

Rehabilitation Alternatives for Structures Used on the Flocculation, Sedimentation and Filtration Processes at the Ponce De Leon Water Treatment Plant in Mayagüez, Puerto Rico

Orlando Vargas Del Valle

Master of Engineering in Civil Engineering

Héctor J. Cruzado, PhD, PE

Department of Civil & Environmental Engineering and Land Surveying

Polytechnic University of Puerto Rico

Abstract – *The Ponce de Leon Water Treatment Plant located in Mayagüez serves 3,777 clients with a population of 10,085 habitants. It could produce 6 million gallons per day. A visual structural evaluation of the concrete structures and metallic elements on the flocculation, sedimentation, and filtration units was done to assess actual conditions and present rehabilitation alternatives. This article presents the findings and the analysis used to weigh rehabilitation alternatives. Damages found on concrete structures were cracking and spalling. Meanwhile, on metallic elements, general corrosion, and material thickness loss were found. The investigation concluded that the best economical alternative to repair concrete cracks is routing and sealing. For spalled concrete, the recommended alternative is the partial concrete section repair. Finally, the project concluded that the best alternative to treat corrosion on metallic elements at the WTP is the use of protective coatings.*

Key Terms – *Concrete Repair, Corrosion Inhibitor, Epoxy Grouting, Polyurethane Coating.*

INTRODUCTION

The Puerto Rico Aqueduct and Sewer Authority (PRASA) owns and operates the facilities of the Ponce de Leon Water Treatment Plant (WTP) located at Ernesto Ramos Antonini Street at the Ponce de Leon Residential Area (Urbanization) at Mayagüez Arriba Ward in Mayagüez, Puerto Rico, which is part of PRASA's West Region. This water treatment plant was originally constructed in 1927 and was designed as a conventional water treatment plant for 3 million gallons per day (MGD). In 2005, the WTP was expanded with an

addition of a metal package plant (Actiflo®) of 3 MGD to produce a maximum of 6 MGD with a Solid Treatment System (STS). The WTP can only produce a maximum flow of 4 MGD due to the actual process configuration. Since that date, no major improvements or expansions have been made to the plant. Figure 1 shows the Ponce de Leon WTP site and its components.



Figure 1

Ponce de Leon WTP Site and its Components

Only maintenance repairs required by the normal wear and tear of equipment and facilities had been done. After Hurricane Maria (2017), the Ponce de Leon WTP was severely damaged and PRASA requested funds from the Federal Emergency Management Agency (FEMA) to make a complete rehabilitation of the WTP. It was in the interest of PRASA to evaluate the existing conditions of the structures and process units of the Ponce de Leon WTP after Hurricane Maria.

The intent of this project was to present a structural evaluation and rehabilitation analysis for the concrete structures and metallic elements on three of the water treating processes in the Ponce de Leon WTP. The structural elements and facilities used on the flocculation, sedimentation, and

filtration processes of the old plant were assessed and recommendations for their rehabilitation presented. The emphasis was on two main categories: concrete structures rehabilitation (including surface restoration) and corrosion treatment methods for the metallic elements. An analysis of the different rehabilitation alternatives for each of these categories in terms of durability, performance, cost, advantages, and disadvantages were included as part of the project. Also, a conceptual cost estimate for each rehabilitation alternative was developed. Finally, a selection criteria matrix with a weighted scoring system was used to select the best alternative for each category. The structural assessment of elements outside the flocculation, sedimentation and filtration processes of the old plant were beyond the scope of this project.

LITERATURE REVIEW

Description Of Evaluated Structures

Old Plant Flocculation Area

The flocculation channel is a deep rectangular open channel made of reinforced concrete covered with a serrated galvanized steel grating at the top. It is part of a monolithically compartmentalized reinforced concrete structure that shares a common wall with the sedimentation tanks. Elevated six inches concrete slabs are used on different locations to connect channel walls and as a work platform to operate manual valves. Figure 2 shows the actual condition of the flocculator channel and the steel grating. Channel has dimensions of 110 feet long x 5 feet width x 12.3 feet depth. The structures inspected were floor slabs, top of concrete walls, steel structures, pipe supports, and mechanical components.



Figure 2

Flocculation Channel and Steel Grating

Old Plant Sedimentation Area

The old plant sedimentation area consists of two basins of dimensions of 110 feet long x 26 feet width x 12.7 feet deep. Each basin has three reinforced concrete tanks that are connected to the flocculation channel. The perimeter walls of the southeast and southwest sides of the tanks are gravity walls constructed in 1928. The interior main structural system consists of reinforced concrete beams and columns that are submerged and sustain the walkways or bridges over the tanks. Figure 3 presents the sedimentation tanks of the Ponce de Leon WTP.



Figure 3

Old Plant Sedimentation Tanks

Old Plant Filters Area

The old plant filters area consists of five (5) rectangular concrete trains of dual media filter units with sand and anthracite. Each of the old filter units has dimensions of 18 feet long x 10 feet width with

180 square feet of filtration area. The process works by gravity. The filters backwash system uses air from two (2) old blower units and gravity water from the Backwash Tank inside the WTP facilities to wash the filter units. Figure 4 shows old plant filter #2.



Figure 4
Old Plant Filter #2

Cracks Repair Alternatives

Alternative CR-1: Concrete Injection Grouting

Concrete injection grouting is a procedure that includes filling the breaks and cracks to reestablish the first quality of the concrete structure [1]. Grout can be infused into concrete elements such as beam, column, etc. to anchor its components or to fortify and solidify its elements firmly filling empty units or open depressions. Figure 5 presents a picture of a typical crack repair utilizing concrete injection grouting. The polyurethane resin injection was evaluated for this project because it has the capacity to expand and solidify within the concrete crack cavity, thereby eliminating the crack and stopping water leakages [2]. Also, they cost less than epoxy grout.



Figure 5
Crack Repair with Concrete Injection Grouting

Alternative CR-2: Routing and Sealing

Routing and sealing involve enlarging the crack along its exposed face and pouring a sealant into it to seal it. Common sealants used include epoxies, silicones, urethanes, polymer mortars, polysulfides, or asphaltic materials. The routing and sealing method are highly effective for waterproofing by sealing cracks on the concrete surface where water stands, or where hydrostatic pressure is applied. Figure 6 shows a diagram of the routing and sealing method.

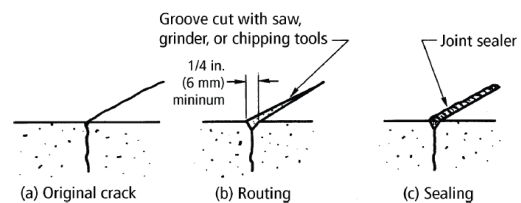


Figure 6
Crack Repair Using the Routing and Sealing Method

Concrete Spalling Repair Alternatives

Concrete spalling repair or concrete cancer repair refers to the process of fixing or restoring concrete that has experienced spalling or deterioration of the concrete surface due to excessive tensile strength on the hardened concrete [3]. This excessive tensile strength could be caused by the expansion pressures of corroded reinforcement when it increases in volume [4]. To repair concrete spalling, the damaged or deteriorated areas are typically removed, and the surface is prepared for restoration [5]. The repair process may involve cleaning the affected area, applying a bonding agent, and then patching or resurfacing with a suitable material.

Alternative CSR-1: Partial-Depth Repair (PDR)

Partial-Depth Repair (PDR) alternative encompasses the removal of small, unsound areas of concrete and their replacement with suitable repair materials. Partial depth repair is commonly used to repair low severity spalling, but it can also be used for small areas with scaling problems. It restores localized surface distresses, which do not extend beyond the upper one-third of the concrete

slab thickness. Figure 7 shows a partial depth repair ready to be patched with structural mortar.

Partial depth repairs could restore the structural integrity of concrete elements without the need for complete demolition. The exposure and the treatment of the affected reinforcement in the concrete matrix allow to extend the service life of the structure. Partial depth repairs are not suitable for severe spalls with exposed reinforcing steel and on areas where the distress is caused by a material problem. On those cases, a full depth repair is recommended.



Figure 7
Partial Depth Repair

Alternative CSR-2: Full-Depth Repair (FDR)

The Full-Depth Repair (FDR) entails removing and replacing at least a portion of a slab to the bottom of the concrete, to restore areas of deterioration. A full depth repair is an effective method to extend the service life of a floor slab that has distresses that are material related or distresses that extend beyond the upper half of the slab. It is used when concrete surface is completely deteriorated and embedded reinforcement is heavily corroded causing severe spalling.

Corrosion Treatment Alternatives

The following alternatives were evaluated for the rehabilitation of metallic elements affected by corrosion on the Ponce de Leon WTP:

Alternative CT-1: Epoxy/Polyurethane Coating

Epoxy and polyurethane coatings are used as an effective way to protect steel and metallic elements against corrosion. They are also used to rehabilitate and maintain facilities and equipment that are continuously exposed to weather, abrasive

environments and prone to chemical attack. Epoxy and polyurethane coatings are widely used in potable water systems due to their excellent adhesion properties and resistance to corrosion. They form a barrier that prevents water and chemicals from reaching the metal surface, thereby inhibiting corrosion.

Protective coatings have limited durability and may degrade over time, requiring periodic recoating or replacement to maintain effectiveness. This is the reason they require periodic inspection and maintenance.

For consideration, coatings must comply with the National Sanitation Foundation (NSF) and the American National Standards Institute (ANSI) 61 standard (NSF/ANSI 61). Alternative CT-1 considered the use of a corrosion treatment system that included an inorganic zinc-rich coating as primer and a high solids polyamide epoxy in combination with a high-performance acrylic polyurethane for intermediate and top coating respectively. The surface preparation assumed was Power Tool Cleaning to Bare Metal as defined by the Society of Protective Coatings (SSPC) on its Surface Preparation Standard SSPC-SP11.

Alternative CT-2: Cathodic Protection (CP)

Cathodic protection works by reducing the corrosion rate of a metal surface by making it the cathode of an electrochemical cell. This is achieved by either providing a sacrificial anode that corrodes instead of the protected metal (galvanic cathodic protection) or by applying an external electrical current to the metal surface (impressed current cathodic protection). Cathodic protection can be expensive to install and maintain.

Alternative CT-3: Material Change

The last alternative evaluated for corrosion treatment was the substitution of metallic elements (i.e. valves) with corrosion-resistant materials such as stainless steel, brass, and fibred-reinforced plastic (FRP). This Alternative CT-3 was evaluated only for severely corroded metallic elements that could not be rehabilitated and require replacement

after inspection. It was included as an alternative for those items that the WTP identified as critical for the operation and their change in material could be more cost-effective in the long term.

METHODOLOGY

The following methodology was used to evaluate the structural elements and facilities on the flocculation, sedimentation, and filtration processes of the old plant:

- Two site reconnaissance visits to visually appraise the structural damage on the concrete structures and metallic components of the above-mentioned areas of the facility were done on January 11, 2024, and February 06, 2024. Observations were documented in writing and with photographs using a digital camera. No destructive testing or sampling was done, only visual inspection.
- Meeting with PRASA plant operators to gather personal impressions on operational constraints and deficiencies.
- Collection and review of available technical information about the facility such as record as-built drawings, specifications, and other relevant data.
- Concrete surface cracks, concrete spalling, reinforcement corrosion and detachment were evaluated on concrete structures and elements.
- Corrosion, pitting, coating failure and delamination were assessed on structural steel, piping systems, and ancillary assemblies.
- The findings on each category for the flocculation, sedimentation and filtration processes were collected and analyzed to propose different rehabilitation alternatives.
- For each rehabilitation or treatment alternative, a conceptual cost estimate was developed, and an investigation performed to better assess their viability as a potential solution.
- The best rehabilitation alternative for each category was selected using a selection matrix with a weighted scoring system.

FINDINGS

Old Plant Flocculation Area

The structural deficiencies observed on the old plant flocculation area during the reconnaissance visit done on January 11, 2024, were:

- Concrete floor cracks and spalling were present on the elevated concrete slabs and wall edges of the flocculation channel. Figures 8 and 9 show those conditions on the flocculation channel.
- General corrosion due to coating delamination and contaminant accumulation on metallic elements such as: valves, appurtenances, pipes, and structural steel handrails.
- Valves and mechanical components, including supports, show pitting and general corrosion. Coating delamination and flaking were observed during inspection.

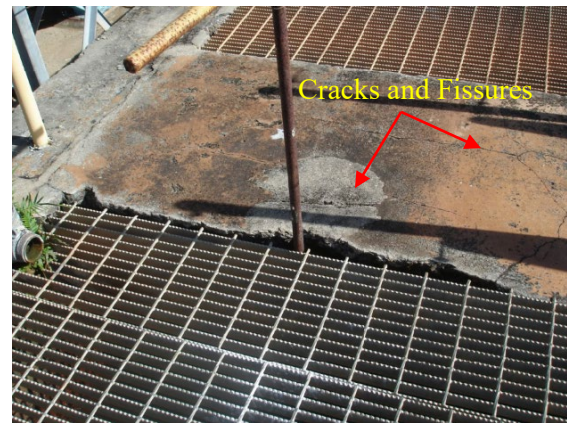


Figure 8
Concrete Cracks on Elevated Concrete Slab



Figure 9
Concrete Detachment on Channel Wall Edge

Old Plant Sedimentation Area

The deficiencies observed on the old plant sedimentation area during the reconnaissance visit were:

- Concrete walls on sedimentation basins show cracks and fissures. Concrete spalling and detachment were found on several areas. Evidence of tar used to seal cracks was observed. Figure 10 presents the condition of a sedimentation basin concrete wall on the Ponce de Leon WTP.
- General and crevice corrosion were observed on metallic elements such as: valves, appurtenances, pipes, structural steel handrails, bolts and pipeline supports due to coating failure and contaminant accumulation.
- Spot corrosion and pitting was observed on handrails base plates and bolts due to coating failure and delamination.
- Vertical ladder at sedimentation tank #3 showed evidence of general corrosion and complete material loss. Figure 11 shows the actual condition of vertical ladder at tank #3.

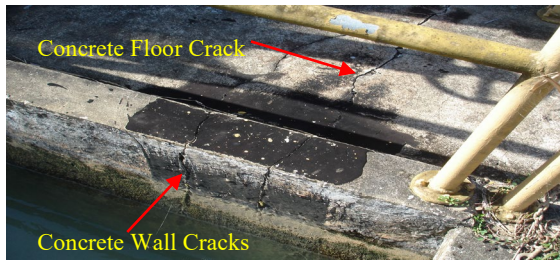


Figure 10

Concrete Floor and Wall Cracks on Sedimentation Basin

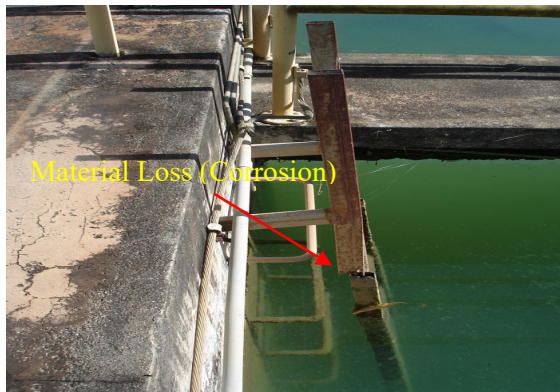


Figure 11

Material Loss Due to Corrosion on Tank #3 Vertical Ladder

Old Plant Filters Area

The structural deficiencies observed at the old plant filters area were:

- Concrete walls on old filters basins show cracks and fissures. Concrete spalling and detachment were found on several areas. Evidence of tar used to seal cracks was observed. Figure 12 presents the concrete surface condition of filter #4 on the Ponce de Leon WTP.
- Spot corrosion and pitting was observed on handrails due to coating delamination. Missing bolts were observed on handrails base plates.

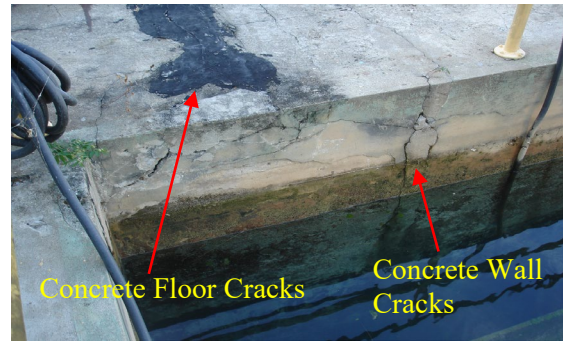


Figure 12

Old Filter Basin Concrete Wall Cracks

Cracks Repair Alternatives Cost Estimates

Table 1 shows a conceptual cost estimate of Alternative CR-1 using polyurethane injection grouting to repair concrete cracks observed on the flocculation, sedimentation, and filtration areas on the Ponce de Leon WTP.

Table 1
Alternative CR-1 - Cost Estimate

Item	Description	Unit	Quantity	Unit Price (\$)	Amount (\$)	
General Requirements						
1	Mobilization and Demobilization	LS	1	\$45,000.00	\$45,000.00	
2	Project Signs	LS	1	\$4,000.00	\$4,000.00	
4	Field Office	Mo.	2	\$4,790.00	\$9,580.00	
5	Contractor's Permits (PUI, POC, others)	LS	1	\$15,000.00	\$15,000.00	
6	As-Built Drawings	Mhrs	120	\$130.00	\$15,600.00	
7	CES Plan Implementation and Maintenance	Mo.	2	\$2,500.00	\$5,000.00	
8	Quality Control and Testing	Mo.	2	\$3,200.00	\$6,400.00	
<i>Sub - Total General Requirements</i> \$100,580.00						
Concrete Injection Grouting						
9	Surface Preparation & Cleaning	SF	600	\$2.00	\$1,200.00	
10	Ports Installation for Grout Injection	EA	3000	\$0.65	\$1,950.00	
11	Non Structural Cracks Repairs With Polyurethane Injections	LF	500	\$13.35	\$6,675.00	
12	Removal of Ports & Surface Finishes	SF	600	\$4.00	\$2,400.00	
<i>Sub - Total Concrete Injection Grouting</i> \$12,225.00						
					SUB-TOTAL	\$112,805.00
					35% INDIRECT COSTS AND CONTINGENCIES	\$39,481.75
					TOTAL	\$152,286.75

Table 2 shows a conceptual cost estimate of Alternative CR-2 using the routing and sealing method to repair concrete cracks with a polyurethane sealant.

Table 2
Alternative CR-2 - Cost Estimate

Item	Description	Unit	Quantity	Unit Price (\$)	Amount (\$)
General Requirements					
	Mobilization and Demobilization	LS	1	\$45,000.00	\$45,000.00
1	Project Signs	LS	1	\$4,000.00	\$4,000.00
2	Field Office	Mo.	2	\$4,790.00	\$9,580.00
4	Contractor's Permits (PUI, POC, others)	LS	1	\$15,000.00	\$15,000.00
5	As-Built Drawings	Mhrs	120	\$130.00	\$15,600.00
6	CES Plan Implementation and Maintenance	Mo.	2	\$2,500.00	\$5,000.00
7	Quality Control and Testing	Mo.	2	\$3,200.00	\$6,400.00
8	Sub - Total General Requirements				\$100,580.00
Routing and Sealing Method					
	Surface Preparation & Cleaning	SF	600	\$2.00	\$1,200.00
9	Sawcut V-shaped groove along crack with grinder.	LF	500	\$1.25	\$625.00
10	Clean of groove using air	LF	500	\$1.50	\$750.00
11	Non Structural Cracks Repairs With Polyurethane Sealant				
12	Surface Finishes	SF	600	\$2.00	\$1,200.00
13	Sub - Total Routing and Sealing Method				\$8,275.00
SUB-TOTAL					\$108,855.00
35% INDIRECT COSTS AND CONTINGENCIES					\$38,099.25
TOTAL					\$146,954.25

A conceptual cost estimate for Alternative CSR-1 using Partial-Depth Repair (PDH) is presented on Table 3.

Table 3
Alternative CSR-1 - Cost Estimate

Item	Description	Unit	Quantity	Unit Price (\$)	Amount (\$)
General Requirements					
	Mobilization and Demobilization	LS	1	\$45,000.00	\$45,000.00
1	Project Signs	LS	1	\$4,000.00	\$4,000.00
2	Field Office	Mo.	2	\$4,790.00	\$9,580.00
4	Contractor's Permits (PUI, POC, others)	LS	1	\$15,000.00	\$15,000.00
5	As-Built Drawings	Mhrs	120	\$130.00	\$15,600.00
6	CES Plan Implementation and Maintenance	Mo.	2	\$2,500.00	\$5,000.00
7	Quality Control and Testing	Mo.	2	\$3,200.00	\$6,400.00
8	Sub - Total General Requirements				\$100,580.00
Concrete Spalling Repair - Partial Depth Repair					
	Surface Preparation & Cleaning (Blasting)	SF	1400	\$5.00	\$7,000.00
9	Sounding Testing (ASTM D4580)	LS	1	\$7,000.00	\$7,000.00
10	Chipping of Damaged Concrete on Detached Concrete Areas	SF	800	\$20.00	\$16,000.00
11	Cleaning of Exposed Corroded Reinforcement Steel	SF	625	\$10.00	\$6,250.00
12	Corrosion Inhibitor Application	SF	750	\$12.00	\$9,000.00
13	Structural Repair Mortar	SF	835	\$15.00	\$12,525.00
14	Application Surface Finishing, Curing and Sealing	SF	835	\$10.00	\$8,350.00
15	Sub - Total Concrete Spalling Repair (PDR)				\$66,125.00
SUB-TOTAL					\$166,705.00
35% INDIRECT COSTS AND CONTINGENCIES					\$58,346.75
TOTAL					\$225,051.75

A conceptual cost estimate for Alternative CSR-2 using Full-Depth Repair (FDH) is presented on Table 4.

Table 4
Alternative CSR-2 - Cost Estimate

Item	Description	Unit	Quantity	Unit Price (\$)	Amount (\$)
General Requirements					
	Mobilization and Demobilization	LS	1	\$45,000.00	\$45,000.00
1	Project Signs	LS	1	\$4,000.00	\$4,000.00
2	Field Office	Mo.	2	\$4,790.00	\$9,580.00
4	Contractor's Permits (PUI, POC, others)	LS	1	\$15,000.00	\$15,000.00
5	As-Built Drawings	Mhrs	120	\$130.00	\$15,600.00
6	CES Plan Implementation and Maintenance	Mo.	2	\$2,500.00	\$5,000.00
7	Quality Control and Testing	Mo.	2	\$3,200.00	\$6,400.00
8	Sub - Total General Requirements				\$100,580.00
Concrete Spalling Repair - Full Depth Repair					
	Surface Preparation & Cleaning (Blasting)	SF	1400	\$5.00	\$7,000.00
9	Sounding Testing (ASTM D4580)	LS	1	\$7,000.00	\$7,000.00
10	Demolition of Full Depth Damaged Concrete on Detached Concrete Areas	SF	800	\$30.00	\$24,000.00
11	Cleaning of Exposed Corroded Reinforcement	SF	625	\$10.00	\$6,250.00
12	Corrosion Inhibitor	SF	700	\$12.00	\$8,400.00
13	Structural Repair Mortar	SF	825	\$35.00	\$28,875.00
14	Application Surface Finishing, Curing and Sealing	SF	825	\$10.00	\$8,250.00
15	Sub - Total Concrete Spalling Repair (FDR)				\$89,775.00
SUB-TOTAL					\$190,355.00
35% INDIRECT COSTS AND CONTINGENCIES					\$66,624.25
TOTAL					\$256,979.25

Corrosion Treatment Alternatives Cost Estimates

For the coating system evaluated for Alternative CT-1, a minimum total Dry Film Thickness (DFT) of 9.0 mils (0.229 mm) was specified. This minimum DFT was used as the basis for the development of the conceptual cost estimate for Alternative CT-1 shown on Table 5.

Table 5
Alternative CT-1 - Cost Estimate

Item	Description	Unit	Quantity	Unit Price (\$)	Amount (\$)
General Requirements					
	Mobilization and Demobilization	LS	1	\$45,000.00	\$45,000.00
1	Project Signs	LS	1	\$4,000.00	\$4,000.00
2	Field Office	Mo.	2	\$4,790.00	\$9,580.00
4	Contractor's Permits (PUI, POC, others)	LS	1	\$15,000.00	\$15,000.00
5	As-Built Drawings	Mhrs	120	\$130.00	\$15,600.00
6	CES Plan Implementation and Maintenance	Mo.	2	\$2,500.00	\$5,000.00
7	Quality Control and Testing	Mo.	2	\$5,200.00	\$10,400.00
8	Sub - Total General Requirements				\$104,580.00
Corrosion Treatment With Epoxy/Polyurethane Coatings					
	Pressure Wash of Surfaces (4,000 psi)	SF	5000	\$1.85	\$9,250.00
9	Surface Preparation & Cleaning as per SSPC-SP11	SF	5000	\$3.00	\$15,000.00
10	Application of Inorganic Zinc-Rich Coating (DFT = 3.0 mils)	SF	5000	\$4.25	\$21,250.00
11	Application of Polyamide Epoxy Mastic Coating (DFT = 4.0 mils)	SF	5000	\$4.65	\$23,250.00
12	Application of High-Performance Acrylic Polyurethane (DFT = 2.0 mils)	SF	5000	\$6.85	\$34,250.00
13	Sub - Total Corrosion Treatment With Epoxy/Polyurethane				\$103,000.00
SUB-TOTAL					\$207,580.00
35% INDIRECT COSTS AND CONTINGENCIES					\$72,653.00
TOTAL					\$280,233.00

Table 6 is a conceptual cost estimate of how much cost the implementation of Alternative CT-2.

Table 6
Alternative CT-2 - Cost Estimate

Item	Description	Unit	Quantity	Unit Price (\$)	Amount (\$)
General Requirements					
Mobilization and Demobilization					
1	Demobilization	LS	1	\$45,000.00	\$45,000.00
2	Project Signs	LS	1	\$4,000.00	\$4,000.00
4	Field Office	Mo.	2	\$4,790.00	\$9,580.00
Contractor's Permits (PUI, POC, others)					
5	POC, others	LS	1	\$15,000.00	\$15,000.00
6	As-Built Drawings	Mhrs	120	\$130.00	\$15,600.00
CES Plan Implementation and Maintenance					
7	Implementation and Maintenance	Mo.	2	\$2,500.00	\$5,000.00
Inspection During Construction					
8	Inspection During Construction	Mo.	2	\$5,200.00	\$10,400.00
Sub - Total General Requirements					\$104,580.00
Corrosion Treatment With Cathodic Protection					
Conducting site surveys and soil resistivity tests.					
9	Conducting site surveys and soil resistivity tests.	LS	1	\$5,000.00	\$5,000.00
Anodes (galvanic or impressed current).					
10	Anodes (galvanic or impressed current).	EA	70	\$250.00	\$17,500.00
Rectifiers (for impressed current CP)					
11	Rectifiers (for impressed current CP)	EA	70	\$275.00	\$19,250.00
Cables (include connectors and junction boxes).					
12	Cables (include connectors and junction boxes).	LF	1500	\$6.00	\$9,000.00
13	Reference electrodes.	EA	70	\$300.00	\$21,000.00
Excavation and trenching for anode placement.					
14	Excavation and trenching for anode placement.	LF	2000	\$12.00	\$24,000.00
Anode installation and backfilling.					
15	Anode installation and backfilling.	EA	70	\$300.00	\$21,000.00
Installation of rectifiers and wiring.					
16	Installation of rectifiers and wiring.	EA	70	\$300.00	\$21,000.00
Potential measurements and system verification.					
18	Potential measurements and system verification.	LS	1	\$8,000.00	\$8,000.00
Sub - Total Corrosion Treatment With Cathodic Protection					\$145,750.00
SUB-TOTAL					\$250,330.00
35% INDIRECT COSTS AND CONTINGENCIES					\$87,615.50
TOTAL					\$337,945.50

Table 7 shows the conceptual cost estimate of Alternative CT-3 for the material change on items identified as critical for plant operation and safety on Ponce de Leon.

Table 7
Alternative CT-3 - Cost Estimate

Item	Description	Unit	Quantity	Unit Price (\$)	Amount (\$)
General Requirements					
Mobilization and Demobilization					
1	Demobilization	LS	1	\$45,000.00	\$45,000.00
2	Project Signs	LS	1	\$4,000.00	\$4,000.00
4	Field Office	Mo.	2	\$4,790.00	\$9,580.00
Contractor's Permits (PUI, POC, others)					
5	POC, others	LS	1	\$15,000.00	\$15,000.00
6	As-Built Drawings	Mhrs	120	\$130.00	\$15,600.00
CES Plan Implementation and Maintenance					
7	Implementation and Maintenance	Mo.	2	\$2,500.00	\$5,000.00
Inspection During Construction					
8	Inspection During Construction	Mo.	2	\$5,200.00	\$10,400.00
Sub - Total General Requirements					\$104,580.00
Corrosion Treatment With Material Change					
Change of Valves to Stainless Steel					
9	Change of Valves to Stainless Steel	EA	8	\$5,000.00	\$40,000.00
Change of Handrails To Galvanized Steel					
10	Change of Handrails To Galvanized Steel	LF	200	\$25.00	\$5,000.00
Change of Steel Grating to FRP					
11	Change of Steel Grating to FRP	SF	800	\$18.00	\$14,400.00
Change of Rigid Galvanized Conduits For PVC Coated Conduits					
12	Change of Rigid Galvanized Conduits For PVC Coated Conduits	LF	3000	\$15.00	\$45,000.00
Change of Structural Steel Supports For Piping With FRP					
13	Change of Structural Steel Supports For Piping With FRP	EA	85	\$200.00	\$17,000.00
Sub - Total Corrosion Treatment With Material Change					\$121,400.00
SUB-TOTAL					\$225,980.00
35% INDIRECT COSTS AND CONTINGENCIES					\$79,093.00
TOTAL					\$305,073.00

EVALUATION OF ALTERNATIVES

Four alternatives were evaluated for concrete rehabilitation (two for cracks and two for spalling) and three for the corrosion treatment of metallic components. To help in the decision making of what alternative was the best in each category, a

weighted scoring method was used. The alternatives were compared using the following criterion and weights:

- Durability and resilience (30%)
- Cost (20%)
- Constructability and less time for implementation (20%)
- Aesthetics (10%)
- Disruption to normal operation (20%)

The scoring range used for the evaluation was from 1 to 5, 1 being the lowest score that could be assigned if the criterion was not achieved. If the alternative complied completely with the criterion, then a score of 5 was assigned. The scores on each criterion of an alternative were multiplied by the weights given to that criterion and then a weighted score was obtained. Then all weighted scores of an alternative were added to get a final score result. The alternative with the highest score was considered the best to be implemented for rehabilitation in the category (concrete rehabilitation and corrosion treatment).

Table 8 presents the evaluation matrix developed for the selection of alternatives on the concrete cracks repair category. From the results, it is observed that the routing and sealing method for concrete cracks repairs (Alternative CR-2) was favored over concrete injection grouting with polyurethane resin (Alternative CR-1) in the criterion of cost. Alternative CR-2 has an estimated cost of \$146,954 versus \$152,287 for the injection grouting. The difference of \$5,333 is not much and could lean the decision to Alternative CR-1 knowing that injection grouting is a more permanent solution and not a remedial one like routing and sealing. From the constructability and time of implementation perspective both alternatives have the same score. Disruption to plant operations is the same for both alternatives. Final scores were 3.4 for Alternative CR-1 and 3.5 for Alternative CR-2. Both alternatives and a combination of them could be considered to do the concrete cracks repairs at the Ponce de Leon WTP.

Table 9 presents the evaluation matrix developed for the selection of alternatives on the

concrete spall repair category. From the results, it is observed that concrete spall repair using partial depth (Alternative CSR-1) was favored over concrete spall using full depth repair in the criteria of cost and time of implementation. Alternative CSR-1 has an estimated cost of \$225,052 versus \$256,979 for the full depth repair. The difference of \$31,927 is due to the costs incurred on the demolishing and disposal of concrete debris and the restitution of the complete concrete section. From the constructability and time of implementation perspective Alternative CSR-1 has a better score than Alternative CSR-2. Disruption to plant operations is the same for both alternatives. Final scores were 3.9 for Alternative CSR-1 and 3.3 for Alternative CSR-2. Partial depth repair is considered the most adequate to attend concrete spalling deficiencies found at the Ponce de Leon WTP.

Table 10 presents the evaluation matrix for the three alternatives considered to treat corrosion on metallic elements at Ponce de Leon WTP. The use of epoxy and polyurethane high-performance coatings (Alternative CT-1) had the highest score of 6.9. This alternative is the best in terms of constructability, time of implementation, cost, and aesthetics. It received the highest score of all those criteria. Compared to the other two alternatives, Alternative CT-1 had the least economic impact with a cost estimate of \$280,233. Alternative CT-3 follows Alternative CT-1 with a cost estimate of \$305,073 and a weighted score of 5.1. As mentioned before, this alternative (material changes) was considered only for components critical to the operation of the plant that if changed could significantly extend the useful life of the facility. Alternative CT-2 (cathodic protection) ranked the lowest with a score of 4.2, being the least favorable mainly due to its highly cost of implementation (\$337,946) and the disruption it could cause to the normal operation of the water treatment plant during installation of sacrificial anodes.

Table 8
Concrete Cracks Repair Alternatives Comparison

Criterion	Weight	Desirability Score		Weighted Score	
		Alternative CR-1 Concrete Injection Grouting	Alternative CR-2 Routing and Sealing	Alternative CR-1 Concrete Injection Grouting	Alternative CR-2 Routing and Sealing
Durability & Resilience	0.3	4	3	1.2	0.9
Cost	0.2	3	5	0.6	1
Constructability and Less Time For Implementation	0.2	4	4	0.8	0.8
Aesthetics	0.1	2	2	0.2	0.2
No Disruption To Normal Operation	0.2	3	3	0.6	0.6
Total	1			3.4	3.5

Table 9
Concrete Spall Repair Alternatives Comparison

Criterion	Weight	Desirability Score		Weighted Score	
		Alternative CSR-1 Partial Depth Repair (PDR)	Alternative CSR-2 Full Depth Repair (FDR)	Alternative CSR-1 Partial Depth Repair (PDR)	Alternative CSR-2 Full Depth Repair (FDR)
Durability & Resilience	0.3	5	5	1.5	1.5
Cost	0.2	4	2	0.8	0.4
Constructability and Less Time For Implementation	0.2	4	2	0.8	0.4
Aesthetics	0.1	4	4	0.4	0.4
No Disruption To Normal Operation	0.2	2	2	0.4	0.4
Total	1			3.9	3.1

Table 10
Corrosion Treatment Alternatives Comparison

Criterion	Weight	Desirability Score			Weighted Score		
		Alternative CT-1 Protective Coatings	Alternative CT-2 Cathodic Protection	Alternative CT-3 Material Change	Alternative CT-1 Protective Coatings	Alternative CT-2 Cathodic Protection	Alternative CT-3 Material Change
Durability & Resilience	0.3	4	4	5	1.2	1.2	1.5
Cost	0.2	5	1	2	1.5	0.3	0.6
Constructability and Less Time For Implementation	0.2	5	2	3	1.5	0.6	0.9
Aesthetics	0.1	5	5	4	1.5	1.5	1.2
No Disruption To Normal Operation	0.2	4	2	3	1.2	0.6	0.9
Total	1				6.9	4.2	5.1

CONCLUSION AND RECOMMENDATIONS

The objective of this project was to make a structural evaluation and an analysis of the possible alternatives that could be used to rehabilitate the deteriorated concrete structures and metallic elements present on the flocculation, sedimentation, and filtration water treating processes of the old plant in the Ponce de Leon WTP.

Based on results, the recommended alternative for cracks repair is the routing and sealing method with polyurethane sealant and for concrete spalling is the partial depth repair. The structural evaluation concluded that cracks and spalling on concrete structures at the Ponce de Leon WTP could be

repaired using both alternatives because visually they do not appear to be severe. Even so, it is highly recommended to make additional studies on the concrete surfaces using sound testing or ground penetrating radar (GPR) to verify the extent of concrete delamination and corrosion spread inside affected concrete structures at the WTP. Another recommendation on the Juan Ponce de Leon WTP, that is justified by its age, is to make core sampling on the concrete elements (e.g., walls) at the flocculation channel, the sedimentation tanks, and the filter basins. This will help in knowing the actual strength, permeability, petrography, and chemical analysis of the concrete matrix on the existing structures at the Ponce de Leon WTP.

Related to corrosion treatment on metallic elements, the analysis concluded that the best and most cost-efficient alternative was the use of epoxy and polyurethane high-performance coatings. Protective coatings can extend the useful life of metallic structures and mechanical components because they chemically adhere to the metallic substrate and create a barrier against corrosion. For this reason, a good surface preparation is of utmost importance before applying the coatings.

For the Ponce de Leon WTP, it is recommended to perform a full corrosion assessment with a certified inspector of the National Association of Corrosion Engineers (NACE) on all metallic structures to know the full extent of damage caused by general corrosion. Also, to take material loss measurements on pipes and structural steel to adequately specify corrosion restoration methods.

The following additional recommendations could benefit PRASA to save in O&M costs related to concrete and metallic structures:

- Create a monthly visual inspection checklist for plant operators in where they can grade and document the condition of structures.
- Establish a coating program to be implemented during the year to address corrosion on metallic structures and mechanical components.

REFERENCES

- [1] S. A. Kasassbeh, A. A. Tamseh, and E. A. Kharabsheh, "Modern techniques for the restoration and rehabilitation of concrete structures," *International Journal of Recent Technology and Engineering*, vol. 9, no. 1, pp. 1826–1833, May 2020, doi: 10.35940/ijrte.fl104.059120.
- [2] ACI Committee 224, "224.1R-07: Causes, Evaluation, and Repair of Cracks in Concrete Structures," Technical Documents, Detroit: *American Concrete Institute*, 2007, ch.2, pp. 13-17.
- [3] D. Kaminetzky, "Concrete," in *Design and Construction Failures: Lessons from Forensic Investigations*, 1st ed., New York, NY, USA: McGraw-Hill Companies, 1991, ch.2, sec. 2.9, pp. 107-114.
- [4] K.N. Derucher and G.P. Korfiatis, "Performance Characteristics of Concrete," in *Materials for Civil & Highway Engineers*, 2nd ed., New Jersey, NJ, USA: Prentice Hall, 1988, ch.7, pp. 150-167.
- [5] International Concrete Repair Institute, "310.1R-2008: Guideline for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion," ICRI Technical Guideline, Illinois: International Concrete Repair Institute, 2008, pp. 12.