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PIPELINEINTELLIGENCE

Joint Industry Project -
Operational Guidance for Avoiding Failures of Spooled Composite Pipelines

Project Participation Fee: $7,500 - $10,000
(variable based upon number of contributors)

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Smart-Project Management Inc. /
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TOKU

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Project Proposal - Operational Guidance for Avoiding Failures of Spooled Composite Pipelines

Smart-Project Management Inc. / Schlumberger - OLGA

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1 PROJECT SUMMARY

1.1 Background & Objectives

This Joint Industry Project (JIP) Proposal has been prepared in response to discussions with both manufacturers and operators of spooled composite pipelines over the past 14-months. These discussions were initially triggered by the ground-breaking realization of a disparity between historical classification of composite pipeline failure causes and the real factors contributing to elevated failure-incident-rates clustered within a small number of production sub-regions throughout western Canada.

The JIP is designed to position operators to reduce and even eliminate future failure events by quantifying the role of detrimental multiphase flow patterns as a previously unrecognized key contributor to composite pipeline failure events. The onset of detrimental transient flow conditions triggers excessive axial and unbalanced buckling forces attributed to severe terrain-induced slugging within multi-phase gathering and water hammer events within high-pressure water injection systems.

Development of time-to-failure vs frequency-of-exposure operating envelopes for detrimental hydraulic slugging and water hammer events will position operators to pin-point high-risk production and / or water injection pipelines. Once identified, high-risk pipelines can be fitted with real-time pressure monitoring devices as a tool to measure the onset of harmful situations and as a tool for evaluating the effectiveness of operational adjustments designed to moderate the severity of the hydraulic events.

1.2 Historical Pipeline Performance:

Preliminary detailed engineering analysis of well and pipeline operating conditions associated with 780 composite pipeline failures in western Canada (2000 – 2020) suggests approximately 85 percent of all failures can be attributed to cyclic exposure to sub-critical unbalanced axial forces triggered by short-duration terrain-induced slugs and water hammer.

Detrimental slugging events are generated during well start-up events exhibiting short-duration production surges and during normal pipeline operations in multi-phase gathering service. Similarly, harmful axial forces and unbalanced bucking forces contribute to failures within water-injection service associated with high-rate back-flow from injection wells coincident with rapid system shutdown events.

The modes of failure for composite pipelines within both services exhibit either; 1) pipeline movement (elongation / bending) followed by rupture; or 2) a shear-like rupture attributed to unbalanced bucking forces concentrated at fixed joints where pipeline movement is otherwise sufficiently constrained.

An increasing trend in pipeline failures suggests a gap in the understanding of key factors contributing to pipeline failures, heightening both the value and urgency for the proposed JIP for all stakeholders.

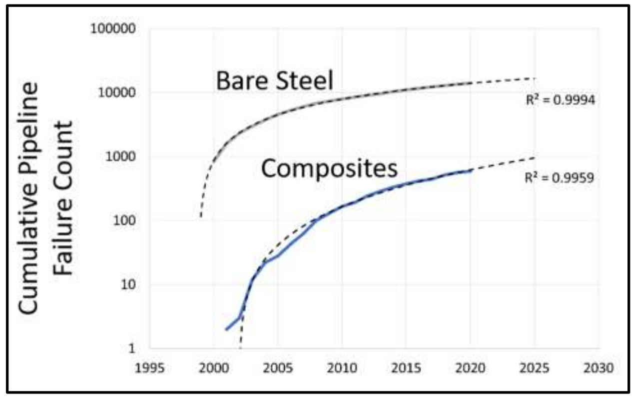

Figure 1.0 - Alberta Cumulative Pipeline Failure Incidents vs Year

1.3 Project Plan

The Schlumberger / OLGA Slug Tracking module will be used to similiuate the transient behaviour of actual pipeline configuration and operating conditions know to have contribute to pipeline failures. Dynamic and static forces associated with transient hydraulic events (terrain-induced slugging and high-rate flow-back from water injection wells) and the associated unbalanced buckling forces applied onto the pipeline structures will be calculated for a range of operating conditions known to cause harm to composite pipeline systems.

OLGA has the unique capability to track each individual slug from formation to either exit from the pipeline or extinction. The model considers dynamic and static forces associated with the mechanisms of slug formation, merging of slugs, growth and decay of slugs and, in particular, the implication of severe transient slugs originating at risers.

1.4 Project Deliverables

1) Quantify the severity of axial and unbalanced forces for a range of terrain-induced slug flow conditions combined with a variety of installation configurations associated with historical failure events for composite pipelines.

2) Create a suite of operating envelopes defining the severity of terrain-induced slugging vs frequency-of-exposure most likely to cause pipeline failures; for multi-phase production and high-pressure water injection service.

3) Publish a likelihood-of-failure model for incorporation into corporate risk assessment tools so operators can pin-point problematic pipelines for installation of pressure monitoring devices as a tool to characterize detrimental operating conditions and for evaluating the effectivenss of operating changes designed to moderate exposure to harmful conditions.

1.5 Project Participation and Schedule

The cost for participation in the JIP is $10,000, with a potential discounted price of $7,500 (conditional upon the number of participating companies). The Project will be completed within 60-days after securing a minimum of five participants. The results of the JIP will be held confidential among the participating companies.

2 THE INDUSTRY CHALLENGE

Discussions with manufacturers of composite pipeline products and operating companies experiencing failure events was initially prompted in December 2019 by an observation that a clustered spatial distribution exists for composite pipeline failures within a small number of production regions, and the patterns are nearly identical to the pattern for bare steel pipeline failures.

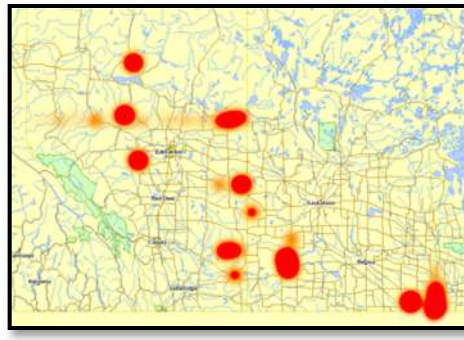

Figure 2.0 - Skewed Failure Distribution Shared by Steel and Composite Pipelines

Sharing of spatial patterns is consistent for both production gathering multi-phase pipelines and for water-injection (fresh and produced water) pipelines.

Production Gathering: The shared spatial distribution for steel and composite pipeline failures in production gathering service is skewed towards sub-regions where detrimental well start-up hydraulics (for an identifiable subset of wells) is known to cause issues in steel pipelines.

Based upon the shared spatial distribution of failure events for steel and composite pipeline, it was deduced detrimental well start-up hydraulics is likely to be a significant contributing factor for failures of spooled composite pipelines, especially considering failures outside of these shared sub-regions (an absence of detrimental flow conditions) is a rare occurrence for composite pipeline systems.

Figure 3.0 – Failure by High-Rate Back-Flow from Injection Wells

Water-Injection: A similar binary relationship exists between the shared spatial distribution for steel and composite pipeline failures in water-injection service; nearly all composite pipeline failures occur within sub-regions showing elevated failure rates for bare steel water injection pipelines.

Coincident with rapid system shut-in events, sytem-wide hydraulic balancing causes high-rate water back-flow from a subset of injection wells. The ferocious back-flow events cause the transfer of excessive axial and unbalanced bucking forces onto connected composite pipelines causing failure-by-rupture.

3 PROJECT EXECUTION PLAN

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WHITECAP RESOURCES INC

Step 1 - Industry Performance Data

- Pipeline failure data (AB / SK)
- Failure investigation reports
- Operating conditions associated with failed pipelines & non-failed pipelines
- T / P / daily flow rate data
- physical pipeline configuration / as-built isometric drawings

Schlumberger OLGA

OLGA
Multi-Phase Transient Modelling Group

Step 2A – Create Pipeline Models

- Prepare a collection of physical pipeline models representative of typical pipeline installation configurations for multiphase gathering and water injection services

Step 2B – Prepare Modelling Strategy

- Prepare a modelling strategy to be applied onto each physical pipeline configuration representative of the spectrum of operating conditions associated with historical failure events

Step 3 – Execute Pipeline Modelling / Baseline Conditions

- Execute pipeline modelling projects for detrimental operating conditions

Step 4 – Execute Pipeline Modelling / Define Detrimental Operating Envelopes

- Implement an iterative modelling strategy that manipulates operating conditions to establish safe operating boundaries for each pipeline configuration necessary to avoid inflicting harm onto composite pipelines

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Project Report / Communication of Results

Step 5 – Project Report – Summary of Findings / Safe Operating Guidelines

- Publish a suite of operating envelopes and boundary conditions that define the frequency-of-exposure vs severity of terrain-induced slugging necessary to prevent failure of composite pipelines; multiphase production; and water injection service.
- Publish a quantitative likelihood-of-failure calculation model for incorporation into corporate risk assessment tools.

4 PROJECT TEAM - QUALIFICATIONS

Schlumberger

Tena McCarthy, Business Development, Production Engineering at Schlumberger Software / JIP Coordinator – OLGA Modelling Group

- 35 years of client support and project coordination in the field of pipeline hydraulic modelling;

Carlos Magno Nascimento, Petroleum Engineer, P.Eng.

- Petroleum Engineer with more than 18 years of experience in multiphase flow simulations, mainly transient analysis using OLGA simulator, for flow assurance studies, artificial lift methods design (e.g., gas lift, ESP, Plunger Lift, and Jet Pump) and to evaluate new technologies (e.g., Subsea separators and multiphase pump) for both conventional (offshore and onshore) and unconventional applications(e.g., SAGD, Shale Gas and Geothermal wells).
- Considerable experience in pipeline flow studies (e.g., gas condensate, steam, steam-oil-gas, sand transportation and deposition) teaching in flow simulations courses (e.g., OLGA and PIPESIM) and developing computational tools to help engineers with oil and gas production issues.

Smart-Project Management Inc. / Trusted Pipeline Advisor

David Richardson, P.Eng. / JIP Project Manager

- Recognized as a global technology leader and innovator in the field of pipeline integrity hazard characterization through collaboration with international, multi- disciplinary teams in the field of pipeline hydraulic modelling and corrosion science;
- Developed enhanced spatial data model (TRIAGE) for upstream oil and gas pipeline networks including application of complex data pattern analytical methods for characterization of over-life internal corrosion hazard conditions as a foundation for effective integrity management strategies including mitigation, monitoring, and optimized in-line inspection programs;
- Developed quantitative Q-ICDA internal corrosion threat assessment method incorporated by Interstate Natural Gas Association of America (INGAA) Washington, D.C. (2002 – 2003) as the technical foundation for ICDA standards for wet-gas and normally dry-gas pipelines, later evolving (in a simplified form) into NACE – ICDA standard methods;
- Provider of integrity hazard classification and mitigation services proven to reduce, and often eliminate internal corrosion failures with substantial reduced operating expense.

5 PROJECT SUMMARY STATEMENT

This Proposal for a strategic JIP is designed to position participating companies with an industry-leading hazard identification model designed to complement their existing corporate risk assessment and hazard mitigation programs.

The encouraging outcome of the JIP is that participating oil and gas operating companies will be able to; 1) identify their most vulnerable composite pipelines; 2) pin-point locations for on-line pressure monitoring to establish the severity of detrimental flow conditions contributing to a potential failure; and 3) apply ongoing pressure monitoring of vulnerable pipelines to evaluate the effectiveness of operating practices designed to avoid exposure to detrimental flow conditions.

If successful, the JIP will contribute to a rapid measurable reduction in the failure incident rates for composite pipelines in both production gathering and water injection service.

We look forward to hearing feedback on the proposed JIP, and towards working with participating companies on a successful project.

With appreciation of your consideration,

David Richardson, P.Eng.
Sr. Pipeline Integrity Engineer

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Technical Reference Section

Pipeline Failure Re-Classification, Deterioration Mechanisms & Failure Modes

A. RE-CLASSIFICATION OF HISTORICAL FAILURE EVENTS

Even though exposure to detrimental hydraulic behaviour has not been recorded in the public record as the primary cause of any historical composite pipeline failure (western Canada), detailed analysis of operating conditions, preliminary calculation of dynamic and static forces, and observation of actual failure specimens suggests approximately 85 percent (660 of 780 failure events) have been affected by detrimental hydraulic behaviour.

Preliminary calculation of actual dynamic impact forces and subsequent axial and unbalanced buckling forces confirms an irrefutable connection between failure events and cyclic exposure to either; 1) severe terrain-induced slugging in multiphase production service; or 2) high-rate back-flow from water injection wells. Moreover, the absence of composite failures within regions not exhibiting detrimental hydraulic behaviour (and a corresponding absence of steel pipeline failures) adds credence to the hypothesis.

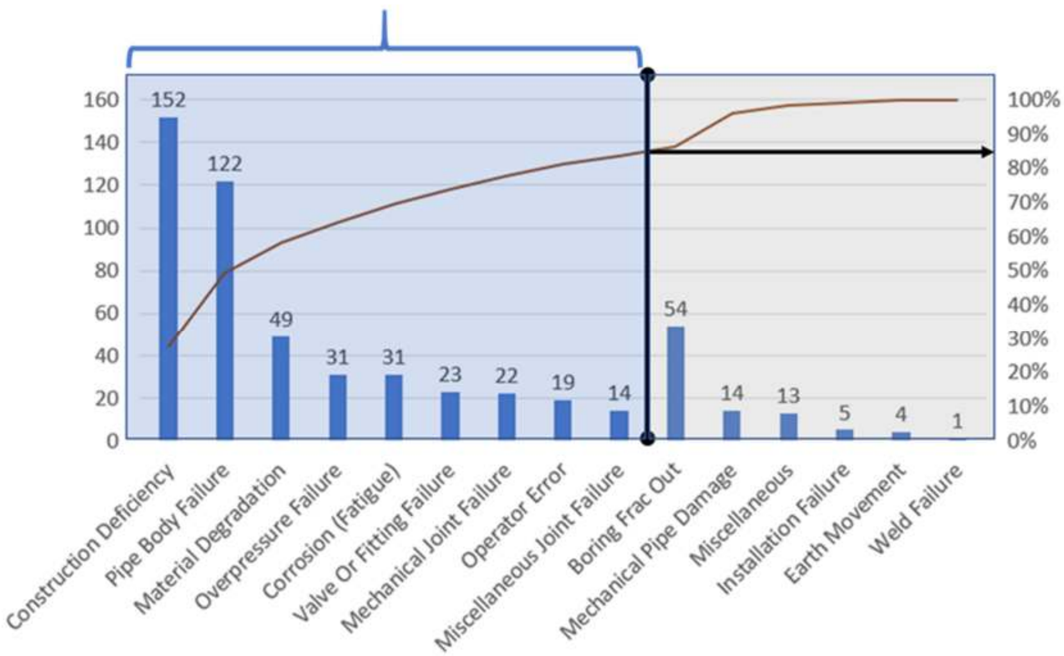

Figure A.1 – Reclassification of Historical Composite Failures Influenced by Cyclic Exposure to Detrimental Hydraulic Behaviour

B. DETERIORATION MECHANISMS AND FAILURE MODES

B.1 The Role of Terrain-Induced Slugs

Terrain-induced slugging is caused by differences in the velocities of the gas and liquid phases. When the relative velocity between the two phases is sufficiently large, waves can form on the surface of the liquid. When the amplitudes of these waves become large enough, they can bridge the diameter of the pipe, resulting in liquid slugs that can travel many-times faster than the steady-state liquid film.

Terrain-induced slug flow is a typical two-phase flow where a wave is picked up periodically by the rapidly moving gas to form a frothy slug, which passes along the pipe at a greater velocity than the average liquid velocity. In this type of flow, slugs can cause severe and, in some cases, dangerous vibrations and impact forces within piping and pipeline systems because of the impact of the high-velocity slugs against fittings such as bends and risers.

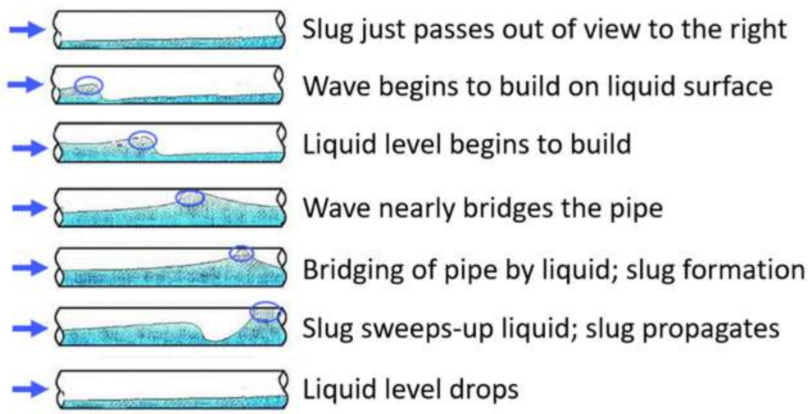

Figure A.2 Terrain-Induced Slugging Mechanism

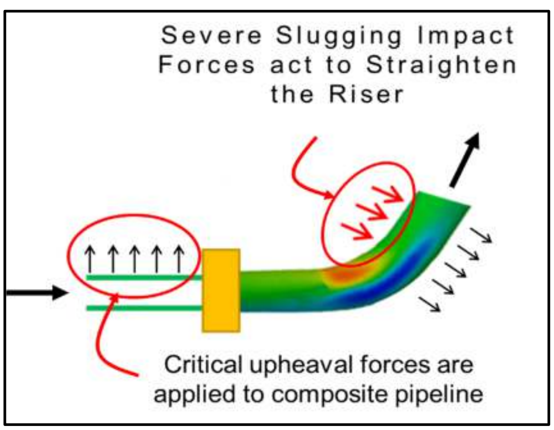

Figure A.3 – Axial & Unbalanced Buckling Forces Generated by Impact of Severe Terrain-Induced Slugging

Like steady-state slug flow, terrain-induced slugs form because of liquid accumulation in the pipeline. In contrast to steady-state slugs, terrain-induced slugs cause the in-situ liquid inventory to be pushed along the pipeline. When terrain-induced slugs travel at an elevated velocity, the momentum of the travelling liquid causes considerable impact forces upon collision with fixed risers or bends with a tendency to elongate the pipeline. For buried / constrained pipelines the applied axial forces translate into bending forces being applied onto the pipeline structure and / or unbalanced buckling forces at fixed riser connections.

B.2 Failure Mechanism – Multiphase Production

Critical unbalanced axial forces result from high-velocity terrain-induced liquid slugs traveling down the pipeline and colliding with fixed risers or bends. The impact force of terrain-induced slugs acts to open-up (straighten) the riser or bend. The resultant axial stresses contribute to a tendency for the pipe to elongate upwards. For buried pipelines, the forces are transmitted as unbalanced upwards buckling forces concentrated at the fixed joint causing pipeline movement and rupture, or rupture at fixed / anchored riser connections.

Repeated exposure to severe terrain-induced slugs contributes to a gradual weakening and fatigue failure of the spiral-wound fibers contributing to eventual rupture of the internal HDPE liner once pressure containment by the fibres is compromised.

In contrast, calculation of applied static forces associated with normal steady-state hydrodynamic slug flow confirms they are insufficient to cause harm; affirming the damage is solely attributed to elevated axial forces triggered by short-duration severe terrain-induced slugging conditions.

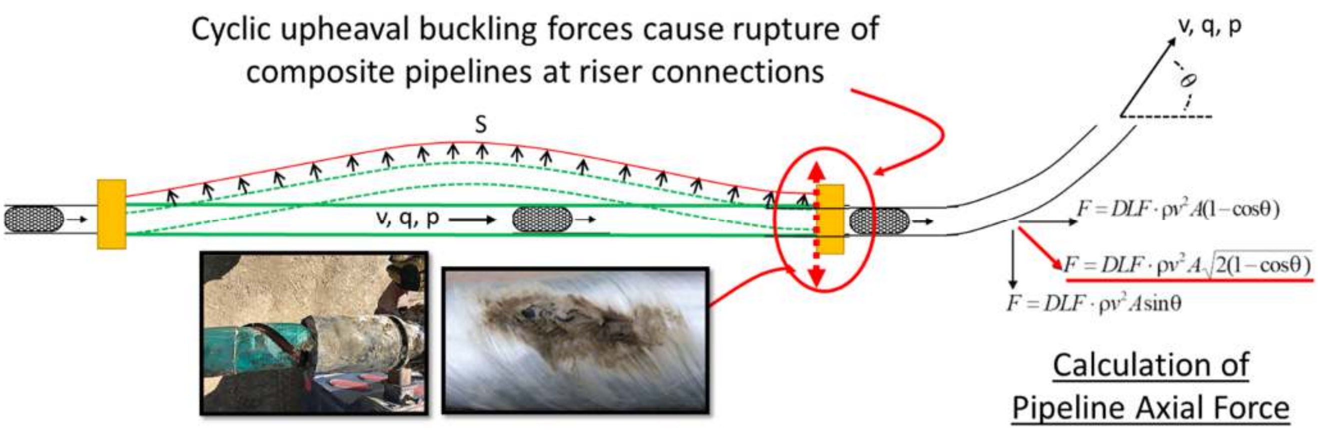

Figure A.4 – Repeated Exposure to Severe Terrain-Induced Slugging Causes Pipeline Elongation and Rupture or Shear-Type Failure at Fixed Joints for Fully Constrained Pipeline Systems

B.3 Pressure Cycles Associated with Terrain-Induced Slug Flow

Severe terrain-induced slugging associated with short-duration production surges at well start-up and during normal pipeline operation trigger transient pressure cycles substantially higher than normal operating pressures, but much lower than the maximum pressure rating for the composite pipeline material.

Calculated axial forces associated with severe slugging at detrimental well start-up events are considered sub-critical vs. physical tensile properties of the spiral-wound fibers, explaining why failures do not occur upon exposure to a single terrain-induced slugging event.

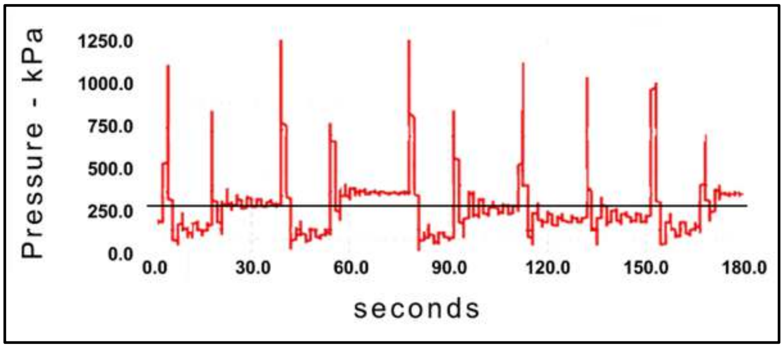

Figure A.5 – Pressure Cycling Associated with Production Surges and Terrain-Induced Slugging

Observed deterioration and breakage of fibers is consistent with a repeated / cyclic exposure to sub-critical axial forces as a root-cause contributing factor to cyclic fatigue failure of composite pipelines.

Figure A.6 – Breakage of Spiral-Wound Fibers Attributed to Cyclic Detrimental Impact Forces

B.4 Failure Mechanism – Water Injection

Detailed investigation of failures supports the conclusion that repeated exposure to sub-critical axial forces associated with water water-injection systems (triggered by rapid injection pump shutdown events) is a root-cause contributing factor to composite pipeline failures.

Similar to severe slugging in production gathering pipelines, rapid changes and elevated water flow-back contributes to the application of critical unbalanced buckling forces at fixed bends and riser connections in water injection service adjacent to the injection well.

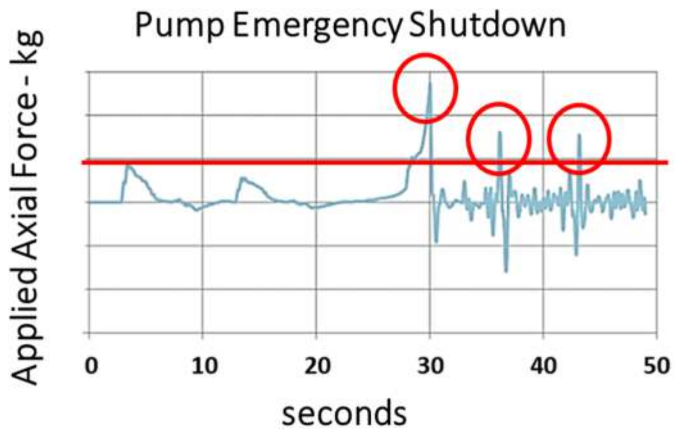

Figure A.7 – Pressure Cycling & Applied Forces Associated with Flow-Back from Water Injection Wells

High-rate flow-back of water from an injection well is a single-phase phenomenon caused by a sudden change in the flow velocity (during an emergency pump trip). High-rate surges in flow-back water rates causes sub-critical impact forces and subsequent critical unbalanced upwards buckling forces at the fixed riser connection as the water impacts the fixed riser or bends.

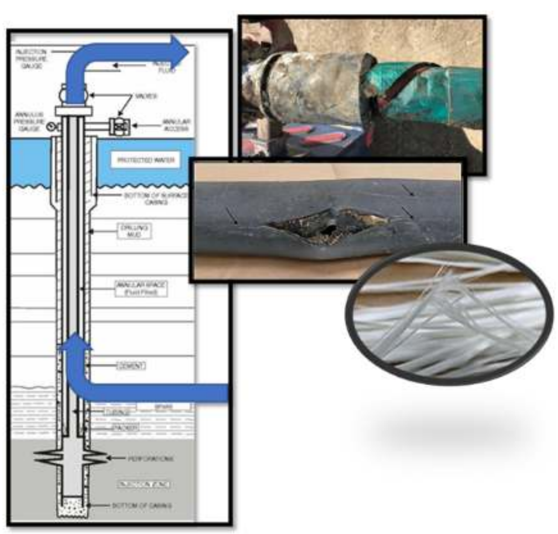

Figure A.8 – High-Rate Flow-Back from Water Injection Wells Triggers Cyclic Forces Contributing to Pipeline Rupture

Like severe slugging, static forces are considered sub-critical vs. physical properties of the spiral-wound fibers suggesting a failure mode based upon a single flow-back event is unlikely to occur.

Observed deterioration and breakage of fibers is consistent with a repeated / cyclic exposure to sub-critical axial forces as a root-cause contributing factor to cyclic fatigue failure of composite pipelines within water injection systems.