Low-Rise Category

Pentagon Renovations—Exterior Wall Repair and Interior Structural Repair

Arlington, Virginia

Submitted by Concrete Protection & Restoration, Inc.

Pentagon in all its majesty

The Pentagon Renovation is a 10-year project that will restore or replace all building system components. Concrete repair, both interior and exterior, is a fundamental and necessary part of the renovation. PENREN, the governing agency for the renovations, has dictated that these repairs must last 50 years. Therefore, the repair program needs to take into consideration a protection system designed to resist damage for the next 50 years.

FIELD INVESTIGATION

Concrete testing performed revealed that the existing concrete walls were carbonated to a depth of 3 to 4 in. (76 to 102 mm). Destructive testing revealed that during construction, the outer layer of wall reinforcing was placed approximately 1/2 in. (13 mm) from the finished exterior surface. The improper placement of the reinforcing steel was mainly due to the fast-paced construction of the Pentagon. The reinforcing steel placement and wooden forms were not coordinated to ensure proper coverage. The rough-cut board forms exaggerated this condition by not providing a uniform surface exterior to the steel. The improper placement of the reinforcing steel, coupled with the years of carbonation, has created an environment ideal for corrosion.

As carbonation lowers the alkalinity of the concrete, it causes a loss of the reinforcing steel's natural protection from corrosion. Furthermore, the exterior finished surface of the concrete is very porous as a direct result of the rough-cut lumber-formed surface and the low concrete strength. Moisture is easily absorbed into this porous surface every time it rains. With the carbonation being well below the threshold limit, corrosion was induced; and the unprotected reinforcing steel began to oxidize.

Originally designed as a four-story structure, the fifth floor was added after construction began. Selective demolition of existing conditions revealed inadequate reinforcing bar splices between what was the fourth floor parapet wall and the base of the new fifth floor wall. The exterior wall repairs included a splice detail to correct this situation.

Through visual inspection, the lightwell walls indicated telltale signs of concrete spalling and exposed reinforcing steel corrosion. Exposed reinforcing steel was observed at many locations on the lightwell wall finished surfaces. Reinforcing steel ends, chair legs, and tie wire were on the exterior formed surfaces and exposed to the elements. Initially, it was estimated that approximately 20 to 30% of the exterior wall was in need of repair.

PROJECT EXECUTION—LIGHTWELL WALLS

A concrete repair program was designed by the Structural Engineer of Record to accomplish the following:

- Repair work shall incorporate the ICRI Technical Guidelines for concrete repair;
- Delaminated, spalled, and cracked concrete related to corrosion of the steel and any unsound concrete around the reinforcing bar should be removed down to sound concrete;
- The steel reinforcing bar that is exposed should be mechanically cleaned to remove all existing rust and scale. Where corrosion extends around the entire circumference of the bar, the bar must be undercut to allow sandblast cleaning of its entirety;
- Reinforcing steel should be relocated to provide, at a minimum, 1-1/2 in. (38 mm) of concrete cover;
- Once cleaned, the reinforcement would be treated with a corrosion-inhibiting coating;
- New concrete patching material would then be installed in the areas of removal. New patching material should match existing formed board surface in color and texture. Specification requirement is that the repair shall not be noticeable from a distance of 30 ft (9 m); and

Repair crews working on Pentagon walls

Work area showing extensive scaffolding

View of interior lightwell work area

- When the concrete repairs are complete, all surfaces of the building should be cleaned; and all exposed concrete surfaces of the building should be treated with a penetrating corrosion inhibitor, a solid silane sealer, and a mineral-based coating, providing a preventative waterproof surface for the original concrete surfaces, protection for the new repairs, and a uniform finished appearance for the building exterior.

To accomplish these tasks, the contractor worked with the material supplier to develop a custom repair concrete that matched the strength and color of the existing material. Full-scale mock-ups and laboratory analysis were conducted to ensure the material met all of the requirements. This material was developed in two formulations: one was pumpable for larger repair areas and the other was trowelable for the minor amount of hand patching on smaller repair areas.

Interior beam repair work—notice the extensive shoring

View of the full-depth beam repair

To meet the specification requirements that the repairs are not detectable from a distance of 30 ft (9 m), the contractor used rough-cut lumber to match the texture of the original surface. Each board was cut specifically to match the varying widths of the existing wall, and the edges were beveled to create the "ribbed" finish.

Another interesting aspect of the repairs was the complete rebuild of intricate concrete cornices. Skilled craftsmen produced an exact mold of the existing cornice out of fiber-reinforced polymer (FRP) to be used as a form liner. This enabled work crews to form and pump large sections of the cornice at one time, eliminating cold joints while exactly matching the existing contours of the cornice.

To meet the 50-year design life requirement, the following steps were taken:

- In areas of inadequate cover, the concrete was undercut and the reinforcing bar was recessed to provide a minimum of 1-1/2 in. (38 mm) cover; and
- After sandblasting, a corrosion inhibiting coating was applied to the reinforcing.

After completion of the structural repairs, two different corrosion scenarios had to be addressed to provide protection for the new and the unrepaired areas of the wall. One was to overcome the carbonation, and the other was to arrest the water migration into the walls. The following approach was chosen to address these problems:

- A migrating corrosion inhibitor, selected to compensate for the loss of alkalinity around the reinforcing steel, was applied to the entire wall surface. This amino-based migrating inhibitor was topically applied to the concrete surface, and this water-based inhibitor penetrates the concrete's pour structure through capillary action, causing it to diffuse throughout the concrete molecular matrix. Furthermore, the amino molecules have an ionic reaction with the reinforcing steel, causing a physical attraction creating a tenacious bond to the reinforcing steel, and thus recreating a passive layer of high alkalinity;
- After the application of the migrating corrosion inhibitor, a 100% silane sealer was applied to the walls to repel water and reduce moisture absorption; and
- A mineral-based coating was applied to provide a preventative waterproofing for the unrepaired concrete areas, protect the new repairs, act as further prevention against water absorption, and give the building a uniform appearance. This potassium silicate coating was chosen to form a chemical bond with the concrete, yet allow the cast-in-place structure to breathe and be permeable. The coating system chosen is high in pH to protect the reinforcing steel and concrete from carbonation.

PROJECT EXECUTION—INTERIOR REPAIRS

The lightwell walls were not the only concrete at the Pentagon in need of protection and restoration. Following asbestos and lead abatement, the interior finishes were removed to bare concrete, revealing a structure in distress. The inspecting engineering agency then sounded the concrete structural system components and marked areas that required repair. Some repairs included full-depth column and beam repairs requiring the use of extensive shoring. As with the exterior lightwell repairs, the large repairs were formed and placed, and the small interior repairs were placed with the hand-applied method.

In one particular area, the removal of the interior finishes uncovered a large section of the second-floor structure that had been damaged by an historical fire. This unexpected repair required full-depth removal of beams and girders, some more than 4 ft (1.2 m) deep. After the floor slab was extensively shored, the damaged concrete was removed, the beams were formed, and ready mixed concrete was placed from the above level.

Other repairs to the interior include removal and replacement of floor coating, expansion joint repairs/installation, and window sill replacements.

CHALLENGES

Although the nature of the concrete repairs and the theory of how to repair were quite elementary in respect to the science of concrete repair, there were several obstacles that made this a very difficult project. They are as follows:

- Active office complex housing our nation's defense command;
- Security clearances;
- Limited work schedule and hours, making it a multi-shift, multi-phase, and multi-year project;
- Noise-producing work was restricted to certain time frames on different sections of the building;
- Access was difficult and different forms of scaffold/overhead protection were required to maintain access to building entrances and drive lanes;
- A high-profile client occupied building;
- Selection of repair material to meet performance specification and to allow for color and texture match; and
- Extravagant formwork necessary to achieve desired textured finishes.

To meet the demanding schedule, it was decided to perform the work in two shifts. This enabled the same scaffolding to be used for demolition on the night shift that was used for forming and placing on the day shift. In addition, the noise generated by demolition did not impact office workers in adjacent spaces.

Close-up of repaired area on walls, before and after

Before and after coating application

This project presented many unique obstacles, the most difficult of which was access. Although the work in the lightwells was outdoors, all material and equipment had to pass through the interior of the building to the third-floor access to the work area. For example, all scaffolding and form boards had to be loaded onto carts, moved to a material hoist, and rolled through the building. A self-contained hydraulic concrete pump was specially manufactured to fit through a standard 3 ft (0.9 m) wide door opening. Due to limitations of the material hoists, large equipment such as air compressors had to remain outside the building. Bull hoses had to be run over the roof to the interior work areas, sometimes over 500 ft (152 m) away.

The contractor was able to meet and exceed everyone's expectations by staffing the crew with an experienced project management team that welcomed these challenges and worked together to solve the details. The schedule was very fast paced and complicated by the occupancy of the building that has many different uses and needs. The contractor had to accommodate these needs and work with the client while maintaining schedule and cost.

This project was a perfect example of the importance of everyone on the repair team working together to provide a durable, economical, and quality repair. Through communication, innovation, and strategic planning, the project was a success from the beginning to the end.

The Pentagon

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Completed repairs