Concrete Repair of Hangar Building 340

Naval Air Station, North Island, San Diego, California

By Roy Becker and Adriano "A. B." Bortolin

Hangar Building 340 is a conventionally reinforced cast-in-place concrete structure that was constructed by the Navy in 1940 for use by large seaplanes. The structure consists of a double-arch type of construction, with overall dimensions of 250 x 600 ft (76 x 183 m) with a maximum height of 80 ft (24 m) at the crown of the arches. The clear span of arches is almost 300 ft (91 m). The load-carrying system consists of a thin shell concrete roof slab supported by reinforced concrete arches. The thin shell concrete roof has a thickness of 4 to 6 in. (10 to 15 cm). The concrete arches have a depth of 6 ft (1.8 m) at their crown and 14 ft (4.3 m) at their base, with widths varying from 2 to 7 ft (0.6 to 2.1 m). Both the thin shell concrete roof slabs and the concrete arches are heavily reinforced with both plain and deformed reinforcing bars.

Hangar Building 340

Interior of Hangar Building 340

Due to the uniqueness of the framing system coupled with its massive size and very long clear span of almost 300 ft (91 m), Hangar Building 340 is recognized by the American Society of Civil Engineers as a historic building.

At the present time, this hangar is utilized by the Navy for housing four squadrons of helicopter craft, with a total staff of approximately 1000 Navy personnel assigned to this maintenance hangar that is considered an essential facility.

Reasons for Repair

This 62-year-old reinforced concrete structure has experienced significant concrete spalling on both the underside of the thin shell concrete roof and the exterior arches. The spalling was mainly due to the corrosive marine environment that exists at this hangar, which is located about 400 ft (120 m) from San Diego Harbor.

The most significant spalling occurred in the year 2000 and greatly concerned the Navy, as some spalls fell from a height of nearly 80 ft (24 m) onto the hangar bay floor that was occupied by large numbers of Navy personnel and costly helicopters. Some of the concrete spalls were from previously repaired spalls, and they weighed as much as 5 lb (2.3 kg).

Obviously, the Navy became very concerned with these concrete spalls falling on the hangar bay floor, and, consequently, all personnel and equipment were evacuated from the hangar bays to the adjacent apron areas. Hence, the maintenance functions of Hangar Building 340 were compromised and the efficiency of the operation decreased, especially during the winter months.

Inspection and Evaluation Methods

As a result of the spalling that occurred and the evacuation of the two hangar bays, structural engineers were engaged to both evaluate the overall structural integrity of Hangar Building 340 and then provide repair methods that could be quickly performed.

A thorough structural analysis was made using a three-dimensional computer program known as SAP 2000. This analysis indicated that the basic design for this hangar was quite adequate to resist gravity and wind loads.

An extensive inspection program was then made to determine the extent of the corrosion of the reinforcing steel on the underside of the roof shell and the exterior arches. The primary inspection method for this evaluation was provided by a large number of "soundings" made by the impact of a hammer on the concrete. The results of the soundings determined that the corrosion of the reinforcing steel had spalled/delaminated the concrete in a large number of locations, especially on the exterior outer portion of the arches.

In addition to this inspection methodology, a testing procedure was established to determine:

- Compressive strength of concrete obtained by taking cores;
- Thickness of the thin shell concrete slabs determined by roto-hammer penetrations;
- Ultrasonic testing to determine concrete compressive strength;
- Half-cell potential measured to determine corrosion activity of the reinforcing steel; and
- Quality of concrete, depth of carbonation, and chloride content obtained by cores examined by a testing company in Skokie, Illinois.

Finally, portions of the concrete that were spalled were removed at a number of locations to determine the extent/degree of corrosion of the underlying reinforcing steel.

Test and Inspection Results

The results of this thorough testing and inspection program indicated the following:

- In general, concrete compressive strengths were relatively high, ranging from 3500 to 8000 psi (24 to 55 MPa);
- The concrete portion of the thin shell roof was constructed to the specified thickness shown on the design drawings;
- The concrete quality was good, and the depth of carbonation was not unusually deep (about 1 in. [2.5 cm]);
- Corrosion of reinforcing steel ranged from slight to severe, and especially severe in the outer faces of the exterior arches; and
- The number of spalled/delaminated concrete surface areas was much larger than that obtained by visual examination alone.

Typical spall on underside of thin shell

Causes of Deterioration

The basic causes of the concrete/reinforcing steel deterioration were attributed to the following factors:

- The proximity of Hangar Building 340 to salt water;
- Insufficient concrete cover of the reinforcing steel, especially in the exterior arches, and carbonation of the concrete;
- Localized poor consolidation and segregation of the concrete mix; and
- The age of the structure (62 years).

Repair System Selection

Although the Navy had considered suspending a heavy fabric from the underside of the thin shell concrete roof to protect both personnel and helicopters from falling spalls, it was determined that this was not an optimum solution because it did not prevent additional deterioration of the concrete structure. Also, the cost of this suspended fabric would have been nearly $2 million, which is about twice the cost of the repair system that the structural engineers recommended to the Navy. The structural engineers recommended to the Navy that the selected repair do the following:

- Restore the original structure;
- Prevent future deterioration for approximately 25 years;
- Limit the expenditure of repair funds; and
- Accomplish the repair in 3 months so that the Navy could quickly utilize the hangar bays.

The structural engineers, using a repair method that directly attacked the problem of reinforcing steel corrosion and concrete spalling/delaminations, achieved these objectives. This repair/restoration consisted of the following basic procedures in this sequence:

1. Removing spalled concrete by hand methods;
2. Applying high-strength polymer repair mortar to spalls by hand methods;

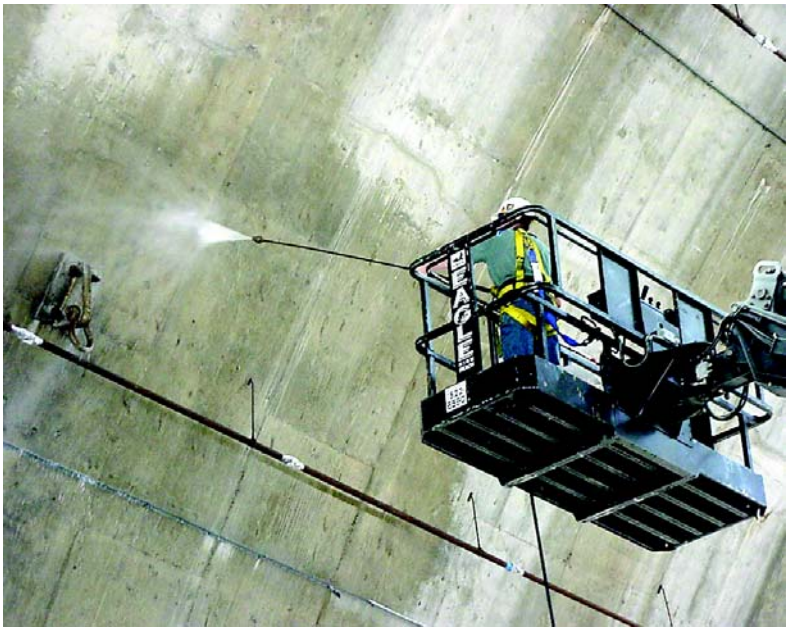
3. Applying a penetrating, corrosion inhibiting impregnation to all exposed concrete surfaces; and
4. Applying a protective, anticarbonation acrylic coating to all exposed concrete surfaces.

Site Preparation

Prior to construction, full-height temporary dustproof/waterproof curtains were installed to protect shops and offices adjacent to the hangar bays. Also, dams of polyethylene tubing were provided around the perimeter of both hangar bays to contain water and debris from the hydroblasting operations.

On the outside of the hangar bays, temporary foreign object damage (FOD) control fencing was constructed to prevent debris from spreading to areas where aircraft were parked on the adjacent aprons.

Cleaning spalled areas prior to repair



Surface preparation by hydroblasting

Demolition Method

No extensive demolition was required, only localized removal of spalls.

Some spall removals were as large as 3 x 5 ft (1 x 1.5 m) for the entire thickness of the thin shell roof slab. This was often the result of poor consolidation and segregation of the concrete mix that was placed in 1940.

Surface Preparation

To thoroughly determine the extent of the concrete deterioration, all exposed concrete surfaces were hydroblasted using pressure of 4000 to 6000 psi (27 to 41 MPa), and then any suspected surfaces were carefully visually and impact hammer inspected to determine which additional areas should be repaired.

The spalled areas were removed to a geometrically regular configuration by sawcutting to a depth of 1/2 in. (1.2 cm) around the perimeter of the spalled areas. Then, 15 lb chipping hammers were used to remove all unsound concrete and expose the reinforcing steel.

Reinforcing steel was then cleaned to white metal by abrasive bead blasting. Reinforcing steel that was badly corroded was replaced with new reinforcement (this occurred infrequently).

Application Method Selection

Because the hangar bays are as high as 80 ft (24 m), seven high lifts were used to expedite the construction process and to eliminate scaffolding. The high-strength polymer repair mortar was hand applied and hand finished. The corrosion-inhibiting impregnation and the anticarbonation acrylic coating were applied by air-actuated spray guns.

Repair Process Execution

After the basic surface preparation, the repair methodology and sequence of application was in this manner:

1. Application of a bonding agent and reinforcement protection to the prepared concrete and reinforcing steel surfaces;
2. Application of a high-strength polymer repair mortar for all spall repairs;
3. Application of a penetrating, corrosion-inhibiting impregnation to all concrete surfaces; and
4. Application of a protective, acrylic-based, anticarbonation coating to all concrete surfaces.

In many cases, the lateral extent of the concrete spalls and reinforcing steel corrosion was greater than that initially determined in the investigative process.

Unique Features of the Project

The most unique features of this project for the repair of Hangar Building 340 can be summarized as follows:

- Guidelines for a State Historical Structure were met because the repairs did not change the physical appearance of the hangar;
- Life of this essential facility for the Navy was extended at least 25 years;
- All repair/restoration work was completed in less than 3 months. Thus, the Navy was able to utilize the hangar for maintenance of helicopters much earlier than anticipated;
- Cost of this repair/restoration was accomplished for about $950,000; this is about $5/ft^2 of facility and about 1/2 the cost of other proposed methods, such as heavy fabric suspended from the thin shell concrete roof;
- Repair employed a significant number of unique repair products in combination with each other that were used to extend the life of the structure by reducing future corrosion of the reinforcing steel and carbonation of the concrete;
- No construction accidents or injuries occured, despite the fact that most of the work was performed by high lifts working at heights of 80 ft;
- Since completion a year ago, there has not been even one new concrete spall;
- Project requirements established minimum on-site training by material manufacturer for all personnel; and
- Project requirements established a quality standard of repair for spalls to determine minimum acceptable standards for repair. This was aided by the use of onsite mockups that the contractor was required to install prior to the commencement of any work.

Repairing spalls

Applying coating to exposed concrete surfaces

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North Island Naval Station Hangar Building 340

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Repair Contractor
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