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# LANTANA CONDOMINIUMS
# INDIAN HARBOUR BEACH, FLORIDA
# POST-TENSIONING TESTING

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VCS Project Number – F20028FL
June 5, 2020

## Introduction

The Lantana Condominiums are located at 1811 Florida A1A in Indian Harbour Beach, Florida and consist of four individual buildings. It is understood that all four building were constructed at about the same time in 1998 making the building 22 years old; based on design drawings provided to VCS. The buildings are located on the Atlantic coast of Florida. Figure 1 provides an overview of the Lantana Condominiums.

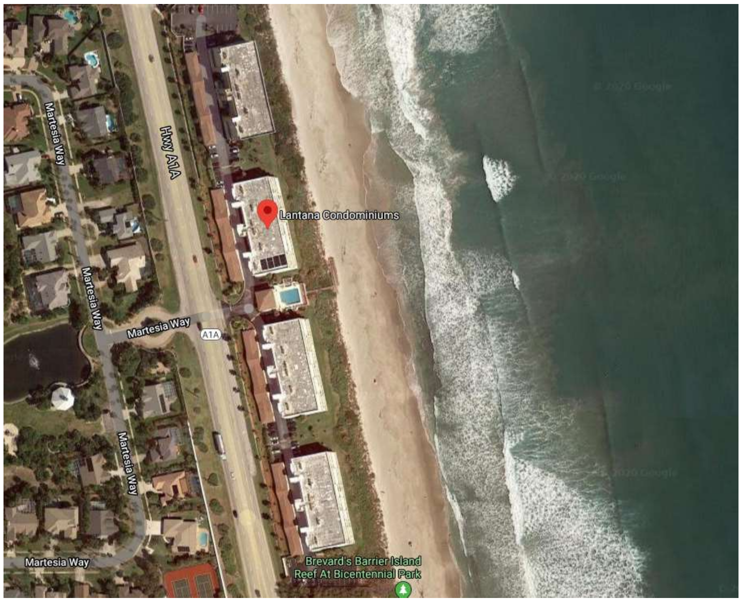


Figure 1: Overview of Lantana Condominiums

The Lantana Condominium buildings utilize unbonded mono-strand post-tensioning (PT) cables in the elevated slabs together with black steel reinforcement bars. The PT is housed inside an extruded plastic sheath that is filled with grease to protect the high strength steel strand from corrosion. One balcony (unit 3201) in Building #3 has a concrete spalled area that has exposed the PT reinforcement as well as black steel rebar. Vector Corrosion Services (VCS) was contracted by CFA Construction to determine the cause of the damage, its effect on the structure and provide recommendations regarding any required rehabilitation. VCS partnered with MBV Engineering (MBV), a Vero Beach-based structural engineering firm, to provide support regarding the structural implications of the PT condition.

As requested by the owner, the evaluation conducted by VCS/MBV was limited to Building #3 and 1 day of field work. The work consisted of visual inspection and sounding of select balconies carried out by MBV to identified signs of potential concrete deterioration. Also ground penetrating radar (GPR) survey to identify the location of post-tension reinforcement, post-tech corrosion evaluation (PTCE) of the tendons to assess the risk of corrosion, and chloride concentration testing of the concrete at rebar depth conducted by VCS. This report presents the findings from the VCS evaluation. The MBV findings and repair recommendations are presented in separate report. A brief overview of the MBV report is also provided within this report.

## Summary of the MBV Report

MBV conducted a visual and sounding inspection of the balconies in units 3201, 3202, 3205, 3206, 3303, 3305, 3306, 3401 and 3402. Delaminations in the top of the balcony slabs indicated by a hollow sound when the slab is struck with a hammer were identified in 8 out 9 inspected balconies. Hollow sounding areas were typically aligned with a banded group of tendons along column line A (north-south tendons) on the 2nd floor and in units 3305 and 3306 on the 3rd floor. Delaminations along column line B were found in the end units (3201 and 3206) of the 2nd floor and in unit 3306 on the 3rd floor. MBV recommended inspecting unit 3301 to confirm that deterioration observed in unit 3306 is mirrored on the other end of the building as on the 2nd floor.

For repair of delaminated areas along column line A, MBV recommended detensioning the tendons along column line A from both ends to allow for patch repairs and then retensioning them after repairs are completed. This would require shoring of all the balconies on the floor that is being repaired. For repair of delaminations along column line B, MBV recommended to either detension the tendons from both ends with temporary shoring of all the balconies or to detension one end unit at a time, which would require temporary tendon lock-offs inside the units. These repairs may affect uniform (east-west) tendons, which would require lock-offs inside the units.

For patch repairs, MBV recommended applying corrosion inhibitor to the reinforcing steel after it has been cleaned of all corrosion product. MBV also recommended applying a waterproofing system to the balcony slabs and a migrating corrosion inhibitor to the concrete surfaces not receiving the waterproofing system.

## Test Methods & Results

This section describes the methods used by VCS for the condition assessment of the Building #3 balconies along with the results from these methods. A detailed discussion regarding each result is provided along with conclusions.

### Ground Penetrating Radar Survey

*Cover Depth Analysis*

Ground penetrating radar (GPR) is a quick and effective way of identifying the location and depth of metal objects within reinforced concrete. Steel reinforcement can be easily identified in a GPR scan due to the significant difference in the electromagnetic properties of steel and concrete. As a result, the location and depth of steel elements (i.e. cover-depth) in concrete can be determined accurately and efficiently.

Cover-depth is an important factor in determining the service life of a reinforced concrete structure. There is a correlation between cover-depth and concrete durability; a reduced cover-depth exponentially impacts the durability of reinforced concrete structures. Inadequate cover-depth allows for contaminates and moisture to reach the embedded steel much faster, which in turn initiates corrosion activity at a premature stage in the structure's life. Inadequate cover-depth is also associated with early-age cracking, which provides a direct path for corrosive agents to attack the steel.

The results of the GPR scans are presented in Table 1. The reinforcement in the north-south direction is labeled as longitudinal and the reinforcement in the east-west direction is labeled as transverse. It should be noted that there is approximately 1 inch of stucco covering the concrete surface of the balconies. The GPR scans were conducted from the top of the stucco surface and the reported cover-depths include the depth of stucco and concrete. With regards to chloride exposure, a cover-depth less than 2 inches provides minimal protection to the steel.

Table 1: Reinforcement Cover-Depth

| Reinforcement Direction | Average Cover-Depth (in) | Standard Deviation (in) | Minimum (in) | Maximum (in) |
|---|---|---|---|---|
| Transverse | 2.0 | 0.7 | 1.2 | 4.7 |
| Longitudinal | 2.6 | 0.9 | 1.4 | 5.4 |

In addition to determining reinforcement cover-depth, GPR was utilized to locate the PT tendons for the Post-Tech Corrosion Evaluation (PTCE) testing procedures.

### Electrical Continuity

Electrical continuity of the reinforcing is necessary for possible future corrosion mitigation by cathodic protection and to conduct efficient corrosion potential measurements. In most cast-in-place reinforced concrete structures conventional reinforcement is electrically continuous due to the crossing of bars and tie wires. If the reinforcement if found to be electrically isolated then continuity bonds will be required for the implementation of cathodic protection (CP). Electrical continuity is verified by contacting various steel elements with the lead wires from a high impedance multi-meter using the DC millivolts and/or resistance settings. As per ACI 222R-19 Standard in Section 5.3.1.6, if the potential difference between the reinforcing elements is less than one (1) mV, then the reinforcing steel is deemed electrically continuous.

The black steel rebar in the balconies was found to be electrically continuous. If a form of CP were to be applied to the balconies, a more robust evaluation of electrical continuity would be required during the construction phase of the CP. However, it is expected that limited continuity corrections would be required. As expected, rebar was electrically isolated from the PT. The PT is commonly isolated due to the plastic sheathing.

### Corrosion Potential Survey

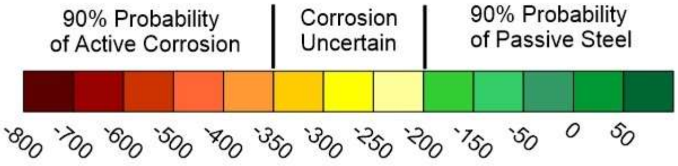
VCS attempted to perform corrosion potential measurements on the balconies, but accurate readings could not be collected through the layer of stucco water-proofing paint. Therefore, corrosion potential measurements were performed only on the unit 3201 balcony around the perimeter of the spall and in a delamination where stucco was removed as well as in unit 3303 where small holes were drilled through the stucco to gain access to the concrete surface.

Corrosion potential measurements were collected per ASTM C876 *Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete*. A copper/copper sulfate (CSE) reference electrode was used to collect corrosion potential measurements. The CSE reference electrode was placed on the concrete surface with a saturated sponge used to make an electrical couple with the concrete. The reference electrode was then connected to the negative terminal of a volt-meter. The positive terminal of the volt-meter was connected to the embedded reinforcement of the structure, and the potentials at various points along the walls were recorded. The magnitude and spatial variation of the measured potentials provides the probability for active corrosion at the test location.

A generally accepted interpretation of normalized CSE measurements is provided in the appendix of ASTM C876 (Table 2 and Figure 2). It is important to understand that the interpretation values provided in ASTM C876 are a general guideline based on values normalized to 72 degrees Fahrenheit, and are not absolute values. The threshold values can shift based on the concentration of moisture and oxygen in the concrete, as well as other environmental factors like temperature.

Table 2: ASTM C876 Interpretation of Data

| Corrosion Potential | Probability of Active Corrosion |
|---|---|
| < -350 mV | 90% |
| - 350 mV to -200 mV | Uncertain |
| > −200 mV | 10% |



Scale Per ASTM C876 Corrosion Potentials
of Uncoated Reinforcing Steel in Concrete

Figure 2: Corrosion Potential Survey Scale for Color Maps

All corrosion potential measurements collected on the unit 3201 balcony (Figure 3) were either at the 90% probability of active corrosion or in the uncertain range. This is not surprising given the condition of the spall area. When the stucco was removed in a delaminated area in front of the northeast column in unit 3201, cracks were observed in the concrete, indicating that this delamination was caused by concrete deterioration rather than debonding of the stucco. Although it was only possible to take one corrosion potential measurement in this area, it indicates that concrete deterioration is likely due to rebar corrosion.

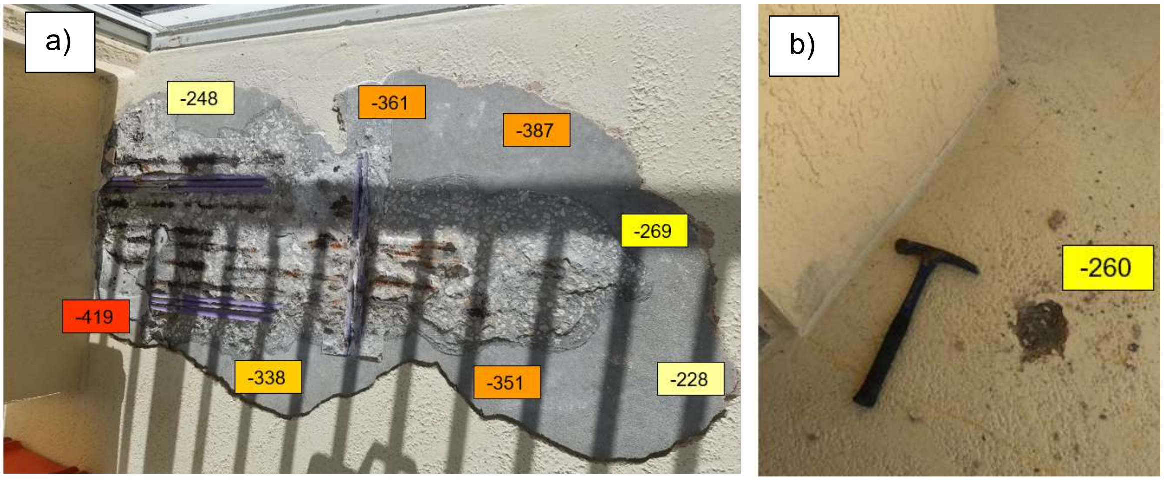


Figure 3: Corrosion Potential Measurements in Unit 3201 Balcony: a) Spall in Front of the Balcony Doors, b) Delamination in Front of the Northeast Column

All measurements taken on the unit 3303 balcony were at the 90% probability of passive steel. This may indicate that the delamination observed in this unit may be due to debonding of stucco.

## Concrete Chloride Sampling

In order to gain an understanding of the amount of chloride ion contamination within the concrete matrix from exposure to the costal environment. Two concrete powder samples were obtained by drilling from unit 3201 where the most severe concrete deterioration was observed and from unit 3306. Concrete samples were collected from the top of the balconies at the depth of reinforcing steel and tested per ASTM C1152 *Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete*.

Reinforcing steel in concrete is protected from corrosion by the high alkalinity of the concrete pore solution, typically greater than a pH of 12. The high pH of the pore solution causes formation of a passivating film on the surface of rebar, effectively sealing it and preventing corrosion. Corrosion of reinforced concrete exposed to a chloride-containing environment, such as deicing salts, marine exposure or chlorinated water in swimming pools, is typically initiated by chloride ions, which have the ability to break down the passivating film. Chloride ions diffuse from the concrete surface, and once their concentration at reinforcement depth reaches a threshold value, corrosion is initiated. The quantity of chlorides required to depassivate the steel is known as the threshold concentration. Chloride threshold is a critical value in determining the initiation time for the service life model. In the literature, threshold concentrations for chloride in concrete can vary significantly and depend on a number of factors. ACI 222R-19 indicates that for acid-soluble chloride testing the generally accepted chloride threshold in the United States is between 1.0 and 1.5 lbs of chloride per cubic yard of concrete (263 to 395 ppm assuming a concrete density of 3,800 lbs/yd$^3$).

For the service life modeling, VCS typically implements a chloride threshold of 350 ppm with a standard variation of 50 ppm. It is important to consider the variation of the threshold as chloride threshold is not a single value. Due to many influencing factors, corrosion of steel in concrete can initiate at a range of chloride concentrations. As a result, it is important to take into consideration this variation. There are many environmental and concrete material conditions that can cause the corrosion to initiate at a lower or higher threshold. For example, if the moisture content is high in an area then corrosion may initiate at a lower chloride concentration. If the concrete is drier in an area it may take more chloride to cause corrosion.

Table 3 presents the results of the chloride concentration testing. Chloride concentrations at both locations were above the 350 ppm corrosion initiation threshold. Even though the sample in unit 3306 was taken from a sound area, its high chloride concentration suggests that corrosion is this area is active and delaminations are expected to form there in the next 5-10 years if no rehabilitation is carried out.

Table 3: Chloride Concentration Testing Results

| Location | Chloride Concentration (ppm by Mass of Concrete) |
|---|---|
| Unit 3201 | 3,172 |
| Unit 3306 | 512 |

## Post-Tech CE Post-Tension Corrosion Evaluation

The PTCE method was implemented to evaluate the potential risk for corrosion of the PT tendons. The PTCE method determines how much moisture is present along the tendon thus allowing VCS to identify the risk of corrosion activity. The PTCE testing system requires that the PT tendons be accessed at a minimum of two locations to permit sampling of the PT tendon environment. The moisture content of the air within the PT tendons is evaluated by controlled injection of -40°C dew point dry gas at an "IN" port and measuring the moisture content of the gas at a distant "OUT" port. The "IN" and "OUT" ports are located along the length of each tendon and installed by carefully drilling a hole into the cover concrete to reach the PT. A valve is then installed into the concrete port that allows for a connection to the dry gas tank. At the "OUT" port, another valve is installed so that a temperature and relative humidity sensor can be connected inline. The air expelled from the "OUT" port is measured and recorded. The moisture content of the tendon air is then calculated and the tendon is graded for corrosion probability using the PTCE formulas. Table 4 provides the three-point grading system that reflects the potential for corrosion of the tendon at the time of testing.

If bulk water is encountered, PTCE testing is not performed as the presence of liquid water reflects a high potential for corrosion at the water-to-air interface inside the tendon. These wet tendons are then noted as "visibly wet" in the data and assigned a relative humidity (RH) value of 100% (MC=1.0). At no location in the Building #3 of the Lantana Condominiums were tendons observed to have bulk water.

Table 4: Post-Tech CE Classifications

| **Moisture Content (kg $H_2O$/kg air)** | **Exterior – Not Climate Controlled** | |
|---|---|---|
| | **Description** | **Corrosion Risk** |
| $MC \leq 0.003$ | Dry | Low |
| $0.003 < MC < 0.007$ | Dry/Wet | Moderate |
| $MC \geq 0.007$ | Wet | High |

If the plastic sheathing around the PT tendon is continuous and there is no air loss through cracks or voids in the concrete, this test can be performed across the full length of the tendons. First, air flow continuity in longitudinal (north-south) PT tendons was checked along column line A between units 3201 and 3202. No visible cracks or voids were observed at this location. Initially, the spacing between the "IN" and "OUT" ports were approximately 20 ft. No air flow was recorded. The spacing was then reduced to approximately 10 ft and all subsequent testing was conducted with "IN" and "OUT" ports located in the same unit. Moisture testing of the transverse (east-west) tendons was conducted at the distance of approximately 6 ft between the "IN" and "OUT" ports.

Table 5 shows the locations of all the PTCE tests carried out on the Building #3 balconies. Out of the 6 exposed tendons, no air flow was measured at the "OUT" port in 4 of the tendons. Although no air flow was achieved in 67% of the tested tendons, grease was visible at the "OUT" port locations in all instances as shown in Figure 4. Presence of large amounts of grease in the sheathing around the tendons can also prevent air flow through the tendons during the PTCE testing. This indicates that the tendons are well protected by the grease and the risk of corrosion is low. Air was able to flow along two tendons. In one tendon (test 5) a "dry" condition was indicated, while a "wet" condition was indicated in the other tendon (test 7) (Figure 5).

Table 5: PTCE Moisture Testing Locations

| Test # | Unit # | Tendon | Location | Temperature (ºC) | Relative Humidity (%) |
|---|---|---|---|---|---|
| 1 | 3201 to 3202 | Longitudinal | Column line A | NF | -- |
| 2 | 3201 | Longitudinal | Column line A | NF | -- |
| 3 | 3201 | Transverse | Column line 2 | NF | -- |
| 4 | 3306 | Longitudinal | Column line A | NF | -- |
| 5 | 3306 | Transverse | Column line 31 | 24.6 | 6.66 |
| 6 | 3401 | Longitudinal | Column line A | NF | -- |
| 7 | 3401 | Transverse | Column line 2 | 24.2 | 70.27 |

NF = no air flow

Figure 4: Drops of grease at the “OUT” port location after moisture testing (typical)

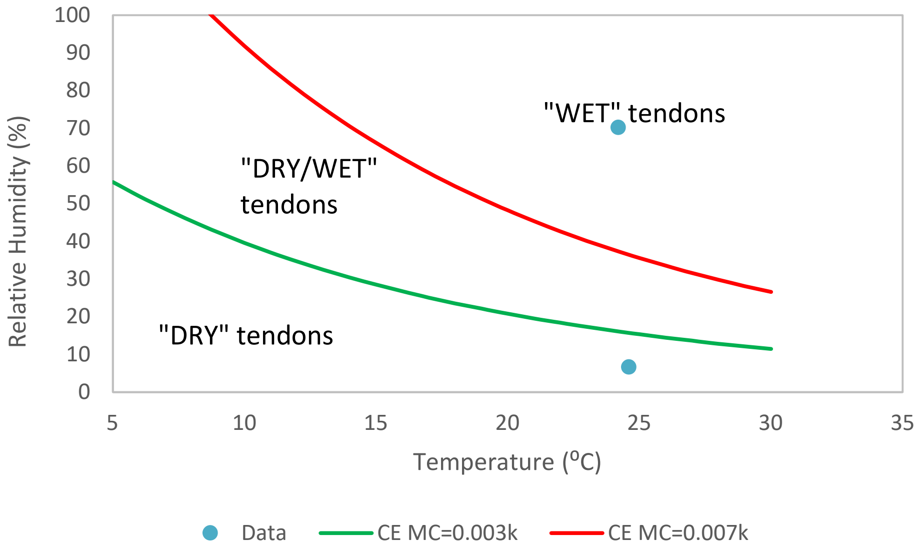


Figure 5: PTCE Moisture Testing Results for Tests 5 and 7

## Openings

In addition to moisture testing, VCS visually inspected the condition of the tendons in the spall area where tendon sheathing has been cut. Ample amounts of grease were visible in the sheathing (Figure 6). The tendons were free of corrosion and appeared to be under tension. Tension was checked by attempting to drive a screwdriver between the individual strands of the tendon. If the tendon is under tension then the screwdriver should not be able to fit between the strands. If tension is lost then the screwdriver will be able to fit between the strands. The screwdriver was unable to fit between the stands indicating that tendon is under tension. The screwdriver test was also performed in the openings made for PTCE testing. In all cases, it was not possible to fit the screwdriver between the wires of the tendons and the tendons appeared to be under tension.

Figure 6: Opening in the Tendon Sheathing

## Conclusions

1. The observed concrete deterioration in unit 3201 is due to corrosion of black steel rebar caused by penetration of chloride ions to the rebar depth.

2. Chloride concentrations within the balcony concrete are at levels that would initiate corrosion activity. It is expected that this condition would be present at most of the balconies in the Lantana Condominium complex.

3. PTCE moisture testing showed that the sheathing for PT tendons is filled with grease, which should protect the PT from corrosion. However, a “wet” condition was indicated in one of the tested tendons. More “wet” tendons may exist within the building, although it is difficult to anticipate how may tendons may be in the “wet” condition due to the small sampling size.

4. Openings of the PT tendons confirmed that the sheathing is filled with grease and the PT strands show no signs of corrosion.

## Recommendations

### Option 1: Basic Repairs

The Basic Repairs option is that only currently delaminated areas are repaired and no corrosion mitigation is conducted. That would mean that the reinforcing steel would continue to corrode due to the high concentration of chlorides and concrete would continue to delaminate. This will lead to more and more spalls developing each year. Corrosion deterioration is exponential in growth so each year more and more damage will occur until the structure deteriorates to a point where serviceability becomes a concern. While this is the cheapest option in the short term, in the future when repairs are required to address serviceability concerns, the cost of those repairs will be much greater. Repairs during a state of severe deterioration are always significantly more expensive than conducting smaller-scale repairs earlier in the structure's life so that it does not develop severe deterioration.

*Delamination Repair*

For the Basic Repair option, the currently spalled and delaminated areas will need to be repaired. In addition to the patch repair recommendations provided by MBV, VCS recommends installation of galvanic anodes around the perimeter of the patch repairs.

When the localized concrete repairs are completed, chloride-contaminated concrete is left in place adjacent to the repair. The reinforcing steel crosses the interface between the original contaminated concrete and the completed concrete repairs which are chloride-free and alkaline. This incompatibility can accelerate corrosion around the repairs in the adjacent chloride-contaminated concrete; this phenomenon is referred to as the ring anode effect (Figure 7). A common method to mitigate the effects of ring anode corrosion is the use of embedded galvanic anodes within the repair area. Embedded galvanic anodes consist of zinc as a sacrificial metal encased in an activating mortar. When connected to the reinforcing steel within the completed concrete repairs, a small level of protective current is generated to mitigate the formation of new corrosion sites in the surrounding concrete. Embedded galvanic anodes are available in a range of sizes and shapes and are spaced along the steel surface area based on the risk for corrosion. A good ACI reference for the use of embedded galvanic anodes is *Repair Application Procedure Bulletin #8 – Installation* of Embedded Galvanic Anodes. For this application VCS recommends Type 1A anodes (standard concrete repairs, alkali activated). Installation of Type 1A will have an additional cost of approximately \$15-25 per ft$^2$ of patch repair area.

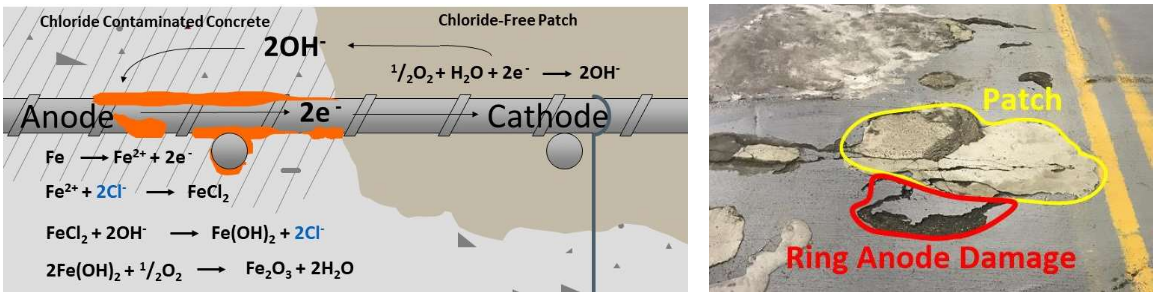


Figure 7: Ring Anode Effect

*Contractor Selection and Inspection*

In addition to a well-developed technical specification, contracting and inspection practices should be incorporated in the repair strategy. For example, utilizing prequalified specialty concrete repair contractors that have successfully completed similar types of work has been a successful approach. For improved inspection, utilizing an ICRI Certified Concrete Surface Repair Technician (CSRT), which is a competency-based program, should be considered.

### Option 2: Global Galvanic Cathodic Protection

This option provides a global cathodic protection through installation of discrete anodes in the balconies. In this option, concrete in all the spalled and delaminated areas should be removed following the delamination repair procedures described in Option 1, including the installation of Type 1A anodes within the repair areas. Type 2 drilled galvanic anodes would then be installed over the entire surface of the balconies except in the newly patch repaired areas, which will prevent formation of future spalls in the actively corroding areas.

Under this option, anodes would be placed in each balcony on a grid prior to the application of a waterproofing system recommended by MBV. Once the anodes are placed into the drilled holes, a wire is used to connect them to the reinforcement, and then the anodes and the wires are grouted in place. Galvanic anodes can be designed for a 20-25 year life span, so a 30-year service life extension can be expected before new delaminations and spalls start to form. The estimated unit cost for installation of Type 2 anodes is \$120/ft$^2$, which does not include the cost of patch repairs.

*Contractor Selection and Inspection*
In addition to a well-developed technical specification, contracting and inspection practices should be incorporated in the repair strategy. For example, utilizing prequalified specialty concrete repair contractors that have successfully completed similar types of work has been a successful approach. For improved inspection, utilizing an ICRI Certified Concrete Surface Repair Technician (CSRT), which is a competency-based program, should be considered.

### Option 3: Localized Galvanic Cathodic Protection

This option is very similar to Option 2, except Type 2 anodes would only be installed in the balconies in areas of active corrosion as determined by corrosion potential measurements. In this option, concrete in all the spalled and delaminated areas should be removed following the delamination repair procedures described in Option 1, including the installation of Type 1A anodes within the repair areas. When all the stucco and coatings have been removed from the surface of the balconies, corrosion potential measurements would be conducted on each balcony to identify areas of active corrosion. Type 2 anodes would then be installed on a grid pattern in these actively-corroding areas that are still sound prior to the application of a waterproofing system recommended by MBV. The estimated unit cost for installation of Type 2 anodes will be the same as in Option 2, but it is expected that an overall lower quantity of anodes will be required. However, since it was not possible to conducted corrosion potential measurements through the stucco and waterproofing paint, it is not possible to estimate the quantity of anodes that would be required under this option.

It should be noted that if localized galvanic protection option is selected, areas that are not actively corroding at the time of anode installation may become active in the future since high chloride levels were observed at the rebar depth. These areas may require patch repairs in the during the 30-year period.

*Contractor Selection and Inspection*
In addition to a well-developed technical specification, contracting and inspection practices should be incorporated in the repair strategy. For example, utilizing prequalified specialty concrete repair contractors that have successfully completed similar types of work has been a successful approach. For improved inspection, utilizing an ICRI Certified Concrete Surface Repair Technician (CSRT), which is a competency-based program, should be considered.

**Option 4: Application of Penetrating Corrosion Inhibitor**

This option would provide some additional protection against continued corrosion of the balcony reinforcement although it will not be an effective long-term solution like the installation of anodes. If the Lantana Condominiums wants to consider a cheaper option to Type 2 anode installation, a penetrating corrosion inhibitor can be applied to the exposed concrete surface of the balconies after the stucco has been removed and prior to installation of a waterproofing system. A penetrating corrosion inhibitor is easy-to-apply and provides an economical option of reducing the rate of corrosion. While this option will not stop the current corrosion progression of the balconies it will help to delay the progression of the damage.

Under this option, all spalled and delaminated areas will need to be repaired as recommended by MBV and described previously under Option 1, including the installation of Type 1A anodes around the perimeter of the patch repairs. After the localized repairs have been completed, a penetrating corrosion inhibitor, like MasterProtect 8500CI by BASF, is then applied to the concrete surface. This particular product also contains a penetrating silane sealer, its compatibility with the waterproofing system recommended by MBV will need to be verified prior to use.

Prior to application of the sealer the concrete surface should be cleaned to remove all stucco or other coating and dirt or other contaminants, which can be achieved with shotblasting, waterblasting, sandblasting, grinding or chemical cleaning. The sealer can be applied to the dry concrete surface by spraying, painting or rolling. Typically, 2-3 coats of sealer are need to be applied to achieve the required concentration of corrosion inhibitor at rebar depth. The expected service life of the sealer is 7-10 years, after which time it will no longer be effective in slowing down the rate of corrosion. The estimated unit cost for application of corrosion inhibitor is $\$1/ft^2$.

Thank you for the opportunity to work with you on this project and if you have any questions please don’t hesitate to contact me directly.

Sincerely,

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