



Strain-Based ECA Round-Robin

Technology Qualification

24-Nov-15

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It is expected that this document and its contents, including work scope, methodology and commercial terms will be treated in strict confidence by and that the contents will be used only for the purpose of proposing a joint industry project.

PROPOSAL NO 401029-00077-SS084 – STRAIN-BASED ECA ROUND-ROBIN: TECHNOLOGY QUALIFICATION

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Executive Summary

Engineering Critical Assessment (ECA) for pipeline girth weld is performed to assess the criticality of flaws or defects found at the girth welds during inspection. Conventionally, the assessment is carried out based on the Failure Assessment Diagram (FAD) approach using guidelines in standards or recommended practice such as BS7910, API 579, SINTAP and FITNET. Amongst them, the most widely accepted procedure, in the pipeline industry, is based on BS7910 [Ref. 1]. However, this procedure is essentially stress-based and will result in unnecessary conservatism when applied in its unaltered form to modern pipelines requiring plastic design with large strains. The uncertainties, in terms of robustness of the approach, are greater when the large strains are applied in combination with other factors such as multi-material domains (from clad/lined pipe) and non-overmatching weld.

The alternative, Strain-Based ECA (SBECA), has been proposed and developed recently within the industry. Nevertheless, there is lack of a unified approach presented in any design standard. In the absence of a clear codified guidance, installation contractors and design houses have executed a number of SBECA studies in various approaches limiting the confidence level on SBECA. This proposal of a collaborative round-robin exercise is motivated as an initial step towards the development of a unified methodology and framework for performing SBECA within the industry.

Why is this Round-Robin Beneficial?

Main Issue	Benefits to Participants
✓ Variation in SBECA approaches	Able to identify the approaches currently deployed within the industry and capture the magnitude of variation in their results.
✓ Variation in parameters consideration	Able to identify the variations in parameters considerations deployed within the industry and capture the impact of these variations.
✓ Lack of Industry Awareness on SBECA	<p>Able to identify the potential for the different approaches and assumptions and identify its acceptability among stakeholders.</p> <p>Collective contribution to a common problem raises the general awareness of the industry on the potential of a unified SBECA methodology</p>

1 Introduction

1.1 Study Objectives

The objective of this work is to understand the diversity of approach and assumptions practised for Strain-Based Engineering Critical Assessment (SBECA) in the oil and gas industry and subsequently capture the magnitude of the potential issues posed by various approaches and assumptions. This work will aspire to involve collaboration between operators, pipe manufacturers, installation contractors and design consultants, where each participant contributes in terms of expertise and/or information towards the setup of sample cases followed by a round-robin exercise.

At the moment, the key objective of the project is to give an indication on the severity of the consequences arising from the diversity of approaches and identify gaps within the practices. At the end of this round-robin exercise, whether or not a JIP on unifying the methodology for SBECA should be carried out will be open for discussion.

1.2 Project Benefit

Existing codes and standards present only general guidelines with limited information for consideration of SBECA. Diversity in the approaches and open interpretation of key parameters is a concern and affects the efficiency of the SBECA studies in terms of both integrity of the design and the cost saving from welding activities. Hence, there is value in gaining a consensus within the regular practitioners in the industry to aid the establishment of a unified methodology within the industry. The first step to achieving the consensus of a unified methodology is to understand the magnitude of the problem posed by this diversity and raising awareness on SBECA.

1.3 Scope of Work

The scope of work involves conducting an open round-robin exercise within a pool of industry participants for a number of sample cases deemed sufficient to capture the key variations in approaches and assumptions in a SBECA study. Subjected to data availability, a comparison of the different tolerable flaw size predictions from the participants and the observed real behaviour may be performed. In this revision of the proposal, the scope of the activities proposed is limited to external surface breaking flaws at girth welds of pipelines. However, this scope of work may be extended to embedded and internal flaws if agreed by all participants.

Section 1**Introduction****1.4 Abbreviations**

API	American Petroleum Industry
BS	British Standards
CDF	Crack Driving Force
C-Mn	Carbon Manganese Steel
CRA	Corrosion Resistant Alloy
CTOD	Crack Tip Opening Displacement
DNV	Det Norske Veritas
ECA	Engineering Critical Assessment
FAD	Failure Assessment Diagram
FE(A)	Finite Element (Analysis)
FITNET	European Fitness-for-Service Network
FTP	File Transfer Protocol
GTN	Gurson-Tvergaard-Needleman
HAZ	Heat Affected Zone
JIP	Joint Industry Project
J-integral	A measure of energy release rate
PWHT	Post Welding Heat Treatment
SBECA	Strain-Base Engineering Critical Assessment
SINTAP	Structural Integrity Assessment Procedures for European Industry
SMYS	Specified Minimum Yield Stress
Y/T	Yield over Tensile Strength Ratio

2 Literature Review

This section presents a brief literature review on strain-based ECA with some remarks on key parameters. It should be noted that a literature review will be completed to a level required for understanding the outcome of the round-robin exercise and this review will be included in the final report.

2.1 Approaches to Carry Out Strain-based ECA for Pipeline Girth Weld in Public Domain

One of the most widely accepted ECA procedures is based on BS 7910 [Ref. 1], which forms the basis of ECA methodology recommended by popular pipeline design codes, i.e. DNV -OS-F101 [Ref. 3] and API Standard 1104 [Ref. 2]. The FAD approach recommended in [Ref. 1] is widely performed for stress-based design for C-Mn pipe and overmatching weld.

Development in the oil and gas industry driven by the search for oil in more challenging environments has pushed beyond the limits of stress-based design for both onshore and offshore pipelines. A majority of modern subsea pipeline operational scenarios require plastic design for strain levels up to 2-3% (reeling installation) and exceeding 0.6% (operating in high pressure/high temperature fields). Similarly, onshore pipelines subjected to seismic/ice gouging/frost heaves are designed to cater for strains in excess of 2.5%. Design criteria for avoiding plastic instability and collapse while allowing locally large plastic strains are formulated in some pipeline design documents and this approach is generally referred to as strain-based design. It should be noted that the use of CRA clad/lined pipe, which is considered as a solution to transport corrosive fluids, creates additional complexities to the problem. This is due to the introduction of additional material domain near the crack tip and the fact that weld metal for CRA clad/lined pipe does not necessarily have strength characteristics that overmatches the parent pipe, especially at high temperature.

Published literature does exist and provides a good starting point for SBECA works with successful deployment on pipeline projects. However, the available approaches are varied and some aspects are still under development through various research forums. As a result, the SBECA have been executed based on open interpretation by engineering consultants and installation contractors on public domain information and/or in-house project specific test data.

With a focus on the fracture resistance assessment, the available approaches for SBECA can be separated into two major categories:

- Assessment using relatively simple closed-form analytical solutions and,
- Assessment using numerical modelling.

The closed-form solutions assessment can be performed using the FAD or empirical formulations which allow the computation of the strain limit for stable ductile tearing. The FAD approaches to SBECA vary from an essentially stress-based FAD approach with a relaxation of the plastic collapse limit [Ref. 4] to the development of a strain-based FAD [Ref. 7]. Additionally, the strain capacity determination from empirical formulations are proposed in [Ref. 10] and [Ref. 17] and is based on extensive experimental and numerical programs.

Meanwhile, the more computationally intensive SBECA using 3D FEA can be performed using mapping or damage-based techniques. The former approach requires the modelling of various stationary cracks to simulate crack growth; for which the strain capacity of the initial crack is derived based on the comparison

between the crack driving force (CDF), described either by J-integral or crack tip opening displacement (CTOD) parameter, and the fracture resistance of the material, determined from material testing. This can be done using solid elements [Refs. 13,19, 20] or line-spring elements [Ref. 6]. Meanwhile, the explicit modelling of the crack growth using damage-based technique has also been being developed with Gurson–Tvergaard–Needleman (GTN) models [Ref. 14] or modified Mohr Coulomb models [Ref. 15].

These approaches, especially for the closed-form analytical solutions, are subjected to various limitations of applicability and accuracy. For example, the stress-based FAD approach as suggested in [Ref. 4] is limited to weld material that overmatches the strength of the parent pipe material and uniaxial loading although modifications to the approach has been suggested to extend its validity [Refs. 9, 16]. While the stationary crack model may overestimate the CDF for conditions with very large plastic strains [Ref. 14]; and the propagating crack model needs to calibrate the model parameters with actual test data.

Numerical tools that are commonly utilised in the industry for ECA include CrackWise (fatigue crack growth and fracture resistance assessment with FAD approach), FlawPro (closed-form analytical solution for CDF), LinkPipe (numerical model using line-spring elements) and Abaqus (general 3D FEA).

As shown above, the variety in approaches with varying levels of in-built conservatism and limitations in approach validity creates an environment of uncertainty when performing strain-based ECA. As such, a unified approach to SBECA is required.

2.2 Remarks on Key Input Parameters for SBECA

Current approaches to SBECA are deterministic and the cases included in a study are based on the reasoning of a deterministic worst case scenario, emphasizing the importance in establishing the key parameters that constitutes the worst case scenario. The preference of a deterministic approach to SBECA is mainly due to the validity limitation of the analytical solutions and the computational cost of the numerical models. It should be noted that, at present, performing numerical based SBECA with the probabilistic consideration of key input parameters may impose a huge computational cost that is beyond the means of most project cost and schedule. Regardless of the approaches used for ECA, the key parameters affecting the acceptability of a flaw at the girth weld are well documented in projects. However, the consideration/treatment of some key input parameters varies between projects and may depend on individual findings or experience of the practitioners.

2.2.1 Loading

The first and foremost parameter is the effect of bi-axial loading. Bi-axial loading for a flaw in the girth weld of a pipeline comes in the form of the combined loading from pressure (hoop direction) and axial tension (longitudinal direction), which occurs during operation. It is well documented that the presence of internal pressure in an axially loaded pipe increases significantly the CDF and [Ref. 12] suggests that the maximum biaxial effect occurs at pressure induced hoop stress of approximately 50% SMYS. It is also noted that the effects of bi-axial loading on the strain capacity is not explicitly considered in the stress-based FAD approach, but may be dealt with by an adjustment of the material yield stress value [Ref. 9].

2.2.2 Geometry

Hi-Lo misalignment between two adjoining pipe ends introduces strain concentration which is made more localized with internal pressure [Ref. 8]. Hence, hi-lo misalignment has the undesirable effect of increasing the CDF and subsequently lowering the strain capacity of a flaw at the girth weld. There are two common

ways for considering hi-lo in numerical models, i.e. either modifying the diameter of the matching concentric pipes or introducing misalignment with pipe centre-line offset [Ref. 18].

2.2.3 Material Properties

The previous two parameters pertain to the loading and geometry of the girth weld which are generally well established and do not involve much difference in interpretation in practice. The following parameters on the materials involved in and at the vicinity of the girth weld, however, are rife with opportunities for significant differences in interpretation and hence variation in results.

Generally, the weld material preferably has strength characteristics that overmatch the parent pipe material. As shown in [Ref. 13], the degree of weld material matching influences the CDF. A weld material that under-matches the parent material increases significantly the CDF in comparison with that of a homogenous material, while a weld material that overmatches the parent material has the opposite effect. Weld material under-matching the parent pipe material is especially onerous and is evident in the weld material for girth welds of pipes with CRA liner or when higher grades of C-Mn pipes are used. The variation in the treatment and interpretation of this parameter occurs generally from the definition of the characteristic material properties for the weld and parent material, i.e. the statistical treatment of the material test data and interpretation of the characteristic material properties.

The issue with the statistical treatment and interpretation of characteristic material properties is compounded when considering C-Mn pipe with CRA liner. While the girth weld for C-Mn pipe involves only two different materials, i.e. weld metal and parent pipe, the girth weld for pipe with CRA liner involves at least three different materials, i.e. weld metal, C-Mn steel and CRA material. A DNV JIP [Ref. 5] explores the issues with C-Mn pipe with CRA liner material and provides guidance on scenarios where the CRA liner material may be considered beneficial to the CDF of flaws away from the CRA liner. However, there is still doubt with the interpretation of the effects of CRA liner especially at the weld root area where a flaw exists within/near the interacting domain of all three materials.

For a system where the weld material overmatches the strength of the parent pipe, a higher yield over tensile strength ratio (Y/T) of the parent pipe material is reported to be beneficial by resulting in a decreased CDF for a given strain [Ref. 12]. Literature is however scarce for the scenario where the weld material does not overmatch the strength of the parent pipe.

The effect of material anisotropy, i.e. the difference in axial, hoop and through-thickness tensile properties, has not been generally considered in design. However, [Ref. 12] has reported that a reasonably small change in through thickness tensile properties or hoop tensile properties may produce a significant change in the crack driving force of a bi-axially loaded pipe.

Softened heat affected zones (HAZ), primarily evident in higher grades C-Mn pipe material, generally introduces a band of weak material between the weld and parent pipe. [Ref. 8] reported the effect of HAZ softening on strain concentration is significant, especially for bi-axially loaded pipes. Similarly, the increase of CDF in HAZ softened zones is observed and reported in [Ref. 12].

2.2.4 Additional Parameters

Weld residual stress/strain must be considered in determining the acceptability of flaws as per guidance in [Refs. 1 and 3]. However, there is variation in how the weld residual stress should be treated in practice, i.e. as a secondary stress applied in FAD based assessment or conservatively included directly to the applied

Section 2

Literature Review

strain as an addition primary strain. The variation extends further when considering weld residual stress relaxation from post-welding heat treatment (PWHT) or the application of large plastic strains.

It is noted that while the current scope emphasizes the ductile fracture failure mechanism in determining the strain capacity. Other failure mechanism, such as fatigue crack growth with high peak strain in each loading cycle, may require a re-evaluation.

Considering all of the above, it is very apparent that a single problem may involve a huge variation of approaches and open interpretations by designers and contractors. This variation complicates the process of designing and verifying, perhaps leading to unnecessary conservatism or risk that the industry does not need at present.

3 Project Execution Plan

3.1 Overview

A round-robin exercise, with two sets of problems identified to be sufficient to gauge the diversity of responses in approach and key parameters shown in Section 3.4, is proposed where each practitioner will provide an independent solution for each problem.

It is proposed that anonymity is maintained with the use of an FTP site and a common username for the submission of results and assumptions to the JIP Coordinator, i.e. INTECSEA. In addition, discussion and clarifications will be conducted through the use of common questionnaires to all participants.

Upon completion, the results will be reviewed, categorised and statistically evaluated. A report documenting all information, including assumptions used, corresponding results, remarks etc., will be prepared by the coordinator and disseminated to all participants. Note that anonymity of the sources will be preserved in the documentation prepared.

Finally, a meeting between all participants will be carried out to discuss if the findings obtained from this round-robin will be used as an attempt to unify the SBECA approach between all participants or to be submitted to the Standard writers, e.g. DNV, for an industry standard update. The former approach may require an additional JIP whilst the latter one does not.

3.2 Participant Categories

The activities proposed involve the collaboration of three (3) categories of participants:

Type A – Operators

Type B – Pipe manufacturers and material test houses

Type C – Design consultants and installation contractors (including INTECSEA)

Each category of participants holds a different role within the proposed round-robin exercise.

It is proposed that participant Type A, with their broad exposure to the variety of pipeline scenarios involving SBECA and its practices, operate as the steering committee for the study as well as provide records of their experience with SBECA in completed projects.

Participant Type B are responsible for providing material test data while participant Type C will perform the SBECA for the specific set of problems independently.

It should be noted that INTECSEA shall participate as Type C participant and as the project Coordinator.

3.3 Round-Robin Process

- 1) Preliminary communication will be carried out and coordinated by INTECSEA and potential participants to officially inform the study and to register the interest. Proposed participating methodology and fee will be included.

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Project Execution Plan

- 2) Upon confirmation of participation by all identified interested parties, INTECSEA shall host the kick-off meeting to present the execution plan followed by a discussion of the proposed sample problems, required inputs and interface requirements.
- 3) INTECSEA will create a list of fixed parameters and collaborate with participants for inputs as per Figure 3-1.

These inputs will, as much as possible, reflect the typical real life scenario and the common requests from operator point of view. Importantly, the inputs for material properties will be provided by participant type B, in the form of raw test data and material test reports.

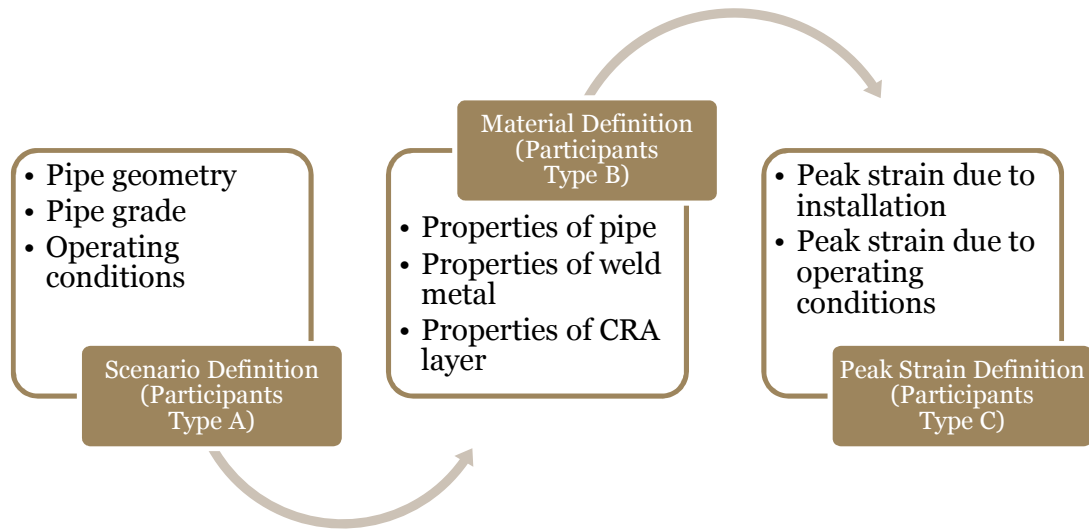


Figure 3-1: Flow Chart for Inputs Definition and Contribution

- 4) Analysis problems and corresponding inputs will be packaged and sent to each participant Type C to confirm if sufficient data has been provided to carry out the analyses.
- 5) Participant Type C shall deploy their normal approach for executing SBECA to the two sets of sample problems independently and submit the results along with key assumptions for subsequent review and analyses. Subjected to the consensus of participants, it is proposed that anonymity of the results and assumptions is maintained through the use of a FTP site and a common username for submission to the coordinator.
- 6) INTECSEA will review and analyse the results from various participants and obtain clarifications and discussion through the use of common questionnaires to all participants.
- 7) The results from the round-robin exercise and individual discussions shall be collated and presented anonymously in a review meeting. The findings from INTECSEA's review and analyses shall also be presented and discussed among all participants.
- 8) The results and findings from all the above activities will be reported and distributed amongst participants.

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It should be noted that the round-robin exercise is not a competition. The major objective of the exercise is to determine the current state of knowledge and practices of performing SBECA within the industry. As such, the contributions from participants are acknowledged, but anonymity shall be preserved in both the material performance inputs from individual pipe manufacturers and outputs of SBECA from individual organisations.

3.4 Proposed Sample Cases

Based on the key parameters potentially affecting the results from an ECA shown in the literature review, Table 3-1 presents the matrix of possible scenarios and the corresponding key influencing parameters.

Table 3-1: Matrix of Pipeline Scenarios Normally Considered in ECA

No.	Scenario	Pipe Type		Biaxial Loading	Weld Matching		Weld Residual Stress		HAZ Softening	Low Cycle Fatigue	Strain	
		C-Mn	CRA clad/lined		Non-overmatched ⁽¹⁾	Overmatched	Full	Relaxed			$\epsilon \leq 0.5\%$	$\epsilon > 0.5\%$
1	Subsea – S-lay/J-lay Installation – C-Mn	X				X	X				X	
2	Subsea – Reel-lay Installation – C-Mn	X				X	X ⁽²⁾	X ⁽²⁾		X		X
3	Subsea – S-lay/J-lay Installation – CRA clad		X			X	X				X	
4	Subsea – Reel-lay Installation – CRA clad		X		X ⁽³⁾	X ⁽³⁾	X ⁽²⁾	X ⁽²⁾		X		X
5	Subsea – Operation – C-Mn	X		X		X		X		X ⁽⁴⁾	X	X ⁽⁴⁾
6	Subsea – Operation – CRA clad		X	X	X			X		X ⁽⁴⁾	X	X ⁽⁴⁾
7	Onshore – Operation – Normal C-Mn	X		X		X	X					X
8	Onshore – Operation – High Strength C-Mn	X		X	X		X		X			X

Notes:

1. Non- overmatched welds includes weld material that partially overmatches the parent material as well as that which completely under-matches the parent material
2. Reel-lay installation subjects the pipeline to multiple cycles of large plastic strains. Hence, weld residual stress relaxation is commonly considered after the first large strain cycle.

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3. ECA for reel-lay installation may potentially see non-overmatching welds, especially during spooling when the weld between pipe stalks may still be above the ambient temperature due to field joint coating application.
4. High levels of operational strain in subsea pipelines are not very common as suitable buckle mitigation design is usually deployed to keep the operational strains low.
5. The proposed scenarios for the round-robin exercise are highlighted.

The matrix presents eight (8) common pipeline scenarios and it is acknowledged that the matrix is not all encompassing. The matrix is motivated by the need to identify realistic pipeline scenarios for the purpose of defining the minimal number of sample cases required to sufficiently evaluate the variation in the identified parameters.

The parameters reported to be influencing SBECA includes the consideration of the CRA liner for CRA clad/lined pipes, biaxial loading, the degree of weld matching (particularly if a weld undermatches the parent material), the consideration of weld residual stress, HAZ, low cycle fatigue and finally the methodology used especially for high plastic strain levels (assumed here as in exceedance of 0.5% strain).

Reel-lay installation is differentiated from S-lay and J-lay because it is subjected to multiple cycles of high plastic strains in excess of 1% and may involve the consideration of weld residual stress relaxation after the initial high strain cycle. Whereas, S-lay and J-lay are very similar in terms of the peak strains experienced. While S-lay may experience peak strains at overbend and sagbend, the tearing is not cumulated as the tensile strain occurs on different hemisphere of the pipe at each location.

C-Mn pipes are differentiated from CRA clad/lined pipes due to potential variation in the consideration of the contribution from the CRA liner. Additionally, temperature degradation of the weld metal for CRA clad/lined pipes is generally greater than that of the parent metal, hence under high temperature operating conditions, there is potential for the strength of weld metal under-matching the parent metal of CRA clad/lined pipes.

Onshore pipelines, especially when constructed with high strength C-Mn pipes and operated in permafrost or seismic regions, faces the potential of weld under-matching, the development of HAZ when welded with conventional welding processes as well as high plastic strains.

Base on the matrix, it is proposed that scenarios 4 and 8 are selected as the sample scenarios for the round-robin exercise. These two cases are proposed as they are considered sufficient to capture most of the key variation in parameters identified.

Between the two scenarios, Scenario 4 – reel-lay installation of subsea CRA clad pipeline and Scenario 8 – operating condition of onshore pipelines with high strength C-Mn pipes, all of the parameters influencing SBECA tabulated in Table 3-1 have been considered with the exception of the conditions involving small plastic strains. This omission is considered acceptable as the focus of the round-robin exercise is on SBECA, of which pipeline experiencing tensile strains exceeding 0.5% must require the application of strain-based design. Consideration of scenarios where peak tensile strain is within 0.5% may however provide further insight into the variation of methodology as the lower strains may provide necessary justification for the use of stress-based FAD approach.

It is noted that material anisotropy is not considered in the current proposed scenarios for the round-robin exercise as it has not been generally considered in design. However, this parameter may be included as a topic for future work.

3.5 Deliverables

INTECSEA shall deliver the list of deliverables defined below:

- Information package of the common problems for the round-robin
- PowerPoint presentation of the results from round-robin
- Final Report of Industry Round-Robin on SBECA

3.6 Project Management

INTECSEA shall host the kick-off meeting within 1 week of contract being awarded at INTECSEA's nominated office (or via video conference) and present to all participants the plan for scope execution and introduce extended team to company representatives. The kick-off meeting shall discuss the scope, methodology, required input data and interface requirements.

An allowance for travel has **not** been made, hence in order to perform presentations and conduct discussions during the work, video or teleconference will be utilised, where physical presence is cost inhibitive.

INTECSEA shall submit progress reports by the end of each fortnight, which shall contain the following as a minimum:

- Tasks completed this fortnight, and tasks planned for next fortnight
- Issues and mitigations
- Schedule progress

INTECSEA shall allow 10 working days for participants to review the deliverables before issuing of the final report.

3.7 Preliminary Proposed Schedule

The preliminary schedule is presented in Figure 3-2.

Activities	Wk 1	Wk 2	Wk 3	Wk 4	Wk 5	Wk 6	Wk 7	Wk 8	Wk 9	Wk 10	Wk 11	Wk 12	Wk 13	Wk 14	Wk 15	Wk 16	Wk 17
Initial Data Gathering																	
Problem & Input Finalisation																	
Perform Analysis																	
Clarification Discussions																	
Collate & Present Results for Discussions																	
Prepare Final Report																	
Review Period																	
Issue Final Report																	

Figure 3-2: Preliminary Schedule

4 Project Organisation and Key Personnel

4.1 Study Management and Coordination

The study will be coordinated by INTECSEA's, Joe Tran, who will be the participants' primary point of contact during the round-robin exercise. Joe will ensure that the study is completed in accordance with the contract and all cost and schedule targets are met. Joe will be performing his role with the advisory support from INTECSEA's Technical Advisor, Andrew Low.

As this is proposed as an industry wide collaboration, it is proposed that a steering committee is formed amongst participants to provide advice and identifying the priorities and concerns as the study develops.

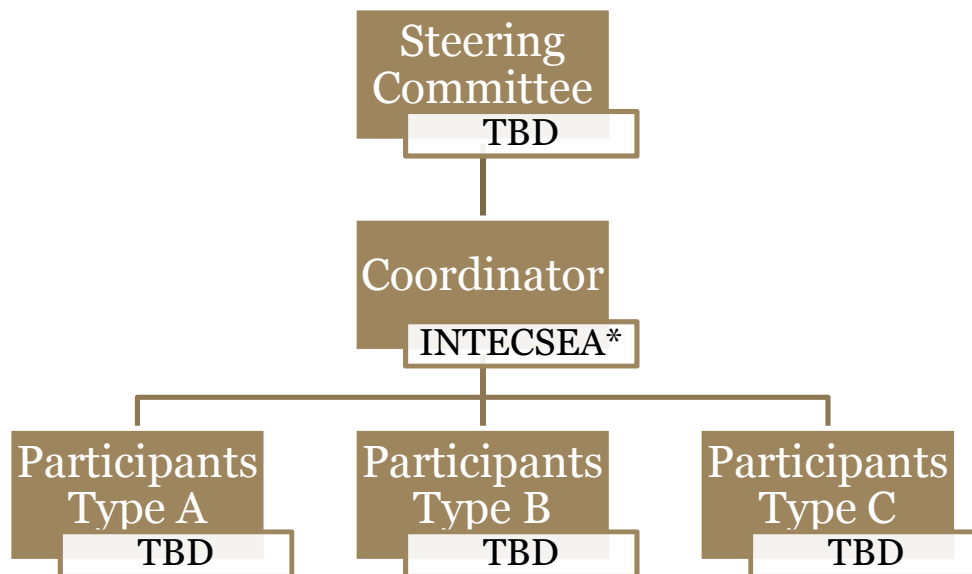
4.2 Proposed Study Location

The project will be conducted from the INTECSEA office in Perth at the following address:

Level 3, 600 Murray Street, West Perth, WA 6005, Australia

4.3 Study Organisation

INTECSEA's proposed organisational structure is shown in Figure 4-1.



*Lead Coordinator – Joe Tran
Technical Advisor – Andrew Low

Figure 4-1: Study Organisational Structure

Section 4 Project Organisation and Key Personnel

4.4 Key Personnel

As this exercise involves industry wide collaboration with INTECSEA as coordinator as well as participant, the list of Key Personnel shall be populated by all participants. In the position as project Coordinator, INTECSEA is seeking to provide the best personnel to ensure the round-robin's objectives are met in a timely and technically robust manner. To achieve this, we have proposed the most suitably qualified and experienced personnel. An overview of the proposed key personnel is provided in Table 4-1, while full CVs are included as Appendix B.

Table 4-1: Key Personnel

Name, Position on Project	Qualifications & Experience
Andrew Low Technical Advisor	Mr. Andrew Low is the Global Technology Director in INTECSEA and has more than 15 years of experience in the offshore oil and gas industry. He is actively involved in INTECSEA projects globally to ensure successful and practical design solutions as well as system integrity across pipelines, risers and materials disciplines. He is also responsible for the development and technical delivery of INTECSEA Joint Industry research projects and stewardship of technology partnerships globally.
Joe Tran Lead Coordinator	Mr. Thao Tran (Joe) is a Senior Engineering Specialist at INTECSEA. He has more than eight years of experience in Finite Element Analysis (FEA), specialized in fatigue, damage/failure analysis and fracture mechanics. He has solid background in fracture mechanics and FEA and significant working experience in Engineering Critical Assessment (ECA) as well as in Fitness-for-Service (FFS) studies. He has performed ECA and FFS for subsea pipelines, ranging from C-Mn pipes to CRA Clad/Lined pipes, and onshore facilities, such as storage tanks and fittings, utilizing various techniques, from analytical solution approach to three-dimensional fracture mechanics-based numerical model.

5 Commercial

5.1 Terms and Conditions

The tentative terms and conditions are attached in Appendix A.

5.2 Estimated Cost and Participation Cost

INTECSEA's Scope of Work, being the coordinator for the project, relates to the following activities: relates to the following activities: initial problem setup, progress and final report, coordinator and administrative duties. The resources required for conducting the SBECA for the sample problems are not included in this cost and is considered as INTECSEA's contribution to the project.

The detailed activities to be performed by INTECSEA are:

- i. Collate information and gather data from participants
- ii. Develop the sample problems for distribution to participants
- iii. Collate results on sample problems and sanitise them to promote anonymity
- iv. Conduct clarification discussions with participants on results
- v. Prepare a Final Report comprising of:
 - a. A more detailed literature review
 - b. Results (corresponding to each sample cases) obtained from the round robin exercise
 - c. Summary of answers obtained from discussion section
 - d. Remarks and gap identification on standards and industry practices for Strain-Based ECA
 - e. Recommendation for future works or development directions

The deliverables to be issued by INTECSEA are:

- i. Minutes of meetings
- ii. Bi-weekly progress report
- iii. One set of sample problems with all necessary data
- iv. One set of clarification questionnaires
- v. Final JIP Report

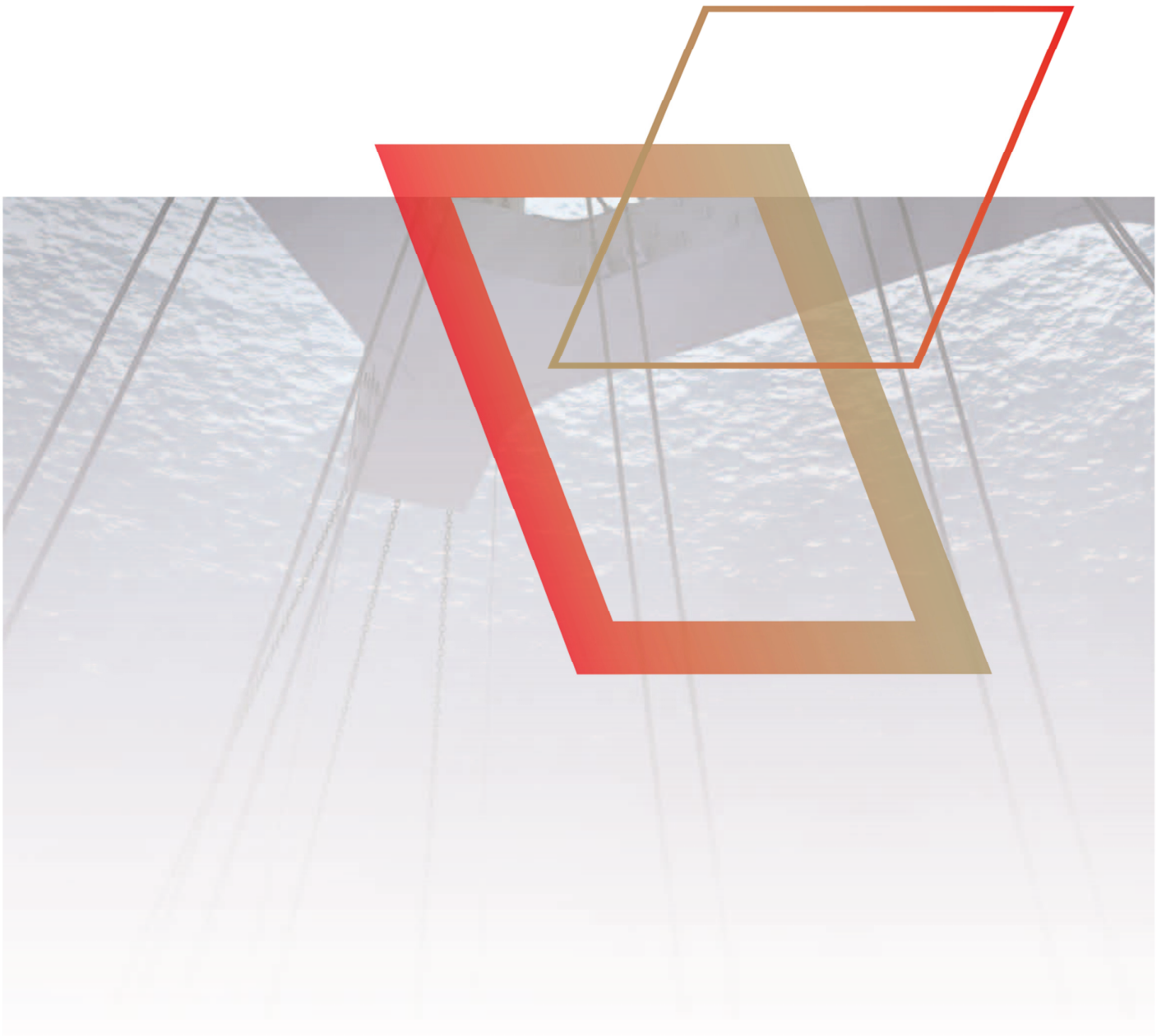
In total, it is estimated that the target total cost is \$USD 100,000. The target number of participants is 10. Therefore, the participation cost would be \$USD 10,000, each. However, if there are more participants, this cost will be reduced accordingly.

6 References

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5. *DNV JIP on Lined and Clad Pipeline Material Activity 3 - Welding and Fracture Capacity*. 2007.
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12. Gordon JR, Zettlemoyer N, Mohr WC. "Crack Driving Force in Pipelines Subjected to Large Strain and Biaxial Stress Conditions", *International Offshore and Polar Engineering Conference*, Lisbon, Portugal, 2007.
13. Yang ZM, Kumar S, Tronskar JP. "ECA of Pipeline with Girth Weld Strength Mis-Matching Subjected to Large Strain", *ASME 2009 28th International Conference on Ocean, Offshore and Arctic Engineering*, Honolulu, Hawaii, USA, 2009.
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15. Paredes M, Wierzbicki T. "Effect of Internal Pressure on Tensile Strain Capacity and Constraint of Defective Pipes using Damage Model", *International Ocean and Polar Engineering Conference*, Kona, Hawaii, USA, 2015.
16. Carlucci A, Bonora N, Ruggiero A, Iannitti G, Testa G. "Integrity Assessment of Clad Pipe Girth Welds", *International Conference on Ocean, Offshore and Arctic Engineering*, San Francisco, California, USA, 2014.
17. Liu M, Wang YY, Song Y, Horsley D, Nanney S. "Multi-Tier Tensile Strain Models for Strain-Based Design Part 2 - Development and Formulation of Tensile Strain Capacity Models": *International Pipeline Conference*, Calgary, Alberta, Canada, 2012.
18. Kibey SA, Minnaar K, Issa JA, Gioielli PC. "Effect of Misalignment on the Tensile Strain Capacity of Welded Pipelines", *International Offshore and Polar Engineering Conference*, Vancouver, Canada, 2008.
19. Tomasz K, Aurelien P, Sylvain D. "Fatigue and Fracture Performance of Reeled Mechanically Lined Pipes", *International Offshore and Polar Engineering Conference*, Rhodes, Greece, 2012.
20. Navarro J, Low A, Tran T. "Comparison of Numerical Methods for Strain-based ECA", *International Offshore and Polar Engineering Conference*, St. John's, Canada, 2015.

Appendix A

Terms and Conditions



TERMS OF ENGAGEMENT FOR CONSULTING SERVICES - INTECSEA (EUA) – WOKING

1. (Services) INTECSEA (UK) Limited ("INTECSEA") agrees to provide to you [xxxxxxxxxx] (the "Client") the services described in the accompanying proposal document ("Services"). Unless agreed otherwise in writing, the accompanying proposal document reference [xxxxxxxxxx] ("Proposal"), the attached Scope of Work and these terms and conditions comprise the entire agreement between the parties ("Agreement") and supersede any previous verbal or written communications or representations relating to the same subject matter. For the avoidance of doubt, this Agreement shall not oblige INTECSEA to perform the following types of services (for which a more appropriate form of agreement can be provided) notwithstanding that such types of services may be expressly referred to or may be implied from the Proposal.
 - i) Process guarantees
 - ii) Feasibility studies for use by financiers;
 - iii) Due diligence;
 - iv) Procurement;
 - v) Secondment or staff augmentation;
 - vi) Owner's engineer or check engineering type services;
 - vii) Construction management; or
 - viii) Construction
2. In providing the Services, INTECSEA will exercise the degree of skill, care and diligence which would reasonably and ordinarily be expected from a skilled, competent and experienced professional providing services that are similar to the Services.
3. The Client must, within the time set out in the Proposal, provide INTECSEA with all information necessary for INTECSEA to perform the Services. INTECSEA will not be liable for any loss or damage suffered by the Client or any third party (including, without limitation, delay) caused by incomplete or inaccurate information provided to INTECSEA.
4. Unless otherwise agreed in writing, the Services are provided for the exclusive benefit of the Client and INTECSEA accepts no liability to third parties with respect to the Services. If the Client makes the Services available to any third party, the Client must (i) indemnify INTECSEA from and against all claims, demands, actions, costs, liabilities, expenses, damages and proceedings (including reasonable legal and other associated costs of defending or settling any action or claim) made, suffered or incurred by INTECSEA at the suit of any such third party, and (ii) mark any document (whether electronic or in hard copy) that originates from INTECSEA pursuant to the Services with a clear disclaimer of any liability on the part of INTECSEA to any third party.
5. (Term) This agreement shall commence on the [xxxxxxxxxx] ("Commencement Date") and subject to the provisions of this Agreement, shall continue in force for the period specified in the accompanying proposal, unless terminated in accordance with clause 27.
6. (Acceptance) Acceptance of the Services by the Client shall be given in writing upon client approval of each deliverable, but shall also automatically occur 30 days from the date of INTECSEA's submission of a deliverable, unless the deliverable is notified as being defective in accordance with clause 16.
7. (Payment) The Client agrees to pay INTECSEA for the Services [either on a lump sum or on a schedule of rates basis], as set out in the Proposal, and for any reimbursable expenses (plus 5% on such expenses) as set out in the Proposal, together with any tax due thereon. The Client also agrees to pay INTECSEA for any other amounts related to any variation of Services directed, or agreed to, by the Client.
8. (Escalation) Where this Agreement is in force for a period greater than twelve (12) months, the parties agree that INTECSEA may review and increase its rate by no more than [xx%] at the end of each twelve (12) month period. INTECSEA shall give the Client at least 5 working days written notice of any such increase.
9. All monies payable to INTECSEA for the Services performed must be paid within 30 days of the Client receiving an invoice for the Services. Monies not paid within that period will attract interest until payment at an annual rate of 3% above the base lending rate of the London branch of HSBC (calculated daily from the due date) plus any debt collection fees.
10. If the Client is in breach of any obligation to make payment to INTECSEA, INTECSEA shall be under no obligation to the Client to continue to perform the Services, which will not amount to a waiver of any right to reclaim any unpaid amounts.
11. (Taxes) INTECSEA shall be responsible for the direct payment of all UK income, sales, corporation, excise, use and other UK taxes imposed on INTECSEA and/or its employees and subcontractors in connection with the performance of the services.
12. Unless otherwise stated in the Proposal, the rates and prices set out in the Proposal do not include for the cost of any non-UK taxes, and the rates shall be adjusted accordingly where any non-UK taxes are applicable to the Services or any payments made hereunder, even if such taxes are not identified until after expiry or termination of this Agreement.

Where the Client is required by law to withhold taxes, the Client shall withhold the sums legally due and shall furnish original tax receipts to INTECSEA for all taxes paid by the Client on behalf of INTECSEA. Where the Contract rates have been adjusted to allow for such withholding and INTECSEA subsequently successfully reclaims any foreign tax paid over on its behalf (even if such rebate occurs after the expiry or termination of this Agreement), it shall promptly reimburse the rebated sum to the Client.
13. (Insurance) Each party shall procure and maintain, at its own expense, insurance covering its liabilities arising from this agreement.
14. (Foreign Travel) Where foreign travel is required by INTECSEA in order to perform the Services set out in this Agreement, the Client shall provide:
 - i) all necessary visas, work and resident permits, licences, permissions, currency exchange control permits, custom duties exemption certificates, tax exemption documents or any other license or permit required by INTECSEA for the performance of the services;
 - ii) adequate office accommodation during business trips as reasonably required by INTECSEA for INTECSEA employees engaged on services and secretarial, typing, photocopying, post, telephone, facsimile and e-mail facilities, and courier services and such other services as necessary for the performance of the services; and suitable transport (with drivers if required) for the purposes of INTECSEA employees whilst engaging in the performance of the Services.
15. (Suspension) In the event that any of the governments of the United Kingdom, The United States of America, Canada, Australia or the European Union, recommend all of its citizens to depart from any country within which the Client has required INTECSEA to undertake a business trip, INTECSEA shall have a right to suspend performance of the Services within that country without incurring

TERMS OF ENGAGEMENT FOR CONSULTING SERVICES - INTECSEA (EUA) – WOKING

any liability to the Client as a result of such suspension.

16. (**Liability**) If INTECSEA fails to perform any of the Services in accordance with this Agreement, INTECSEA's sole liability, subject to the limit set out in clause 19 shall be to re-perform the relevant Services at no cost to the Client within a period of six (6) months from Acceptance. The Client shall be solely responsible for the use of any design, information, opinions or advice provided under these Services including any provision of such design, information, opinions or advice to third parties.

17. INTECSEA shall not be liable to make good any defect in the Services due to drawings, designs or specifications not prepared by INTECSEA and/or the work of any other person employed by the Client and/or the use of materials and goods supplied or specified by the Client.

18. Without in any way limiting the foregoing, by entering into this Agreement, the Client acknowledges that the Services (including any reports or documents provided by INTECSEA in the course of performance of or in connection with the Services) are performed and provided by INTECSEA for the exclusive benefit of the Client. The Client acknowledges and agrees that:

- i) INTECSEA accepts no liability to any person other than the Client in respect of any claim arising out of or in connection with the Services (including any reports or documents provided by INTECSEA in the course of performance of or in connection with the Services) or any relationship established by this Agreement whether arising in contract, in tort (including but not limited to negligence), in equity, by operation of statute or under any law or otherwise.
- ii) Any reports or documents provided by INTECSEA in the course of performance of or in connection with the Services have been prepared pursuant to the Scope of Work provided by the Client to INTECSEA and are based on the information that was made available to INTECSEA during the process of preparing said reports or documents.
- iii) INTECSEA does not accept any liability for any reliance on the information provided by the Client or any third party as part of the Services (including that within any reports or documents provided by INTECSEA in the course of performance of or in connection with the Services);

19. INTECSEA's total liability under this Agreement will be limited in aggregate and will not exceed the fees payable to INTECSEA for the Services. INTECSEA will not be liable for any costs or damages due to any delay in performance of the Services, nor any liability (howsoever arising or caused) arising out of or in connection with pollution or contamination.

20. For the avoidance of doubt, INTECSEA's liability will be reduced proportionately to the extent that a breach of this Agreement, breach of a relevant law or negligent act or omission of the Client or its employees, agents or contractors contributed to any claim, action, damage, loss, liability, expense, outgoing or payment.

21. Notwithstanding any other clause in this Agreement, neither party is liable to the other party for any (a) indirect or consequential loss, (b) loss of profits or anticipated profits, opportunity, revenue, goodwill, or contracts or (c) loss of data or (d) loss arising from business interruption, even in each case if INTECSEA has been advised of the possibility of such loss or damage.

22. (**Indemnities**) Client and INTECSEA each agree to indemnify, defend, and hold the other harmless from and against any liability for injury to or death of their respective employees or damage to or loss of use of their respective equipment or property, regardless of the cause or reason

therefore, and regardless of the negligence of the indemnified party. However, nothing in this Agreement shall limit or exclude the liability of either party to the other for death or injury to persons caused by negligence which cannot by law be limited or excluded.

23. The Client will indemnify INTECSEA and its respective subsidiaries and/or affiliates and the officers, agents, employees and authorised representatives of the foregoing from and against any and all claims, demands, suits, actions, legal or administrative proceedings whatsoever and howsoever arising, that are, or may be, made by or on behalf of any third parties and from any losses or damages of any name or nature (including solicitor's costs, expenses and interest) arising therefrom or in connection therewith whether arising before the completion of the Agreement or Services or within six (6) years after completion of the Agreement or the Services and in any manner caused, or claimed to be caused, occasioned or contributed to in whole or in part, by reason of any act, omission fault or negligence (whether active or passive) of the Client, its suppliers, subcontractors or anyone acting or purporting to act under its direction or control or on the Client's behalf.

This indemnity shall expressly include indemnity by the Client to INTECSEA for property damage and injury to or death of any third party including any person who is employed by or acting under the direction or control of the Client, and for any cost incurred or any penalties or fines suffered by INTECSEA pursuant to any statute, law or regulation concerning greenhouse gas emissions, environmental incident or damage and / or pollution, as a result of the provision of Services.

24. (**Intellectual Property**) All rights, title and interest in and to any intellectual property including, without limitation, any copyright, moral right, trade mark, patent, design or any other intellectual property right as well as any discovery, invention, secret, process or improvement in procedure made, developed or discovered by INTECSEA while performing the Services is, and will remain, vested in INTECSEA. INTECSEA agrees to grant to the Client a non-exclusive, irrevocable, world-wide, payment-free licence to use, reproduce, publish, adapt and exploit that intellectual property to the extent necessary to enable the Client to enjoy the full benefit of the Services and for no other purpose.

25. (**Confidentiality**) The parties undertake to keep all information and/or material furnished, derived or created under this Agreement (whether in oral, written or electronic format) confidential and may only disclose any such information and/or material with the prior written approval from the other party or as required by law or the rules of an applicable securities exchange. The parties agree not to use any information and/or material furnished, derived or created under this Agreement for any purpose not expressly permitted under this Agreement.

26. (**Dispute**) If a dispute arises between the Client and INTECSEA, the aggrieved party must (as soon as practicable) notify the other party in writing of the nature of the dispute. Within 7 days of being notified of the dispute, the parties must meet to resolve the dispute. If the parties fail to resolve the dispute after 30 days, either party shall have the option to refer the matter to the English Courts for resolution. Nothing in this clause 26 will prevent any party to a dispute from seeking interlocutory relief in respect of any such dispute.

27. (**Termination**) Unless terminated under clause 27a or 27b, this Agreement ends on the date set out in the Proposal.

- a. Termination for Convenience:
Either party may terminate this Agreement by giving the other party one month's written notice to terminate.

TERMS OF ENGAGEMENT FOR CONSULTING SERVICES - INTECSEA (EUA) – WOKING

- b. Termination for Default:
Either party may terminate this Agreement if the other:
- i) commits a material breach and does not remedy that breach within 30 days of being notified of the breach in writing; or
 - ii) ceases or threatens to cease to carry on the whole or a substantial part of its business;
 - iii) becomes unable to pay its debts as and when they fall due or makes an arrangement or composition with its creditors or an administrator or an administrative receiver or trustee is appointed over all or any of the assets of the defaulting party or the defaulting party goes into liquidation; or
 - iv) is the subject of the commencement of any bankruptcy proceedings or the passing of a resolution or presentation of a petition for winding up (which is not dismissed, withdrawn or set aside within 14 days of presentation) or upon the appointment of a receiver over all or any of the assets of the defaulting party or the equivalent process in any other jurisdiction.
28. The expiry or termination of this Agreement for any reason shall not affect:
- i) any rights, obligations and/or liabilities accrued before the date of termination or expiry; or
 - ii) any rights, obligations and/or liabilities expressed to continue in force after and despite expiry or termination.
29. (i) If this Agreement is terminated under clause 27a, or under clause 27b through the default of the Client, then the Client must pay INTECSEA all due fees for Services performed up to and including the date of termination, including any reimbursable expenses and any reasonable and unavoidable costs incurred by INTECSEA as a direct result of the termination.
- (ii) If this Agreement is terminated under clause 27b ii), iii) or iv) for INTECSEA default, then the Client must pay INTECSEA all due fees for Services satisfactorily performed up to and including the date of termination, including reimbursable expenses and any reasonable and unavoidable costs incurred by INTECSEA as a result of the termination.
- Where the termination is under clause 27b i) through default of INTECSEA, where any Services have not been satisfactorily performed, and INTECSEA do not subsequently correct the defect in accordance with clause 16, the Client shall have no obligation to make payment in respect of any defective part of the Services, and shall pay only those sums due for Services that have been satisfactorily performed.
30. (Relationship) INTECSEA is engaged as an independent contractor. Nothing in this Agreement constitutes a relationship of employer and employee, principal and agent, or partnership between INTECSEA and the Client. INTECSEA agrees not hold itself out, in any way so as to bind the Client.
31. (Severability) Each of the provisions contained within this Agreement shall be construed as independent of every other such provision, so that if any provision of this Agreement shall be determined by any competent authority to be illegal, invalid and/or unenforceable then such determination shall not affect any other provision of this Agreement, all of which other provisions shall remain in full force and effect. Notwithstanding the above, if any provision of this Agreement shall be determined to be illegal, invalid and/or unenforceable, but would be illegal, valid and enforceable if amended, the parties shall consult together in good faith and agree the scope and extent of any modification or amendment necessary to render the provision legal, valid and enforceable and so as to give effect as far as possible to the intention of the parties as recorded in this Agreement.
32. (Waiver) A failure or delay by either party to exercise any right or remedy under this Agreement shall not be construed or operate as a waiver of that right or remedy nor shall any single or partial exercise of any right or remedy preclude the further exercise of that right or remedy. A waiver by either party of any breach of or a default under this Agreement shall not be considered a waiver of a preceding or subsequent breach or default. A purported waiver or release under this Agreement is not effective unless it is a specific authorised written waiver or release.
33. (Third Parties) Neither party intends that any term of this Agreement shall be enforceable by virtue of the Contracts (Rights of Third Parties) Act 1999 by any person who is not a party to this Agreement.
34. (Variation) This Agreement may only be varied with the written consent of each party, and the variation shall take effect when it is agreed in writing.
35. (Assignment) Neither party may assign, novate or otherwise deal with any right or obligation under this Agreement (whether in whole or in part).
36. (Governing law) This Agreement is governed by and is to be construed in accordance with the laws of England. Each party irrevocably and unconditionally submits to the non-exclusive jurisdiction of the English courts and any courts which have jurisdiction to hear appeals from any of those courts and waives any right to object to any proceedings being brought in those courts.
37. (Interpretation) In this Agreement:
- (i) a party which comprises of two or more persons/entities means each of them jointly and severally;
 - (ii) the use of the word "include" or its derivative forms do not imply any limitation;
 - (iii) a provision must not be construed against INTECSEA only because it prepared it; and
 - (iv) these terms and conditions will prevail in the event of any ambiguity or inconsistency with the accompanying Proposal, and in the event of conflict, the Proposal takes precedence over the Scope of Work.
38. (Entire Agreement) This Agreement together with the documents referred to herein, sets out the entire agreement and understanding between the parties and supersedes and extinguishes all prior agreements and understandings, any prior drafts and all previous contracts whether or not in writing between the parties in relation to its subject matter. No modification shall be effective unless it is in writing and executed by both parties.
39. (Notices) All notices and communications required or permitted to be given under this agreement to either party shall be sent to the following addresses:
- For Client:**
- Address:**
- Attention:**
- Telephone:**
- Fax:**

**TERMS OF ENGAGEMENT FOR
CONSULTING SERVICES -
INTECSEA (EUA) – WOKING**

Date: / /

For INTECSEA:

Address:

Attention:

Telephone:

Fax:

40. (Bribery) Each party shall:

- (i) co-operate with the other in respect of any requirement of anti-bribery and anti-corruption laws including but not limited to the UK Bribery Act 2010, and
- (ii) co-operate with any reasonable requirement of the other to secure compliance with such legislation, and
- (iii) maintain its own policies and procedures to secure such compliance.

Executed in duplicate as an agreement:

Signed on behalf of INTECSEA (UK) Limited:

Signature

Name

& Title (please print)

Date: / /

Signed by: _____ ("Client")
(please print full company name (i.e. PLC or Ltd, etc.))

by its duly authorised representative:

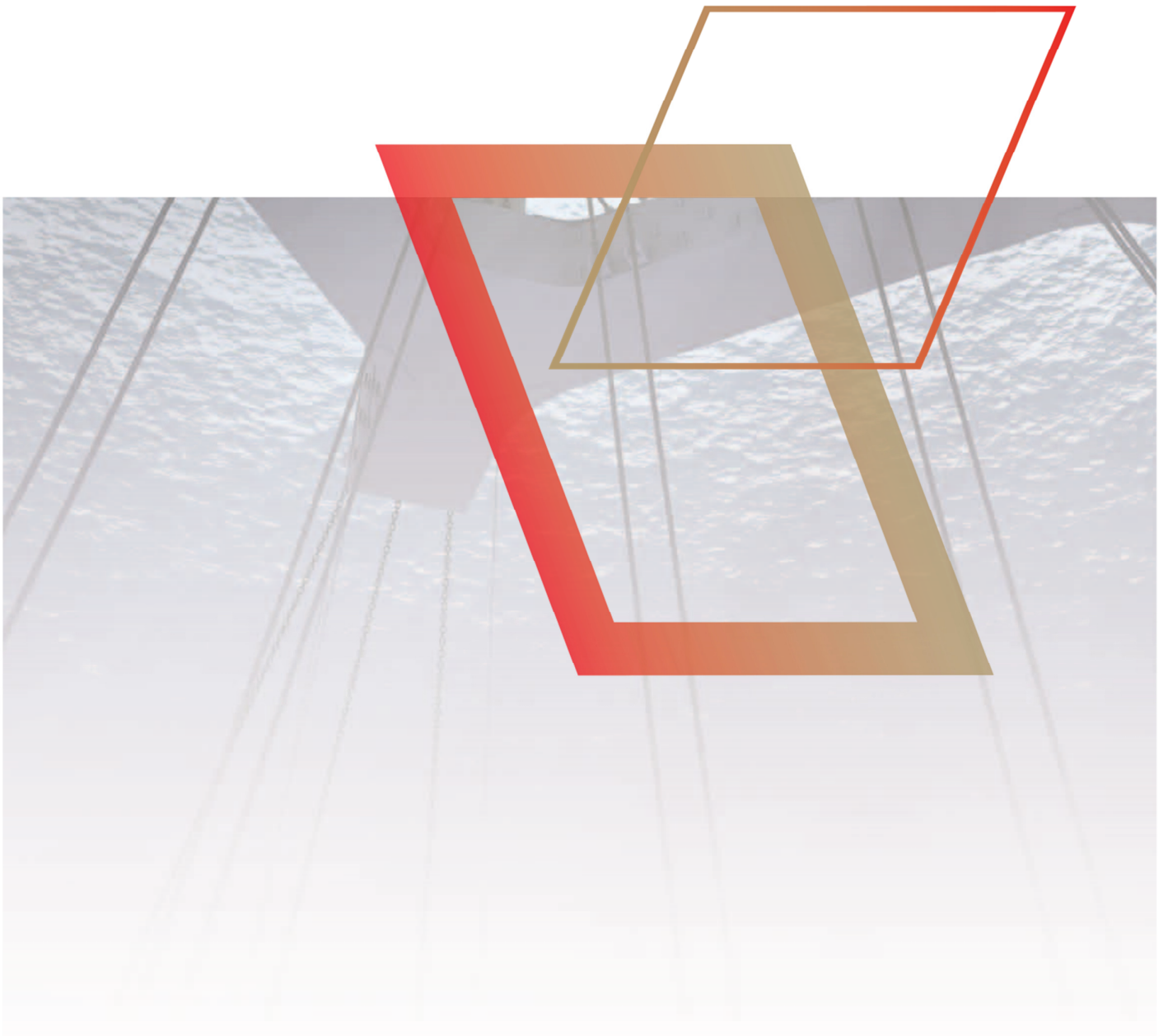
Signature

Name

& Title (please print)

Appendix B

CVs



Andrew Low

Global Technology Director

Overview

In his position of Global technology Director Andrew is responsible for leading technology initiatives for INTECSEA, globally. This includes working closely with our clients and our people to implement key technology and innovation activities which add value to projects and help drive our industry forward. He also works closely with the INTECSEA, Advisian and WorleyParsons Leadership teams to ensure relevance and focus of technology and business objectives, and will lead the Global Technology Committee in facilitating communication and engagement with technology initiatives in offices around the globe.

Andrew brings over 15 years' experience in offshore oil and gas research and development and technical engineering management to INTECSEA. He has been engaged in multiple offshore developments where innovative engineering solutions were required to be deployed in areas of subsea pipelines, risers, welding, materials, advanced analysis and structural integrity to meet client requirements and successful technical delivery.

Prior to his role as Global Technology Director Andrew has held multiple management roles including technology Manager, Deputy Engineering Manager (UK), Chief Engineer for Materials and Welding, Chief Engineer for Advanced Analysis and Chief Engineer Asset Integrity.

Areas of Expertise

- | | |
|---|------------------------------|
| ▪ Technology and People Management | ▪ CRA Material Technology |
| ▪ Fatigue and Fracture of Offshore Structures | ▪ Specialist Team Leadership |
| ▪ Collaborative Project Management | ▪ HP/HT Pipeline Engineering |

Relevant Experience

Technical Advisor | Ichthys Production Line – Fatigue & Fracture – Offshore – Perth Australia | Detailed Design/Execution | HMC/MDR | 2013 to 15

- Responsible for delivering the Fatigue design for Clad (or Lined) Pipe Subject to Lateral Buckling and Sour Service for Ichthys project.

Technical Advisor | Flowline, Trunkline & Welding Packages Wheatstone Project – Offshore – Perth Australia | Detailed Design/Execution | Chevron | 2012 to 2015

- Working with the flowline team and responsible for overseeing the CRA girth weld integrity requirements when under high strain & high temperature loading and associated qualification program

Technical Advisor | West Nile Delta – Egypt – Offshore – London | FEED | BP | 2010 to Present

- Support and advisory services to flowline, trunkline, materials and welding packages

Technical Advisor | Browse – SCR – Offshore – Houston | Pre-FEED/FEED | Woodside | 2009 - 2010

- Support provided on full scale fatigue qualification program of pipe

Andrew Low

Technology Manager

Subsea Project Engineer | USAN – SURF – Offshore – Nigeria | EPCI | Total | 2008 - 2009

- Subsea Engineer on the USAN oil offloading system to achieve decoupled fatigue performance through flexible hose design and qualification, also active within the FPSO anchoring and flowline packages. Andrew acted as technical lead for anchor pad eye and subsea mooring connectors on FPSO anchoring system and bonded flexible hoses, linepipe, buoyancy modules, fatigue qualification and fracture program on Offloading system.
- Andrew was the technical lead for the swage weld pipe in pipe ECA methodology for the flowline package using reference stress solutions and stress intensity factors via cracked and uncracked FEA models under required load scenarios to develop flaw acceptance criteria for UT inspection

Programme Manager | Structural Integrity Group | Multiple | 2006 - 2007

Andrew was responsible for maintaining and developing the portfolio of joint industry projects within the technology group and also the Oil & Gas industry sector. The primary focus was to develop new areas for O&G research to benefit TWI industrial members

Qualifications & Affiliations

- BEng (Honours) Degree in Mechanical & Design Engineering
- CEng Engineering Council UK
- EurIng European Federation of national Engineering Association

Publications/Presentations

- Low A., Speck J., Dacre A.: Validating the integrity for re-use of a land pipeline. Presented at 7th International symposium, risk, economy and safety, failure minimisation and analysis, Cape Town, South Africa 2006
- Low A., Don S., Mackellar I., Pisarski H, C Geertsen., Dugat P., Kleijne E.: A Simplified Methodology for Fracture Integrity of Cold Formed Pipe-in-Pipe Systems. Presented at ISOPE, Beijing, China 2010
- Low A., Cooper P., Navarro J.: Workmanship Flaw Criteria for HPHT Clad and Lined Pipeline Applications. Presented at OPT Amsterdam 2011
- Low A, Don S, Cooper P.: Strain Capacity of Lined Pipe Girth Welds for HPHT Flowline Applications. Presented at SUT Perth 2011
- Smith A, R Williamson (DNV), A Low.: Ensuring the Integrity of Hot Tap Welded Joints in Lieu of Hydro testing. Offshore Europe, Aberdeen 2011
- Peng DJ, Pak A, Chinello L, Wood T, Low A.: Advances in Multiphase Flow CFD Erosion Analysis, OTC, Houston 2013
- Annan I, Low A, Jones S (BP).: External FBE Pipeline Coatings Under Hot Immersed Conditions, Pipeline Coating, Vienna 2013
- Tran J, Lee Chinyang, Alastair Walker, A Low.: Effect of Weld Material on ECA for Reeled Installation of CRA Clad/Lined pipe, AOG, Perth 2015
- Amadioha, A U, Low A (INTECSEA), R Martin & G Morgan (Element Materials Technology).:HISC

Andrew Low

Technology Manager

Performance Validation of DSS Welds for Large Strain, HT HP Subsea Applications, AOG, Perth 2015

- Navarro, J, Low A.: Comparison of Numerical Methods for Strain Based ECA, OMAE 2015, St Johns.
- Deng J Peng, Low A.: Quantitative Risk Assessment of Downhole Continuous Chemical Injection for Subsea Multiphase Production System, 17th International Conference on Multiphase Technology, Cannes 2015

IT Knowledge & Industry Codes

- Microsoft Office Suite
- Multiple software programs
- DNV OS-F101
- DNV RP F108
- DNV C203
- BS7910,
- BS7608
- BS7448 Parts 1, 2 & 4
- PD5500
- API 5L

Work History

2009 to Present	INTECSEA (UK) Ltd
2007 to 2009	Saipem S.A (Paris)
2001 to 2007	TWI Ltd
1999 to 2001	Scottish Enterprise

Thao (Joe) Tran Diep Phuoc

Senior Engineering Specialist



Overview

Dr. Thao Tran (Joe) is a Senior Engineering Specialist at INTECSEA. He has more than eight years of experience in Finite Element Analysis (FEA), specialized in fatigue, damage/failure analysis and fracture mechanics. He has solid background in fracture mechanics and FEA and significant working experience in Engineering Critical Assessment (ECA) as well as in Fitness-for-Service (FFS) studies.

He has performed ECA and FFS for subsea pipelines, ranging from C-Mn pipes to CRA Clad/Lined pipes, and onshore facilities, such as storage tank and fittings, using various techniques, from using analytical solution approach to developing three-dimensional fracture mechanics-based numerical model.

Dr. Thao Tran (Joe) has extensive experience and in-depth knowledge in ECA software such as Crackwise, Linkpipe and Abaqus. Additionally, he has strong background in structural analysis (both static and dynamics) as well as practical experience in mechanical designs and advanced analysis for subsea pipelines.

Areas of Expertise

- Working experience with Clad/Lined Pipe
- Working experience in Engineering Critical Assessment for pipeline girth welds and seam welds
- Working experience in Fitness-for Service Studies for onshore and offshore facilities
- Strong knowledge in Fatigue, Fracture and Damage analysis
- In-depth understanding of material testings with test results justification and statistical analysis capability
- Experienced FE Analyst and Numerical Modeling
- Working experience of using ABAQUS with ability of writing Python Scripts as well as User Subroutine
- Experienced user with in-depth understanding fracture mechanics softwares such as LinkPipe and CrackWise
- Structural analysis (static and dynamic), steel design, reinforced concrete design, smart structure/material analysis and design

Relevant Experience

Senior Engineering Specialist | INTECSEA | 2012 – Present

Engineer Specialist | Mad Dog Phase 2 | EMAS-AMC | 2015

Provide technical support on ECA and fatigue analysis for Mad Dog Phase 2 project bidding.

- Prepare methodology document for ECA and fatigue analysis for flowlines and risers taking into account effects of large strain due to reeling installation and of accelerated fatigue crack growth due to sour service condition;
- Prepare recommended material testing program for ECA inputs and integrity checks

Thao (Joe) Tran Diep Phuoc

Senior Engineering Specialist

Lead ECA Engineer | Wheatstone | Chevron | 2012 to 2015

Perform ECA design for 14" and 24" Clad/Lined pipeline with partially overmatching girth welds (under high pressure and high temperature during operating condition)

- Perform strain-based ECA design using FEA (i.e. level 3C ECA) for Preliminary and Final ECA design;
- Provide support on weld metal selection and material test program development based on Preliminary ECA results;
- Review WPQ test program and results;
- Determine and optimize tolerable flaw size for the pipelines girth welds;
- Develop ECA program for repair welds;
- Provide training for other team members;
- Provide technical review and QA sections for works done by other members;
- Support the project manager on CTRs and technical issues.

Support Chevron on fracture / damage related issues

- Review ECA design for the 44-inch Trunkline;
- Develop 3D Fracture Mechanics FE models to assess the suitability of flanges, which does not meet the requirements on material properties;
- Review ECA works carried out by other consulting parties;
- Perform ECA for an inline tee with defects detected.

Perform LinkPipe Evaluation Study

- Carry out an evaluation study on LinkPipe by comparing fracture parameters found from LinkPipe Models and 3D FEA Models using Abaqus;
- Collaborate with LinkFTR and SINTEF specialists to clarify and justify LinkPipe technical issues;
- Provided User Suggestions for some improvements of LinkPipe.

Engineering Specialist | Confidential HP/HT Pipeline Project, Australia | Chevron | 2015

Perform FFS Study for 16", 18" and 24" Clad Spools experiencing low Charpy Value only at the location of Fusion Line +5mm.

- Prepare the proposal and CTRs;
- Communicate with clients and support the project manager on technical issues;
- Consolidate the material data and load data and review the original design;
- Consult additional fracture mechanics tests to obtain characteristics fracture resistance properties at the girth weld;
- Perform the FFS study in accordance to DNV-OS-F101 and BS7910;
- Provide technical basis on the acceptance of the welding procedure.

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Engineering Specialist | Confidential HP/HT Pipeline Project, Australia | Chevron | 2015

Perform FFS Study for a CRA Valve missing the application of Post Weld Heat Treated on the CRA welds. This is a highly time constrained task to support the customer's response on an incident. Quick response is required to provide technical basis for Chevron management team to make decision on the rejection of the valve.

- Consolidate the material data and load data and review the original design;
- Perform assessment on the effect of not having the Post Weld Heat Treatment;
- Provide fracture analysis on the valve;
- Provide technical basis on the valve integrity to support the management team's decision;
- Support the risk assessment study.

Lead ECA Engineer | Ichthys | INPEX | 2012 to 2015

Conduct ECA design for 18" clad pipeline with partially overmatching girth weld (under high pressure and high temperature during operating condition)

- Perform strain-based ECA design using FEA (i.e. level 3C ECA) for Preliminary and Final ECA design;
- Perform statistical analysis of material properties and recommend the test program to obtain inputs for ECA;
- Support weld metal selection based on results obtained with the Preliminary ECA;
- Review test results obtained from welding procedure qualifying (WPQ) tests;
- Determine tolerable flaw sizes for the girth weld;
- Provide training to team members and review their works;
- Manage man hours and job distribution;
- Communicate with clients and related parties on Cost, Time, Resources (CTRs) and other technical issues;
- Communicate with other design teams for optimised solutions.

Conduct ECA design for the 12" Clad pipeline to be installed by reeling

- Perform strain-based ECA using FEA (i.e. level 3C ECA) for a clad pipe subjected to large strain during installation, caused by reeling process, and low cycle fatigue during operation, due to lateral buckling;
- Develop displacement controlled fracture mechanics based FEA models for reeling ECA;
- Perform the preliminary ECA to provide rational basis for weld metal selection;
- Provide training and check to team members in Perth and Woking offices;
- Provide technical review for the WPQ test program and test results;
- Support the project manager on CTRs and technical issues.

Engineering Specialist | Confidential Project | Woodside Energy Ltd. | 2014

Fracture Assessment for the storage cylinders at very low temperature.

- Perform the fatigue calculation and fracture analysis for the storage cylinders at low operational temperature (-30°C);
- Perform the Leak-Before-Break assessment for the storage cylinders in the event of blowdown using chilling out temperature (up to -80°C);

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- Perform fracture analysis and sensitivity studies to determine allowable pressure vs. chilling out temperature curve. This curve is then compared to the pressure-temperature blowdown curve to determine if the system is robust;
- Review material test results supplied by the vendors;
- Comments on the integrity of the system.

Engineering Specialist | Fracture Mechanics Assessment of Low Pressure LPG Storage Tank | Wesfarmers LPG Pty Ltd | 2014

Fracture Assessment for LPG storage tanks at low temperature.

- Perform the fatigue calculation and fracture analysis for the storage tanks at low operational temperature (-10°C and -50°C);
- Perform the check to see if the tanks are able to demonstrate Leak-Before-Break condition;
- Review and comment on the life extension of the tanks;
- Provide recommendation on the future inspections.

Engineering Specialist | Fitness-for-service Assessment for Low CVN Flanges and Fittings | Woodside Energy Ltd. | 2013-2014

Fitness-for-Service (FFS) Assessment for the low Charpy Value flanges and fittings use in various Woodside projects.

- Prepare the proposal and CTRs;
- Communicate with clients and support the project manager on technical issues;
- Provide training, QA and reviews on works done by another team member;
- Prepare the 3D FEA-based fracture mechanics models to calculate the crack driving force at the crack tip. Compare the crack driving force to the material fracture resistance obtained from material test;
- Provide rational basis for the decision whether the flanges should be accepted or rejected.

FEA/Pipeline Engineer | INTECSEA, Singapore | 2011 – 2012

FEA Engineer | Bukom SBM 48" Subsea Pipeline Repair Project | Shell Eastern Petroleum | 2012

- Review FE Analysis for 48" #300 Ball Flange.

FEA Engineer | Angola Programme | British Petroleum | 2012

Study Pipe Collapse Capacity subjected to Girth Weld Misalignment.

- Perform FE Analysis to capture the de-rating of Pipe Collapse Capacity caused by girth weld angular misalignment and hi-lo issues.

Pipeline Engineer | Gaolan Island to Lamma Island Subsea Gas Pipeline | Husky China Oil Ltd. | 2012

Feasibility Study of gas pipeline whose length is around 100km.

- Perform mechanical design for Wall Thickness, On-bottom Stability and CP Design;
- Perform anchor protection and outline installation analysis studies

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Pipeline Engineer | Danau and Bubut Gas Field Development Project | Burnei Shell Petroleum | 2012

- Review of ECA report prepared by Installation Contractor for a 23.3km 12.75" gas pipeline.

Pipeline Engineer | Bukom SBM 48" Subsea Pipeline Repair Project | Shell Eastern Petroleum Pte. Ltd | 2012

Design pipeline trench and rock armour to protect the pipeline.

- Numerical verify pipeline protection using trench and rock armour by modeling a 20-tonne anchor drop and drag and its interaction with pipeline protected by trenching and rock backfill;
- Perform Sensitivity Study for the numerical model;
- Perform local buckling check for the pipeline subjected to the pulling force imposed by the anchor's dragging.

FEA Engineer | Black Point Gas Supply Project, Hong Kong | Castle Peak Power Co Ltd | 2011

Conduct optimization study of pipeline protection configuration using trenching and rock backfill.

- Develop in-house numerical model using ABAQUS to model anchor's drop and drag in the seabed and its interaction with pipeline protected by trenching and rock backfill;
- Perform parametric study on trench depth and profile, rock backfill thickness and placements to optimise the configuration of the protection.

Pipeline Engineer | RasGas Barzan Offshore Project, Korea | Hyundai Heavy Industries Co Ltd | 2011

For the detailed engineering of 2 nos. of 32" Gas Export Pipelines, 2 nos. of 24" CRA-Clad Intrafield Pipelines, 1 no. of 4.5" MEG Pipeline, 2 nos. of 3.5" MEG Pipelines

- Performed Checks and MTO for subsea structures such as Steel Sleepers, Drop Object Protection, and Subsea Cable Crossing Bridge;
- Design and Check for Concrete Sleepers;
- Perform Spanning Analysis for MEG Risers;
- Perform Checks and Sensitivity Study for ECA reports;
- Perform Optimization Study for Pipeline Global Buckling.

Research Scholar | National University of Singapore | 2007 – 2011

- Conduct research in partial fulfillment of a Ph.D. degree in the topic of "Quasi-brittle self-healing material: Numerical modeling and applications in civil engineering";
- Model and analyse crack propagation in composite materials (micro-level) and structures (macro-level) using ABAQUS;
- Develop, both experimentally and analytically, sustainable and protective reinforced structure by implementing self-healing function in concrete elements;
- Tutor for modules: Material and Structural Steel System, Structural Analysis and Numerical Methods
- Supervise seven undergraduate students for their final year projects

Structural Design Engineer | Bluescope Buildings Vietnam | 2006 – 2007

- Work as a structural design engineer for two steel structure projects: Stada, and Vinh Long markets.

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IA Student | Nagecco – Enterprise 6, Vietnam | 2004 – 2006

- Research on the application of British Standards to Vietnam projects;
- Support design team in Saigon Pearl and Hoan Cau Building Projects.

Qualifications & Affiliations

- Ph.D. in Civil Engineering, National University of Singapore, 2011
- B.Eng. 1st Class Honours Degree in Civil Engineering (First Ranking), Hochiminh City University of Architecture, 2006

Publications/Presentations

- T. Tran, K. Gomez, A. Low, G. Russell (2016). Overmatching in Engineering Critical Assessment from Statistical View Point. *Australian Oil and Gas Conference, AOG 2016, Perth, Australia* (accepted)
- T. Tran, K. Gomez, C. Lee, A. Low (2016). Effect of CRA Layer on Clad Pipe Girth Weld Integrity during Reeling. *Australian Oil and Gas Conference, AOG 2016, Perth, Australia* (accepted)
- D.K. Reeves, T. Tran (2016). Practical Considerations for Standard Flaw Acceptance Criteria on Subsea Pipeline Girth Welds. *Offshore Technology Conference, OTC 2016, Kuala Lumpur, Malaysia* (accepted)
- I. Ripoll, T. Tran, W. Heaps, C. Sicilia, A. Low (2015). Automation of Engineering Critical Assessments in Subsea Pipelines using ABAQUS. *Abaqus UK Regional User Meeting, Cheshire, UK*
- L. Chinello, T. Tran, I. Ripoll, A. Low, D. Lee (2015). Improved Approach to Assessing the Weld Integrity of High Risk Deepwater Pipelines. *Deep Offshore Technology International, DOT 2015, Texas, Houston, USA*
- J. Navarro, A. Low, T. Tran. (2015). Comparison of Numerical Methods for Strain Based ECA. *Proceedings of the ASME 2015 34th International Conference on Ocean, Offshore and Arctic Engineering, OMAE 2015, St. John's, Newfoundland, Canada*
- T. Tran, C. Lee, A. Walker (2015). Effect of Weld Material on the ECA for Reeled Installation of CRA Clad/Lined Pipe. *Australian Oil and Gas Conference, AOG 2015, Perth, Australia*
- T. Tran, A. Walker (2014). Defect Evaluation using Advanced ECA. *Woodside Pipeline Forum, Perth, Australia*
- T. Tran, S.D. Pang, S.T. Quek (2011). Does representative volume element exist for quasi-brittle materials? *Material Science and Engineering: Part A*
- S.D. Pang, T. Tran, S.T. Quek (2011). Self-healing concrete structural members. *The 3rd International Conference on Self-Healing Materials – June 27-29, 2011, Bath, UK*
- S.D. Pang, T. Tran, S.T. Quek (2011). Numerical simulation of micro-capsule based self-healing materials. *The 3rd International Conference on Self-Healing Materials – June 27-29, 2011, Bath, UK*
- T. Tran, S.D. Pang, S.T. Quek (2009). On implementation of self-healing function in concrete – proof of concept and practical issues. *The 2nd International Conference on Self-Healing Materials – June 28th to July 1st, 2009, Chicago, Illinois USA*
- T. Tran, J. S. Tay, S.T. Quek, S.D. Pang (2009). Implementation of self-healing in concrete – Proof of concept. *The IES Journal Part A: Civil and Structural Engineering*
- T. Tran, S.D. Pang, S.T. Quek (2008). Numerical model to capture the Young's modulus of self-

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healing material. *First American Academy of Mechanics Conference – June 17-20, 2008, New Orleans, USA*

Work History

2012 to Present	Senior Engineering Specialist, INTECSEA, Perth
2011 to 2012	FEA/Pipeline Engineer, INTECSEA, Singapore
2007 to 2011	Research Scholar, National University of Singapore
2006 to 2007	Structural Design Engineer, Bluescope Buildings, Vietnam
2004 to 2006	IA Student, Nagecco, Enterprise Six, Vietnam