# REPAIR OF THE COMMERCIAL DECK OF QUETZAL MARINE TERMINAL

## INSPECTION, DIAGNOSIS, MATERIALS, AND PROCESSING METHODS

Quetzal Marine Terminal, located in Puerto Quetzal on the pacific coast of Guatemala (13° 55" N, 90° 47" W), was built from 1980 to 1984 to satisfy the urgent need of a modern port for import/export activities at the Pacific Ocean route. The terminal is managed by a state-owned company and is considered one of the main ports in Guatemala due to the large import-export volumes. The whole complex has 2063.7 acres (835.15 ha) divided into 10 zones involving general port activities, cargo storage, commercial and industrial development areas, administration buildings, and other services. Its strategic geographic localization allows it to serve the Pacific Basin and the West Coast of North America, and because of its nearness to the Panama channel, it can be accessed from any place around the world.

*Fig. 1: Aerial view of Puerto Quetzal*

*Fig. 2: Damage on the concrete sheet piling crowning beam*

At the eastern part of the terminal lies the principal dock destined for general national and international commerce (Fig. 1). Its principal structural element is a steel sheet piling crowned by a reinforced concrete beam. The concrete beam is a continuous structure that is 3445 ft (1050 m) long, 14.76 ft (4.5 m) high, and 3.3 ft (1 m) wide.

### OBSERVED PROBLEMS

Due to its exposure to seawater and ship collisions, the bridge has been subject to chemical and physical stress, which has resulted in visible deterioration of the structure.

Maintenance records indicate that in 2007, the front part of the pier was repaired; but according to the port's staff, the repair works were incomplete, leaving several areas with exposed steel reinforcing bar (Fig. 2). Apparently, repair works limited the substitution of steel parts in the concrete structure but neglected to restore the damaged or demolished concrete. The exposed steel structure was considerably deteriorated due to corrosion.

### REPAIR OBJECTIVES

Within the realization of this project, the corrosion mitigation alternatives included:

- Mechanical strength tests;
- Concrete core sample tests;
- Free corrosion potential measurements; and
- Evaluation of hidden corrosion zones by acoustic test.

### CONDITION EVALUATION

To properly diagnose the concrete structure's integrity, it was necessary to gather existing information about the site—such as construction plans, technical drawings, and historical information about the site operation, such as maintenance and repair reports—and previous integrity studies of the last 12 months. Once all necessary information was obtained for starting the diagnostic studies on the concrete structure, a series of tests were performed to assess the extent of the damage on the concrete and the steel reinforcing bar.

## CORROSION PROTECTION AND REPAIR OPTIONS

Corrosion of steel reinforcing bars in concrete structures is one of the most significant maintenance and repair challenges faced by civil engineers. Chloride ion contamination, carbonation, alkali-silica reaction, and reaction with sulfate species are the most common forms of concrete deterioration that can increase corrosion risk on reinforcing steel bars inside concrete structures. Using epoxy-coated steel reinforcing bar and special concrete mixture compositions can significantly reduce corrosion risks. But when the structures are already built, a common way of protecting the steel reinforcing bar is the installation of cathodic protection systems.[1]

Concrete structures in oceanic ports and piers are especially prone to corrosion. They are exposed to a series of physical and chemical processes that can cause the rapid deterioration of both concrete and steel reinforcing bar. Such structures must therefore receive special attention by performing periodic assessments of their structural integrity and by installing cathodic protection systems.

Concerned about visible deterioration of a reinforced concrete structure that crowned the sheet piling of the commercial pier of Puerto Quetzal, the company responsible for the operation and maintenance of the commercial port asked for engineering services for repairing and protecting the damaged concrete structure.

Following standards from ASTM International,[2,3] NACE International (National Association of Corrosion Engineers), and ICRI,[4-6] diagnostic and repair procedures were implemented on the damaged concrete structure. In addition, corrosion protection systems were designed and installed to avoid further deterioration of the reinforcing metal bars of the reinforced concrete in question.

## EVALUATION METHODS AND RESULTS

### MECHANICAL STRENGTH TESTS

The mechanical strength of the studied concrete was evaluated using procedures described in ASTM C805. Physical impacts were made on the concrete structure using a sclerometer (Fig. 3). Results showed that the strength of the concrete was acceptable because 97% of the readings showed impact resistance values higher than 4267 psi (3 kg/mm$^2$), while only 3% of the readings had unacceptable values (Table 1).

### CONCRETE CORE SAMPLE TEST

Cylindrical concrete core samples were taken from the concrete beam of the pier using a pedestal drill machine (Fig. 4). The core samples served as specimens for the study of pH, carbonation, and penetration of chloride species. The samples had between 2 to 3 in. (50 to 75 mm) in diameter and different depths, and were taken from severely damaged sections and from areas where concrete appeared in good condition. To retrieve the concrete cores as near as possible to the internal steel reinforcing bar, a metal detector was used. The specimen cutting, preparation, and analysis were performed according to ASTM C42.

TABLE 1: RESULTS OF THE SCLEROMETER TEST AT THE CONCRETE SURFACE

| | |
|---|---|
| 2134 to 4266 psi (1.5 to 2.9 kg/mm$^2$) | 3% |
| 4267 to 5689 psi (3 to 4 kg/mm$^2$) | 14% |
| Greater than 5689 psi (4 kg/mm$^2$) | 83% |

*Fig. 3: Strength tests*

*Fig. 4: Concrete core removal*

The chemical analysis of the concrete samples indicated that there was no significant amount of carbonate species, but the chloride content was above the recommended limit of 0.025% by weight in almost all of the core samples (Table 2). This indicated that active corrosion of the metal reinforcing bar was most likely present.

## FREE CORROSION POTENTIAL MEASUREMENTS

Free corrosion potential ($E_{corr}$) values of reinforced concrete are related to the probability of corrosion of its steel reinforcing bars. The $E_{corr}$ measurements were carried out using a standard copper/copper sulfate ($Cu/CuSO_4$) reference electrode connected to a high impedance input multimeter according to ASTM C876 (Fig. 5). Table 3 presents the percent of the tested concrete surface with low, moderate, and high probabilities of corrosion. The results show that less than the half of the testing points presented potentials above the low corrosion risk limit.

*Fig. 5: Concrete core removal*

TABLE 2: CHEMICAL ANALYSIS RESULTS ON CHLORIDE CONCENTRATION OF CONCRETE SAMPLES

| Depth of concrete samples, in. (mm) | Samples with chloride concentration above 0.025% by weight, % |
|---|---|
| 0 to 0.5 (0 to 12.7) | 100 |
| 2.5 to 3.5 (63.5 to 90) | 94 |

TABLE 3: PERCENT OF CONCRETE SURFACE WITH LOW, MODERATE, AND HIGH PROBABILITY OF CORROSION

| Corrosion probability according to ASTM C876 | Area, % |
|---|---|
| Low probability of corrosion ($E_{corr} > -200$ mV versus $Cu/CuSO_4$) | 40 |
| Moderate probability of corrosion ($-200$ mV $< E_{corr} < -350$ mV versus $Cu/CuSO_4$) | 35 |
| High probability of corrosion ($E_{corr} < -350$ mV versus $Cu/CuSO_4$) | 25 |

TABLE 4: DEGREE OF INTERNAL CORROSION ON THE INSPECTED CONCRETE SURFACE

| Degree of deterioration by corrosion | Inspected surface area, % |
|---|---|
| Severely damaged zones (urgent attention) | 20 |
| Moderately damaged zones (short-term maintenance) | 73 |
| Minimal corrosion problem zones (long-term maintenance) | 7 |

## EVALUATION OF HIDDEN CORROSION ZONES BY ACOUSTIC TESTS

Steel reinforcing bar corrosion in reinforced concrete is sometimes not visible from the surface of the concrete. When carbonate or chloride species and water penetrate the structure and reach the metal reinforcing bar, corrosion processes take place without any visible manifestation on the surface of the structure. Acoustic tests can be used to detect hidden metal corrosion zones. Acoustic tests were performed according to ASTM D4580 (Fig. 5). Combined with $E_{corr}$ and resistivity measurements, hidden corrosion zones were identified (Table 4).

## REHABILITATION STRATEGIES

To avoid further deterioration by corrosion of the concrete crowning beam of the port sheet piling, the following actions were applied:

- Replacement of fragile or contaminated concrete;
- Cleaning and rehabilitation of damaged or contaminated reinforcing steel (Fig. 6);
- Installation of zinc sacrificial anodes; and
- Application of a protective coating on the concrete surface.

Photographic evidence and amounts of replaced concrete, rehabilitated steel reinforcing bar, and installed zinc anodes are presented in Fig. 7 and Table 5.

After the cathodic protection system was installed, several monitoring devices were placed so polarized potentials and current output could be measured. A fixed referenced electrode was placed near every monitoring device. In all cases, over 100 mV in polarization were achieved over 75 hours of decay.

## SUMMARY

The concrete crowning of the commercial dock sheet piling in Quetzal Marine Terminal, Guatemala, had visible signs of deterioration, including the corrosion of exposed steel reinforcing bars. A team of engineers performed historical background research; executed a complete diagnosis of the integrity of the structure, including chemical analysis and the localization of corroded internal steel reinforcing bar; and carried out rehabilitation activities. In addition to concrete and steel

*Fig. 6: Removing and cleaning concrete*

*Fig. 7: Installation of zinc anodes*

reinforcing bar repair, a cathodic protection system was installed using zinc sacrificial anodes and a protective coating was applied on the reinforced concrete structure. With the applied measures (Fig. 8), further corrosion of the reinforcing bars will be stopped, and the useful life of the repaired concrete structure will be considerably extended.

## SPECIAL PROJECT FEATURES

1. By itself, this is the main infrastructure in Guatemala.
2. All the refurbishing was accomplished without affecting the ports operations.
3. A significant investment was made to extend the service life of the structure.

### TABLE 5: AMOUNTS OF REPLACED CONCRETE, REHABILITATED STEEL, REINFORCING BAR, AND INSTALLED ZINC ANODES

| Rehabilitation activity | Quantity | |
|---|---|---|
| | Top face | Front face |
| Replacement of damaged or contaminated concrete | 11,302 ft$^2$ (1050 m$^2$) | 50,859 ft$^2$ (4725 m$^2$) |
| Cleaning and rehabilitation of damaged or contaminated reinforcing steel | 3968 lb (1800 kg) | 4630 lb (2100 kg) |
| Installation of zinc sacrificial anodes | 4116 anodes | 13,967 anodes |
| Application of a polymer coating to protect the entire surface of the concrete beam | 62,162 ft$^2$ (5775 m$^2$) | |

4. The monitoring of current and potentials is possible in different points of the structure.
5. Potential shifts were measured and compared before and after the installation of the cathodic protection system.
6. Polarization curves were registered showing over 100 mV in polarization (Fig. 9).

*Fig. 8: Monitoring system in place*

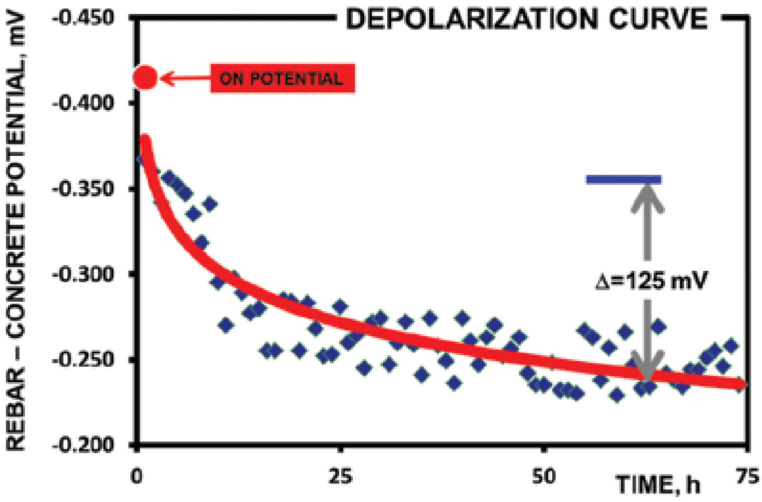

*Fig. 9: Depolarization curve*

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## REFERENCES

1. Whitmore, D.W., and Ball, J.C., “Galvanic Corrosion Protection Systems for Concrete Bridge Structures,” Vector Corrosion Technologies.

2. Andrade, C.; Castelo, V.; Alonso, M.C.; and Gonzalez, J.A., “The Determination of the Corrosion Rate in Steel Embedded in Concrete by the Polarization Resistance and A. C. Impedance,” ASTM STP 906, V. Chaker, ed., ASTM International, West Conshohocken, PA, 1986.

3. Hannson, M., and Sorensen, B., “The Threshold Concentration of Chlorides in Concrete for the Initiation of Reinforcement Corrosion,” ASTM STP 1065, N.S. Berke, V. Chaker, and D. Whiting, eds., ASTM International, West Conshohocken, PA, 1990, 3 pp.

4. Manual de Inspección, Evaluación y Diagnóstico de Corrosión en Estructuras de Hormigón Armado, Red DURAR (Durabilidad de la armadura), CYTED, 1997.

5. Millard, S.G.; Harrison, J.A.; and Eduards, A.J., “Measurement of the Electrical Resistivity of Reinforced Concrete Structures for the Assessment of Corrosion Risk,” *British Journal of Non-Destructive Testing*, V. 31, 1989, 616 pp.

6. Vico, A.; Morris, W.; and Vazquez, M., “Evaluación del Avance de la Corrosión de Refuerzos en Estructuras de Hormigón” División Corrosión, INTEMA Facultad de Ingeniería, Universidad Nacional de Mar del Plata, Argentina.

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