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WHEN BAD THINGS HAPPEN TO GOOD PRESSURE VESSELS: A STORY OF LOCALIZED METAL LOSS

BY MICHAEL TURNQUIST, CONSULTING ENGINEER - ADVANCED ENGINEERING, QUEST INTEGRITY GROUP
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WHEN BAD THINGS HAPPEN TO GOOD PRESSURE VESSELS

When Bad Things Happen to Good Pressure Vessels: A Story of Localized Metal Loss
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INTRODUCTION
While there are many types of damage mechanisms that can occur in a piece of equipment, localized metal loss is one of the most common. If an inspection reveals that metal loss has occurred, many questions are raised: Can I continue operating? If so, for how long? Is a repair needed right away? Finding a solution to these questions can be difficult and costly. However, a solution can be reached through the application of finite element analysis (FEA) as outlined in API 579/ASME FFS-1 Fitness for Service.

This article describes the process of performing a fitness-for-service (FFS) assessment of a CO2 absorber tower located at a refinery, where internal corrosion was discovered on the vessel shell. Ultrasonic thickness (UT) inspection uncovered four localized regions of metal loss, referred to as local thinned areas (LTAs). Using the methodology identified in Part 5 of API 579, the localized metal loss was evaluated to determine if the damaged equipment could be considered fit for continued operation.

INSPECTION DATA
Thickness data for each LTA was provided in the form of a 1 inch by 1 inch equally-spaced, rectangular thickness grid, and two sets of thickness readings were provided from separate inspection dates. This allowed for the estimation of a corrosion rate. When estimating the remaining life of a component subject to local metal loss, it is important to obtain a good estimate for the corrosion rate so that the equipment can be evaluated with respect to a future date, such as a planned shutdown. This helps determine whether the equipment can be operated up to the next scheduled shutdown without the need for repair.

LEVEL 2 VS. LEVEL 3 FFS ASSESSMENT
Generally, as outlined in API 579, a Level 2 FFS assessment is performed before a Level 3 assessment, since the Level 2 assessment is simpler and performed more quickly than a Level 3. Level 2 calculations can generally be performed by hand, in a spreadsheet, or with the aid of a software package such as Signal™ Fitness-For-Service, while a Level 3 assessment requires numerical evaluation of the component, typically through the execution of FEA. However, Level 2 assessments present certain limitations: they can only be applied in instances of simple geometry and loading conditions. For example, when performing a local metal loss assessment, a Level 2 assessment cannot be performed if the LTA is too close to a structural discontinuity, such as a nozzle or manway. The presence of a structural discontinuity invalidates the Level 2 assessment procedure.

In the assessment of the absorber tower, only one of the four LTAs was sufficiently far from a structural discontinuity for a Level 2 FFS assessment to be applicable. The absorber tower passed the Level 2 assessment at this location. This assessment considered loads due to gravity and internal pressure, as well as supplemental loading due to wind. The wind loads were calculated using ASCE-72, a standard that is commonly used for the evaluation of wind loading on a structure.

FINITE ELEMENT ANALYSIS
A Level 3 FFS assessment was required for the remaining three LTAs which were near various structural discontinuities. The Level 3 assessment required the construction of a finite element model (FEM) of a section of the vessel around each LTA. All three meshes explicitly modeled the geometry of the corroded area. Figure 1 shows the inside and outside surfaces of the mesh near one local thinned area.

**Figure 1. Finite element mesh of an LTA**

In addition to the corrosion measured on the 1 inch by 1 inch thickness grid, a uniform amount of corrosion (calculated from the estimated corrosion rate) was applied to the entire vessel so that the vessel was evaluated at a time...
corresponding to the next scheduled shutdown. The purpose of including the additional corrosion was to determine if the absorber tower would be fit for continued service up to the date of the next scheduled shutdown.

The FEA was performed in order to determine the peak stress and strain locations in the absorber tower. The stress and strain results were then used to evaluate the LTA in accordance with Annex B1 of API 579 and determine whether or not the absorber tower could be returned to service and operated up to the date of the next scheduled shutdown without the need for repair.

API 579 suggests that an elastic-plastic FEA be performed for a local metal loss assessment. An elastic-plastic FEA incorporates a material stress-strain curve into the numerical evaluation, thus simulating the effects of material yielding. While this requires more computational effort, the result is a more accurate solution. If a stress-strain curve cannot be obtained directly from laboratory testing, one can be calculated using the procedure provided in Annex 3.D of ASME BPVC Section VIII Division 23.

RESULTS
Annex B1 of API 579 identifies four criteria which must be satisfied in order for the FFS assessment to pass. These criteria are plastic collapse, local failure, buckling collapse and failure due to cyclic loading. The critical acceptance criterion for the absorber tower was the local failure criterion.

An elastic-plastic evaluation of local failure compares the equivalent plastic strain to a limiting strain at all locations in the FEM. The limiting strain value is a function of the triaxiality of the material at the specified location. If there is a location where the limiting strain equals or exceeds the equivalent plastic strain, then the local failure criterion is not satisfied and the component does not pass the assessment.

Additionally, factored load combinations must be applied when evaluating the local failure criteria. The factored load combinations which must be considered are found in Table B1.4 of API 579. The value of the load factor depends on the design code to which the equipment was originally designed. This absorber tower was designed in accordance with ASME BPVC Section VIII Division 2. When considering the effects of gravity, internal pressure, and wind only, the two relevant factored load cases are:

1. (gravity + internal pressure loads) x 2.4
2. (gravity + internal pressure loads) x 2.1 + (wind loads) x 2.7

Two of the remaining three LTA’s satisfied the strain limit criterion for local failure. This meant that three of the four LTA’s (recall the LTA which passed the Level 2 FFS assessment) did not require a repair and could be operated normally until the next scheduled shutdown.

Figure 2 and Figure 3 show contour plots of von Mises stress and equivalent plastic strain for the local thinned area, which did not satisfy the strain limit criterion for local failure. These contour plots correspond to the first load case. It is observed that the peak stress in the LTA (81.3 ksi occurring near the smaller nozzle) is well above the material yield strength. This results in the development of very high plastic strains at this location.

Figure 2. Von Mises stress (scale in psi)

Figure 3. Equivalent plastic strain (scale in in/in)

The LTA, which did not satisfy the local failure criterion, required a repair in order to be returned to service. The repair consisted of the installation of a plate which was welded over the critical area and shaped to fit around the nearby nozzle. Additional FEA simulation, similar to the methodology described in this article, was used to determine the required thickness, size, and location of the plate. The installation of the plate increased the thickness of the shell in the critical area such that the local failure criterion was satisfied.
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CONCLUSIONS
The application of finite element analysis as outlined in API 579/ASME FFS-1 Fitness-for-Service allowed for the evaluation of four local thinned areas identified by UT inspection of a CO2 absorber tower. Of the four LTAs that were identified, the analysis demonstrated that three were fit for continued service up to the next scheduled shutdown without the need for repair.

Using a Level 3 assessment including FEA, one of the four LTAs was identified as requiring repair. Additional FEA simulation was performed to determine the exact location and size of the repair plate in order for the absorber tower to be considered fit for service until the next planned shutdown. The methodology described in this article demonstrated that four areas potentially requiring repairs were reduced to a single, less significant repair. The need for a less significant repair in turn saved the equipment operator time and money.

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Michael Turnquist has 3+ years of experience providing fitness-for-service (FFS) assessments in a wide variety of industries. He has worked on various types of engineering FFS assessments, with the majority of that experience in the application of finite element analysis (FEA) and fracture mechanics to assess asset integrity. Michael works closely with fellow staff members to develop and execute complex finite element modeling techniques for various structures. He is an invaluable member of Quest’s Advanced Engineering (AE) Group, which strives to develop and incorporate the most efficient and effective practices in the engineering consulting industry.

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