Onshore and offshore production systems (pipelines, flowlines, spools, risers, manifolds, etc.) are typically cleaned or intelligently inspected using operational or smart pigs, respectively. The pig is deployed from a pig launcher and received on the other end at a receiver or received at the same launcher, if a tethered or Bi-Di (Bi-directional) pig is used. A very large amount of data is generated post In-line inspections (ILI) which require review, analysis and assessment since they provide information about integrity of the system therefore shall be carefully analysed.

Data Collation and Review

Post ILI completion, Z-Subsea integrity assessment experts with in-depth knowledge and experience, get involve in gathering and reviewing crucial information for assessing integrity of the oil and gas assets. The information to be reviewed and analysed as a minimum are:

- System drawings (as-built, PFD, P&ID, alignment sheet, etc.),
- Basis of design,
- Historical and most recent inspection (intelligent pig and NDT) - survey data including field data, tool operational data, tool calibration, pipe tally, list of anomalies and clusters, anomaly ranking etc.
- Historical and most recent operational data (pressure, temperature, pipelines product fluid composition with the emphasis on the content of CO_2, H_2S, water, corrosion mitigation (inhibition), etc.
- Welding Procedure Specification (WPS) and associated Welding Procedure Qualification Record (WPQR)
- Mitigation and repair activities. (historical and most recent)
- Failure data (e.g. leak history)
- Historical risk assessments and Risk-Based Inspections (RBI).
- Previous integrity assessment reports

Typically at the launch of an integrity assessment project a kick-off meeting is organised so that any missing information is collated by Z-Subsea integrity assessment team.

Anomalies Grouping and Matching

Anomalies typically reported in an intelligent pig inspection report will be grouped into one of the following categories by Z-Subsea integrity assessment team for further assessment:

- Longitudinal or circumferential internal or external metal loss (corrosion).
- Longitudinal or circumferential manufacturing metal loss (metal loss)
- Longitudinal or circumferential dents (plain, kinked or smoothed on the welds)
- Longitudinal or circumferential gouges (isolated or combined with dents)
- Girth weld anomalies
- Seam weld anomalies
- Others (not listed above)

If Magnetic Flux Leakage (MFL) ILI technique is used, grouped anomalies will be then represented by simple individual or cluster boxes and their interactions are checked (See Figure 1). For ILI performed using UT technique, typically a more detailed (complex) profile of metal loss anomalies (river-bottom profiles) is obtained.

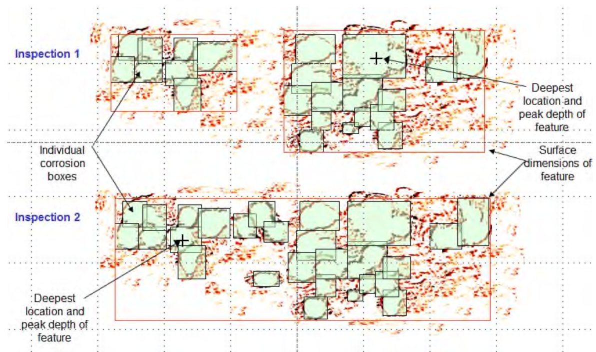

Figure 1

If more than one intelligent pig inspection data is available, matching of the similar anomalies will be performed. Any change in dimensions of the anomalies (depth, width and length) compare with that pre-existing, will be checked as a measure of growth rate. As clearly shown in the Figure 1, two different inspection data (inspection#1 and #2) are compared. Inspection#2 identified new corrosion anomalies and change in dimensions of the pre-existing anomalies over time.

Immediate Integrity Assessments

Immediate (current) integrity assessment of the system for simple (Figure 1) and complex shape metal loss anomalies (Figure 2) are explained in this section.

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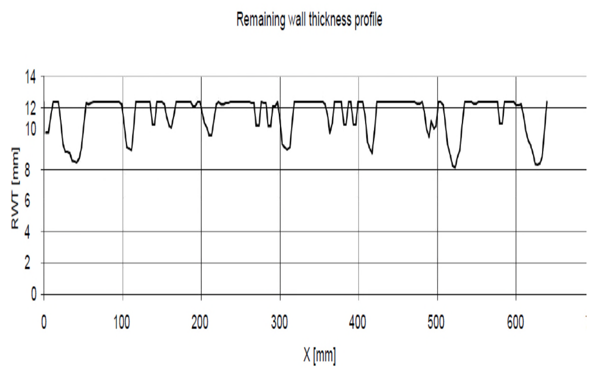


Figure 2

Safe working pressure of the system at presence of those anomalies will be estimated taking into account inspection techniques tolerances (inaccuracy) as well as design safety margins.

Metal loss anomalies to be assessed include corrosion (Internal and external) or manufacturing (gouges, pits, seams, arc burns, laps and laminations). An acceptance curve for anomalies as shown in Figure 3 will be developed. Dots on this Figure demonstrate depth and length of the metal loss anomalies which are checked against the acceptance curves (Blue, Red and Green). Each curve represents a given MAOP value.

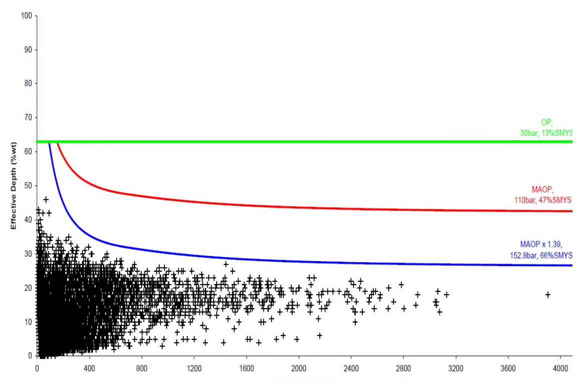
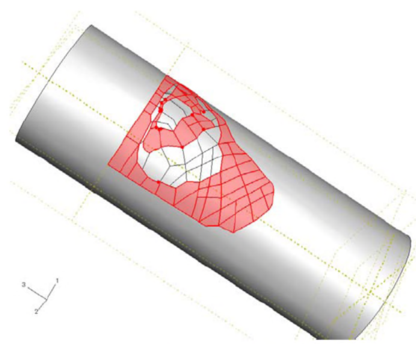


Figure 3

For longitudinally oriented metal loss anomalies, immediate assessment can be performed using either semi-empirical methods (e.g. ASME B31G, modified B31G, RSTRENG) that are biased towards older, lower toughness steels or the 'new' methods based on failure controlled by plastic collapse (limit load), defined by the ultimate tensile strength of the material (e.g. DNV-RP-F101 Part A and B). The 'new' methods are biased towards the behaviour of modern, high toughness line steels.

For circumferentially oriented metal loss anomalies, Kastner local plastic collapse solution will be used for the integrity assessments. Kastner solution only considers internal pressure, however, if the corroded pipeline is subjected to internal pressure and axial loads or in-plane bending, DNV RP-F101 part A approach will be used.

For complex shape metal loss anomalies, Z-Subsea integrity assessment team use DNV RP-F101, ASME FFS-1/API 579-1 or RSTRENG (effective length and area methods) procedures for assessing integrity of the components. In these procedures, the profile is divided into a number of subsections, and after checking the possibility of interaction, failure pressure for the entire system is taken as the minimum failure pressure calculated for each subsection which is an iterative process. Upon the request of asset owner or when more detailed assessment using complex shape corrosion anomaly is required, Z-Subsea integrity assessment team could also model the corrosion profile using a fully FEA method as demonstrated in Figure 4 below. River-bottom profile from the intelligent pig inspection was modelled as a metal loss on the outer surface of a pipeline.



Material Loss Area Ranges (mm)	Assigned Average Thickness (mm)
No Loss, Nominal Thickness	25.8
0 < Loss < 5	23.4
5 < Loss <7	20.3
7 < Loss < 9	18.2
Loss > 9 – Right	16.4
Loss > 9 - Left	16.3
Loss > 9 - Centre	15.5

Figure 4

The above model was then pressurised incrementally until the stress at the deepest point in the profile reaches to the limiting stress, which defines pipeline burst capacity.

In-house fully verified software based on the applicable standards will be used to perform the simple and complex shape assessments. Complex shape metal loss assessment is time-

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consuming therefore is not suited to hand calculations.

Future Integrity Assessment (Remaining Life Calculations)

For the assets passed the immediate integrity assessments (safe for future operation), future integrity assessments shall be performed.

This includes prediction of estimated remaining life and establishing future inspection frequency by advancing the corrosion profile over a year period based on an estimated representative corrosion rate for the system.

Corrosion growth rate can be calculated using one of the following three methods:

- **Method 1 - Corrosion modelling:** At presence of CO_2 and water (condensed, formation or etc.), Z-Subsea integrity assessment experts, with the support from material experts in the company, use Electronic Corrosion Engineer (ECE) software or NORSOK M506 tools for estimation of CO_2 corrosion growth rate that to be used in the integrity assessments. Selection of each tool depends on the limitation and applicability of each model.
- **Method 2 - Anomaly Matching:** As shown in above Figure 1, change in dimensions of the matched corrosion anomalies identified in inspection #1 and #2, over time is a measure of corrosion growth rate as defined in equation below:

$$Corrosion\ Growth\ Rate = \frac{(d_{inspect\#1} - d_{inspect\#2})}{time}$$

  Where

  $d_{inspect\#1}$ is the depth of the feature reported in the inspection #1 and

  $d_{inspect\#2}$ is new depth of the feature increased in inspection #2.

- **Method 3: Corrosion coupons, UT spot checks and corrosion probes readings -** Readings (weight reduction) from monitoring systems such corrosion coupons or probes and/or NDT wall thickness readings (using UT) can be also used as another method of corrosion rate calculation (weight reduction over time is equal to corrosion rate).

Z-Subsea integrity assessment and materials/corrosion experts will review the outcome of the above methods and recommend a representative corrosion growth rate for the entire system and for use in the integrity assessments.

For a simple corrosion anomaly, the future integrity assessment involves increasing the depth and length of based on the corrosion rate and calculating safe working pressure until the assessment point locates on the corresponding acceptance curve (Red crosses against the blue and orange curve in Figure 5).

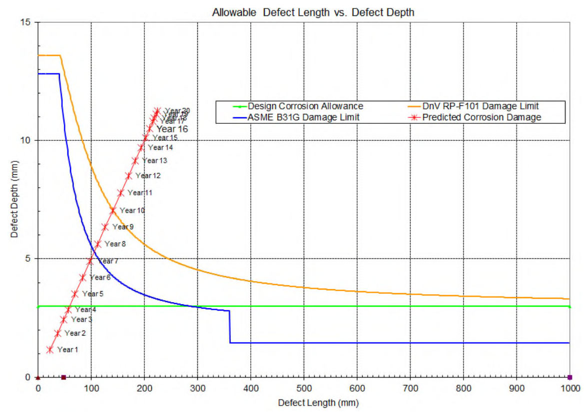

Figure 5

For a complex-shape corrosion anomaly the future integrity assessment involves advancing river-bottom profile in depth and length directions, based on rate of corrosion growth (Figure 6).

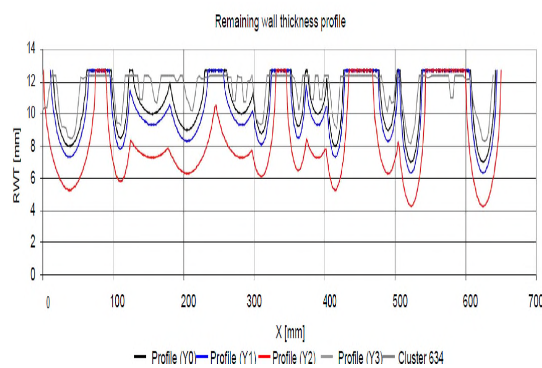

Figure 6

Associated safe working pressure for each new profile is then calculated until the limit on safe working pressure is reached. Number of years taken to reach to the limiting condition defines remaining life.

Other method for calculation of the remaining life is a combined deterministic and semi-probabilistic approach. This approach is a deterministic approach but with consideration of corrosion rate calculation uncertainties similar to that considered for the defect dimensions due to inspection inaccuracies. Having uncertainty in corrosion rate makes the future

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dimension of the defects uncertain so in this approach adjustment on the corrosion rate will be made by introducing an average and standard deviation value.

Establishing Frequency of Future Inspections

For systems with acceptable remaining life, frequency of the future inspections shall be updated post integrity assessments. The frequency of the inspections is usually defined in a document called Inspection, Maintenance and Repair (IMR) however this is a risk-based and live document and after each integrity assessment the frequency of the inspections shall be updated in the document if required. Z-Subsea integrity assessment experts will review the IMR document and suggest modifications based on the similar risk-based approach used in the original IMR document followed by new inspection frequency according to the recent integrity assessments.

Developing Repair Plan/Procedures

For the anomalies with no remaining life, mitigating measures in form of pressure de-rating, repair or replacement will be advised by the Z-Subsea integrity assessment experts. This project specific plan/procedure can be developed for a given period of time, e.g., next 10 years according to client request. This is a live document and can be updated as and when required.

Corrosion Control Recommendations

Based on the historical operational, process and monitoring data, e.g., temperature, pressure, Oxygen, H_2S, CO_2 level, dew point, pH, water content, corrosion inhibition dosage, hydrate prevention strategy, bacteria counting and control, CP readings and any other related parameters, Z-Subsea integrity and corrosion team of experts perform hazard assessment (root cause analysis) in order to identify the mechanism of the metal loss anomalies reported in the intelligent pig inspections.

The outcome of this analysis will identify effectiveness of the existing corrosion management and control. This in-line with the integrity management system (if available) will be reviewed and recommendations for any possible improvements to the existing corrosion control and management system will be provided to the asset owner. .

For further information please contact us on enquiries@z-subsea.com.

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