Overprotection”

- “Overprotection” occurs when the reinforcing steel is polarized beyond optimal levels and can result in hydrogen embrittlement of the steel – **Reducing Ductility!**

- The Energisation phase of the Hybrid Process presents very real risks of overprotection if not managed properly.

- BLB 1 Project adopted a sophisticated remote monitoring and control system for all temporary power supplies
    - Alarms (Email & SMS)
    - Voltage & Current Limiters
    - Data Logging & Assessment

- **Full Project Visibility – All Stakeholders**



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In Summary

1. The implication of corrosion of prestressed concrete can be catastrophic and is not to be underestimated
2. Management & Control requires a Proactive Approach from Asset Owners and corrosion practitioners
3. Whilst there are complexities with designing and installing electrochemical treatments for these structures, it is a viable – long term solution

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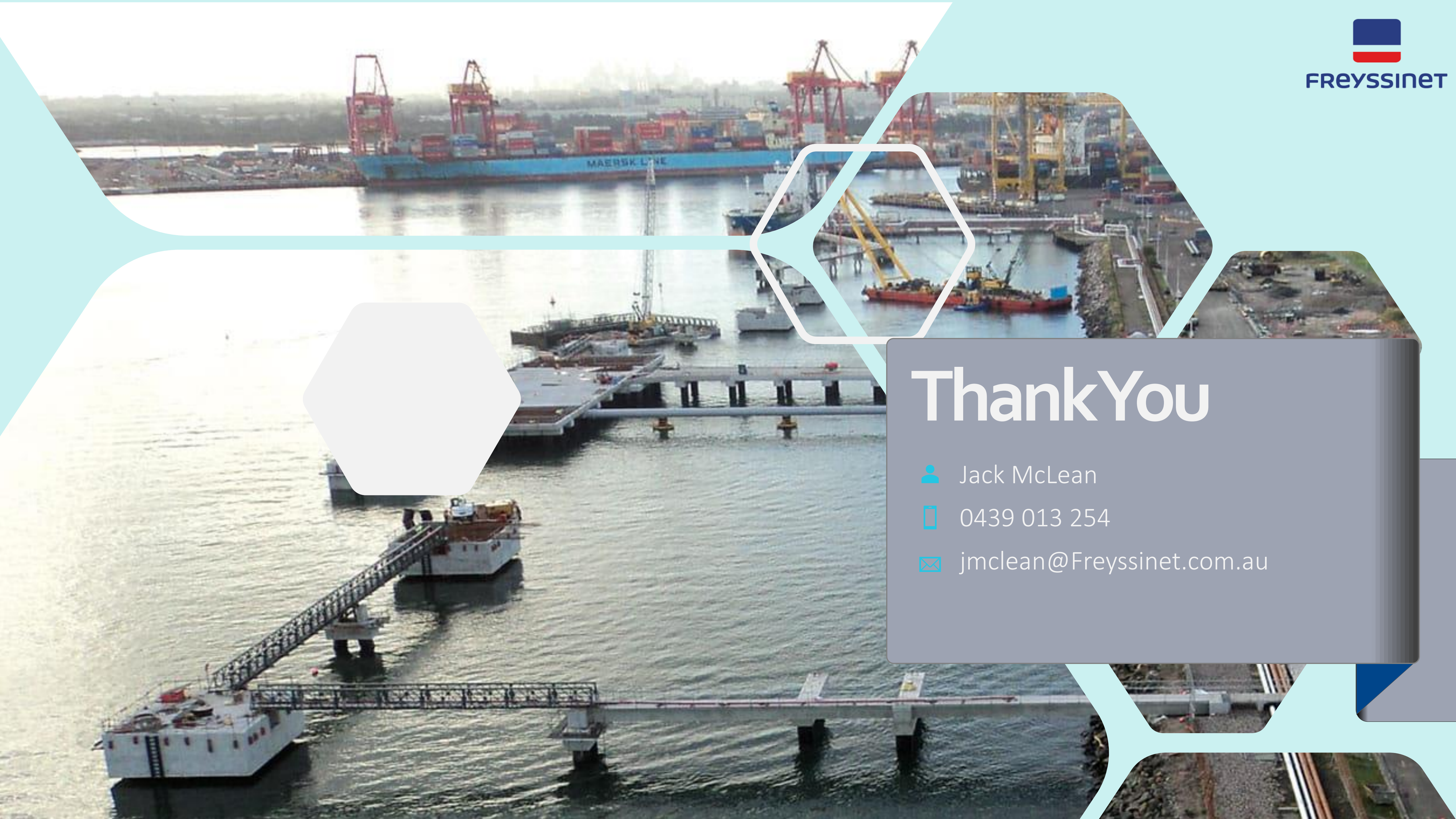

Thank You

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