CATHODIC PROTECTION FOR THE SOUTH POWER PLANT REINFORCING STEEL, DIEGO GARCIA, BIOT

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DIEGO GARCIA

BACKGROUND

- **SOUTH POWER PLANT FOR THE NAVY SUPPORT FACILITY, DIEGO GARCIA WAS BUILT IN TWO PHASES.**
  - **PHASE 1, BUILT IN 1975 BY US NAVY SEABEES.**
  - **PHASE 2, BUILT IN 1977 BY CONTRACT LABOR, EXTENDED THE FACILITY TO THE SOUTH**
- **PHASE 1 WALL CONSTRUCTION IS REINFORCED CONCRETE FRAME WITH CMU INFILL; ROOF FRAMING IS REINFORCED CONCRETE SLAB ON STEEL TRUSSES AT 12-FT SPACING.**
- **PHASE 2 CONSTRUCTION SIMILAR EXCEPT FOR USE OF STEEL FORM DECK AT THE ROOF.**

BACKGROUND (cont.)

- **FACILITY WAS NOT CURRENTLY IN REGULAR USE, BEING USED AS A BACK-UP TO THE NORTH POWER PLANT. RECENT MISSION REQUIREMENTS REQUIRED ITS REACTIVATION AS A REGULAR USE POWER PLANT.**

Figure 1.
South Power Plant, view from southwest. First six bays are Ph. II construction

BACKGROUND (cont.)

- **AFTER REACTIVATION AND SEVERAL WEEKS OF OPERATION OF THE POWER PLANT, SPALLING CONCRETE AND CORROSION OF THE REBAR WAS NOTED THROUGH OUT THE PHASE 1 STRUCTURAL MEMBERS INCLUDING:**

  - **Moderate to severe concrete spalling and rebar corrosion at west spandrel beam. Worst locations appeared to coincide with areas of poor roof drainage.**

BACKGROUND (cont.)

- **Isolated spalling of the roof slab.**
- **Delaminated concrete (longitudinal splitting parallel with primary reinforcing bar) at base of several columns.**
- **Spalled concrete at two concrete truss supports.**
- **Generally poor condition of roof membrane, particularly along west eave and under generator exhausts. Membrane along west eave did not drip properly over the gutter and allowed water migration back underneath roofing**

BACKGROUND *(cont.)*

Corrosion of rebar and spalled concrete in the west side beam

Corrosion of rebar and spalled concrete in the west side eaves

PRELIMINARY STRUCTURAL INVESTIGATION CONCLUSIONS

- Concrete spalling/delamination are results of rebar corrosion, likely due to high chloride concentration in concrete. High chloride concentration likely due to use of unwashed coral aggregate or contaminated mix water during phase 1 construction, and to lesser extent, ingress of airborne salts from marine environment.
- Roof leakage/poor drainage along west eave maintains moisture conditions conducive to corrosion - and acted as catalyst for chloride attack in roof eave/spandrel. Rebar corrosion proceeded at accelerated rate in this high moisture zone (corrosion rate increases with moisture, temperature, and humidity).

PRELIMINARY STRUCTURAL INVESTIGATION CONCLUSIONS

- **Deterioration at west spandrel beam can continue without significant degradation of roof structure's load capacity. However, there were aesthetic as well as a safety concerns about cracked and spalling concrete.**
- **Integrity of roof structure not yet significantly degraded by current stage of deterioration at concrete columns/supports along the west wall. However, continued deterioration would significantly degrade integrity, seriously jeopardizing support of roof trusses and creating an unsafe building.**

PRELIMINARY STRUCTURAL INVESTIGATION CONCLUSIONS

- **Current form of corrosion irreversible and accelerates with time if current conditions are maintained.**
- **Conventional repair methods (removal of spalled concrete and repair with cementitious patching materials) ineffective in abating chloride attack of rebar. Patching leads to electrochemical macro-cells near interface of chloride contaminated concrete and new chloride-free concrete, creating strong potential gradients and accelerated corrosion. Patched areas may deteriorate in as little as two years.**

PRELIMINARY STRUCTURAL RECOMMENDATIONS

- **Replace roof membrane.** ***Ensure positive drainage from membrane to drip edge.***
- **Repair damaged concrete structural members.**
- **Recommend site analysis to determine feasibility of installing cathodic protection system to extend facility life for 10 years or more. If no remedial action taken, structure probably has 6 to 8 yrs remaining life.**

SITE CORROSION SURVEY

- **Based on structural recommendations, Navy contracted CORRPRO Companies, Inc. to conduct condition survey to determine extent to which corrosion affected rebar and if cathodic protection is feasible to mitigate corrosion.**
- **Field study included:**
  - **Visual Examination**
  - **Electrical Continuity Testing for the Reinforcing Steel (Rebar)**
  - **Half-Cell (Corrosion) Potential Survey**
  - **Concrete Cover Measurements over Rebar**
  - **Chloride Ion Concentration Analysis**

CORROSION SURVEY FINDINGS AND CONCLUSIONS

- **Corrosion of rebar in roof slab wide spread. If present conditions remain, further concrete damage expected in several years due to rebar corrosion.**
- **Severe corrosion activity found in west side beams due to high chloride concentrations and heat from exhaust system.**
- **Severe corrosion observed in upper portion of columns on west side of building.**
- **New building section. No corrosion related distresses observed, consistent with chloride analysis results.**

CORROSION SURVEY FINDINGS AND CONCLUSIONS

- **Majority of rebar in beam located on west side of building not electrically continuous due to heavy corrosion. However, rebar in west and east sides of roof slab are continuous.**
- **Corrosion potentials in areas of visual concrete damage by corrosion indicated low negative potentials (uncertain probability of corrosion). Coral aggregates used for old building section influence potentials though the steel is corroding.**

CORROSION SURVEY FINDINGS AND CONCLUSIONS

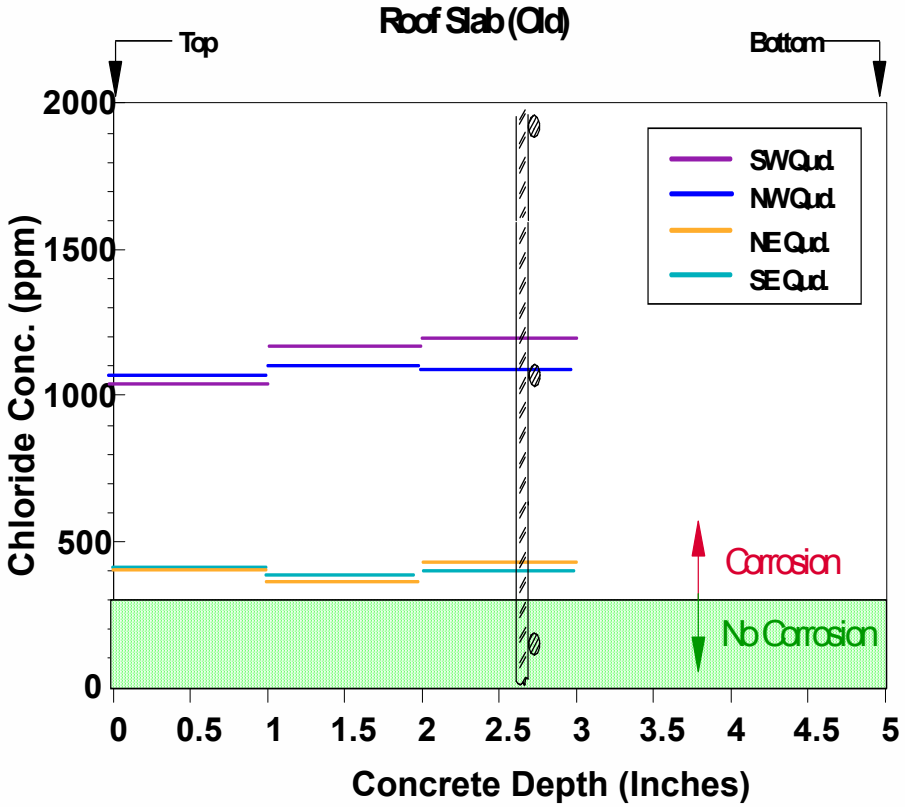
- **CONCRETE COVER OVER THE REBAR IN VARIOUS LOCATIONS.**

Structure Member	Average (inches)	Standard Deviation.	Maximum (inches)	Minimum (inches)
A. Roof Slab -Soffit	2.20	0.45	3.00	0.80
B. Beams - outside	2.09	0.36	2.55	1.45
C. Columns (old)	1.92	0.68	3.80	0.85
D. Columns (new)	1.73	0.31	2.10	1.05

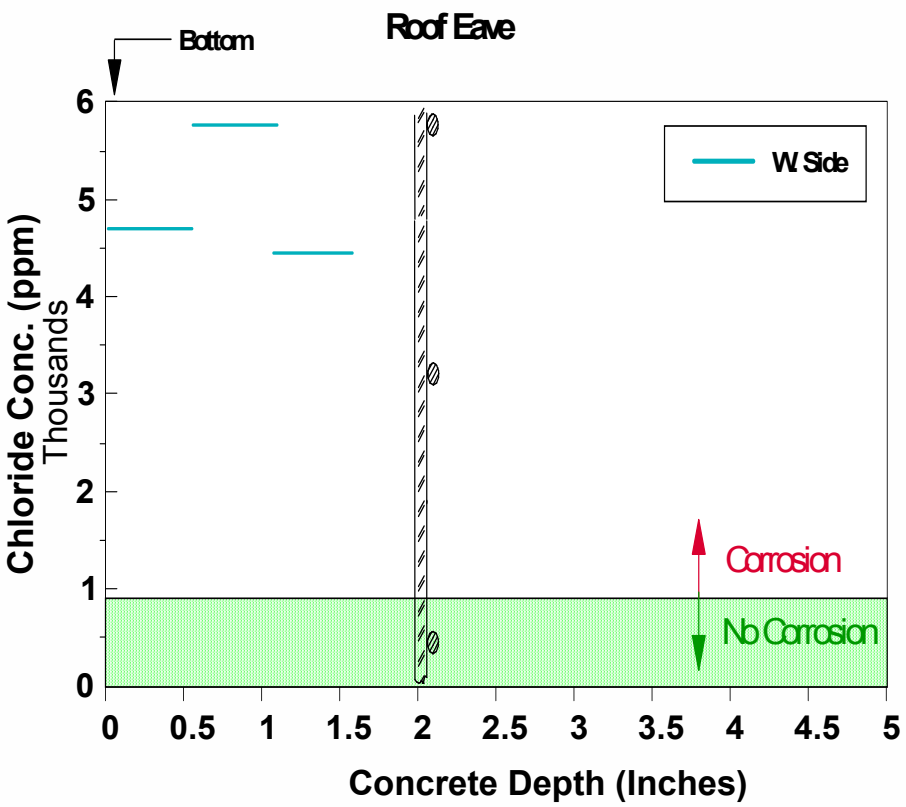
CORROSION SURVEY FINDINGS AND CONCLUSIONS

- **The salt, likely from coral aggregate mixed into the concrete, is responsible for corrosion of the reinforcing steel.**
- **Salt penetration from surrounding marine environment appears to be minimal.**
- **High corrosion activity observed in west side of building due to higher chloride concentrations and heat from exhaust system.**
- **Some amounts of chlorides are detected in other areas.**

CORROSION SURVEY FINDINGS AND CONCLUSIONS

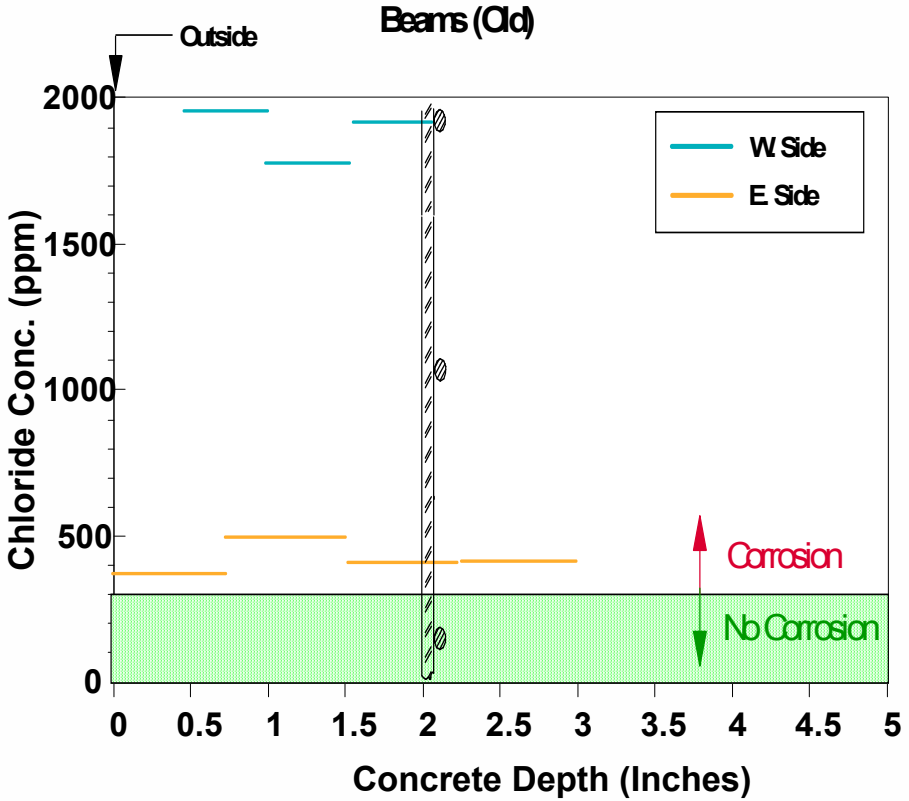


Chloride Concentration Profiles for the Roof Slab (Old Section)

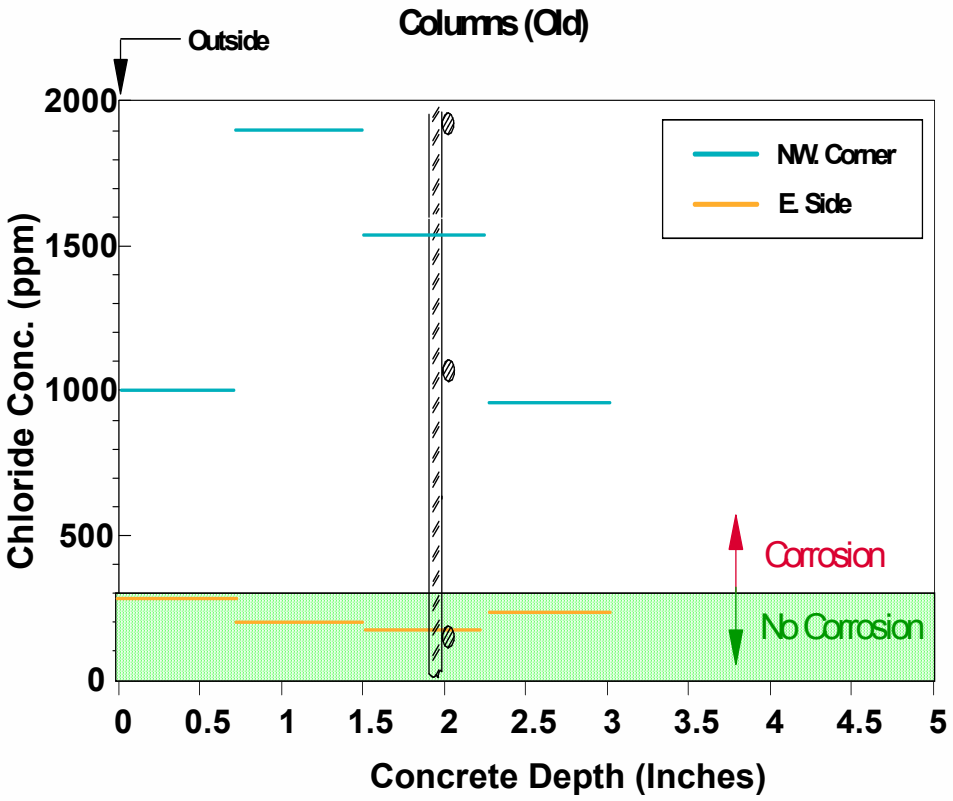


Chloride Concentration Profiles for the West Side of Roof Eave

CORROSION SURVEY FINDINGS AND CONCLUSIONS



Chloride Concentration Profiles for the Beams (Old Section)



Chloride Concentration Profiles for the New Building Section

CORROSION SURVEY RECOMMENDATIONS

- **PROVIDE CP SYSTEMS FOR ROOF, BEAMS AND COLUMNS FOLLOWING PRIORITY LISTED BELOW. DUE TO REBAR CORROSION, JUST PARTIALLY REPAIRING CONCRETE WILL NOT PREVENT FUTURE CONCRETE DAMAGE.**
  - **REPAIR/REPLACE BEAM IN WEST SIDE OF BUILDING WITH NEW REBAR. IF ENTIRE BEAM NOT REPLACED, INCLUDE CP FOR REPAIRED BEAM. ESTIMATED CP COST: $8 K. EXPECTED ANODE SYSTEM LIFE: 40 YEARS**
  - **PROVIDE TITANIUM RIBBON MESH SLOTTED CP SYSTEM ON ROOF SLAB. REPAIR ANY DAMAGED CONCRETE BEFORE SAW CUTTING INTO SLAB. ESTIMATED CP COST: $125 K. EXPECTED ANODE SYSTEM LIFE: 40 YEARS**

CORROSION SURVEY RECOMMENDATIONS

- PROVIDE DISCRETE ANODE CP SYSTEM FOR BEAMS AT NORTH, EAST AND SOUTH SIDES. ESTIMATED CP COST: $32 K. EXPECTED ANODE SYSTEM LIFE: 30 YEARS MINIMUM
- PROVIDE DISCRETE ANODE CP SYSTEM FOR COLUMNS. ESTIMATED CP COST: $5 K. EXPECTED ANODE SYSTEM LIFE: 30 YEARS MINIMUM.
- NEW BUILDING SECTION. NO CORROSION CONTROL IS REQUIRED AT PRESENT.

- **ABOVE COST INFORMATION IS FOR THE CP INSTALLATION ONLY. STRUCTURAL REPAIR COSTS NOT INCLUDED.**

CP SYSTEM INSTALLATION AND COMMISSIONING

- **CONCRETE REPAIRS/ INSTALLATION OF CP SYSTEM COMPLETED APRIL 2005 BY ON-ISLAND BOS CONTRACTOR. CP MATERIALS, SUPERVISION AND SYSTEM COMMISSIONING SERVICES PROVIDED BY CORRPRO COMPANIES, INC.**

- **RIBBON MESH ANODE ORIGINALLY RECOMMENDED FOR WEST SIDE BEAM, TO BE INSTALLED CONCURRENTLY WITH STRUCTURAL REPAIRS. HOWEVER, DUE TO BAD CONDITION OF BEAM AND CRITICAL OPERATIONAL REQUIREMENTS, BEAM REQUIRED REPAIR BEFORE CP MATERIALS COULD BE PROVIDED ON-ISLAND. DISCRETE ANODE SYSTEMS PROVIDED INSTEAD.**

CP SYSTEM INSTALLATION AND COMMISSIONING

Discrete anode system being installed in the west beam

CP SYSTEM INSTALLATION AND COMMISSIONING

- **SYSTEM INSTALLED IAW THE DESIGN DRAWINGS AND THE SPECIFICATIONS.**
- **CONSISTS OF 7 CP ZONES. EACH ZONE POWERED BY SEPARATE CIRCUIT OF THE TRANSFORMER-RECTIFIER.**

CIRCUIT NO.	Rectifier Rating	ZONE	STRUC. COMPONENT	TYPE OF CP SYSTEM
1	12V/8A	1	Roof slab	Titanium ribbon mesh anodes in slots
2	12V/8A	2	Roof slab	Titanium ribbon mesh anodes in slots
3	12V/8A	3	Roof slab	Titanium ribbon mesh anodes in slots
4	12V/8A	4	Roof slab	Titanium ribbon mesh anodes in slots
5	12V/8A	5	Columns	Discrete anodes
6	12V/4A	6	Beams (E. N, S)	Discrete anodes
7	12V/4A	7	Beam (W)	Discrete anodes

CP SYSTEM INSTALLATION AND COMMISSIONING

Multi-circuit transformer rectifier unit

CP SYSTEM INSTALLATION AND COMMISSIONING

- **CP SYSTEM WAS COMMISSIONED IN APRIL 2005. TESTING PROCEDURES INCLUDED:**
  - **TESTING OF REBAR STATIC POTENTIALS USING EMBEDDED REFERENCE ELECTRODES.**
  - **STEP-BY-STEP INCREASE OF CURRENT UNTIL ALL REFERENCE ELECTRODES INDICATED AT LEAST 100 MV POLARIZATION DEVELOPMENT FROM THE STATIC POTENTIALS.**
  - **SYSTEM ENERGIZED AT SELECTED CURRENT, AND AFTER 24 HOURS OF CONTINUOUS OPERATION, DEPOLARIZATION TESTS CONFORMING TO NACE INTERNATIONAL CRITERION USED TO EVALUATE PERFORMANCE OF CP SYSTEM.**

CP SYSTEM INSTALLATION AND COMMISSIONING

			24 Hour Depolarization, mV			
Zone ID	Structure Component	Current (Amps)	RE 1	RE 2	RE 3	RE 4
1	Roof slab	2.0	253	284	168	-
2	Roof slab	2.0	229	230	256	-
3	Roof slab	2.5	108	28*	-	-
4	Roof slab	1.0	232	267	-	-
5	Columns	1.5	58	231	157	103
6	Beams (E, S, N)	0.4	191	116	103	-
7	Beam (W)	0.09	1181	-	-	-

Note: * Indicates electrically discontinuous rebar.

SUMMARY AND CONCLUSIONS

1. **INITIAL PERFORMANCE OF EACH SYSTEM EVALUATED BY DEPOLARIZATION TESTING IS AS FOLLOWS:**
   - **A. CP system providing sufficient corrosion protection to rebar in roof slab.**
   - **B. CP system providing adequate corrosion protection to rebar in the columns.**
   - **C. CP system providing sufficient corrosion protection to rebar in the beams along north, south and eastern sides of the bldg.**
   - **D. The cp system is providing sufficient corrosion protection to rebar in the beams along western side of the bldg. The 90 mA operating current is lower requirement than expected.**
2. **NEED TO MONITOR AND MAINTAIN THE CP SYSTEM BASED ON THE O&M MANUAL PROVIDED.**

BACKUP SLIDES

PRESENTER CONTACT INFO

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