PERFORMANCE OF AN IMPRESSED CURRENT CATHODIC PROTECTION SYSTEM FOR A REINFORCED CONCRETE TANK

Dr. S. Ehtesham Hussain
&
Dr. Hamed A. Al-Ghamdi

(Hamed Al-Ghamdi Consulting Engineers (CONTEC)
Khobar, Saudi Arabia
(Email: info@contec.com.sa)

INTRODUCTION

- **REINFORCED CONCRETE STRUCTURES SUFFER PREMATURE DETERIORATION DUE TO AGGRESSIVE ECPOSURE CONDITIONS IN JUBAIL**
- **MAIN CAUSE OF CONCRETE DETERIORATION IS REINFORCEMENT CORROSION**
- **INGRESS OF CHLORIDE SALTS FROM SEAWATER, SOIL, GROUNDWATER AND ATMOSPHERE**
- **STRUCTURES BUILT DURING EARLY EIGHTIES USING NORMAL CONCRETE SPECIFICATIONS SUFFERED DETERIORATION AFTER A SERVICE LIFE OF 10-15 YEARS**
- **CONCRETE SPECIFICATIONS WERE MODIFIED TO SUIT THE ENVIRONMENT**

INTRODUCTION (cont'd)

CURRENT CONCRETE SPECIFICATIONS

- TYPE I CEMENT
- MINERAL ADMIXTURES (mostly SILICA FUME)
- LARGER CONCRETE COVER
- ADDITIONAL PROTECTION (as required)
- BETTER QUALITY CONTROL (limits on chloride content in concrete & chloride permeability)

INTRODUCTION (cont'd)

ADDITIONAL PROTECTION

- REQUIRED WHEN STRUCTURE EXPOSED TO SOIL, GROUNDWATER, SEAWATER, WASTEWATER AND OTHER CORROSIVES
- DIFFERENT TECHNIQUES AVAILABLE
  - CONCRETE SURFACE COATING
  - WATERPROOFING MEMBRANE
  - COATED REBARS
  - CATHODIC PROTECTION
- SELECTION OF PROTECTION TECHNIQUE DEPENDS ON MANY FACTORS incl. IMPORTANCE & REQUIRED LIFE OF THE STRUCTURE

INTRODUCTION (cont'd)

CATHODIC PROTECTION IS

- **A PROVEN TECHNIQUE TO CONTROL CORROSION OF REINFORCING STEEL**
- **IT STOPS CORROSION BY APPLYING DC CURRENT (MAKING THE STRUCTURE CATHODE OF THE CORROSION CELL)**
- **APPLICABLE TO NEW AS WELL AS EXISTING DETERIORATING STRUCTURES**
- **DURABLE (MORE THAN 50 YEARS)**

INTRODUCTION (cont'd)

ADVANTAGES OF CP

- PROVEN TECHNIQUE WITH EXCELLENT TRACK RECORD WORLDWIDE AND IN THE MIDDLE EAST
- CHLORIDE REMOVAL IS NOT REQUIRED IN EXISTING CONTAMINETD STRUCTURES
- AVOIDS EXTENSIVE CONCRETE BREAK-OUT & MINIMZES DISTURBANCE TO OPERATIONS
- SERVICE LIFE EXTENSION OF 50 YEARS CAN BE DESIGNED
- EXPERTISE AVAILABLE LOCALLY

INTRODUCTION (cont'd)

ADVANTAGES (cont'd)

- OH- GENERATED AT STEEL INCREASES ALKALINITY
- NEGATIVELY CHARGED Cl^- REPELLED AWAY FROM STEEL
- $[Cl^-] / [OH^-]$ REDUCES
- STEEL PASSIVITY INCREASES
- CURRENT DEMAND REDUCES WITH TIME

INTRODUCTION (cont'd)

CANDIDATE STRUCTURES FOR CP

- FOUNDATIONS OF CRITICAL STRUCTURES
- MARINE STRUCTURES (SEAPORT BERTHS, JETTIES)
- BRIDGE FOUNDATIONS AND DECKS
- SEAWATER INTAKE & DISCHARGE STRUCTURES
- WATER TANKS
- CONCRETE PIPELINE

INTRODUCTION (cont'd)

LIMITATIONS OF CP

- CAN CAUSE INTERFERENCE PROBLEMS
- NEEDS PERIODIC MONITORING
- OVERTORTECTION CAN CAUSE COATING DAMAGE, REDUCTION IN BOND BETWEEN STEEL & CONCRETE AND H_2 EMBRITTLEMENT OF PRESTRESSING WIRES
- SUBJECT TO POWER FAILURE AND VANDALISM

INTRODUCTION (cont'd)

DESIGN CRITERIA (DESIGN CURRENT DENSITY)

- 20 mA/m2 FOR EXISTING STRUCTURES (CHLORIDE-CONTAMINATED CONCRETE)
- 3-5 mA/m2 FOR NEW STRUCTURES

PROTECTION CRITERIA

- INSTANT OFF POTENTIAL OF -720 mV OR MORE NEGATIVE VERSUS Ag-AgCl RE
- POTENTIAL DECAY OF MORE THAN 100 mV IN 24 HOURS

COMMONLY USED CP SYSTEMS

1. MMO COATED TITANIUM MESH SYSTEM WITH CONCRETE OVERLAY
2. MMO COATED TITANIUM RIBBON MESH SYSTEM
3. MMO COATED TITANIUM RIBBON MESH SLOTTED SYSTEM
4. DISCRETE ANODE SYSTEM
5. CONDUCTIVE COATING SYSTEM
6. THERMALLY SPRAYED ZINC SYSTEM
7. MMO COATED TITANIUM MESH ANODE INTEGRAL PILE JACKET SYSTEM
8. ZINC MESH ANODE INTEGRAL PILE JACKET SYSTEM

MMO COATED TITANIUM MESH SYSTEM WITH OVERLAY

- **APPLICATIONS**
  - ALL TYPES EXISTING & NEW STRUCTURES
  - DRY, MOIST & IMMERSED CONDITIONS
- **CURRENT RATING**
  - 110 mA/m^2 OF ANODE SURFACE AREA
  - (15-35 mA/m^2 OF CONCRETE SURFACE AREA)
- **LIFE**
  - MORE THAN 50 YEARS
- **COST**
  - USD 150/m^2

MMO COATED TITANIUM MESH SYSTEM WITH OVERLAY (cont'd)

- **CHARACTERISTICS**
  - **MOST DURABLE AND WELL ESTABALISHED**
  - **EXCELLENT TRACK RECORD; USED ON MANY STRUCTURES WORLDWIDE**
  - **FLEXIBLE IN PROVIDING REQUIRED CURRENT OUTPUT (15-35 mA/m^2 OF CONCRETE SURFACE AREA)**
  - **OVERLAY MAY ADD TO DEAD LOAD OF THE STRUCTURE**
  - **MAX. OPERATING VOLTAGE: 12 V**

MMO COATED TITANIUM MESH SYSTEM WITH OVERLAY (cont'd)

MMO COATED TITANIUM MESH SYSTEM WITH OVERLAY (cont'd)

CASE STUDY

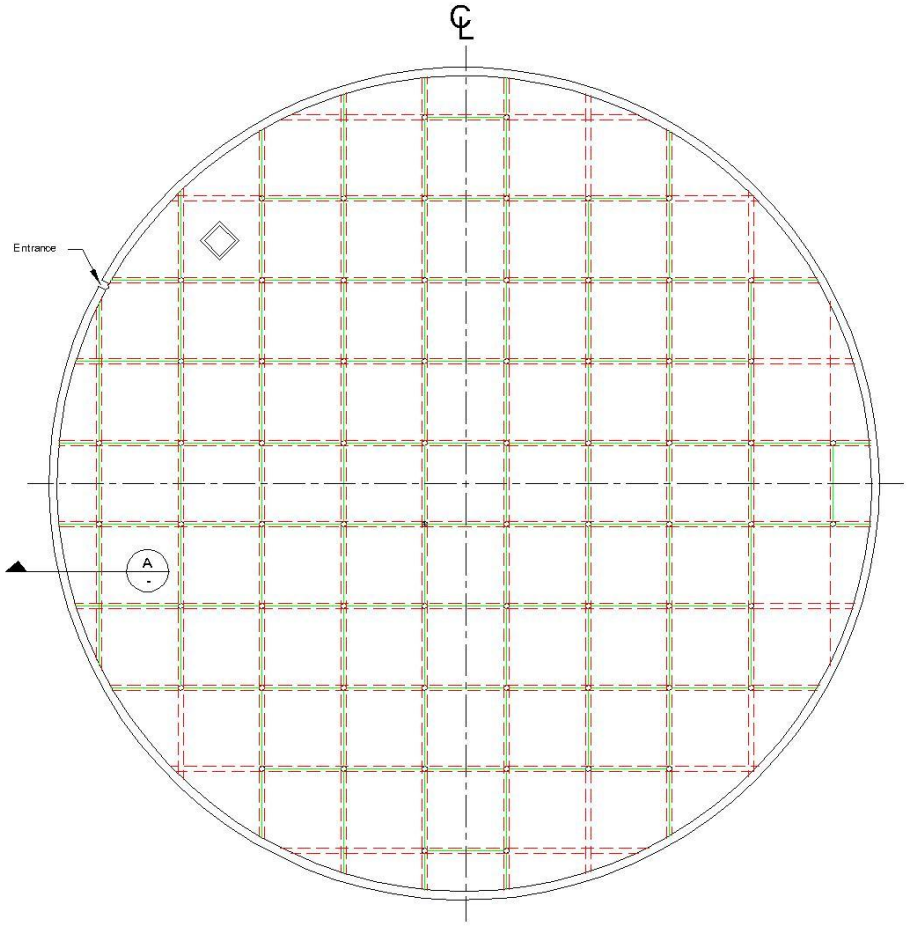
FOUNDATIONS OF REINFORCED CONCRETE TANK

CASE STUDY

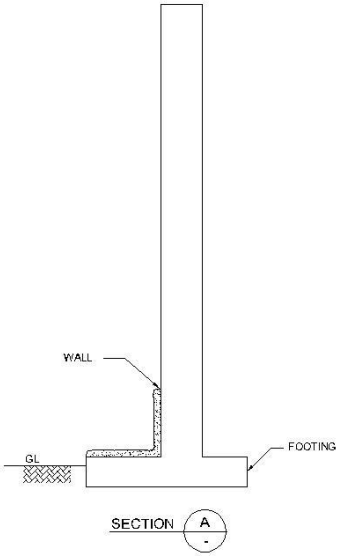
STRUCTURE DETAILS

- 63 M DIA. AND 7 M HEIGHT WATER STORAGE TANK
- TANK CONSTRUCTED IN 1982
- CP SYSTEM APPLIED IN 1991
- CP APPLIED TO PROTECT TOP OF FOOTING & WALL UP TO XX M HEIGHT

CASE STUDY



PLAN



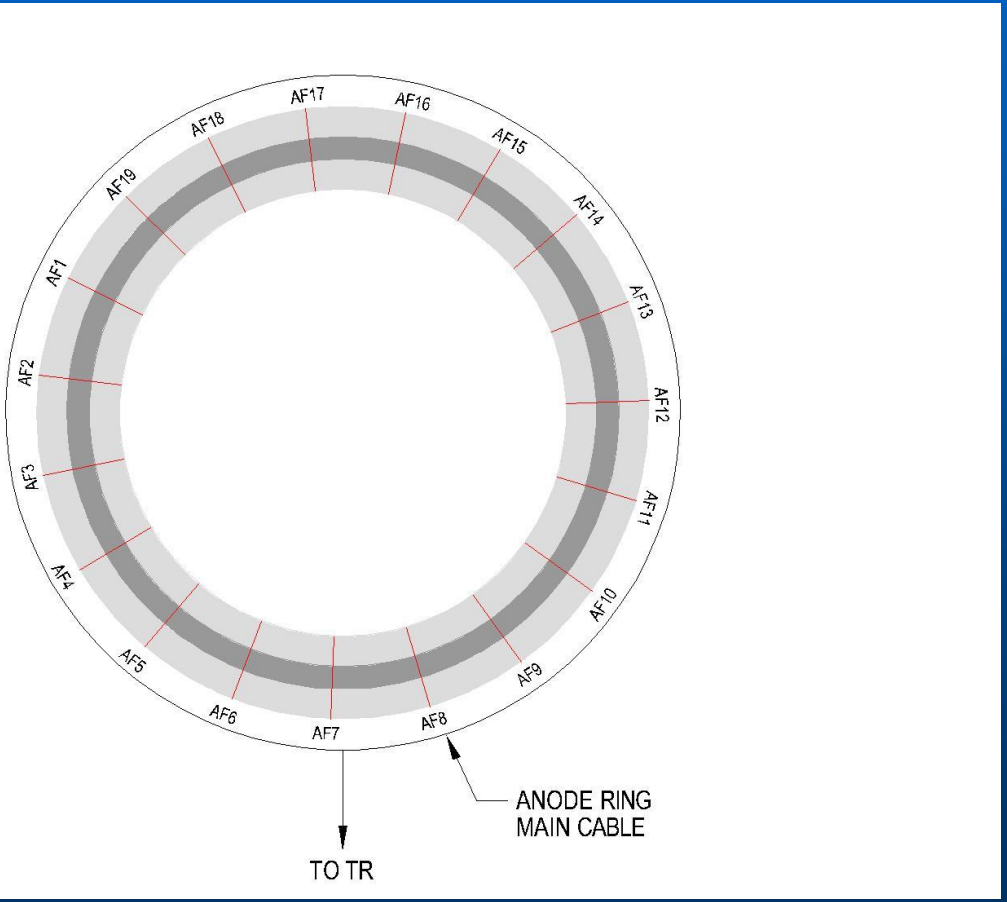
CASE STUDY(cont'd)

CP SYSTEM DETAILS

- IMPRESSED CURRENT SYSTEM
- CONCRETE SURFACE AREA: 700 M^2
- SINGLE ZONE
- AV. STEEL/CONCRETE AREA RATIO: 0.95
- DESIGN CURRENT DENSITY: 20 mA/m^2
- DESIGN CURRENT: 13.35 A
- OIL COOLED TR (25 V, 25 A)

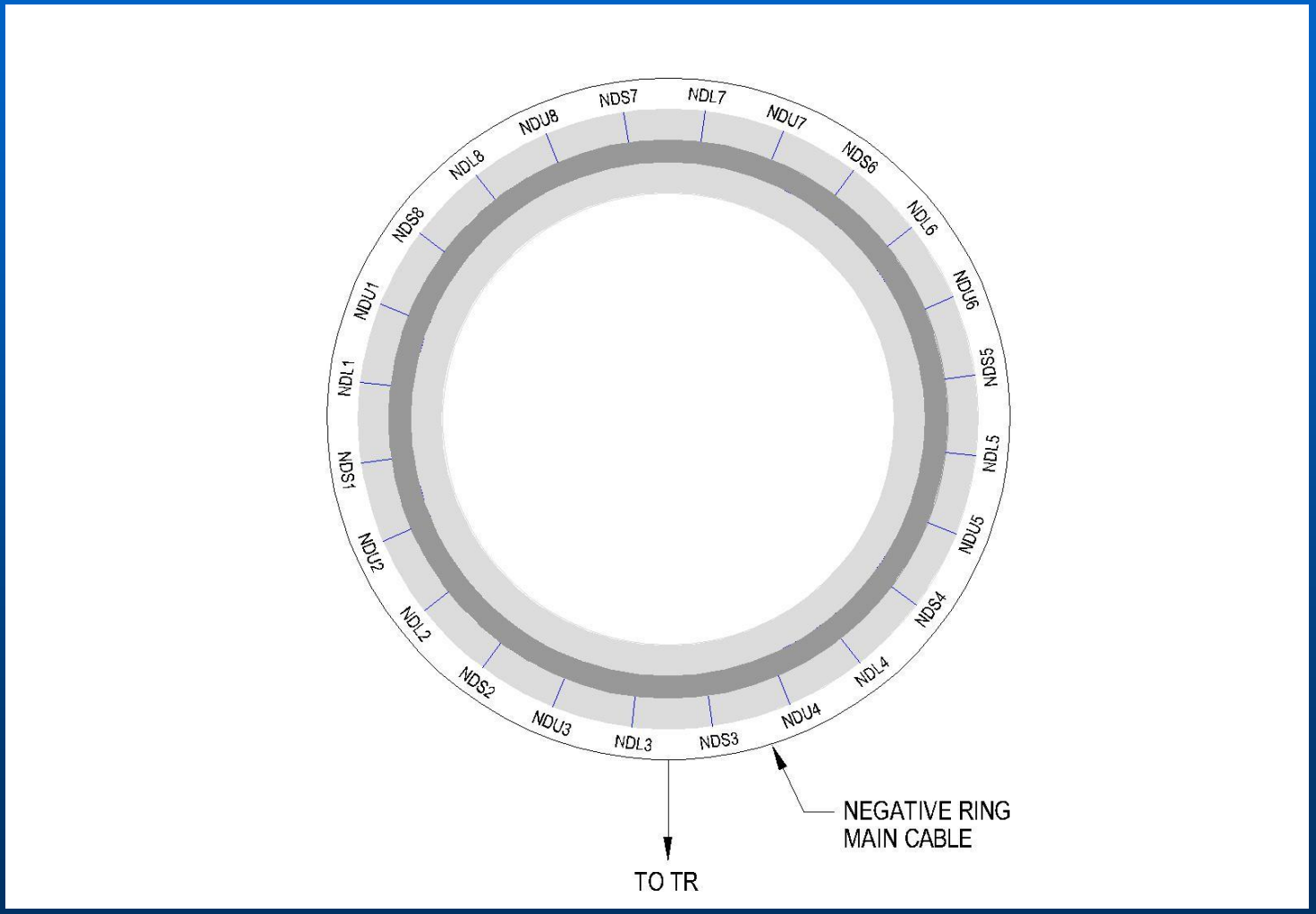
ANODE SYSTEM

- MMO COATED TITANIUM MESH WITH OVERLAY
- TITANIUM CONDUCTOR BAR AT 10 M SPACING
- ANODE FEEDER CABLES CONNECTED TO CON. BAR
- AF CABLES CONNECTED TO RING MAIN CABLE



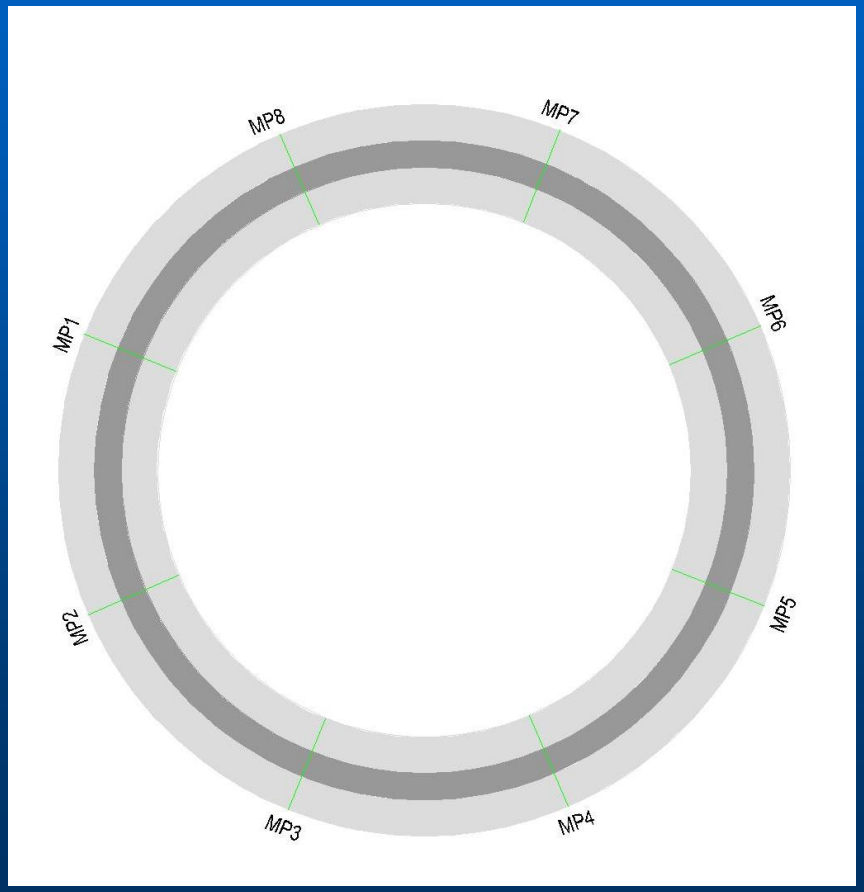
NEGATIVE CONNECTIONS

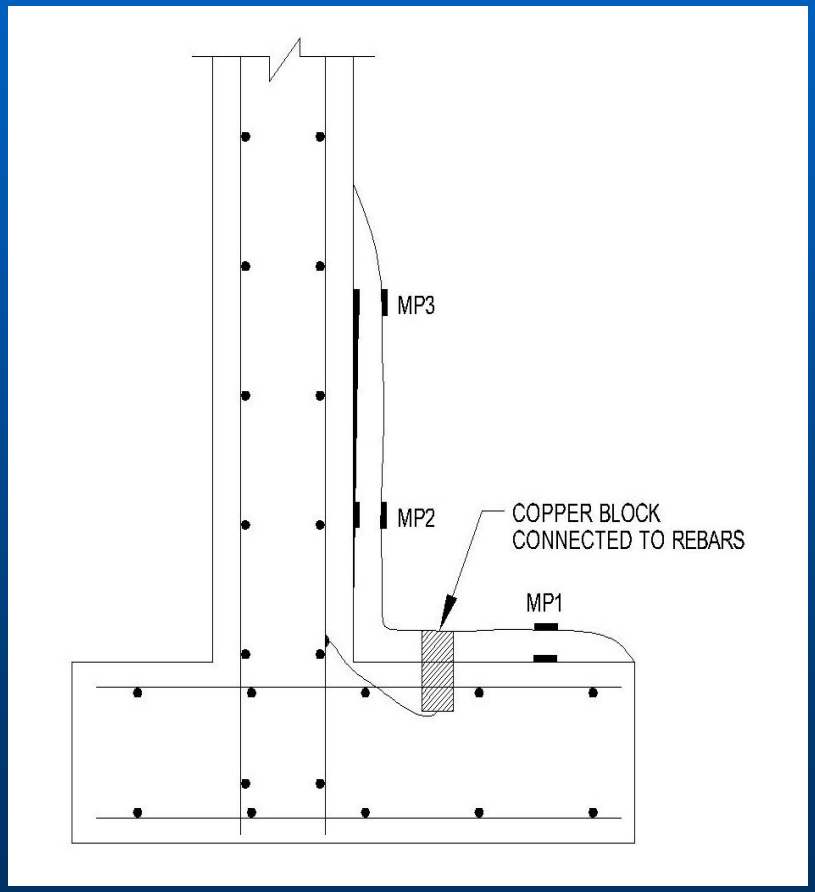
- AT 25 M SPACING, CONNECTED TO RING MAIN CABLE & TERMINATED IN TR



MONITORING SYSTEM

- COPPER BLOCKS CONNECTED TO REBARS INSTALLED ON CONCRETE SURFACE
- MONITORING POINTS MARKED ON SURFACE
- POTENTIALS MEASURED USING PORTABLE RE





CASE STUDY(cont'd)

CP SYSTEM PERFORMANCE

- TR CONDITION & OUTPUT MONITORED MONTHLY
- POTENTIALS MEASURED EVERY SIX MONTHS
- SYSTEM PERFORMING SATISFACTORILY W/O MAJOR MAINTENANCE
- SYSTEM PROVIDING ADEQUATE PROTECTION (INSTANT OFF POT. OF LESS THAN -720 mV)

CASE STUDY(cont'd)

CP SYSTEM PERFORMANCE

- **OPERATING VOLTAGE: 2.6 V**
- **OPERATING CURRENT: 1.80 A**
- **OPEARTING CURRENT DENSITY: 2.7 mA/m^2 OF STEEL AREA AFTER 20 YRS.**
- **REBARS IN GOOD CONDITION**
- **LOW CHLORIDE CONTENT IN CONCRETE AROUND REBARS**

CONCLUDING REMARKS

- **CONCRETE STRUCTURES EXPOSED TO AGGRESSIVE CONDITIONS NEED ADDITIONAL PROTECTION**
- **CATHODIC PROTECTION IS A PROVEN TECHNIQUE AND IS SUITABLE FOR PROTECTING STRUCTURES EXPOSED TO AGGRESSIVE CONDITIONS**

CONCLUDING REMARKS

- **CANDIDATE STRUCTURES FOR CP ARE**
  - **FOUNDATIONS OF CRITICAL STRUCTURES**
  - **MARINE STRUCTURES (SEAPORT BERTHS, JETTIES)**
  - **BRIDGE FOUNDATIONS AND DECKS**
  - **SEAWATER INTAKE & DISCHARGE STRUCTURES**
  - **WATER TANKS**
  - **CONCRETE PIPELINE**

CONCLUDING REMARKS

- **CASE STUDY DEMONSTRATED ADEQUATE PERFORMANCE OF ICCP SYSTEM FOR 20 YRS.**
- **OPERATING CURRENT DENSITY AFTER 20 YEARS IS 2.7 mA/m2 ONLY**
- **REBARS INSPECTED AND FOUND IN GOOD CONDITION**
- **CHLORIDE CONTENT IN CONCRETE AROUND REBAR WAS LOW DUE TO CP CURRENT**