

Half-Cell Potential Corrosion Survey Aids Repair Design

By F. Carter “Bud” Karins and Andy Schrader

440 West Condominium consists of two 16-story towers and a central plaza deck overlooking Clearwater Beach, FL. The structure rests on an elevated parking deck and 94,000 ft² (8732 m²) garage. The suspended parking deck is constructed of nominal 11 in. (27.9 cm) thick, two-way, cast-in-place, conventionally reinforced concrete flat-plate slabs.

Constructed in 1975, the structure had never undergone a concrete restoration job prior to this project, and the concrete slab went without a waterproofing membrane on top for many years. Large-scale corrosion damage was obvious throughout the garage; stalactites were growing from some ceiling cracks.

The corrosion appeared to have been caused in part through exposure to a salt-rich coastal environment, exacerbated by cracking and inadequate coverage over the reinforcing steel. The Gulf coast of Florida is an extremely harsh climate for most construction materials. All exposed surfaces are continually coated with salt residue carried by the Gulf breezes. Significant condensation occurs on a daily basis as the temperature of the building components fall below the dew point during the early morning hours. Structures are subjected to severe thunderstorms

and tropical storms that include strong winds combined with substantial rainfall rates. The wind creates positive pressure areas on the windward face of the building elements and low pressure areas on the sides and leeward faces of the elements. This combination of pressures serves to suck moisture into the building elements through any existing cracks or holes, thereby transporting salt and water to the interior.

Tests performed on the concrete at 440 West Condominium repeatedly indicated high chloride contents. The humidity within the garage area (moisture availability) routinely reaches 100%. No high-level petrographic analysis of the concrete had been performed to quantify its porosity. A simple visual inspection of the concrete slab within the garage, however, indicated that the placed concrete was not of the highest quality. Small holes and poor consolidation of the concrete were visible everywhere. These conditions suggested elevated porosity and resultant increased corrosion severity.

A consulting engineer was hired to oversee the required repairs for the garage. Nondestructive half-cell potential measurements of the slab were performed to give an indication of the corrosion risk of the slab’s reinforcing steel. The tested areas



Fig. 1: Aerial view of 440 West Condominium



Fig. 2: Workers performing the concrete repairs



Fig. 3: Work Area "A" test site as seen from roof of building



Fig. 4: Worker taking potential readings

were later opened up for the purpose of concrete repair. This project was a rare opportunity to correlate the half-cell potential measurements with physical evidence of corrosion damage to the steel reinforcing.

Testing Procedure

Electropotential measurements, commonly referred to as half-cell potential measurements, can be used to map areas of likely corrosion activity in a reinforced concrete slab. The method is described in ASTM C876-91. This nondestructive testing method is generally accepted as a measure of the likelihood or potential for corrosion. It is generally not a means to determine the rate of corrosion that is actually occurring.

The half-cell test is so called because the tester uses a reference cell as one-half of a battery and the anodic (corroding) site on the reinforcing steel is the complementary other one-half of the battery. When the two elements are connected via the pore water in the concrete, a whole battery is created. The potential generated by this battery is measured by connecting copper wires from a sensitive voltmeter to the reference cell and to the reinforcing steel to complete an electrical circuit. Because voltage must be measured relative to some known potential, the reference cell is constructed of materials that will provide a stable and reproducible potential (copper sulfate in this case). The data collected in the mapping is stated in terms of voltage relative to the type of reference cell used.

An electrical connection was made between the voltmeter and an exposed piece of reinforcing steel embedded in the slab. The voltmeter was mounted at the top of the stick that carries the reference cell and the second wire from the voltmeter was connected to the cell. The concrete slab was flooded with a garden hose prior to taking the measurements to ensure a saturated surface condition to provide good ionic contact between the reference cell and the concrete.

A grid composed of 10 x 10 ft (3 x 3 m) squares was marked out on the surface of the concrete slab. Potential measurements were then taken at the corner of each square. ASTM C876 states that if the steel is passive and protected against corrosion, measured potential differences will be relatively small (less than -200 mV). As the vulnerability of the steel to corrosion increases, the measured potential difference increases. Potential differences greater than -350 mV indicate a high probability that the steel is corroding. It is important to understand that the potential measured by this process is a measure of the driving force for corrosion but is not necessarily a measurement of the rate of corrosion.

Test Data

On-site potential measurements varied between -224 mV and -510 mV relative to the reference cell. All readings were more negative than -200 mV, indicating that the reinforcing steel throughout the test area was susceptible to corrosion damage.

The potential measurements recorded within the test area are shown in Fig. 6.

- It is important to note that no point within the test area produced a potential measurement more positive than -200 mV. As a result, there appeared to be no safe areas for the reinforcing steel: only areas of medium to severe corrosion risks;
- When the data was plotted on a map of the test area, hot spots of increased electrical potential appeared;
- The colored areas and hot spots indicated where there was a greater potential for corrosion to

occur than on the rest of the deck. As stated previously, the entire area was susceptible to corrosion. The colored areas (refer to Fig. 6) represent those sections that appear to be most vulnerable; and

- Based on the test results, the Far West, Far East, and North-Central locations exhibited the greatest potential for corrosion.

Correlation with Destructive Exploration

When the concrete repairs that were performed in Work Area A were mapped and overlaid on top of the corrosion potential map, correlations between suspected corrosion potential and actual concrete repairs appeared. Concrete repair areas are shown as the hatched areas with thick black lines (refer to Fig. 6).

Spalling and cracking due to corrosion was most obvious at the North-Central and Far-West side of the test area. However, the steel in that area generally appeared similar to steel in other concrete repair areas with a smaller measured electrical potential.

Additionally, the area where the greatest electrical potential was observed corresponded to the area of the greatest corrosion. The hot spot in the North-Central area contained multiple pieces of reinforcing steel that were so badly corroded that they required replacement. No other section within the test area required replacement.



Fig. 5: Corroded steel in 440 West Condominium

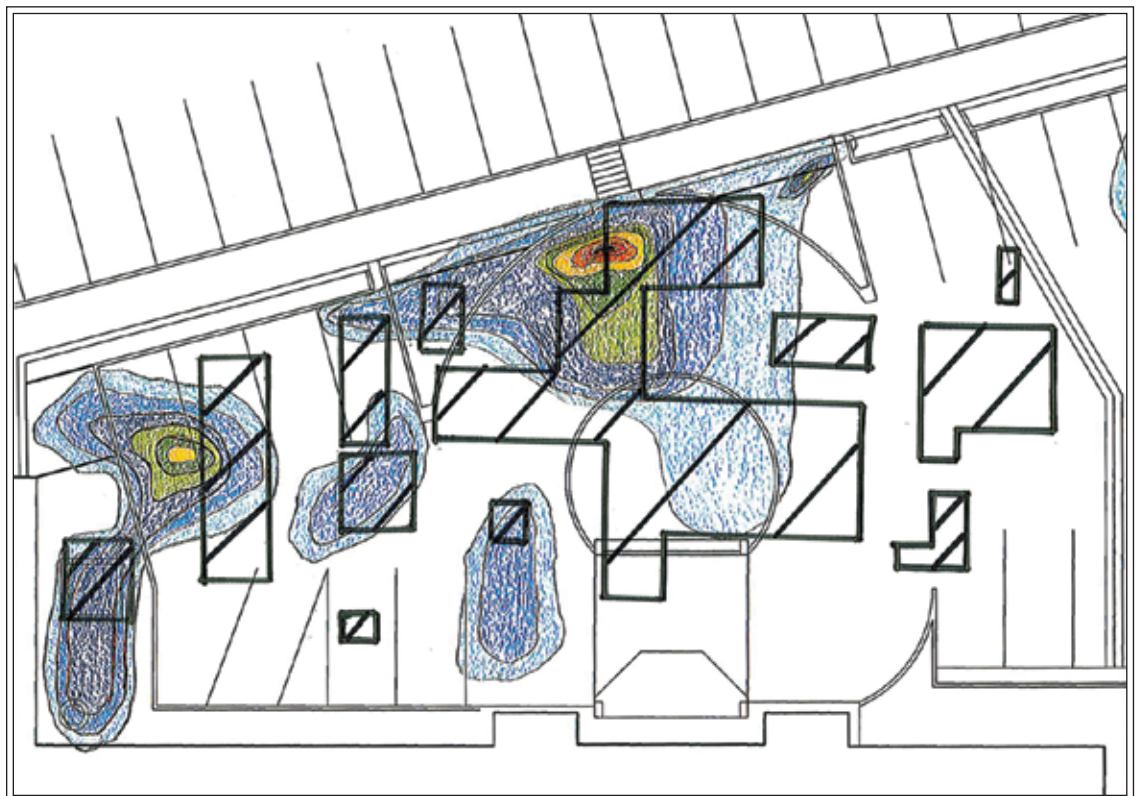


Fig. 6: Half-cell corrosion test with hatched concrete repair overlay



Fig. 7: Concrete and reinforcing steel being prepared for repair

Data Analysis and Conclusions

The data indicated that the entire survey area was susceptible to corrosion. The protective passivating layer had been compromised and nearly 30% of the area was highly vulnerable. Due to the advanced age of the structure and the high chloride environment in which it resides, the Engineer initially suspected this condition may be true and recommended that an impressed current cathodic protection (ICCP) system be installed during the repair project. This would have effectively halted the corrosion process on the steel reinforcing and ultimately reestablished the passive layer on the steel. Budget constraints precluded adopting this option for the project.

The concrete repairs currently being installed can be expected to have a service life of more than 20 years. The concrete surrounding the steel is freshly placed, highly alkaline, and able to protect the reinforcing steel from corrosion. The areas that have not been repaired will continue to deteriorate with age and may exhibit significant corrosion damage

440 West Condominium Plaza Deck Repair

Owner

440 West Condominium
Clearwater, FL

Project Engineer

Karins Engineering Group, Inc.
Sarasota, FL

Repair Contractor

RestoCon Corporation
Tampa, FL

in 5 to 10 years. This outcome is to be expected in traditional chip-and-patch repair projects.

The half-cell corrosion survey required access to the bare concrete surface. This was not possible until the contractor had removed the existing interlocking concrete pavers, sand setting bed, and a defective waterproofing membrane. Correlation of the potential map with areas of concrete repair demonstrates the utility of this method of nondestructive corrosion testing when it can be applied.

The project is expected to be completed in December of this year, and remains on time and under budget with nearly 50% of the job complete. In total, approximately 2500 ft³ (71 m³) of concrete repair is anticipated.

F. Carter "Bud" Karins and Andy Schrader are engineers with Karins Engineering Group, Inc., consulting engineers with four Florida offices and specializing in the design and restoration of buildings. They are both members of ICRI and ASCE, and have both studied at the University of South Florida.