3DSL NDT Software Suite

Pipeline Analysis 1.4.1

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1 Getting started with Pipeline Analysis

Pipeline Analysis is the leading software module for analyzing anomalies in pipelines and other infrastructure. The analysis focuses on metal loss, whether from corrosion or gouges, and mechanical deformation (for example, dents). This manual provides an in-depth look at the software functions. The Glossary section of the manual contains definitions of a variety of terms that are used throughout the manual.

1.1 Loading and saving data

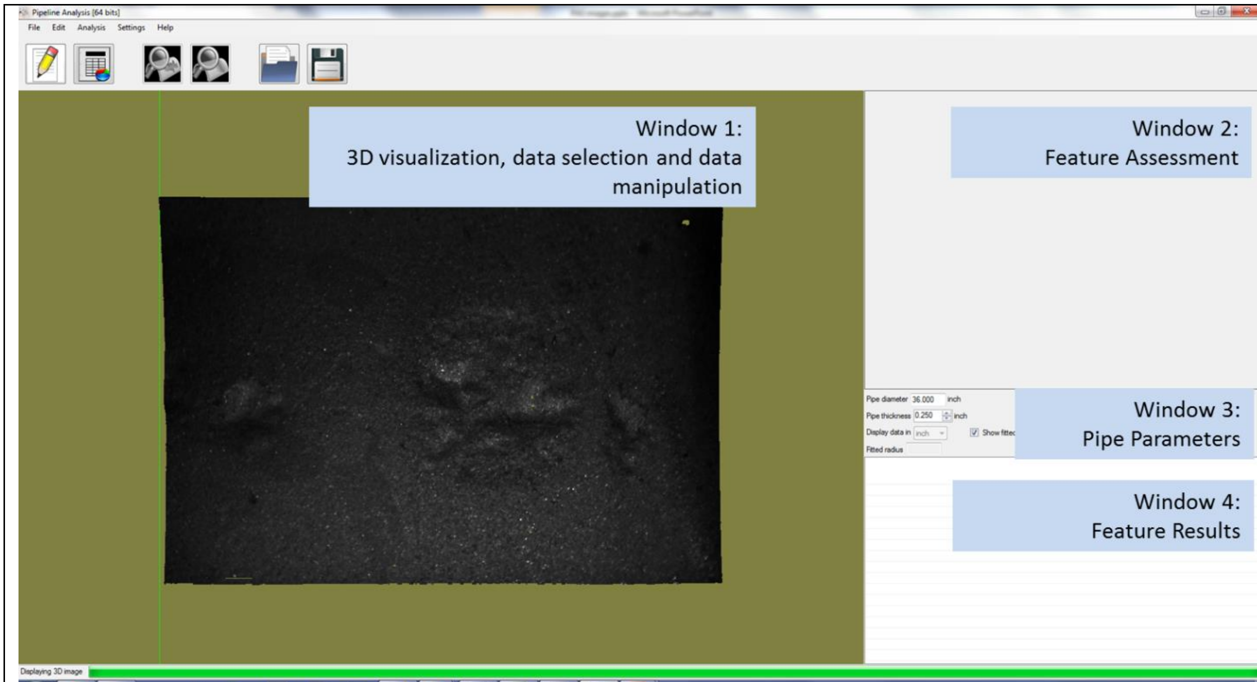
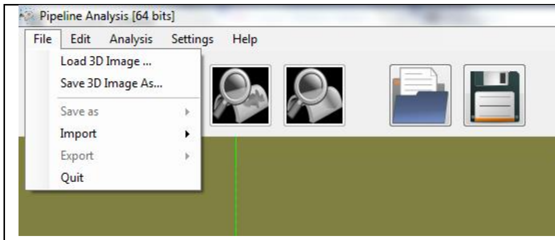
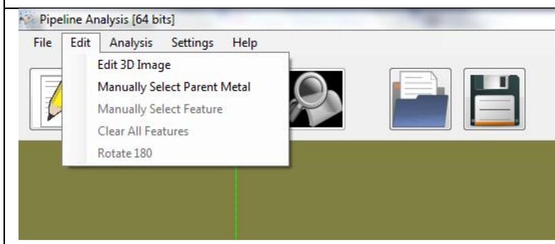
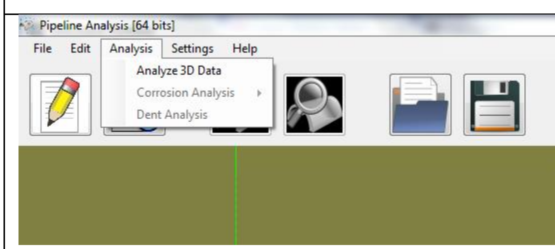


Figure 1.1 Pipeline Analysis Window Layout

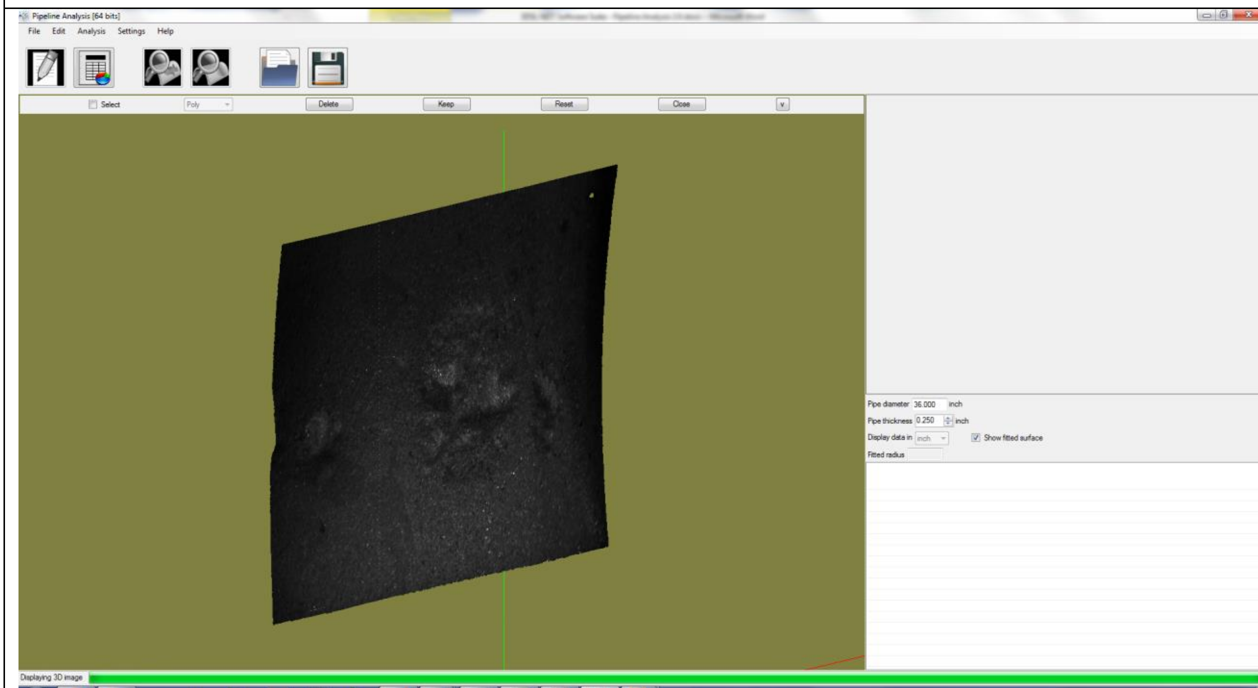
Data is loaded directly into Pipeline Analysis from Portfolio by selecting the 3D image to analyze and then selecting the Analyze 3D Image button. Data may also be loaded into Pipeline Analysis from the module by selecting File and then Load 3D Image (as shown on next page). Pipeline Analysis has four major windows. Throughout the manual, these windows will be referred to as Window 1, Window 2, Window 3, and Window 4. Window 1 is for 3D data visualization, data selection, and data manipulation. Window 2 provides access to the feature assessment options and displays a 2D image of the analyzed features. Window 3 displays key pipe parameters. Window 4 displays key feature results (for example, maximum depth).

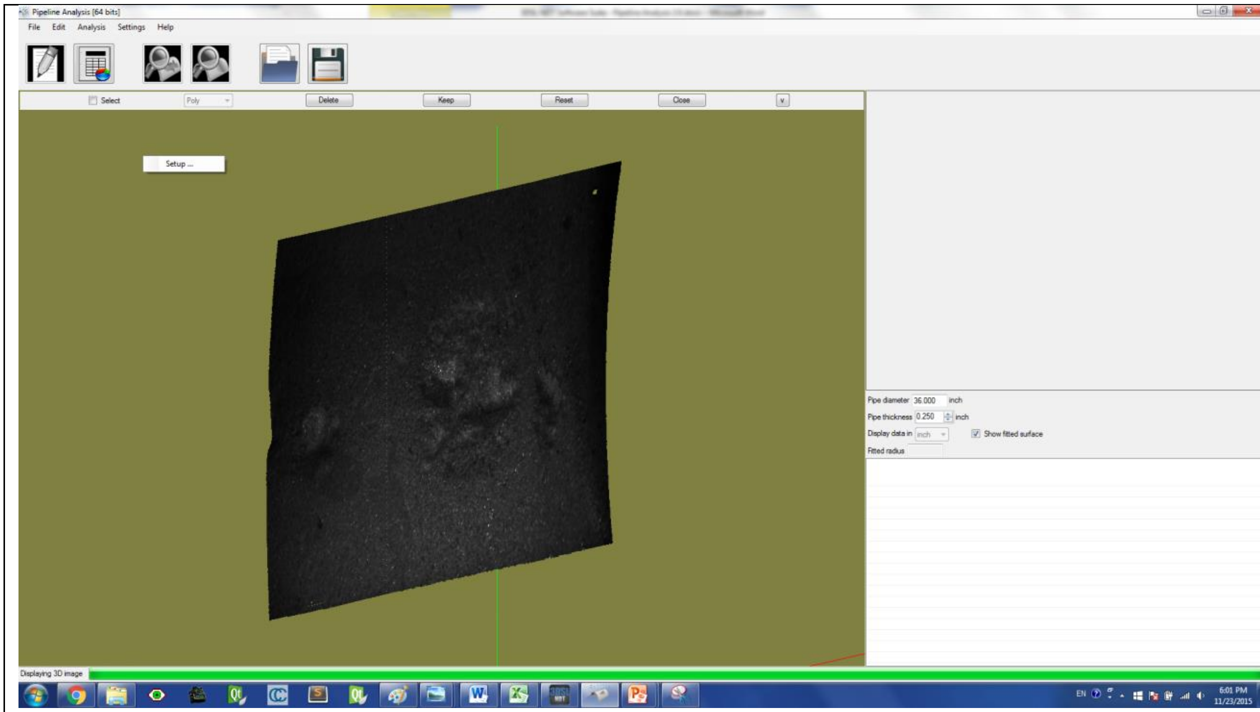
<table>
<tr>
<td>
</td>
<td>Pipeline Analysis has menu options and buttons for accessing the key functions. The menu options under the File option are shown at right. Load 3D Image allows the user to load a ply file. Images can also be saved as ply files. This is useful for instances when data is edited. The Save as, Import and Export functions will be described in detail in Section 3.</td>
</tr>
<tr>
<td>
</td>
<td>There are several options under the Edit menu. Edit 3D Image allows the user to edit the 3D data; this is done in Window 1. This is useful when stray points from background objects are in the scan of the pipe, tank, or other object under inspection.</td>
</tr>
<tr>
<td colspan="2">Parent metal, or undamaged metal, is needed to establish the reference surface. Metal loss and deformation are determined relative to the reference surface. In most situations, Pipeline Analysis is able to automatically identify parent metal. However, there are situations where the severity of the damage prevents automatic detection of parent metal. In these situations, parent metal can be manually selected by the user; this is done in Window 1. The tools used to manually select of parent metal are similar to those used to edit images.

Manual selection of features, clearing of all features, and rotating the image 180 degrees are all Window 2 functions. These features can also be accessed by right-clicking the mouse in Window 2. Manually selecting. These functions will be described in further detail in Section 2.</td>
</tr>
<tr>
<td>
</td>
<td>Analyze 3D Data initiates the analysis of the 3D data. Details on how the analysis is performed, including corrosion and dent analysis, are explained in Section 2.</td>
</tr>
</table>

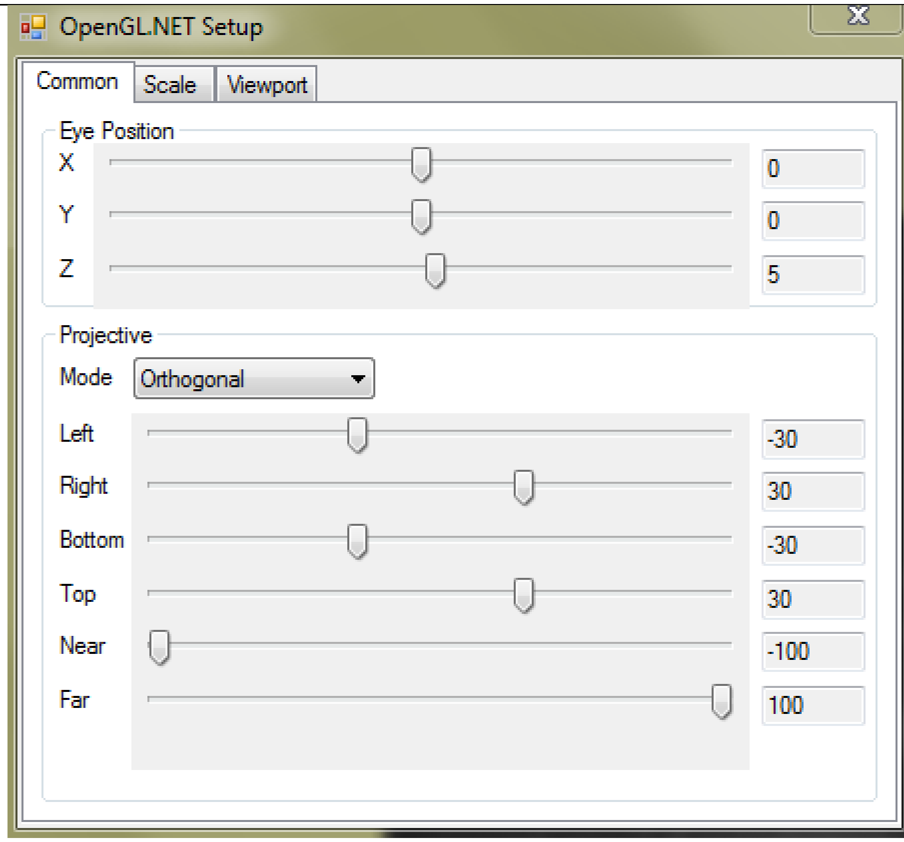
1.2 Manipulating and selecting data

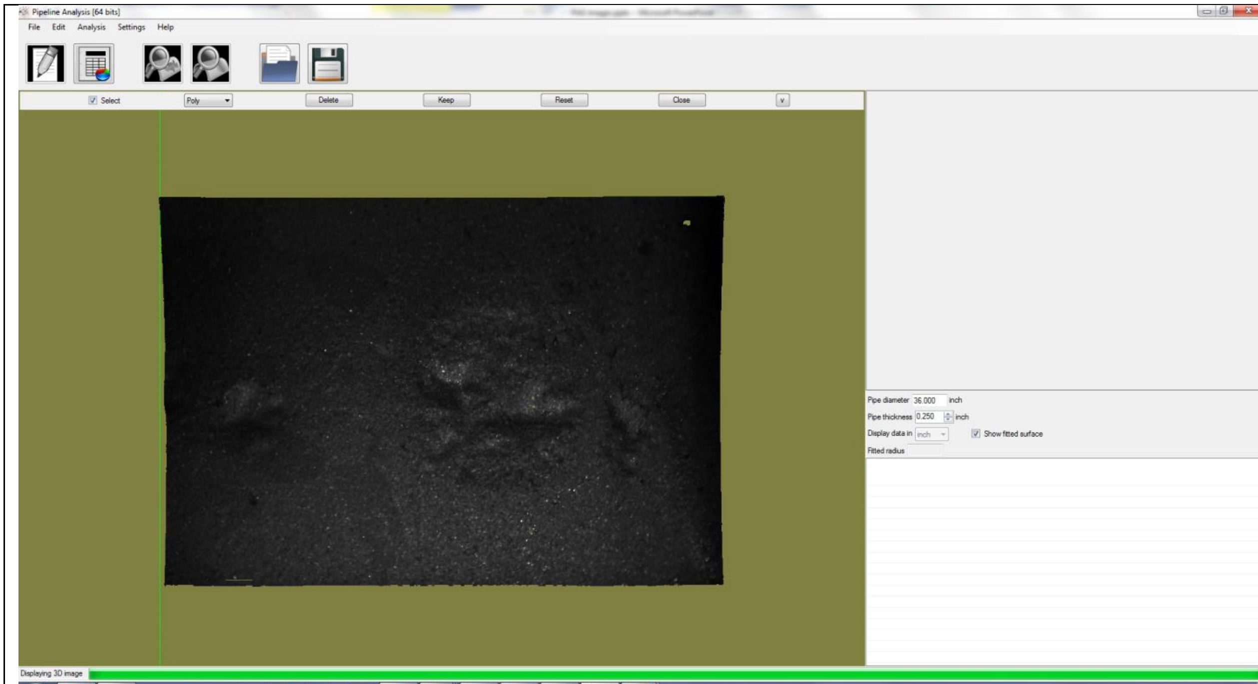
The 3D image in Window 1 can be manipulated using the mouse. Left-clicking the mouse allows the image to be rotated. Right-clicking the mouse allows the image to be translated. The scroll bar on the mouse can be used to zoom in or out. Many laptops use a multi-touch approach to enable the zoom feature. Please check the mouse settings on your PC or laptop for more information.

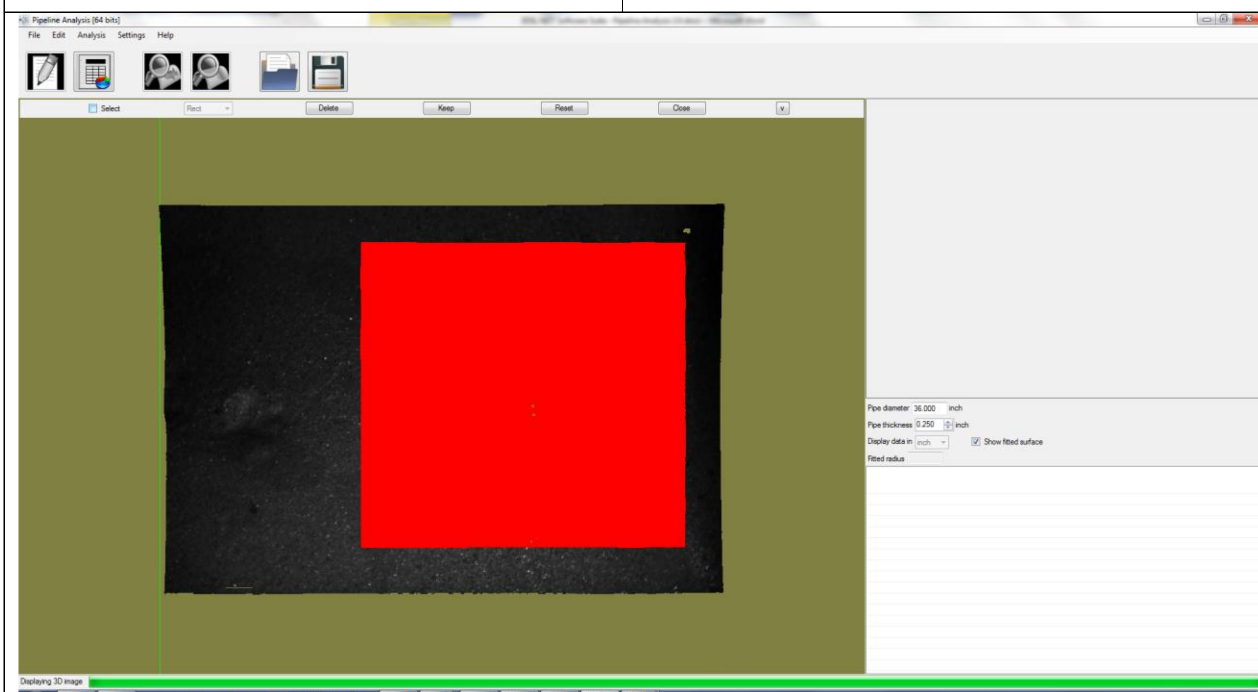




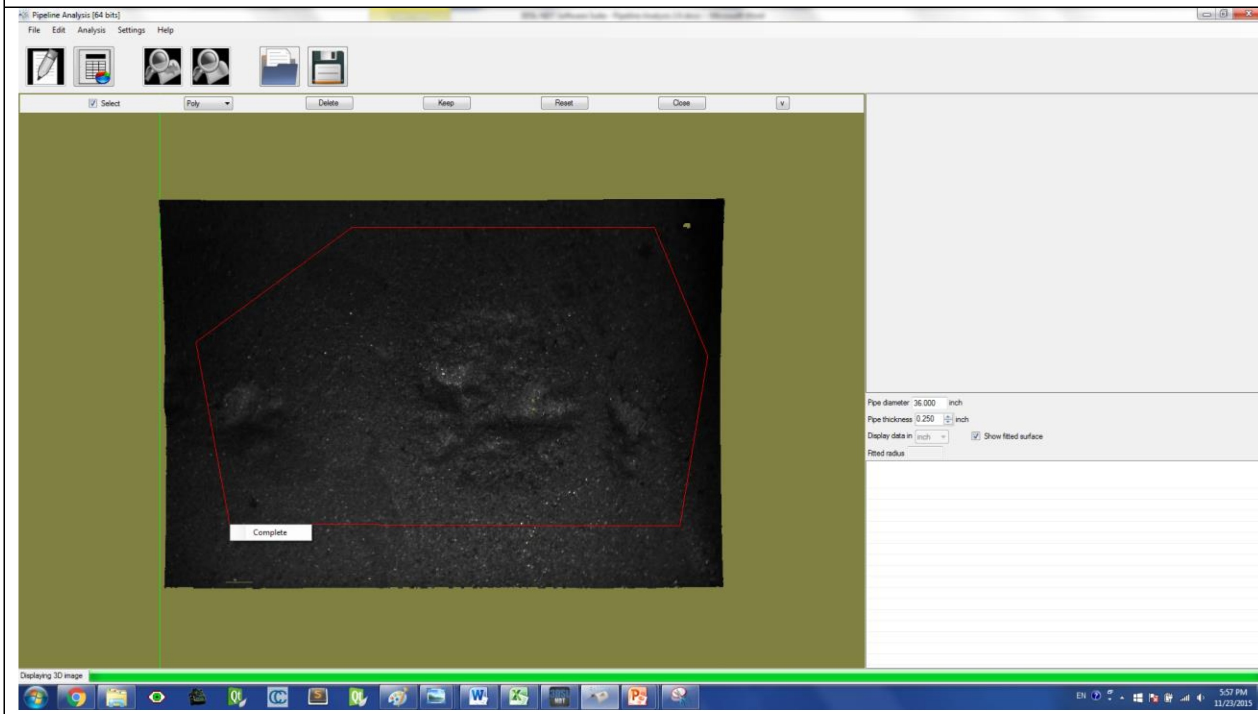
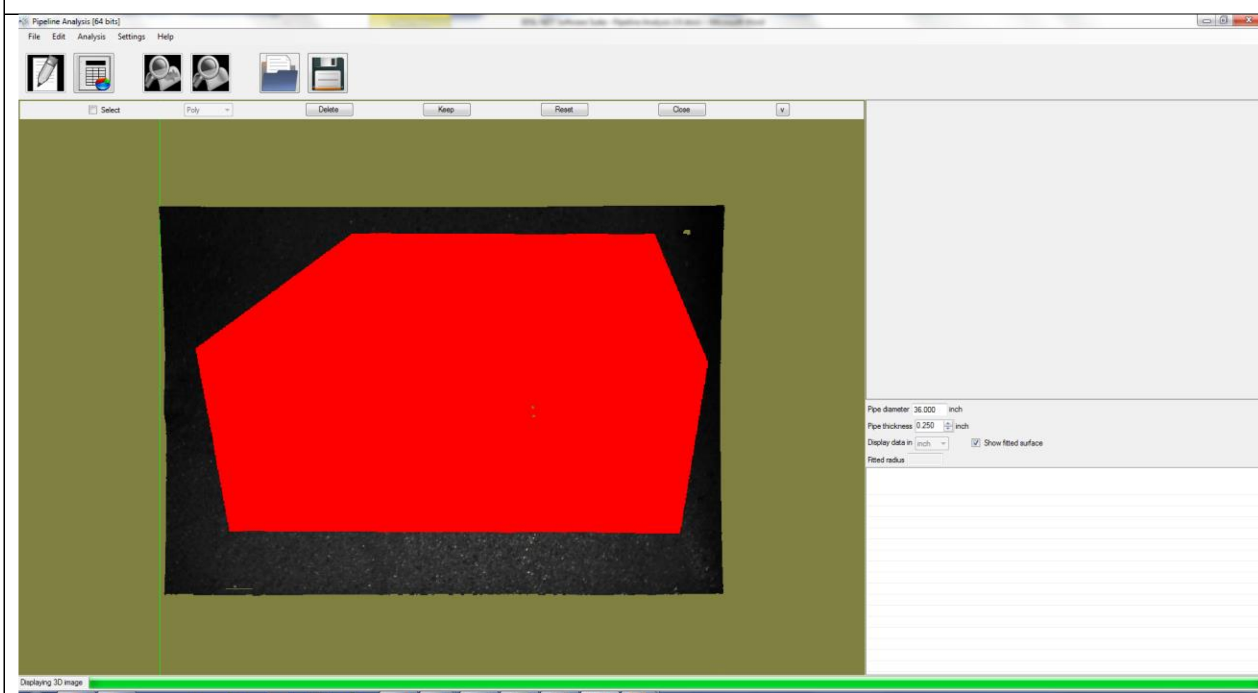
More complicated changes to Window 1 can be achieved by right-clicking in Window 1. This will bring up a Setup option. Selecting the Setup option will bring up the window shown below.

<table>
<tr><td>From this window, the eye position, projection method, scale and viewport options may be modified.</td><td>
</td></tr>
<tr><td colspan="2">When the Edit 3D Data option is selected, the Select box switches the mode between data manipulation and data editing. When the Select box is checked, data may be selected. Data may be selected using either a rectangle or a polygon shape.</td></tr>
</table>

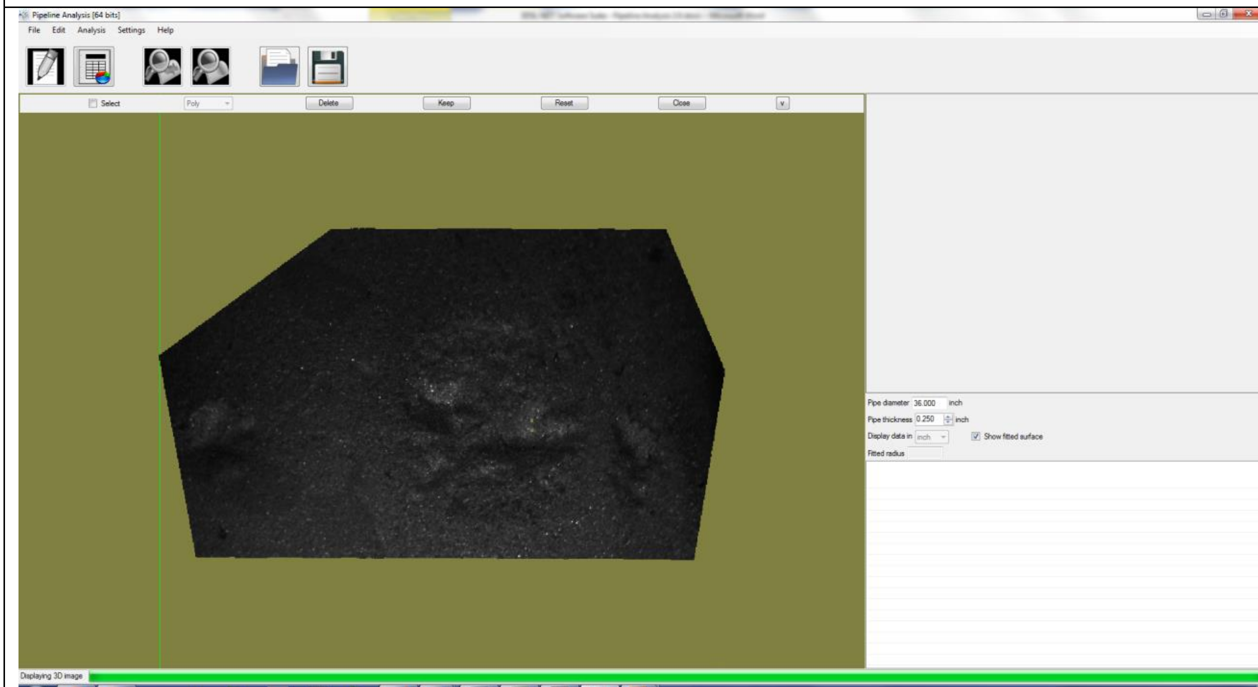




In the above example, the rectangle shape was used to highlight a portion of the 3D data. The highlighted data is shown in red. Highlighted data can either be deleted or kept. The reset option restores all data and returns the scan to its original condition. Data can also be selected using a polygon shape. Left-click the mouse to start drawing the shape. Move the mouse to draw a line. Left-click to

terminate the first line and begin drawing the second line.

Continue in this manner until the desired shape is achieved and the right-click. This will bring up the Complete button. Selecting the button will highlight the data inside the polygon shape.


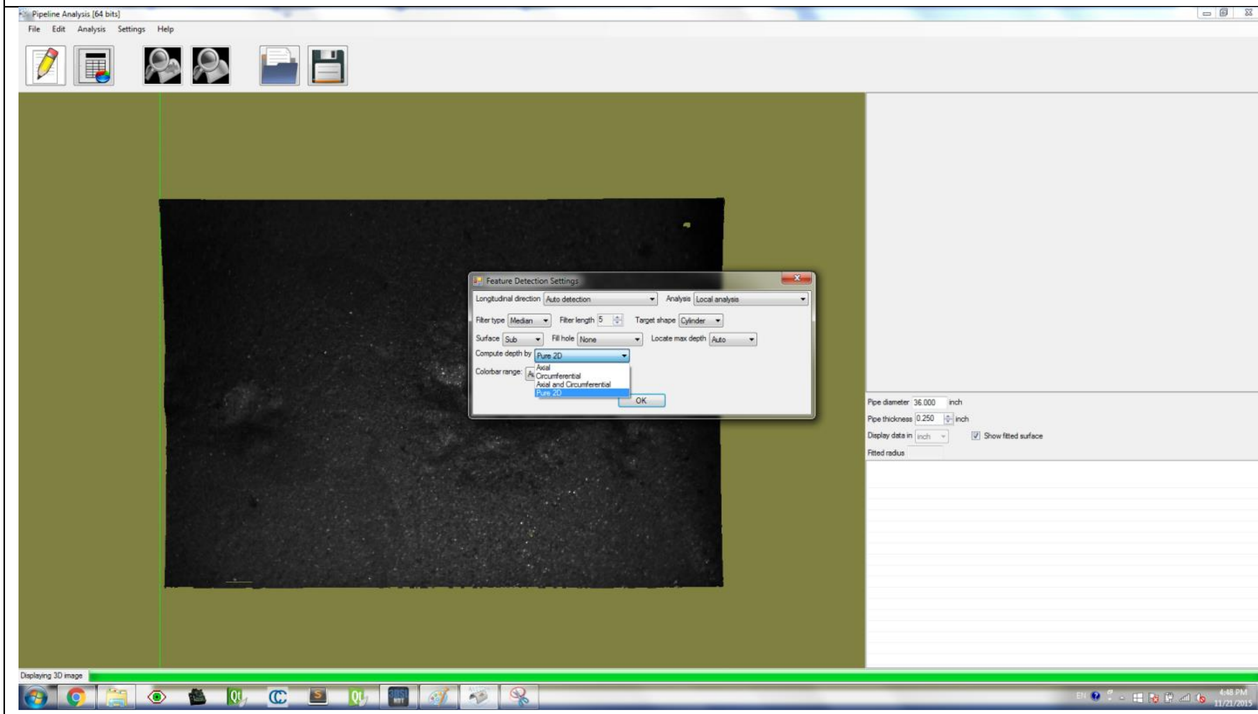
Selecting Keep will keep the data in the highlighted area and delete all other data.



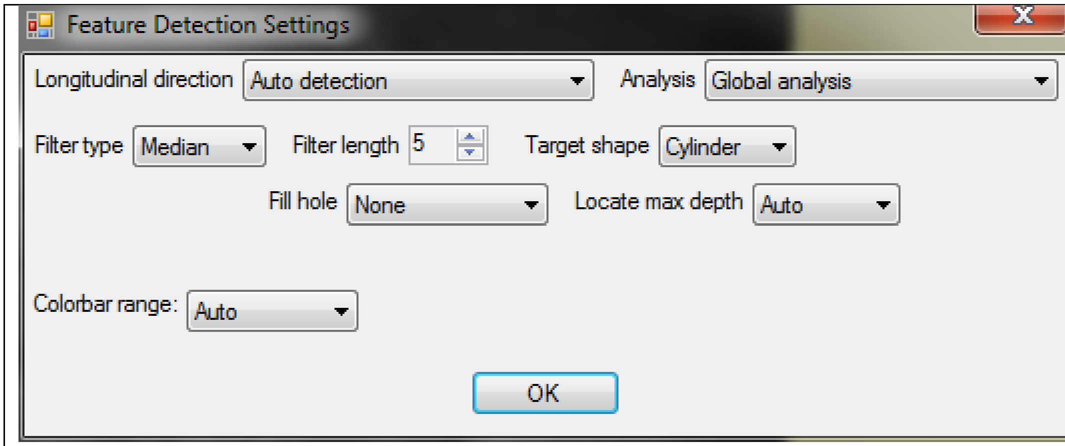
2 Analyzing 3D data

2.1 Feature selection

To properly analyze 3D data for metal loss or mechanical damage, the appropriate analysis method must be selected. Selecting the Settings option from the menu brings up the Feature Detection Settings window. From this window the analysis option can be selected.

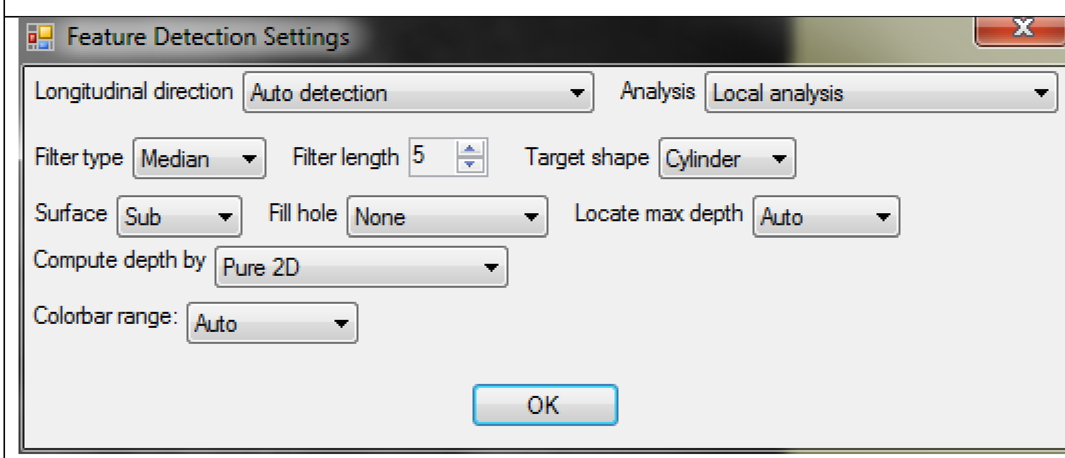


There are two basic categories of analysis methods: Global analysis and Local analysis. The main difference between the two methods is the technique for determining the reference against which the damage is measured. Global analysis uses 3D data from the entire 3D image to establish a reference. This is the appropriate approach when analyzing a pipe or plate for mechanical damage. The Global analysis function will establish a reference based on the Target shape: cylinder or plane. Deviations from the target shape are assumed to be from mechanical damage. Many large pipes have ovality. The ovality of the pipe may have resulted from the pipe being buried in the ground for an extended period of time. It is appropriate to include the ovality in the calculation of the mechanical damage. However, ovality should not be included when assessing metal loss. The Local analysis option is a method that ignores pipe ovality when determing the metal loss. Typically, metal loss is assessed using the Local analysis option. Because small diameter pipe, 8 inches (400mm) or less, generally has no ovality, Global analysis can be used to assess small diameter pipe.



Local analysis uses only data that is near the feature being assessed. Parent metal in the vicinity of an area of metal loss is used to establish a reference. There are several methods by which the depth can be computed:

- Methods that simulate a pit gage approach (depth is calculated relative to a linear reference); scan noise will impact the repeatability of the following methods. When comparing multiple scans of the same surface, the scan noise will result in a repeatability of +/- 2mils
    - Axial: this method simulates a pit gage placed perfectly in the axially direction; this is the appropriate method when assessing metal loss along a long seam weld
    - Circumferential: this method calculates depth looking at the deviation between parent metal and the area of metal loss in the circumferential direction; this is the appropriate method when assessing metal loss along a girth weld
    - Axial and Circumferential: this method applied both the Axial and Circumferential method to determine the metal loss; this is best for areas that do not contain welds
- Pure 2D: this method creates a two dimensional reference against which metal loss is measured. Because the reference is established over a two dimensional area, the impact of scan noise is reduced.

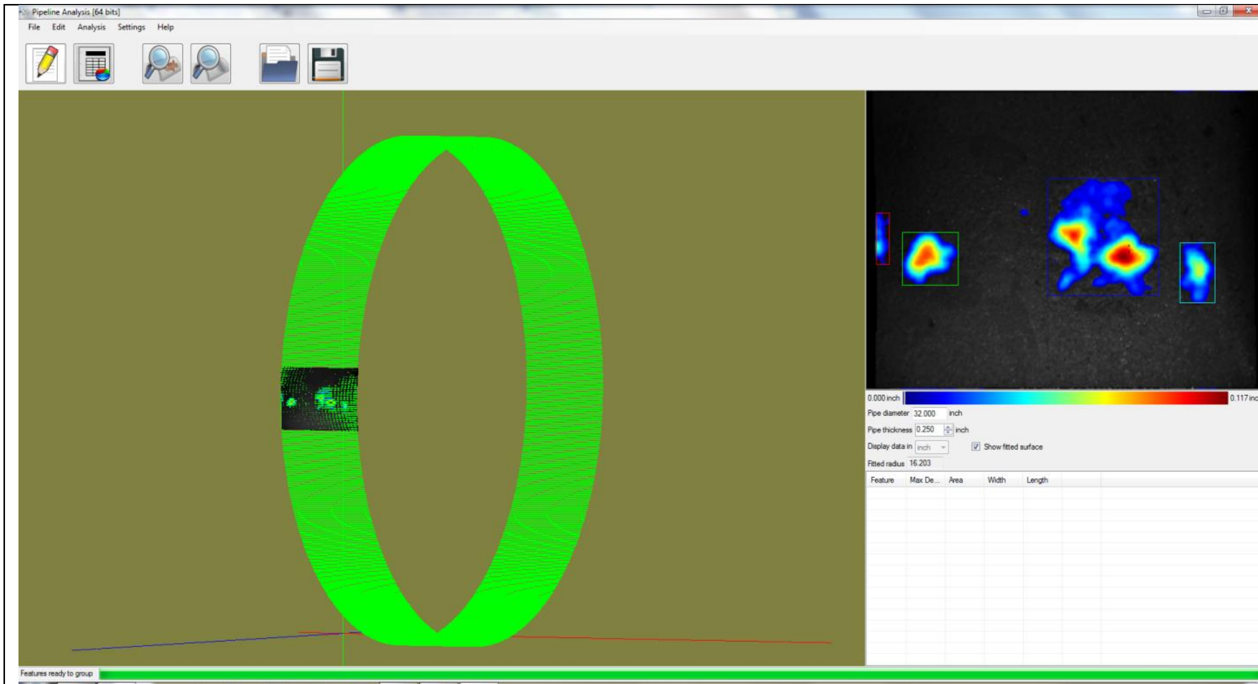


There are several options that should be selected. The software will automatically detect if the scanned surface is from the outside or inside of a pipe, tank, or pressure vessel. If metal loss needs to be assessed, the Surface option should be set to Sub. If weld parameters (height, width) need to be assessed, the Surface option should be set to Above. For most applications, the Filter type should be set to Median with a Filter length of 5: these parameter simulate a pit gage with a tip size that is greater than 0.5mm. Holes are generally caused by missing data. Data can be missing because the signal-to-noise may be below a threshold or because the area was in shadow. The Fill hole option can be used to fill holes left by missing data. The interpolation option will fill holes based on the positions of nearby neighbors. The default option is none. In this case, the holes are left unfilled.

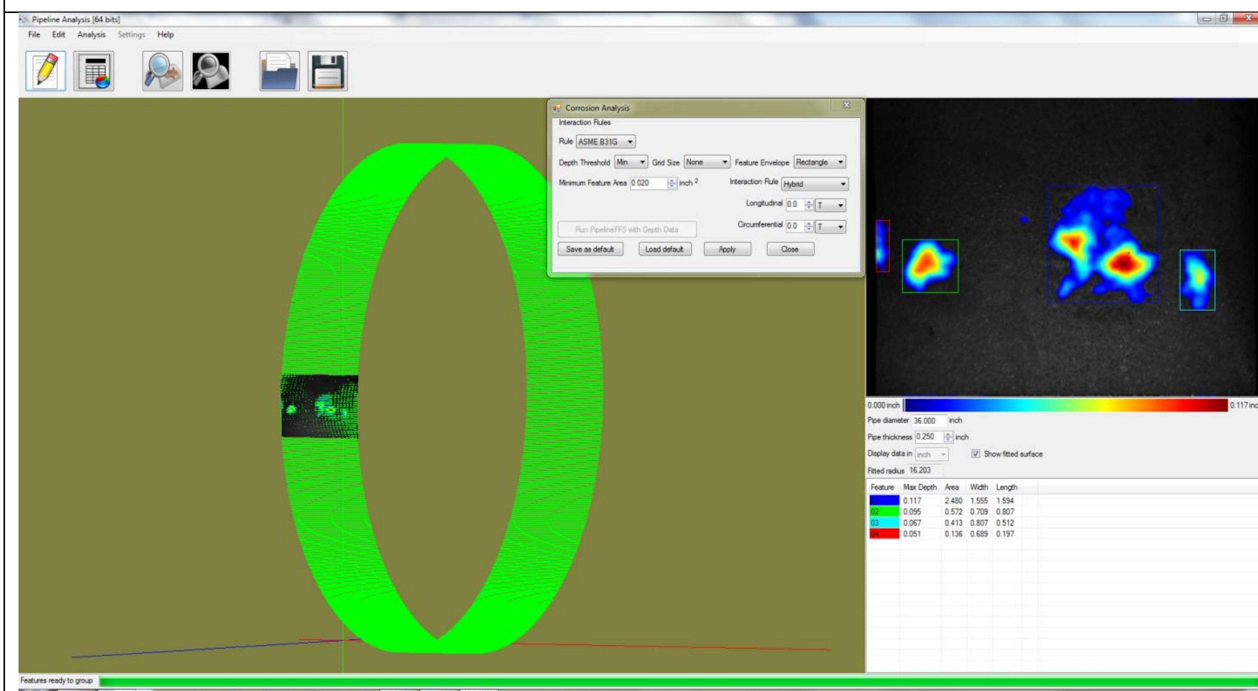
The Colorbar range defaults to Auto. In this case, the software automatically sets the range of the colorbar based on the analysis of the features. However, the use can set the colorbar manually. This is useful in cases where, for example, all defects that exceed 80% wall thickness need to be in red. Manually setting the colorbar also ensures that the colorbar is the same across features that are from the same pipe but are in separate scans.

2.2 Corrosion Analysis

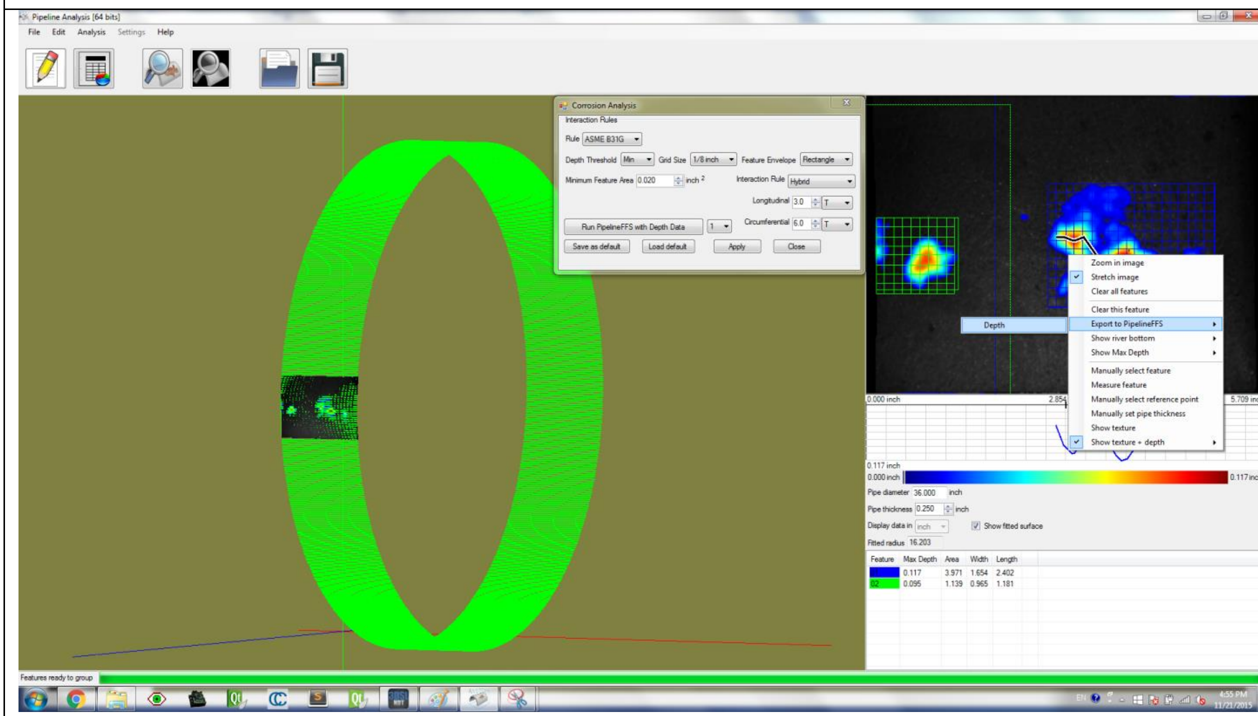
Once the feature settings have been selected, the feature identification should be performed. Feature identification can be performed either by selecting the second button from the left (Analyze 3D Data) or selecting the Analysis option from the menu and choosing Analyze 3D Data.



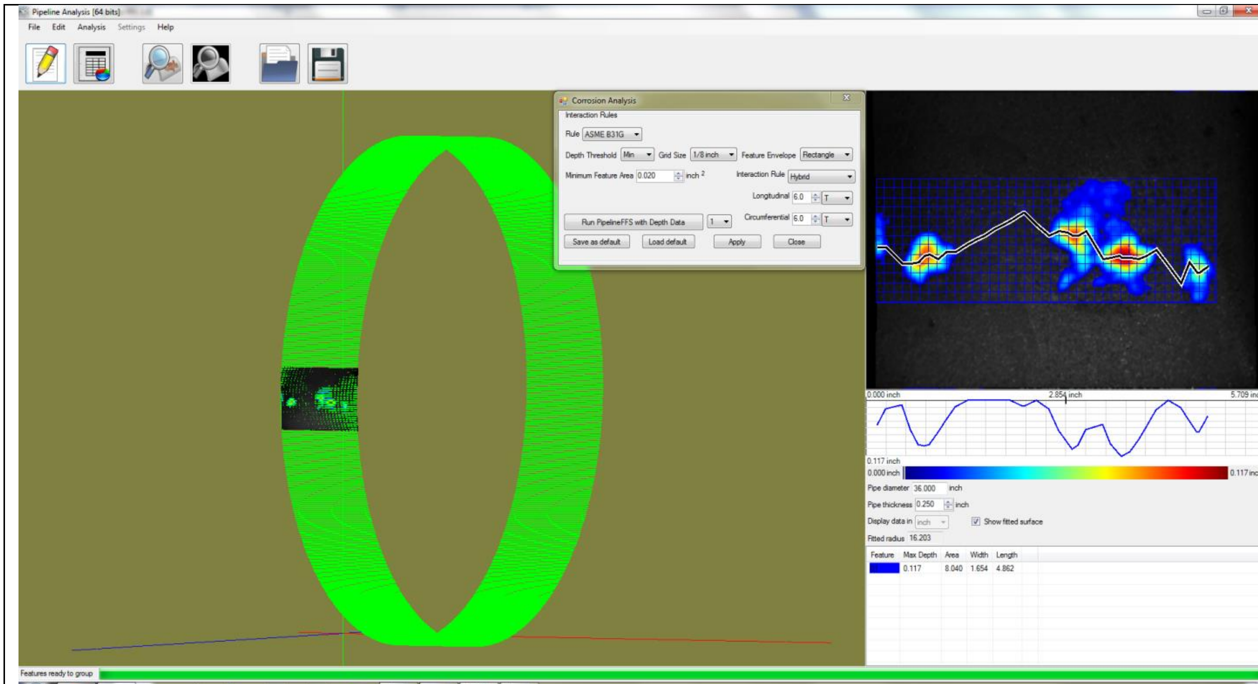
The feature identification analysis will calculate a fitted surface, which can be shown colored in green. The fitted surface is used in the Global analysis method to determine the extent of mechanical damage. The Local analysis method does not use the fitted surface to determine metal loss. The fitted surface does provide a good indication of the quality of the scan and the analysis in either case. Features are false colored for depth in Window 1 and Window 2.



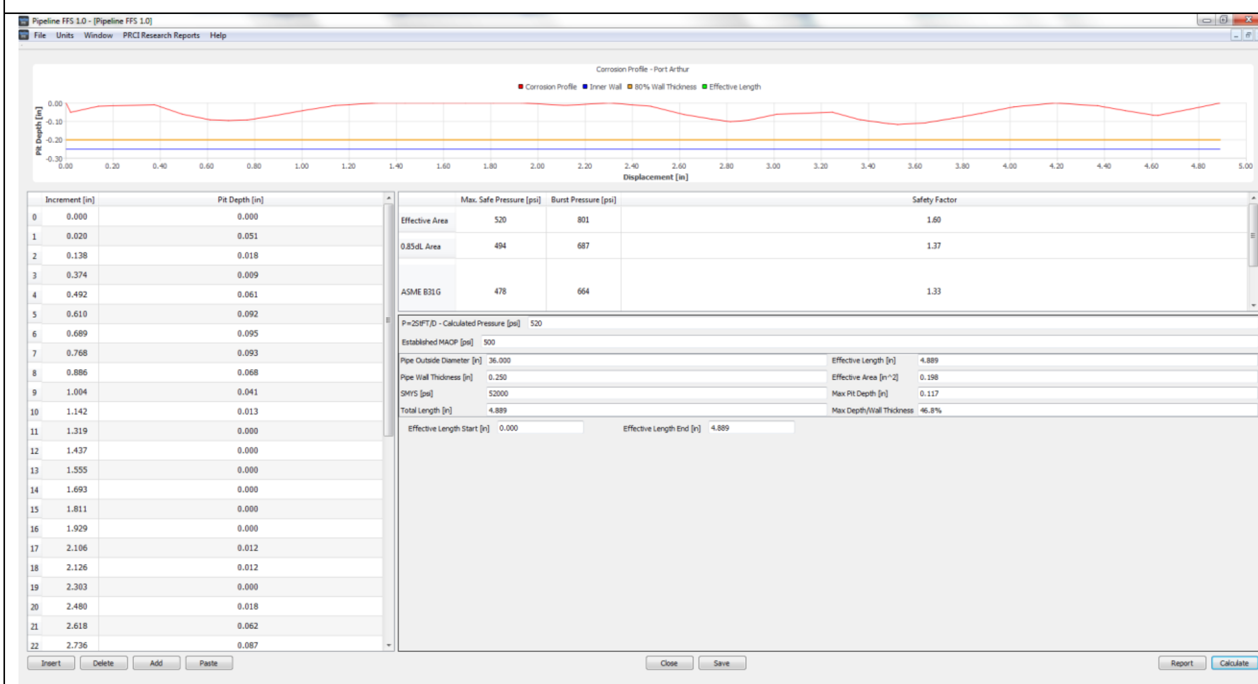
Selecting Corrosion Analysis, either the third button from the left or under the Analysis menu option, will initiate the corrosion analysis process and open up a dialog box. If ASME B31G rules are selected, interaction rules can be modified to meet operator requirements. If CSA Z662 rules are selected, the interaction rules are automatically applied. Interaction rules can be specified as either a multiple of the pipe thickness, and exact distance, or a hybrid of both. Often, when comparing data to ILI runs, or processing ILI data, 6T circumferential interaction and 1" longitudinal interaction are used. The 3DSL and 3D Toolbox imaging systems can detect very small features: on the order of 2mils (0.050mm). Often, in order to focus only on the major areas of corrosion, it is desirable to ignore small features. Features can be filtered either by depth or by area. For RSTRENG (effective area) calculations, filtering features does not impact the fitness-for-service results. However, because ASME B31G and Modified ASME B31G (0.85dL) calculations assume a geometric model for the feature based on the feature length, the fitness-for-service calculation will change based on the filtering of small features. RSTRENG will always provide the best fitness-for-service calculation.



Once the appropriate interaction rules and filters have been set, the software will automatically calculate the corrosion profile, also known as the river bottom profile or critical profile. The corrosion profile can be displayed by placing the cursor over the feature of interest in Window 2, right-clicking the mouse and selecting the option to display the river bottom profile.



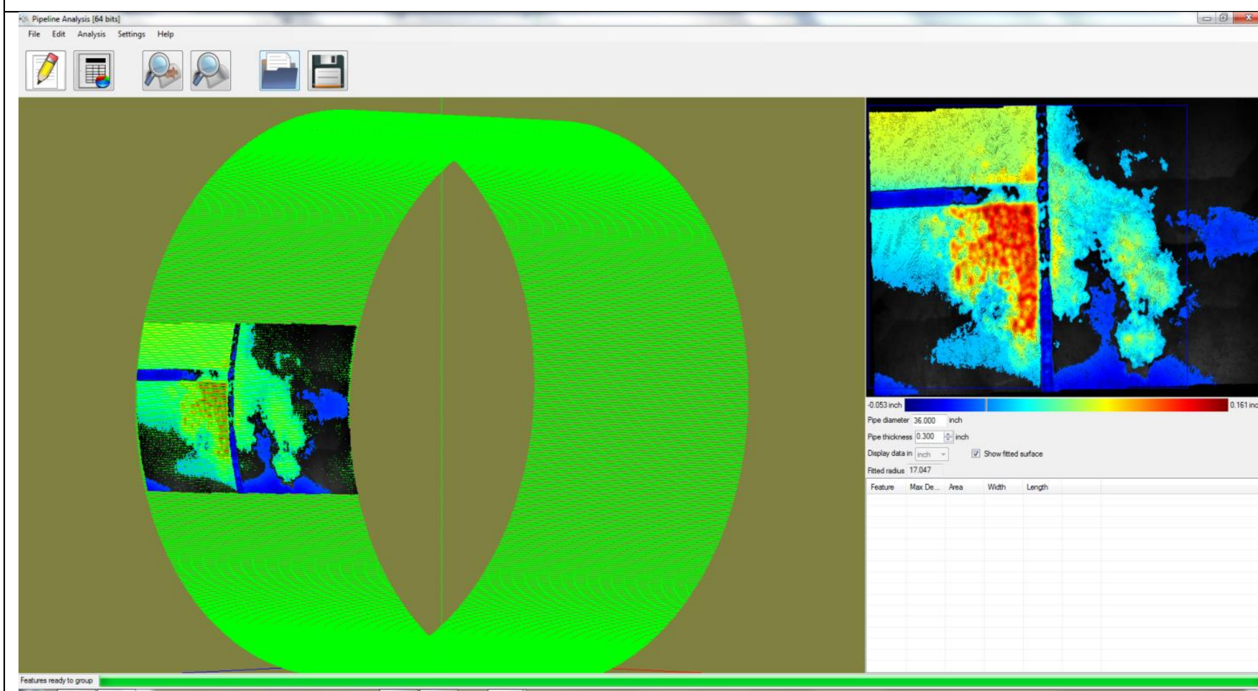
A single 3D surface may contain multiple features each with a unique corrosion profile. Each feature needs to be process independently using Pipeline FFS. Features may be selected from either the Corrosion Analysis dialog window or by right-clicking in Window 2. Once a feature is selected, the Pipeline FFS window will automatically open.



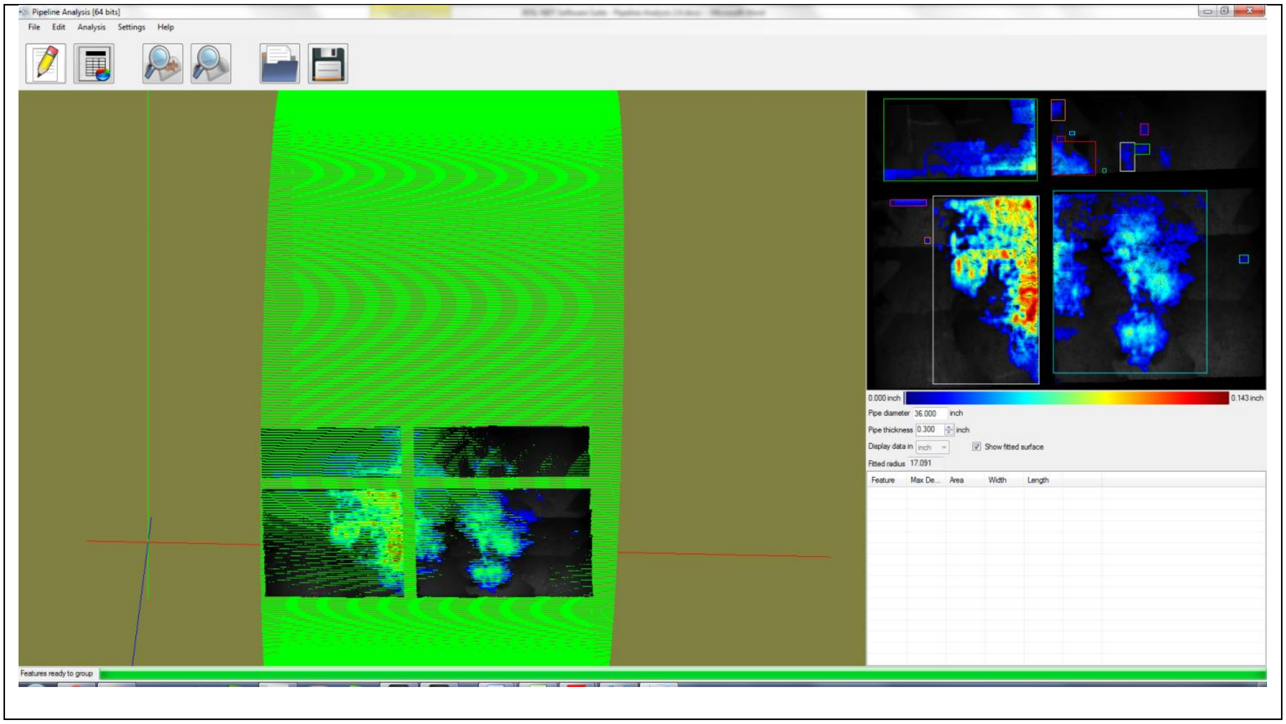
From this window, the maximum safe pressure, burst pressure, and safety factors can be calculated for the RSTRENG (effective area), Modified B31G (0.85dL), and ASME B31G methods. For details on how to operation Pipeline FFS, please refer to the Pipeline FFS manual.

Analysis of corrosion near welds is challenging. Under Local Analysis, the Axial and Circumferential feature analysis options can be used to assess corrosion near long seam and girth welds. However, there are situations where a long seam weld intersects a girth weld. There are two methods for determining metal loss at the intersection. The first method is to use the Global Analysis option. This method will create a reference surface based on all of the data in the scan. If the pipe is not deformed, this will produce an accurate result. In circumstances where the pipe is deformed, the editing feature of PAS can be used to remove the weld from the scan. Local Analysis can then be used to determine the metal loss.

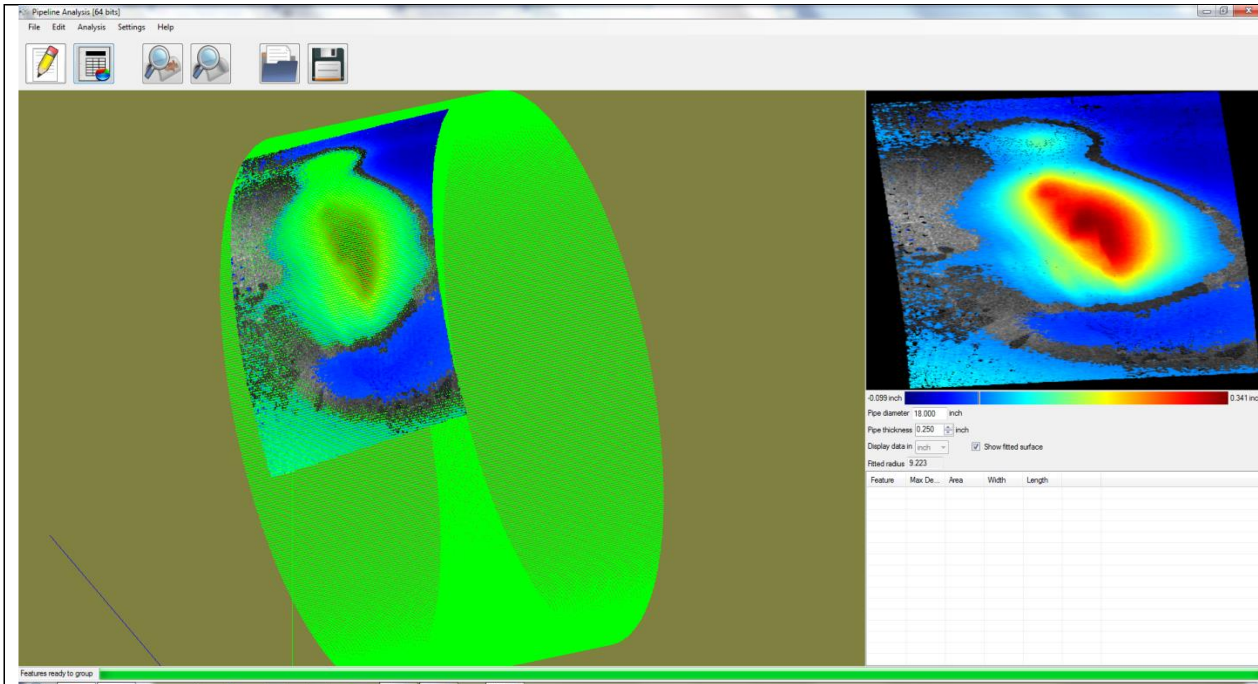
The following example shows the results of both methods.



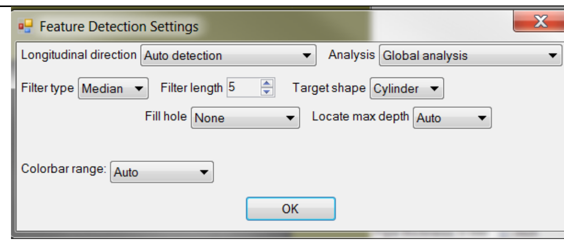
A comparison of the two results indicates that the deepest points differ slightly. This is primarily because of distortion in the pipe at the weld. This distortion is evident in the Global Analysis result (above) by the areas of blue in the lower right and the areas of yellow in the upper left. The more accurate result is below. In this case, after removing both the long seam and the girth weld, Local Analysis was applied. This option ignored the deformation in the pipe.



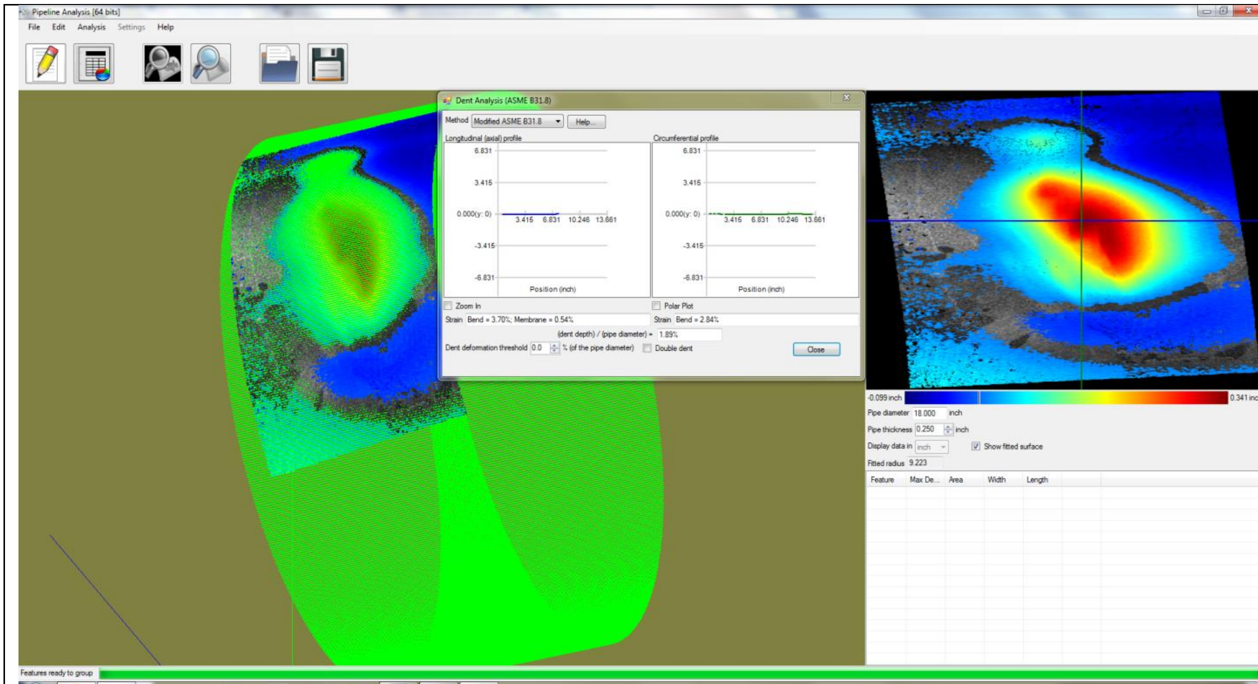
2.3 Dent Analysis



Under Feature Detection Settings, the Global analysis option should be selected when analyzing dents. Cylinder should be selected as the Target shape. The other options may be left in their default settings. Global analysis will compare the 3D data to a cylinder.



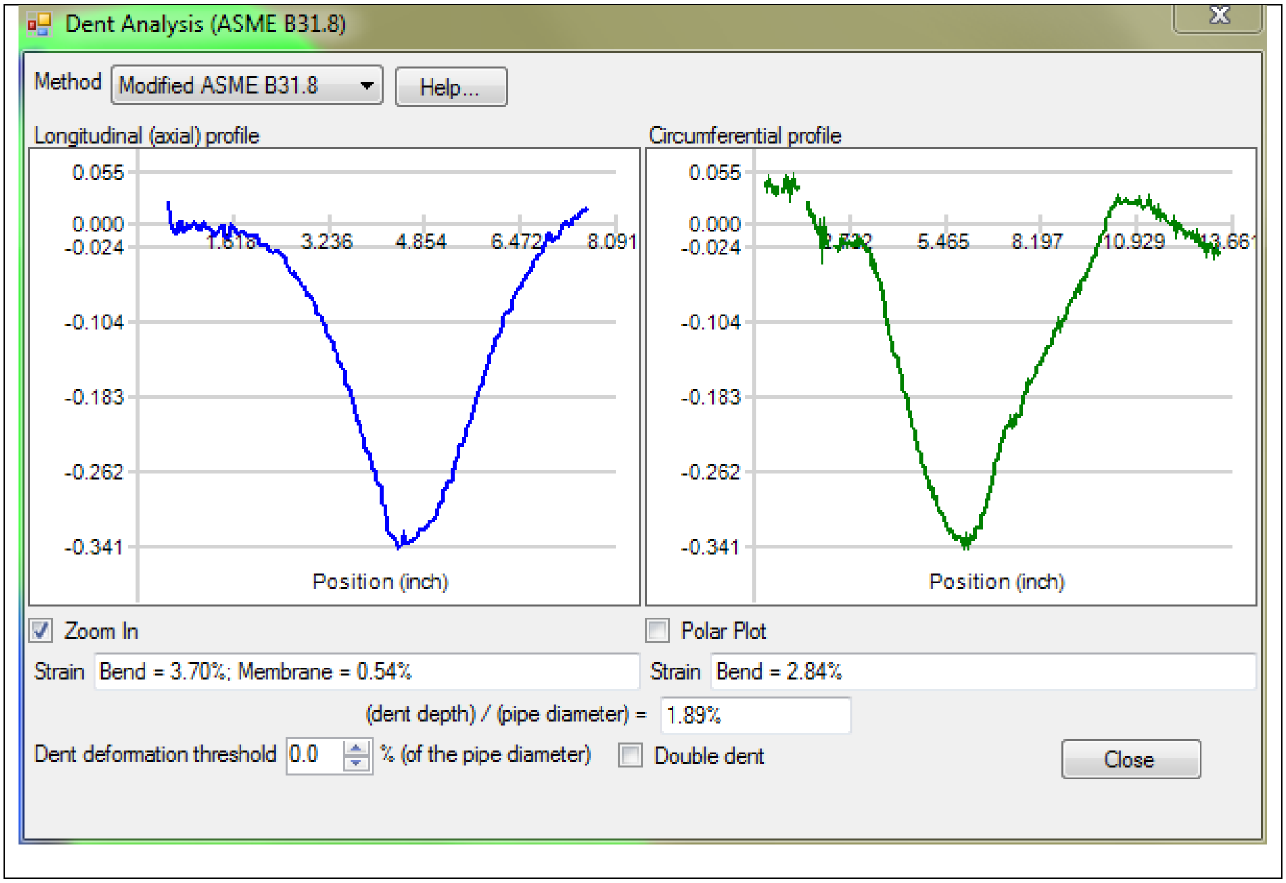
The 3D image will be compared to the cylindrical shape to determine the extent of the deformation. This complies with ASME B31.8 and B31.4 and enables strain calculations per these recommendations.

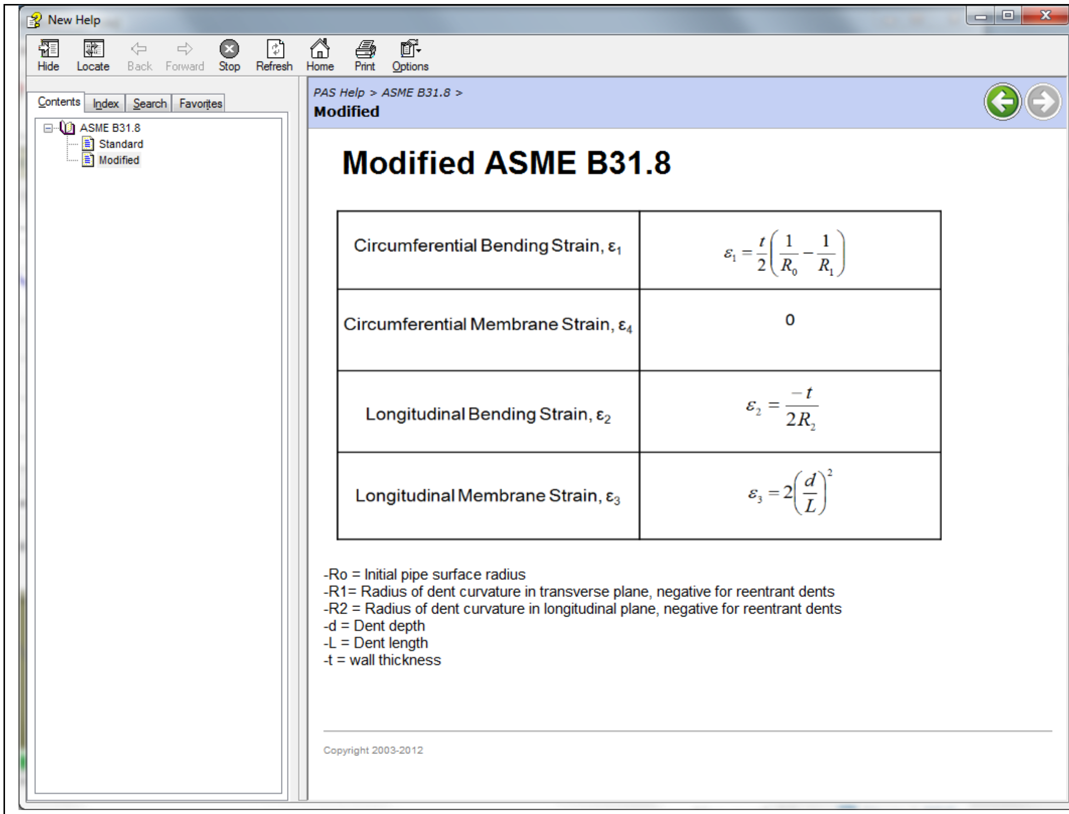


After the cylindrical reference surface has been computed, selecting the Dent Analysis option will calculate the dent depth and the dent strain parameters. There are two options for calculating the dent strain: 1) ASME B31.8 (identical to ASME B31.4); 2) Modified ASME B31.8. The modified calculations adjust the longitudinal membrane strain calculation. Details can be found in the following pages and in the help section of the dent analysis window.

Because dents are often shallow, details of the dent are often more visible with an expanded view. Checking the Zoom In box will re-scale the dent depth axis and allow for a more detailed examination of the dent profile. Gouges and other areas of metal loss inside a dent are more visible using this feature.

The dent length is used in calculating the longitudinal (axial) membrane strain. The Dent deformation threshold is used to define the beginning and end of the dent. This determines the dent length. The Federal Code of Regulations 49 CFR 192 defines the dent length as the length between the beginning of a deformation to the end of a deformation. Consequently, the dent deformation threshold should generally be set to 0 (this is the default value). However, because manual measurements and ILI tools are not as sensitive to depth as the 3DSL Rhino, 3D Toolbox, and other 3D imaging systems, the dent deformation threshold can be adjusted to enable correlation with these other methods.


Dent Analysis (ASME B31.8)
Method
Modified ASME B31.8
Help...
Longitudinal (axial) profile
Circumferential profile
0.055
0.000
-0.024
-0.104
-0.183
-0.262
-0.341
1.618
3.236
4.854
6.472
8.091
Position (inch)
5.465
8.197
10.929
Position (inch)
Zoom In
Polar Plot
Strain
Bend = 3.70%; Membrane = 0.54%
Strain
Bend = 2.84%
(dent depth) / (pipe diameter) =
1.89%
Dent deformation threshold
0.0
% (of the pipe diameter)
Double dent
Close

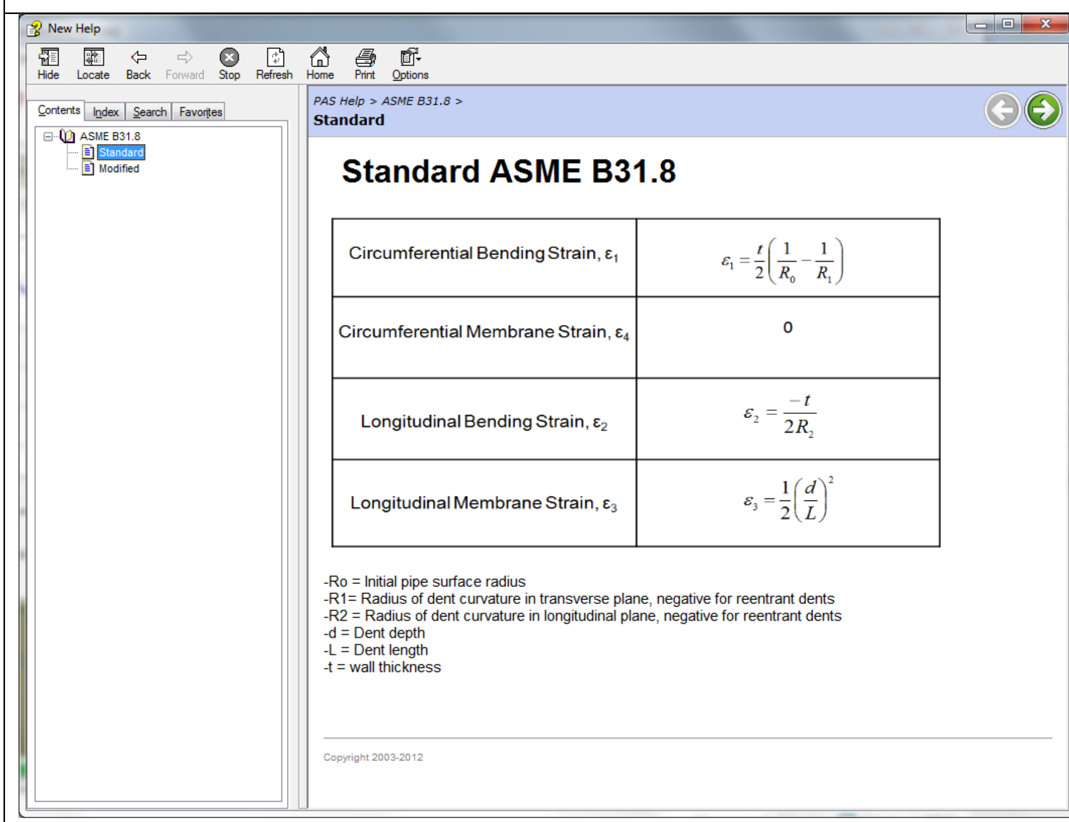


Modified

Modified ASME B31.8

Circumferential Bending Strain, ε_1	$\varepsilon_1 = \frac{t}{2}\left(\frac{1}{R_0} - \frac{1}{R_1}\right)$
Circumferential Membrane Strain, ε_4	0
Longitudinal Bending Strain, ε_2	$\varepsilon_2 = \frac{-t}{2R_2}$
Longitudinal Membrane Strain, ε_3	$\varepsilon_3 = 2\left(\frac{d}{L}\right)^2$

-Ro = Initial pipe surface radius
-R1= Radius of dent curvature in transverse plane, negative for reentrant dents
-R2 = Radius of dent curvature in longitudinal plane, negative for reentrant dents
-d = Dent depth
-L = Dent length
-t = wall thickness



Standard

Standard ASME B31.8

Circumferential Bending Strain, ε_1	$\varepsilon_1 = \frac{t}{2}\left(\frac{1}{R_0} - \frac{1}{R_1}\right)$
Circumferential Membrane Strain, ε_4	0
Longitudinal Bending Strain, ε_2	$\varepsilon_2 = \frac{-t}{2R_2}$
Longitudinal Membrane Strain, ε_3	$\varepsilon_3 = \frac{1}{2}\left(\frac{d}{L}\right)^2$

-Ro = Initial pipe surface radius
-R1= Radius of dent curvature in transverse plane, negative for reentrant dents
-R2 = Radius of dent curvature in longitudinal plane, negative for reentrant dents
-d = Dent depth
-L = Dent length
-t = wall thickness

The calculation of the longitudinal membrane strain differs between the standard and modified versions of ASME B31.8. In the modified version, the factor of ½ is replaced by a factor of two. This was done to ensure that the strain calculation more closely matched the definition of engineering strain:

$$\varepsilon_1 = \Delta L / L_o$$

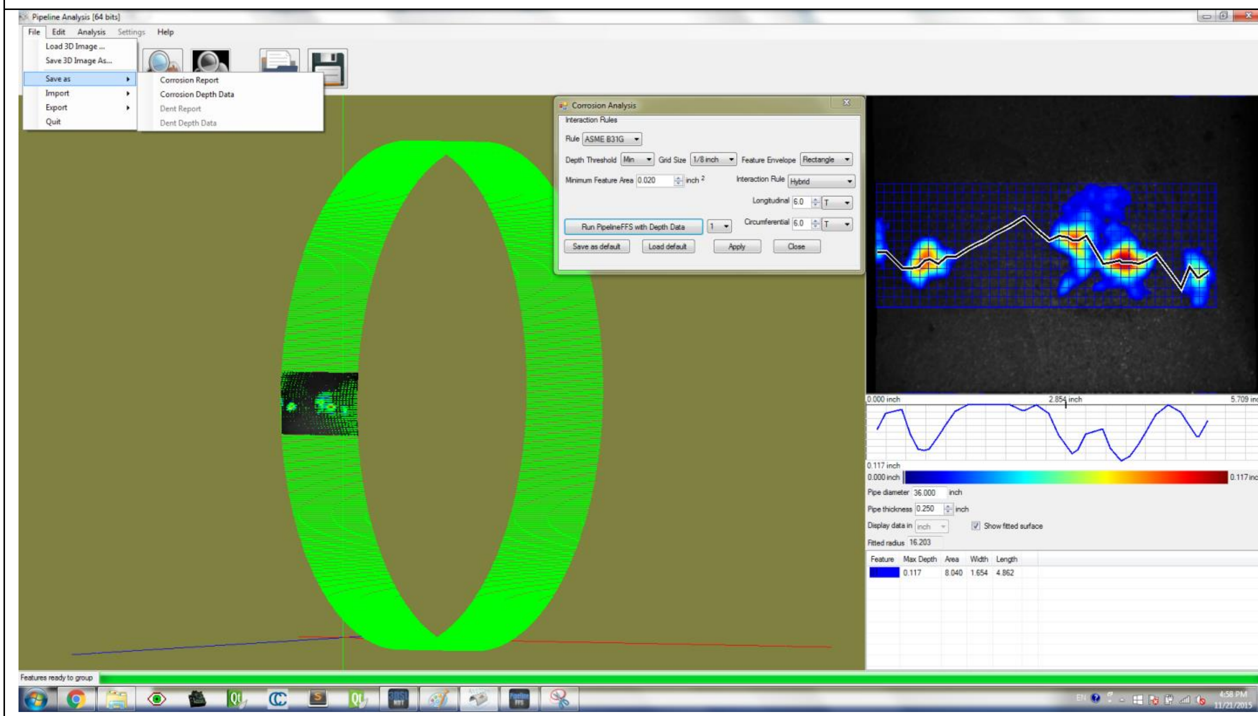
Where is ΔL the change in length that resulted from the dent and L_o is the original length of the un-deformed metal.

3 Output

3.1 Generating reports

A critical step in any damage assessment is the ability to generate reports. Pipeline Analysis offers several standard reports as well as the ability to export data to other programs for further analysis. The standard reports comply with ASME B31G for corrosion and ASME B31.8 and ASME B31.4 for dent assessment.

Corrosion reports may be generated when the Corrosion Analysis window is active. The report can be generated by selecting File→Save as→Corrosion Report (see the figure below). The report is saved in an Excel format. The corrosion depth data, including the river bottom or corrosion profile, can be saved as a csv file by selecting File→Save as→Corrosion Depth Data.

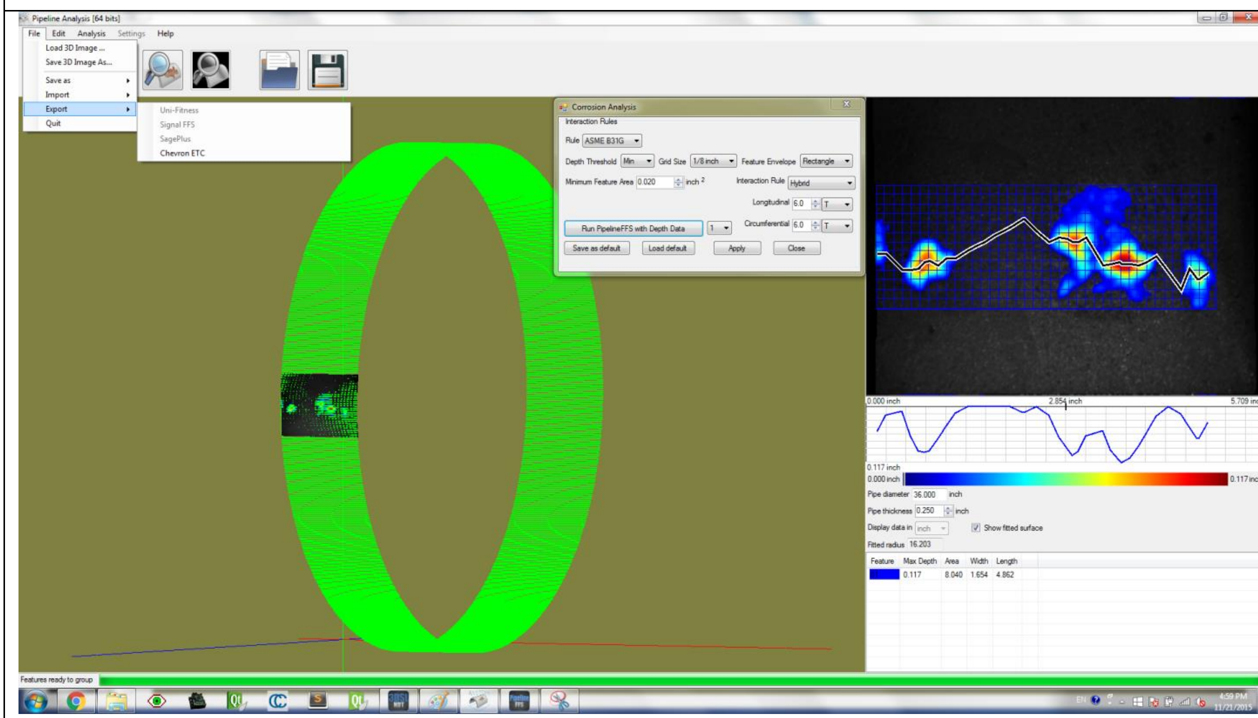


Dent reports can be generated when the Dent Analysis window is active by selecting File→Save as→Dent Report. The dent depth data can be saved as a csv file by selecting File→Save as→Dent Depth Data.

3.2 Exporting data to other applications

Currently, Pipeline Analysis has built in functions for assessing the impact of damage per ASME B31G, CSA Z662, ASME B31.8 and ASME B31.4 recommendations. We export data in a format that is compatible with other software packages. This extends the analysis to API 579, DNV F101, and other assessment methods.

To export corrosion data, the Corrosion Analysis window needs to be active. To export dent data, the dent analysis window needs to be active. In either case, select File→Export and then the appropriate export option. Available options will be listed in black. Options that are not available will appear in gray. Options may be unavailable because the option is not associated with the open analysis window. For example, a corrosion export option will be gray if the dent analysis window is active. Options may also be unavailable if the optional feature has not been installed. Some options, such as the Uni-Fitness export option, require additional software modules that need to be purchased.



4 Index of Functions

Window	Access Path	Feature	Detailed description
1.1	File	Load 3D Image	Enables loading of ply files. Definitions of ply files can be found in the glossary section.
1.2	File	Save 3D Image As	Saves a file in a ply format. This can done after editing.
1.3	File	Save as	Pipeline Analysis can export a corrosion report, a dent report, as well as the raw corrosion and dent data in a csv format.
1.4	File	Import	Data from UT or other corrosion assessment tools can be imported for analysis.
1	File	Export	Pipeline Analysis version 2.0 and later integrates directly with Pipeline FFS for performing ASME B31G and RSTRENG calculations. In addition, data can be exported for further analysis in other software packages. The export function creates files that are correctly formatted for a variety of standard fitness-for-service software tools.
1	File	Quit	Quits the program.
2	Edit	Edit 3D Image	Enables editing of the 3D image. Selecting the Edit Icon (first on the left) will also launch this function.

2	Edit	Manually Select Parent Metal	For most 3D images, there is sufficient parent metal for automatic detection of parent metal and automatic calculation of defects. However, there are situations in which it may not be possible to acquire data that has sufficient parent metal. The user can manually select areas of the scan as parent metal. These areas will be used to establish the appropriate reference for determining metal loss and deformation. The user does not need to select all areas of parent metal.
2	Edit	Manually Select Feature	Pipeline Analysis will automatically identify features for evaluation. This option allows the user to manually select a feature for evaluation.
2	Edit	Clear All Features	This option clears all features.
2	Edit	Rotate 180°	Pipeline Analysis will automatically orient the image of the scan in the upper right (Window 2) such that the longitudinal axis of the pipe is running from left to right. However, the direction of flow is not necessarily left to right. If the direction of flow is not oriented in the direction desired, this rotates the image by 180°.
2	Edit-->Edit 3D Image	Select	When editing data, there are two modes of operation: 1) 3D image manipulation; 2) 3D data selection. The default mode is 3D image manipulation. In this mode, the 3D data in the Window 1, the 3D window, can be rotated, translated, and scaled. Checking the Select box, enables data to be selected for editing.

2	Edit-->Edit 3D Image	Poly	Data can be selected using an arbitrary polygon shape. Once the data has been selected, the operation is completed by clicking the right mouse button and selecting Complete. The selected area will be highlighted in red.
2	Edit-->Edit 3D Image	Rect	Data can be selected using a rectangle. The height and width of the rectangle are controlled by the mouse. To select data: 1)left-click and hold the mouse button; 2) drag the mouse to create the desired rectangle; 3) release the mouse. The selected area will be highlighted in red.
2	Edit-->Edit 3D Image	Delete	Red highlighted data is deleted when this option is selected.
2	Edit-->Edit 3D Image	Keep	Red highlighted data is saved when this option is selected.
2	Edit-->Edit 3D Image	Reset	This option resets the scan to the original size.
2	Edit-->Edit 3D Image	Close	This option terminates the edit function.
2	Edit-->Manually Select Features	(enables Window 2 function)	This option enables manual selection of features. This option is identical to the right-click option available in Window 2.
2	Edit-->Manually Select Parent Metal	Select	When manually selecting parent metal, there are two modes of operation: 1) 3D image manipulation; 2) 3D data selection. The default mode is 3D image manipulation. In this mode, the 3D data in the Window 1, the 3D window, can be rotated, translated, and scaled. Checking the Select box, enables data to be selected for editing.

2	Edit-->Manually Select Parent Metal	Poly	Data can be selected using an arbitrary polygon shape. Once the data has been selected, the operation is completed by clicking the right mouse button and selecting Complete. The selected area will be highlighted in green.
2	Edit-->Manually Select Parent Metal	Rect	Data can be selected using a rectangle. The height and width of the rectangle are controlled by the mouse. To select data: 1)left-click and hold the mouse button; 2) drag the mouse to create the desired rectangle; 3) release the mouse. The selected area will be highlighted in green.
2	Edit-->Manually Select Parent Metal	Clear	This option clears all selected areas.
2	Edit-->Manually Select Parent Metal	Done	The user should select this option when done selecting parent metal.
3	Analysis	Analyze 3D Data	When this option is selected, the data will be analyzed for features according to the options selected under feature detection. Selecting the Analyze 3D Data Icon (second from the left) will also launch this function.
3	Analysis	Corrosion Analysis	This option can be used to launch the corrosion analysis function or to select more advanced corrosion analysis. The Corrosion Analysis Icon (third from the left) will also launch the corrosion analysis function.
3	Analysis	Dent Analysis	This option can be used to launch the dent analysis function. The Dent Analysis Icon (fourth from the left) will also launch the dent analysis function.

3	Analysis-->Corrosion Analysis	Level 1 Metal Loss	This option displays the Level 1 Metal Loss assessment in Window 4, the Feature summary window. The metal loss calculation is performed using a rectangular model of the defect and calculating the metal loss as the product of the length, width, and depth of the defect.
3	Analysis-->Corrosion Analysis	Level 2 Metal Loss	This option displays the Level 2 Metal Loss assessment in Window 4, the Feature summary window. The metal loss calculation is performed using the critical profile, or river bottom profile, model of the defect. The metal loss for a circumferential grid column is calculated as the product of the axial width of the grid column, the circumferential extent of the feature, and the maximum depth in the grid column. The products for each individual grid column are then summed across the entire length of the feature.
3	Analysis-->Corrosion Analysis	Level 3 Metal Loss	This option displays the Level 3 Metal Loss assessment in Window 4, the Feature summary window. The metal loss calculation is calculating by summing the metal loss for each individual grid cell. The metal loss in a grid cell is the product of the length and width of the grid cell multiplied by the maximum depth of the grid cell.

3	Analysis-->Corrosion Analysis	Volumetric Metal Loss	This option displays the volumetric metal loss in Window 4, the Feature summary window. The metal loss calculation is calculating by summing the metal loss for each individual 3D data point. The metal loss for each data point is the product of the axial and circumferential point spacing multiplied by the depth of the point. For most systems, the axial and circumferential point spacing is 0.020 inches.
3	Analysis-->Corrosion Analysis (dialog)	ASME B31G	Selecting this option applies ASME B31G requirements to the feature assessment.
3	Analysis-->Corrosion Analysis (dialog)	CSA Z662	Selecting this option applies CSA Z662 requirements to the feature assessment.
3	Analysis-->Corrosion Analysis (dialog)	Depth threshold	This option allows the user to set a threshold for the minimum depth of a feature. All features with a depth that exceeds 0.002 inches will be detected. When analyzing a pipe for defects and remaining strength, small features can be ignored using this filter. Because the defect model for ASME B31G and 0.85dL is based on a definition of the defect width and length, changing this parameter may change the ASME B31G and 0.85dL calculations. See the Pipeline FFS manual for more detail.
3	Analysis-->Corrosion Analysis (dialog)	Grid size	The user can select a grid for a feature. The grid will encompass the feature and have cell sizes as specified by the user.

3	Analysis-->Corrosion Analysis (dialog)	Feature envelope	There are two methods for determining the area of the feature: 1) the product of length (axial extent) and width (circumferential extent); 2) the area encompassed by a contour drawn around the feature.
3	Analysis-->Corrosion Analysis (dialog)	Interaction rule - Hybrid	Interaction rules are used to group defects. Defects that exceed the distance indicated in the interaction rule setting will remain isolated defects. The Hybrid setting allows the user select a combination of absolute distance, specified in either inches or millimeters, and relative distance, specified as a multiple of the pipe wall thickness.
3	Analysis-->Corrosion Analysis (dialog)	Interaction rule - Absolute	The Absolute setting requires the user to specify the distance separating defects in either inches or millimeters (for example, 1 inch).
3	Analysis-->Corrosion Analysis (dialog)	Interaction rule - Relative	The Relative setting requires the user to specify the distance separating defects as a multiple of the wall thickness (for example, 3T).
3	Analysis-->Corrosion Analysis (dialog)	Run Pipeline FFS with Depth Data	This option will launch the Pipeline FFS module and analyze the river bottom profile, or corrosion profile, of the selected feature.
3	Analysis-->Corrosion Analysis (dialog)	Save as default	This option will save the current Corrosion Analysis settings as the default settings for future analyses.
3	Analysis-->Corrosion Analysis (dialog)	Load default	This option will load the saved settings into the Corrosion Analysis window. These settings are also loaded when the window if first opened.
3	Analysis-->Dent Analysis (dialog Help)	Re-entrant dent	A re-entrant dent has a radius of curvature that is in the opposite direction of the radius of curvature of the original, undamaged pipe.
3	Analysis-->Dent Analysis (dialog Help)	Non re-entrant dent	A non re-entrant dent has a radius of curvature that is in the same direction as the radius of curvature of the original, undamaged pipe.
3	Analysis-->Dent Analysis (dialog Help)	R0	The radius of curvature of the original, undamaged pipe.

3	Analysis-->Dent Analysis (dialog Help)	R1	The radius of the dent curvature in the transverse plane. This plane is perpendicular to the direction of flow. The value is negative for re-entrant dents.
3	Analysis-->Dent Analysis (dialog Help)	R2	The radius of the dent curvature in the longitudinal plane. This plane is aligned with the direction of flow. The value is negative for re-entrant dents.
3	Analysis-->Dent Analysis (dialog Help)	Dent length	This is the length of the dent as defined using the dent deformation threshold option. The dent begins at the start of the deformation and terminates at the end of the deformation. The default value for the dent deformation threshold is zero. When set to zero, the deformation begins at the first location where the deformation deviates from parent metal; the dent terminates at the location immediately before a return to parent metal. The dent deformation threshold allows the dent to start and terminate at other values. For example, the dent deformation threshold may be set to 0.1% (a percentage of the pipe diameter). As the dent deformation threshold is increased, the dent length will decrease and the longitudinal membrane strain will increase.
3	Analysis-->Dent Analysis (dialog)	Longitudinal membrane strain	The strain resulting from the stretch in the longitudinal (axial) direction caused by a deformation (dent, mechanical damage). Usually denoted as ε_3 and equal to the following (standard ASME B31.8 and B31.4): $\varepsilon_3 = ½ (d/L)^2$ Where d = dent depth and L = dent length
3	Analysis-->Dent Analysis (dialog)	Longitudinal bending strain	The shear strain in the longitudinal (axial) direction caused by a deformation (dent, mechanical damage). Usually denoted as ε_2: $\varepsilon_2 = -t/(2R_2)$ Where t = pipe wall thickness and R_2 = radius of curvature in the longitudinal plane (negative for re-entrant dents)
3	Analysis-->Dent Analysis (dialog)	Circumferential membrane strain	The strain resulting from the stretch in the circumferential direction. This strain, denoted as ε_4, is assumed to be zero per ASME B31.8 and ASME B31.4.

3	Analysis-->Dent Analysis (dialog)	Circumferential bending strain	The shear strain in the circumferential direction caused by a deformation (dent, mechanical damage). Usually denoted as ε_1: $\varepsilon_1 = (-t/2)(1/R_0 - 1/R_1)$ Where t = pipe wall thickness, R_0 = radius of the original, undamaged pipe, and R_1 = radius of curvature in the transverse plane (negative for re-entrant dents)
3	Analysis-->Dent Analysis (dialog)	Dent deformation threshold	The dent begins at the start of the deformation and terminates at the end of the deformation. The dent deformation threshold defines the deviation from parent metal that begins and ends the dent.
3	Analysis-->Dent Analysis (dialog)	Double dent	The dent length and strain calculations are more complicated for double dents. This box should be selected when processing double dents.
3	Analysis-->Dent Analysis (dialog)	Dent depth	The maximum depth of the dent as measured from the reference cylinder. A spring back or rebounding correction factor is not applied. Because dents are typically measured under pressure, if an estimate of the dent depth at zero pressure is needed, a spring back correction factor should be applied. The correction factor in PDAM, recommended by the EPRG is 1.43: $D_0 = 1.43D$ Where D_0 = the dent at zero pressure and D = the dent depth at pressure. The dent depth will include an ovality that may have been in the pipe prior to the dent formation. This follows the method defined by Rosenfeld [1,2]
3	Analysis-->Dent Analysis (dialog)	Polar plot	This option presents dent deformation in the circumferential direction in the form of a polar plot. The circumferential cross section of the dent and the location (clock position) of the dent are more easily viewed in this format.
3	Analysis-->Dent Analysis (dialog)	Pipe diameter	The nominal diameter of the pipe should be entered in this dialog box.
4	Settings	View	Opens a window in which view options can be adjusted.
4	Settings	Feature Detection	Opens a window in which feature detection options can be selected.
4	Settings	Report Logo	Opens a window in which a png, jpg, or bmp file can

			be selected. The file will be inserted in corrosion and dent reports.
4	Settings-->Feature Detection	Feature Detection Settings	Selecting this option opens the Feature Detection Settings window.
4	Settings-->Feature Detection	Longitudinal direction	The pipe scan is oriented with flow along the horizontal axis in Window 2. The detection of the direction of flow is selected from the Longitudinal direction drop down box. For most pipe data, the default setting, Auto detection, is the appropriate setting. In some instances, such as pipe data of dents with severe deformation, it may be necessary to force the alignment. The options Up-down and Left-right will force the alignment of the direction of flow along the selected axis.
4	Settings-->Feature Detection	Analysis	The Analysis drop down menu allows the user to select the type of feature detection analysis that will be performed.
4	Settings-->Feature Detection	Local Analysis	Local analysis uses 3D in the vicinity of a feature to determine the depth of the feature. This option requires that the feature have parent metal on at least two side.
4	Settings-->Feature Detection	Global Analysis	Global analysis uses all of the 3D data to calculate a reference cylinder. This option must be used when analyzing dents (for more information, see section 2.3 or the papers by Rosenfeld [1,2] listed in the references section).
4	Settings-->Feature Detection	Filter type	This option is only active when Local analysis is selected. The option enables the application of a filter to the 3D data that mimics a pit gage. To mimic a pit gage, the filter type should be set to Median and the filter length set to 5. These were the settings used during qualification of the 3D Toolbox (and 3D Rhino) systems and are correlated with the system accuracy, precision, and noise as reported in the manual. The filter may be turned off by selected none.
4	Settings-->Feature Detection	Filter length	A filter length of 5 corresponds to the width of a typical pit gage. A filter length of 3 corresponds to the width of a fine tip CMM (coordinate measurement machine).
4	Settings-->Feature Detection	Target shape	When determining the extent of a deformation, the 3D data is compared to a target shape. The target shape is the original shape of the undamaged structure. Currently, there are two target shapes: cylinder and plane. Cylinder should be selected when

			analyzing pipes and tank walls. Plane should be selected when analyzing tank bottoms and gusset plates.
4	Settings-->Feature Detection	Fill hole	The default setting for this option is None. When None is selected, holes in the 3D image will not be filled. Selecting Interpolation fills holes in the 3D image by analyzing the positions of nearby 3D points. When Pipe thickness is selected, holes are filled with points that are located at a depth equal to the pipe thickness.
4	Settings-->Feature Detection	Surface	This option is active when Local analysis is selected. The option allows the user to detect features that are above the surface (select Above) or below the surface (select Sub).
4	Settings-->Feature Detection	Compute depth by	There are three main algorithms for computing depth when using the Local analysis option: Pure2D, Axial, Circumferential. Details for each are below.
4	Settings-->Feature Detection	Pure 2D	Pure2D computes the depth of an area of corrosion by creating a reference surface that is anchored to parent metal in the immediate vicinity of the corroded area. The algorithm is the most robust algorithm for computing depth.
4	Settings-->Feature Detection	Axial	Axial computes the depth of an area of corrosion by creating a series of reference lines in the axial (longitudinal) direction. The reference line is anchored to parent metal on either side of the corroded area in the axial direction. This option mimics a pit gage. In situations where there is corrosion along a long-seam weld, this option is the preferred approach to measuring the pit depth.
4	Settings-->Feature Detection	Circumferential	Circumferential computes the depth of an area of corrosion by creating a series of reference lines in the circumferential direction. The reference line is anchored to parent metal on either side of the corroded area in the circumferential direction. In situations where there is corrosion along a girth weld, this option is the preferred approach to measuring the pit depth.
4	Settings-->Feature Detection	Axial and Circumferential	This option averages the results of the Axial and Circumferential method. The option is similar to the Pure2D method.
4	Settings-->Feature Detection	Colorbar range	The range, or scale, of the colorbar can be automatically determined based on the range of deviations from parent metal. The range may also be set manually. This can be useful when highlighting

			areas that are deeper than a specific threshold.
5	Window 1	Setup	A right mouse-click in Window 1 will open a Setup option. A left mouse-click will launch the OpenGL.NET Setup window. There are many display features available in this window.
5	Window 1-->Setup	Common	In the Common tab, the eye position can be changed by adjusting X, Y, and Z sliders. The projective mode can be changed. There are two projective modes: orthogonal (default) and perspective. Parameters associated with these modes can be changed using sliders.
5	Window 1-->Setup	Scale	The scale tab can be used to scale the image. Entering the same value for X, Y, and Z in this section will ensure the image is not deformed. Selecting the Lock Ratio box will also ensure that the image is not deformed. The Rotation and Translation sections allow the 3D data to be rotated and translated about any axis.
5	Window 1-->Setup	Viewport	There are several functions in Viewport related to the display of the 3D data.
5	Window 1-->Setup-->Viewport	Point Size	The size of the individual 3D points (voxels) can be adjusted. When viewing the 3D data under high magnification (scale or zoom), the points may begin to separate. Increasing the size of the points can be useful in maintaining a smooth image.
5	Window 1-->Setup-->Viewport	Background Color	The background color can be changed from the default olive to any color that is a combination of RGB values.
6	Window 2	Zoom in image	Enables viewing of small features.
6	Window 2	Stretch image	Stretches the image to fit inside the area of Window 2.
6	Window 2	Clear all features	Clears all detected features.
6	Window 2	Clear this feature	Clears the selected feature.
6	Window 2	Run PipelineFFS with Depth Data	Computes the remaining strength values using the river bottom profile, or corrosion profile, from the selected feature.
6	Window 2	Show river bottom	Displays the river bottom profile, or corrosion profile, on screen.

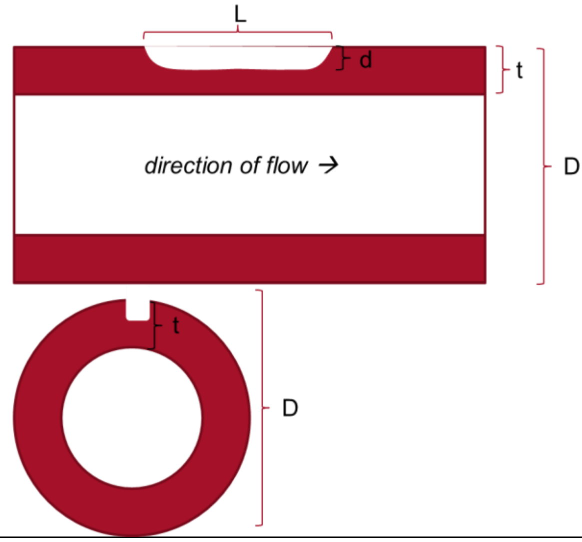
6	Window 2	Show Max Depth	Shows the position of the deepest point.
6	Window 2	Manually select feature	Allows manual selection of a feature.
6	Window 2	Measure feature	Allows manual measurement of the distance between two points. This can be used to manually measure the length or width of a features.
6	Window 2	Manually select reference point	Allows a point to be selected and established as a known reference point in the 3D data set. The point is the tagged with a name, an axial location, and a circumferential position. This establishes a global coordinate system for the 3D data set. All 3D data is then transformed into the global coordinate system.
6	Window 2	Manually set pipe thickness	Allows the pipe thickness to be entered.
6	Window 2	Show texture	Displays the data with only the texture (grayscale) values.
6	Window 2	Show texture + depth	Overlays the false coloring for depth onto the texture values.
7	Window 3	Fitted surface	This check box toggles the display of the Fitted surface on and off. The Fitted surface is a reference pipe model and show the 3D data oriented on a pipe. The Fitted surface is the reference for determining deformations (e.g. dents).
7	Window 3	Fitted radius	The Fitted radius is the calculated radius of the pipe based on the 3D data set. The radius is calculated using an iterative process in which the radius is based on a subset of the 3D data set that is parent metal.
7	Window 3	Feature	This is a list of features that have been automatically identified or manually selected.
7	Window 3	Max depth	This is the maximum depth for each feature.
7	Window 3	Area	This is the area of the feature; this area is determined by multiplying the length of the feature by the width of the feature.
7	Window 3	Width	The width of the feature.
7	Window 3	Length	The length of the feature.
7	Window 3	Color bar	The 3D data in Window 1 and Window 2 is false colored for depth. The definition of the false color is indicated in the color bar that is displayed in Window 3.
7	Window 3	Pipe thickness	This is the thickness of the pipe as entered by the user.
8	Window 4	Clear all features	This option is accessed by a right mouse click. The function of this option is identical to feature 6.3 (see above).

8	Window 4	Clear this feature	This option is accessed by a right mouse click. The function of this option is identical to feature 6.4 (see above).

5 Glossary of terms

Term	Definition
API 579	API 579 is a standard released by the American Petroleum Institute (API) in July of 2007 which describes several standardized fitness-for-service (FFS) assessment techniques for pressurized equipment that are used in the oil & gas industries
ASME B31.4	ASME B31.4 covers piping transporting liquids between production facilities, tank farms, natural gas processing plants, refineries, pump stations, ammonia plants, terminals (marine, rail, and truck), and other delivery and receiving points.
ASME B31.8	ASME’s B31.8 Gas Transmission and Distribution Piping Systems covers gas transmission and distribution piping systems, including gas pipelines, gas compressor stations, gas metering and regulation stations, gas mains, and service lines up to the outlet of the customer’s meter set assembly. It includes gas transmission and gathering pipelines, including appurtenances that are installed offshore for the purpose of transporting gas from production facilities to onshore locations; gas storage equipment of the closed pipe type that is fabricated or forged from pipe or fabricated from pipe and fittings; and gas storage lines.
ASME B31G	ASME B31G describes a methodology for evaluation corroded pipe. The methodology is based on an adaptation of Barlow's formula for surface flaws described by W. Maxey in the 1960's. The burst pressure, relative to Barlow's formula, is reduced based on the area of the defect and a Folias factor that accounts for the bulging resulting from a reduction in wall thickness. See diagram below.

Parabolic defect model for defects



$$P = \left(\frac{\sigma_{flow} 2t}{D}\right)\left(\frac{1 - \frac{2d}{3t}}{1 - \frac{2d}{3tM}}\right)$$

Where

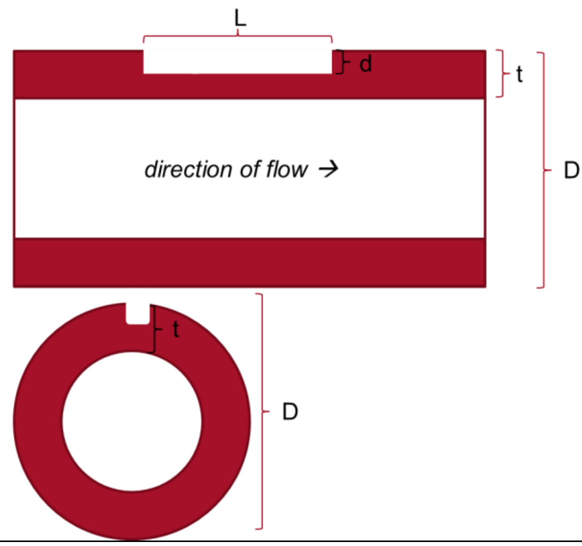
$$A = \frac{2}{3} dL$$

$$\sigma_{flow} = 1.1 SMYS$$

$$M = \sqrt{1 + \frac{0.8L^2}{Dt}}$$

L = defect length
d = maximum defect depth
D = pipe diameter
t = pipe wall thickness
$SMYS$ = Specified Minimum Yield Strength
For defects defined as $L \le \sqrt{20Dt}$

Rectangular defect model for long defects



$$P = \left(\frac{\sigma_{flow} 2t}{D}\right)\left(1 - \frac{d}{t}\right)$$

Where

$$A = Ld$$

$$\sigma_{flow} = 1.1 SMYS$$

L = defect length
d = maximum defect depth
D = pipe diameter
t = pipe wall thickness
$SMYS$ = Specified Minimum Yield Strength
For defects defined as $L > \sqrt{20Dt}$

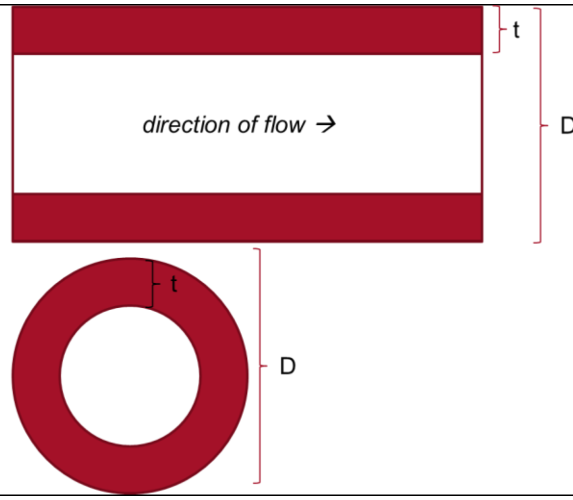
Burst Pressure	The internal pressure at which a pipe will burst. For undamaged pipe, this pressure is determined using Barlow's formula (see below). For damaged pipe, ASME B31G, DNV F101 and other methods may be used to determine the burst pressure.

<table>
<tr><td colspan="2">

- **Barlow's formula calculated the maximum internal pressure that a pipe can withstand using the dimensions and material properties of the pipe**

$$P = \frac{\sigma_o 2t}{D}$$

- **Where**
  - P = pressure
  - σ_o = allowable stress
  - t = pipe wall thickness
  - D = outside diameter of the pipe



</td></tr>
<tr><td>Corrosion Profile</td><td>The corrosion profile, also referred to as the river bottom profile or critical profile is the basis for calculating the effective area of a corrosion defect. The corrosion profile is generally extracted from a matrix, or grid, of measurements made on the area of corrosion. The profile is a plot of the deepest point in each circumferential grid column versus the axial or longitudinal position.</td></tr>
<tr><td>DNV F101</td><td>An alternative method to ASME B31B for determining the maximum safe pressure and burst pressure of a corroded pipe.</td></tr>
<tr><td>File format - ply</td><td>The ply file format is a computer file format also known as the Polygon File Format or the Stanford Triangle Format. The format was principally designed to store three-dimensional data from 3D scanners. It supports a relatively simple description of a single object as a list of nominally flat polygons. A variety of properties can be stored including: color and transparency, surface normals, texture coordinates and data confidence values.</td></tr>
<tr><td>File format - skw</td><td>The skw file format is a computer file format that is specific to Seikowave 3D imaging systems. Unlike the ply or stl file formats, the skw file format is organized: the xyz surface points are stored in a regular matrix in which the spatial relationships of neighboring points are preserved.</td></tr>
<tr><td>File format - stl</td><td>The stl file format (STereoLithography) is a computer file format native to the stereolithography CAD software created by 3D Systems. The format is commonly used in many 3D graphics and CAD/CAM software tools.</td></tr>
</table>

Flow stress	Flow stress is defined as the instantaneous value of stress required to continue plastically deforming the material - to keep the metal flowing. It is the yield strength of the metal as a function of strain. For purposes of fitness-for-service calculations, flow stress is often calculated as SMYS + 10,000psi or 1.1SMYS.
Folias factor	The Folias factor, or bulging stress magnification factor, is used to calculate the impact of a surface flaw on the burst pressure of a damaged pipe. A variety of equations have been used to calculate the Folias factor. These equations are generally dependent on the length of a defect, the thickness of the undamaged pipe, and the diameter of the pipe.
GUID	A GUID (global unique identifier) is a unique number used to identify each 3D image acquired by the 3D Toolbox or 3DSL Rhino system. The GUID is used to allow for correlation of the original 3D data to related parameters such as location, pipeline number, burst pressure, corrosion profile.
IP67	IP 67 is an ingress protection rating and indicates the level of protection against environmental damage. The first digit determines protection against solids. The second digit determines protection against liquid. An IP 67 rated equipment is dust tight, complete protection against dust, and waterproof up to a one-meter immersion in water.
Kastner Method	The Kastner Method is a method for assessing the impact of circumferential corrosion on the remaining strength of pipe.
MAOP	Maximum Allowable Operating Pressure
Modified ASME B31G	A method listed in the ASME B31G specification for determining the remaining strength of a pipeline with metal loss.

0.85dL Method

$$P = \left(\frac{\sigma_{flow} 2t}{D}\right)\left(\frac{1 - 0.85\frac{d}{t}}{1 - 0.85\frac{d}{tM}}\right)$$

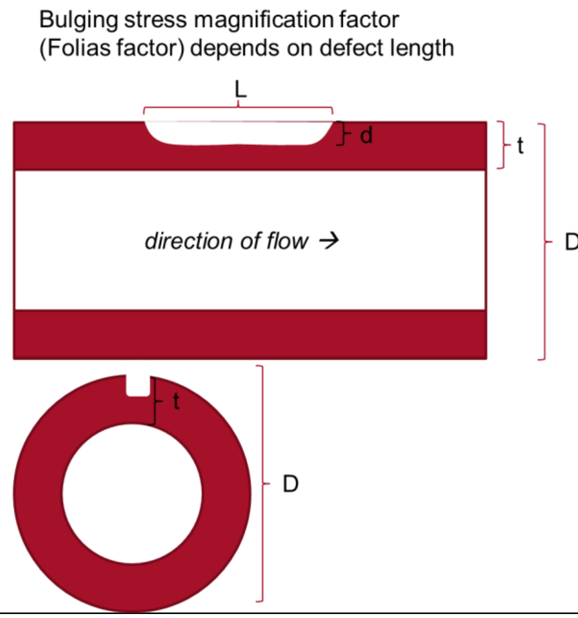
Where

$$A = 0.85dL$$

$$\sigma_{flow} = SMYS + 10{,}000psi$$

$$M = \sqrt{1 + 0.6275\frac{L^2}{Dt} - 0.003375\left(\frac{L^2}{Dt}\right)^2}$$

L = defect length
d = maximum defect depth
D = pipe diameter
t = pipe wall thickness
$SMYS$ = Specified Minimum Yield Strength
For defects defined as $L \leq \sqrt{50Dt}$



0.85dL Method

$$P = \left(\frac{\sigma_{flow} 2t}{D}\right)\left(\frac{1 - 0.85\frac{d}{t}}{1 - 0.85\frac{d}{tM}}\right)$$

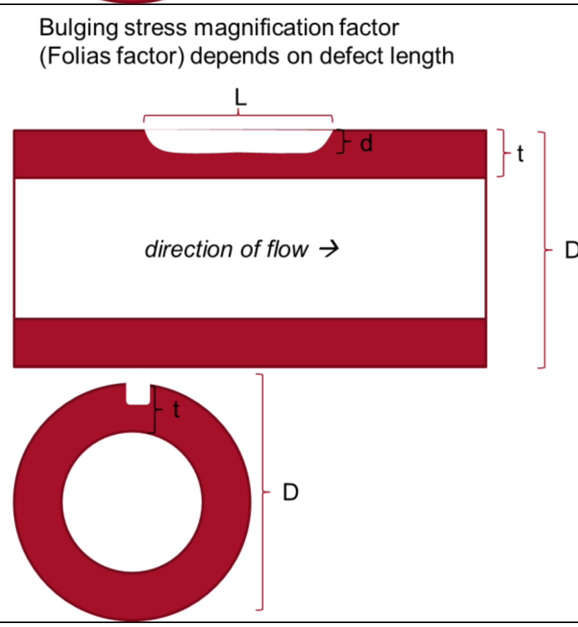
Where

$$A = 0.85dL$$

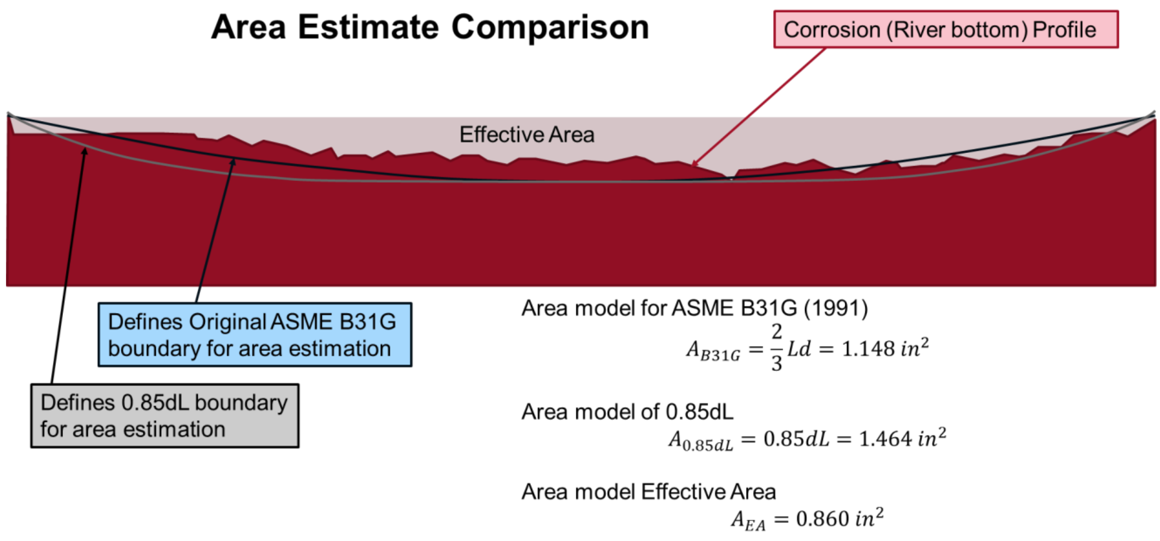
$$\sigma_{flow} = SMYS + 10{,}000psi$$

$$M = 0.032\frac{L^2}{Dt} + 3.3$$

L = defect length
d = maximum defect depth
D = pipe diameter
t = pipe wall thickness
$SMYS$ = Specified Minimum Yield Strength
For defects defined as $L > \sqrt{50Dt}$



OpenGL	Open Graphics Library (OpenGL) is a cross-language, cross-platform application programming interface (API) for rendering 2D and 3D vector graphics. The API is typically used to interact with a graphics processing unit (GPU), to achieve hardware-accelerated rendering.
RSTRENG (Effective Area)	RSTRENG is an abbreviation for Remaining STRENGth. The abbreviation refers to a method first developed by John Kiefner at Battelle Memorial Institute for determining the remaining strength of pipes with surface flaws (typically corrosion). The diagram below is a comparison of the damaged area calculation for the three main methods: Original ASME B31G, Modified B31G (0.85dL method) and the RETRENG of Effective Area method.



Safety factor	The ratio of the burst pressure of a pipe relative to the pipe MAOP
SMTS	Specified Minimum Tensile Strength
SMYS	Specified Minimum Yield Strength
SQL	SQL, Structured Query Language) is a special-purpose programming language designed for managing data held in a relational database management system (RDBMS), or for stream processing in a relational data stream management system (RDSMS).
Strain	Strain, represented by the Greek letter ε, is a term used to measure the deformation or extension of a body that is subjected to a force or set of forces. The strain of a body is generally defined as the change in length divided by the initial length.
Structured Light	Structured light is a triangulation method for reconstructing a 3D digital representation of a scene. Typically, a time-varying waveform is projected onto an object that is observed by a camera containing an image sensor with an array of pixels. The time-varying response of each pixel is then demodulated to determine the 3D position of the object observed by the pixel.

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7 References

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2	Rosenfeld, M.J., *Proposed New Guidelines for ASME B31.8 on Assessment of Dents and Mechanical Damage*. 2001, Topical Report GRI-01/0084, Gas Technology Institute.

8 About Us

Seikowave, Inc.

Seikowave, Inc. was founded to commercialize new technologies that can make high speed 3D measurements at reasonable costs suitable for diverse markets. Seikowave systems can acquire 3D point clouds with 350,000 points per point cloud at rates up to 1,000 point clouds per second. The key technologies are in the areas of digital signal processing, image processing, optical systems, and the interactions among these technologies.

We live in a three-dimensional world of length, width, and height. Our ability to make accurate measurements of these dimensions is critical to a wide variety of applications as diverse as measuring parts for automobiles, inspecting pipelines, inspecting coatings, inspecting welds, inspecting composite materials on aircraft, examining teeth for dental restoration, and many others.

Seikowave provides portable, ruggedized 3D imaging systems that even go 100 meters deep under water. The 3D imaging techniques pioneered by Seikowave are also used in the motion control of the robots – we give “eyes” to robots. This allows our robots to be used in applications other than inspection (for example, welding, coating application).

Seikowave uses 3D measurements to solve common problems encountered in general NDT applications. Our solutions acquire 3D data, analyze the data for defects and anomalies, and generate reports that determine the fitness for service and can help guide repair procedures if necessary. Our software tools enable characterization of infrastructure damage and determination of fitness-for-service using methods defined in API-579, ASME B31G, RSTRENG, ASME B31.8, ASME B31.4, and other guiding regulatory documents. Seikowave develops and manufactures all of the 3DSL hardware and software for these solutions.

More information can be found at www.seikowave.com . Our headquarters is located at:

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