FYI

3D Imaging for Nondestructive Testing – Part 2
by Matt Bellis

Introduction
This is the second in a series of articles on the use of 3D imaging for nondestructive testing. The first article discussed the basics of 3D imaging and focused on laser triangulation and structured light techniques. This article will focus on the application of 3D imaging in the assessment of corrosion on pipelines. In this application, 3D imaging will be used to identify areas of corrosion, determine the maximum amount of metal loss, extract the river bottom profile, and calculate the remaining strength of a pipeline.

Pipeline Maximum Safe Pressure Calculation
3D surface information, often referred to as 3D scans or 3D images, is an excellent technique for characterizing the shape of an object. In nondestructive testing applications, 3D surface information is used to detect and assess corrosion, gouges, cracks, dents, and other types of surface damage.

Both ASME and API define levels of inspection (ASME, 1991; Osage, 2003). For inspection of midstream piping, for example, a level one inspection of a corrosion pit can be performed by measuring the deepest part of the pit and the length of the pit. Based on these two measurements, the maximum safe operating pressure of the damaged pipeline can be calculated. This approach is based on Maxey’s surface flaw equations (consider Figure 1a).

For undamaged pipe, Barlow’s formula can be used to calculate the maximum internal pressure that a pipe can withstand. The formula, depicted in Equation 1, requires knowledge of the pipe dimensions and material properties:

\[ P_{\text{burst}} = \frac{\sigma_o 2t}{D} \]

where
- \( P_{\text{burst}} \) = burst pressure
- \( \sigma_o \) = allowable stress
- \( t \) = pipe wall thickness
- \( D \) = outside diameter of the pipe
Figure 1. Diagrams of pipes: (a) undamaged pipe; (b) damaged pipe with rectangular discontinuity; (c) damaged pipe with parabolic discontinuity; and (d) corrosion profile of damaged pipe (t is the pipe wall thickness, D is the outer diameter of the pipe, d is the depth of the discontinuity, and L is the length of the discontinuity).
In the 1960s, W.A. Maxey developed a technique for determining the maximum allowable pressure of a damaged pipe using Barlow’s formula (Eiber et al., 1967; Eiber et al., 1968). Maxey recognized that for situations where failure was caused by hoop stress, the impact of surface flaws could be modeled as a reduction in the pipeline wall thickness over a cross-sectional area, as shown in Figure 1b. The research to follow (Kiefner et al., 1973; Kiefner and Vieth, 1989; Maxey et al., 1972) led to the following formula:

\[ P_{\text{burst}} = \frac{\sigma_{\text{SMYS}}}{D} \left( 1 - \frac{A}{A_0} \right)^{1 - \frac{A}{A_0} M} \]

where
- \( A = Ld \)
- \( d = \) depth of a rectangular defect
- \( A_0 = Lt \)
- \( M = \sqrt{1 + \frac{0.8L^2}{Dt}} \)

The factor \( M \), referred to as the bulging or folias factor, accounts for bulging that occurs over the area of metal loss.

The simplified discontinuity model shown in Figure 1b was replaced by a more complicated discontinuity model in the ASME B31G-1991 recommendation (ASME, 1991), but it still required only two measurements: maximum depth and length of the damaged area.

\[ P_{\text{burst}} = \frac{\sigma_{\text{flow}}}{D} \left( 1 - \frac{2d}{3t} \right)^{1 - \frac{2d}{3tM}} \]

where
- \( A = \frac{2}{3}dL \)
- \( \sigma_{\text{flow}} = 1.1 \text{ SMYS} \)
- \( M = \sqrt{1 + \frac{0.8L^2}{Dt}} \)

and
- \( L = \) discontinuity length
- \( d = \) maximum discontinuity depth
- \( D = \) pipe diameter
- \( t = \) pipe wall thickness
- \( \text{SMYS} = \) specified minimum yield strength for discontinuities defined as \( L \leq \sqrt{20Dt} \)

The AMSE B31G technique, shown in Figure 1c, is a level one technique and is similar to the API level one technique used for assessing pipeline inside plants. Although acquisition of the required data is simple, the cross-sectional area of metal loss is generally overestimated, resulting in a burst pressure calculation that is much lower than the actual burst pressure.

Both ASME and API developed level two techniques to provide a more accurate calculation of the burst pressure. The level two techniques require a more sophisticated discontinuity description.

Level two techniques require the collection of data at points other than the deepest point. To manually collect the necessary data, technicians would typically draw a grid over the damaged infrastructure and measure the deepest point in each grid cell. Accurate assessment of large areas might require several hundred measurements. This is difficult to achieve with manual measurements. Figure 1d shows a corrosion profile, also referred to as a river bottom or critical profile.

Figure 2 is a 3D image of the surface of a liquid pipeline. The areas of corrosion are...
readily apparent from the 3D image. Using analysis tools developed for metal loss assessment, the corrosion profile was extracted from the 3D surface information.

The corrosion profile, also known as the river bottom profile, was used as the basis for determining the actual cross-sectional area of damage. Unlike level one techniques, the impact of the discontinuity on the remaining strength pipe was not estimated using a rectangular or parabolic model. Instead, the exact area of damage was determined. Figure 3 compares the exact cross-sectional area of damage, as determined from the 3D surface information, to the estimated area of damage calculated using two level one techniques: the ASME B31G and the modified form of ASME B31G (0.85dL technique). The metal loss estimates for each technique are shown in Table 1.

The maximum safe pressure using each technique is also shown in Figure 3. The overestimation of the metal loss from both of the level one techniques results in an underestimation of the remaining strength of the pipe; this is reflected in the maximum safe operating pressures calculated using each technique.

The ASME level two technique, commonly referred to as the RSTRENG or effective area technique, has been validated extensively using burst tests. The API level two technique has also been validated using burst testing.

**Conclusion**

Assessing the impact of metal loss on damaged infrastructure is just one of many examples of the use of 3D imaging in the field of nondestructive testing. 3D imaging can also be used to assess the impact of mechanical damage on structures, to determine whether or not the surface roughness of a substrate will result in good coating adhesion, to compare as-operated conditions of infrastructure to the as-designed or as-built condition, and many other applications.

Laser scanning and structured light imaging have emerged as two technologies...
capable of acquiring 3D surface information. Both technologies determine depth based on triangulation between a light source, the object under inspection, and a camera sensor. Both technologies have demonstrated accuracy, precision, and probabilities of detection sufficient to meet the demands of nondestructive testing.

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**REFERENCES**


