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AWARD OF
EXCELLENCE

SPECIAL PROJECTS CATEGORY

Rehabilitation of 30-Year-Old Monolithic Salt Dome

SAVAGE, MINNESOTA

SUBMITTED BY VECTOR CONSTRUCTION, INC.

Monolithic Salt Dome, Savage, Minnesota

Since 1962, Cargill Salt has been one of the world's leading marketers of salt products. Cargill operates a salt storage and packaging facility on the Minnesota River south of Minneapolis, Minnesota, consisting of several monolithic concrete domes (Fig. 1) along with other site infrastructure.

Monolithic dome construction dates to the early 1960s when concrete was placed over mounded dirt and the dirt was excavated through doors after the concrete hardened. Modern dome construction methods include a reinforced concrete foundation ring beam, a temporary air-filled fabric form, a grid of reinforcing steel, and sprayed concrete (shotcrete). Monolithic domes are known to be strong, durable structures and are commonly used to store commodities such as sand, salt and cement.

The Cargill facility includes a 30-year-old monolithic dome that required rehabilitation to preserve and extend its useful service life. Chloride ions in the salt over time will penetrate through the concrete cover by diffusion and eventually reach the reinforcing steel in sufficient quantities to initiate corrosion. Corrosion in the interior of a dry, enclosed facility is expected to be less aggressive than exposed structures such as a bridge or parking ramp, but in this case, localized corrosion damage was visible.

The salt dome dimensions are 173 ft (53 m) diameter by 65 ft (20 m) high. A majority of the 35,000 sf (3250 m^2) shell surface area was 3 ½ in (90 mm) thick and reinforced with welded wire fabric with two stiffener rings near the crown. The shell sits on a 4 ft (1.2 m) high reinforced concrete ring beam. Post-tensioning tendons were used in lower sections of the dome between and over the door opening as part of the original structural design. Shotcrete was used on the inflated fabric form (Fig. 2 and 3).

CONDITION ASSESSMENT

A comprehensive assessment was conducted to evaluate the existing condition of the structure and to develop a repair strategy that would meet the owner's 30-year service life extension objective. The assessment included a review of existing documents; interviews with maintenance personnel; visual assessment; corrosion potential survey; chloride, carbonation and strength sampling; an evaluation of the post-tension tendons; and a lidar survey to make digital 3-D representations of the dome.

The condition assessment revealed the following issues:

- Widespread shadowing in shotcrete behind reinforcing (Fig. 4);
- Chloride contamination and carbonation, and a loss of alkalinity due to exposure to atmospheric carbon dioxide, progressed along the cracks causing localized corrosion that severed the steel reinforcement;
- Water infiltration and increased humidity around the skylights and penthouse structure on top of the dome, combined with chloride contamination at the level of the reinforcement, caused localized corrosion-induced concrete spalling and delaminations; and
- Exposed and corroding post-tension anchors, poor concrete consolidation behind some anchors, and complete loss of prestress in all tested tendons (Fig. 5).

REPAIR DESIGN AND PROGRAM

Despite the defects, rehabilitation of the structure was selected as the preferred option due to several factors including cost and operational impact to the important industrial facility. The objective of the dome rehabilitation was to extend its service life for an additional 30 years while minimizing disruption to the facility, which operates 24 hours a day, 7 days per week.

The structural engineer performed a finite element analysis utilizing the data collected from the laser survey and assumed complete loss of tension in the PT system. This information was critical to developing an appropriate repair/strengthening solution (Fig. 6).

The structural repair design included:

- Removal of conveyor loads;
- Repair of spalled and delaminated concrete utilizing ICRI 310.1R[1], Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion;
- Removal of skylights and filling in cavities to eliminate locations for potential water leakage from the exterior;
- Inject and bond/seal larger vertical cracks with low viscosity epoxy resin and strengthen with strips of glass fiber reinforced polymer (GFRP) applied to the concrete surface across the cracks;
- Removal and replacement of post-tension tendons between the doors;
- Casting of new doorjambs and eyebrows;
- Installation of external post-tensioning above the eyebrows (Fig. 7) with pilaster encasement of post-tension dog-bones; and
- Application of surface-applied GFRP strengthening at the top of the dome around stiffener ring (Fig. 8) and over epoxy-injected cracks.

In addition to the repair and strengthening design, implementation of a corrosion management plan was necessary to mitigate the ongoing

Fig. 1: Overhead view of salt storage and packaging facility

Fig. 2: Monolithic dome reinforcing during original construction prior to shotcrete placement

Fig. 3: Shotcrete placement over welded-wire fabric and post-tensioning tendons during original construction

Fig. 4: Shadowing of shotcrete created voids behind welded wire fabric reinforcement and post-tensioned tendons

corrosion risk to meet the 30-year service life extension objective. Despite the widespread exposure to chlorides, the dry interior environment limited active corrosion to localized areas of the dome. It was determined that the main corrosion risk was at repair locations and other interfaces between new and existing concrete where electrochemical compatibility can cause new corrosion cells to form around remaining penetrations, which may be subjected to high moisture content.

The corrosion mitigation plan included the following:

- Discrete galvanic anodes were placed at the perimeter of all concrete repairs and around the interface between the new and old concrete where the skylights were infilled (Fig. 9);
- Distributed alkali-activated galvanic anode strips were used in reconstructed doorjambs and eyebrows at the interface between new and old concrete, and to address the potential for new corrosion activity at these construction joints; and
- Surface-applied zinc anode sheets were installed around remaining penetrations into the dome (conveyor locations, etc.), connected to the embedded reinforcing steel and covered with the newly-applied roofing system.

CONCLUSION

Keys to the success of the project included teamwork and a design-build process that included input for all stakeholders including the owner, production staff, structural engineer, durability engineer, repair contractor and suppliers; a substantial condition assessment by qualified and experienced professionals; performing the work efficiently and safely; and an owner that was committed to maintenance and safety and willing to invest in its facilities with a long-term view.

REFERENCES

1. ICRI 310.1R, *Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion*, International Concrete Repair Institute, St. Paul, MN, 2008, 8 pp.

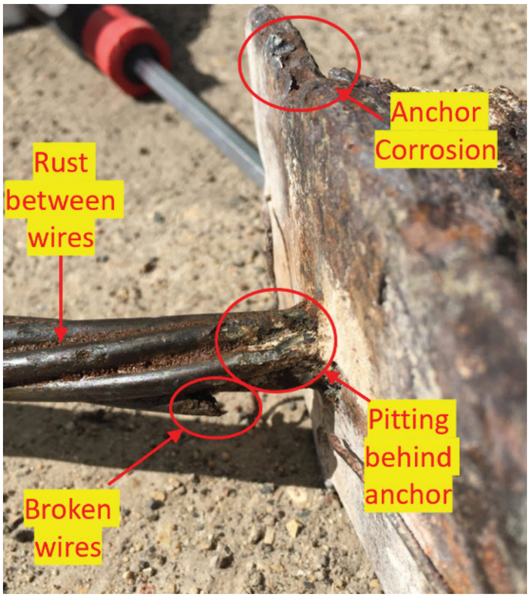

Fig. 5: Condition of extracted post-tension anchor and tendon

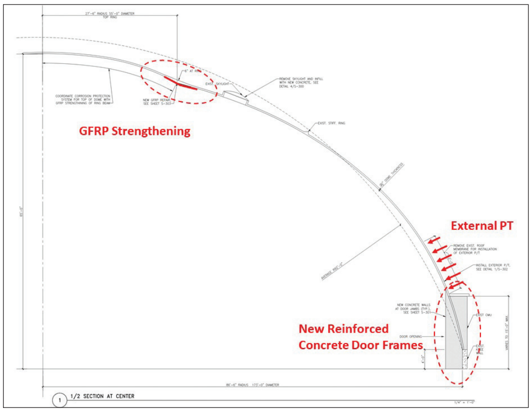

Fig. 6: General strengthening plan including GFRP and external post-tensioning

Fig. 7: Installation of new external post-tensioning system on dome above doorway eyebrows

Fig. 8: GRFP strengthening system applied externally under upper stiffener ring

Fig. 9: Type 1A embedded galvanic anodes were installed in traditional concrete repairs and skylight closure pours

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