Rehabilitation and Cathodic Protection of Reinforced Concrete Seawater Cooling Towers

NACE -JUBAIL SECTION
JUBAIL Intercontinental Hotel, September 27, 2010

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MATERIALS & CORROSION SECTION
SABIC TECHNOLOGY CENTER-JUBAIL

SUMMARY OF PRESENTATION CONTENTS

A. Case History of a Rehabilitation of Seawater Cooling Tower (CT)

- Condition Survey of CT
- Diagnosis & Selection of Repair Method
- CP System Design & Installation
- CP System Performance Assessment

B. Development of a User Friendly Remote Monitoring Software. (Time Permitting)

C. Installation of Cathodic Prevention Systems in new Seawater Cooling Towers. (Time Permitting)

CONDITION SURVEY
OF
COOLING TOWER

COOLING TOWER: *STRUCTURE DETAILS & PROBLEM*

A. SUPER STRUCTURE

B. SUPPORT STRUCTURE

1) Footing & Pedestals (155 nos.)
2) Columns (155 nos.)
3) Beams (274 nos.)
4) Slab Panels (600 nos.)

COMMISSIONED: 2004

PROBLEM :

Leaks in HDPE liner in 2005, contaminated slab panels, beams, and columns, which caused corrosion of steel reinforcement and that led to cracking of these concrete elements in 2007.

Contamination of Slab Panels: 2005 Survey

Contamination of Beams & Corbels: 2005 Survey

Contamination of Beams at Periphery : 2005 Survey

Cracking of Slab Panels: 2007 Survey

Cracking of Slab Panels: 2007 Survey

Cracking & Spalling of Slab Panels: 2007 Survey

Cracking of Beams: 2007 Survey

Cracking of Columns: 2007 Survey

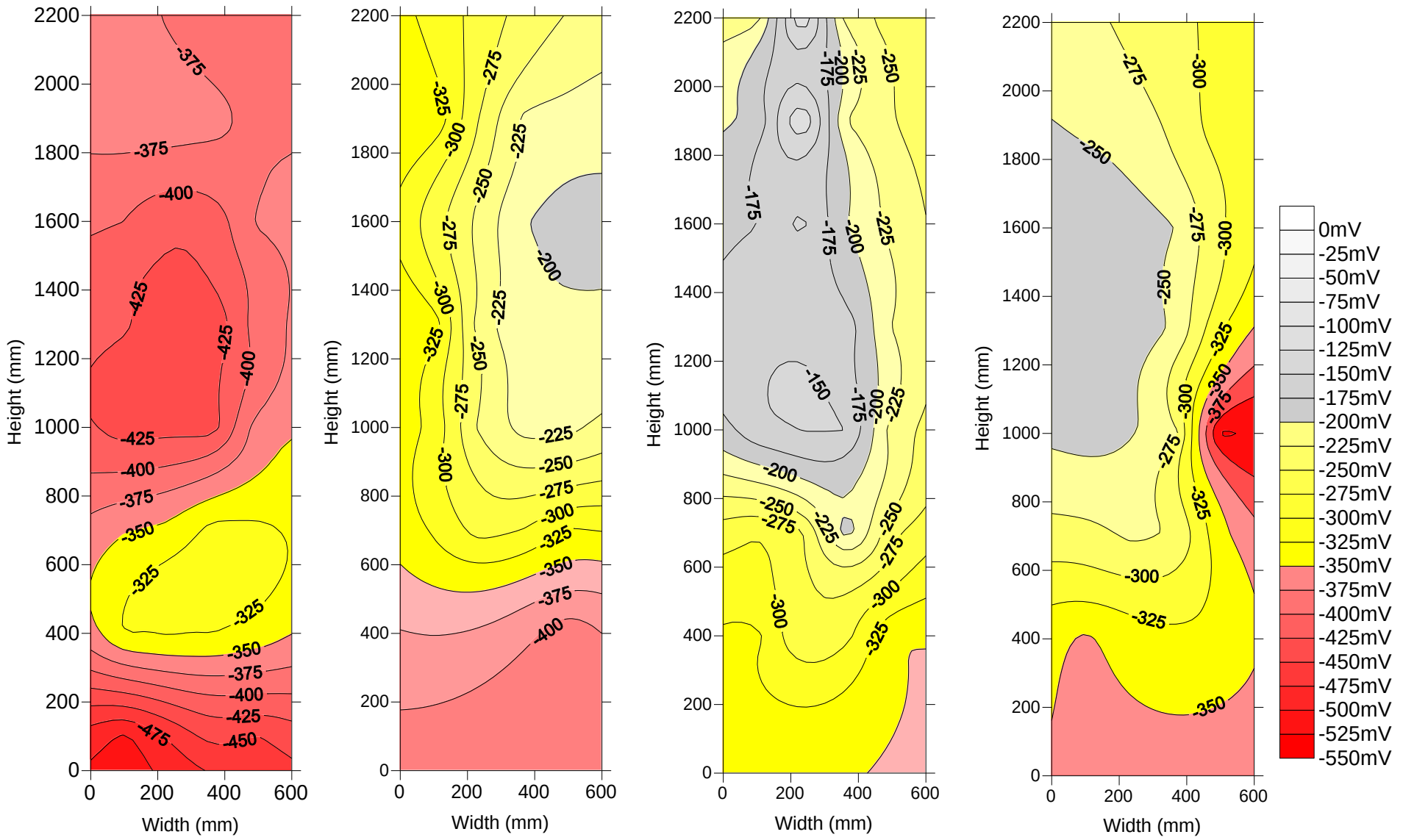
SUMMARY OF CONDITION SURVEY RESULTS

Investigation	Observation
Visual Inspection	**2005 Survey:** 97 Rust spots, 176 SW leaks and 184 seepage spots. *No Cracks were noted.* **2007 Survey:** 217(37%)Slab panels, 61 Beams (22%), and 44 Columns (28%) *were found cracked.*

SUMMARY OF CONDITION SURVEY RESULTS

Investigation	Observation
Steel Half-Cell Potentials (HCP)	44% data showed 95% corrosion risk. 40% data showed 50% corrosion risk.
Corrosion Rate (CR)	60% results showed "High" CR >1.0 uA/cm^2 20% results showed "moderate to high" CR i.e., 0.5 to 1.0 uA/cm^2 .

POTENTIAL MAP OF COLUMN#2.

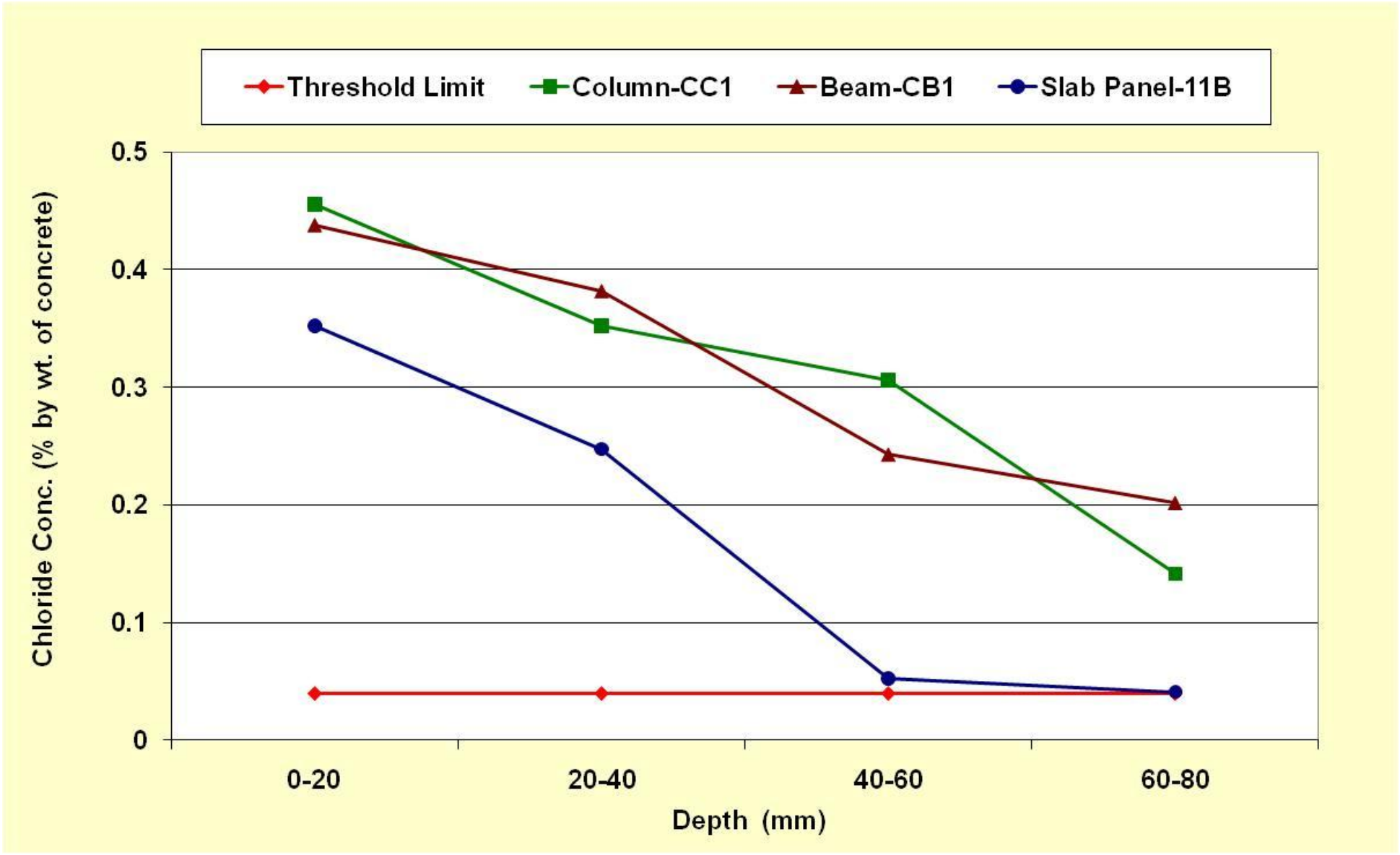


North Face | West Face | South Face | East Face

SUMMARY OF CONDITION SURVEY RESULTS

Investigation	Observation
Average Chloride Content at Rebar Depth	Slab panels: 0.051% by wt. of concrete Beams: 0.18% by wt. of concrete Columns: 0.13% by wt. of concrete 2 to 4 times > threshold limit of 0.04%, by wt. of concrete .

CHLORIDE PROFILES: Column, Beam, & Slab



DIAGNOSIS

&

SELECTION OF REPAIR METHOD

DIAGNOSIS

- **Cracking and delamination of the slab panels, beams and columns resulted due to chloride-induced corrosion of the reinforcing steel.**

- **Reinforcing steel underneath the sound concrete is actively corroding across the entire support structure.**

- **Ongoing corrosion of the reinforcing steel would eventually result in further cracking and delamination of concrete (if not arrested in the near future) which would lead to loss of serviceability and integrity of the structure.**

SELECTION OF REPAIR METHOD

REPAIR OPTION	PROS & CONS
Local Patch Repairs & Coating	**Pros:** ➢ Economical ➢ Only cracked & delaminated areas repaired. **Cons:** ➢ Short-term solution. ➢ Does not control and/or eliminate root cause of problem. ➢ Enhance corrosion in close areas.

SELECTION OF REPAIR METHOD

REPAIR OPTION	PROS & CONS
Re-Skinning or Conventional Repair	**Pros:** ➢ Provides durable & long service life. No maintenance is required. **Cons:** ➢ Expensive, ➢ Require extensive concrete breakout for Chloride removal & temporary supports during repairs. ➢ May cause operational constraints.

SELECTION OF REPAIR METHOD

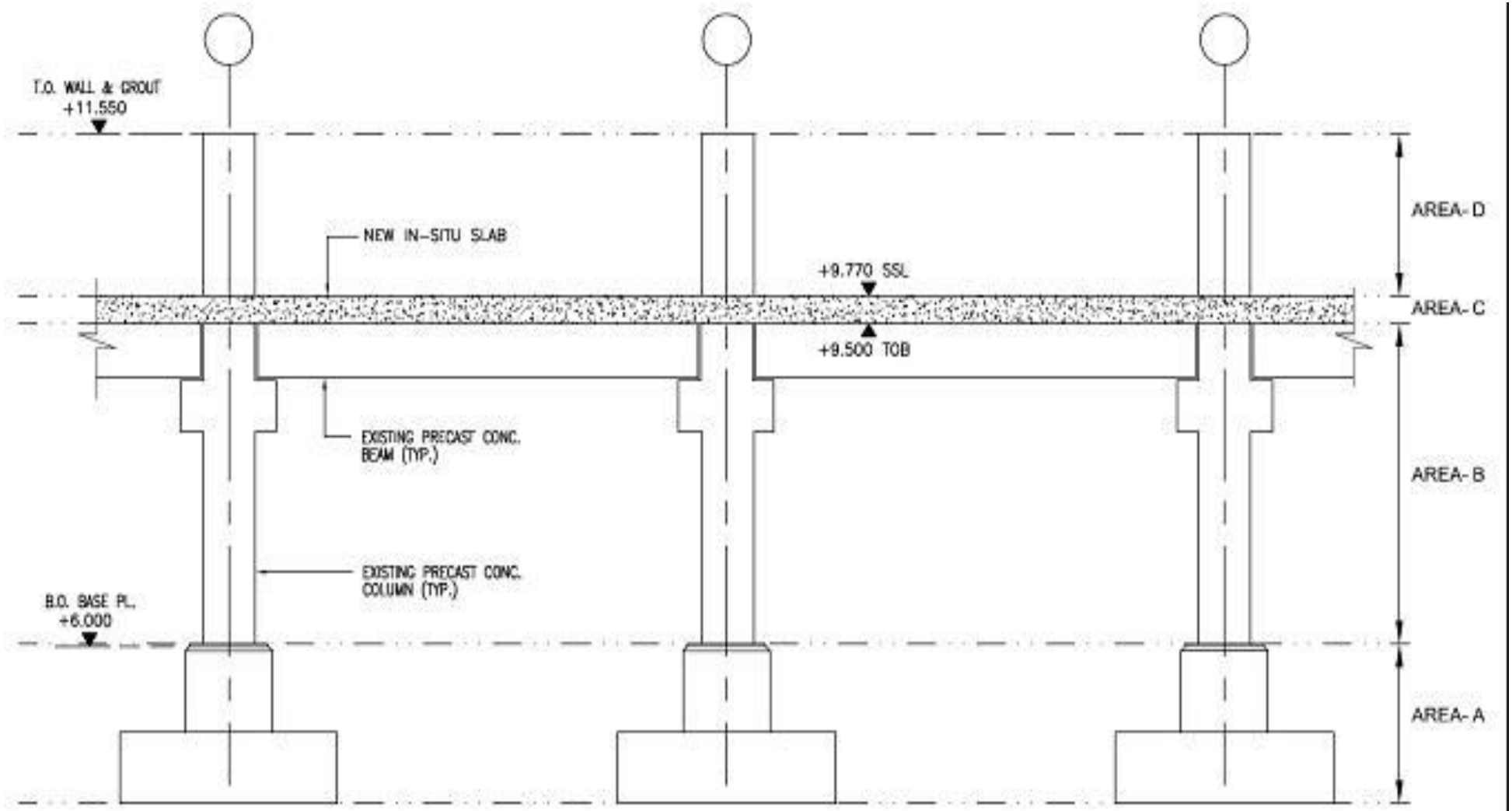
REPAIR OPTION	PROS & CONS
Patch Repairs & Cathodic Protection	**Pros:** ➢ Only cracked & delaminated areas repaired. ➢ Long term solution. ➢ Control root cause of the problem. ➢ Proven long track record. ➢ No operational constraints. **Cons:** ➢ Require electrical continuity, AC power, system monitoring and adjustment. ➢ Relatively costly.

SELECTED REPAIR METHOD

Concrete Element	Repair Approach
Slab Panels	A. Remove all pre-cast slab panels. B. Design and cast in-situ new slab with fewer joints and built-in ICCP (prevention) system.
Beams, Columns, Corbels, & Foundations	A. Remove all loose and delaminated concrete and repair using cementitious repair materials. B. Install ICCP system.

CATHODIC PROTECTION SYSTEM DESIGN & INSTALLATION

COOLING TOWER CATHODIC PROTECTION AREAS



TYPICAL CP AREA DIVISIONS

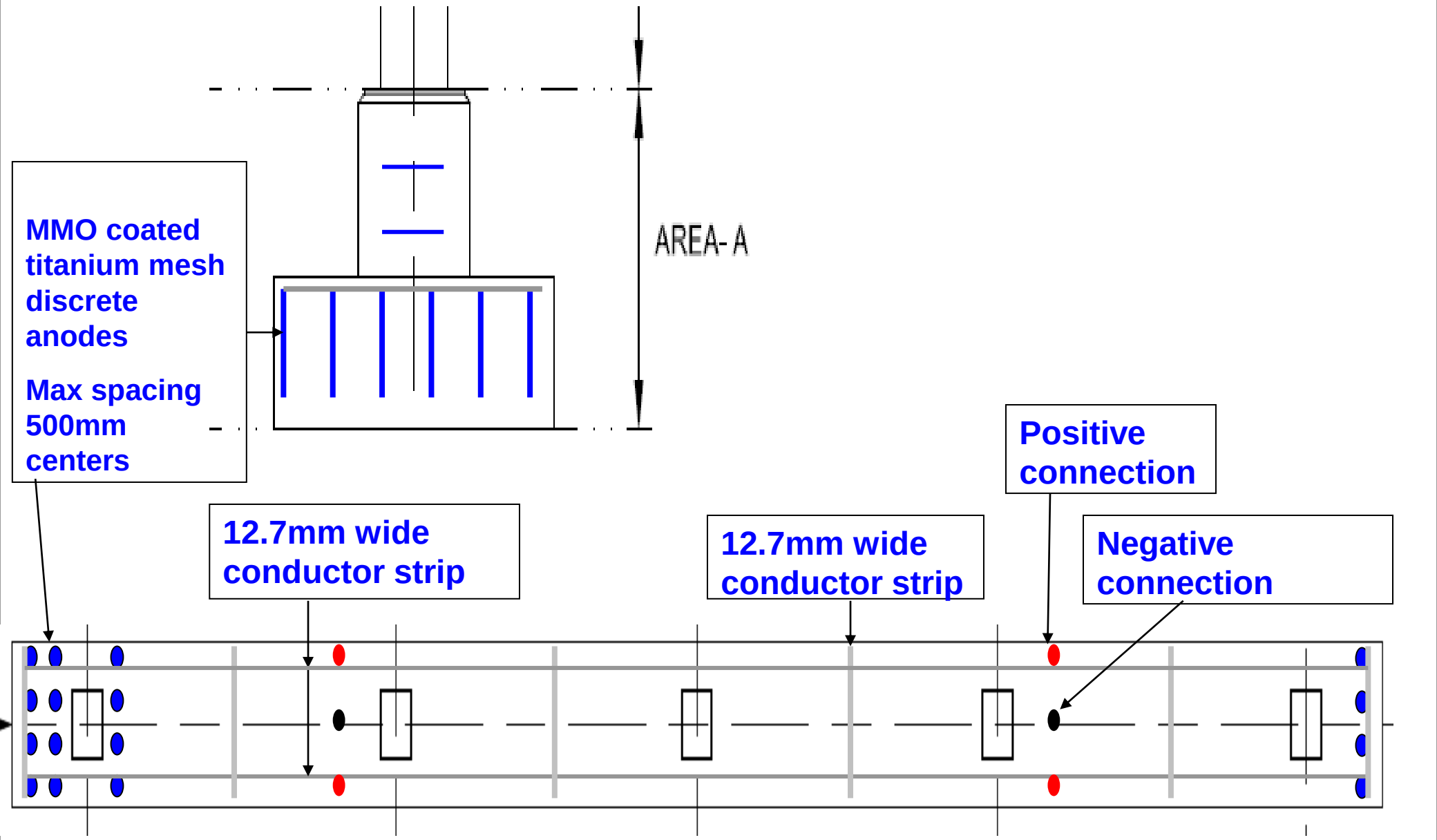
CP DESIGN CRITERIA & ANODE SYSTEM

Area	Structural Element	Environment	Design Current Density	Anode System
A	Foundation, Footings and Pedestals	Buried and coated	10 mA/m^2	Mixed metal oxide (MMO) coated Ti mesh discrete anodes.
B	Columns, Corbels, Beams	Atmospherically exposed	20 mA/m^2	MMO coated Ti mesh ribbon anode.
C	New slab & Retaining wall	Coated and submerged, & Atmospherically exposed	5 mA/m^2	
D	Columns above new slab	Coated and submerged	20 mA/m^2	

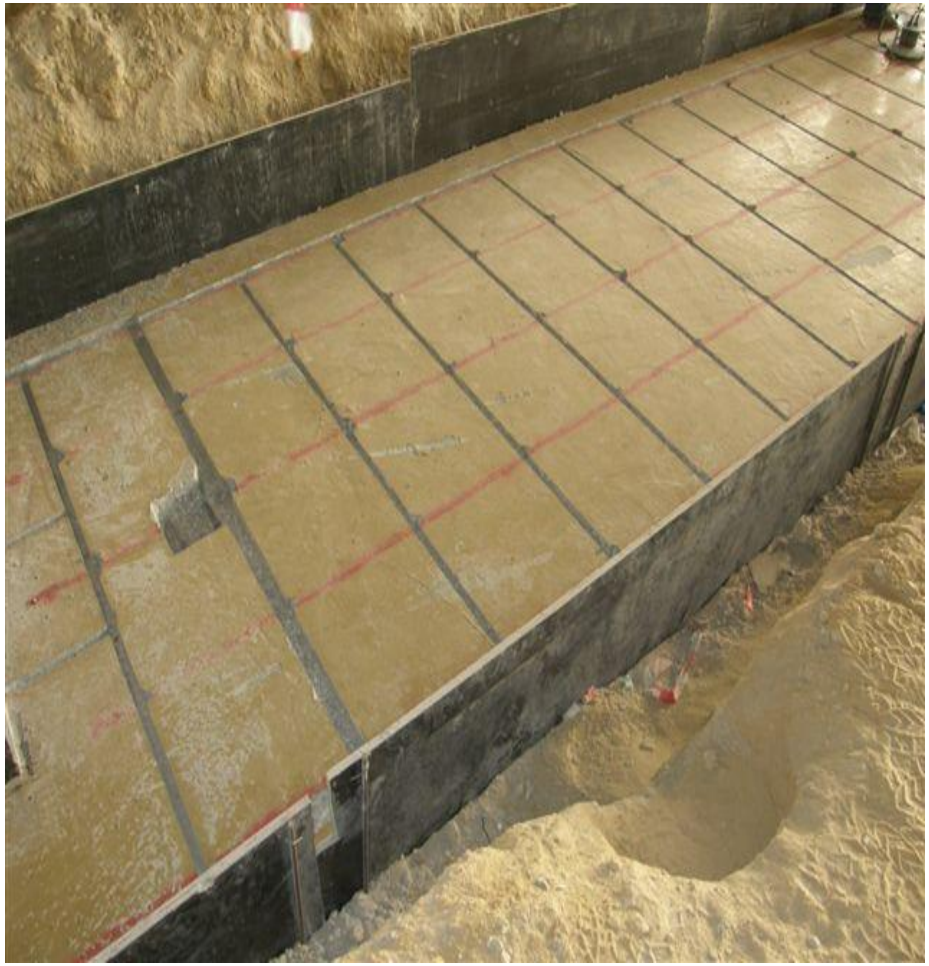
SUMMARY OF CP DESIGN DETAILS

Area	Zones (Nos.)	Average Zone Size (m^2)	Average Current Required (A / zone)	TR Capacity (A / zone)	Reference Electrodes (Nos./zone)
A	8	1358	9.50	12	10
B	21	360	9.66	12	8
C	16	575	8	10	6
D	3	348	7.5	12	6

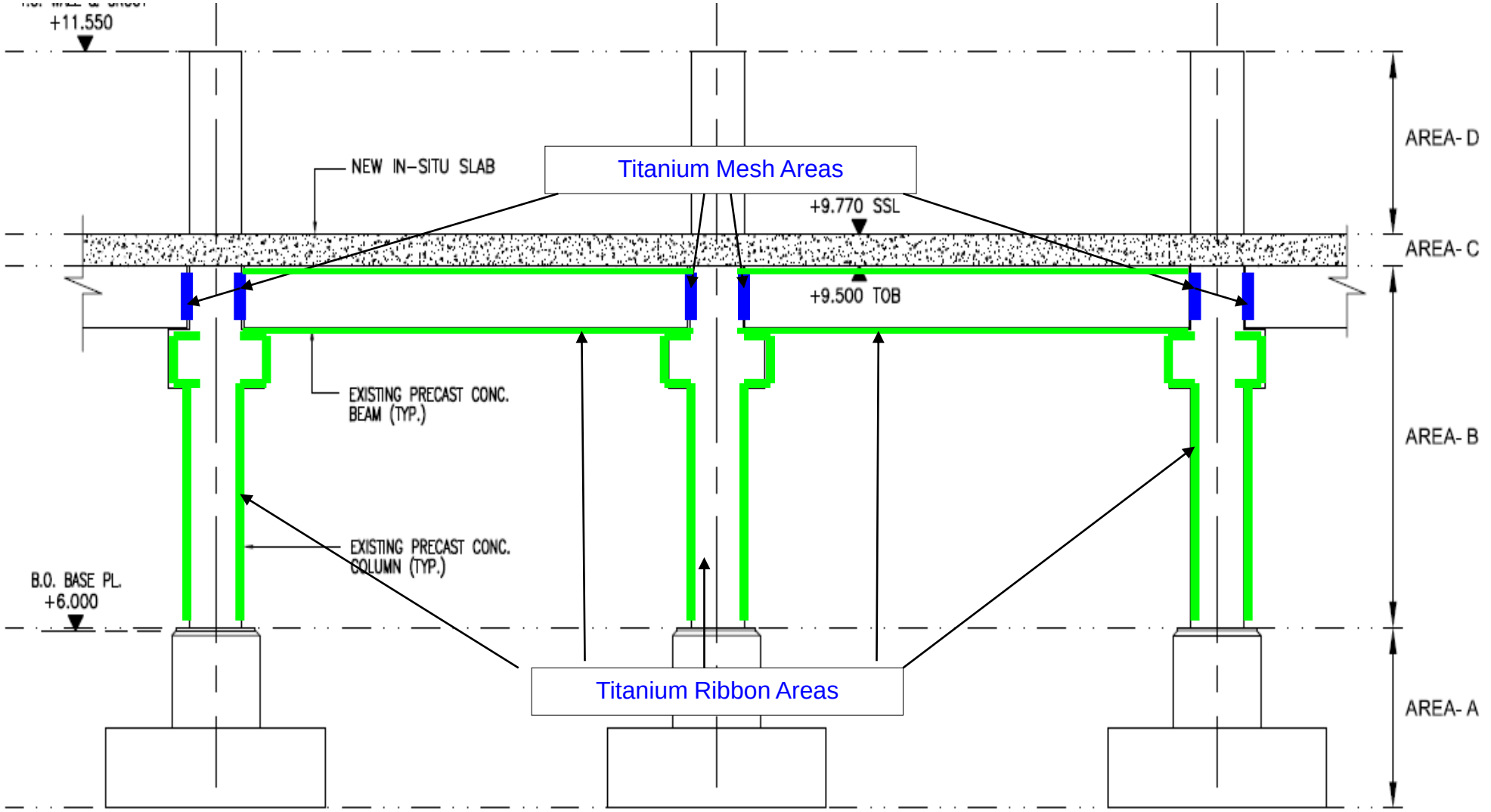
AREA A: *TYPICAL ANODE & CONNECTIONS LAYOUT*



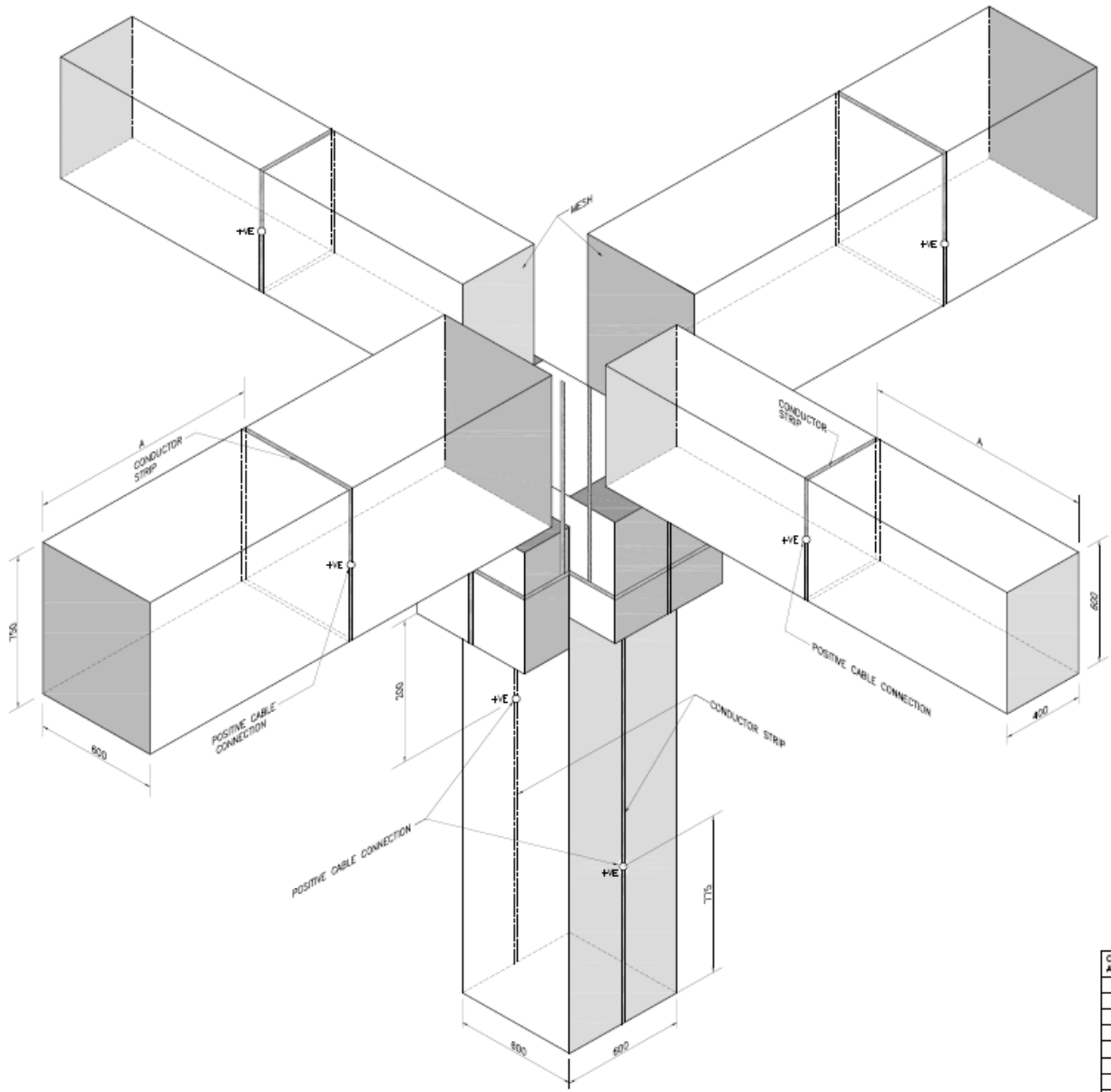
AREA A: *ANODE & CONDUCTOR BAR INSTALLATION*



AREA B: *TYPICAL ANODE LAYOUT ON BEAMS & COLUMNS*



AREA B: *TYPICAL ANODE LAYOUT ON BEAMS & COLUMNS*

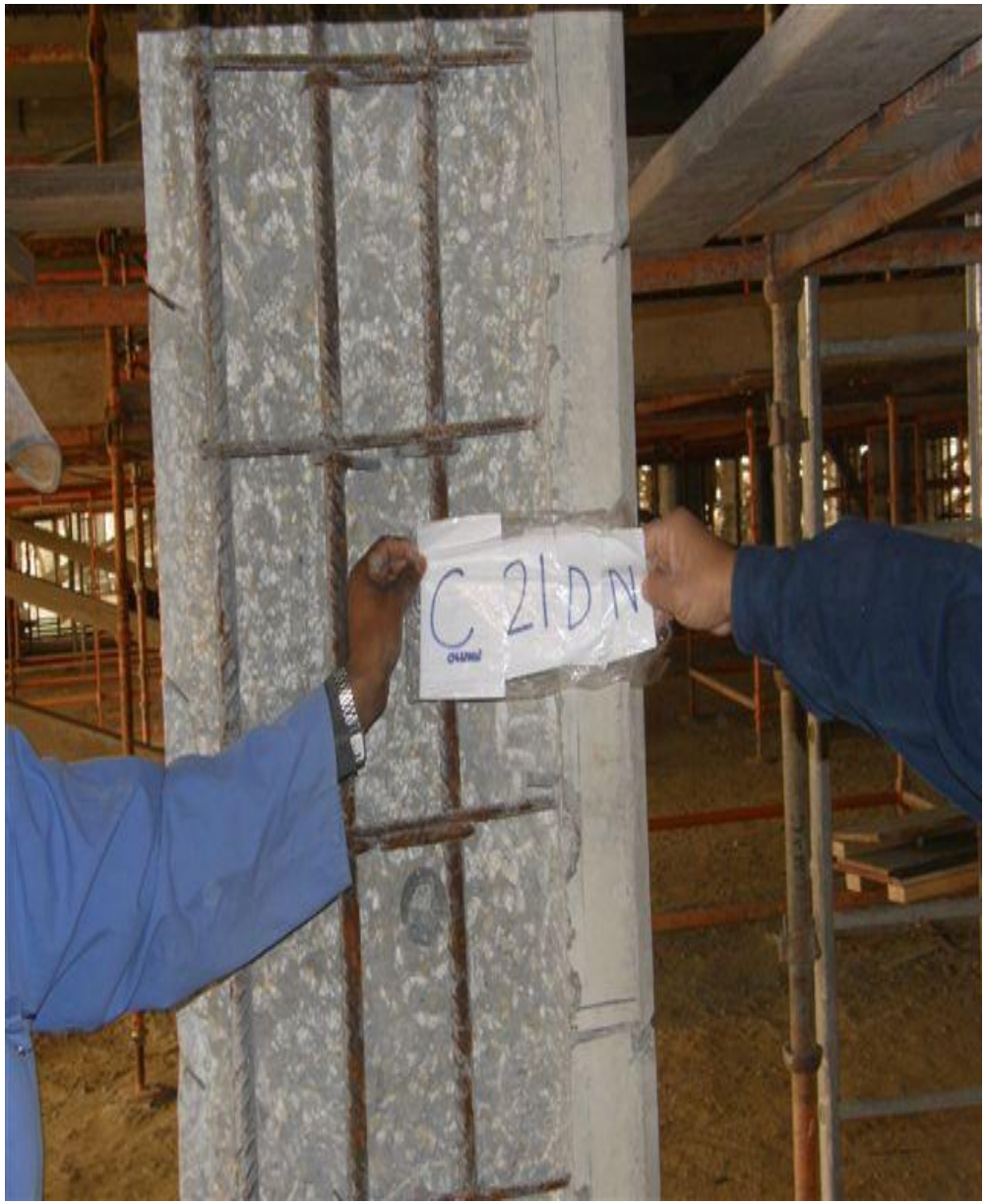


TYPICAL BEAM CORBEL COLUMN INTERFACE SHOWING CONDUCTOR STRIP & POSITIVE CABLE CONNECTION DETAIL

CONDUCTOR STRIP LOCATION AND LENGTH TABLE

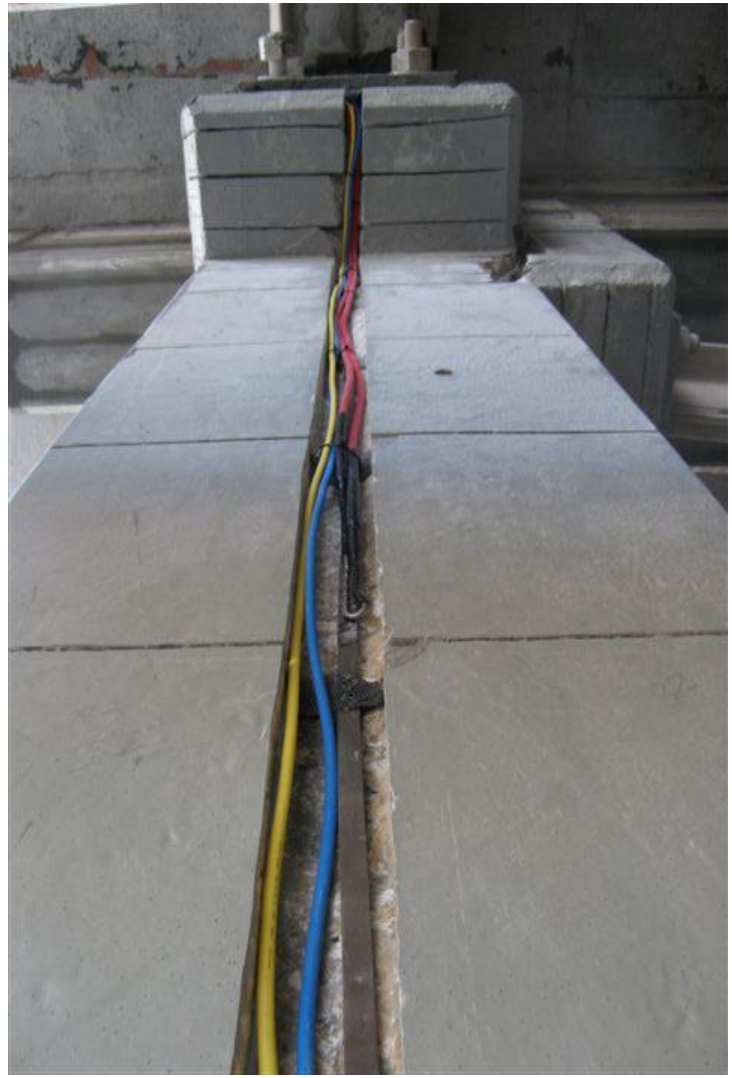
	A
BEAM B1	2427.5
BEAM B2	2300
BEAM B3	2532.5
BEAM B4	2402.5
BEAM B5	3762.5
BEAM B6	3557.5
BEAM B7	2075

AREA B: *BEAM & COLUMN REPAIRS*



AREA B: *BEAM & COLUMN REPAIRS*

AREA B: *MESH RIBBON INSTALLATION ON COLUMN*



AREA B: *MESH RIBBON INSTALLATION ON CORBEL*

AREA C & D: *MESH RIBBON INSTALLATION*

AREA C & D: *MESH RIBBON INSTALLATION*

AREA C & D: *FINAL FINISH: SLAB & COLUMNS*

CP SYSTEM PERFORMANCE ASSESSMENT

CP ASSESSMENT CRITERIA

- **An instant-off steel potential more negative than –720 mV with respect to Ag/AgCl.**
- **A potential decay of at least 100mV from instant-off steel potential over a period of 24 hours.**

Performance Assessment after 6-12 Months operation

Zone Area	No. of Zones Nos.	Applied CD Range mA/m²	Total REs Nos.	RE with ≥100 mV Decay or -720 mV Instant Off Steel Potential Nos.	RE with 50-99 mV Decay Nos.	Criteria Compliance %
A	8	3-6	82	82	0	100
B	21	15-18	168	147	19	88
C	16	2.5-3.5	94	84	10	90
D	3	10-14	18	15	2	83
Total	48		362	328	31	91

CONCLUSIONS

- **Cathodic Protection repair method was opted, as it offers durable, long-term & economical solution for rehabilitation of the structure.**
- **The CP system of all 48 zones has been successfully installed and commissioned.**
- **Monitoring data (after 6-12 months of system operation) has shown criteria compliance at 328 (91%) monitoring locations out of the total of 364.**
- **This shows that the CP system is affording required protection to all protected areas of the CT.**

REMOTE MONITORING SYSTEM

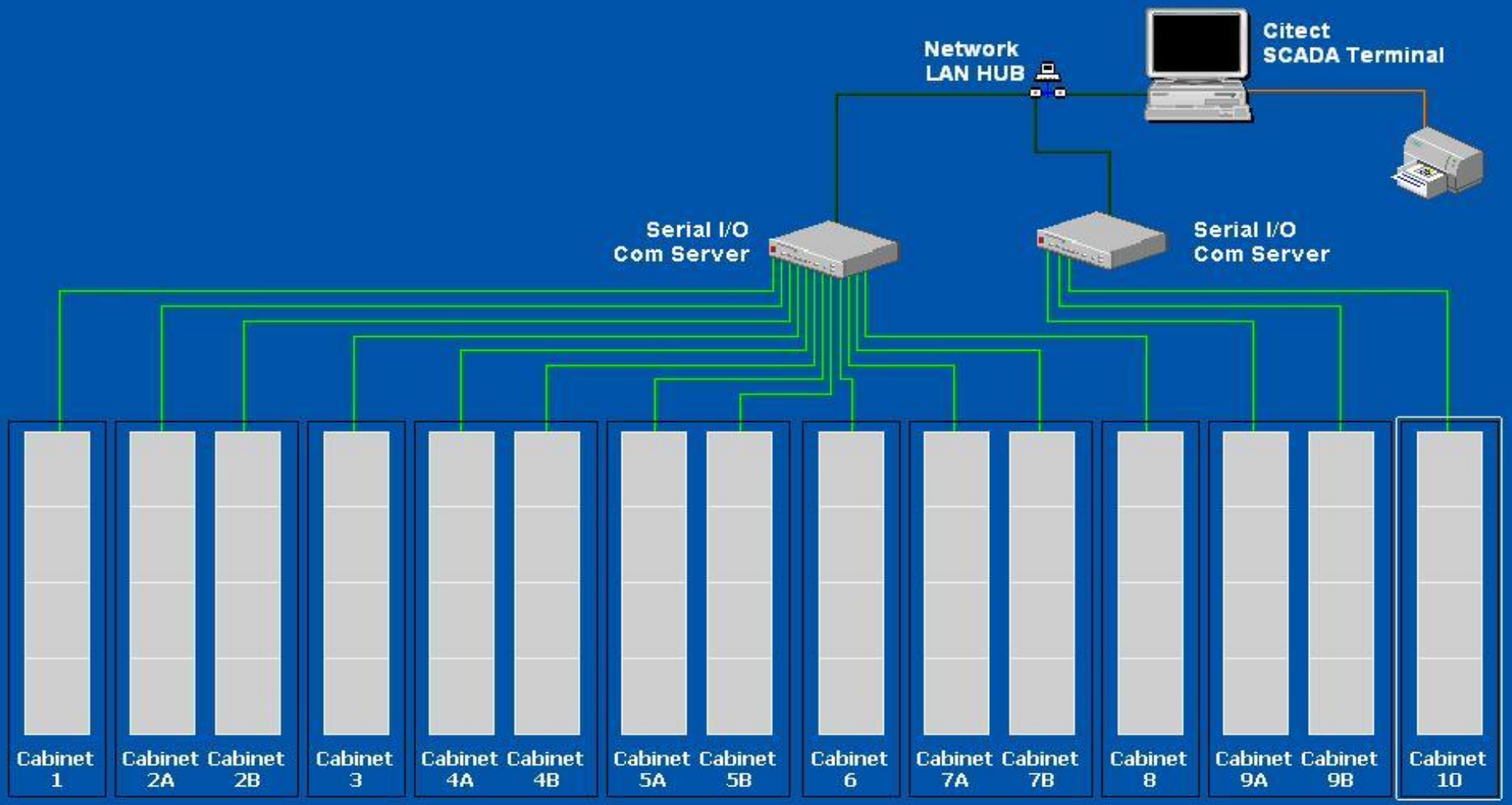
REMOTE MONITORING SYSTEM

- **RMS consists of:**
  - **SOFTWARE**
  - **HARDWARE**
    - **AC/DC Converters**
    - **Relays**
    - **Constant Current Source Cards**
    - **Analog/Digital converters**
    - **Current Interrupters**
    - **Micro-processors & Key Pad**
    - **Master Control Unit (MCU)**
      - **Industrial computer**
      - **Server Communication Server**
      - **Printer**

- **The system is controlled by a PC Main Control Unit (MCU-PC) that is running a SCADA Interface.**
- **Network is controlled by MCU-PC when it is powered.**
- **When MCU-PC is off, each cabinet will continue to operate independently and can be controlled by the Micro Control**


electrotechCP
CABINET 8A
CABINET 8A
CABINET 8A


electrotechCP
UNIT 3B, DYSART WAY, DYSART ROAD
GRANTHAM
LINCOLNSHIRE
NG31 7EJ
UNITED KINGDOM
WWW.ELECTROTECHCP.COM
TEL: +44 (0) 1476 564650
FAX: +44 (0) 1476 564030
Kayan Cooling Tower Main Menu
You Must Log In
User Log In
CATHODIC PROTECTION
Seawater Cooling Towers
And
Pump Sump Area
electrotechCP
Manual Log In
Log Out
Citect


Network
LAN HUB
Citect
SCADA Terminal
Serial I/O
Com Server
Serial I/O
Com Server
Cabinet 1
Cabinet 2A
Cabinet 2B
Cabinet 3
Cabinet 4A
Cabinet 4B
Cabinet 5A
Cabinet 5B
Cabinet 6
Cabinet 7A
Cabinet 7B
Cabinet 8
Cabinet 9A
Cabinet 9B
Cabinet 10

REMOTE MONITORING SOFTWARE

➢ The main features of the RMS are as follows:

- Read and set operating parameters
- Monitor each zone in real time
- Daily Log of Current-On, & Instant-off steel potentials at set time intervals
- Conduct global depolarization tests at set intervals
- Retrieve & analyze depolarization data
- Provide criteria compliance summary of all zones
- DC output status screen
- Alarm enabling
- Set high/low limits

CATHODIC PROTECTION

Seawater Cooling Towers
And
Pump Sump Area

electrotechCP

Version 1.1.0, September 2009

User Log In

- Level 1
- Level 2
- Level 3
- SABIC

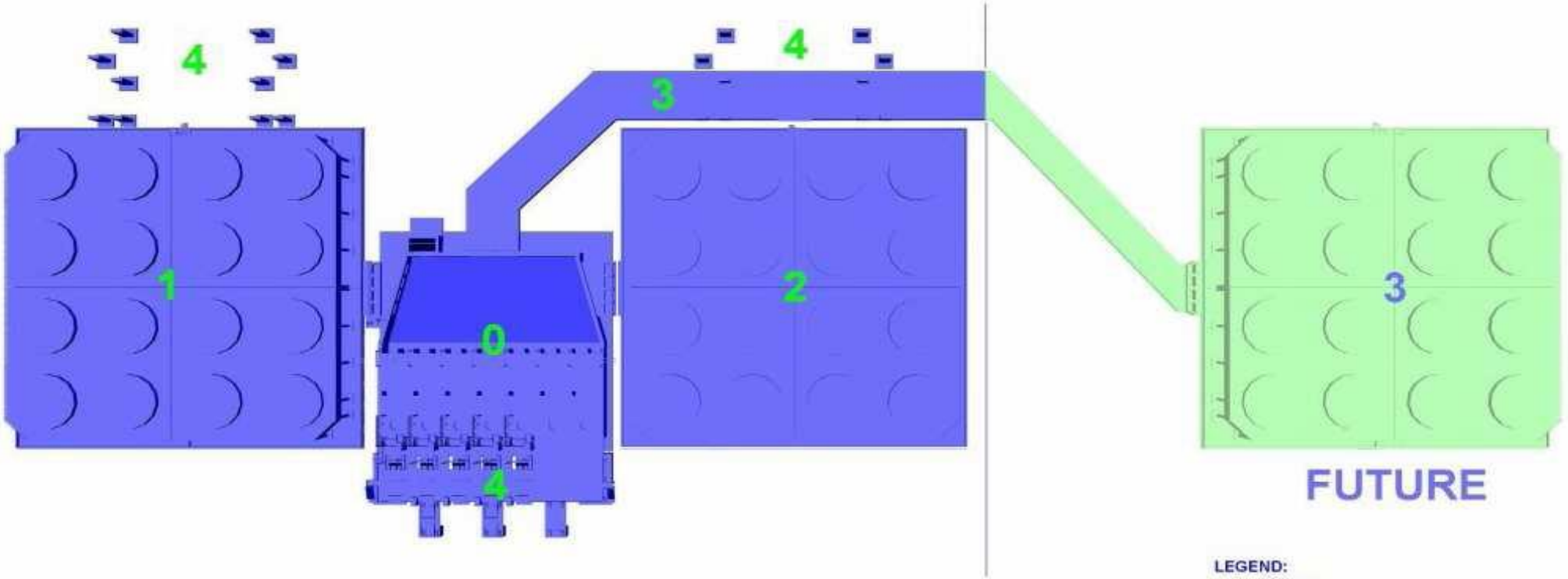
- Plant Overview
- Power Supplies & Monitoring

- Criteria Compliance
- Network Comms
- Depolarisation
- System Settings
- Software Shutdown

Log Out


Pump Station
0FB1 1
0FB2 1
0LB1 1
0LB2 1
0LW1 1
0LW2 1
0LA1 1
0LA2 1
0FW1 1
0FW2 1
0LW3 1
0LW4 1
0DA2 1
0DS2 1
CT 7801
1FB1 2
1FB2 2
1FB3 2
1FB4 2
1FW1 2
1FW2 2
1FW3 2
1FW4 2
1FW5 2
1FW6 2
1FW7 2
1FW8 2
1FA1 2
1RS1 3
1RS2 6
1RW1 3
1RW2 6
1CS1 3
1CS2 3
1CS3 3
1CS4 3
1CS5 3
1CS6 3
1CS7 3
1CS8 3
1CH1 3
1CH2 3
1CH3 3
1CH4 3
1DA1 6
1DA2 6
1DA3 6
1DA4 6
CT 7802
2FB1 4
2FB2 4
2FB3 4
2FB4 4
2FW1 4
2FW2 4
2FW3 4
2FW4 4
2FW5 4
2FW6 4
2FW7 4
2FW8 4
2FA1 4
2RS1 5
2RS2 6
2RW1 5
2RW2 6
2CS1 5
2CS2 5
2CS3 5
2CS4 5
2CS5 5
2CS6 5
2CS7 5
2CS8 5
2CH1 5
2CH2 5
2CH3 5
2CH4 5
2DA1 6
2DA2 6
2DA3 6
2DA4 6
CT 7803
3FB1 7
3FB2 7
3FB3 7
3FB4 7
3FB5 7
3FW1 7
3FW2 7
3FW3 7
3FW4 7
3FW5 7
Auxillaries
4CA1 7
4FB2 7
No Load on Zone
Load on Zone
= 3A Channel
= 6A Channel
= 9A Channel
= 12A Channel

YANSAB PLANT PLAN

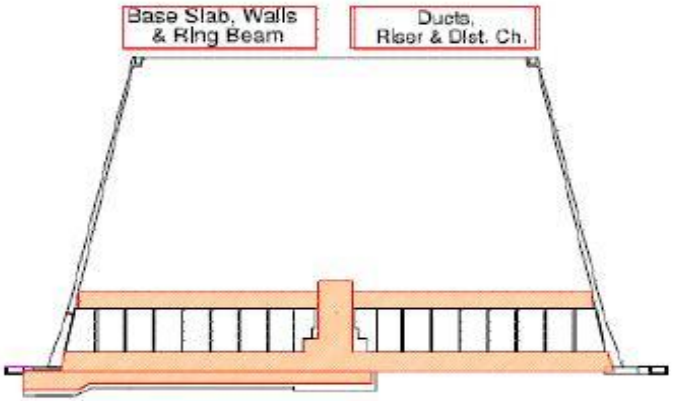


LEGEND:

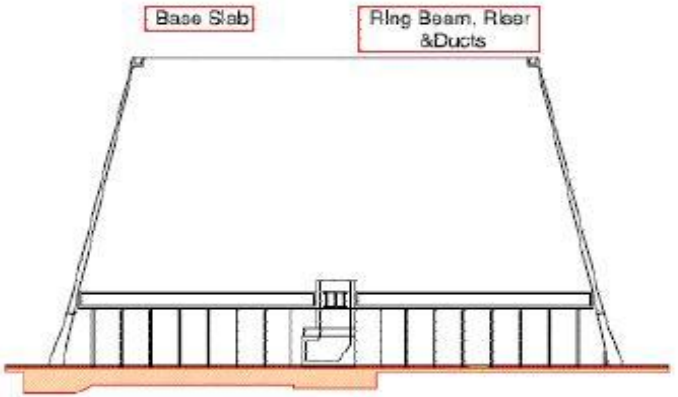
0 PUMP STATION
1 CT-7801
2 CT-7802
3 CT-7803
4 AUXILLIARIES

CT-72101B :- ENVIRONMENTAL ZONING ARRANGEMENT

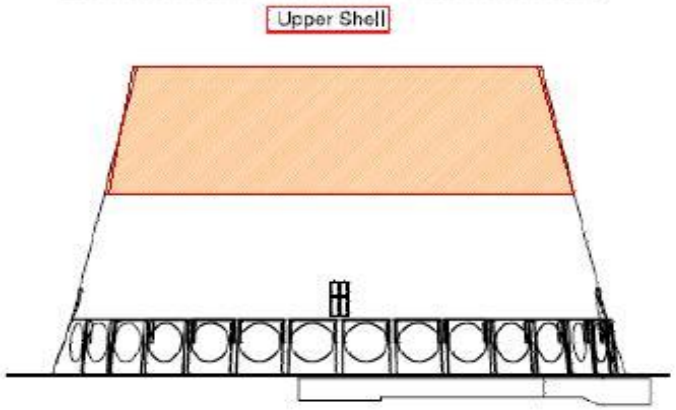
SUBMERGED ZONES



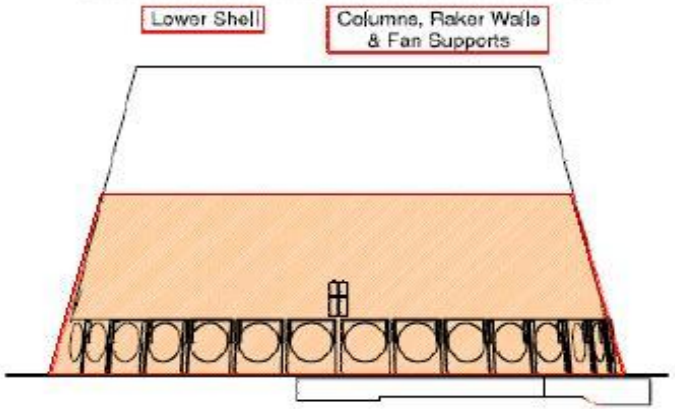
BURIED ZONES



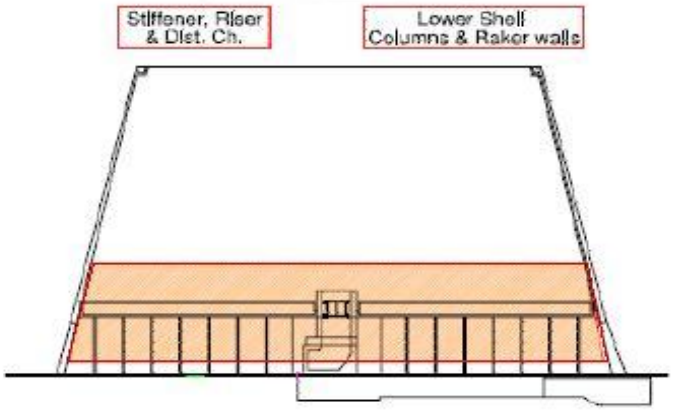
UPPER ATMOSPHERIC ZONES



LOWER ATMOSPHERIC ZONES



HUMID ZONES



ZONE	Design Current (mA)	Max Current (mA)	Op Current (mA)	Op Voltage (V)	Op Curr Density (mA/m²)	REF	RE1 (mV)	RE2 (mV)	RE3 (mV)	RE4 (mV)	RE5 (mV)	RE6 (mV)	RE7 (mV)	RE8 (mV)	RE9 (mV)	RE10 (mV)	RE11 (mV)	RE12 (mV)	RE13 (mV)	RE14 (mV)	RE15 (mV)	RE16 (mV)
Submerged Zones																						
Ring Beam, Base Slab, Column and Raker Walls, Partition and Wall Stiffener																						
8W	3908	6520	0	0.0	3	ON OFF	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0								
9W	3579	6319	0	0.0	0	ON OFF	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0							
10W	2067	4453	0	0.0	5	ON OFF	0 0	0 0	0 0	0 0	0 0	0 0	0 0									
11W	4626	8203	0	0.0	0	ON OFF	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0				
12W	3908	6520	0	0.0	0	ON OFF	0 0	0 0	0 0	0 0	0 0	0 0	0 0									
13W	2087	4489	0	0.0	5	ON OFF	0 0	0 0	0 0	0 0	0 0	0 0	0 0									
14W	3995	6734	0	0.0	0	ON OFF	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0				
15W	4000	7671	0	0.0	0	ON OFF	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0						
16W	3908	6520	0	0.0	3	ON OFF	0 0	0 0	0 0	0 0	0 0	0 0	0 0									
17W	1965	4272	0	0.0	0	ON OFF	0 0	0 0	0 0	0 0	0 0	0 0	0 0									
18W	3632	6405	0	0.0	3	ON OFF	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0						
19W	4425	7728	0	0.0	0	ON OFF	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0				
20W	4617	7164	0	0.0	2	ON OFF	0 0	0 0	0 0	0 0	0 0	0 0	0 0									
21W	4170	7481	0	0.0	0	ON OFF	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		
23W	4421	8003	0	0.0	2	ON OFF	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0		

Cooling Tower A, Zone - 1W

Set Points

Voltage V	Current mA
0.4	0

Set Output Limits (V & I)

V	mA
15.0	6000

Read Points

Voltage V	Current mA
0.00	0

RELAY ON/OFF: OFF

PSU ON/OFF: OFF

Design Settings

Design Current - mA	3743	Operating Current Density - mA/m²	0.00
Design Current Density - mA/m²	5.00		
Maximum Current Anode - mA	6106		

Depolarisation Number: 0 — Depolarisation Carried Out On:

	Native - mV	Instant OFF - mV	Max Decay - mV	-720 mV	100mV Decay	Meet Criteria
R1	0	0	0	NO	NO	NO
R2	0	0	0	NO	NO	NO
R3	0	0	0	NO	NO	NO
R4	0	0	0	NO	NO	NO
R5	0	0	0	NO	NO	NO
R6	0	0	0	NO	NO	NO
R7	0	0	0	NO	NO	NO
R8	0	0	0	NO	NO	NO

Load Test Data

No. of Tests: 8

Reference Cells - mV (Ag/AgCl)

Mon Aug 23 2010 11:06:11

	R1	R2	R3	R4	R5	R6	R7	R8
Nat.	0	0	0	0	0	0	0	0
ON	2014	2014	2014	2014	2014	2014	2014	2014
OFF	2014	2014	2014	2014	2014	2014	2014	2014

Update Reference Electrodes

Depolarisation Number: 8 Depolarisation Carried Out On: Sun Sep 13 2009

Area	R 1	R 2	R 3	R 4	R 5	R 6	R 7	R 8	R 9	R 10	R 11	R 12	R 13	R 14
CTA_1A	NO	NO	NO	NO	NO	NO	NO							
CTA_2A	NO	NO	NO	NO	NO	NO	NO							
CTA_3A	NO	NO	NO	NO	NO	NO	NO							
CTA_4A	NO	NO	NO	NO	NO	NO	NO							
CTA_5A	NO	NO	NO	NO	NO	NO	NO							
CTA_6A	NO	NO	NO	NO	NO	NO	NO							
CTA_7A	NO	NO	NO	NO	NO	NO	NO							
CTA_8A	NO	NO	NO	NO	NO	NO	NO							
CTA_9A	NO	NO	NO	NO	NO	NO	NO							
CTA_10A	NO	NO	NO	NO	NO	NO	NO							
CTA_11A	NO	NO	NO	NO	NO	NO	NO							
CTA_12A	NO	NO	NO	NO	NO	NO	NO							
CTA_13A	NO	NO	NO	NO	NO	NO	NO							
CTA_14A	NO	NO	NO	NO	NO	NO	NO							
CTA_15A	NO	NO	NO	NO	NO	NO	NO							
CTA_16A	NO	NO	NO	NO	NO	NO	NO							
CTA_17A	NO	NO	NO	NO	NO	NO	NO							
CTA_18A	NO	NO	NO	NO	NO	NO	NO							
CTA_19A	NO	NO	NO	NO	NO	NO	NO							
CTA_20A	NO	NO	NO	NO	NO	NO	NO							
CTA_21A	NO	NO	NO	NO	NO	NO	NO							
CTA_22A	NO	NO	NO	NO	NO	NO	NO							

Next Page

Depolarisation Test Start Date

Select Start Date

Scheduled Test Start Date:Wed Aug 12 2009 00:00:05
Next General Log:

Depolarisation Test Frequency

Every Month | Every 2 Months | Every 3 Months

Every 4 Months | Every 6 Months | Every 12 Months

Disable Depol Test

Disable Depol

NOTES:
Start Date and Frequency can only be set when depolarisation is disabled
Depolarisation date must be set within one month of current Date, or date will default to one month.

Last Depol Date: Mon Oct 12 2009
Last Depol No.: 8

Depolarisation Set to Every 3 Months

Fast Logging Settings

Fast Log Frequency
Min. 15Mins
Max. 30Mins
60 mins — Set Fast Log Frequency

Fast Log Duration
Min. 30Mins
Max. 240Mins
32 mins — Set Fast Log Duration

Fast Logging
On/ Off
ON — Fast Logging On / Off

Next Fast Logging Due:

Fast Logging End Time:

General Log Settings

Logging Frequency
Min. 30 Mins
Max. 240Mins (4Hrs)
50 mins — Set Logging Frequency

Logging Duration
Min. 1Hrs
Max. 336Hrs (14 Days)
15 Hrs — Set Logging Duration

Next Depol Logging Due:

Depol Logging End Time:

Manual Depolarisation

Manual Depol Start

Manual Start Time:

System Settings

Trends Alarms Tools

Sabic

Back

Instant Off Settings

Minimum: 500 Milliseconds | Maximum: 2000 Milliseconds

Cabinet 1	500.00	Change Instant Off
Cabinet 2A	500.00	Change Instant Off
Cabinet 2B	500.00	Change Instant Off
Cabinet 3	500.00	Change Instant Off
Cabinet 4A	500.00	Change Instant Off
Cabinet 4B	500.00	Change Instant Off
Cabinet 5A	500.00	Change Instant Off
Cabinet 5B	500.00	Change Instant Off
Cabinet 6	500.00	Change Instant Off
Cabinet 7A	500.00	Change Instant Off
Cabinet 7B	500.00	Change Instant Off
Cabinet 8	500.00	Change Instant Off
Cabinet 9A	500.00	Change Instant Off
Cabinet 9B	500.00	Change Instant Off
Cabinet 10	500.00	Change Instant Off

File Copy

Insert USB Memory Stick to Copy Log Files
Set Drive to: D

Copy All Logging Data To USB

Report Status

	STATUS	NEXT DUE
Daily Log:	Enabled	Tue Aug 24 2010 06:00:00
Depolarisation:	Enabled	Wed Apr 20 2011 07:00:00
Depol Fast Log:	Disabled	Wed Apr 20 2011 07:00:00
Depol Fast Log End:	Disabled	Wed Apr 20 2011 07:00:00
Depol Normal Log:	Disabled	Wed Apr 20 2011 07:00:00
Depol Long Log:	Enabled	Wed Apr 20 2011 07:00:00
Depol Log End:	Disabled	Wed Apr 20 2011 07:00:00
Environmental:	Enabled	Mon Aug 23 2010 12:00:00

Daily Log Settings

Minimum: 60Minutes | Maximum: 4320 Minutes (72hrs)

Log Interval: 1440 mins

Time Remaining: Thu Oct 15 2009 06:00:00

1440 = 24Hrs
2880 = 48Hrs
4320 = 72Hrs

Change Log Interval | Manual Log | Logging Off

Daily Logging Enabled

Log Out Idle

Set Logout Time to 1 Minute	1 Minute
Set Logout Time to 10 Minutes	10 Minutes
Set Logout Time to 60 Minutes	60 Minutes
Turn Logout Time OFF	Turn Logout Time Off

Logout Idle Time: 10 Min.

electrotechCP

11:09:06
Mon Aug 23 2010

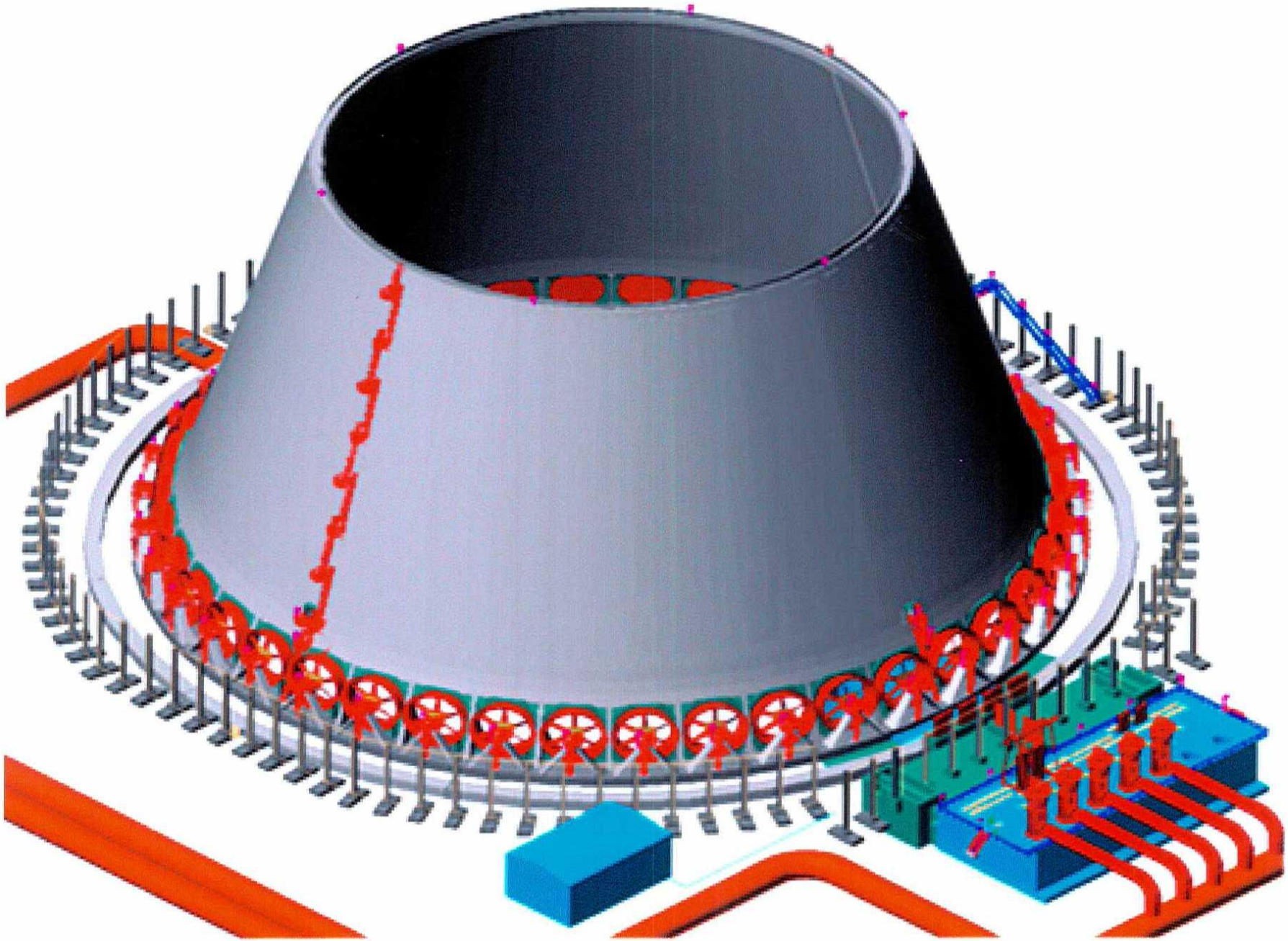
INSTALLATION

OF

CP SYSTEMS

IN

NEW SEAWATER COOLING TOWERS




WOLFF
23 3 2006
23-03-06


doka
Frami 300

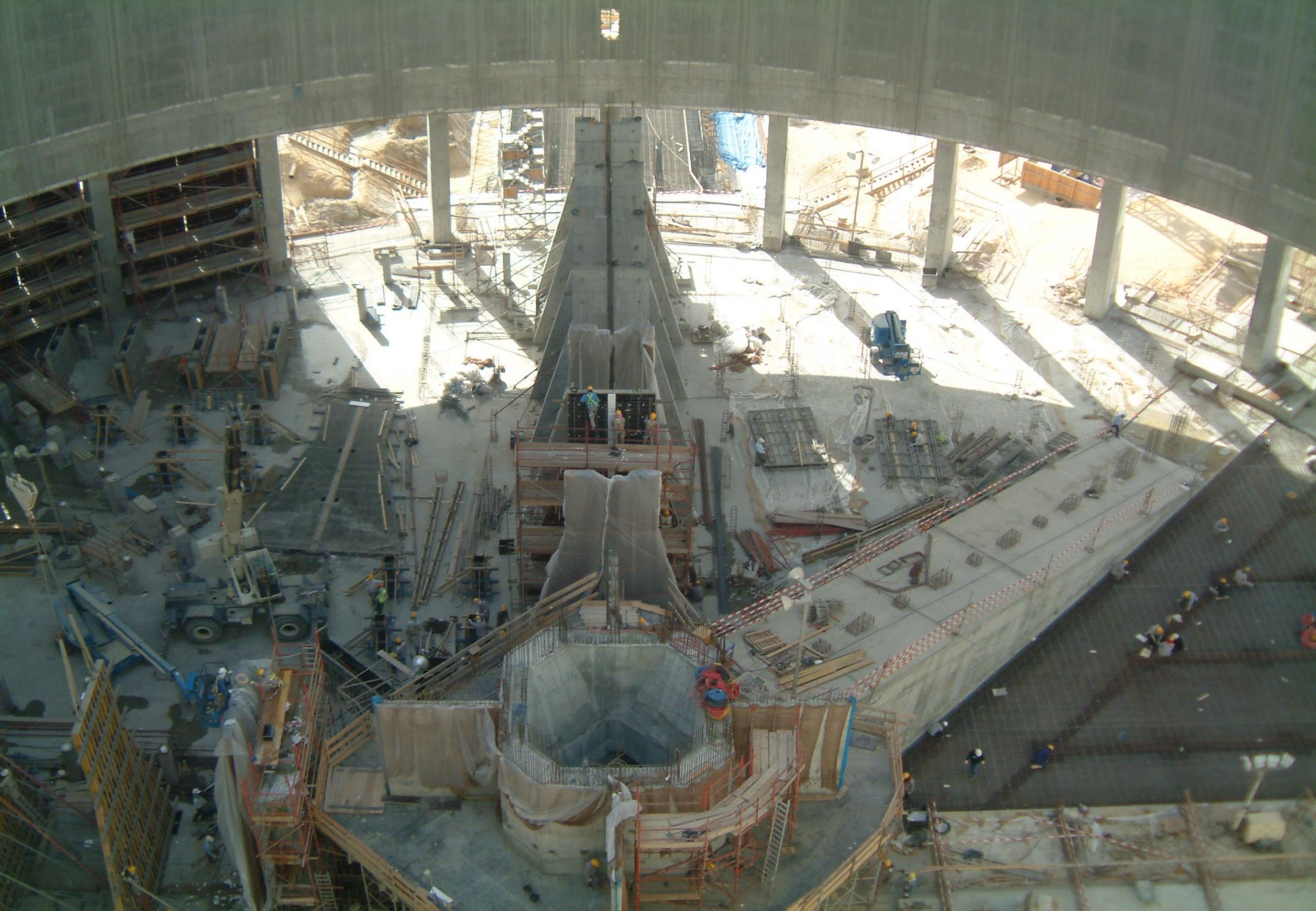
19-07-06

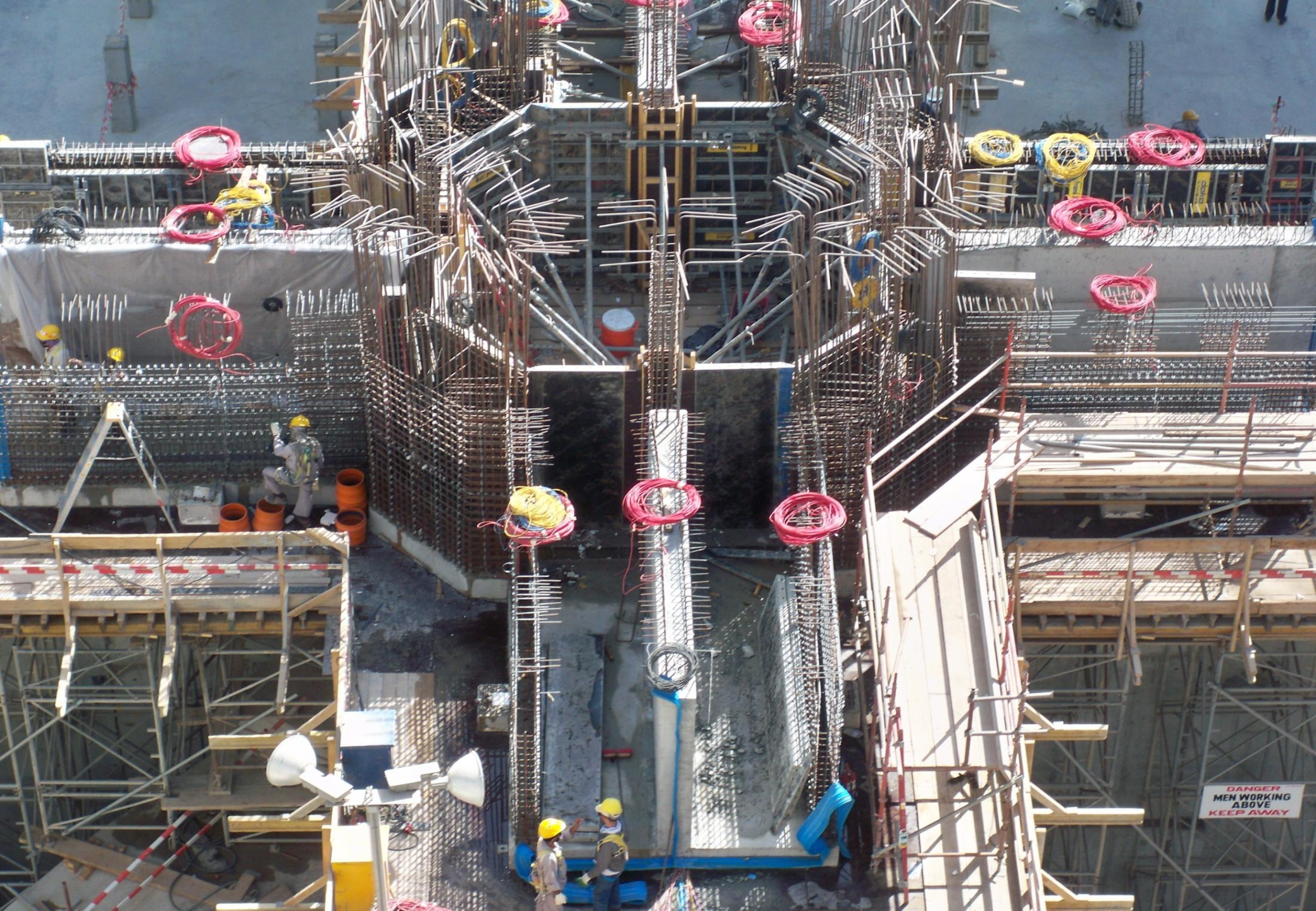

30 8 2006
30-08-06


25 10 2006
25-10-06


29 11 2006
29-11-06


2 5 2007
02-05-07




DANGER
MEN WORKING
ABOVE
KEEP AWAY

THANKS