Z-Subsea is an ISO 9001 and ISO 14001 accredited independent, Subsea Design and Integrity Management consultancy providing full cycle integrated solutions to our oil and gas clients worldwide.

Our full cycle services commence with conceptual definition and continue with detailed design, construction and move into operation up to end of life.

Safe Operation beyond the original design life (life extension) is also of high interest in Z-Subsea. We employ innovative and cost effective approaches in order to maximise our client's safe operation time and to minimise assets shut down and downtime.

Technical personnel of Z-Subsea include 3 directors holding PhD degrees and 20 associates covering various disciplines including Fitness for Service Assessments, Materials and Corrosion, Flow Assurance and Process Engineering, Safety and HSE and Pipeline and Riser Analysis, who are working with the company on an ad-hoc basis.

With offices located in London and Aberdeen, Z-Subsea have the advantage of being close to the operators in the North Sea while its London office acts as an international hub serving global clients.

Z-subsea clients since its establishment in Dec 2011 have been, PetroVietnam Gas (Vietnam), Petro Vietnam Drilling Technology (Vietnam), Bureau Veritas (BV) UK, DNVGL, PDO (Oman), TAQA (UK), Tullow oil (UK), Peritus International (UK), Neptune Marine Services (Australia), Theon Ltd. (UK), Oman Gas Company (Oman) and Fairlead Maritime (UK). Individual personnel of z-subsea have been working for major operators, consultancies and third party verification bodies before establishing Z-Subsea.

Z-Subsea is specialised in the following technical areas with global projects track records available upon request:

- Subsea Design and Advanced Analysis
- Risk-Based integrity management
- Engineering Critical Assessment (ECA) to BS7910, DNV RP F-108, API 1104 and ASME FFS-1/API 579-1
- Fitness for Assessment (FFS) to ASME FFS-1/API 579-1 and ASME B31G
- Material Selection and Corrosion Assessment and Management

Z-Subsea material and integrity engineering manager is part of the following codes, standards and procedures development committee:

1. BS7910 (fracture, fatigue, material properties chapters and Annex I)
2. European Fitness for Service code (FITNET) - Fracture and fatigue sections
3. Appendix A of DNV OS-F101
4. DNV RP F-108
5. European Structural Integrity Assessment procedure.

Summary of Integrity Management Capabilities

S/N	Tasks Description	Additional information	Project phase
1.	Risk Assessments (Qualitative, semi-qualitative, Quantitative)	▪ Developing project-specific Risk ranking matrices	Concept through Operation
2.	Developing Integrity Management System	▪ Management of change policies ▪ Contingency plans Audit and review Information management ▪ Compliance to legislations and HSE guidelines	
3.	Developing Long and Short term (annual) Inspection, Monitoring and Testing Plans	▪ Pipeline segmentation ▪ Pigging Philosophy and Methodology ▪ Selection of appropriate inspection techniques	
4.	Risked-based Inspection (RBI), Monitoring and Testing	▪ Review and annual updating of Risk Assessments ▪ Condition monitoring activities to collect operational data ▪ Direct monitoring of the status of a component (Inspection) ▪ In-direct collection of operational information (Monitoring) ▪ Review and preparation of testing procedure for: ○ System pressure testing ○ Safety equipment, ○ Over-pressure protection equipment ○ Emergency Shutdown System ○ Automatic shutdown valves ○ Safety equipment in connection with piping system (Topside/Onshore) ▪ Trending performance of safety critical elements ▪ Annual condition assessments	Operation
5.	Mechanical Assessment of: ▪ Cracks or crack-like flaws using ECA (Fatigue and Fracture) ▪ Free-Span (Fatigue assessment) ▪ 3rd Party Damage (Global/Local Buckles, Dents, Gouges, and Excessive Deformation)	▪ According to Codes such as BS7910, DNV OS-F101, DNV RP- F108, API 1104, DNV RP-F105, DNV RP-F110 ▪ Identification of inspection intervals ▪ Performing FE Analyses using ABAQUS or ANSYS ▪ Performing Failure Investigation in collaboration with Z-Subsea Materials Group	
6.	Fitness for Service assessment of Corroded assets	▪ According to Codes such as DNV RP-F101, ASME B31G and Modified B31G, ASME-FFS-1/API579-1 ▪ Estimation of the asset remaining life based on the corrosion rate modelling tool available in Z-Subsea Materials group ▪ Advising on Inhibition program (Corrosion control) ▪ Operational CP issues (Failure investigation; current leakage tests, review of survey results, remedial CP designs ▪ Annual corrosion reports update	Operation
7.	In-Direct Assessment of un-piggable pipelines	▪ According to NACE guideline, ASME B31.8S, etc. ▪ Risk assessment input ▪ Input from Flow assurance and Process modeling group Input from Z-Subsea Pipeline/Subsea	
8.	Mitigation, Intervention and Repair	▪ Repair policy according to DNV RP-F113 or similar ▪ Advise on mitigation, Intervention and repair methods ▪ Developing detailed mitigation, intervention and repair procedures	
9.	Re-Qualification	▪ Re-assessment of design under changed design conditions ▪ Change in operations, design code, product, flow direction, ▪ Detecting unaccounted damages in the system	

10.	Life extension	▪ According to standards such as NORSOK, ISO, API, ASME, etc. ▪ Compliance with HSE legislations	**Life Extension**
11.	Abandonment	Permanent removal of full or part of a system from operation with no intention to put it back in service Planning for Abandonment according to national regulations, Health and Safety of the Personnel, Environmental impact, obstruction of ships, fishing activities and corrosion impact on the structure Abandoned parts of the system might need management by IM system (Inspection)	**Abandonment**

Integrity Engineering/Management Services

Overview

Z-Subsea provides Integrity Engineering and Integrity Management services to the oil and gas industry amongst other established services such as Subsea Design, Advanced Analyses and Project Management. We believe in benefit of engaging our experienced integrity engineers with our client project team right from the start (conceptual phase), then design and fabrication to operation. That is why we call our Integrity Engineering services "Full-Life Cycle" service (Figure 1).

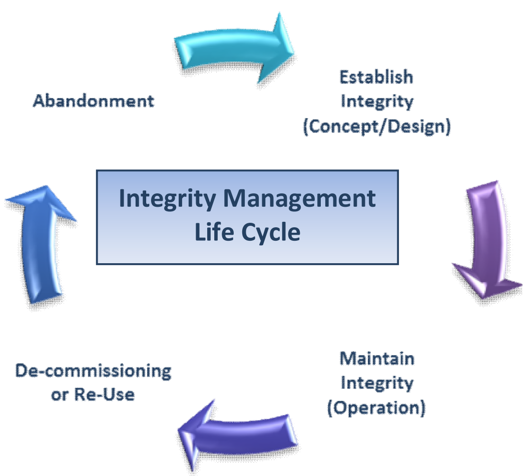

Figure 1. Integrity Management Life Cycle

Integrity management is usually established during the concept/design phase of a project and is maintained during the operation until the end of design life. Z-Subsea's services continue beyond this stage by either de-commissioning or re-use of the pipeline as well as life extension studies before moving to Abandonment. During all these steps, integrity of the pipeline/riser should be managed similar to the pipeline in operation.

Integrity Management Activities

We in Z-Subsea assist our clients by providing expertise, knowledge and flexibility on the following main areas:

- Qualitative and Quantitative Risk assessments.
- Integrity management planning at the design stage.
- Developing and implementing of the Inspection and Monitoring methodologies.
- Performing and implementing intelligent Pigging feasibility studies for piggable and difficult to pig pipeline systems.

Probability categoty	A	B	C	D	E
5	M	H	VH	VH	VH
4	L	M	H	VH	VH
3	VL	L	M	H	VH
2	VL	VL	L	M	H
1	VL	VL	VL	L	M
	Consequences				

Figure 2. A qualitative risk assessment matrix

- Review, audit and modification of existing integrity management systems.
- Management of change.
- Fitness for Service (FFS) assessment of existing assets to ASME-FFS-1/API 579-1, ASME B31G and/or DNV RP-F101 procedures at presence of Dents, Metal loss, Buckles, Lamination, etc.
- Engineering Criticality Assessment (ECA) (Figure 3) of subsea systems at presence of crack-like weld flaws at extreme loading or environmental conditions such as Reeling installations, High Temperature and High Pressure operations and exposure to the hostile environments such as sour (high level of H2S) and sweet corrosion (CO_2 corrosion).
- Remaining life calculation of existing assets and determination of inspection intervals for the most dominating damage mechanism.
- Development and implementation of intrusive/non-intrusive repair systems and associated procedures.

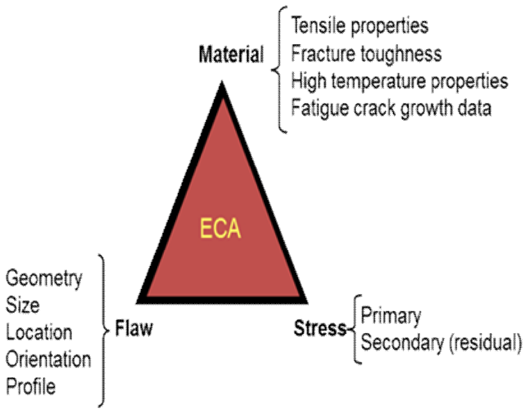

Figure 3. ECA triangle and associated input data

- Life extension of existing assets to standards such as NORSOK N-001, ISO 19900/19902, ISO13822 and API RP2A-WSD.
- Subsea pipeline/risers numerical stress analysis (Figure 4).

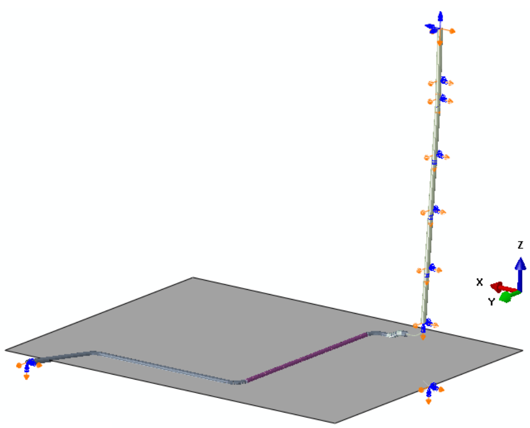

Figure 4. Riser global stress analysis

- Advanced finite element analyses of the Corroded and un-corroded subsea pipelines/risers under extreme loading condition such as cyclic loading (free-span), permanent deformation (lateral or upheaval buckling), third party damages (anchor drag, trawling/fishing activities, etc.) and low cycle fatigue loading during the start-up/shut-down. Figures 5 & 6 show a case of subsea pipeline dragged drastically with an anchor and the corresponding FE model developed by Z-Subsea advanced analysis team to assess the integrity of the pipeline for further safe operation

Figure 5. A subsea pipeline dragged by anchor

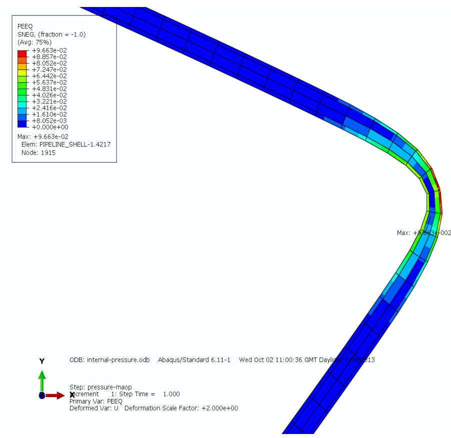

Figure 6. Finite Element modelling of the anchor-dragged pipeline shown above

- Management of standard and specialised mechanical tests such as tensile tests (at low and high temperatures), fracture toughness (SENT, SENB, curved wide plate, etc.) tests and full-scale tests. These will be performed in collaboration with Z-Subsea's testing partners.

Other services (training courses)

Z-Subsea Integrity management team has extensive experience on delivering standard or specialised tailor-made training courses on integrity engineering (assessment) and integrity management of Pipelines/risers, topside facilities, onshore plants.

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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.

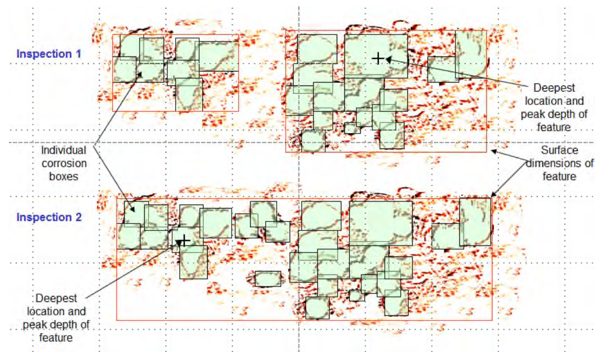

Figure 1

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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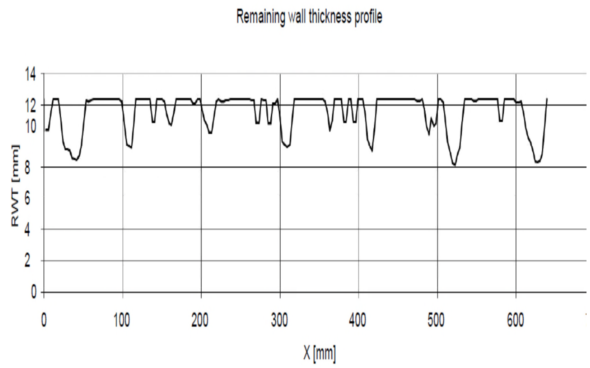


Figure 2

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.

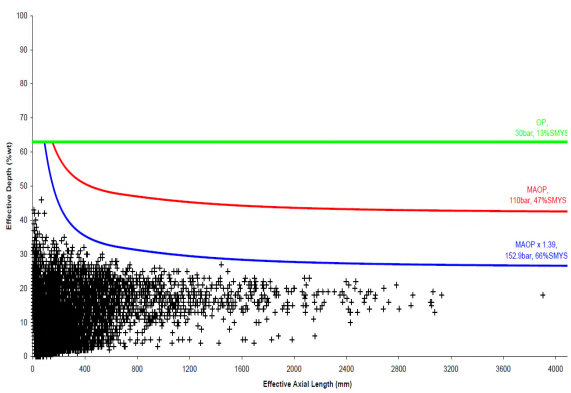
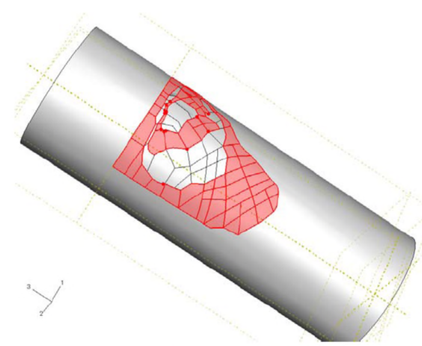


Figure 3

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 timeconsuming 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).

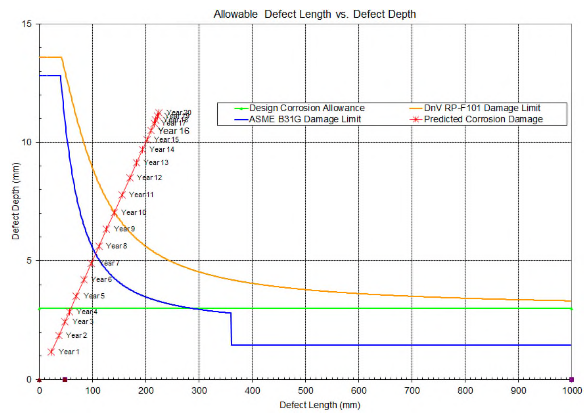


Figure 5

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).

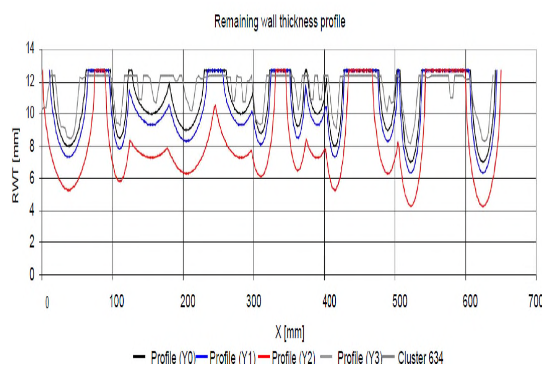


Figure 6

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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Overview

Z-Subsea Integrity team provides in-depth fatigue and fracture consultancy services to the oil and gas industry ranging from fatigue and fracture analysis only to combined fatigue and fracture testing and analyses. In the latter, Z-Subsea will set up, manage and perform project specific testing programs in partnership with a world-wide UK-based laboratory accredited by UKAS (The United Kingdom Accreditation Service) and certified to ISO 17025. The following experiments could be offered by Z-Subsea integrity team and expanded if necessary:

- SENT/SENB Fracture toughness testing of welds and HAZ to BS7448 and/or ASTM E1820 standards in air and/or Sour service and determining resistance curves or single fracture toughness values in terms of crack-tip opening displacement (CTOD) or J-Integral
- Round and flat tensile tests of welds and parent metals to BS EN10002 to obtain full stress-strain curves, Yield and Tensile strengths, Hardening coefficient, etc.
- Tension-Compression fatigue testing to determine S-N curves (stress vs. number of cycles) to BS7608 and DNV RP-C203 in an appropriate environment
- Fatigue Crack Growth (FCG) testing to obtain da/dN – K curves to BS ISO 12180 or ASTM E647 standards in an appropriate environment
- Hardness tests
- Post test metallography of fracture toughness specimens and Fractography (Fracture surface analysis)
- Full-scale static bend testing of pipes with and without presence of internal pressure.

As an example, Figure 1 summarises Z-Subsea flow-diagram for obtaining data in a fatigue analysis.

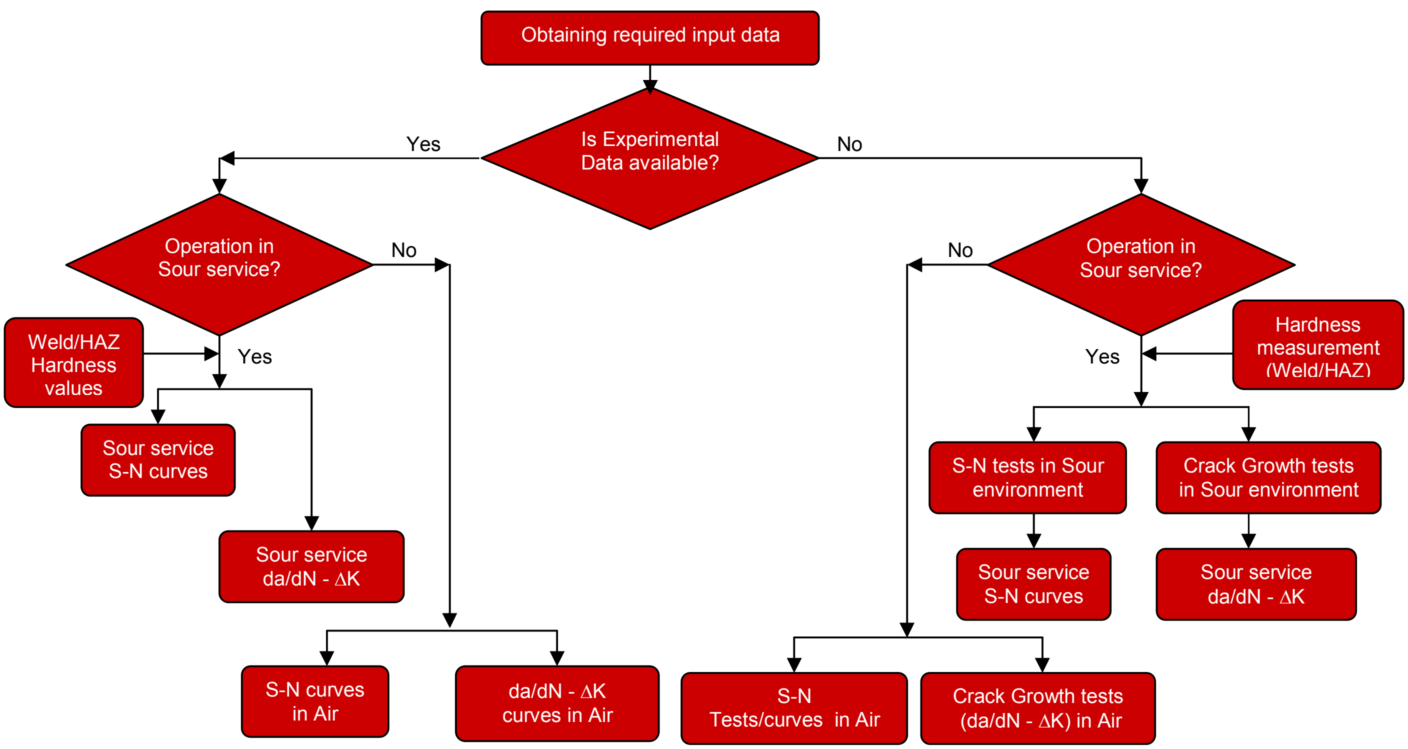

Figure 1. Fatigue analysis data acquisition process

Based on the selected experimental route in Figure 1, Z-Subsea could assist clients by performing S-N based fatigue analysis and/or Fracture mechanics based fatigue crack growth (FCG) analysis as detailed in Figure 2 and explained in more detail in following Section.

Z-Subsea has no intention to compare results of S-N based fatigue analysis results with that obtained from a fracture mechanics analysis because they employ different approaches and hence incomparable. S-N tests/analyses are performed on specimens without a crack whereas the fracture mechanics tests/analyses are applicable to an existing/postulated crack in a component therefore; fatigue life calculated from S-N analysis will include both crack initiation and growth whereas that from a fracture mechanics analysis only includes crack growth.

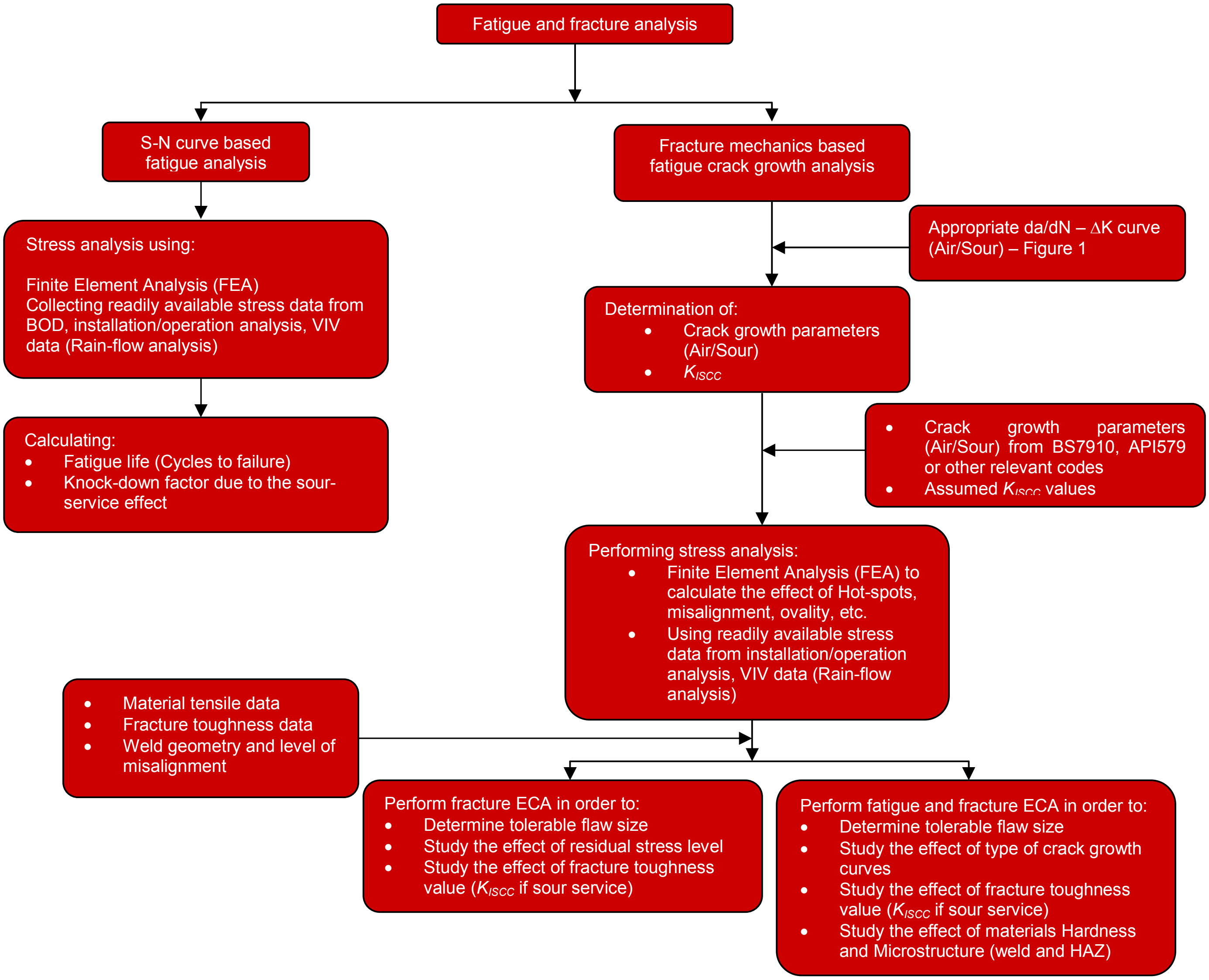

Figure 2. Details of the fatigue and fracture analysis options based on the data from Figure 1

Fatigue and Fracture Analysis

S-N based fatigue analysis

For S-N based fatigue analyses, Z-Subsea experts will collect applied stresses from Basis of Design (BoD),

VIV database and installation/operation procedures, however if the information are unavailable, detailed Finite Element (FE) modelling/analysis using typical FE software, such as ABAQUS will be carried out. Number of cycles to failure (fatigue life) corresponding to the calculated applied stresses will be read-off from the S-N curves and compared with the component design life (e.g. 30 years) to highlight the remaining safety margin and also to establish inspection intervals.

If operation is in sour service, a knock-down factor on the S-N curve, due to the presence of the corrosive environment, has to be applied to the air S-N curves prior to the fatigue life calculations. Currently a factor in the range of 10 to 30 is recommended in available standards such as DNV OS-F101; however, it varies project to project and hence needs to be determined for every project employing experimental data (if possible).

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Fracture Engineering Criticality Assessment (ECA)

After completing experiments and/or data gathering exercise, a fracture mechanics based ECA (static) will be performed. Fracture toughness in terms of Crack Tip Opening Displacement *(CTOD)/J-Integral* for non-sour or K_{ISCC} for sour service will be used in the ECAs. Crack driving force will be either calculated or estimated using FE software, e.g., ABAQUS as shown in Figures 3 and 4.

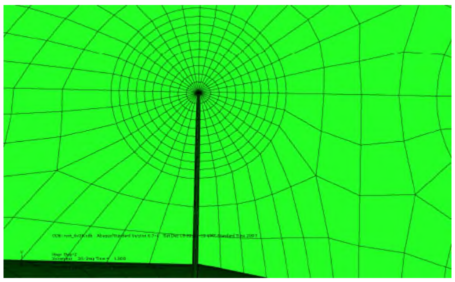


Figure 3. Crack tip FE elements

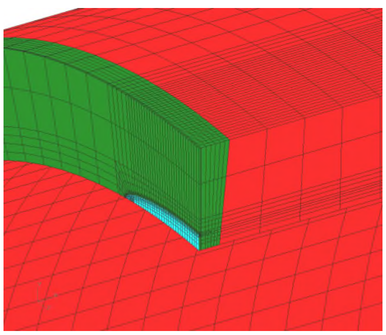


Figure 4. Modelling of crack at a girth weld

The outcome of the assessments will be maximum tolerable flaw sizes as shown in Figure 5.

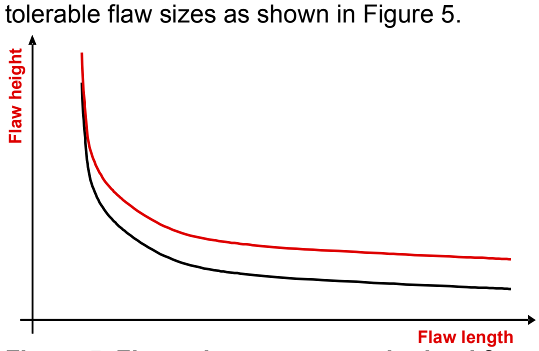


Figure 5. Flaw tolerance curve obtained from ECA

Fatigue and Fracture ECA

Adding cyclic loading (fatigue) to the fracture ECA and employing applicable FCG curves will expand the analysis to a combined fatigue and fracture ECA. Depending on the service environment (Air or Sour), appropriate FCG curve will be selected and used (Figure 1) and associated crack growth parameters will be calculated. Stress Corrosion Cracking (SCC) and stress-intensity factor threshold (KISCC) value also to be determined from the FCG curves for sour service. Similar to the S-N fatigue analysis if applied stresses are not available, Finite Element modelling of cracked components using e.g. ABAQUS (Figure 3 and 4) will be carried out by Z-Subsea advanced analysis team in order to determine the stresses and associated crack driving forces.

From the ECA, results similar to Figure 5 are expected. Sensitivity analysis on the type of FCG curves, K_{ISCC} value and location of crack (effect of materials hardness/microstructure) will be studied by Z-Subsea experts. Some limited data suggest that in harder materials (such as weld metal and Heat-Affected Zone (HAZ), cracks grow faster under fatigue loading and hence hardness measurement and metallurgical study will be also performed as part of the analysis. Results of the ECAs may be validated using pipe full-scale bend testing with and without internal pressure.

Third party experiments witnessing

Upon the request of the client, Z-Subsea can witness testing programs on behalf of the client and issue a report upon the completion of the work.

Secondment to client office

If project work requires, Z-Subsea Integrity Engineering expert(s) could be seconded in the client offices for a short-term period for better implementation of the scope of the work. Details of this arrangement are to be discussed and agreed between two parties.

Engineering Criticality Assessment (ECA)

Engineering Criticality Assessment (ECA)

During the life cycle of oil and gas or petrochemical assets it is required to assure that the safety critical elements (pipeline, pressure vessels, risers, piping, valves, etc.) are fit for service over their design life.

To achieve this, a multi-disciplinary engineering approach (as shown by the ECA triangle below) called Engineering Criticality Assessment (ECA) is widely used.

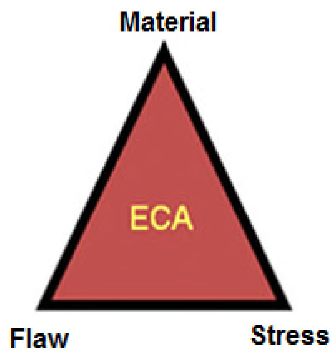


Figure 1. ECA Triangle

Material properties including maerials fracture toughness is required to be obtained using standardized fracture toughness testing on specimens such as SENB or SENT specimens (See Figure 2).

Figure 2. SENT Fracture Toughness Testing

The procedure is based on fracture mechanics and using a diagram called Failure Assessment Diagram (Figure 3) in order to assess safe or unsafe operation of an asset.

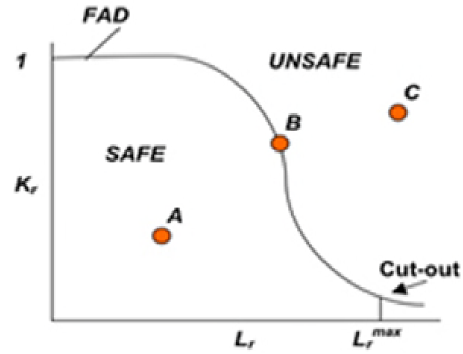


Figure 3. Failure Assessment Diagram (FAD)

Depending on the stage at which an ECA assessment is performed (detailed design, fabrication, operation, retirement), the purpose and outcome of this type of analysis would be different as detailed below:

- Design stage; as part of the material selection process including development of flaw acceptance curves for welds
- Fabrication stage; to assess significance of manufacturing flaws detected by NDT inspections
- Operation stage; to assess significance of flaws detected during the routine inspections of in-service equipment and/or significance of operational change and to decide on the continued operation
- Retirement stage: to establish remaining life of equipment and to decide on whether the component can be utilized beyond its intended design life.

Benefits of ECA

Z-Subsea believe that by performing ECA the following benefits could be achieved which all could potentially result in reducing cost of labor, material and engineering and consequently reduce the design/operational cost:

- Avoid unnecessary shutdowns/repairs and hence assuring safe and continuous operation
- Provide guidance for acceptability of fabrication induced flaws which could be outside the acceptability of current codes (Figure 3)
- Establish NDT, materials and quality acceptance criteria

- Save cost by continued operation and avoiding unnecessary Post Weld Heat Treatment (PWHT)

Delivering Specialist ECA

Z-Subsea integrity team has been actively involved in the development of ECA related codes and standards such as BS7910, DNV OS-F101 (Appendix A), SINTAP and FITNET and use of codes such as DNV RP-F108, API579-1/ASME FFS-1. That said we are confident and fully up-to-date with the cutting edge developments on the relevant/international standards which could be passed on to our clients in their projects.

Z-Subsea integrity engineering team devote their substantial expertise to assist both offshore and onshore oil and gas and petrochemical industries in dealing with go/no-go type decision through the whole life cycle of the assets dealing with assessment of various types of damages including:

- Fracture
- Fatigue
- Crack-like defects (girth weld defects)
- Corrosion (internal or external)
- Stress-corrosion cracking
- Third party damages (dents, gouges, etc.)

Combined with support from well-established Materials/Corrosion and advanced analysis in-house teams, Z-Subsea can conduct sophisticated analyses addressing the following challenging subjects:

- HP/HT operations
- Deepwater applications
- Sour environments
- Arctic loading condition
- Installation/operations under high plastic deformation e.g. Reeling and/or HPHT operations (Figure 4).

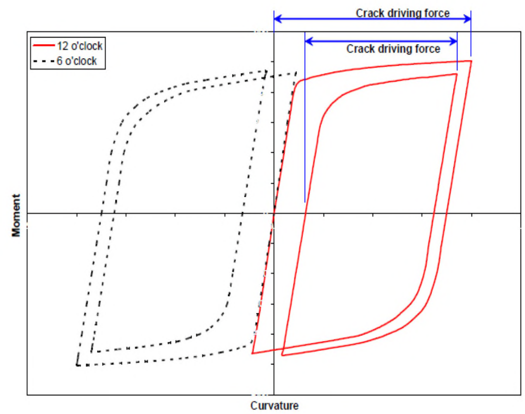


Figure 4. Introduction of Plastic Strain During Reeling Installation

The outcome of ECA would be in the form of tolerable defect sizes (acceptable flaw depth versus defect length) for a project full life cycle (Figure 5), indication of fatigue life of a welded/non-welded component and determination of the inspection intervals.

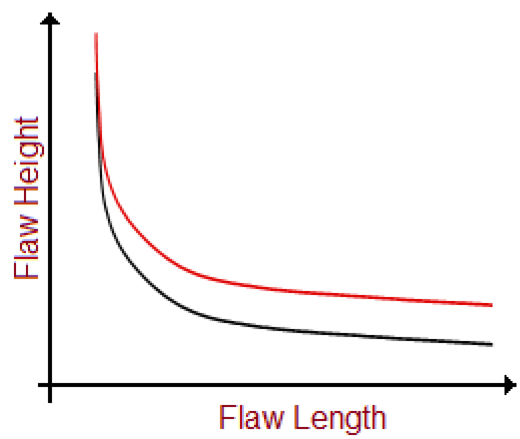


Figure 5. Flaw Tolerance Curve Obtained From ECA

Overview

World-wide the Operators experience that their oil and gas assets (pipelines, risers, structures, pressure vessels, etc.) reaches their original design life while there is still a need and financial viability to operate the systems for more years.

As the system age, the operators have several new challenges to consider when required to operate beyond the design life such as:

- Changes in integrity, e.g. time dependent degradation mechanisms such as corrosion and fatigue or random mechanical damages (e.g. third party damages)
- Changes in infrastructure from the as built, e.g. increased fishing activity or heavier trawl gear for a pipeline
- Changes in operational conditions, either as a natural
- Change in well-stream condition, tie-in to other pipeline system or increased production rates.

Therefore the question would be what should be assessed when required to operate beyond the design life and still ensure compliance with the original safely level.

Life Extension process

The life extension process can also be called a re-qualification.

It is triggered by the decision that the operation of the system will be continued beyond the original service life.

The process that may be followed in a life extension is outlined in Figure 1 (NORSOK Y002).

The purpose of the life extension process is to document acceptable system integrity to the end of the extended service life. The overall life extension process is as follows:

• Define the premise for the extended operation, and identify new threats to the system. The premises for the life extension shall be established.

This may include the following:

  - Life extension period;
  - Battery limits (what to be included/system description);
  - Regulatory requirements (e.g. according to this NORSOK standard);
  - Reference to company specific procedures, if relevant (e.g. procedure for handling of deviations from design codes);
  - Reference to applied design codes;
  - Technical/functional requirements (e.g., design pressure, design temperature, product composition).

- Assess the integrity of the system, in other words as far as possible quantify the current condition;
- Carry out a reassessment of the system based on the available information from integrity assessment and established life extension premises, current industry practice and available technology.
- The reassessment can conclude that the integrity of the system is acceptable up to the end of the extended life, in which case the process moves on to documentation and implementation.
- If the integrity is not acceptable, modifications shall be considered together with the feasibility of the entire life extension.

The life extension process shall take into account the degradation that has taken place since the installation of the system and is initiated well ahead of the end of the original service life (Figure 2).

The original service life is not limited by the original design life, but the operator requested service life shorter than design life.

In the original design, a given degradation model was used, which does not provide sufficient design life for the desired extended service life.

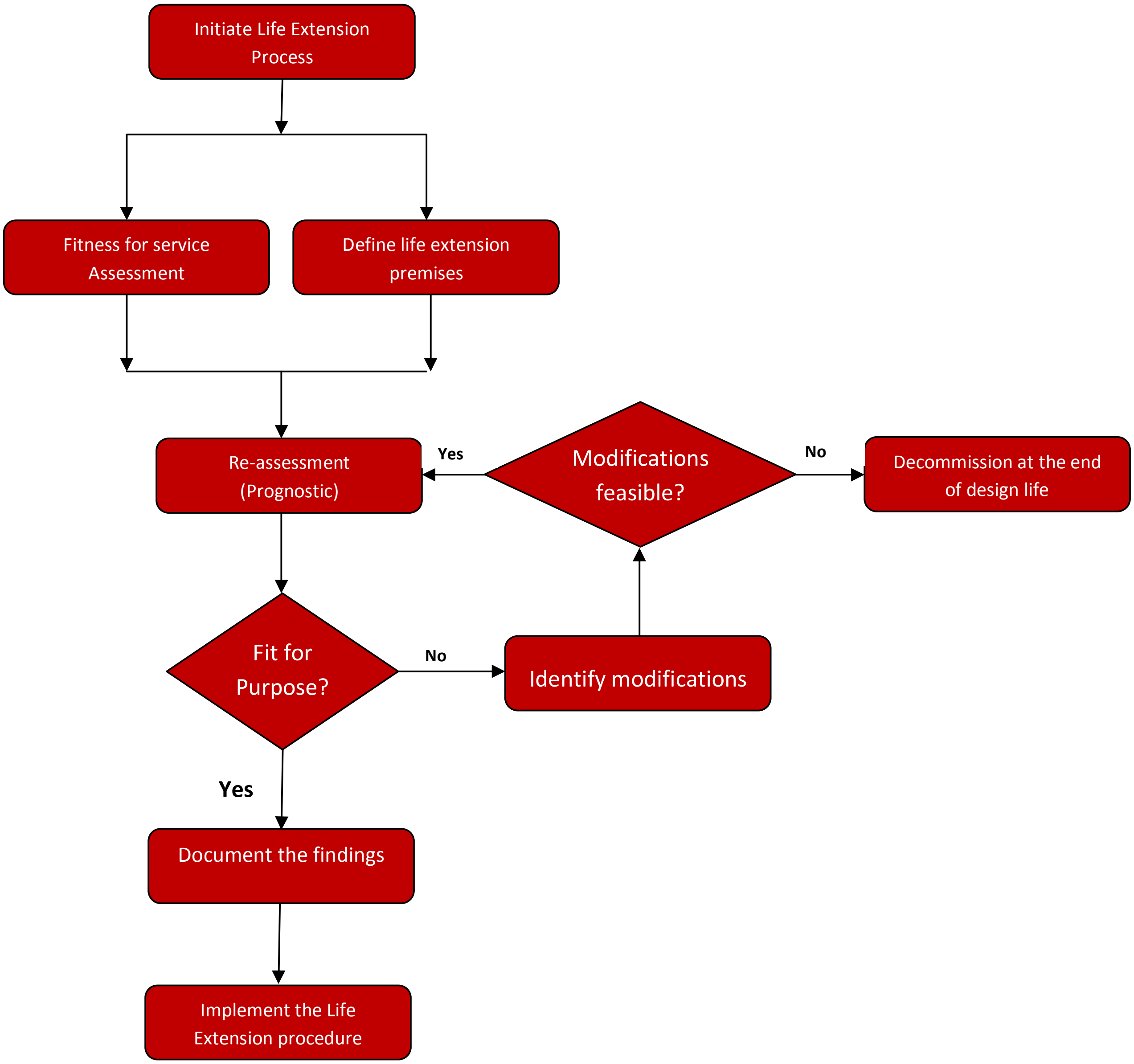


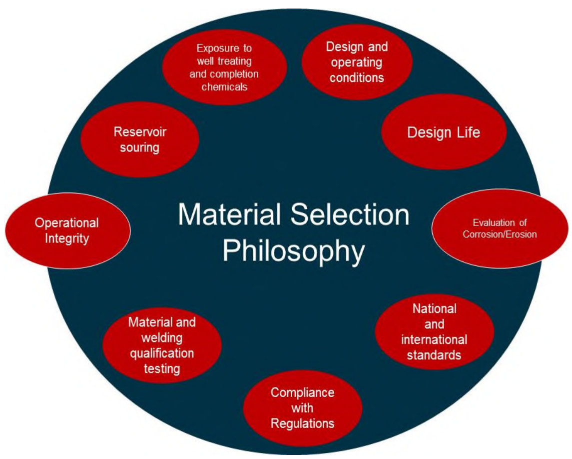
Figure 1 Life extension process flow chart to NORSOK Y002

Figure 2 General corrosion of external surface of pipework

Material Selection, Corrosion Assessment and Protection

Material Selection Process

Z-Subsea philosophy for selection materials for oil and gas assets is a full life cycle material selection approach as illustrated in the chart below.



Material Selection Philosophy

Project information generated during the project concept phase will be the basis of developing a project specific preliminary material selection philosophy.

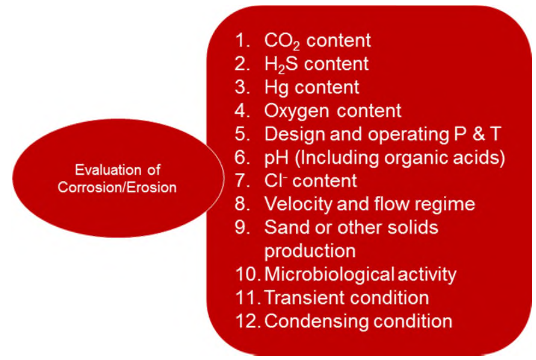
Project data usually further assessed, analyzed and developed during the FEED and project execution which therefor necessitate transferring the philosophy document to a report. This process has been followed by Z-Subsea Materials/Corrosion team in various industrial projects for oil and gas international clients.

The selection process will be based on the information summarized in the chart above which requires interaction with other discipline engineers such as Corrosion engineers, welding engineers, integrity engineers, flow assurance engineers, process engineers, production chemists, design engineers etc.

Corrosion and erosion evaluation

Z-Subsea possesses comprehensive experience in assessment of corrosion and erosion of oil and gas assets including pipelines, risers, topside facilities and subsea production system. The process is followed by the team is summarized in the Figure below.

Depending on the mechanism of the corrosion, assessment and evaluation will be performed for internal and external surfaces of the assets. Typical internal sources of corrosion are CO_2, Oxygen (if >10ppb), H_2S, Bacteria, Chloride and sand.



Corrosion/Erosion evaluation

Corrosion rate for each corrosion mechanism will be calculated using industry-wide acceptable models and tools, such as NORSOK M506, De-Waard Milliams, ECE, etc.

For external corrosion the main consideration will be on the effect of interaction between Cathodic Protection (CP) and material and generation of Hydrogen (HISC susceptibility) as well as exposure to seawater, product, etc. due to coating damage.

The effect of sand erosion or any mechanical erosion on the internal surface of the oil and gas asset shall be studied using applicable codes and standards. Z-Subsea will use DNV RP-O501 approach for the calculation of the sand erosion rate and amount of material loss due to erosion.

Both the above studies will be used to calculate right material with adequate thickness to withstanding in-service corrosion until end of life.

Operational Integrity

This part of the material selection process involves parameters which deal with materials during manufacturing and fabrication, project cost schedule and availability of materials for a project. All these parameters are considered by

Material Selection, Corrosion Assessment and Protection

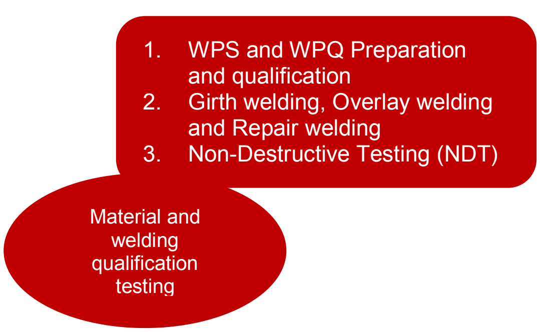
Z-Subsea materials team during the material selection process.

Current and future operation of the system with the potential souring of the production well as a result of cleaning or boosting activities shall be also considered during the material selection process.

Operational Considerations

Welding and NDT

As part of the material selection process, procedure to perform welding (girth welding, overlay welding and repair welding) shall be developed, qualified and tested. Z-Subsea welding engineering team will be using the qualifications based on the requirements of ASME IX, NORSOK M601, DNV OS-F101, BS4515 and ISO 15614 and more depending on the project requirements.



Welding and NDT

Z-Subsea material team prepares project specific welding procedures for project use or will approve and authorize readily available procedure in the projects. Qualification tests shall be performed by a qualified test house accredited to ISO 17025 which can be witnessed by Z-Subsea welding team.

Detailed NDT on welds or forged components shall be performed based on the national and international standards or project specific requirements. NDT method, procedure and extent for each component will be followed as advised in the project. Specific attention will be paid to components exposed to pressure (pressure containing or retaining).

Cathodic Protection (CP)

Cathodic Protection (CP) is an electrochemical corrosion protection method. When CP is applied, the electrochemical potential of the protected structure is lowered to a level where the corrosion rate is acceptable. The protected structure acts as the cathode in the system.

Z-Subsea corrosion team has been involved in design, data survey and analysis of numbers of CP systems for various oil and gas assets immersed in marine and onshore environment.

Compliance with rules, guidance and standards such as DNV RP B-401, ISO 12068, BS 7361-1, NACE SP0169, NACE TM 0479, etc. Specifically for materials susceptible to HISC, such as duplex stainless steel materials, requirements given in DNV-RP-F112 are followed by Z-Subsea corrosion team in various projects.

For further info about Z-Subsea materials and corrosion capabilities contact us on enquiries@z-subsea.com.

Z-Subsea Ltd selected Integrity Management/Assessment Project Track Records (Corporate and Individual)

Item	Project Title	Client name	Project Phase	Country
1	ILI data analysis and Fitness for service and remaining life assessment of 7 offshore pipelines	PetroVietNam GAS SOUTH EAST Transmission Company (PVGAS SE)	Operation	Vietnam
2	Level 1 to 3 integrity/free span assessment of Nam Con Son Gas pipeline phase 1 and recommending remedial actions	PetroVietNam GAS SOUTH EAST Transmission Company (PVGAS SE)	Operation	Vietnam
3	Developing technical integrity procedures for offshore pipelines and risers (12-off)	BV/Dubai Petroleum	-	UAE
4	Scolty Crates Pipeline Remediation Project	EnQuest	Operation	UK
5	Fitness for service and remaining life assessment of 6 onshore pipelines	NISOC	Operation	Middle East
6	Audit of Entire Integrity Management System of Oman Gas Company (OGC)	Oman Gas Company (OGC)	Operation	Oman
7	Developing Emergency Pipeline Repair System (EPRS) for 5 on/off shore pipelines in Oman	Petroleum Development Oman (PDO)	Operation	Oman
8	Ad-Hoc Support to Tullow TEN project as Technical Authority for Integrity Management and Materials Engineering in T.E.N project	Tullow Oil	Design/Operation	UK/Ghana
9	Risk-based Integrity assessment/management of twelve J-Tubes inside concrete caissons in the North Sea	TAQA	Operation	UK
10	Pipeline integrity Technical assessment/management of various BP North Sea Assets - Technical Authority Level	BP	Operation	UK
11	Fitness for Service (FFS) assessment and life extension of SJP-A to SJJT-A 6, 8 and 20" subsea pipelines	Shell	Operation	Malaysia
12	Integrity perspective development for Flexible risers/pipelines	Technip Flexibles	Design	France
13	Fitness for service and remaining life assessment for 8 and 16" pipelines in Oman	BP	Operation	Oman
14	Integrity assessment and management (Fitness for Services assessment and life extension) of 12 subsea pipelines and platforms	Centrica Energy Ltd	Operation	UK
15	Fitness for service assessment and	Pharonic Pipelines	Operation	Egypt

Z-Subsea Ltd selected Integrity Management/Assessment Project Track Records (Corporate and Individual)

Item	Project Title	Client name	Project Phase	Country
	integrity management/life extension study of an anchor damaged subsea pipeline using Finite Element Analysis			
16	Developing pigging and integrity management philosophies for 3 offshore pipeline in Vietnam	CuuLong	Operation	Vietnam
17	OFON Asset Cathodic protection design and retrofitting of pipelines and Platforms	Technip	Operation	France/Nigeria
18	Verification of the Engineering Critical Assessment (ECA) and integrity management of welding Defects on Bend Stiffener systems for Goliat development	Technip Norge	Design, Construction, Fabrication	Norway
19	Development of risk-based Integrity Management system for entire production system of Mari - B assets	Noble Energy	Design	USA
20	Development of integrity management procedure for entire subsea system for the Huntington development	E.ON Ruhrgas UK E & P Limited	Design	UK
21	Forvie Pipelines uprating integrity assessment and remaining life study	Total E&P UK	Operation	UK
22	Fitness for service assessment and remaining life calculation of Dunlin J-Tube/Riser	Fairfield Energy	Operation	UK
23	Fitness for service assessment and remaining life calculation of Triton-Clapham Water injection valve skid	Petro-Canada	Operation	UK
24	Fitness for service (FFS) assessment, remaining life calculations and Life Extension Study and recommendation of the most appropriate remedial actions (Repair and/or Replacement) services to Talisman UK on the subsea/topside assets (risers, pipelines, pressure vessels, piping, etc.) in the North Sea based on the API579 recommended practice: Buchan A Claymore Montrose Tartan Flotta Clyde	Talisman (UK)	Operation	UK

Z-Subsea Ltd selected Integrity Management/Assessment Project Track Records (Corporate and Individual)

Item	Project Title	Client name	Project Phase	Country
25	Fitness for Service (FFS) Assessment, Remaining Life Assessment and Life Extension study for Elgin-Franklin gas export riser	Total E&P UK	Operation	UK
26	Engineering Critical Assessment (ECA) of two OLT LNG pipelines to BS7910	Saipem	Design	Italy
27	Engineering Critical Assessment (ECA) of Long Term Agreement (LTA) pipeline project to BS7910	Saipem	Design	Italy
28	Engineering Critical Assessment (ECA) verification of Board of FDS pipeline to BS7910	Petrobras/Saipem	Design	Brazil
29	Engineering Critical Assessment (ECA) verification of CORRIB field development (phase III) to BS7910	Shell UK	Design	Ireland
30	Fitness for Service (FFS) Assessment, Remaining Life Assessment and Life Extension study for Dunbar Pipeline	Total E &P	Operation	UK
31	Fitness for Service (FFS) Assessment, Remaining Life Assessment and Life Extension study of Al-Shaheen water injection pipes to DNV RP-F101	Mearsk	Operation	Qatar
32	Engineering Critical Assessment (ECA) verification of Camarupium/PDEG gas pipeline (Sour gas)	Petrobras	Design	Brazil
33	Engineering Critical Assessment (ECA) of CNR Lyell 12” pipeline replacement project	Acergy	Design	France
34	Engineering Critical Assessment (ECA) and Fracture characterisation and defect assessment of Sakhaline II 14” pipe to BS7910	Shell	Design	Holland
35	Installation and operation Engineering Critical Assessment (ECA) of two offshore pipelines in Otway Australia to BS7910	Allseas BV	Design	Holland
36	Fitness for service assessment (to BS7910) and burst testing of damaged 30” oil pipes	Sasol	Operation	South Africa
37	Sour Engineering Critical Assessment (ECA) of 10, 12 and 14” clad girth welded pipes to BS7910	Allseas BV	Design	Holland

Z-Subsea Ltd selected Integrity Management/Assessment Project Track Records (Corporate and Individual)

Item	Project Title	Client name	Project Phase	Country
38	Mechanical characterisation and Engineering Critical Assessment (ECA) of 14” clad girth welded pipes to BS7910	Saipem	Design	UK
39	Engineering Critical Assessment (ECA) and Fracture assessment of clad materials using SINTAP procedure	GKSS Research Centre	Research	Germany
40	Engineering Critical Assessment (ECA) and Fracture characterisation of 13% Cr high strength steel girth welded pipes	EU funded project	Research	Germany

Z-Subsea Ltd. And its personnel selected Material and corrosion projects track record

Item	Project Title	Client name
1	Technical Authority for integrity and materials engineering in T.E.N project	Tullow Oil (UK/Ghana)
2	Preparation of Cathodic protection design documents for OFON Platforms	Technip (France)
3	Corrosion Assessment for PL488/15S pipeline	Total (UK)
4	Corrosion and integrity assessment of Al-Shaheen water injection pipes	Mearsk (Qatar)
5	Corrosion Assessment of Elgin-Franklin gas export riser	Total (UK)
6	Material selection philosophy, corrosion assessment and material selection for topsides process facilities and utilities Corrosion assessment for water injection lines (Nigeria); Corrosion assessment and material selection for onshore facility Materials selection for topsides process facilities and utilities Cathodic Protection: Responsible for coordinating cathodic protection design and ensuring consistency between various contractor's work scopes including flexible jumpers, subsea structures, flowlines and risers; reviewed cathodic protection design calculations, anode fabrication, layout and attachment details and approved contractor and supplier documentation; clarified technical queries and resolved non-conformance issues related to anode manufacture. Corrosion management experience: performed life of field corrosion and erosion assessments; material selection and developed the corrosion management philosophy for flowlines and subsea production systems; drafted materials map and specifications for plastic lined pipe, insulation, welding and anode fabrication.	Various
7	BP Devenick - SELECT/DEFINE/EXECUTE Phases - Perform material selection for design and EPIC contracts by calculating CO2 corrosion levels, and evaluating the technical and commercial advantages of available materials	BP
8	BP Harding - Managing materials selection and corrosion selection programmes for potential subsea	BP

Z-Subsea Ltd. And its personnel selected Material and corrosion projects track record

Item	Project Title	Client name
	projects. Conducting corrosion assessments and material selection for topside and subsea projects.	
9	Seventh Crude Oil Storage Tank at Zirku Materials selection, coating and cathodic protection specification for the crude storage tank and production facilities. FEED for the Seventh Crude Oil Storage Tank at Zirku Island (UAE) Materials selection memorandum and tank base corrosion study note have been prepared in addition to coating, CP and corrosion monitoring systems specifications to cover the new facilities.	ZADCO
10	BP - Bruce-Fulla Tieback Project Statoil tieback of the Fulla gas condensate field in the NS Norwegian sector to BP operated Bruce platform. Materials selection study for subsea production pipelines, spools and risers including the proposed use of pH stabilisation to control corrosion.	BP
11	Greater Plutonio Materials, corrosion and welding support to design, procurement, operation and maintenance (TAR) activities for the topside (FPSO) and subsea facilities.	BP
12	Athena detailed design, - Downhole completion, subsea & topsides, UK.	Ithaca Energy
13	Dunga development, - Onshore oil separation and gathering facilities, Kazakhstan	Maersk
14	Grevling feasibility study, - Grevling drilling, production and storage facility	Talisman Norge
15	Columbus FEED, - Materials selection for subsea facilities, pipelines and risers	ADIL
16	Logbaba FEED, - Materials selection support for a gas plant in Cameroon	Victoria Oil & Gas
17	Claymore upgrade, - Claymore platform gas compression train upgrade, UK	Talisman
18	Huntington subsea detailed design, - Subsea facilities, pipelines and risers, UK.	E.ON
19	Laggan-Tormore gas plant FEED, – Materials selection, support to EPC tender, UK.	Total
20	Bream subsea pre-FEED,– Subsea Facilities Material selection, Norway.	BG Norge
21	FEED/EPC – Gorgon LNG, Chevron/Shell/Exxon, Australia FEED – Pluto II LNG, Shell/Woodside, Australia EPC - Pearl GTL, Shell, Qatar EPC – Dragon LNG Import Terminal, BG, UK Revamping - Mongstad Refinery, Statoil, Norway Pre-FEED, FEED study - Mongstad CO2 Capture Project, Statoil, Norway FEED - Nigeria LNG Seven Plus, Shell, Nigeria EPC - Dung Quat Refinery, Petrovietnam, Vietnam FEED&EPC - Karsto Expansion Project KEP 2010,	Various as listed.

Z-Subsea Ltd. And its personnel selected Material and corrosion projects track record

Item	Project Title	Client name
	9Statoil, Norway E10PC - In Amenas Gas Project, BP, Algeria EPC - EPCM Metallurgist, Pearl GTL, Shell, Qatar EPC - Yemen LNG, Yemen FEED - OK LNG, Nigeria. In addition to preparing Materials of Construction reports, Material Selection Diagrams, welding and materials specifications, Andrea has provided the following specialist services for these projects: Recommendations for metallurgical examinations, corrosion testing and welding of steels, stainless steels, and non-ferrous alloys	
22	Consultancy for major O&G Companies on weldability, metallurgy and corrosion of steels, stainless steels and nickel alloys. Responsible for managing numerous single client projects, Core Research Projects and two major JIP projects on duplex and 13%Cr supermartensitic stainless steels. Specific areas of work have included: Weldability and properties of CRA alloys The effects of third phases on austenitic and duplex stainless steels Corrosion and stress corrosion cracking of stainless steels and Ni-alloys The effects of cathodic protection on duplex stainless steels Weldability and properties of low carbon ‘weldable’ martensitic stainless steels Weldability and properties of nickel superalloys for gas turbine and failure mechanism Failure investigations	TWI Ltd.

QMS International plc

ISO 9001 REGISTERED

This document certifies that the quality management systems of

Z-SUBSEA LTD

The Chandlery Business Centre, 50 Westminster Bridge Road, London SE1 7QY

have been assessed and approved by QMS International plc to the following quality management systems, standards and guidelines:-

ISO 9001 : 2008

The approved quality management systems apply to the following:-

THE PROVISION OF SUBSEA DESIGN, INTEGRITY MANAGEMENT, ADVANCED SIMULATION AND ENGINEERING TRAINING COURSES.

Original Approval: 09 September 2014

Current Certificate: 09 September 2014

Certificate Expiry: 08 September 2024

Certificate Number: GB 22513

IAC ACCREDITATION

On behalf of QMS International plc

This Certificate remains valid while the holder maintains their quality management systems in accordance with the standards and guidelines above, which will be audited by QMS International plc

This Certificate is the property of QMS International plc and must be returned in the event of cancellation.

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This document certifies that the environmental management systems of

Z-SUBSEA LTD

The Chandlery Business Centre, 50 Westminster Bridge Road, London SE1 7QY

have been assessed and approved by QMS International plc to the following environmental management systems, standards and guidelines:-

ISO 14001 : 2004

The approved environmental management systems apply to the following:-

THE PROVISION OF SUBSEA DESIGN, INTEGRITY MANAGEMENT, ADVANCED SIMULATION AND ENGINEERING TRAINING COURSES.

Original Approval: 09 September 2014

Current Certificate: 09 September 2014

Certificate Expiry: 08 September 2024

Certificate Number: GB 22514

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