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FITNESS FOR SERVICE OF FRP: MOVING TOWARDS BEST PRACTICES

GEOFF CLARKSON, P.Eng., *Founder and CEO at UTComp Inc.*

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FITNESS FOR SERVICE OF FRP: MOVING TOWARDS BEST PRACTICES

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INTRODUCTION

A Fitness for Service (FFS) assessment of an asset requires the use of certain best practices to determine whether the asset can continue to operate as intended by its design. Best practices have been shown by research and experience—including empirical data—to reliably lead to a desired result. Often these best practices are formalized through consensus of experts into codes and standards that relate original designs to current condition and provide guidance to engineers and operators. There are currently no industry consensus documents that provide this guidance for fiber reinforced polymers (FRP) assets.

This article provides a case study that illustrates how European design standard "glass reinforced plastic (GRP) tanks for use above ground", designation EN 13121 [1] (EN 13121) can be used to calculate expected changes in FRP for FRP vessels. The case incorporates both destructive test results and non-destructive, non-intrusive results from a technique that was discussed in the May/June 2017 and November/December 2017 issues of Inspectioneering Journal [2,3].

The results for the two approaches will be compared.

FRP DESIGN CODES AND STANDARDS

Process equipment design usually starts with defining the operating and usage environment, then making calculations of the material requirements based on a body of codes and standards. The final design of any process equipment, including items such as material selection, thickness and construction details, usually has some allowance for damage, such as corrosion, due to the expected operating environment. In the case of metal pressure vessels where the expected damage mechanism is thickness loss, the design includes the minimum allowable thickness (T-Min) and sometimes a corrosion allowance to allow for some corrosion prior to reaching T-Min. These "end of life" criteria are provided on the drawing, code of construction forms and usually provided directly on the equipment nameplate.

For FRP, the design approach and specification of "end of life" criteria are less transparent. In many circumstances, drawings do not provide manufacturing details or any information on how to determine the end of life. For the most common standards used in North America, by ASME [4,5] and ASTM [6,7], a "Design Factor" is applied to the tensile strength of the FRP to be used to provide a "Design Stress" value. Another term that has been used for this is "Safety Factor". The typical calculation is shown in equation below.

$$\text{Design Stress} = \frac{(\text{Tensile Strength})}{(\text{Design Factor})}$$

In many cases, the design factor required by these standards has a value of 10. This is one of several examples but in all cases, these standards work to ensure that the stress in the FRP is no larger than 10% of the tensile strength.

Normal standards that have been used in North America for FRP piping also use design factors applied to tensile strength of FRP, similar to what is done for tank design.

Common standards that have been used in Europe for FRP typically include EN 13121 [1] and AD Merkblatt N1 [8] (AD-N1). Both of these standards are more complicated to apply than ASME or ASTM standards and they include factors that are determined based on the behaviour of FRP under load for at least 1000 hours (42 days) and possibly exposed to the chemicals to be contained.

As noted in one of my previous articles in Inspectioneering Journal, Novel Inspection System Aligns FRP and Metallic Asset Management Approaches, FRP undergoes a change in bending stiffness while it is in service—known as creep. From more than 800 assets with at least 2 inspections, **Figure 1** shows observed changes of bending stiffness. The chart includes information for assets from 0 years of age to 48 years of age, located around the world. The bending stiffness values are shown as the percentage of the design stiffness.

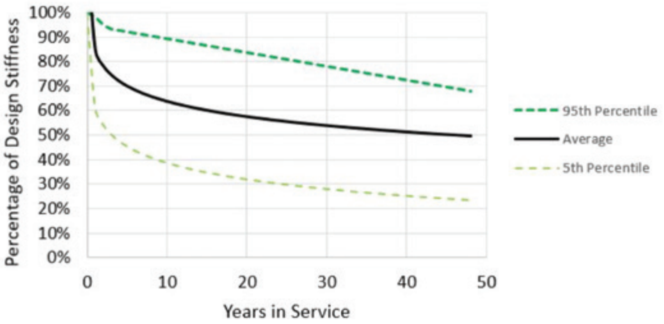

Figure 1. Data on Changes in Stiffness.

Note from **Figure 1** that the there is a wide difference in values from the 5th percentile to the 95th percentile data. In general, it would be safe to assume that the low values correspond to FRP that was thinner or made with lower stiffness values compared to the average or 95th percentile.

In addition to using creep data as part of design calculations, EN 13121 also provides a formula for predicting future bending stiffness of FRP, based on 1000 hour testing. One result of this is to allow a design factor to be created which will allow prediction of a 25 year (about 200,000 hours) tank life.

In the case of FRP piping, many operators specify European standard "Petroleum and natural gas industries—Glass-reinforced plastics (GRP) piping", designation ISO 14692 for piping design and installations. This code requires use of long term testing to qualify piping materials. This same long term testing method

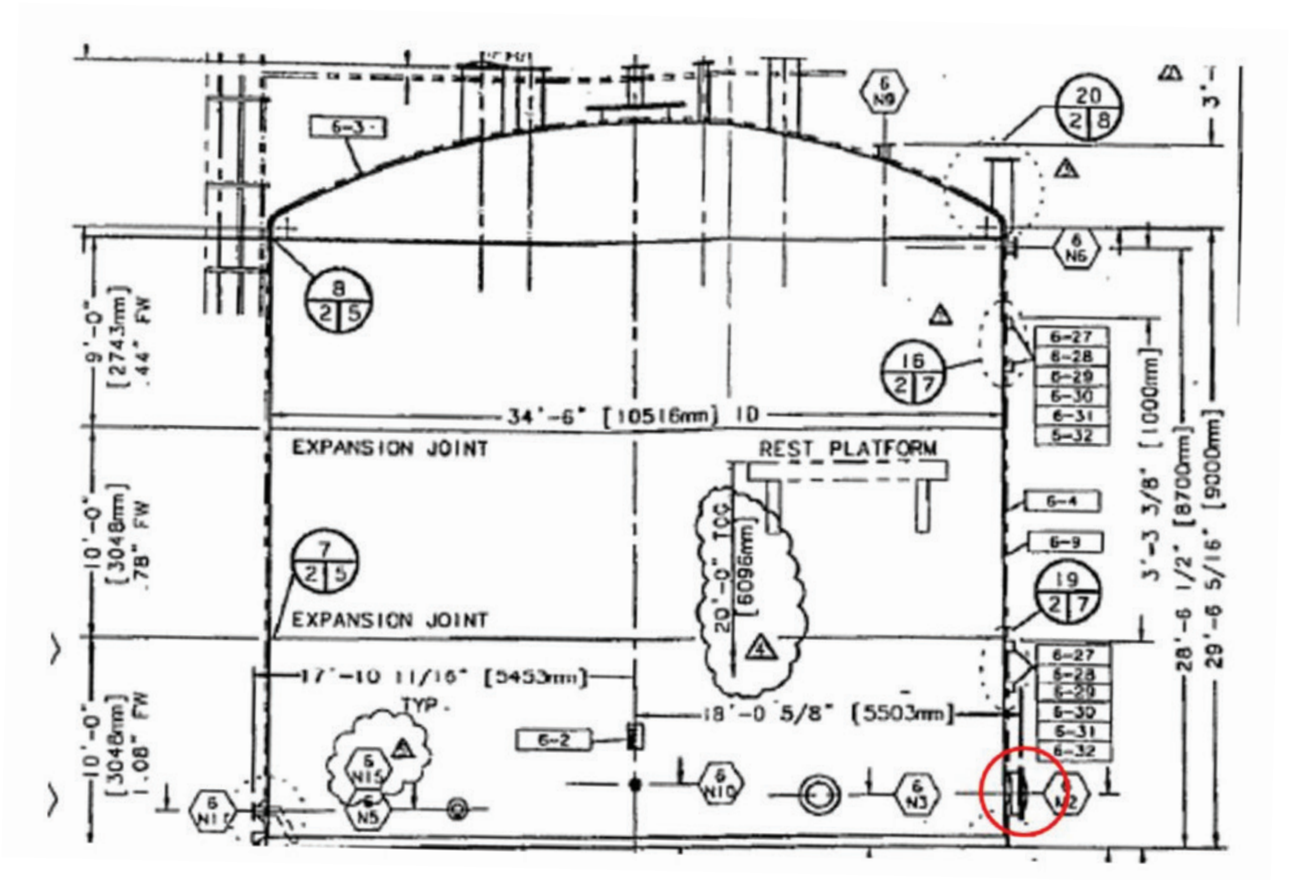

Figure 2. FRP Storage Tank.

could be used on piping removed from locations with high chemical and/or bending loads to determine remaining service life of FRP piping.[9]

CASE STUDY – ASSESSMENT OF HYDROCHLORIC ACID STORAGE TANK

This case study will examine two sets of data on a FRP storage tank that has been in service since 1996. Contents of the tank have been 20% hydrochloric acid at about 90°C (194°F) and the pressure in the tank has ranged from atmospheric (with hydrostatic fluid head) to—4 kPa (0.6 psi). The tank is 10.5 meters (34.4 feet) in diameter with 8.7 (28.5 feet) meters overflow level. The tank is shown in **Figure 2**. In the figure, the manway in the lower shell is circled.

The tank was installed in 1996. Design and construction were completed in accordance with ASTM RTP-1 [4], although the tank was not certified with an ASME stamp. In accordance with the inspection and testing requirements in Part 6 of ASME RTP-1, the design physical properties of the FRP in the tank were verified by destructive tests. In particular for this case, the hoop direction bending stiffness of the shell was verified from the cut-out from the circled manway. The bending stiffness matched the design values used for the tank.

To determine the long term performance of the FRP in the tank, we can use Appendix D.16 of EN 13121. This method considers the time (hours) in service and can be expressed in terms of the bending stiffness of FRP based on measured stiffness.

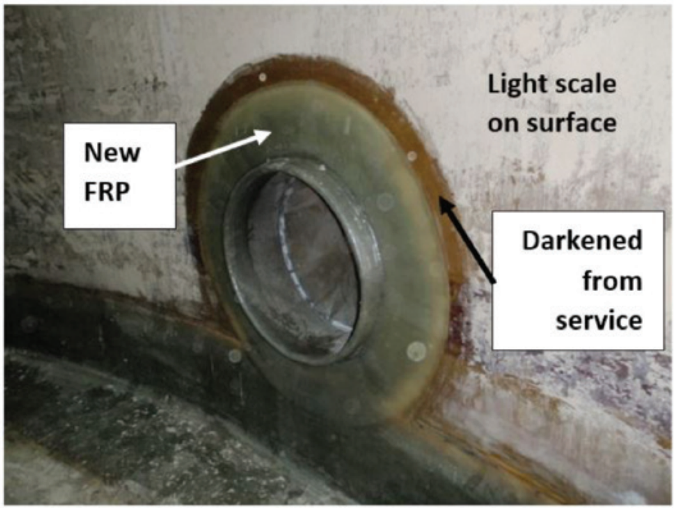

Figure 3. New Manway Added.

Two measurements of bending stiffness are required from cut-outs that have been taken at known times. For this tank, a manway cut-out taken from the new tank is used as the starting point. In 2010, the owner decided to add a new manway at the same tank elevation as the circled manway. The installation of the new manway is shown in **Figure 3**. Note that testing of a cut-out will always require repairs to FRP.

Note from **Figure 3** that the cut-out was removed from the tank shell after it had been in service for 14 years, about 123,000 hours. The inner surface was darkened and some absorption of hydrochloric acid had occurred. From the sample, the opportunity was taken for microscopic and energy dispersive x-ray spectroscopy (EDX) to examine the glass and resin after service. **Figure 4** shows a section of the corrosion barrier. EDX identifies chemical elements that are found in the material. The yellow strip on the left of the photo shows the percentage of the area at each depth that has chlorine from the hydrochloric acid in the tank. Note that the chlorine is shown to a depth of 3.4mm (0.13 inches). The original corrosion barrier thickness was 4.5mm (0.18 inches).

The inner surface of the tank, having a 4.7% chlorine content, was considered to be in good condition and suitable for continued service before EDX. At full depth of the corrosion barrier, chlorine penetration is modest and no changes were made after EDX results were available.

Five strips along the hoop direction were cut from the cut-out and sent for 3-point bend testing according to ASTM D790.[11] The bending stiffness, or modulus, was determined from these strips. Results from this cut-out provided a 2nd bending stiffness value that can be used according to D.16 of EN 13121 to predict future values.

The values of stiffness can be shown as percentage of the new, or design stiffness. The values obtained from the tests, the percentage of design stiffness (PDS) and the time in service are provided in **Table 1**. For the new value, time in service of 0.1 hour has been specified.

One way to make the prediction is to plot the stiffness value and its time in service on a log-log chart, then use a straight line to predict future values. This is illustrated in **Figure 5**. The line connecting the measurements has been extended into the circled area. The extended line can be used to predict future values.

The straight line in **Figure 5** can be used to predict future values of stiffness for the FRP. Using the straight line, a value of stiffness has been predicted for 2013 (149,000 hrs), 2017 (184,000 hours), and for 200,000 hours of time in service (late 2018). The predicted values and the corresponding PDS values using EN 13121 calculations are listed in **Table 2**.

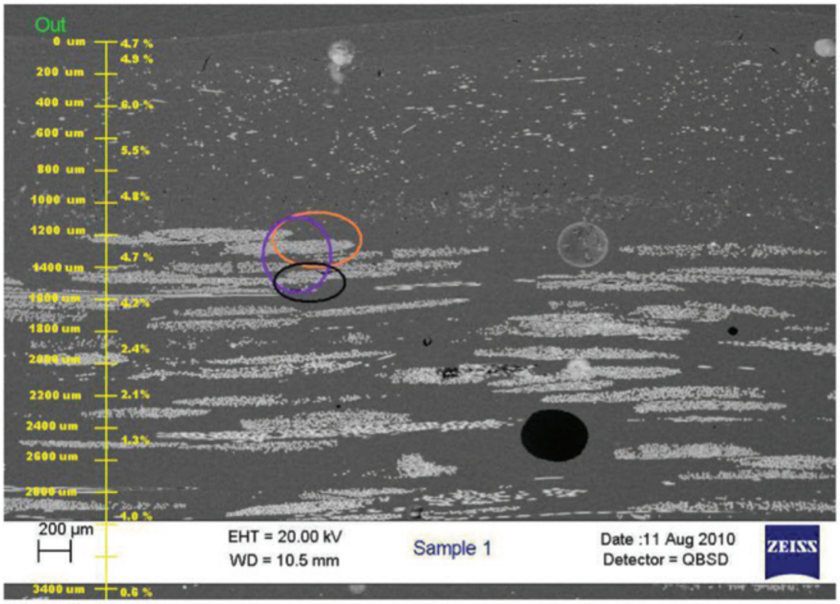

Figure 4. Chlorine from HCl in the cutout.

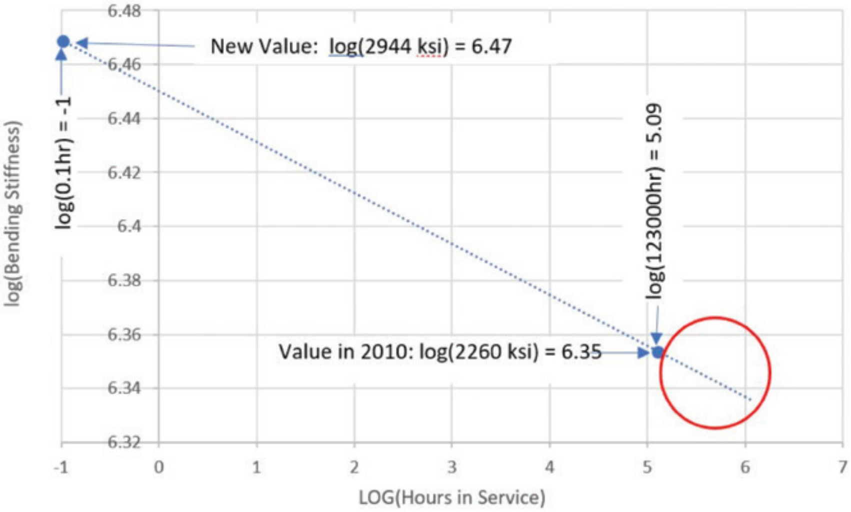

Figure 5. Log-log chart to Predict Future Values.

Table 1. Destructive Test Values

Year	Time in Service (hr)	Bending Stiffness		Percentage of Design Stiffness (PDS)
		(Ksi)	(GPa)	
1996	0.1	2,944	20.29	100%
2010	123,000	2,260	15.57	77%

Table 2. Stiffness Predicted by EN 13121

Year	Bending Stiffness		Percentage of Design Stiffness (PDS)
	(Ksi)	(GPa)	
2013	2,251	15.51	77%
2017	2,243	15.43	76%

Figure 6 shows the log-log chart of the original destructive values and the predicted values.

Now consider the charts shown in **Figures 5** and **6** but not using logarithmic scales. The chart for **Figure 6** becomes **Figure 7**.

Note that we have not used the PDS value in **Tables 1** and **2** on the charts. **Figure 8** shows the same curve as **Figure 7**, but using PDS instead of the actual stiffness value.

Non-Destructive and Non-Intrusive Inspection

Consider now a non-destructive and non-intrusive inspection of the same tank. The technique was described at length in the articles I published in the May/June 2017 and November/December 2017 issues of Inspectioneering Journal.[2,3] As noted in those articles, the output of the inspection analysis is the PDS of the FRP. Results from the non-destructive evaluation of the FRP are provided in **Table 3**. These are also compared to the values from **Tables 1** and **2**.

Table 3. Non-Destructive Evaluation Results

Year	PDS from Table 1 or 2	Non-Destructive PDS	Difference compared to Table 1 or 2 Values
1996	100%	100%	N/A
2010	77%	85%	10%
2013	76%	82%	7%
2017	76%	77%	1%

The PDS values from the non-destructive technique are also shown in **Figure 9**, plotted on the same curve as **Figure 8**. There is good agreement of the non-destructive values. The values determined by the technique in my previous articles in Inspectioneering Journal provide similar predictions.[2,3]

DISCUSSION

As described above, some European codes for FRP design, in this case EN 13121, provide some guidance for evaluation of the rate of change of measurable properties of FRP. In spite of this step forward, there is still no clear definition of the criteria to define the end of service life—this is still somewhat judgemental, except where specifications may exist.

Use of the current European codes to provide prediction of future properties requires destructive testing of the FRP to be evaluated. This approach has significant costs for removal of test specimens, testing and subsequent repair. In addition, this type of testing, after the vessel has been in service, requires shutdown, de-inventory and a safe work plan to obtain the test specimens and repair the assets. Another limitation of this approach is that the full variation of the material cannot be evaluated from a relatively small

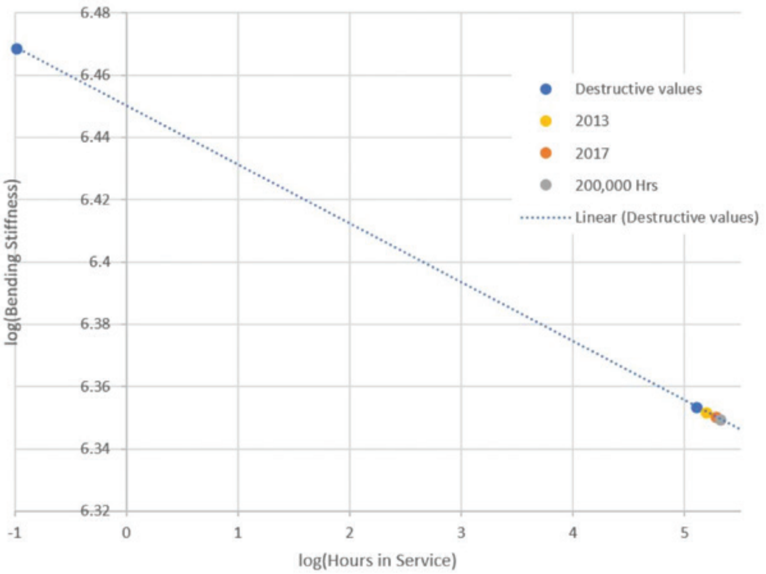

Figure 6. log-log Chart with predicted stiffness.

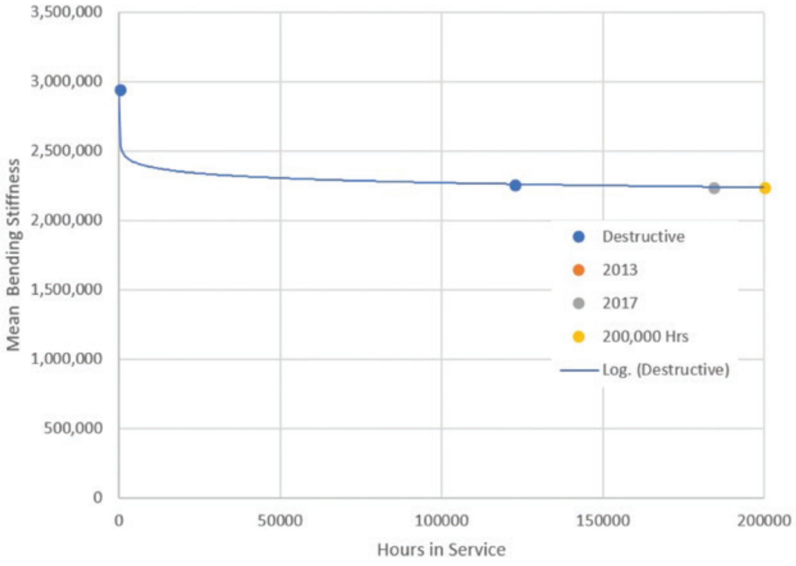

Figure 7. Destructive and EN 13121 Predicted Values

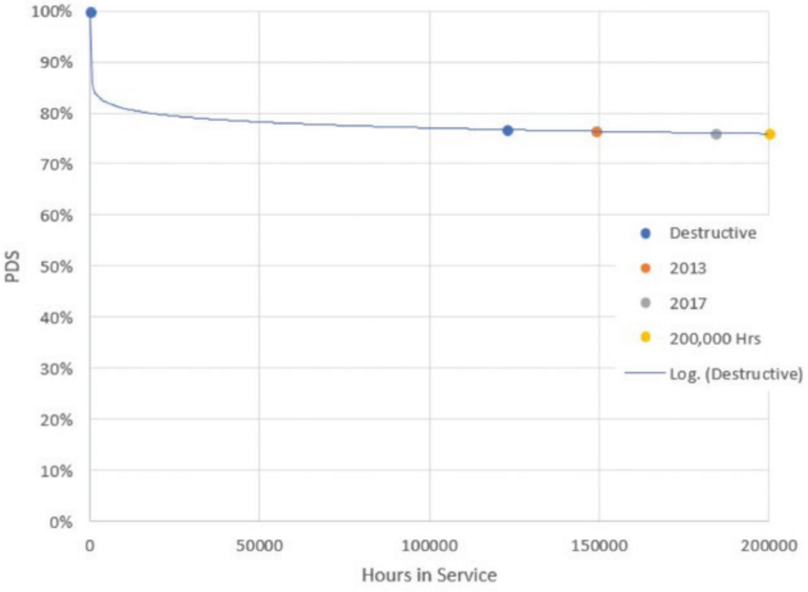

Figure 8. Destructive and Predicted Values using PDS

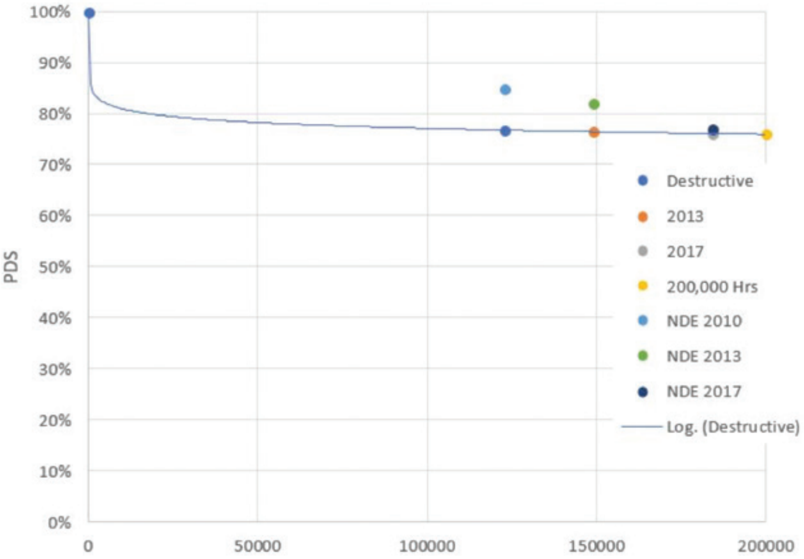

Figure 9. EN 13121 Values and Non-Destructive Values Combined

sample, and the full effects of the service environment may not be included. One must select the test locations carefully to make sure it is taken from the desired representative area/s.

In parallel with the case above with destructive testing used as described in EN 13121, a non-destructive and non-intrusive test method [2,3] was used to determine changes in bending stiffness of FRP in the same tank. When compared, the non-destructive and non-intrusive test method gives similar results to the predictions of EN 13121, at significantly lower cost and no disruption to the service of the equipment. In addition, the total time required for the evaluation can be significantly shorter than the requirements to simply remove the sample.

It appears that there is opportunity to develop evaluation criteria and best practices for determining Fitness for Service of FRP based on the test case presented in this paper and others.

Fitness for Service assessment requires codes and standards that use consistent, measurable and reliable parameters to determine the existing structural capacity of equipment. Further information is required, in particular, definition of the criteria for determining end of service life. This information is crucial for effective reliability programs. It is recommended that consensus standards built on best practices and supported by data are the next step for FRP assets. ■

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

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CONTRIBUTING AUTHOR

GEOFF CLARKSON, P.Eng.

Geoff is the Founder and CEO 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.