JUBCOR 2021
CONFERENCE & EXHIBITION

Deterioration of Reinforced Concrete Structure with Built in Cathodic Prevention System

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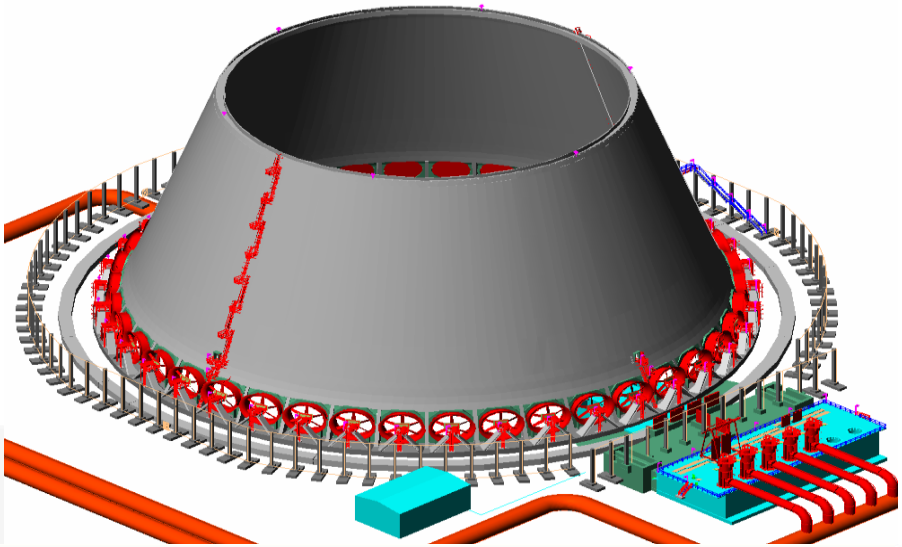
NACE INTERNATIONAL

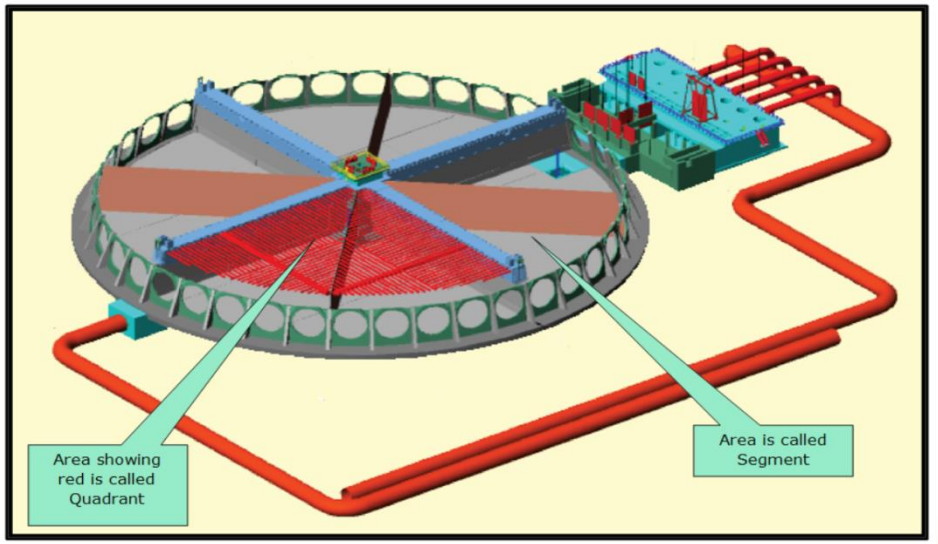
Presentation Stages

1. Background: Structure Details & Problem
2. Stage 1: Condition Assessment
3. Stage 2: Repair Method
4. Stage 3: Site Installation
5. Stage 4: Commissioning
6. Stage 5: Conclusion

Background: Cooling Tower Details & Problem

- Cooling tower:
  - 71.5 m high
  - 124m ring beam diam.
  - Consist of 32 shells
  - Consist of 4 quadrants
  - Constructed with built-in cathodic protection (CP)
  - Energized: 2009





Cont.: Background: Cooling Tower Details & Problem

- **Problem:**
  - Since commissioning Sharq have encountered technical problems with the ETCP power supplies and RMS in SHARQ 3rd expansion and they could not succeed to rectify all problems.
  - Commissioning acceptance of the CP system from SABIC MCE was on hold till the vendor(CTS) rectify TR and RMS issues.
  - Electrical cable tray damage in 2012 and rectified .
  - CP power system turned off for repair but not Re-energized

Cont.: Background: Cooling Tower Details & Problem

- Structure without CP system for almost a year .
- In 2014 fan foundations found Severely cracked and delaminated.
- In 2015 reported Spalling of damaged Concrete from top ring (72 m height)
- Investigation team (MCE/Sharq -Inspection & civil) formed to analyze the root causes for these cracks and concrete delamination.

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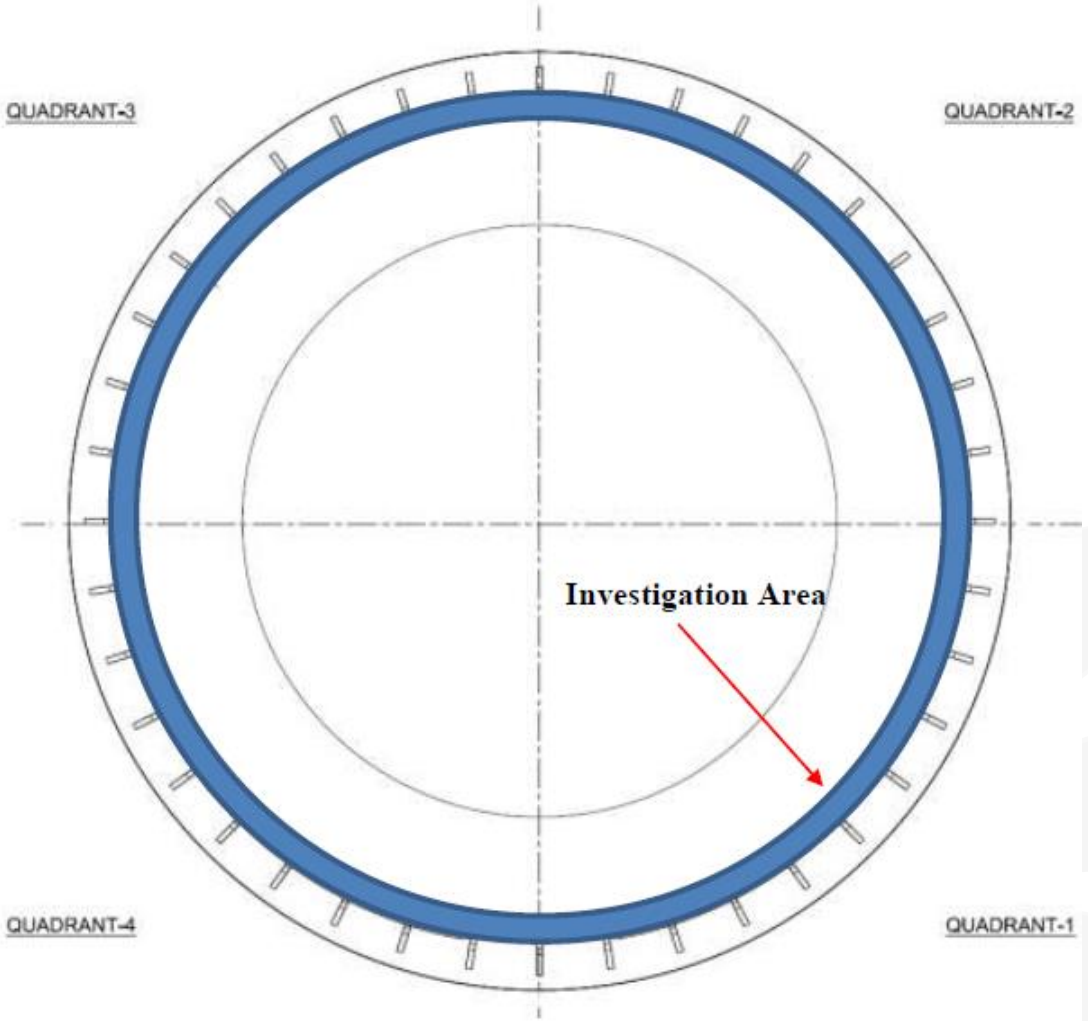
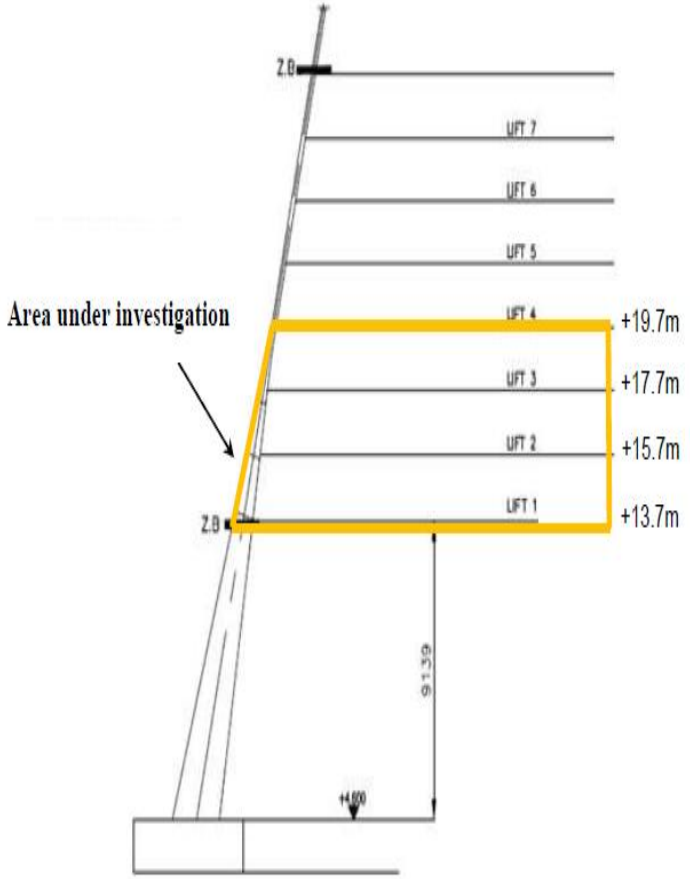
Stage 1: Condition Assessment

- Visual Inspection
- Steel Half-Cell Potentials (HCP)
- Chloride Content testing
- Condition of exposed concrete after breakouts

Cooling tower Plan layout of investigation area & shell lift separation



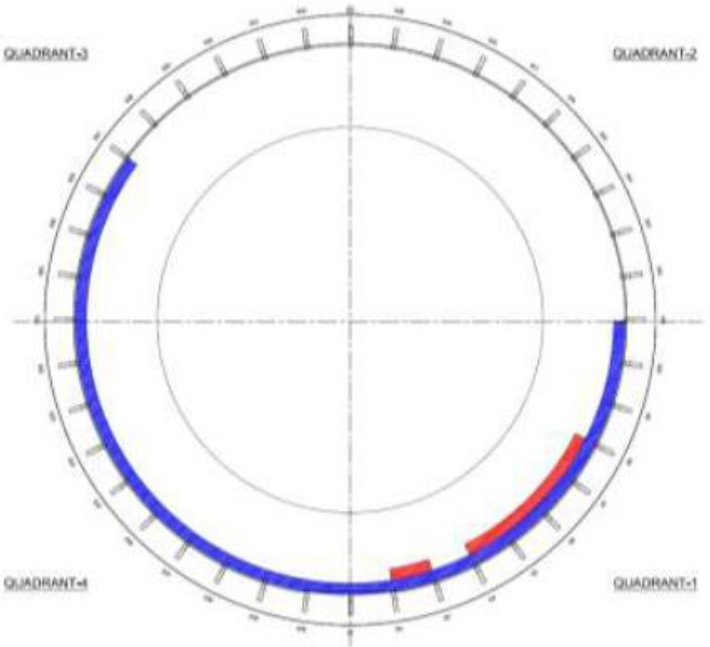


Stage 1: Condition Assessment- Hammer Tap survey

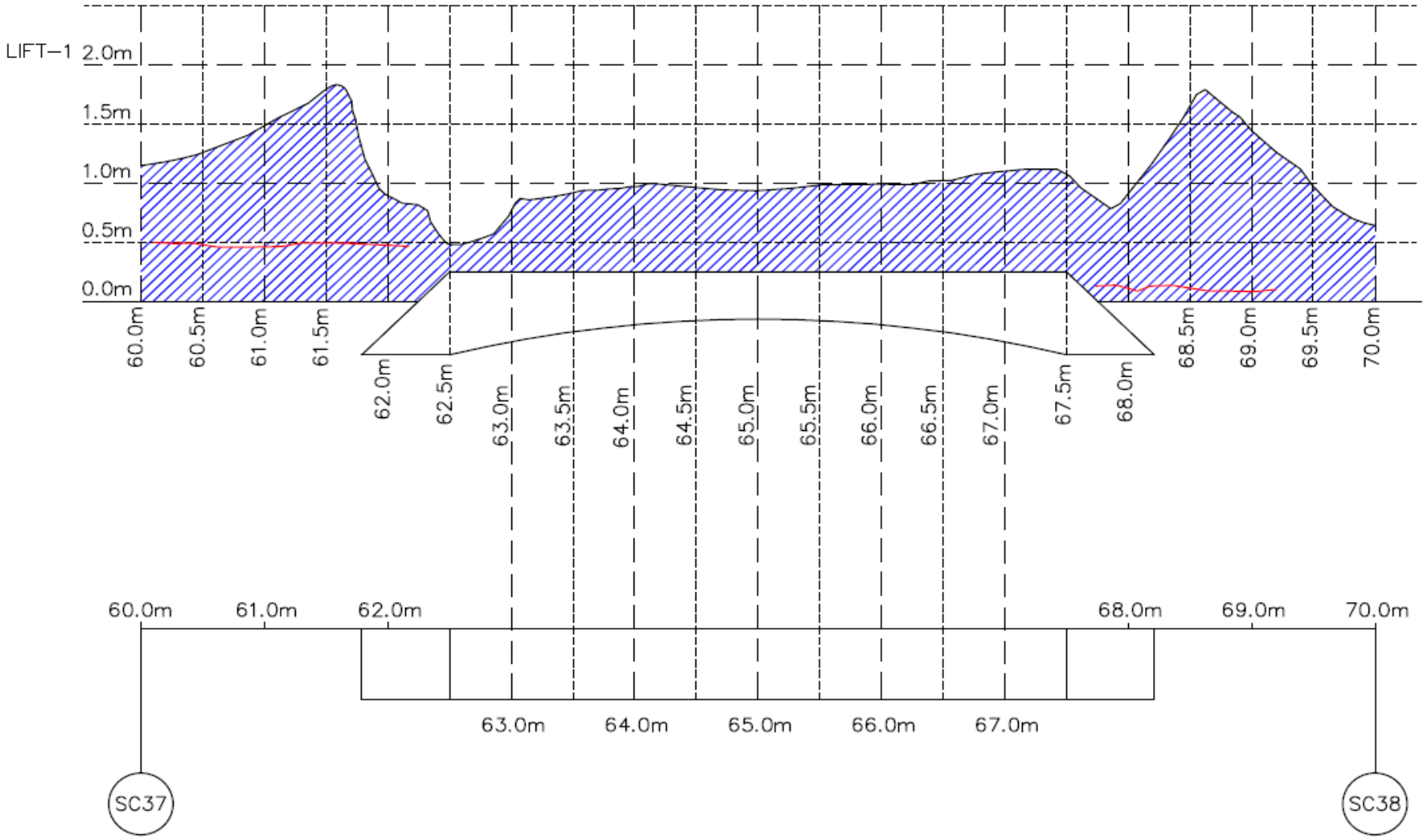
Quadrant	Approx. survey surface area (m^2)	Approx. surface area of unsound concrete (m^2)			Approx. quadrant surface area of unsound concrete (m^2)
		Lift 1	Lift 2	Lift 3	
1	257	123	2	-	125
2	257	-	-	-	-
3	257	26	-	-	26
4	254	70	-	-	70
	Total approx. surface area of unsound concrete (m^2)				221

- Unsound concrete detected in Survey Section in Lift 1

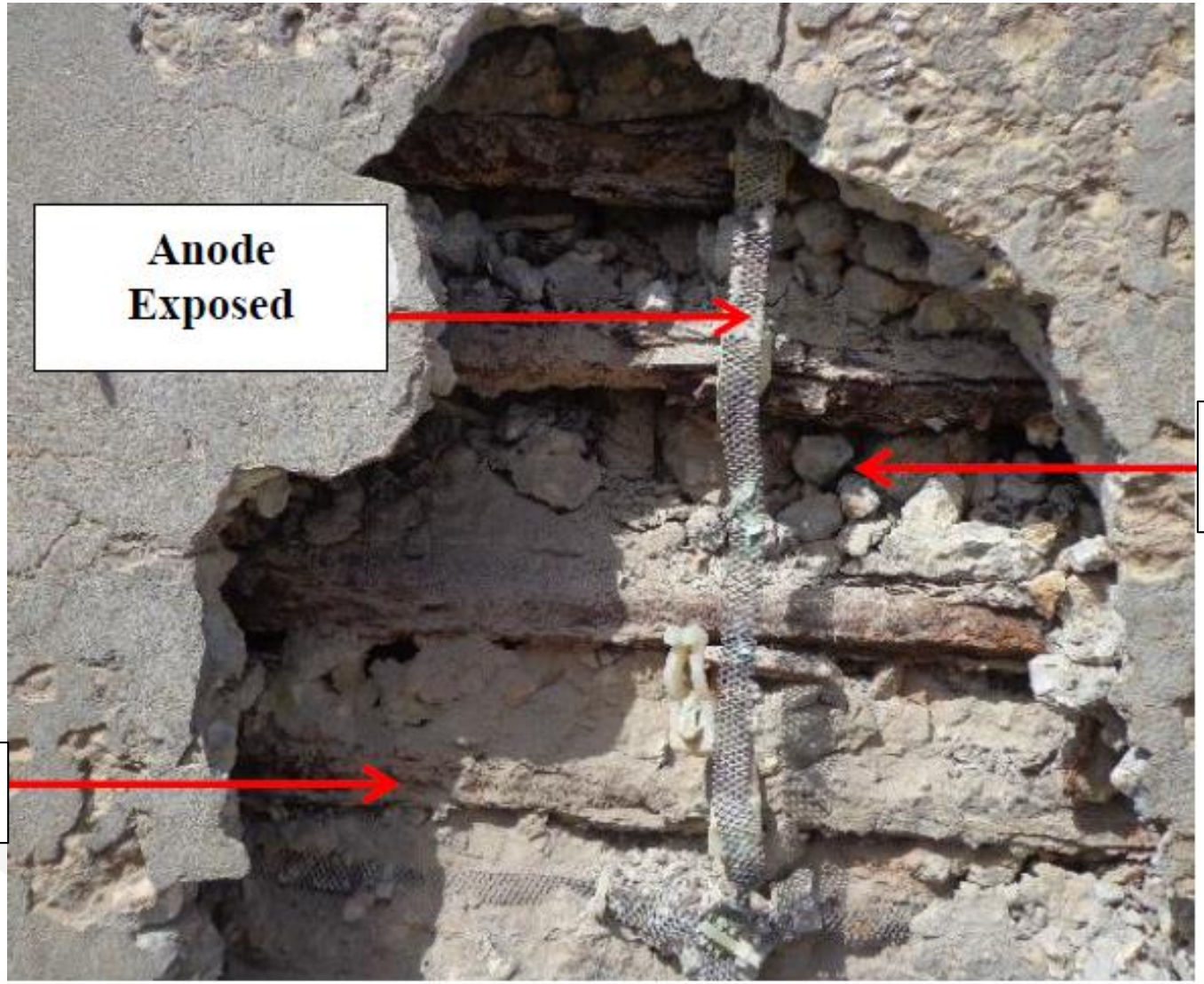
- Unsound concrete detected in Survey Section in Lift 2



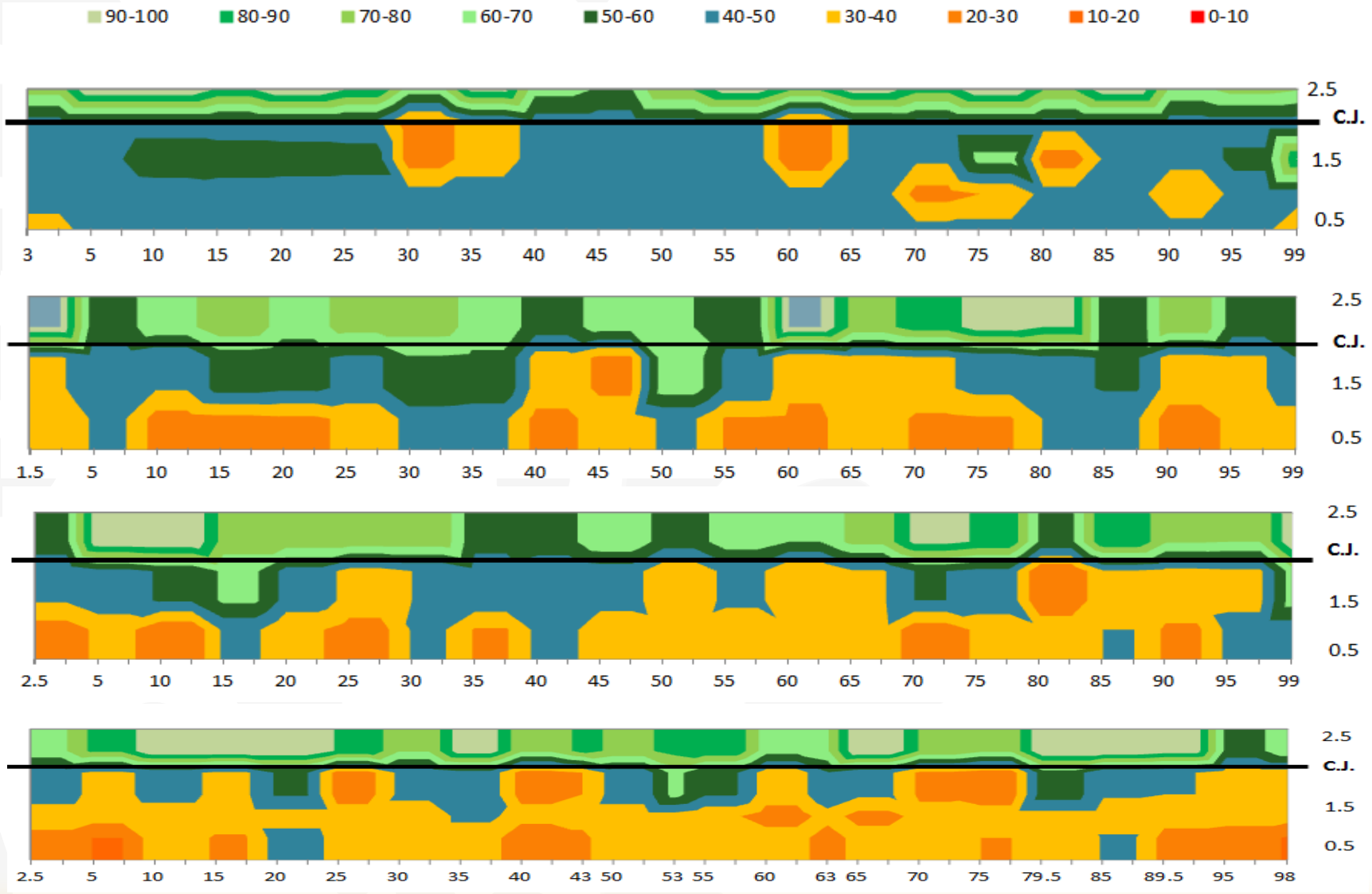
Stage 1: Condition Assessment- Hammer Tap survey



Visual Inspection: Delaminated Areas

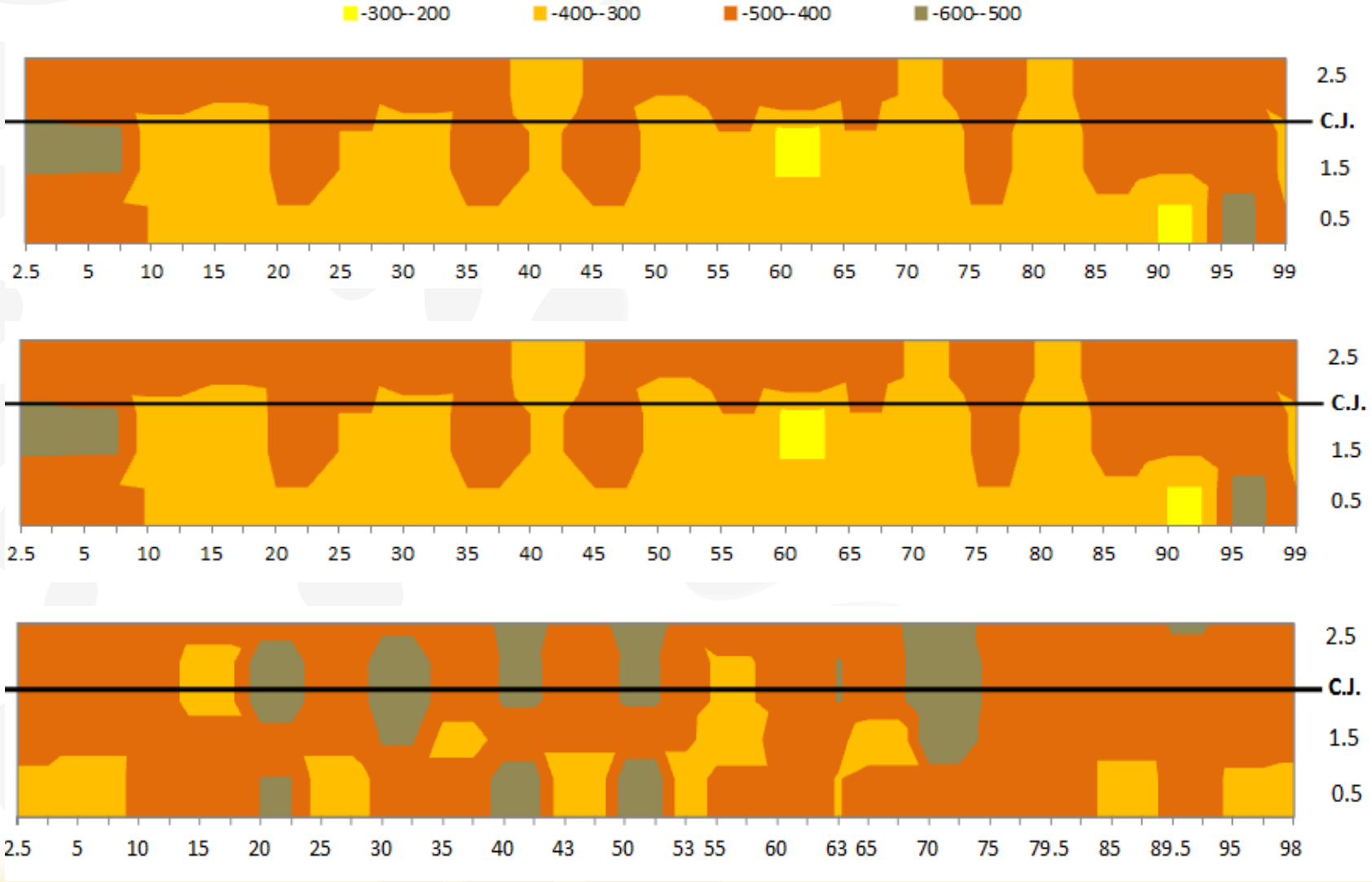

Anode
Exposed
Loose
Concrete
Corroded
Steel

Stage 1: Condition Assessment- Concrete Cover Quadrant 1,2,3&4 (0m to +2.5m) - Concrete Cover Depth (mm)



Stage 1: Condition Assessment- Steel Half-Cell Potentials (HCP)

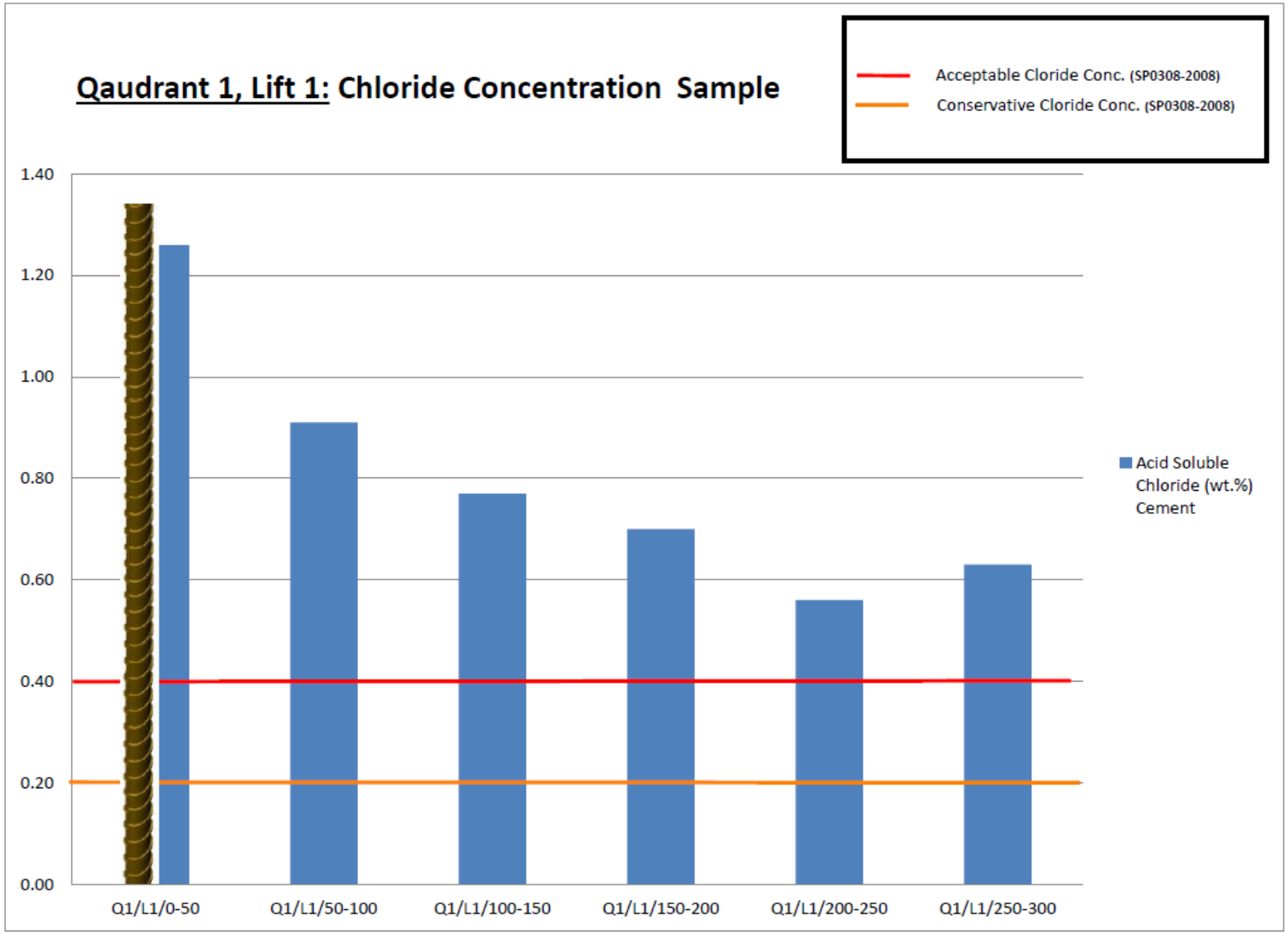
Quadrant 1,3&4 (0m to +2.5m) – Instant Off Potential Surface Chart (mV)



Stage 1: Condition Assessment- Chloride concentration

Quadrant	Lift	Chloride limit for corrosion of steel in concrete exceeded? (Yes/No)					
		0-50mm	50-100mm	100-150mm	150-200mm	200-250mm	250-300mm
1	1	Yes	Yes	Yes	Yes	Yes	Yes
	2	Yes	Yes	Yes	Yes	Yes	Yes
	3	Yes	Yes	Yes	Yes	Yes	Yes
2	1	Yes	Yes	Yes	Yes	Yes	Yes
	2	Yes	Yes	Yes	Yes	Yes	Yes
	3	Yes	Yes	Yes	Yes	Yes	Yes
3	1	Yes	Yes	Yes	Yes	Yes	Yes
	2	Yes	Yes	Yes	Yes	Yes	Yes
	3	Yes	Yes	Yes	Yes	Yes	No
4	1	Yes	Yes	Yes	Yes	Yes	Yes
	2	Yes	Yes	Yes	Yes	Yes	Yes
	3	Yes	Yes	Yes	Yes	Yes	Yes

Stage 1: Condition Assessment- Chloride concentration



Stage 2: Conclusion of the assessment

- Cracking and delamination of the FAN foundation, 1st & 2nd lefts resulted due to chloride-induced corrosion of the reinforcing steel
  - (lift 1 at Quadrants 1, 3 & 4 are in bad condition. While Lifts 2 & 3 for all quadrants appear to be good condition.)
- Concrete cover at Lift 1 is lower than design. The cover in Lifts 2 & 3 in all compliant with the civil design.
- Reinforcing steel underneath the sound concrete is actively corroding across most of the inspected parts of structure.
- Ongoing corrosion of the reinforcing steel would eventually result in further cracking and delamination of concrete which would lead to loss of serviceability and integrity of the structure.
- Absence of suitable coating accelerate the chloride ingress to the concrete.

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Stage 2: Repair Method-Patch Repairs & Cathodic Protection

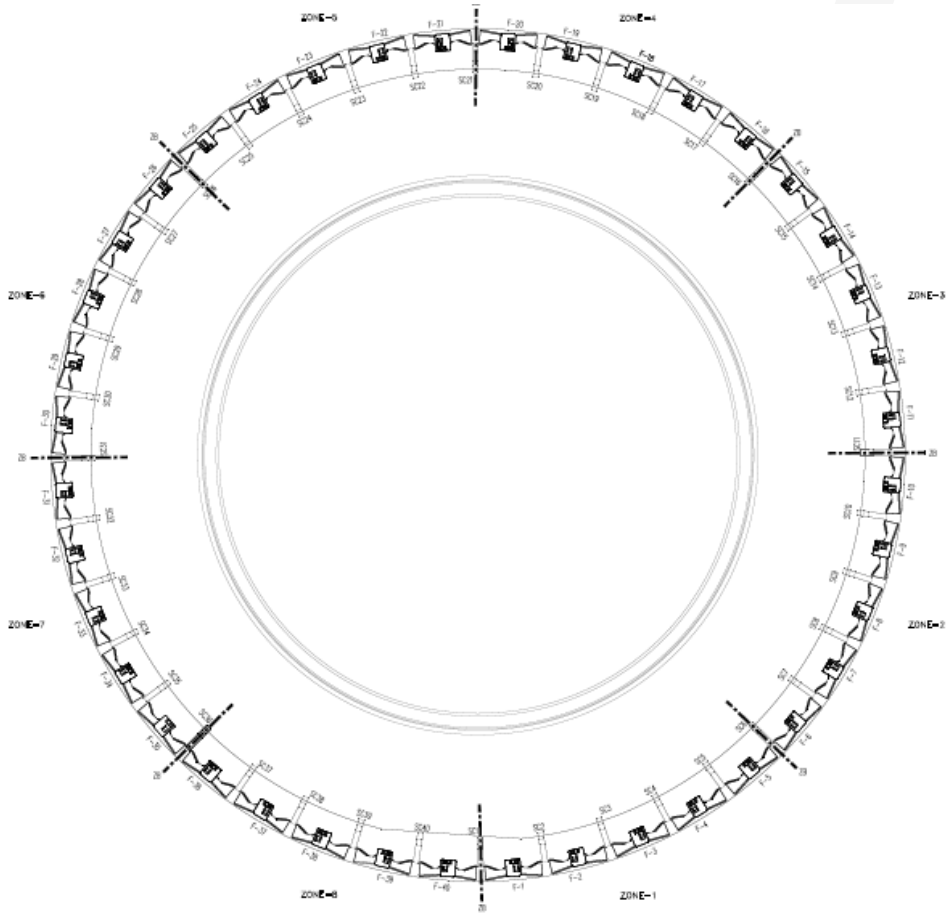
- **Pros:**
  - Only cracked & delaminated areas repaired.
  - Long term solution. **Control root cause of the problem.**
  - Proven long track record.
  - No operational constraints.

- **Cons:**
  - Require electrical continuity, AC power, system monitoring and adjustment.
  - Relatively costly.

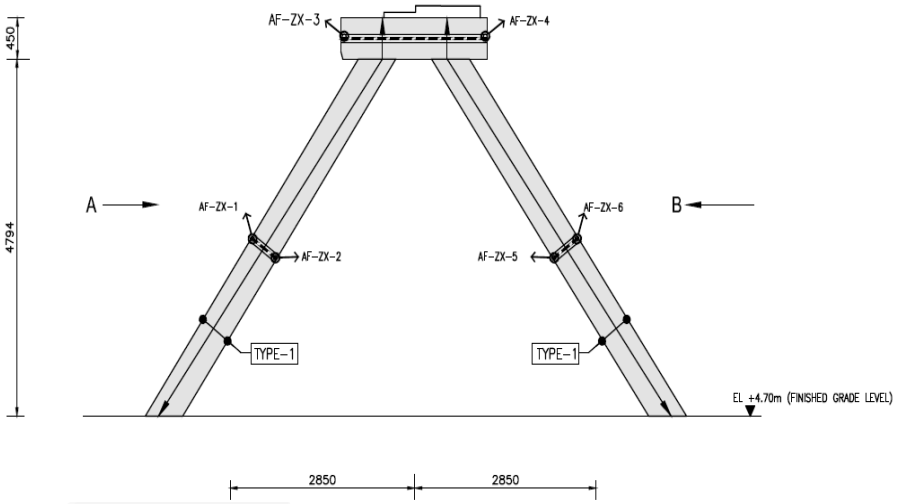
Stage 2: Repair Method-CP DESIGN

S/N	Structure	Repair Approach	Area considered for protection	Targeted Reinforcement
1	40 x reinforced concrete fan supports	A. Remove all loose and delaminated concrete and repair using cementitious repair materials. B. Install ICCP system. C. Apply protective Coating	Atmospherically exposed concrete	External layer
2	Shell wall 1st & 2nd lefts	A. Remove all loose and delaminated concrete and repair using cementitious repair materials. B. Install ICCP system. C. Apply protective Coating	External atmospherically exposed concrete between EL +13.7m and +17.7m	External layer

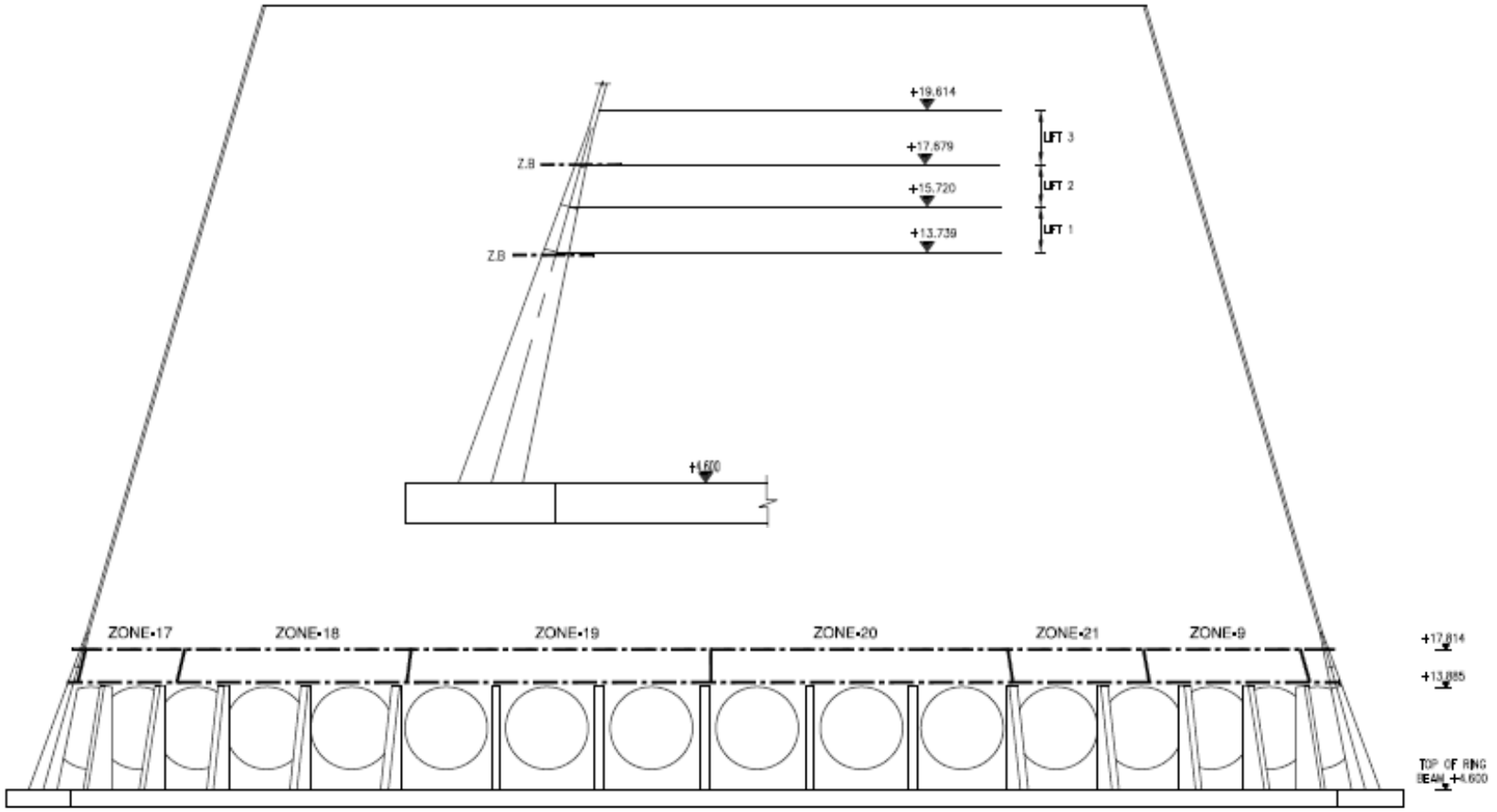
Stage 2: Repair Method-CP DESIGN



ZONING LAYOUT FOR FAN SUPPORTS



Stage 2: Repair Method-CP DESIGN



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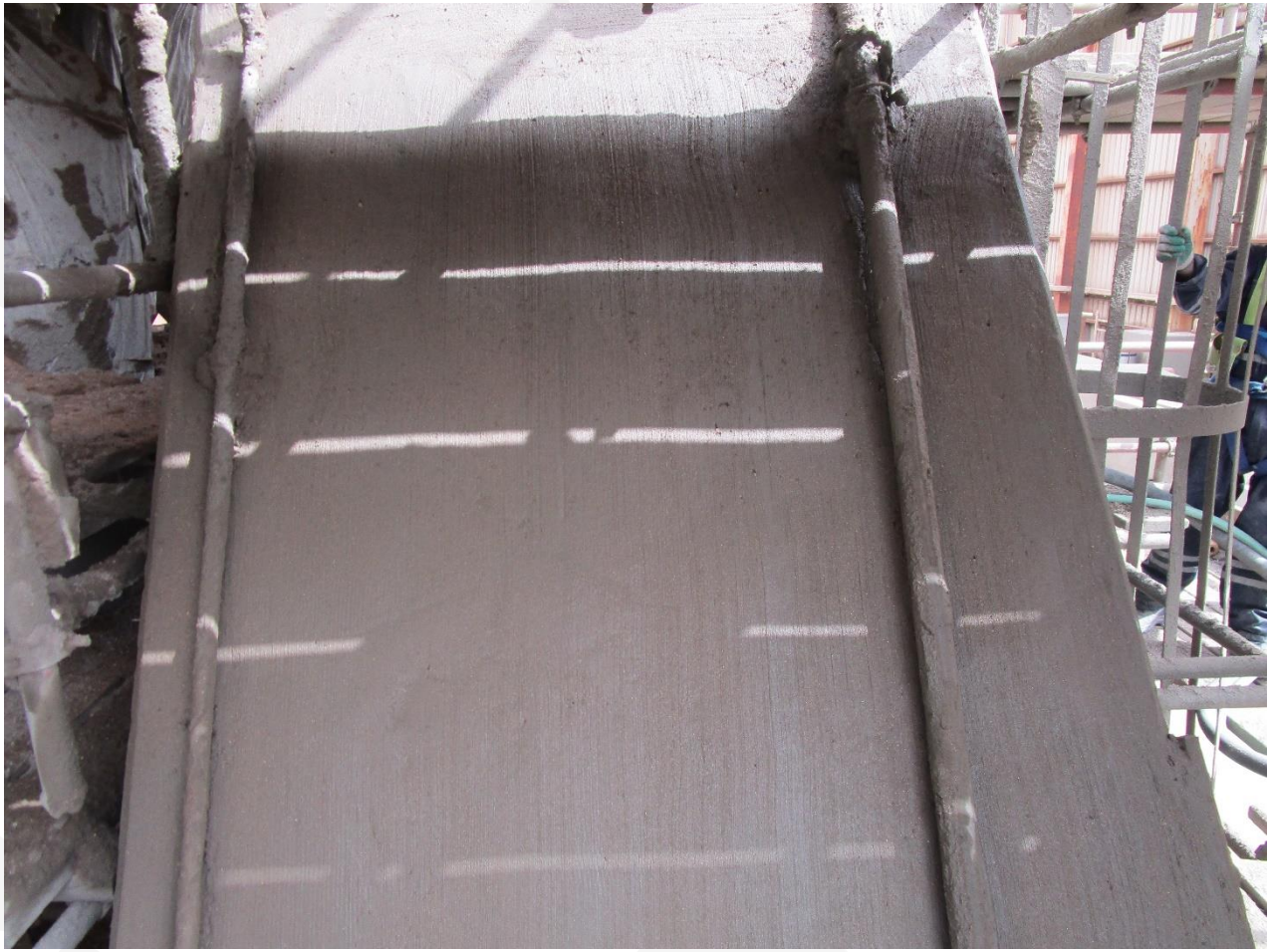
Stage 3: Site Installation

Stage 3: Site Installation

Stage 3: Site Installation



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Stage 4: Commissioning – Initial Results of Energization

TR Channel	Structure	Zone No.	TR Current Capacity (A)	TR Voltage Capacity (V)	Design Current (A)	Maximum Allow. Current (A)	Total number of REs	Nos. of REs "meeting" Criteria	Nos. of REs "NOT meeting" Criteria	Nos. of REs "NOT Working"	% Compliance
TR-01	Fan Supports	Z1	9A	12V	4.473	6.378	10	0	9	1	0.00%
	Lift 1 and 2	Z9	9A	12V	5.493	7.174	3	1	3	0	33.33%
	Lift 1 and 2	Z10	9A	12V	5.493	7.174	3	1	3	0	33.33%
	Fan Supports	Z2	9A	12V	4.473	6.378	10	0	10	0	0.00%
	Lift 1 and 2	Z11	9A	12V	5.493	7.174	3	2	1	0	66.67%
	Lift 1 and 2	Z12	9A	12V	5.493	7.174	3	1	2	0	33.33%
	Fan Supports	Z3	9A	12V	4.473	6.378	10	4	6	0	40.00%
	Lift 1 and 2	Z13	9A	12V	5.493	7.174	3	2	1	0	66.67%
	Lift 1 and 2	Z14	9A	12V	5.493	7.174	3	3	0	0	100.00%
TR-02	Fan Supports	Z4	9A	12V	4.473	6.378	10	9	1	0	90.00%
	Lift 1 and 2	Z15	9A	12V	5.493	7.174	3	2	1	0	66.67%
	Lift 1 and 2	Z16	9A	12V	5.493	7.174	3	3	0	0	100.00%
	Fan Supports	Z5	9A	12V	4.473	6.378	10	1	9	0	10.00%
	Lift 1 and 2	Z17	9A	12V	5.493	7.174	3	2	1	0	66.67%
	Lift 1 and 2	Z18	9A	12V	5.493	7.174	3	3	0	0	100.00%
	Fan Supports	Z6	9A	12V	4.473	6.378	10	3	6	1	30.00%
	Lift 1 and 2	Z19	9A	12V	5.493	7.174	3	1	2	0	33.33%
	Lift 1 and 2	Z20	9A	12V	5.493	7.174	3	1	2	0	33.33%
TR-03	Fan Supports	Z7	9A	12V	4.473	6.378	10	0	10	0	0.00%
	Lift 1 and 2	Z21	9A	12V	5.493	7.174	3	3	0	0	100.00%
	Lift 1 and 2	Z22	9A	12V	5.493	7.174	3	3	0	0	100.00%
	Fan Supports	Z8	9A	12V	4.473	6.378	10	2	8	0	20.00%
	Lift 1 and 2	Z23	9A	12V	5.493	7.174	3	1	2	0	33.33%
	Lift 1 and 2	Z24	9A	12V	5.493	7.174	3	3	0	0	100.00%

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Stage 5: Conclusion

- Cathodic Protection repair method was opted, as it offers durable, long-term & economical solution for rehabilitation of the structure.
- The CP system of FAN foundation, 1st & 2nd lefts zones (24 zones) has been successfully installed and commissioned.
- Initial monitoring data has shown criteria compliance at ### (###) out of the total of 128 monitoring locations.
- This shows that the CP system is affording required protection to all protected areas.

Thank You

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