ICE Flow Corrosion Risk Management: Gold mine

System wide corrosion in gold mine: This site experienced many corrosion challenges due to the climate, acidic ore, low water quality and a lack of corrosion consideration in design. ICE deployed corrosion risk management program as well as reducing risk through corrosion engineering design.

Challenges:

- Systemic and highly aggressive corrosion
- Hidden asset risks
- Unknown maintenance cost / production losses
- Reactive response / minimal skill set

ICE Impact:

- Technical solutions (risk-based prioritization)
- ICE Flow corrosion risk management
- Risk measured and quantified
- Risk-based work prioritization
- Accurate budgets and scheduling
- Financial impact understood
- No catastrophic failures

ICE Flow Corrosion Risk Management: Gold mine

Gold mine using recycled process water: To reduce water use footprint in this remote, sensitive location, this mine recycles water. This results in high salinity in the process and washdown water leading to corrosion challenges. ICE deployed corrosion risk management program (with full site presence) as well as reducing risk through corrosion engineering design.

Challenges:

- Saline process water = rapid onset of corrosion
- High corrosion rates on structures, tank externals, piping, cladding, ducts, handrails etc
- Remote location (difficult access to resources)

ICE Impact:

- Proactive corrosion control input at design stage
- Development and implementation of a corrosion risk management plan (ICE Flow) to stay on top of the risk over the life of the mine (35yrs)

Potash Mine-Early Stage Design:

Corrosion design and early-stage ICE Flow corrosion risk management: Proactive client realized the severe corrosion risk for this project and engaged ICE to review the design for durability and provide Asset Integrity program design for operations.

Challenges:

- Mining salts high in Cl
- High corrosion rates expected
- Long design life 70 years

ICE Impact:

- Created overarching corrosion / durability strategy for project
- Asset by asset corrosion risk assessment and design of resilient solutions (concrete, steel, mechanical equipment, piping, electrical, architectural, civil)
- Coating specifications and QA/QC guidance
- Early development of inspections, processes, data collection and models to allow predictive maintenance capabilities
- Input into op readiness and maintenance plans

Data-informed Structural Steel Integrity

ICE DRAGON CORROSION INC

This site had high levels of salinity in the washdown water which reduced the longevity of structural steel and coatings. Risk was understood through quantitative data collection to allow prioritization of maintenance work.

4	CRITICAL	>80 microns / yr
3	HIGH	50< CR <80 microns / yr
2	MODERATE	25< CR < 50 microns / yr
1	LOW	<25 microns / yr

Challenges:

- High salinity washdown water = corrosion of structural steel
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ICE Impact:

- Created a standard visual inspection proforma for steel in the process plant
- Collected quantitative corrosion data (coupons, UT measurements, exposure data)
- Created a corrosion risk map for tracking and predicting risk
- Updated the coating specification to match the risk type
- Carried out annual audit inspections to track risk and optimize repair

CIL Tank Preservation

After 1 year of operation, CIL process tank inspections revealed higher than expected wear and pitting corrosion. ICE specified liners and oversaw the project to line the tanks and increase service life.

Challenges:

- Entrained solids plus chlorides
- Unlined CS process tank x 6
- 1 year in operation
- Pinhole leaks from erosion-corrosion
- Pitting up to 1 mm depth

ICE Impact:

- Analysis of risk vs. operation
- Specification of internal liner system
- QA/QC design and oversight
- Working well after 1 year in service

Port Cathodic Protection: Coal Terminal

ICE DRAGON CORROSION INC

Coal terminal structures required an upgrade to their CP systems to ensure continuing longevity for their extended service life.

Challenges:

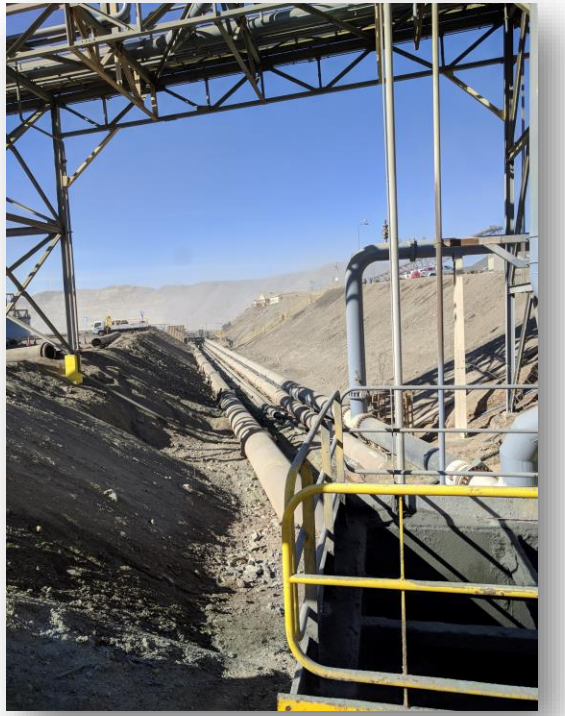
- Marine exposure of port structure / CP system not functioning well

ICE Impact:

- Inspection / review of existing CP system and condition of submerged piling of port
- Re-design of new galvanic anode CP system
- Construction support
- Commissioning of CP system
- Training of client team to carry out annual inspection

Water Conveyance Line: Copper Mine

Section of long water conveyance pipeline had not been lined in construction. Pinhole leaks occurred. Incumbent water treatment was ineffective and giving client false sense of security.



Challenges:

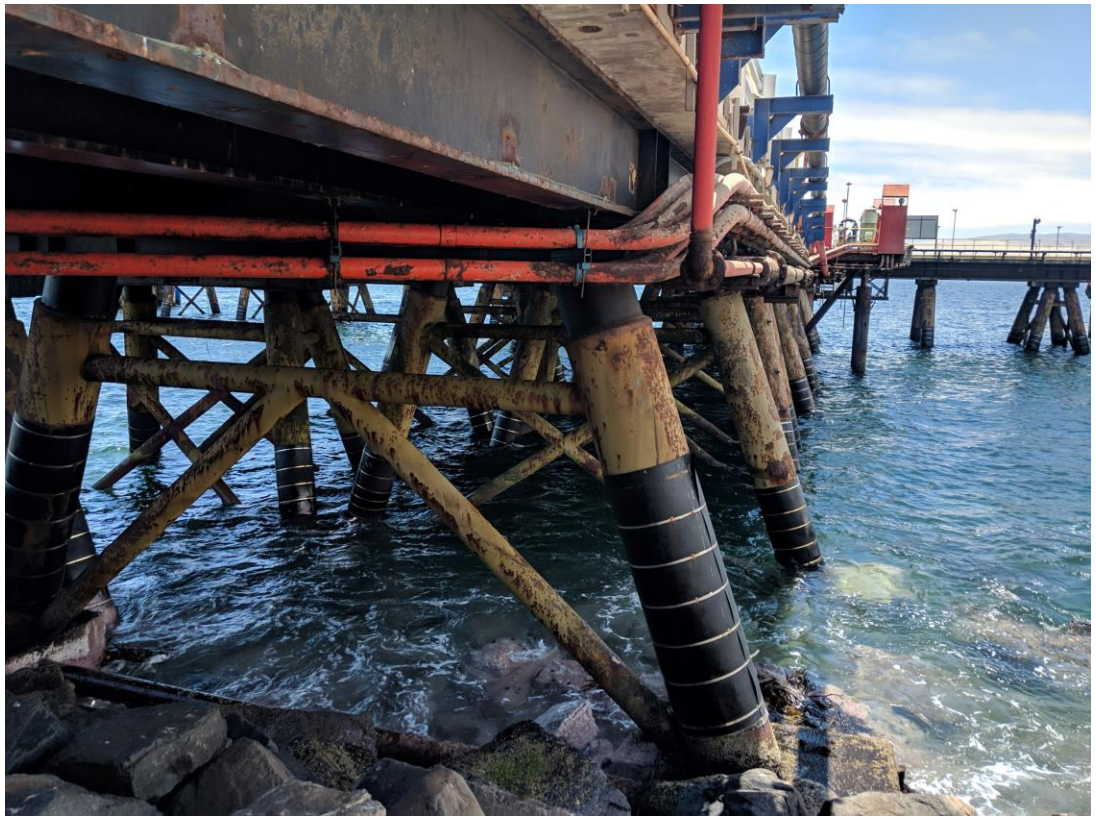
- The conveyance line was exposed to mixed waste/stormwater/desal water.
- Failures occurred due to MIC (Bacterial attack) – this risk was not accounted for in design or corrosion protection strategy.
- The water treatment program in place was not able to effectively identify, control and monitor corrosion risks.

ICE Impact:

- ICE team identified the corrosion risks through inspection and analysis of operational/maintenance data.
- A modified water treatment plan was developed with improved corrosion inspection and monitoring to prevent future failures.
- Client changed water treatment company.

Port Cathodic Protection: Copper Mine

Cathodic protection system had been installed on the port structures during construction but had not been regularly maintained or monitored, resulting in an integrity risk to UW structures.



Challenges:

- Site inspections revealed that the marine structures were under-protected due to failed cathodic protection system and severe coating damage.
- System failure was not detected due to lack of inspection and monitoring leading to structural damage.

ICE Impact:

- System modifications were developed to achieve required protection.
- On-site training for inspections and a monitoring plan was put in place for future maintenance and to prevent future failures.

Concrete Design: Potash Mine

Reinforced concrete used for a potash process plant and shaft liner was required to have a service life of 70 years. Concrete mix was designed for durability.

Challenges:

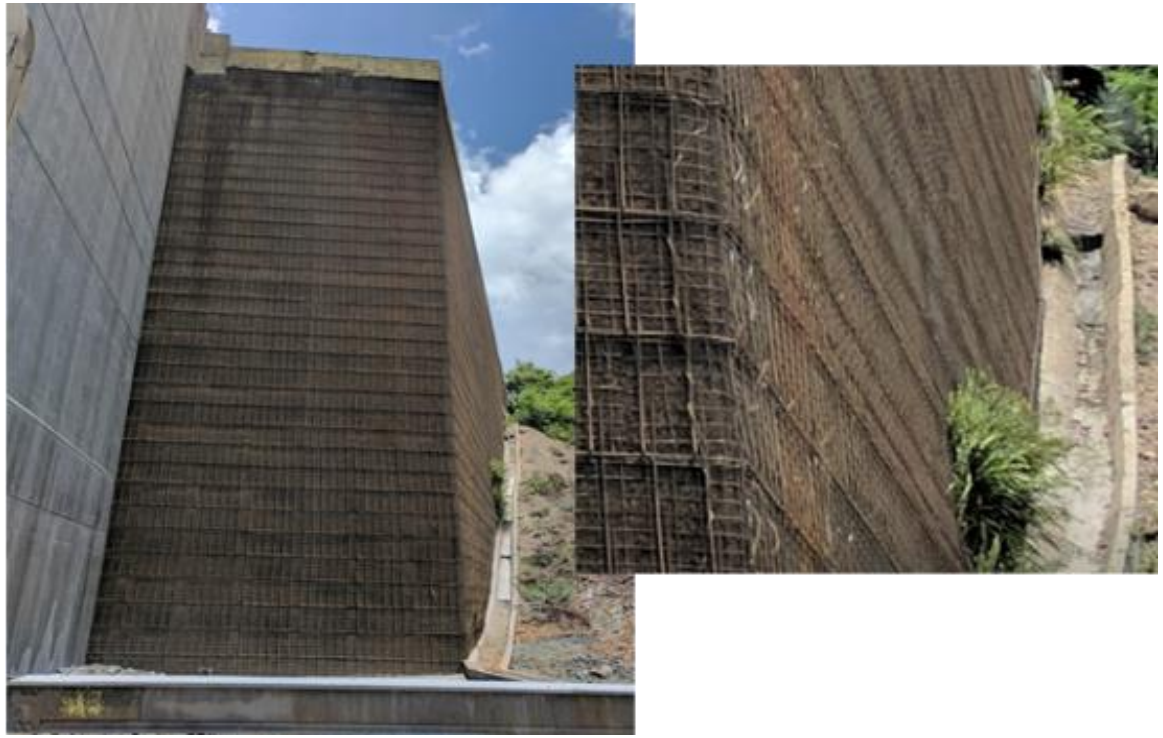
- Very high chloride exposure due to salts from the ore
- Concerns with integrity of concrete structures

ICE Impact:

- Developed a service life model for the current design to find inefficiencies
- Investigated other corrosion control methods to reach the designed service life

MSE Retaining Wall: Gold Mine

Mechanically stabilized earth wall had not considered the impact of acidic ore corrosion on the galvanized structural rebar. Several sections of rebar corroded through. Considered a critical asset in the crushing circuit.



Challenges:

- Mechanically Stabilized Earth wall was showing damage from corrosion of galvanized steel bars and meshes from acidic ore leaching into the ground.
- This wall supports the loading platform for the initial ore crusher. Loss of structural integrity would cause production to stop.

ICE Impact:

- Performed lab testing to estimate remaining life of the galvanized steel structures.
- The worst areas were encapsulated with concrete and galvanic anodes were installed. A corrosion monitoring systems to track corrosion activity was installed on the repaired (high risk) areas.

Concrete Monitoring: Gold Mine

During design, the impact of chloride diffusion rebar had to be considered. While design changes were made to improve durability, the risk was also monitored by embedded corrosion probes.

Challenges:

- Only salinated water is available for washdown
- Site is remote, repairs costly, much of the concrete cannot easily be repaired / replaced
- Cannot 'see' corrosion of rebar until there is concrete damage, client wanted more of a lead-in time to allow repair planning, if required.

ICE Impact:

- Designed a targeted monitoring system - added ~$50k to project capital cost (<0.01% of overall project cost)
- Measuring corrosion rate / likelihood
- Values are being input into a service life model / life of mine calcs
- Visibility on the risk before it becomes visible as concrete damage
- As we can see the difference in exposure conditions – any interventions can be targeted
- Team can plan budget, inspection schedule, and resources

Stockpile Tunnel: Gold Mine

Lack of corrosion consideration in design meant that material selection for the stockpile conveyor tunnel was inappropriate for the conditions.

Challenges:

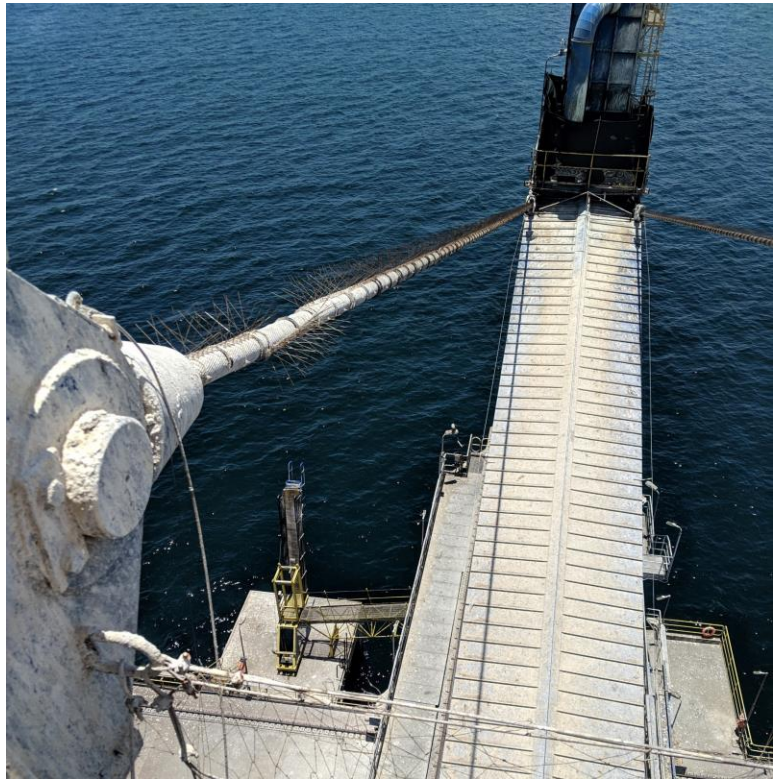
- Corrosion of corrugated steel tunnel liner from acidic soil and stockpile runoff (pH1-2).
- Through-wall corrosion in 6 years.
- Loss of structural integrity would cause safety concerns, production stoppage, and costly unscheduled repair.

ICE Impact:

- Recommended a repair plan which prevented a costly failure.
- Specified excavation, concrete encapsulation of the whole structure and local repair of the steel.
- Have since included the tunnel and conveyor into inspection and maintenance planning

Ship Loader: Copper Mine Loading Facility

Catastrophic and fatal failure of a ship loader at a nearby port created urgency for client to carry out an inspection of their ship loader. Visual inspection considered insufficient to make a decision on condition.



Challenges:

- Coastal / marine exposure of ship loader structure / cables – unknown corrosion damage
- Bird ‘activity’ obscured visual inspection
- Needed quantitative data to determine remaining service life.

ICE Impact:

- Site inspection of ship loader
- Specification for cable crawler NDT inspection to determine corrosion thickness loss
- Data analysis and planning for client for cable replacement – allowed budgets and planned replacement (not reactive)

Structural Steel: Gold Mine

Conveyor (crusher to stockpile) in warm, humid climate, and acidic ore dust was corroding faster than expected. Risk was particularly high under deposited material on the structure at the top and around columns. Considered a critical asset.

Challenges:

- Coatings selected in design were insufficient for exposure
- Conveyor structure – rapid corrosion / difficult to inspect and recoat

ICE Impact:

- Created an inspection and maintenance decision protocol
- Updated coating specifications
- Trialed a ‘lime wash’ approach to reduce acidity on structures

Corrosion Management: WWT Treatment Facility

Wastewater treatment facility required a structured approach to dealing with aesthetic surface corrosion on a plant open to the public.

Challenges:

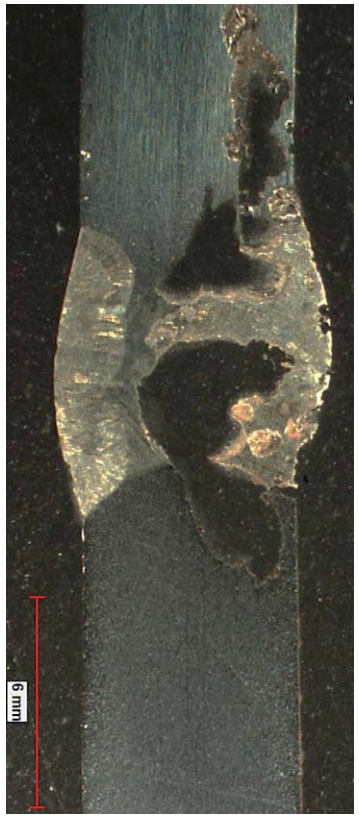
- Lack of alignment in management expectations on coating upkeep versus the perspective of technical risk from maintenance team.

ICE Impact:

- A solution which integrated the operations and management teams on the maintenance strategy
  - **Management**: policy document, define KPIs and targets, communication plan, risk prioritization, etc.
  - **Engineering Solutions**: coating specification update, repair strategy, inspection protocol improvement, risk ranking scheme, etc.

Process Equipment & Microbially Influenced Corrosion: Gold Mine

Stainless steel (316) process tank had pinhole leaks after ~1 year in service. Cause and extent of damage were unknown.



Challenges:

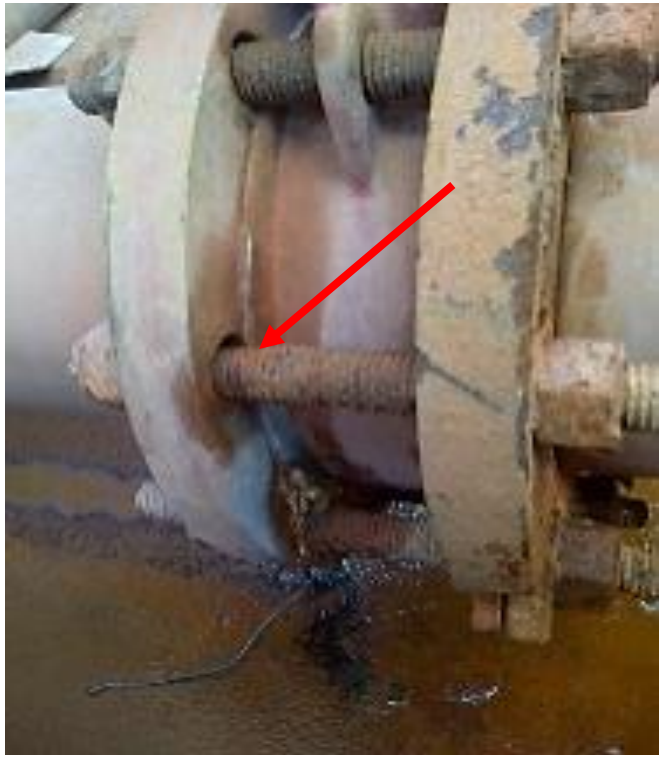
- Cost $250k/day to have it offline with possibility of structural collapse.

ICE Impact:

- Failure analysis revealed MIC attack of welds – water quality / lack of control over internal conditions during commissioning.
- X-ray mapping to find extent of damage needing to be cut out and patched.
- Short-term repairs carried out and tank re-entered service:
  - Prevented structural failure of tank
  - ‘Limited’ downtime costs to $50M by accelerating the failure analysis and design of a solution

Galvanic corrosion

Electrical connection of dissimilar metals must be avoided in design AND construction (field changes). Here the galvanic corrosion of steel bolts was dealt with by operations by replacing like-with-like, perpetuating the issue.



Challenges:

- Carbon steel bolts vs. SS flange
- Significant loss of steel after 1 year
- Vibration / leaking / loss of containment from pipe

ICE Impact:

- Flagged the issue and provided input into material selection for the bolts

Stress Corrosion Cracking in Groundwater

Intergranular stress corrosion cracking in high strength carbon steel exposed to aggressive soil / groundwater with high levels of chlorides.

Challenges:

- Failures within weeks due to brittle fracture.
- Static stress – residual (from forming/welding) or applied
- Environment – corrosive due to the presence of aggressive species, pH, temperature
- Material – susceptible to corrosion in the environment in question

ICE Impact:

- Provided analysis of the cause of failure
- Recommended preventative actions