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ASSET INTEGRITY INTELLIGENCE

Asset Integrity Case Study: Catalytic Reformer Support Structure

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Introduction

The catalytic reformer support structure shown in **Figure 1** is a conventionally reinforced cast-in-place concrete tabletop originally constructed in 1978 that supports a catalytic reformer, or platformer, and associated steel framing in a refinery on the Gulf Coast. The concrete tabletop consists of a 4.25 ft (1.3 m) thick upper deck that measures approximately 26 ft (8 m) by 18 ft (5.5 m). The upper deck has an octagonal penetration that allows the bottom head of the catalytic reformer and associated piping to pass through the deck as depicted in **Figure 2**. Four square conventionally reinforced concrete columns span from the mat foundation to the upper deck.

The ASME Section VIII Division 1 designed catalytic reformer is over 124 ft (38 m) tall and supported with a conical skirt and base ring secured to the tabletop with anchor rods. The catalytic reformer has an operating temperature of 1,000°F (538°C) and weighs nearly 370,000 lbs (168,000 kg) when fully loaded with catalyst.

As a result of the operating temperature of the catalytic reformer, the upper deck of the reformer support structure is exposed to high temperatures. The sides of the octagonal penetration near the bottom head of the catalytic reformer reach sustained temperatures of 530°F (277°C) based on IR inspection. A steam quenching ring is installed near the bottom head to mitigate potential fires resulting from the aggressive thermal transients during operation which challenge flange seal performance; as a result, the sides of the octagonal penetration and bottom of the upper deck have been periodically exposed to steam conditions throughout the service life.

Refinery personnel were aware that the upper deck of the catalytic reformer support structure had some level of deterioration, but the extent was not well known. Concern arose after several large concrete spalls fell onto the level below. Scaffolding was installed to catch future spalls and to mitigate future falling object hazards. Refinery personnel then contracted an engineer to perform a condition assessment to determine the criticality of repairs needed.

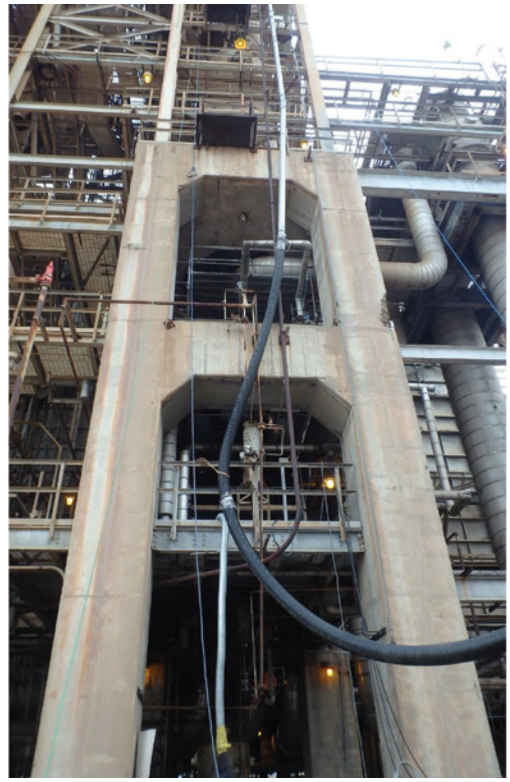

Figure 1. Catalytic reformer support structure.

Figure 2. View of octagonal penetration in upper deck and piping associated with the catalytic reformer.

Condition Assessment

A condition assessment was performed during a planned short-term outage to avoid working in the radiant heat of the catalytic reformer. The assessment consisted of a visual and tactile survey, limited nondestructive examination (NDE), material testing, and structural analysis.

Visual and Tactile Survey

The visual and tactile survey identified widespread spalling with exposed reinforcing and delamination of the sides of the octagonal penetration in the upper deck and along the bottom of the upper deck as shown in **Figure 3**. The original concrete cover was detailed at 3-inch (75 mm) clear; however, in half of the faces, the

Figure 3. Spalled concrete with exposed reinforcing on the sides of the octagonal penetration in the upper deck (fractured stirrups are visible).

Figure 4. Widespread cracking on top of upper deck, typically emanating radially from the catalytic reformer.

Figure 5. Measuring depth of drilled hole used for chloride and carbonation testing.

concrete cover was found to be approximately 4-1/2 inches (115 mm). Widespread cracking and delaminations in the top of the upper deck were also identified shown in **Figure 4**. Even with the deeper concrete cover, corrosion of reinforcing steel was present throughout the sides of the octagonal penetration in the upper deck. Despite the amount of corrosion product observed on the reinforcing bars, the section loss measured on the primary reinforcing bars was generally minor after removing the corrosion product. The most significant finding regarding the exposed reinforcing steel was that many of the No. 5 (5/8-inch [16 mm]) bar stirrups were fractured at the top corner bends. Stirrups are shear reinforcing for the concrete deck—without which, a shear overloading of the deck may result in a brittle failure.

Field and Material Testing

Discrete concrete hole drilling shown in **Figure 5** was also performed for carbonation and chloride testing. Carbonation testing was performed by applying a pH indicator (phenolphthalein) after cleaning the drilled hole and observing the color profile. At each of four test locations, powder was recovered as the hole was drilled, which was analyzed for the acid-soluble chloride content in general accordance with ASTM C1152, *Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete* [1]. The carbonation testing revealed that the depth of carbonation was minimal and ranged from 1/8 to 1/4-inch (3 to 6 mm). The acid-soluble chloride concentrations for the samples retrieved within the octagonal penetration of the upper deck were between 0.15 and 0.24 % by mass of sample. The original mix design for the concrete sampled was unknown; however, for an assumed cementitious content of 564 lbs per cubic yard (6 sack), an accepted chloride threshold for high risk of corrosion initiation of mild reinforcing steel is 0.09 % – (0.5 to 0.6 % by weight of cement) [2]. The chloride concentrations from the samples retrieved from the upper deck were well in excess of values expected to initiate corrosion.

Structural Analysis

Structural analysis of the catalytic reformer support structure was performed to understand the potential structural capacity reduction of the tabletop given the magnitude of the observed deterioration. Member demands were calculated using loads estimated from the available design documentation and a visual survey of the structure and equipment. Concrete capacities were calculated in accordance with ACI 318-14, *Building Code Requirements for Structural Concrete* [3]. Distress conditions observed during the condition assessment were considered in calculating member capacities. The structural analysis demonstrated that the catalytic reformer support structure had adequate structural capacity to support the in-service loads in its deteriorated condition at the time of the assessment. More specifically, although the reinforcing steel stirrups were essentially useless in their deteriorated state, the concrete itself was able to resist the design-level loading conditions.

Findings

Through the findings of the condition assessment, it was concluded that heat-related deterioration of the concrete and chloride-induced corrosion significantly accelerated by the heat were the primary causes of the distress conditions. While the support structure had adequate structural capacity to support in-service loads, repairs were recommended during the next major turnaround as unmitigated corrosion and heat deterioration would continue to occur, potentially endangering personnel working the vicinity and ultimately the mechanical integrity of the platformer vessel itself.

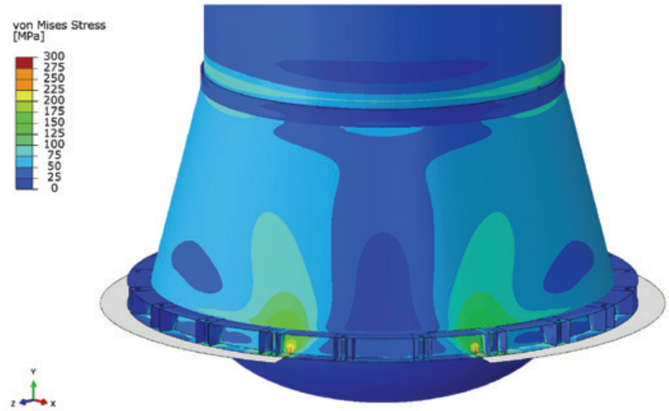

Figure 6. Image from detailed finite element model used to assess catalytic reformer vessel and skirt during concrete removal.

Figure 7. Welded wire reinforcing, galvanic anodes (arrows), and concrete maturity meter in repair area.

Repair Design

Following the condition assessment, refinery personnel authorized the design of repairs for the catalytic reformer support structure. The goals of the repairs were to restore the structural capacity and to extend the service life of the structure. Construction for the repairs was planned for the next turnaround opportunity in the crude unit, which was expected to last six weeks.

The repairs consisted of partial depth concrete repairs with distributed galvanic anodes on the sides of the octagonal penetration and the bottom of the upper deck and required the removal of deteriorated and unsound concrete, and preparation of the concrete substrate to a CSP 7 [4]. Refinery policies prevented the use of abrasive media blasting; as such, all exposed reinforcing was required to be power tool cleaned and meet the requirements of SSPC SP 3 [5]. The fractured stirrups were supplemented with new lapped reinforcing steel. Welded wire reinforcing was detailed as skin reinforcing on the outside of the galvanic anodes to control crack widths on the exposed faces. Cathodic protection was detailed with eight unique zones so refinery personnel could monitor the performance of the system.

The repairs also included partial depth concrete repairs on the top of the upper deck. Localized partial depth concrete repairs were also detailed at specific locations on the columns and beams below the upper deck.

Construction Challenges and Solutions

This project involved several construction and schedule challenges that required unique solutions and a collaborative approach by the project team to successfully repair the deteriorated structure.

The concrete repairs on the sides of the octagonal penetration in the upper deck presented a challenge in the form of difficult working conditions. These repairs had to be completed in the cramped working space between the bottom head of the catalytic reformer and the sides of the octagonal penetration. The difficult working conditions extended the amount of time required to complete the repairs in this area. The contractor identified the construction ergonomics during preconstruction planning and adequately accounted for it during scheduling.

During construction, it was determined that the extent of deteriorated concrete in the upper deck was greater than anticipated, requiring the removal of concrete beyond what was planned, including directly below the catalytic reformer skirt base ring. The removal of concrete below the catalytic reformer skirt base ring would result in the skirt not being directly supported continuously around the base as designed. To address this issue, the construction sequence was modified to occur in two phases with each phase repairing four nonadjacent zones of the upper deck at a time. A detailed finite element analysis (FEA) of the catalytic reformer vessel, skirt, and base ring (**Figure 6**) was performed per the Level 3 procedures in API 579-1/ASME FFS-1, *Fitness-for-Service*, to ensure mechanical integrity and stability of the reformer during the repair procedure [6]. This sequencing allowed the additional deteriorated concrete to be removed, which resulted in a high-quality concrete repair while still meeting the demanding project schedule.

While the turnaround schedule originally spanned six weeks, the schedule coincided with the onset of the COVID-19 pandemic. To minimize the total number of workers at the plant, the owner requested that night work be eliminated and extended the

Figure 8. Completed repair on the sides of the octagonal penetration in the upper deck.

Figure 9. Completed repair on top of upper deck.

overall turnaround duration to 14 weeks. Although the overall turnaround schedule was extended, the owner requested that the concrete repairs be completed as quickly as possible to accommodate other planned inspection, repair, and maintenance activities. Therefore, the contractor was given a special exemption to utilize two 12-hour shifts during portions of the construction to finish in seven weeks.

Given the tight working areas and limited access, the contractor elected to pump a modified ready-mixed, self-consolidated concrete for the repair to achieve the desired properties of rapid strength gain and flowability while maintaining pumpability during the summer months. Furthermore, frequent engineer site visits were made during construction to quickly address questions and concerns. One activity that the contractor identified as being on the critical path was removal of formwork after the first phase of repairs. To support the earliest removal of formwork possible, laboratory testing was performed on the selected concrete mix to develop maturity correlations and maturity meters were installed in the repairs as shown in **Figure 7**. The additional testing and instrumentation provided confidence for the in-place concrete strength and allowed for the formwork to be removed as early as possible.

Conclusion

Despite the significant challenges presented by the difficult working conditions, extent of concrete deterioration, and aggressive project schedule, the repairs to the catalytic reformer support structure shown in **Figures 8** and **9** were completed on time. Refinery personnel were highly satisfied with the assessment, design, and repair implementation of the project team. The collaborative approach of the project team contributed to a safe and well-executed project where the repaired catalytic reformer support structure is anticipated to have a long, useful life extension with minimal maintenance. ■

For more information on this subject or the author, please email us at inquiries@inspectioneering.com.

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