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## NON-INTRUSIVE FRP INSPECTION FOR AVOIDING PREMATURE ASSET RETIREMENT

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## INTRODUCTION

A novel inspection technique for Fiberglass Reinforced Polymer (FRP) that aligns with the systematic approaches and consensus API codes for evaluating steel piping and vessels was discussed in an [article I published in the May/June 2017 issue of Inspectioneering Journal](#)[3]. The technique obtains non-destructive ultrasound readings from the outer surface of the FRP.

This article provides a case study of an actual inspection and evaluation of an FRP column. The client used a retired asset so that the non-destructive and non-intrusive results could be verified by destructive testing.

## INSPECTION TOOLS AND TRAINING

The ultrasonic equipment that was used for these inspections is shown in **Figure 1**. The ultrasonic equipment consists of a flaw detector and a 500 kHz transducer with various delay lines for impedance matching. Other tools such as measuring tape, brushes, scrapers and mirrors will allow inspection and light cleaning of outer surfaces as required.

For conventional ASME and API ultrasonic inspections of metallic assets, many flaw detectors currently on the market provide on-board analysis capabilities for flaws and defects. As of this writing, on-board capabilities do not exist for FRP, so the flaw detector must be capable of saving A-scans and exporting the raw data and settings for analysis by external software.

The inspection technique uses unique settings and calibration methods. The procedures and calibration methods are different from commonly used approaches in ASME (or other) codes and standards, and the technique has been proven to be reliable, even when baseline readings from new FRP are unavailable[4].

## FRP EQUIPMENT CONFIGURATION AND DESCRIPTION

The FRP equipment inspected was a vent scrubber at large chemical facility. The scrubber was used to neutralize hazardous gas with sodium hydroxide solution in a countercurrent flow. The configuration is shown in **Figure 2**.

The scrubber was new in 1995. In 2002, the lower section was replaced. All sections of the scrubber were manufactured by the same manufacturer. In 2015, the scrubber was replaced because the structural integrity was suspect based on visual inspection of the corrosion barrier. The scrubber that was removed in 2015 is the subject of this investigation, since it was no longer in service and could be made available for comparison of non-destructive and destructive evaluation.



Figure 1. Ultrasonic Equipment

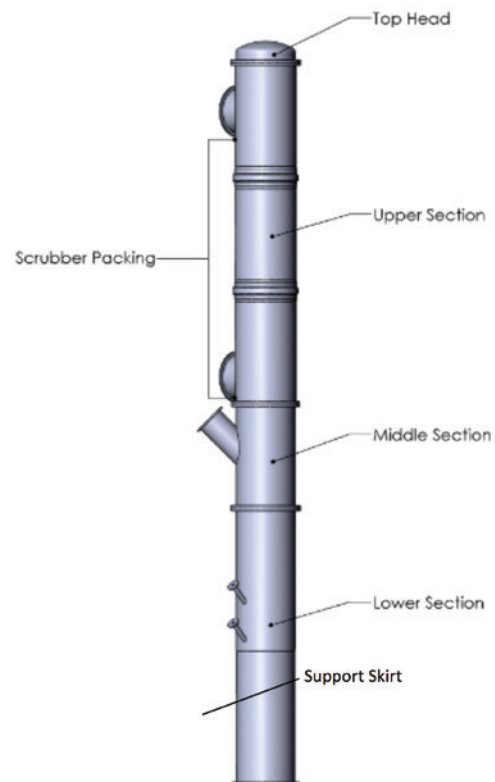


Figure 2. Scrubber Configuration



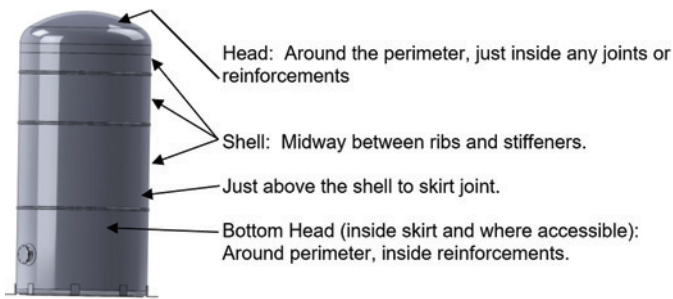


Figure 3. Recommended Inspection Plan

### INSPECTION PLAN - WHERE TO SCAN

Effective inspection of FRP process equipment requires scanning/assessment of the FRP at locations that will provide information on the active damage mechanisms. FRP can be damaged by both mechanical and chemical sources.

In corrosive service, chemical attack of the FRP is usually the dominant damage mechanism to be assessed[3],[5]. For assets where reactions take place—such as reactors, scrubbing columns and piping with injection points—the reactions can create more damage than elsewhere. In some cases, damage due to chemical attack is also magnified where damage to the protective inner surface has occurred due to leaks along internal bonds, leaks in thermoplastic lining welds, cracks and abrasion.

Mechanical damage can occur to any FRP structure, whether chemical attack is expected or not. Common sources are: high stresses, bending movements, fatigue, compression loads, and defective installation.

The first step to inspect an FRP asset is to prepare a plan based on the actual equipment configuration. This plan identifies condition monitoring locations (CMLs) for ongoing, periodic inspections. The locations to be inspected are chosen to provide information for trending areas that can be tracked and allow prediction of remaining service life[3]. The plan must also provide guidance to operators and inspectors for future inspections.

This is similar to the well-established systematic approaches for inspection of steel piping and vessels that are contained within a system of consensus codes such as API 570[1], API 510[2], and API 653[6], which specify in-service inspection and condition-monitoring programs to determine the integrity of storage tanks, piping, and pressure vessels. The inspection results are used with the original design codes to evaluate whether the assets are able to continue in service safely and reliably.

Inspection planning for FRP using this technology does require some assessment of damage sources expected. For the equipment considered here, **Figure 3** shows an example of the recommended inspections based on the operating condition. In addition, because reactions are expected in the packed bed, inspection of the shell in the packed bed areas is recommended to assess damage to the inner surface. This is from a Standard Practice that has been prepared as guidance for all inspectors.

For piping, the same damage sources must be considered. Although each situation is unique, inspection plans should

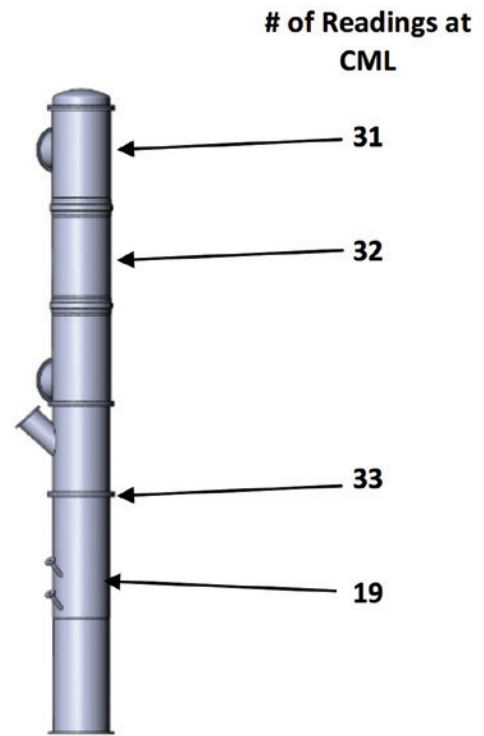


Figure 4. Ultrasonic Inspection Locations

consider accelerated chemical damage near injection points and beside joints. Magnified mechanical damage should be expected beside anchors and supports. These damage sources are often exacerbated where abrasion can occur.

Inspection plans should be prepared in advance, however there have been numerous occasions where assets to be inspected have been added to the work scope in the field. In these cases, the inspector is called upon to develop the inspection plan at the time of inspection, which will involve some additional work such as making sketches, taking photos, reviewing drawings and obtaining operating conditions. Inspection plans that are prepared in advance, can simplify field work. Inspection plans can be used for future inspections.

At the time of the inspection, a systematic, external inspection scan should be completed that focusses on damage that often develops from defective installation of the FRP vessel or piping. This inspection should look for damage or defects in support structures, FRP condition, component damage, flanges and fittings. Many near-term failures can result from defects detected at this stage.

In this case, the actual equipment was out of service. The owner covered any openings in the shell that would allow the inspector to see the inner surface, thus simulating a true non-intrusive condition. The packing was in place. The column was on its side and easily accessible to the inspector. The locations of actual inspections/scans completed and the number of readings that were taken are shown in **Figure 4**. For each of the locations, it is desirable to obtain at least 30 readings so that the variation in the



Figure 5. Non-Intrusive FRP Inspection

material can be understood clearly. In some cases, access to the outer surface of the column limited the number of readings.

Figure 5 shows an image of a typical FRP inspection using the technique.

Completion of the inspection for each CML involved the following steps:

1. Complete A-Scan images and data were saved for each reading taken. The readings were taken as follows:
  - a. Transducer with delay line only.
  - b. Transducer with delay line coupled to the surface of the FRP, generally spaced in a pattern.
  - c. Same as a.
2. A written procedure guiding all equipment and reading was used.
3. After the inspection was complete, the inspector extracted the raw data readings from the flaw detector and added them to a computer file that was created to include asset information, the inspection plan, and the observations from the external inspection. This computer file was submitted as a system of information about the asset to a Subject Matter Expert (SME).

## INSPECTION RESULTS

The inspection results are summarized in Figure 8, at the end of this section.

When the computer file is evaluated, the SME integrates all of the information provided to assist with computer analysis of the readings. The SME uses a computer program to process each reading for environmental and transducer application conditions. Some of the environmental conditions that are considered include ambient temperature during the inspection, surface temperature of the FRP and high magnetic fields from equipment nearby. Application conditions include surface condition of the FRP, UV damage to the resin of the outer surface, and coupling defects due to contaminants on the surface of the FRP. From each processed reading, data is extracted that provides information on the condition of the FRP. Figure 6 shows an example of a reading

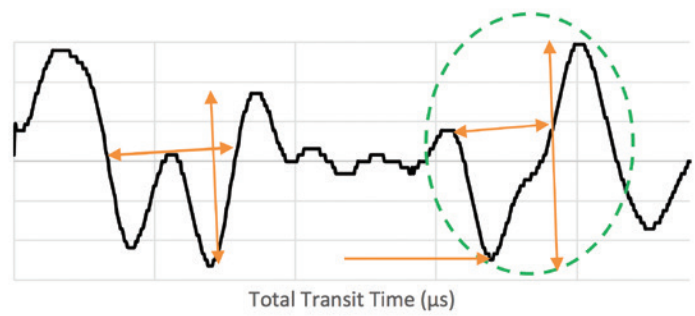


Figure 6. Reading Processing

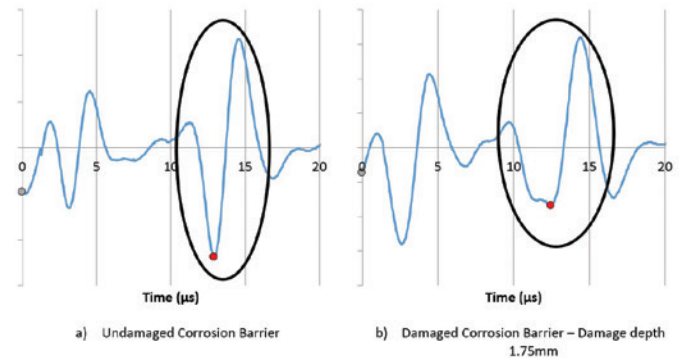


Figure 7. Typical Corrosion Barrier Analysis

that has been corrected for coupling and temperature variation. The colored arrows show some of the measurements taken from the reading.

The primary result provided by the ultrasonic readings is the Percentage of Design Stiffness (PDS) as given in Equation 1.

$$PDS = \frac{\text{Current Flexural Modulus}}{\text{Theoretical Modulus}}$$

The flexural modulus of FRP changed as a result of both mechanical and chemical damage[3],[4] and PDS from reading historical and current analyses showing how the structural condition of the FRP had changed over time. PDS was used in place of thickness for steel[3],[4].

Further evaluation was also used to determine the condition of the corrosion barrier surface. One of the methods used is illustrated in Figure 7.

As mentioned above, the client used this retired asset so that the results from this inspection could be verified by destructive tests. The inspection results and cut-outs that were removed to verify the inspection results are illustrated in Figure 8.

The cutouts were used to verify both the PDS results and the

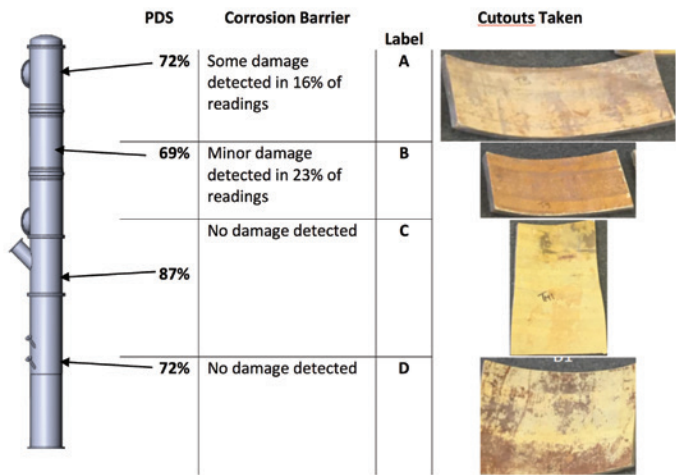


Figure 8. Inspection Results and Cutouts

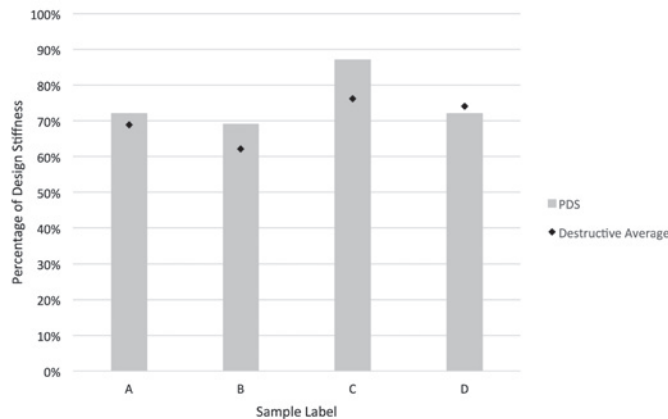


Figure 9. Comparison of Non-Destructive with Destructive Results

corrosion barrier results. To verify the PDS results, flexural modulus was determined for the samples in accordance with ASTM D790 and compared to the theoretical flexural modulus for the actual FRP construction. The testing method is detailed in [5]. Results of this testing are shown in Figure 9. Note that the values from the destructive test are all within 14% of the values from the non-destructive test.

From the same samples, condition of the corrosion barrier was also compared. Results for sample B are shown below in Figure 10. Also, the reading used as illustration in Figure 7b is from this sample.

### Remaining Service Life Prediction

The principal output of the ultrasonic analysis is the current PDS value for the composite. From the PDS, the following calculations are made to provide a prediction of the remaining time when the FRP will have sufficient structural capacity.

The PDS Rate of Change ( $\Delta PDS$ ) is the average linear rate at which PDS is changing for the equipment:

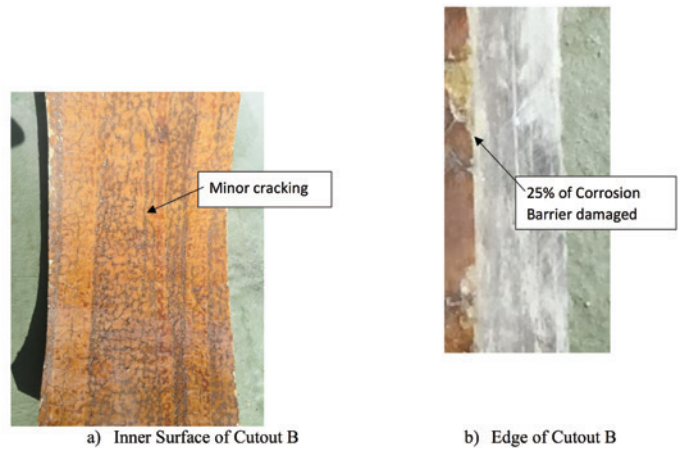


Figure 10. Corrosion Barrier Results

$$\Delta PDS = \frac{\text{Starting PDS} - \text{Current PDS}}{\text{Starting Year} - \text{Current Year}}$$

For this scrubber, this was the first evaluation using this method and no previous data was available. When this occurs, it is conservative to assume that the new FRP had 100% of its theoretical strength when new [4]. Also, note from above that the upper sections and lower section were different ages, therefore different  $\Delta PDS$  values will exist.

The Remaining Service Life (RSL) is the number of years until the PDS of the section is predicted to be at Critical PDS. The calculation to be made is:

$$\text{Remaining Service Life} = \frac{\text{Critical PDS} - \text{Current PDS}}{\Delta PDS}$$

This calculation is consistent with calculations required by API 653 [6] when PDS is substituted for thickness for steel.

The results of the calculations are given in Table 1 for a critical PDS of 20%, which represents a nominal safety factor of 2 based on the original design factor of 10.

Table 1. Remaining Service Life Calculation

Scrubber Section	Current Minimum PDS	Remaining Service Life (yrs)
Bottom Section	72%	25
Upper Shell and Head	66%	27

This remaining service life calculation for Percentage of Design Stiffness is illustrated graphically in Figure 11. The remaining service life could also be determined on the basis of the corrosion barrier (CB) damage detected in this case using the damage depth and criteria for end of corrosion barrier service life. In this case, the corrosion barrier has experienced thickness loss due to

## Remaining Service Life

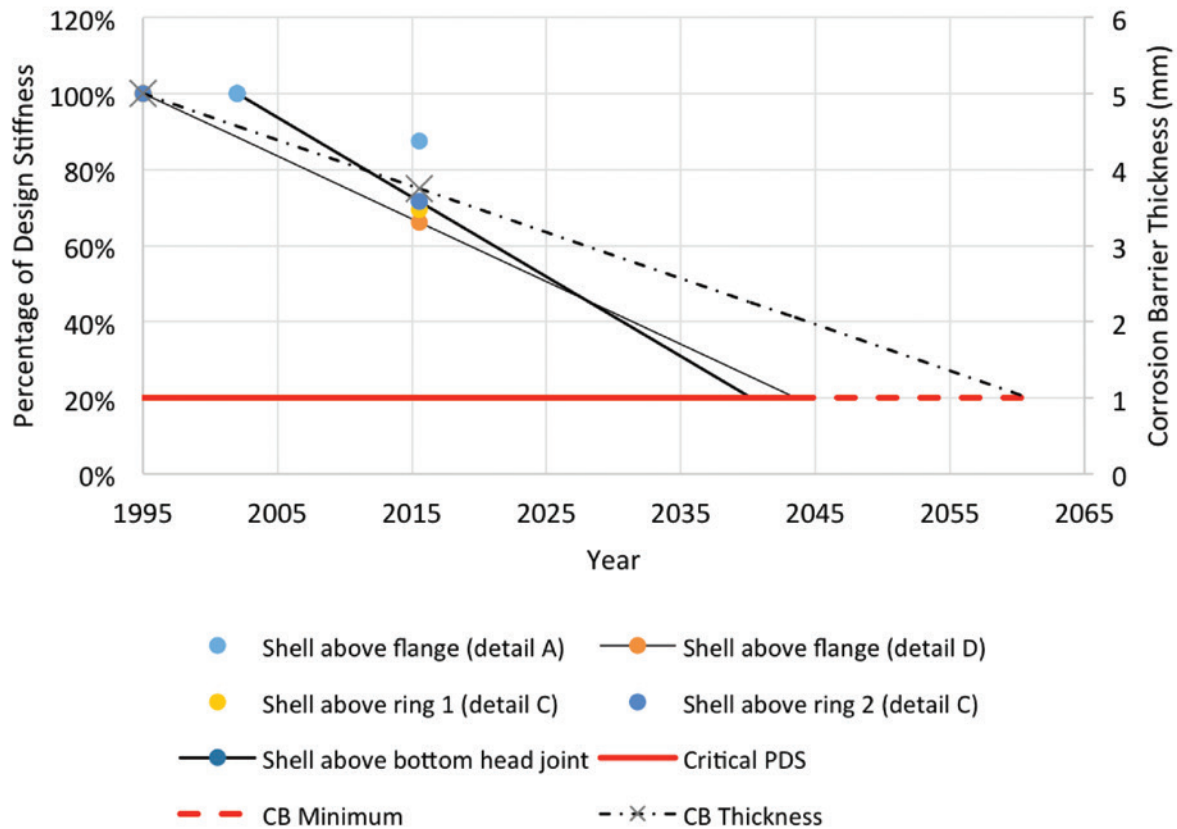


Figure 11. Chart Showing Remaining Service Life Calculations

oxidation from chemical reactions in the column. For the detected corrosion barrier damage depth of 1.25mm (leaving net corrosion barrier thickness of 3.75mm) and using a minimum allowable corrosion barrier thickness of 1mm, the remaining life is about 45 years. Figure 11 also includes calculation of the remaining life based on corrosion barrier damage.

### CONCLUSION

The results provided a good match between information provided by the UT readings and the actual retained mechanical properties of the cut-outs. The examination of the cut-outs also indicated minimal damage to the corrosion barrier thereby suggesting a significant remaining life, which testing also predicted. ■

For more information on this subject or the author, please email us at [inquiries@inspectioneering.com](mailto:inquiries@inspectioneering.com).

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### **GEOFF CLARKSON**

Geoff is the CEO and Founder of UTComp, Inc. His innovative company works globally to help eliminate uncertainty about the condition of FRP assets during production, delivery and in-service, allowing their remaining life to be determined. Geoff completed his engineering degree at the University of Waterloo, Canada in 1982, specializing in Systems Design Engineering. His decades of experience have helped him lead the way in the successful establishment of ultrasonic testing and fitness for service engineering for FRP composites. Geoff is a Member of the Order of Honour of Professional Engineers Ontario and a Fellow of Engineers Canada.