HICKAM AIR FORCE BASE HEADQUARTERS

CRAWL-SPACE COLUMN REPAIRS AND CORROSION MITIGATION

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Fig. 1: Hickam Air Force Base Headquarters PACAF Building, Oahu, HI

The Hickam Air Force Base Headquarters Pacific Air Forces (PACAF) Building is listed on the National Register of Historic Places. The building (Fig. 1) is a landmark World War II structure that was strafed by the Japanese Air Force during the attack on Pearl Harbor. The damage caused by bullets hitting the concrete façade of the building caused popouts, which are now considered historic defects and cannot be repaired.

The original structure, built in the 1940s, is a three-story building constructed of a cast-in-place reinforced concrete frame and floor system. This 500,000 ft^2 (46,450 m^2) facility houses approximately 1900 people working for nearly 30 different organizations, who are responsible for the entire Pacific area.

There are 14 wings in the irregular-shaped building, but this project was limited to 13 wings (no work was scheduled in Wing N because it does not have a crawl space) (refer to Fig. 2). The crawl-space structural framing consists of reinforced

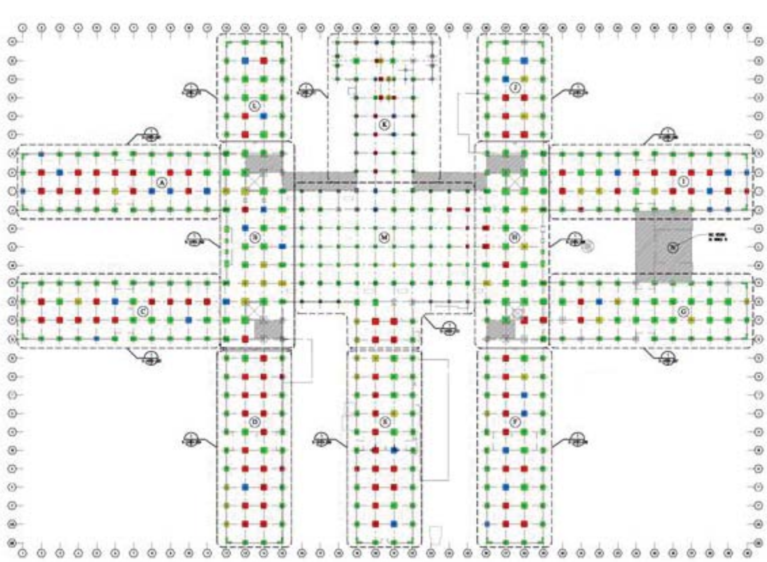

Fig. 2: Headquarters floor plan

Fig. 3: Corrosion damage to the crawl-space columns

Fig. 4: Column with no damage (green condition)

Fig. 5: Column with minor damage (yellow condition)

concrete slabs, beams, and columns supported on pedestals and spread footings with about 4 ft (1.2 m) of overhead clearance.

PROBLEMS THAT PROMPTED REPAIR

Concrete damage and reinforcement corrosion were observed in a substantial number of crawl-space columns (refer to Fig. 3), typically at or near the interface with surrounding soils. In particular, significant corrosion damage was visible at the chamfered edges where there was less concrete cover over the reinforcing steel.

EVALUATION METHODS

It was hypothesized that chlorides had migrated into the columns by flooding or wicking from chloride-bearing soils. The concern about the severity of the deterioration was magnified by the fact that the crawl-space columns support the highest building loads.

During 2006-2007, a condition evaluation of the building was completed by an independent consultant. This study assessed the extent of corrosion activity and evaluated alternatives for corrosion mitigation, preservation, and rehabilitation of the structure.

A subjective rating system was developed and used by the consultant to provide a general representation of the overall condition of the crawl space columns. The columns were rated and color-coded as follows:

- No Damage (green): No discernible structural deterioration (refer to Fig. 4);
- Minor Damage (yellow): Minor levels of cracking and spalling with no visible reinforcement (refer to Fig. 5);
- Intermediate Damage (blue): Larger cracking and medium-sized spalls with localized exposure of reinforcement (refer to Fig. 6); and
- Severe Damage (red): Severe cracking and large spalls with severe corrosion and section loss of the reinforcement (refer to Fig. 7).

The corrosion evaluation also consisted of petrographic analysis, chloride chemical analysis, carbonation testing, delamination surveys, and chloride concentration testing of the soils. After the survey was completed, it was determined that the corrosion damage was confined to the concrete columns in the crawl space. In particular, the corrosion typically occurred at or near the interface of the column with the surrounding surface soils.

Fig. 6: Column with intermediate damage (blue condition)

Fig. 7: Column with severe damage (red condition)

TEST RESULTS

The chloride-ion testing indicated extremely high concentrations of chlorides in the outer 2 in. (50 mm) of the columns, decreasing with depth from the surface. The two worst columns tested had chloride ion contents of 3.22 and 7.00% by weight of cement. Because of the wet conditions in the crawl space, a chloride threshold value of 0.15% was used. This level is applicable for reinforced concrete exposed to moisture in service, as recommended by ACI 318-08.

CAUSE OF DETERIORATION

Based on the field survey and test results, it was determined that the observed problems were caused by chloride-induced corrosion of the reinforcing steel. In sufficient quantities, chloride ions destroy the normal passive oxide protection that encases the reinforcing steel, leaving the structure vulnerable to corrosion. The corrosion by-product is expansive in nature and leads to concrete cracks, delaminations, and spalling.

The process of chip-and-patch concrete repairs will address localized corrosion damage but can also accelerate corrosion in adjacent areas. Additionally, widespread chloride contamination would likely lead to continued corrosion damage. Due to the severity of the problem, it was determined that additional corrosion protection was necessary to achieve an extended service life of the repairs and the structure.

Fig. 8: Galvanic encasement protects and strengthens severely damaged columns

REPAIR SYSTEM SELECTION

The Air Force determined that the historic building needed to be repaired and preserved. The primary objectives were to:

- Repair all crawl-space columns;
- Add a corrosion mitigation system to these columns;
- Include the ability to remotely monitor a sample of columns; and
- Preserve and protect the historic structure for future generations while meeting the needs of the military.

Consideration of corrosion mitigation alternatives primarily focused on electrochemical methods, including:

- Impressed current cathodic protection;
- Various galvanic corrosion protection systems; and
- Electrochemical treatments (that is, chloride extraction).

After considering the various corrosion mitigation options, the plan devised by the consultants and the United States Air Force (USAF) was to use a galvanic corrosion protection system on all crawl-space columns in the work area. This amounted to approximately 570 columns that required both repair and protection in an area with difficult access and low overhead clearance.

The galvanic anodes selected for the Headquarters were designed to provide corrosion control to active corrosion sites while preventing the initiation of new corrosion cells in chloride-contaminated areas, including patch-accelerated corrosion also known as the ring-anode effect. The galvanic anodes selected were intended to extend the useful service life of both the repairs and the remaining structure.

Galvanic anodes are typically embedded in concrete or placed on the surface of the concrete. In either case, zinc is most commonly used as the sacrificial anode that corrodes preferentially to the steel reinforcing. As the zinc corrodes, it provides a small electrical current to the adjacent reinforcing steel sufficient to control or mitigate the initiation of new corrosion sites.

The galvanic protection system consists of two different anode types with the necessary accessories to complete the installation. Chip-and-patch repairs with zinc sheet anodes were employed on columns with little or no damage. Galvanic encasements with cast-in alkali-activated zinc anode strips were installed to provide a combination of corrosion protection and strengthening for the columns with intermediate and severe corrosion damage.

REPAIR PROCESS EXECUTION

At the most severely damaged columns (blue/red), the columns were overbuilt on all four sides and encapsulated with a new reinforced concrete jacket approximately 6 to 8 ft (1.8 to 2.4 m) in height. Both the existing and new reinforcing steel were protected by embedded galvanic anodes, which were 5.5 to 7.5 ft (1.7 to 2.3 m) in length (refer to Fig. 8). The repairs included the following work:

- Soil around the column was removed to expose the footer;
- All loose, spalled, and delaminated concrete was removed using small handheld chipping hammers;
- A new reinforcing bar cage was constructed around the columns;
- Embedded alkali-activated strip anodes were placed on each side of these columns, electrically connected to new and existing reinforcement, and then secured to the inside of the reinforcing bar cage; and
- The columns were then formed and poured with new concrete.

At the columns with little or no existing deterioration (green/yellow), zinc sheet anodes were surface-applied to all faces of the columns after the repairs were completed (refer to Fig. 6). The zinc sheet anodes use a preformed conductive adhesive that bonds the anode to the concrete surface while allowing ionic current flow between the anode and the reinforcing steel. These repairs included the following work:

- Soil around the column was removed to expose the footer;
- Electrical connections were made to the reinforcing steel;
- Concrete patch repairs were completed using ICRI guidelines and cured for 28 days;
- After surface preparation was completed and just immediately prior to installing the zinc sheet anodes, the columns were blown clean and free of dust;
- The zinc sheet anodes were installed in a vertical orientation;
- The zinc sheet anodes were interconnected by soldering zinc foil to each individual anode and connecting it to the electrical connectors;
- Nylon pins were installed at 2 ft (0.6 m) intervals along each edge of the zinc sheet anodes for supplemental anchoring; and
- Protection of the zinc sheet anode consisted of the use of a polyurethane adhesive along the zinc sheet edges with a final waterproof topcoat applied to the entire column (refer to Fig. 9).

The galvanic protection system selected offered an excellent combination of long service life with little or no ongoing system adjustment or maintenance requirements. Of particular benefit was the ease of installation in this difficult environment.

Fig. 9: Surface applied zinc sheet anodes prior to final coating

Anode materials could be carried by hand and installed with handheld tools to protect individual columns with very little cabling required. This allowed the contractor to have significant flexibility over the column repair sequence.

Although a galvanic system was selected, the USAF still wanted the capability to monitor a sample of the repaired columns. Remote monitoring of the protection system (refer to Fig. 10) was important to the owner because access into the crawl space is very difficult and, as a result, rarely done. Instead of requiring every column to be instrumented, a representative sample from each wing was selected. The instrumented sample locations included columns from each damage state.

Fig. 10: Monitoring cabinet in central location

Hickam Air Force Base Headquarters

OWNER
Joint Base Pearl Harbor Hickam
Oahu, HI

PROJECT ENGINEER
Baldridge & Associates
Honolulu, HI

REPAIR CONTRACTOR
Niking Corporation
Wahiawa, HI

MATERIAL SUPPLIERS
Vector Corrosion Technologies, Inc.
Tampa, FL

For more information about the history of Hickam Air Force Base Headquarters, including a link to view its National Historic Landmark Nomination, visit www.nps.gov/nr/travel/aviation/hic.htm

SPECIAL PROJECT FEATURES

Because of its historic significance (listed on the National Register of Historic Places), the Hickam Air Force Base Headquarters PACAF Building in Oahu, HI, was designated for rehabilitation rather than replacement.

The repair design on this project offered an excellent solution, which met the criteria of service life, cost, and maintenance without major impact on the operation of this mission critical historic structure. This rehabilitation project was essential prior to commencing a major interior renovation of the Headquarters. When complete, the structure will be preserved for continued use by future generations of military personnel who are providing our essential national security.

__Tore O. Arnesen__, PE, SE, is the Western U.S. Business Development Manager and Representative for Vector Corrosion Technologies, Inc. Arnesen has over 35 years of experience as a structural engineer, and he is registered in several states with experience in designing timber, steel, pre-cast concrete, cast-in-place concrete, prestressed concrete, masonry, and fabric structures for heavy industrial facilities (power and water/wastewater treatment facilities) and commercial buildings. He has authored numerous publications and participated in developing several national codes and standards. He is also a certified National Association of Corrosion Engineers (NACE) Tester, with specialized experience and knowledge in investigating and resolving the large infrastructure-related corrosion issues and problems our nation is facing.

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