Track	Format	ASME Paper Number	Presenting Author Name	Paper Title	Abstract
Track 1: Pipeline Safety Management Systems	On Demand	IPC2020-9374	Karen Collins	How Do I Ensure "Staff Competency" in My Pipeline Safety Management System?	Standards and regulations are clear: all staff who work on pipelines need to be both "competent" and "qualified." Standards such as API 1173 are clear about competen within a safety management system: " The pipeline operator shall ensure that personnel whose responsibilities fall within the scope of the PSMS [Pipeline Safety Management System] have an appropriate level of competence in terms of education, training, knowledge, and experience." The burden of defining and specifying competence falls on pipeline operators, but they have little guidance regarding the required skills, knowledge and levels of competency. Additionally, we are all biased – different operators will have different ideas and emphases on competencies, which will affect their decision-making. The only way to avoid these cognitive biases is to use consensus standards supported by rigorous surveys that capture the required competencies. This paper explores some of the more common biases that can affect decisions and presents the results of a controlled survey aimed at both specifying and quantifying the necessary competencies needed by a specific engineer working within a PSMS: a pipeline integrity engineer. The survey's objective was to investigate the key skills and knowledge requirements needed in a junior engineering position, i.e. a pipeline engineer with less than three years of relevant experience working under supervision to be "competent." It listed eight core competencies (identif by subject-matter experts) considered essential for a pipeline integrity engineer. Each competency contained a set of skills. Respondents were first asked to rank the eight core competences, then rank the skills within the competency. An analysis of the data provides insights into how 100 pipeline integrity engineers from 25 different countries view key skills required to be "competent." The results of the survey can assist pipeline companies in setting objective competency requirements for their engineering personnel, developing learning programs to address any gaps and improve the overall safety of their pipeline syste
Track 1: Pipeline Safety Management Systems	On Demand	IPC2020-9519	Nikhil Joshi	Comparison of Buried Pipeline Crossing Assessments Using Api Rp 1102, Analytical Methods, and Finite Element Approach	API RP 1102 provides a method to calculate stresses in buried pipelines due to surface loads resulting from the encroachment of roads and railroads. The API RP 11(approach is commonly used in the industry, and widely available software allows for quick and easy implementation. However, the approach has several limitations on when it can be used, one of which is that it is limited to pipeline crossing as near to 90° (perpendicular crossing) as practicable. In no case can the crossing be less than 30° degrees. In this paper, the stresses in the buried pipeline under standard highway vehicular loading calculated using the API RP 1102 method are compared with the results of two other methods; an analytical method that accounts for longitudinal and circumferential through wall bending effects, and the finite element method. The benefit of the alternate analytical method is that it is not subject to the limitations of API RP 1102 on crossing alignment or depth. However, this method is still subject to the limitation that the pipeline is straight and at a uniform depth. The fact that it is analytical in nature allows for rapid assessment of a number of pipes and lo configurations. The finite element analysis using a 3D soil box approach offers the greatest flexibility in that pipes with bends or appurtenances can be assessed. However, this approach is time consuming and difficult to apply to multiple loading scenarios. Pipeline crossings between 0° (parallel) and 90° (perpendicular) are evaluated in the assessment reported here, even though these are beyond the scope of API RP 1102. A comparison across the three methods will provide a means to evaluate the level of conservatism, if any, in the API RP 1102 calculation for crossing between 30° and 90°. It also provides a rationale to evaluate whether or not the API RP 1102 calculation can potentially be extended for 0° (parallel) crossing:
Track 1: Pipeline Safety Management Systems	On Demand	IPC2020-9639	Ramon Loback	Pipeline Class Reclassification - Standards Criteria & Best Practices	The expansion of residential and commercial areas and the building of new ventures in Brazil close to gas pipelines may change their class location. As establish by ASME B31.8, alternatives to suit changes in pipeline class relocation are: Reduction of maximum permissible operating pressure; Pipeline replacement; Hydrostatic test or Route redirection away from the population. Those alternatives may not represent effective measures to solve the problem as they would provide a safety margin guarantee only for failure modes associated with time and internal pressure. Hydrostatic testing or pipeline replacement does not reduce likelihood of failure by third party actions due to increased population density. However, the threat that directly increases the likelihood of a pipeline failure due to population densification around the easement range is the threat of third party actions that may voluntarily or involuntarily strike the pipeline. Additionally, Hydrostatic Testing is effective for stable failure mechanisms (eg fabrication failure) and is used after pipeline construction, but there are other actions more suitable for other failure modes. This paper intends to approach the addiditionl mitigation actions that could increase pipeline safety once class location has increased and third party damage is expected to happen more frequently. ASME B31.8S (supplemental to ASME B31.8) does not consider Hydrotesting as an effective measure for integrity management when applied once. For time-independent threats, ASME B31.8S states that Hydrotest is not the appropriate integrity assessment method. Pipeline protection and signaling measures as well as increased frequency of inspections are most effective in reducing the likelihood of damage from third parties. Besides international operators and regulators requirements, this paper will try to capture all industry worldwide best practices on classs relocation consolidating all mitigation actions with usage propos and cons. In this sense will also try to provide some input to facilitate decision making on this top
Track 1: Pipeline Safety Management Systems	On Demand	IPC2020-9762	Brad Raabis	Digital Quality Management System (Qms) Provides Unprecedented Business Improvements and Return on Investment	Digital Quality Management Software (QMS) is easy to explain - QMS takes what was once a long, tedious process of recording and capturing manufacturing ar construction data with pen, paper and spreadsheets, and simplifies it with a paperless system. While the use of it seems simple, the benefits are endless. The digitalization of data collection and analysis leads to not only productivity gains, but access to reliable, real-time reporting and analytics for project managers, manufacturers and contractors. When it comes to pipeline manufacturing and project management, quality is of paramount importance anf creates a competitive advantage. Implementing a digital QMS supports pipeline quality, while also optimizing capital investment costs through lower construction and inspection costs, reduced inventory, and more efficient construction schedules. A poorly managed project or manufactureinmg process can result in penalties for late pipeline delivery, dalayed operating revenue, rework costs, warranty costs, and increased operating costs over the life-cycle of the pipeline. Following on the heels of IPC 2018-78658 "Creating a Digital Pipeline During Pipeline Construction", this paper captures the business improvement and return on investment benefits, as well as indirect change management benefits, resulting from the implementation of the software in the first year. As the sole natural gas delivery provider in Saskatchewan, the company is facing an exponential construction curve over the three year period 2019 to 2021. Compounded by the fact that they are a Crown Corporation facing pressures keep resource levels flat while meeting the growing needs of the residential, commercial and industrial customers in the province, handling the growing workload demanded a new way of doing business. All pipeline operators are facing new and increased regulatory expectations coincident with significant construction growth and supply demand growth, some of these expectations include; 1) Improved documentation using standardized forms and checklists that coincide with CEPA/INGAA based inspection best practices 2) Proof of Quality throgh standardized time stamped and spatially correlated inspection practices. 3) Alignment of the digital QMS with documented inspection quality manuals ato ensure field practices are regulatory requirements dovetail In addition to strengthened return on investment, improved change management was also evident. Some of the beneifts of digital QMS included; -Access to real-time data analytics;; -Optimized utilization of contractor and inspection resources; -Accelerated timing for receiving turnover package for asset data and project information; -Production data available from a single, reliable source; and -Enhanced communication between office construction managment and field inspection staff. Currently digital QMS has been focused on gas line constructi and project management. In the coming years, the use of QMS will expand, becoming a critical tool to drive business improvement across other key departmentts. These will include: -Land Servicees -Legal -Purchasing and Procurement -Facitliy Construction After only one year of use by TransGas, digital QMS has demonstrated success in meeting the challenge of growing a province wide Natural Gas system and in an environment of increasing constraints a
Track 1: Pipeline Safety Management Systems	Track 1.1	IPC2020-9370	Colin Frazer	Api Rp 1173 Third Party Assessments: A Key Industry Tool for Evaluating and Supporting Implementation of Pipeline Safety Management Systems	Since the publication of API Recommended Practice (RP) 1173: Pipeline Safety Management Systems, in July 2015, the energy pipeline trade groups in North Americ (API, AOPL, AGA, INGAA, APGA and CEPA) have worked collaboratively to develop tools and programs to assist energy pipeline operators with the development and implementation of safety management system (SMS) programs and processes. These resources include a Planning Tool, Implementation Tool and Evaluation Tool, as well as an industry developed Maturity Model that describes a continuum of implementation levels. These resources can be supplemented by the voluntary third-party assessment program developed by API. Applying API's experiences with successful safety programs in other segments and with significant contributions from the Pipeline SMS Industry Team, the assessment program is designed to be a key tool to facilitate SMS implementation, share and benchmark information to drive improvements in safety performance. The Assessments also provide the pipeline industry with an objective, third-party option to test their systems and address t conformity auditing (API RP 1173, Section 10.2.2) and performance and maturity evaluation (API RP 1173, Section 10.2.3 to 10.2.5) requirements of the recommended practice. In 2019, pilot assessments were conducted and in 2020 the assessment program will be implemented. Through the piloting process significant insights were gained into the practical application of the industry Maturity Model and how the assessments can contribute to an operator's journey improving safety performance. Aligning with the flexibility and scalability goals of the RP, the pilot experiences included liquids transmission and gas distribution operators with a variety of different approaches to pipeline SMS implementation. This presentation will discuss the lessons learned through the piloting process and how the plan-do-check act cycle was applied to improve the processes for planning, staffing and conducting the assessments to ensure that value is being provided to the pipeline industry. Additional information regarding the tools that will be provided is: · Planning Tool – used to compare an operator's existing management system to the RP requirements and develop action plans and assign responsibilities to close gaps. It is intended to help operators work through the Planning and Developing levels (Level 1 and 2) of maturity · Implementation Tool – used to evaluate and summarize implementation status by expectation (sub-element), element and overall, and helps track development of program implementation to the Implemented-Conforming (Level 3) level of maturity. · The Evaluation Tool – plays two key roles addressing the conformity and effectiveness of the system. Used to report the level of conformity to the requirements, the "shall" statements, of the RP up to Implemented (Level 3) and Sustaining (Level 4) levels of maturity. The Evaluation Tool also provides the means to appraise the effectiveness of an operator's programs at the Improving level (Level 5) of maturity, which includes achieving the objectives of the RP, asking the key question, "Is the system helping and driving improvement
Track 1: Pipeline Safety Management Systems	Track 1.1	IPC2020-9561	Reena Sahney	Investigation and Adoption of Apga's Pipeline Engineer Competency System - the Canadian Experience	With the recognition of demographic change and impacts on the workforce, there is an increased focus on competency management within the pipeline industry.&nbs The Canadian Energy Pipeline Association (CEPA) is a voluntary, non-profit industry association representing major Canadian transmission pipeline companies that has been particularly active in this area. With recent publication of CEPA's guidance document on competency management, CEPA member companies identified a need for a companion set of competency standards for technical staff. As such, the Pipeline Integrity Community of Practice (CoP) within CEPA formed a task group to identify and better understand potential solutions to address this need. The challenge in maturing competency management within the Canadian pipeline industry, as identified by the work group, is twofold: 1. First, the competency system needs to be flexible to address a broad range of topics, operation types as well as a progression of proficiencies (e.g., engineers in training) through to senior level subject matter experts). 2. Second, there is a need for a system that is practical and can be developed / adopted in a relatively short time frame. In undertaking an assessment of the options available in industry, the adoption of the system that has been developed by the Australian Pipeline and Gas Association (APGA) was selected as the optimal path forward. The APGA Pipeline Engineer Competency System (APGA System) provides a mechanism for understanding competency as well as a means of assessing and documenting competency for pipeline engineers. Specifically, industry expert panels were used develop the competency standards which were then published for broad consultation prior to finalizing. Within Australia, the system is now the responsibility of the APGA's Pipeline Engineering Competency System (PECS) Committee for ongoing development, review and maintenance to ensure the system remains current and fit for purpose. One of the key characteristics of the APGA competency standards is the consistency of elements and a standard format for requirements in every stream of pipeline engineering. Further, the APGA System has been demonstrated to be practical and sustainable through use within Australia. The APGA System is now being customized for use in the Canadian Pipeline industry under an agreement announced in October 2019. This paper will provide insights into key aspects of competency system, the approach taken to assess viable options as well as the experience of customizing the APGA system for Canadian use. T system is anticipated to be available for Canadian companies in 2020 and provides a pathway to meeting the two main challenges identified for managing competency in the Canadian industry

Track 2: Project Management, Design, Construction and Environmental Issues	On Demand	IPC2020-9204	Jim Horner	Pump Station Design 2, a Tale of Two Pump Stations	IPC 2014-33740, "Pump Station Design", summarized the work Enbridge had completed on the design and construction of 65 new pump stations and the modification o a further 16 existing stations. The $4.0 billion dollar scope was completed over 12 years, with the last stations being completed in 2019. This paper documents the application of this body of work on the Keystone XL Pipeline project for TC Energy. This work included the design of 32 new pump stations. This project had experienced delays due to legal and regulatory challenges which gave TC Energy the opportunity to reevaluate their pump station design. The previous station design was piping centric and had a significant foot print. The station design developed for Enbridge was equipment centric and owing to the compact layout, presented the potential for cost savings in excess of $140 million for their project. This paper provides a unique perspective with which to evaluate the design philoophies employed by comparing the two station designs developed independantly. While the basic compact design was proven, new work was completed to validate the design. This effort demonstrated that these pump stations are a unique piping subset. The operating temperature is relatively modest, but the piping is exposed to high pressure and high flow rates (HPF). Prolonged operation with high turbulence and pressure can result in fatigue related failures. These HPF systems require additional tools for the pump station piping design. These tools include: · Erosion studies to validate limiting velocities and pipe sizing · Dynamic piping analysis to minimize induced vibrations due to beat frequencies and pressure pulsations · Finite Element Analysis (FEA) of small bore connections to minimize the potential for fatigue related damage. · Computational Fluid Dynamics (CFD) studies to minimize the impact of any turbulence at the pump suction on pump performance
Track 2: Project Management, Design, Construction and Environmental Issues	On Demand	IPC2020-9239	Tran Mah-Paulson	Understanding Why and How Pipeline Companies Enter Foreign Markets, Such as Brazil	This paper provides guidance for all stakeholders interested in investments in the oil and gas pipeline industry in foriegn markets, with an emphasis on substantia investing in Brazil's oil and gas pipeline market, including building new pipelines or puchasing existing pipeline assets. While the paper focuses on Brazil the oil and gas pipeline industry, many lessons can be learned as to why other markets have fleeting investment and how global factors impact where investment or divestment occurs. Brazil is open for business. Over the past several years, the devaluation of the Brazilian real, the creation of a more flexible tax and fiscal reg in Brazil, the shift from protectionist and resource nationalization to market-oriented and resource liberalization policies of South America in general, and the continued expansion of asset divestment plans of Brazil's largest oil producer – Petrobras – has opened up the Brazil oil and gas pipeline industry for substantial foreign investment opportunities. Foreign investors will learn how to avoid failure and enable success. Unfamiliarity with accessing and navigating the underlying structures, systems and business processes in the oil and gas pipeline industry in Brazil can lead potential foreign investors to hesitate and miss strategic opportunities to enter this rapidly evolving market. Learn how to enter the Brazilian pipeline marketplace. This comprehensive overview of the advantages, challenges and approaches to successfully doing business in the Brazil oil and gas pipeline industry will provide prospective foreign investors with ability to successfully enter and navigate this dynamic economy. This papers contains investment guidance and insights on legal, fiscal, taxation, regulatory and business processes in Brazil's oil and gas pipeline sector that executive teams and boards of directors of large financial institutions, such as large oil and gas companies and large financial institutions can utilize to evaluate and execute investments in the oil and gas pipeline sector in Brazil.&nbs
Track 2: Project Management, Design, Construction and Environmental Issues	On Demand	IPC2020-9309	Emma Perez	Relief Tanks: Parameters to Consider When Designing Relief Systems and Connections to Tanks	Oil Storage facilities (terminals) are usually designed with a pressure rating that is lower than the rating of the actual pipeline transporting the fluids. During abnorm operations, piping can be subject to unexpected transient pressure surges. When these surge pressures exceed the allowed operating pressure of the equipment, certain mitigations need to be implemented, and a common one is the installation of a relief system. If a relief valve is installed, it needs to be connected to a tank and the location of this relief tank is critical for the proper operation of the relief system and the overall mitigation of pressure surges. Design of the relief system always needs to take into account the layout of the valve and its associated piping. Many oil storage facilities contain pipes that are installed above ground and when located in northern countries are prone to experiencing cold temperatures during winter months. In part of the terminal where the fluid stays stagnant in the pipes (such as relief piping and manifold pipes) the cold weather can increase the viscosity of the fluid. Added to this issue is the distance that the relieved fluid has to travel from the valve to the tank. If the relief valve activates, the fluid that has been stagnant in the pipe needs to be pushed out of the pipe and into the tank. This will require a high pressure from the system and this value is directly affected by the distance of the pipe and the properties of the stagnant fluid. This paper will present comparisons of how the transient pressures change for various distances between the relief system and the tanks. It will also compare between cases of heavy oils at different temperatures and viscosities. It will show that the pressures required to push this fluid down the pipe increase as the viscosity becomes higher and as the distance from the tank is longer With these findings, engineers can improve their understanding of the effects of temperature and length on surge pressures and they can design safer systems for liqu
Track 2: Project Management, Design, Construction and Environmental Issues	On Demand	IPC2020-9377	Jeremy Fontenault	Assessing Potential Impacts to Waterways From Small Volume Releases Originating From Facilities or Equipment	Enbridge has established stringent reliability targets for oil entering a waterbody. The risks associated with below grade pipelines have been assessed in detail as par their pipeline integrity management program. However, the level of risk associated with above grade facilities and equipment has not been investigated to the same level. As part of an effort to refine the calculated risks associated with these facilities and valve sites, a focus was made on enhancing the consequence calculations with more accurate site-specific information. An approach was developed to assess whether smaller volume releases from these locations may impact nearby waterways following a release. Enbridge identified 150 sites throughout North America where releases had the potential to contaminate a waterbody. In order to confirm/disprove this potential impact to water, hypothetical releases of multiple hydrocarbon products were simulated using oil spill modeling tools to assess the potential overland and downstream transport and fates of the released products. Hypothetical release scenarios were simulated until all of the modeled oil had been released and had either adhered to the land surface, filled a depression in the land surface, and/or evaporated to the atmosphere; or when oil was predicted to enter a perennial waterbody (stre or lake). The goal was to assess the potential for each release to reach a waterbody. A single release was simulated for each site based on a historical maximum volume for a release associated with the specific equipment type (e.g. valves) that could be released over a 24-hour period. Releases were simulated using conditions selected to produce reasonable, conservative results to maximize the potential for the largest volume of oil to enter a waterbody. These conditions were based on the spring season, where rivers and streams would be under some of the highest flow conditions, intermittent streams and waterbodies would contain water feeding larger water bodies, cool air temperatures would reduce evaporative losses, and no snow cover maximize overland transport. This screening level analysis allowed for identification of each location's potential to reach a nearby waterbody under the conservative set of conditions and assumptions. By eliminating sites where oil would not reach a waterbody, Enbridge was able to focus efforts on the highest consequence areas in order to complete more detailed field-level analysis. In regard to spill modeling, more detailed analyses could be conducted in the future to predict the range of possible outcomes from other types of releases and using more site-specific and season-specific data. As an example, slower releases/leak rates, enhanced evaporative losses, a range of environmental conditions, and/or losses to infiltration could be assessed to bound the range of potential impacts
Track 2: Project Management, Design, Construction and Environmental Issues	On Demand	IPC2020-9391	Graeme King	Hot Bitumen Pipeline Valve Replacement: Pipe Prop Anchoring Design With Mechanical Tensioning	A client operates a buried hot bitumen (hotbit) pipeline in northern Alberta and engaged Worley to provide detailed engineering for the replacement of a buried mainli block valve that had failed open. The hotbit pipeline is NPS 24 Grade 483, designed to CSA Z245.1 with a maximum design temperature of 149 0 C. This paper presents unique aspects of the valve replacement design such as its compact layout to meet restrictive space requirements of the right-of-way, and mechanical tensioning of the buried pipeline to return it to its original prestressed condition. An important concept in its original design was that it be "fully restrained" by the surrounding soil so that thermal expansion forces caused by high operating temperatures would be held in check by the restraining strength of the soil. Because it is fully restrained, its high operating temperature causes large axial compressive stresses which pose a risk of upheaval buckling (UHB) and possible loss of containment if the backfill over the pipe is removed. To control the risk of UHB, the hotbit line was preheated to 90 0 C during original construction and allowed to expand freely prior to being backfilled and locked into the surrounding ground in its expanded state. When the pipeline was cut to install the replacement valve, the original prestress was released, and the cut ends of the pipe pulled back on either side of the valve. The lost prestress had to be reinstated to the same level it had when the pipeline was originally constructed so that when the pipeline was returned to hotbit service at 149°C, axial compressive stresses would not exceed the original design values. Because the valve may have failed open due to the large axial compressive stresses applied on it by the buried pipeline, an early design decision was to replace the failed valve with an aboveground valve and aboveground piping with sufficient flexibility to keep axial loads on the valve well within acceptable limits. The design for the aboveground valve replacement featured a structural belowground component referred to as a "pipe prop" which connected the cut ends of the buried pipeline on either side of the valve. The purpose of the pipe prop was twofold. Firstly, it included a unique bolt tensioning system to restore the original level of prestress in the buried portions of the pipeline; and secondly it prevents movement of the belowground pipeline due to changes in pressure and temperature, and therefore significantly reduces the flexibility required in the aboveground piping to accommodate such movements. This permitted the use of a short offset distance in the aboveground piping which in turn reduced the footprint of the aboveground piping, making it small enough to fit within the restrictive boundaries of the site. Strain gauges were installed on the aboveground piping and on the buried piping upstream and downstream of the valve so that the changes in stress when the buried pipeline was first cut could be measured and the stress state of the buried pipeline could be calculated to determine if axial loads applied to the valve by the buried pipeline may have caused it to fail open. The strain gauges were also used to measure the tension in the buried pipeline while it was being prestressed back to its original value by the bolt tensioning system built into the pipe prop. The measurements confirmed that the tensioning was successful. The aboveground piping was then cold sprung at ambient atmospheric temperature to keep stresses in the arms of the aboveground piping loop within the limits allowed by the Canadian Pipeline Standard CSA Z662. The Hotbit pipeline was returned to hotbit service in August 2019 and has operated continuously since that time without furth

Track 2: Project Management, Design, Construction and Environmental Issues	On Demand	IPC2020-9402	Neetu Prasad	Design and Construction Challenges of a Roped Insulated Pipeline	An insulated pipeline poses a unique set of challenges. This paper discusses special features of the design and construction of the polyurethane insulated NPS 20, 1 km long Husky LLB Direct Pipeline, the longest insulated oil pipeline in Canada. The large temperature difference between pipeline installation temperature and maximu design temperature leads to large axial compressive stresses that can cause movement at bends, crushed insulation, increased temperatures at ground surface, loss of restraint, and in the worst case, upheaval buckling and loss of containment. Special design and construction features to deal with these challenges include pipeli prestressing, long radius bends, deeper burial, and pipeline roping. Bending pipe in the field after the insulation has been applied is difficult because it damages the insulation. One solution is to bend the pipe first and then apply the insulation. This is costly, introduces schedule risks and needs to be done in a controlled shop environment. A less costly solution is to rope the pipeline. The construction technique of "roping" gets its name because the ditch is excavated using long radius progressive bends in such a way that the pipeline can be laid in the ditch like a piece of rope and conform to the ditch profile under its own weight without using externa force, or shop bends, or field bends of any kind. Pipeline roping techniques are distinctly different from traditional pipelining techniques. An engineered grade plan and trench profile based on accurate survey data are developed during the design phase along with step by step guidelines for the construction contractor. A key feature of the guidelines is the use of GPS equipped excavators to enable accurate grading of the working surfaces and bottom of ditch profile. Contractor understanding of rop concepts at the early stages of construction planning is key to successful roping. In rugged terrain, where roping required excessive grading, excavation and soil handling, cost optimization called for the use of manufactured bends at specific locations and space constraints at other locations along the ROW required the use of short radius manufactured bends. Options for bending insulated pipe in either the field or the shop were investigated. It was found that bending small diameter pre-insulated pipe in the field was feasible, but larger diameter insulated pipe, like the NPS 20 LLB pipeline with high strength steel, could not be bent in the field without damaging the insulation. The Project therefore used, in addition to roping, a combination of induction bends and cold bends that were shop insulated after bending. Large thermally induced axial compressive stresses in the pipeline applied large forces to the insulation and to the soil at bends and limited the radius of shop fabricated bends. We generally used 25D radius for induction bends, a much longer radius than is normal for induction bends. Cold bends with radii equal to or higher than 75D were used at other locations where space allowed. These shop fabricated bends had to be brought to site ahead of time, and the combination of roping and bending required detailed and systematic logistics management during fabrication, shipping and construction, The selection and development of specification for the insulation system is important. We selected polyurethane foam for insulating the pipeline and used accelerated aging tests to assure the foam would stand up for the 25-year life of the pipeline. Water ingress into urethane foam can seriously reduce its insulative and structural properties and shorten its effective life. A polyethylene jacket was therefore used to provide a water barrier and mechanical protection. At locations of greater stress, higher strength urethane foam with thicker polyethylene jacket were used. Care was taken to design and construct the roped ditch line, the shop fabricated bends, and the insulation system; and close co-ordination with vendors and the construction contractor was crucial for a successful and timely completion.
Track 2: Project Management, Design, Construction and Environmental Issues	On Demand	IPC2020-9661	Mohammad Katebi	Effects of Slope Grade on Soil-Pipe Interaction—full-Scale Experiments	Pipelines are one of the most popular, widely used, and safest ways to transport hydrocarbons over long distances. Most of the pipelines are constructed below t ground surface, and they traverse through various geological and topographic conditions. Permanent ground movements form one of the significant risks to buried pipelines since resulting soil loads can lead to potentially unacceptable strains in the pipelines. Permanent ground displacements arise from slope instability and ground subsidence, including earthquake-induced ground displacements. In the current industry practice, soil-pipe interaction along the buried pipeline is modelled using nonlinear soil springs; currently, the stiffness of these springs is developed based on the assumption of a horizontal ground surface (PRCI 2009). However, there are many cases where the ground surface would not be flat but inclined, and so the stiffness of soil springs is significantly affected by this inclination. A research program was undertaken to study the effects of slope grade on soil-pipeline interaction. Full-Scale tests are performed using the Advanced Soil Pipe Interaction (ASPIRe) Facility at the University of British Columbia (UBC). Three experiments were conducted in the ASPIRe soil chamber [3.8 m (L) x 2.5 m (W) x 2.5 m (H)] to simulate the expected lateral soil pipe interaction at the centre of a landslide in the field; herein, a buried pipe was pulled horizontally to move in an inward direction to the slope. Similarly, a test to simulate the soil pipe interaction in the anchor zones in the field (i.e., outside the sliding zone) was performed by pulling the pipe in a horizontal outward direction to the slope. All experiments are carried out using Fraser River sand as the backfill material and a 300 mm (NPS 12) steel pipe with a buria depth ratio (H/D) of 1.6. Sand backfill was placed and subjected to controlled compaction to achieve uniform soil mass with a surficial grade of 0%, 25% and 40%. The pipe was pulled with cables attached to the hydraulic actuators, and the loads were measured using loadcells; the pipe deformation was monitored using the string potentiometers. Plexiglass panels were used as the front wall of the sand chamber, which enabled us to observe and capture the soil deformation during the pull by a camera. The force-displacement response is normalized to the pipe burial depth, length, diameter and soil density and is presented as normalized p-y curves. These normalized p-y curves are compared to those suggested by current pipeline guideline PRCI (2017) for cases representing the flat ground. The research provides an insight into the characteristic soil pipe interaction that takes place in buried pipeline subject to movements in sloping groun
Track 2: Project Management, Design, Construction and Environmental Issues	On Demand	IPC2020-9673	Kshama Roy	Streamlining the Gis to Cad Workflow for Automated Pipeline Alignment Sheet Generation	Pipeline alignment sheet which is basically a blueprint showing the route including the other existing features and virtually all the engineering that was done during th design phase is a key integral of the pipeline design and construction. It is probably the best asset that a pipeline owner can have for the successful completion of a pipeline project. However, the generation of extremely good quality automated alignment sheets received increased attention in recent years due to the increased errors while done manually. The use of Geographic Information System (GIS) in managing pipeline database and automating routine engineering processes has become a standard practice in the pipeline industry. While maintaining a central database provides security, integrity, and easy management of data throughout the pipeline's lifecycle, GIS enables a spatial analysis of pipeline data in addition to streamlining access and visualization of results for clients. One of the major benefits of GIS integration lies in the ease of automating the alignment sheet generation for pipelines. However, the existing 3 rd -party software packages generally provide the outputs native software format, instead of the much-preferred Computer-Aided Design (CAD) format. In other words, organizations that prepared the data to adopt pre-defined commercial-off-the-shelf (COTS) designs and have little or no control over the design/customization of the alignment sheet's layout. Therefore, a detail investigation is required for the proper integration of GIS and CAD to produce high quality pipeline alignment sheets. This paper introduces a simplified sheet generation workflow that seamlessly blends GIS routines to produce highly-customizable alignment sheets in AutoCAD. The design philosophy is based on (i) separating the processing task from the design task, (ii) giving full control—over the layout—to the data creator/preparer, and (iii) producing state-of-the-art CAD drawings while maximizing the inherent capabilities of the GIS (geo-processing) and AutoCAD (drafting/design) environments. By weaving existing GIS/CAD algorithms and methods to generate the alignment sheet, writing new geoprocessing or drawing algorithms become unnecessary, which in turn minimizes the risks and probabilities of committing any systematic errors arising from newly-untested code. The paper also conducts a parametric study to show the efficiency of the workflow through practical design examples. This is a robust and cost-effective workflow that can easily be adopted by teaming up the GIS and CAD departments/counterpart
Track 2: Project Management, Design, Construction and Environmental Issues	On Demand	IPC2020-9730	Joseph Hlady	Comparison of Remote Sensing Techniques for Centreline and Weld Mapping in Place of Manual Survey in Hazardous Environments	Many places where pipelines are built have soil, basal material and water table conditions which can create suboptimal environments for centerline as-builting and we mapping. Furthermore, ditches containing multiple pipelines can make as-built and weld mapping particularly complex especially when the pipes are of varying sizes. The complexity of the laying in multiple pipes may also result in the ditch being exposed longer than desired, enabling further deterioration of ditch conditio and even flooding. At times, circumstances can become so hazardous that manual survey of the pipeline centerline can only be completed while the pipe is outside of the ditch (requiring a transposition) and a variety of survey techniques must be used to capture the centreline locations. Surveying at a distance from the pipes can make verification to weld mapping and field inspection problematic. Recent advancements in remote sensing, particularly mobile LiDAR and imagery collection technology, have lowered collection and processing costs and expanded the applicability of the technology to complex collection environments and harsh conditions on pipeline construction right-of-ways. Additionally, there has been a marked improvement in overall data accuracy and precision from mobile mapping systems. Up until recently, these technologies have only been useful in static construction environments where periods of inactivity construction afforded the time to set up and collect data in a safe and accurate manner. New remote sensing systems, designed for more rugged, fast-paced, and complex environments are expanding the use of mobile remote sensing to the pipeline construction right of way. These mobile mapping technologies have significant advantages over drone collected data particularly with respect to the logistics of the data collection. Recently, advanced mobile mapping technology was employed on various pipeline construction projects and the accuracy of LiDAR and imagery collection for centerline as-builting and weld mapping was assessed. Some of the project locations were in areas where the traditional manual collection of data could be deemed hazardous or unsafe. This paper evaluates the collection technique against the traditional methods used under hazardous or inaccessible conditions and discusses the benefits of mobile remote sensing for this scenario. The authors also provide an analysis of the remote sensing based as-built and weld mapping data against those acquired through that traditional technique during this trial. Opportunities for adoption of this method as well as improvements to its application are also discusse
Track 2: Project Management, Design, Construction and Environmental Issues	On Demand	IPC2020-9735	Sukhi Gill	4d Inspection: A Comprehensive Platform to Digitize Pipeline Construction Inspection and Generate Data Driven Continuous Improvement	TC Energy operates 92,600 kilometres of natural gas pipelines and 4,900 kilometres of liquids pipelines all while advancing a $30 billion capital program throug 2023. Despite the scale of this capital infrastructure, prior to 2018, essentially all construction inspection reporting was completed using Microsoft Word and Excel documents in a manual workflow. This method of data gathering and validation presented several systemic issues including: delayed construction issue identification and dispositioning, inconsistent quality assurance and control during field construction, no reliable method of data validation, no data standardization or aggregation of critical progress and quality data, and data transferred via unsecure email servers. Beginning in 2018, TC Energy began the implementation of the Dynamic, Digital, Data and Diagnostics platform otherwise known as "4D Inspection". The 4D Inspection platform is intended to evolve inspection reporting to a digital platform to create standardized construction reporting and records embedded with real-time compliance validations for efficient and effective management of field construction issues, progress tracking, and over-all construction quality monitoring. The result is a platform that pursues the following benefits: early identification and resolution of non-compliance issues, efficient access to inspection data for audit and regulatory purposes, consistent and standardized construction inspection processes and data, and data aggregation for automated progress reporting and portfolio-wide data analysis for continuous improvement. Currently, the 4D inspection is nearing the end of its first year of a multi-year implementation plan, the platform is in use on projects in both Canada and the United States spanning four different time zones with more than 465 inspectors on over $7.5 billion in capital projects. This paper will describe the results of this comprehensive effort to digitize pipeline construction inspection as well as the key lessons learned undertaking an effort to drive technology adoption in an area of the pipeline industry with long held cultural norms that make innovative technologies challenging to implement. Leveraging key functionality like automated inspection report document control, simplified photo capture with geo-tagging and automated daily progress reporting and weld logging, 4D Inspection sought to earn adoption with pipeline construction management personnel by improving their daily tasks while simultaneously capturing data that ultimately benefits the corporate operational objective of improved quality. In addition TC Energy overcame the challenge of undertaking an enterprise-wide implementation that met corporate cybersecurity requirements while simultaneously designing a system that operates at the flexibility, rapid pace and remote environments of pipeline construction. There are still more years to come in the full multi-year 4D Inspection Platform implementation plan, but as of this point, it possible to evaluate the platform and claim that it has successfully achieved its intended benefits and continues to add value as the data captured is leveraged to drive continuous improvements for years to come.

Track 2: Project Management, Design, Construction and Environmental Issues	On Demand	IPC2020-9769	Ryan Phillips	Formulation of 3d Soil Springs for Pipe Stress Analyses	This paper will highlight the importance of considering interdependence between pipe-soil interaction springs in a pipe stress analysis. This work focused on single pipe configuration “wished” in place in a clay soil and was sponsored by the International Pipeline Conference Foundation. A conventional pipe stress analyses often idealizes the pipe soil interaction with a beam-spring finite element model where independence is assumed between reactions in axial, lateral and vertical directions. There is however interdependence between these springs as recognized in recent PRCI guidelines. For a frictional interface, axial resistance can be much higher than indicated by PRCI guidelines when accounting for increased lateral and vertical bearing pressure. At the same time, lateral and vertical capacities are shown to be reduced in comparison to pure vertical and lateral loading directions. This paper will highlight the development of a 3D soil-spring interaction model based on a continuum finite element analysis approach. By developing a soil capacity envelope based on 3D continuum modeling, updated soil springs can reflect modified capacities depending on the direction of pipe movement. For the constructed landslide scenarios considered in application of the model, the directional dependency is shown to change the accumulated plastic strain profile in the pipe This paper will highlight the importance of considering interdependence between pipe-soil interaction springs in a pipe stress analysis. This work focused on a single pipe configuration “wished” in place in a clay soil and was sponsored by the International Pipeline Conference Foundation. A conventional pipe stress analyses often idealizes the pipe soil interaction with a beam-spring finite element model where independence is assumed between reactions in axial, lateral and vertical directions. There is however interdependence between these springs as recognized in recent PRCI guidelines. For a frictional interface, axial resistance can be much higher than indicated by PRCI guidelines when accounting for increased lateral and vertical bearing pressure. At the same time, lateral and vertical capacities are shown to be reduced in comparison to pure vertical and lateral loading directions. This paper will highlight the development of a 3D soil-spring interaction model based on a continuum finite element analysis approach. By developing a soil capacity envelope based on 3D continuum modeling, updated soil springs can reflect modified capacities depending on the direction of pipe movement. For the constructed landslide scenarios considered in application of the model, the directional dependency is shown to change the accumulated plas
Track 2: Project Management, Design, Construction and Environmental Issues	Track 2.1	IPC2020-9334	Sheldon Smith	Does Open Cut Pipeline Installation Affect the Geomorphology of Rivers?	Open cut has traditionally been the preferred method of pipeline installation traversing watercourses. It is well understood and accepted that open cut excavation of channel bed and banks during construction causes temporary disturbance to watercourse and aquatic habitat. Horizontal directional drilling, direct push and other subsurface installation methods can potentially avoid channel bed and bank disturbance but may have unique environmental effects such as frac-outs of drilling fluid. Although highly dependent on site conditions, open cut crossings are generally less costly than comparable subsurface installations methods. When a pipeline is installed in an open cut, the pipe is typically installed on gravel or sand bed, laid in place, surrounded by a sand pack and surrounding soils placed back in the cut in a manner that attempts to replicate the soil lithology, horizons and native compaction of the cut. It has long been thought that this sediment and soil disturbance and backfilling has the potential create a zone of geomorphological weakness at the cut where soil and sediment becomes dissimilar to the surround channel bed and banks and can result in acceleration of bed scour, bank erosion, widening and slope instability. In this paper we examine the longer term effects of open cut pipeline installations on the geomorphic characteristics of watercourses. Over the course of four years of field investigation over 900 pipeline watercrossing throughout Ontario were visited and assessed for geomorphic stability and depth of cover. The fluvial geomorphology of Ontario is diverse and ranging from alluvial, sinuous, unconfined, low gradient watercourses in the southwest to karst-influenced morphologies in eastern Ontario and often greater slope, confined and bedrock dominated watercourses in the north. By examining the field-based geomorphological characteristics of pipeline watercourse crossings in Ontario installed by open cut and crossing a wide range of fluvial geomorphological types we will explore and draw statistically-based conclusions on whether open cuts do in fact affect the long term geomorphological conditions of the watercourse.
Track 2: Project Management, Design, Construction and Environmental Issues	Track 2.1	IPC2020-9753	Yong-Yi Wang	Development of Lifting and Lowering-in Plan for the Control of Construction Stresses	Construction of a cross-country pipeline involves lifting the pipeline off the skids and lowering it into the trench (lifting and lowering-in). This can introduce the highe stress magnitude that the pipe may experience over its service life. If not managed properly, overly high stresses may cause integrity issues during construction and/or service. If the girth welds are qualified and accepted using alternative flaw acceptance criteria, such as those in API 1104 Annex A and CSA Z662 Annex K, these stresses must be kept below a preset level during lifting and lowering-in to satisfy the requirements of those standards. This paper covers the development and usage of a stress analysis tool for the continuous lifting and lowering-in of pipe strings without a concrete coating or river weights. The outcome of the stress analysis can be used to develop lifting and lowering-in plans for construction crews. The core functionality of the application tool is to calculate the stresses from bending in the vertical and horizontal planes. The stresses from vertical bending are derived from an extensive analysis of continuous lifting and lowering-in processes. The stresses from horizontal bending are calculated using closed-form analytical solutions. The tool provides a graphical interface that interprets the background stress analysis results and displays information necessary for the development of lifting and lowering-in plans. The tool can be used to evaluate what-if scenarios for various tentative lifting and lowering-in scenarios. The process of using the tool to develop lifting and lowering-in plans is demonstrated in this paper through an example problem. The number of sidebooms a other lifting and lowering-in parameters such as sideboom spacing and lifting height range are changed to make the lifting and lowering-in plan easy to use for the laying contractors. Such tradeoffs can be addressed proactively with construction contractors to ensure that a mutually acceptable approach to lifting and lowering-in is tak
Track 2: Project Management, Design, Construction and Environmental Issues	Track 2.1	IPC2020-9770	Ryan Phillips	Developing a Representative Soil Response Model	This paper will present a multi-year project which has developed a testing procedure and methodology for predicting realistic pipe-soil response curves for differing s types, ditch configurations, backfill age and pipeline construction seasons. Such curves will help to reduce overall pipeline costs and increase the reliability of the pipe soil interaction analyses. Reduced conservatism in definition of springs for pipe-soil interaction should result in use of thinner walled pipelines. Pipe-soil spring response is now generally determined by geotechnical engineering estimation of the soil properties which are used as inputs to pipe-soil interaction models such as ALA (2001) or PRCI (2004). A new dual axis field test procedure, including equipment and interpretative methodology has been developed over the past 4 years for predicting more realistic soil response curves for bearing and shear intertactions. The objective is to advance a new simple field testing protocol from which a direct assessment can be made of pipe-soil spring response, rather than relying on simplified guidelines. This paper will include the field & laboratory testing and associated numerical modelling used in this development, and initial results of trials with the new dual axis test system. The future of this initiative will be a database of generic field test data, from which significant advancements can be made to improving pipe spring recommendations. This paper will present a multi-year project which has developed a testing procedure and methodology for predicting realistic pipe-soil response curves for differing soil types, ditch configurations, backfill age and pipeline construction seasons. Such curves will help to reduce overall pipeline costs and increase the reliability of the pipe soil interaction analyses. Reduced conservatism in definition of springs for pipe-soil interaction should result in use of thinner walled pipelines. Pipe-soil spring response is now generally determined by geotechnical engineering estimation of the soil properties which are used as inputs to pipe-soil interaction models such as ALA (2001) or PRCI (2004). A new dual axis field test procedure, including equipment and interpretative methodology has been developed over the past 4 years for predicting more realistic soil response curves for bearing and shear intertactions. The objective is to advance a new simple field testing protocol from which a direct assessment can be made of pipe-soil spring response, rather than relying on simplified guidelines. This paper will include the field & laboratory testing and associated numerical modelling used in this development, and initial results of trials with the new dual axis test system. The future of this initiative will be a database of generic field test data, from which significant advancements can be made to improving pipe spring recommendations
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9205	Otto Jan Huising	H2 in an Exisiting Natural Gas Pipeline	N.V. Nederlandse Gasunie has converted an existing natural gas pipeline to an gaseous transportation line. The pipeline currently is transporting 70% hydrogen and 3 syngas. this paper will describe all steps taken to convert the existing line and include all elements from material assessment, valve operation, maintenance issues, emergency response control and external safety risk assessment. The paper will review the various hydrogen embrittlement/corrosion mechanisms and will review their applicability in this situation. Based on the review the applicable mechanism, increased fatigue growth rate, will be discussed. Based on the outcome of this review the integrity of the actual pipeline was evaluated. A parallel step was the review of existing guidelines and standards such as EIGA 121/14 hydrogen pipeline systems and ASME B31.12. Since a number of deviations of these standards were found from the requirements of these documents a review was performed of papers on the transportation and use of gaseous hydrogen. This to be able to support the allowance of the deviations found based on research. For the conversion a new part of the pipeline had to be constructed and it was decided to exchange the existing valve stations, this based on uncertainty for their operation and leak tightness under hydrogen service. But to evaluate the necessity for exchange in the future, one of the existing valve station was used for experimental purposes. It has been leak tested and operated under 100% hydrogen conditions. The results of the tests will be discussed in the paper. External safety rules in the Netherlands are more stringent for gaseous hydrogen transportation as for natural gas, these rules where evaluated and any changes in the external safety was addressed. Operation safety was evaluated and subsequent changes in operational procedures where implemented for the involved personal. Safety and emergency procedures where evaluated for the change from natural gas to hydrogen, this resulted in a number of procedures and instructions to be amended to include the new hydrogen pipeline. Currently the line is almost a year in service and the exchange of the valve station seems to be an overly conservative measure. The outlook is in the future a large part of the existing natural gas transmission network will be converted to the transport of hydrogen gas. This to create a hydrogen backbone for industry, transportation and an alternative for other current natural gas use
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9268	Lyndon Lamborn	Near-Neutral Ph Stress Corrosion Cracking Growth Model Trials: Pipeonline	The pipeline industry has long sought a unified near-neutral pH stress corrosion cracking (NNpHSCC) growth model, which fully describes salient growth elements. response to this gap, the Pipeline Research Council International (PRCI) has funded a multi-year research project, partnering with the University of Alberta (Project SCC-2-12). With the project nearing completion, testing of the proposed near neutral pH stress corrosion cracking growth model to an operating pipeline with a known population of stress corrosion crack features is presented. The remaining life of each crack feature detected by crack in-line inspection tools, under known loading, is calculated for several segments of an operating pipeline in North America. Calibration of the length and depth of the ILI feature calls provided by the in-line inspection vendor is reviewed and the efficiency improvements gleaned from calibration are illustrated. While this calibration methodology is unique to the pipeline operator, the method is reviewed to allow other operators to readily implement the technique if found to be beneficial. The model is tested for the raw in-line inspection feature dimensions and the calibrated dimensions and compared to prior growth models. Each of the required inputs is defined and methods of quantification are shown. No-growth thresholds are reviewed and the truncation of stress cycles below growth threshold is discussed and the method of deployment shown, along with the proportion features which are predicted to remain in dormancy. Methods to account for mean stresses and load application frequency are presented. The resulting re-inspection interval is compared to that predicted by typical existing growth models, and then contrasted with excavation results on the asset. Calibration of the governing equation coefficients with rationale for each term is proposed for the pipeline segments examined in the study, and recommendations made for potential implementation for other operators, along with follow-on research. &nbsr

Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9269	Leping Li	Pipe Stress and Deflection During an Integrity Dig	As part of pipeline integrity management, there were on average more than 2900 integrity digs per year in Canada during the decade of 2008–2018, according to t Canadian Energy Pipeline Association. During a pipeline excavation, additional pipe stress and deflection can be produced due to altered soil support beneath the exposed pipe, which might bring in additional integrity concerns. Classical beam theories and soil-spring modeling are inadequate for the complex pipe-soil interactions and boundary conditions. The objective of the present study was to develop a computational model that can be used to predict pipe stress and deflection during an axial strain-relief excavation. The present study was motivated by a recent 40-m NPS 24 pipe strain-relief dig in Alberta, which occurred at a farm land underneath a foreign pipeline crossing. Within the vicinity of crossing location, the peak strain event of 0.16% is reported and suspected to increase the likelihood for occurrence of CSCC. Until the progressing excavation to 12 m, the deflection for exposed section continued to increase due to loss of soil support beneath while the overburden was removed. Eventually, the pipe deflection was reduced at 24-m excavation after abnormal soil constraints were eliminated. The pipe-soil interaction was modeled with 3D finite elements using surface-to-surface contact approximation in ABAQUS. The pipe was assumed to be partially exposed with a minimum 20-m buried length on either end mimic a buried pipeline under excavation. Both static and soil consolidation analyses were performed. Surprisingly, theoretically when the soil support below the buried section was assumed to be 3 m deep, the calculated pipe deflection was one order of magnitude smaller than the measured, even relatively a small soil modulus of 15 MPa was used. The deflection was reduced to 50% if the soil modulus was 50 MPa. However, the calculated deflection increases drastically with the increased soil dep For the pipe with 12-m exposed length, the model predicted a maximum deflection of 62 mm, comparing to 120 mm in measurement, when 8.4-m deep soil support was considered, which was reasonable for the farmland. In conclusion, the depth of soil beneath is a dominant factor in predicting the pipe stress and deflection during an integrity excavation. Furthermore, soil consolidation could increase the pipe deflection by 20-40% in 24 hours, which is also important because an excavation takes a couple of days. The model may be used to estimate the pipe stress and deflection prior to an integrity dig based on the soil type and depth. Keywords: Pipe-soil interaction, soil consolidation, finite element modeling, measurement, intergrity di
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9285	Yannick Beauregard	Assessing Soil Corrosivity for Buried Structural Steel	Corrosion of steel structures in soils has been a topic of industrial research for many decades. The research has shown that the corrosivity of a soil is highly variable an function of numerous interconnected parameters including soil resistivity, moisture content and pH. Despite the complexity of the soil environment, methods to evaluate soil corrosivity and guidelines for corrosion control during the design phase and lifetime of a structure have been developed. An opportunity exists to apply this understanding to optimize the corrosion protection and capital expenses for new projects, e.g., identifying regions of low corrosivity where coatings are not required could lead to cost savings without compromising the integrity of the structure. However, within the industry, there is no universally accepted method to guide such decisions. This work helps address this issue by presenting a literature review and a case study on the topic. The literature review identifies the factors that influence the corrosion of buried steel structures, the range of corrosion rates observed on buried steel structures and quantitative and qualitative methods for assessing soil corrosivity. In the case study, industry standards identified during the literature review (AASHTO R27-01, DIN50929-3:2018, ANSI/AWWA C105/A21.5 and Eurocode 3-5) are applied to evaluate the soil corrosivity of three meter station project sites in Alberta. The structures for which the standards are intended, the information required to apply each standard, and the nature of the results are compared in the case study. Eurocode 3-5 provides corrosion rate estimates for broadly defined soils and was found to not always be conservative relative to the other standards. AASHTO R27-01 and ANSI/AWWA C105/A21.5 provide qualitative soil corrosivity results and prescriptive mitigation strategies whereas DIN50929-3:2018 provides both qualitative and quantitative soil corrosivity results without providing mitigative strategies. A data collection protocol for geotechnical site investigation is recommended to support and improve the assessment of soil corrosivi
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9303	Shawn Laughlin	Full Encirclement Engineered Laminated Steel Sleeve System for Repairs and Augmentation of Pipelines: The Engineering Development, Validation Test Results, and Implications for Mitigation of Both Stress and Strain Dependent Integrity Threats	A full encirclement thin layer steel laminated sleeve system has been designed, developed, and optimized for pipeline integrity management applications. Developme goals included the elimination of thixotropic concerns as well as the exclusion of the degradation of material properties of composite repairs. Elimination of cyclical fatigue of welded repairs and safety concerns associated with hot work were also considerations. The use of thin layer steel with a modulus match to base pipe and steel's homogenous isotropic properties enable axial calculations and evaluation of strain based concerns. The thin layer steel laminated design results in extremely high fracture toughness and promotes intrinsic mitigation of potential future third party damage. The resulting system has demonstrated the reliable engineering data and analysis required for pipeline repairs and demonstrates applicability for the augmentation of existing pipes without defects. An Engineering Critical Assessment (ECA) has been completed. This ECA follows the industry's precedents of ASME B31G and ASME PCC-2 Article 4 type assessments and provides operators with greater functionality. This ECA has been named the Leewis Augmentation Analysis (LAA) and is presented, reviewed, and discussed. Third party full scale ASME PCC-2 style burst testing has been completed. The results are presented. Highly instrumented tests were also conducted to determine an effective modulus of elasticity of the installed system as well as a determination of any delay in system acceptance of load. As installed, an effective modulus of 14 million PSI with loading in layer 3 of the laminate at only 50 micro strain is reviewed. Long term creep and cyclical fatigue testing of the steel/adhesive laminate is presented and reviewed. 10 million cycles at 50% of ultimate lap shear has been achieved, which exceeds current industry practice by several orders of magnitude. The classic metal loss defect mitigation principle is reviewed and updated in light of these available technical advances. Finally, the implications for mitigation of both stress and strain dependent integrity concerns is discusse
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9307	Smitha Koduru	A Bayesian Approach for Effective Use of Multiple Measurements of Crack Depths	An industry-wide database for crack in-line inspection (ILI) data, along with non-destructive examination (NDE) field data, was developed over a series of PRCI proje since 2013. The database can be used to evaluate capabilities of crack ILI technologies, identify potential improvement to ILI tool performance, and guide selection of ILI tools for specific pipelines. As the industry gained experienced in using crack ILI tools, multiple ILI runs were performed for some pipelines, which resulted in multiple depth measurements for the same set of crack features. As part of these projects, two data sets were made available for performing multiple tool run analyses. The first data set included two ILI runs and the corresponding field excavations, and the second data set included three ILI runs and field measurement performed with two different NDE methods. A Bayesian methodology was applied to make effective use of data from multiple ILI runs and field measurements with NDE tools to increase confidence in crack size estimates. Multiple crack depth measurements were used in two different ways— namely, to improve the characterization of ILI sizing error bias and to update the maximum depth distribution of individual crack features. For the ILI sizing bias estimate, the tool sizing error bias was defined as the difference betwe field and ILI measurements. It was shown that using a Bayesian updating approach resulted in a higher confidence in the estimated tool sizing bias in comparison to a simple averaging of the combined data from multiple ILI runs. For the sizing of individual features, Bayesian updating was used to improve estimates of the mean and standard deviation of the depths of individual features. The Bayesian updating procedure increased confidence for the individual feature depths as compared to combining the data into one data set and performing a simple averaging. The approach allows operators to more accurately characterize ILI uncertainties within their crack management program, potentially improving both effectiveness and efficiency. &nbs
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9312	Xinfang Zhang	Failure Pressure Prediction of Cracks in Corrosion Defects Using Xfem	Coating and cathodic protection degradation can result in the generation of several types of flaws in pipelines. With the increasing number of aging pipelines, such defe can constitute serious concerns for pipeline integrity. When flaws are detected in pipelines, it is extremely important to have an accurate assessment of the associated failure pressure which will aid in choosing the approprite integrity decision of repairing or replacing the defected pipelines in a timely manner. Cracks in corrosion (CIC) are an example of defect types that have no agreed upon method of assessment with no existing analytical or numerical models to predict their failure pressure. This paper aims to create validated numerical finite element analysis models that are able to predict the failure pressure of 3D cracks in corrosion defects accurately using the eXtended Finite Element Method (XFEM) technique. Five burst tests of API 5L X60 specimens with different defect depths (varying from 52% to 66%) that are available in the literature were used to calibrate the XFEM damage parameters (the maximum principle strain and the fracture energy) using ABAQUS v.6.16. These parameters were varied until the numerical results matched the experimental results. Symmetry was used to reduce the computation time. A longitudinally oriented CIC defect was placed at the exterior of the pipe. The profile of the corroded area was assumed to be semi-elliptical. The pressure was monotonically increased in the XFEM model until the crack/damage reached the inner surface of the pipe. The extended finite element method (XFEM) was found to be very effective in predicting the failure pressure. In addition, compared to the traditional FEM which requires extremely fine meshes and is impractical in modelling a moving crack, the XFEM is computational efficient while providing accurate predictions. Future studies will investigate the effect of different CIC parameters on the failure pressu
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9328	Michael Turnquist	An Improved Methodology for Prioritizing Pipelines With Respect to Fatigue Seam Weld Cracking	The threat of fatigue seam weld cracking continues to be a primary issue for pipeline operators. Cyclic pressure loading can cause initial manufacturing flaws in a pipeli seam weld to sharpen and grow over time. While this behavior is most prevalent in pre1979 electric resistance welds (ERW) and electric fusion welds (EFW), historical data also shows that submerged arc welds (SAW) have been observed to develop cracks at the toe of the weld, and those cracks have exhibited fatigue growth from transit fatigue, operating pressure cycles, or both. When managing a large pipeline network, it is important to understand which pipelines exhibit higher priority with respect to fatigue seam weld cracking. While there are industry-accepted methodologies used to prioritize pipelines with respect to seam weld integrity (TTO-5 and API 1176 being the most well-known), these methodologies contain some disadvantages when applied specifically to fatigue. TTO-5 was published in 1994 as a way for operators to execute a baseline assessment to determine susceptibility to seam weld cracking. This resulted in many pipelines being identified as "not susceptible". However, the history of seam-related failures since 1994 has shown there is susceptibility for pipe made with any longitudinal seam manufacturing process, and it is no longer appropriate to assume that a seam welded pipe is not susceptible to seam weld cracking, just because it is high frequency ERW for example. API RP 1176 Annex B (published in 2016) provides guidance for the prioritization of pipelines with respect to all seam weld cracking threats associated with ERW and EFW pipe. The intent of this section was to provide a methodology to reprioritize pipelines previously classified as "not susceptible" per TTO-5. However, it is important to note that this methodology is only applicable for ERW and EFW pipe, and it addresses all seam weld cracking threats, not just fatigue. Saudi Aramco and Quest Integrity developed a methodology to determine a ranking of prioritization for a group of pipelines specifically with respect to fatigue seam weld cracking. This improved methodology was developed to consider other data in addition to seam type to rank the likelihood for a fatigue failure to occur. The primary metrics used to determine the prioritization ranking are cyclic pressure aggressiveness, predicted remaining life with respect to recent hydrostatic testing, and the API 1176 Annex B prioritization classification. Together, these metrics consider all contributors to the likelihood of a fatigue failure in the seam weld, including: · Vintage and seam weld type · Operating stress level · Hydrostatic test level · Prior failure history (in-service or during hydrostatic testing) · Cyclic pressure aggressiveness The methodology developed to determine this ranking will be implemented into Saudi Aramco's integrity management program (IMP) such that it can be applied to other pipelines. This will allow Saudi Aramco to prioritize all pipelines specifically with respect to seam weld fatigue crackinc
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9329	Chee Wong	Life Expectancy of Decommissioned Pipelines Under External Corrosion - Probabilistic Modeling	Pipelines form an integral part of energy resource transportation worldwide for over 150 years. The energy resources that are moved around include crude oil and natu gas. The typical service lives of operational pipelines are up to 50-70 years. The existing lines would subsequently be decommissioned and replaced with new lines. Decommissioned lines can be dealt with in two possible ways. The first method involves soil excavation along the existing line right-of-way and the pipe gets extracted. The excavated trench is backfilled at the completion of pipe extraction. The second method involves leaving the decommissioned line untouched in the ground. Despite the latter option being the most economical from a time and effort perspective, there exists uncertainty in the structural integrity of decommissioned lines under external corrosion over time. External corrosion could be local pitting and uniform. In pitting corrosion which is a localized form of corrosion, perforations are produced in the pipe material. Overburden soil has a tendency to migrate into and along the pipe under gravity and hydraulic gradient, thereby causing ground subsidence and possible formation of sinkholes. Uniform corrosion results in continuous thinning of the pipe wall thickness. The weaken pipe section eventually yields and collapses under soil overburden load. This paper introduces reliability-based integrity assessment of decommissioned pipelines that remain in the ground. Two limit state functions are developed to quantify (i) formation of perforations under pitting corrosion, and (ii) thinning of pipe wall thickness under uniform corrosion and initiation of pipe yielding under soil and traffic loading. Corrosion occurrence and growth are modeled as stochastic processes to account for its spatio-temporal uncertainty. The reliability and safe remaining lifetime of an entire pipeline sections are determined using enhanced Monto-Carlo simulations. A sensitivity analysis is performed to identify the governing factors of the life expectancy. The proposed integrity assessment is illustrated on an exampl

Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9335	michael sirois	Advanced Eddy Current Array Tools for Stress Corrosion Cracking Direct Assessment on Pipelines	Advanced Eddy Current Array Tools for Stress Corrosion Cracking Direct Assessment on Pipelines Michael SIROIS*, Mathieu BOUCHARD*, Anne SWEEDY* *Eddyfi Technologies 3425, rue Pierre-Ardouin, Québec (QC) CANADA G1P 0B3 www.eddyfitechnologies.com ABSTRACT Magnetic Particle Inspection (MPI) has been the main reference for Stress Corrosion Cracking (SCC) detection in pipeline integrity for years. Although this technique is relatively economical and easy to deploy – thanks to a large pool of certified technicians – it remains time-consuming and highly user dependent. Some of the factors impacting results during SCC Direct Assessment (SCCDA) include the total surface area requiring examination, hard-to-reach positions underneath pipes during inspection, improper surface preparation due to poor sandblast or contrast, condensation on pipes, and operator fatigue. Recent trials have proved that Eddy Current Array (ECA) technology compares favorably against MPI on many aspects in the field, and that ECA has the potential to become the new standard for SCCDA on pipelines. Offering an impressive speed, combined with a particularly high Probability of Detection (PoD), ECA could transform the work of technicians in ditches and above all, offer greater control over the human factor. Besides detection, ECA has also proved its reliability for SCC characterization on real SCC colonies in both lab and field environments. Comparisons with metallography cuts, grinding measurements and X-Ray Computed Tomography (XCT) data have greatly contributed to optimized depth sizing algorithms for this new solution, providing accurate SCC depth readings. Although ECA and Phased Array Ultrasonic Testing (PAUT) are often complementary techniques in the field, the main advantage of ECA over PAUT resides in the short amount of time required to locate and size the deepest cracks among colonies containing sometimes thousands of cracks. Within a few minutes, technicians and engineers know where to concentrate and how critical SCC really is so that decisions can be made instantly. Combining ease of use and repeatability (ways to control the human factor) is another key benefit of ECA technology. This paper provides information about a complete ECA solution for SCC detection and depth sizing on pipelines. It reveals results from the field, comparing ECA with MPI, covering several key points and demonstrating how ECA stands out as improving the overall screening process efficiency during examinations in digs. Furthermore, it also exposes and compares ECA data with both destructive and non-destructive testing performed on test pieces containing real SCC. Keywords: Non-Destructive Testing, Stress Corrosion Cracking, Direct Assessment, Carbon Steel, Eddy Current Array, Pipeline Integrity, Magnetic Particle Inspecti
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9357	Stijn Hertelé	Crack Driving Force Calculation in Arbitrarily Shaped Defects Based on 3d Non-Destructive Evaluation and Finite Element Analysis	The development of girth weld defect acceptance criteria has been historically influenced by the technological limitations of non-destructive examination (ND technology. The actual shape of a read defect differs from the simplified shapes that are assumed within an engineering critical assessment. Additionally, the re-characterization of interacting defects into one simplified defect is known to introduce conservatism, which may be undesirably large. Ongoing and expected technological advances allow to assume that defect simplification will no longer be required in the future, thus bypassing the uncontrolled conservatism resulting from defect simplification. Advanced NDE techniques such as X-ray CT and full-matrix capture ultrasonics provide three-dimensional (3D) information related to defects and/or pipe and weld surface geometry. A recently finished EPRG project (201/2018) has shown the feasibility of integrating the information provided by 3D NDE systems in finite element models containing arbitrarily shaped defects, obtained by deleting elements within a densely, regularly meshed element grid. This approach eases the model construction as the mesh design becomes independent of the defect geometry. Potential downsides of the approach, however, are inaccurate crack driving force calculations due to the discretized, stepwise nature of the obtained defect geometry, and long computational times. These potential downsides have been scrutinized and a first optimization attempt. Promising results are obtained which, with additional effort, will provide a solid basis for in-the-field application. This paper first reports on the overall procedure of obtaining a defect assessment out of 3D NDE information by means of finite element analysis. Both linear-elastic (e.g. high-cycle fatigue, brittle fracture) and elastic-plastic (e.g. ductile fracture) assessments are considered. Next, the feasibility of coupling the FE model construction with the non-destructive evaluations information is demonstrated for three scans obtained from different sources (one X-ray CT, two by different ultrasonic full matrix capture scan systems). Finally, the paper reflects on concrete opportunities to improve the robustness, speed and accuracy of the methodolo
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9361	Johannes Emil Otto Palmer	Concerted, Computing-Intense Novel Mfl Approach Ensuring Reliability and Reducing the Need for Dig Verification	Magnetic Flux Leakage (MFL) is a robust technology with high data coverage. Decades of continuous sizing improvement allowed for industry-accepted sizing reliabili The continuous optimization of sizing processes ensures useful results in categorizing metal-loss features. However, the identified selection of critical anomalies is not always optimal; sometimes containing anomalies are dug up too early or unnecessarily and, in rare cases, false under-calls can take place. Today, complex empirical formulas together with multifaceted lookup tables, fed by pull tests, synthetic data and dig verifications, machine learning, artificial intelligence, and, not least, human expertise are translating MFL signals into metal-loss assessments with high levels of success. Nevertheless, two important principal elements are limiting the possible MFL sizing optimization. One is the empirical character of the signal interpretation. The other is the implicitly induced data and result simplification. The reason to go this principal route for many years is simple: it is methodologically impossible to directly calculate the metal-source geometry from the signals. In addition, the pure number of possible relevant geometries is so large that simplification is necessary and inevitable. Moreover, the second methodological reason is the ambiguit the signal, defining the metal-loss-sizing target as the most probable solution. However, even under the best conditions, the most probable one is not necessarily the correct one. The paper describes a novel, fundamentally different approach as a basic alternative to the common MFL analysis approach described above. A calculation process is presented, which overcomes the empirical nature of traditional approaches by using a result optimization method that relies on intense computing and avoids any simplification. Additionally, the strategy to overcome MFL ambiguity will be shown. Together with the operator, detailed blind-test examples demonstrate the enormous level of detail, repeatability and accuracy of this groundbreaking technological method with the potential to reduce the need for field verification of ILI-identified corrosion anomalies.
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9373	Jason Skow	Distribution Reliability Assessment Using Machine Learning	This paper describes the results of a project to assess the reliability of a distribution pipeline network in the city of Regina, Saskatchewan. The assessment w used to help prioritize integrity, maintenance and replacement programs for mains and services. It complements existing prioritization programs based on lagging indicators such as leak surveys and slope movement occurrence rates. The model is a historical-based reliability model that aggregates the expected failure rate neighborhood within the city. The neighborhoods were prioritized based on those that have a higher expected failure rate. In cases where recent leak surveys have not detected significant leak rates, the model is used to prioritize neighborhoods with a higher potential for leaks. Failures were categorized into to two groups, human-factor threats and system factor threats because the strategies to mitigate each is driven by differnt activities and personel within the company.&nbs Both leading and lagging indicators are combined to help with resource allocation decisions-making. The model was regressed against a failure database and uses as-build documentation, customer information data, GIS data layers, land plot data sets and work request databases. Failures were classified by failure cause and included field notes describing particular unique circumstances. The model is based on a logistic regression algorithm with machine learning functions that help optimize the regression. It associates the historical failure rate with the asset type, age, pipe material, diameter and pressure. One advantage of the model is the ability estimate the reliability for an area of arbitrary size. For this project, neighborhoods were used as areas of evaluation, but sub-neighborhood sized areas, such as a block-by-block evaluation are also possible. The model was trained using 70% of the data set and then tested with the remaining 30%. This was done to prevent over-fitting and to evaluate the model performance. The details of the model and key data processing steps are described in this paper. The results for a neighborhood by neighborhood assessment are also describe
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9389	Sergio Limon	Vintage Pipeline Steel Fracture Toughness Measurements	In order for the pipeline industry to usher in next-level fracture mechanics engineering analysis, reasonable and prudent fracture toughness characterizations of pipel materials are needed to improve failure pressure predictions and fatigue crack growth analysis of pipelines with planar flaws. Converting Charpy toughness test results to fracture toughness via different correlation models derived throughout the years, while laudable, have inherent shortcomings. The main issues being that the Charpy toughness test is not a fracture mechanics-based measurement and the transferability of sub-scale toughness testing is often not completely understood nor is correctly applied. This paper expands on these shortcomings and presents solutions which are supported by fracture toughness measurement correlations conducted on recent Crack Mouth Opening Displacement (CMOD) measurements obtained from full scale testing of in-weld and base metal vintage pipeline steels. In this manner, best available toughness derivations for mean toughness in base metal and long seam weld are completed exclusively based on full-scale vintage pipe tests. Probabilistic characteristics and error predictions (accuracy and precision) and scatter about the mean for the recommended mean toughness values are presented. Suggestions for standard fracture mechanics coupon testing on pipeline steel samples are delineated with rationale for each test type. Transferability of sub-scale coupon test results to demonstrated full-scale equivalents are shown. This initial vintage pipe steel fracture toughness test database and other similar data sets can be combined and serve as the basis for establishing an industry wide Pipeline Material Database which would mirror established material databases maintained by the aerospace industry such as NASGRO and AFGROW. It is envisioned that a centralized and validated Pipeline Material database will obviate the need for gross material properties assumptions and increase the accuracy of structural integrity predictions of pipelines and improve the overall effectiveness and efficiency of pipeline threat management. Such a database will also facilitate emerging probabilistic methods as population analysis becomes readily accomplished on the pooled da
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9392	Brian Leis	Modelling Stress-Activated Creep at Axial Cracks in Pipelines	A number of major incidents have occurred on pipelines that had recently survived a high-pressure hydrotest, or had recently passed an in-line inspection (ILI).&nbs While uncertainty remains concerning detection and sizing in the context of an ILI, pressure testing is not subject to such concerns. Thus, the failure of a pipeline that had just passed a proof-pressure test as it was being re-pressurized for its return to service (a so-called pressure reversal) reflects the stable growth of a near-critical anomaly that is still stable as the proof test ends. In the same way that stable growth of a near-critical anomaly can lead to a pressure reversal, stable growth can occur but remain stable at the pressure first imposed upon the pipeline's return to service. Scenarios for which time-dependent degradation mechanisms such as corrosion are not plausible causes of failure have been termed time-delayed failures. As pressure reversals occurred during the early years of hydrotesting pipeli understanding emerged regarding a defect's response to pressure, and criteria for a pressure reduction were established to avoid leaks becoming ruptures that in turn could pose issues for company personnel and/or first responders. The advent of tough steels opens to the possibility that such line pipe can sustain deep cracks at high pressures, which in turn opens to the potential for crack initiation and stable tearing of that cracking at service pressures under circumstances that differ from that for the early line pipe steels. Whether cracking remains stable or continues to grow slowly at sustained pressure is a concern regarding long-term integrity management, as well as for company personnel and first-responders called in to deal with a leak from a gas or HVP-liquid pipeline. The 2004 incident at Ghislenghien involving a modern high-toughness X70 pipeline raised the need to better understand how to manage leaks that could become ruptures in such steels. This paper develops a model to quantify the extent of stable tearing and possible instability at axial part-through-wall (PTW) defects as a function of the steel, the length and depth of the defect, and the operating pressure. First, the theoretical basis for the model is developed in terms of nonlinear fracture (NLFM) mechanics analysis for such defects. Thereafter this model is recast for time-marching analysis that is coupled with isochronous stress-strain curves for the X70 steel of interest. As the NLFM solution generalizes handbook results, a finite-element analysis (FEA) of the specific pipe and flaw geometry are used to benchmark that solution. The model then is used to predict cracking and instability in a step-load and hold testing first for a compact-tension (CT) specimen, and then for a pipe containing PTW slits. It is shown that the time-marching scheme leads to accurate blind predictions of the stable tearing in the CT specimen, and for the failure response of the full-scale pipe tests. The predictive results are shown to be consistent with the failure response of full-scale tests under constant pressure leading to delayed failures. Companion papers present the other aspects of this multiyear proje

Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9396	Pablo Cazenave	An Onshore Pipeline Failure Produced by Cathodic-Protection-Induced Hydrogen Cracking – Case Study	A 22-inch onshore natural gas transmission pipeline experienced an in-service rupture on January 2018. The rupture was caused by an axial crack that occurred 150 K (93 miles) downstream of the closest compression station. While the root cause analysis investigation of the rupture was in progress, the pipeline operator carried out excavations starting approximately 42 km (26 miles) downstream of the rupture with the purpose of investigating indications reported by a Hard Spot In-Line Inspection (ILI). These excavations discovered predominantly circumferential crack colonies, with a number of the excavation locations leaking. The pipeline section was constructed in 1960 in the Buenos Aires Province, Argentina, with API 5L X52 steel, with a nominal diameter of 22 inches (558.8 mm) and a nominal thickness of 0.250 inches (6.35 mm). The pipes were fabricated by A.O. Smith (USA), the first 118 Km (74 mi) with longitudinal Electric Flash Welded (EFW) seam weld, the remaining 34 Km (21 mi) with seamless pipe, in both cases with asphaltic coating. The design pressure of the section and the MAOP coincides in 59.8 Kg/cm2 (850 psi, 72% of the SMYS). Transportadora de Gas del Norte (TGN) engaged Blade Energy Partners, Ltd. (Blade) to conduct the root cause analysis investigation, which concluded that the axial and circumferential external cracks found are neither related to high pH SCC, near-neutral pH SCC nor fatigue, that the characteristics of the fracture morphology are consistent with hydrogen cracking, and that the hydrogen is generated by the impressed-current cathodic protection system operated near the -1200 mV pipe-to-soil recommended potential limit. TGN implemented a series of preventive and corrective tasks that included pressure testing, cathodic protection improvement, coating rehabilitation programs and In Line Inspection programs among others. This paper discusses the background and approach used in the root cause investigation, summarizes the methodology, results and findings of the root cause analysis, and discusses their implications in the management of the Pipeline Integrity of the affected pipeline section and of the rest of the pipeline system operated by TGN
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9399	Chike Okoloekwe	Reliability-Based Assessment of Safe Excavation Pressure for Dented Pipelines	Dents or permanent deformations in a pipe result in alteration of its structural response when subjected to internal pressure. Excavation activities further lead to change load and boundary conditions of the pipe segment which may exacerbate the stress state within the dented region. Depending on the severity of a dent, excavation under full operating pressure may lead to failure, injuries or fatalities. While current pipeline regulations require that operators must depressurize a line to ensure safe working conditions during repair activities, there are no detailed guidelines available in the codes or standards on how an operator should determine such a safe excavation pressure (SEP). As a result, the safe excavation process of dents has received attention in the industry in recent years. A detailed review of the recent research on dent SEP showed that the current recommendations are primarily dependent on one of two aspects: careful assessment of inline inspection (ILI) data, or a fitness for purpose (FFP) assessment of the dent feature leveraging numerical models. Enbridge Liquid Pipelines Inc. had previously demonstrated a feature specific assessment approach which incorporated both ILI data and finite element analysis (FEA) to determine the SEP. This assessment also accounted for uncertainties associated with material properties and ILI tool measurement. In the previous publication, the authors demonstrated a methodology for assessing the SEP of dents at a conceptual level from both deterministic and reliability-based standpoints. The authors also indicated that further work was required prior to implementation of this model. In this paper, a validation study has been performed to compare the results of fracture mechanics based FEA models against eleven full scale burst tests available in literature. The study showed good agreement of the burst pressure of dent-crack defects predicted by FEA models with those observed in the full scale tests. The assessment method is further streamlined by incorporating the API 579 Failure Assessment Diagram (FAD) method on an uncracked FEA model as opposed to explicitly modeling the crack geometry during FEA. The results of FEA in conjunction with FAD are compared with the full scale tests to ensure accuracy and conservatism of burst pressure prediction. A reliability-based approach is then designed which accounts for the uncertainties associated with dent and pipe geometry, material properties, and crack dimensions. Three case studies are presented where the reliability-based SEP assessment method has been implemented and feature specific SEP for each case has been recommended to ensure target reliability during excavatior
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9400	Jason Skow	Manufactured Cracks in Pipe Used to Evaluate ILI Measurement Performance	Recently transmission pipeline operators have started designing pipe spools with manufactured cracks of very precise size and orientation for the purposes of qualify measurement technologies. The manufactured cracks are very similar to naturally occurring cracks and can be made to have varied profiles and off-planar shapes (like hook cracks). The manufactured spools are installed on a transmission pipeline at either the pipe launcher, the receiver or in-line such that an ILI tool passes through it during a field run on a transmission pipeline. This produces excellent data to evaluate measurement performance because the crack sizes are precisely known, crack morphologies are similar to realistic cracks and the ILI tool is tested in field conditions. This paper describes the effect on the estimated ILI tool measurement performance for various combinations of manufactured cracks in a pipe spool. The cases described include varying the number of manufactured cracks in the spool (the value of each additional crack), varying the distribution of sizes used (the value of large vs small cracks), and varying the number of measurements made on each crack (the value back-to-back ILIs). Traditionally, inline inspection tools have been evaluated based on field measurements. However, since field measurements are subject to measurement errors, a larger data set is required to have confidence in the estimated ILI measurement performance. In addition, a bias in both the ILI and the field measurements is difficult to ascertain without knowing the true sizes of a few cracks. The model used to asses the effects of manufactured cracks simultaneously solves for the bias, slope, standard deviation error, linearity and probability of detection performance using a Markov Chain Monte Carlo simulation of a hierarchical Bayesian model. Each parameter is described by its mean performance and 95% credible intervals and plotted as a full distribution which are compared to evaluate the performance of each case. Manufactured cracks are a new technology and present an interesting opportunity gain better insights into key measurement technologies that help integrity engineers maintain reliable transmission pipeline networ
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9464	Lawrence Matta	Pipe Knocked From Supports by Hydraulic Transient Event	During what was considered routine switching of liquid product lines and tankage at a storage and transfer facility, an incident occurred that resulted in approximate 1000 ft of 20-inch nominal pipeline being displaced laterally and falling from its supports. The event also resulted in the failure of a gasket at a valve flange and loss of containment. This paper discusses hydraulic and structural analysis of this event. Because the pipe movement was identified during what was believed to be normal pumping, the earlier alignment activities and pump startup were investigated for the potential to generate a hydraulic transient capable of generating sufficient force to cause the movement. A transient hydraulic model of the fluid in the piping as it was aligned at the time of the event was generated to assist in determining the cause and to help prevent a similar occurrence in the future. Several scenarios were modeled and are discussed in this paper: 1) pump shutdown from steady flow, 2) pump start up with the discharge valve open, 3) pump startup with the discharge valve closed, and 4) pump start up with a vapor cavity present near a closed valve at the high point in the line. The hydraulic simulations showed that cavitation in the pump likely occurred when starting the transfer pump with the discharge valve open. The effects of cavitation in the suction line could not be fully modeled and cannot be ruled out as a potential source of a hydraulic shock. However, the highest forces generated in this scenario are more likely to occur on the suction side of the pump than the location of the pipe displacement. A section of branch pipe leading to the closed valve at which the gasket failure occurred was elevated above the rest of the pipeline. Due to the high vapor pressure of the product, it is possible that a vapor pocket formed along this section of piping. The collapse of a vapor pocket and the resulting high velocity liquid impact on the closed valve at pump startup can result in high pressure transients. Modeling showed that this behavior could cause forces high enough to overcome the static friction of the pipeline and result in the type of incident observed. Due to the high forces generated and the damage at the closed valve, this scenario was considered to be a likely cause of the incident. Pipe stress and finite element analysis were used to assess the displaced pipe and to assist with lifting it back onto the supports. The piping stress analysis indicated that the highest stress in the piping was significantly less than the yield stress of the material. Results from a detailed Finite Element Analysis with material nonlinearity showed that there is no global plastic strain in the piping due to the event. This left a potential for local plastic strain due to the impact of the pipe against any hard surfaces, and this was addressed with visual examination. In the end, the pipe was lifted back onto the supports, horizontal supports were added, and procedural changes were implemented to reduce the likelihood
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9472	Janine Woo	Improved Semi-Quantitative Reliability-Based Method for Assessment of Pipeline Dents With Stress Risers	Dents, especially those interacting with stress risers, can pose integrity threats to pipeline systems. Regulations in Canada and the United States mandate the repair dents based on depth and interaction with stress risers, however, there have been cases in the past where dents that have passed these criteria have ended up failing a leaking. The recommendations currently available in the industry for dent analysis are predominantly based on strain, and the dent-fatigue models have been proven to be limited in their application. Additionally, these models or methodologies are generally deterministic and as such, do not account for uncertainties associated with pipe properties and in-line inspection (ILI) tool measurement. Enbridge Liquid Pipelines Inc. had previously presented a framework to support system wide dent assessment with a probabilistic semi-quantitative analysis method for dents (SQuAD), which elicits potentially injurious features from thousands of features within a system in a reasonable timeframe. This paper expands on the authors' previous work and presents several critical improvements that have since been made to the SQuAD model to address the limitations in the initial version of the model and other dent assessment methods available in the industry. The previous version of SQuAD was strain-based and did not explicitly account for pressure-cycling induced, fatigue-based failure. An approximate circle fitting method was adopted for estimating the radii of curvature in order to calculate strains within dents. In the improved model, filtering techniques have been employed to reduce the noise in the ILI-reported data while preserving the dent shape. Furthermore, a simplified FEA process has been developed to calculate the stresses within a dent due to pressure cycles, thus the fatigue-based Probability of Failure (PoF) of a dent can now be estimated using S-N approach. The filtered data allows for better accuracy in quantifying the radius of curvature of dents as repor by ILI tools, which are used for calculating dent strain as recommended in the updated version of ASME B31.8, Appendix R. Finally, the feasibility of applying this improved SQuAD model is discussed from an operator's perspective. The improvements allow the enhanced SQuAD model to be used as an effective screening tool on system-wide basis as part of a comprehensive, reliability-based dent assessment framewor
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9476	Dane Burden	Puddling Puddle Welds	Unique characteristics of individual pipelines come from over a century of evolving design, construction, maintenance, regulation and operation. These characteristics a especially true for legacy, pre-regulated pipelines. Due to the unique nature of the threats present on these assets, there is a need for unique inspection technologies and techniques that can increase a pipeline's life. Reconditioned and repaired pipe utilizing puddle weld repairs is one such threat. An "advanced analysis" was completed on a 10-inch, 68-mile light products pipeline. The pipeline was constructed with reconditioned pipe that was estimated to contain tens of thousands of puddle welds. Historical In-Line Inspection (ILI) data generally underperformed in classifying and discriminating puddle welds versus metal loss features. The primary objective of this project was to assess the Probability of Detection (POD) of a multiple dataset ILI tool utilizing multiple Magnetic Flux Leakage (MFL) magnetization directions and RESidual (RES) magnetization measurements. A secondary objective was to scrutinize data for signs of coincident features. Hydrostatic testing failures showed that puddle welds with porosity and cracking were susceptible to failure and the identification of these features would be beneficial. Analysis of historical puddle weld investigations and the multiple dataset ILI data revealed detection principally in the RES dataset. The high-field magnetizations offered secondary confirmation, but often saturated out thermal effects or material differences. The final report included over 40,000 detected puddle welds and four classifications for further investigation. Field investigations for 212 features were completed and the results compared to the ILI data to assess performance. A truth table was created for True Positive (TP), True Negative (TN), False Positive (FP) and False Negative (FN) conditions. The smallest TP puddle weld dimension was 0.7" x 0.7" and the population had a statistical sensitivity value of 98% (132 TP and 3 FP). Three additional anomalies denoted as abnormal were also investigated. The ILI signatures at these locations were consist with previous repairs in which puddle welds with cracking were sleeved. Two of the three were found to have cracking. Crack propagation was found to be both axial and non-axial in orientation. The results demonstrated by utilizing a multiple dataset ILI platform show that puddle welds can be detected with extremely high accuracy. In addition, the preliminary classification results show a high potential for identifying secondary coincident features. This paper details the stages, deliverables and results from an ILI advanced analysis focused on puddle welds

Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9481	Johannes Becker	Improving Data Collection With In-Line Inspection in Low-Pressure Gas Distribution Networks	A large majority of urban gas distribution pipelines are designed to accommodate future inspection surveys with in-line inspections tools. While this remains true, even with typical inspection design parameters considered, many pipelines end up on a “difficult-to-inspect” list and fall into a “gray” zone. Much of this can be due to operational parameters, which may have adverse effects on how in-line inspection technologies perform. One of these effects may be stop-start behaviors of the tool itself. Although technically piggable, vintage pipeline design practices such as numerous 1.5D bends, multiple heavy wall transitions, and narrow ID fittings have continually shown to be an ongoing issue when running ILI tools in gas distribution lines. The first assessment characteristically indicates that standard inspection tools can be used for this type of pipeline, but results from previous inspections have shown or show, after the first inspection of the pipeline, that regular technologies cannot be applied, or rather, do not deliver satisfactory results. New methodologies and technologies are required to reduce the incidents of stationary tools, reduce, if not eliminate, potential areas of degraded data and improve overall data quality. In the end, operators consider these lines a critically important component of their entire system and are keen to gain a clear picture of the assets' integrity. Suitable in-line inspection solutions are therefore in demand to instill confidence in the assets safe and efficient operation This paper outlines several elements (including technologies, procedures, or mechanical adaptations) that can be overlooked when selecting and applying inspection and cleaning technologies to these gray-zone pipelines. Applying these elements may allow for the inspection tool to traverse various obstacles and often debris while still providing a high-resolution data set. A detailed case study of a NPS 08” pipeline will be used to support the content. This pipeline did not provide the required operational parameters to gather acceptable data when utilizing standard ILI technologies. This NPS 08” line contained various challenges, such as: · Unknown or unreliable pipeline information, specifically bend radii and wall thicknesses. · No previous cleaning and inspection records. · Low operational pressures of 1000 to 2100 kPa. · Pipeline length over 100 km. · MOP restrictions did not allow for higher pressures. · Flow rate only available i limited windows. · Cleanliness is unknown, assumed to be a concern. · Pipe grade verification Many technical issues initially affected the project, one of which resulted in a stationary cleaning tool. The lessons learned will also be discussed and outlined to better support the approach chosen. In the end, tailored geometry and low-friction MFL technologies, capable of safely traversing the pipeline and gathering high-quality data, were utilized for the inspection. This case study will provide other operators valuable insights into how to inspect similar assets while also outlining specialized
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9493	Tim Edward	Statistical Analysis of Dig Operations Leading to Productive Repairs	Inline inspection data from several runs spanning many years is available for individual pipeline segments, but compilation of this data into a comprehensive picture pipeline integrity necessarily relies on computational tools. A critical advantage of modern data storage, analysis, and visualization techniques is the relative ease of performing statistical assessments of integrity operations. Data from a single user of OneBridge Solution’s software may comprise over 1,000 ILI runs, hundreds of pipe segments, several million aligned anomalies, and thousands of repair records. Automated alignment of ILI data allows a single physical anomaly to be reliably tracked through many years of growth and repeated measurement and then correlated to repair records. We present a study of cases where ILI anomaly measurements warranted a dig operation in which repair actions were either performed or found to be unnecessary. The fraction of dig operations leading to a productive repair varies with the condition triggering the dig and discretionary choices about dig condition parameters. The analysis is done through the exploration of different methods of corrosion growth forecasting in use by operators and how they compare. The measures that have been taken into consideration for the purpose of this study include 6 MPY vs. Half-Life vs. Pit-to-Pit where the effectiveness of identifying and mitigating fast-growing anomalies is compared across models. Further exploration of how forecasting and building a dig program based on Pit-to-Pit alignments and a comprehensive growth model through the advances in data science and machine learning can bring efficiency improvements and an overall reduction in risk. We analyze the relationship between these parameters, ILI measurements, dig-to-repair ratios and the impact on operational spend. We examine whether the reduction in overall inspection frequency and expenses is possible through advanced growth modeling. Ultimately this would provide a more accurate view of long-term operating costs and allow for operators to consider scenarios relating to repair and replacement of ass
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9499	Gregory Quickel	In-Service Cracking/leak at Bottom Side Repaired Dent	Pipeline operators are often faced with excavating deformations caused by bottom side indenters (e.g., rock dents). These dents are typically constrained by t rock, but during excavation, after the rock is removed, the dent is no longer constrained. Many operators have felt that it is prudent to perform in-the-ditch (ITD) non-destructive examination (NDE) techniques, such as liquid penetrant testing (PT) and magnetic particle inspection (MPI), to determine if external cracking is present so that an appropriate repair method can be selected. Unfortunately, these external surface ITD NDE methods do not identify internal cracking on pipelines. Recent research, along with metallurgical analyses of cracks at bottom side dents, demonstrates that the fatigue behavior of constrained dents is different than that of unconstrained dents, and that identifying the correct crack mechanism can be difficult if not all of the information is evaluated. The paper discusses cracking mechanisms (e.g., stress corrosion cracking, fatigue, etc.) at bottom side dents, ITD crack identification methods, differences between constrained vs non-constrained dents, repair methods at dents, and presents a case study that uses non-destructive (MPI, unconventional PT, laser scanning) and destructive techniques (metallography fractography, hardness testing) to determine the metallurgical cause of a failure. The case study involves a preformed composite sleeve system that was used to repair a dent in which correct installation procedures were followed but ultimately resulted in a delayed in-service failure. In hindsight, if ITD NDE methods were chosen based on our current knowledge of recent research, the repair selection would have been different and therefore would have likely prevented an in-service failure. This paper provides a case study to help increase awareness regarding how to properly evaluate cracking in dents. Operators should ensure that their excavation and repair procedures are updated to reflect the most current industry knowledge to help prevent a similar failure.&nbs
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9501	Rhett Dotson	Judge Me by My Size, Do You? Or: How Reliable Are Dent Assessments Based on Ili Data?	Pipeline dents have historically been regulated and assessed using dent depth as the primary metric. Many of the earliest analytical models for dent remaining life a based upon depth. Current assessment guidelines from ASME and the US Code of Federal Regulations utilize depth as a primary metric. Consequently, ILI caliper tool capabilities are stated in terms of dent depth. However, the best modern dent assessments, including both strain and fatigue assessments, are based on dent shape. At a minimum, these models require both axial and circumferential dent profiles, or the models may utilize the full three-dimensional shape of the dent. The utilization of advanced dent assessments is expected to grow in the future as the methods are incorporated into API Recommended Practices and US regulations. While operators may have confidence in the ability of an ILI tool to confidently capture dent depth, the shape of a dent is a recent consideration that is not addressed by current tool specifications. Unlike depth alone, dent shape is often a function of sensor coverage, speed, and caliper technology. Unfortunately, there is virtually no information available on the reliability of these assessment methods when they are based on ILI data. To-date, there have been no published comparisons examining the variation in strain or remaining life in identical features between multiple inspections. The reliability of these dent assessment methods is critical when choosing safety factors or reinspection intervals. This study presents a first look at the repeatability of strain and remaining life assessments based on two separate caliper runs. The study examines dent strain according to ASME B31.8 and remaining life calculated using shape factors and finite element methods calculated for over three hundred dents. T paper examines the variation in each of the methods and provides guidance on how users should understand the results when they are based on a single inspect
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9503	Nima Parsi	Integrity Validation of Small Diameter-Thin Wall Pipeline Susceptible to Cracking or Crack-Like Indications-a Case Study	The integrity validation of small diameter, thin wall pipelines can be challenging. In-line inspection tool limitations for diameters below approximately 4.5-inch contribu significantly to this challenge. This paper will describe experiences related to the successful integrity validation of a 3-inch vintage high vapour pressure (propane) pipeline which was susceptible to external cracking as well as crack-like indications at the seam weld (e.g. hook crack and lack of fusion). This line pipe was manufactured in 1967 with a low frequency electric resistance welding (ERW) process. The external coating is a wrapped tape and the pipeline has been operating in a cyclic pressure service. Over time, three magnetic flux leakage (MFL) in-line inspection (ILI) surveys were completed. The major threat was identified to be external corrosion since external metal loss up to 70% of the wall thickness was reported by ILI. The cut-out samples obtained from integrity digs following the ILI were examined by magnetic particle inspection methods. Some external features on these cut-out samples were reported as cracks. The pipeline licensee involved Skystone to complete an engineering assessment and provide a short-term and long-term integrity plan to validate the integrity of the pipeline for continued service. The cut-out samples were re-examined. This examination included cross-sectional metallography of the area suspected to contain crack-like indications. No external cracking was identified; however, crack-like indications such as lack of fusion were found on the ERW seam. A pressure-spike test was designed as an integrity validation technique and completed successfully. This paper reviews the difference between the pressure-spike test and conventional pressure tests, the technical basis for the pressure-spike test, its limitations, and practical considerations that need to be considered. The regulatory recognition of spike testing as well as available recommended practices that refer to this approach will be discussed. A long-term integrity plan was developed by establishing an interval for the next pressure-spike test using fatigue life estimation. The size of the crack-like indication that survived the spike test was calculated and then the time required for the indications to grow by pressure-cycle-induced fatigue to reach a critical size at the licensed maximum operating pressure was calculated. The interval for the next pressure-spike test is selected as half of the shortest calculated fatig
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9506	Alireza Kohandehghan	An Engineering Assessment Methodology to Evaluate Arc Burns	Arc burns, also known as arc strikes, are caused by momentary interaction of an electric arc, e.g., welding electrode or welding ground clamp, and a pipe or fitting, upo which a minimal or no amount of weld metal is deposited. Arc burns typically correspond with localized alteration of microstructures, shallow pitting, sharp surface contours, re-melting, and/or cracking. The damaged microstructures manifest in the form of a locally harder material due to accelerated cooling rates. Arc burns are mainly a result of the pipeline construction activities and are typically adjacent to manually installed girth welds. The hard microstructures associated with arc burns are susceptible to hydrogen-induced cracking (HIC) in the presence of atomic hydrogen. Pipeline maintenance codes consider arc burns as defects and require their complete removal by grinding. Due to the relatively small dimension of arc burns, removal by grinding followed by etch contrast testing is often the simplest and most reliable permanent repair for such defects. However, grinding to the maximum allowable depth might not completely remove the affected microstructures. Also, removal of arc burns often requires grinding near girth welds and significant grinding depths may require through-thickness inspection of the welds to ensure safety. Type B pressure containing steel sleeves are another permanent repair method that can be used to repair arc burns or partially removed arc burns within grinding metal loss features. Installation of permanent repairs over an arc burn are costly and may introduce additional or higher risks to the integrity of pipeline when scarce industry studies are available that conclusively demonstrate the dangers of leaving arc burns or partially removed arc burns in pipes. Despite the need, there is no validated engineering assessment (EA) method for the evaluation of arc burns. This paper will summarize an EA methodology and the findings of the evaluation of arc burns and partially removed arc burn features in a vintage liquid pipeline. A combination of one- and three-dimensional finite element models was utilized to investigate the effect of arc bu and/or partially removed arc burns on the integrity of the pipeline based on plastic collapse, local yielding, and fatigue failure modes. The effect of the buried pipeline profile and soil was considered in the assessment of the axial load capacity of the pipeline. The geometrical and metallurgical stress concentrations of the features were considered in the EA. The EA determined if the pipeline with the arc burns and/or partially removed arc burns can survive the damage mechanisms during its operation and if reinforcement of the area or cut-out is requirec

Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9508	Axel Aulin	Comparison of Non-Destructive Examination Techniques fo Crack Inspection	Effective and efficient crack management programs for liquids pipelines require consistent, high quality non-destructive examination (NDE) to allow validation of crack line inspection (ILI) results. Enbridge leveraged multiple NDE techniques on a 26-inch flash-welded pipe as part of a crack management program. This line is challenging to inspect given the presence of irregular geometry of the weld. In addition, the majority of the flaws are located on the internal surface, so buffing to obtain accurate measurements in the ditch is not possible. As such, to ensure a robust validation of crack ILI performance on the line, phased array ultrasonic inspection (PAUT), time-of-flight diffraction (TOFD), and a full matrix capture technology were all used as part of the validation dig program. All methods were used on most of the flaws characterized as part of the dig program providing a relatively large data set for further analysis. Encoded scans on the flash welded long seam weld were collected in the ditch and additional analyses were performed off-site to identify and size the flaws. Buff-sizing where possible and coupon cutouts were selected and completed to assist with providing an additional source of truth. Secondary review of results by an NDE specialist improved the quality of the results and identified locations for repeat scans due to data quality concerns. Physical defect examinations completed after destructive testing of sample coupon cutouts were utilized to generate a correlation between the actual defect size from fracture surface observation and the field measurements using various NDE methods. This paper will review the findings from the program, including quality-related learnings implemented into standard NDE procedures as well as comparisons of detection and sizing from each methodology. Finally, a summary of the benefits and limitations of each technique based on the experience from a challenging inspection program will be summarized.
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9511	Hamid Niazi	The Impact of Pressure Fluctuations on the Early Onset of Stage Ii Growth of High Ph Stress Corrosion Crack	Steel pipelines undergo the following sequential stages prior to high pH stress corrosion cracking (HpHSCC) failure viz. formation of occluded environment, initiation of intergranular cracks followed by cracks coalescence to form critical crack size (Stage I), mechanically dictated crack growth with higher rate (Stage II) compared to Stage I , rapid crack propagation to failure (Stage III). From fracture mechanics perspective, the crack size reaches the critical value at the onset of stage II; consequently, stress intensity factor (K) ahead of the crack tip exceed the critical value (K_{ISCC}). Although many researches have been devoted to understanding HpHSCC behavior, the mechanical conditions that accelerate the onset of stage II remains unknown. This study investigates the mechanical loading conditions that yield to early onset of stage II with respect to the most severe loading condition in operating pipeline, underload-minor-cycle type of pressure fluctuation. In this study, several loading scenarios were applied to pre-cracked CT specimens exposed to 1 N $NaHCO_3$ -1N Na_2CO_3 at 4C and -590 mV SCE . The first series of tests were conducted through applying variable amplitude loading waveforms to determine the K value below the K_{ISCC} . It was observed the crack growth rate decreases from 1.5×10^{-7} to 2.5×10^{-8} when K_{max} decreases from 36 to 15 MPam$^{0.5}$. Then, both constant amplitude and variable amplitude loading scenarios with the K_{max} =15 MPam$^{0.5}$ we applied to pre-cracked CT specimens. It was observed that low R-ratio constant amplitude cycles yield to highest crack growth rate (3.6×10^{-7} mm/s), which was one order of magnitude higher than other waveforms. However, comparing the intergranular crack advancement per block resulted in similar crack growth rates for those waveforms containing low R-ratio cycles. These results implying that stage I of crack growth is assisted by fatigue due to low R-ratio cycles. It was observed that loading/unloading frequency of low R-ratio cycles has a direct relation with crack growth rate at stage I i.e. high frequency cycles accelerate onset of stage II. The implication of these results for pipeline operator is avoiding the internal pressure fluctuation, particularly large and rapid pressure fluctuation at the sites susceptible for HpHSCC. This practice increases pipeline lifespan and prevent cataphoretic damages by intergranular stress corrosion crack growth through delaying the onset of stag
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9512	Syed Haider	Integrity Management of Flange Connections Using Reliability Model	There is demonstrated potential for failures to occur on station piping assets in facilities, therefore it is critical to take measures to manage preventable releases. In 20 Enbridge developed a semi-quantitative reliability model that uses readily available asset information to quantify the likelihood of failure of station piping assets. Enbridge based this model on the CFER PIRIMID software, with some modifications to minimize the use of default values and to meet the company’s integrity management program requirements. With successful implementation of station piping model, Enbridge realized opportunity to develop a much-needed flange model leveraging the station piping model. Historical leak data indicates that flanged connections often experience a higher leak frequency than other assets in a facility. While there are industry guidelines that provide guidance for the assembly of process flange connections in a facility, there are few that discuss integrity management of flange connections once they are operational. Most published condition assessment flange models require inputs which are not readily available, e.g. condition of flange faces and gaskets. These inputs often require the flange to be disassembled just to obtain the data. For pipeline operators, data gathering is even more challenging as there are stations (with numerous flanges) that are spread out along the entire pipeline. Given the high number of flange connections and their wide variation in parameters within transmission pipeline facilities, there is benefit in developing a reliability-based model to guide the integrity management of flange connections. A semi-quantitative reliability model that works in two stages was developed for this purpose. The pre-inspection assessment stage was designed to utilize readily available inputs to prioritize groups of flanges for inspection, and the post-inspection assessment (second) stage is then applied to select the specific flanges that require maintenance action. Enbridge utilized industry guidelines, relevant standards, historical failure data, and subject matter experts’ inputs to develop the station piping and flange models. This paper will discuss the design concepts, model architectures, the contributing factors, and their sensitivities to the likelihood of failure results. These concepts may be utilized by any operator managing such assets, and the model designs may be tailored to suit a wide range of facility environmen
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9520	Aaron Woo	A Prudent Approach to Evaluate Dig Effectiveness	Pipeline operators analyze in-line inspection (ILI) reported pipeline anomalies to determine if excavation of pipeline is required to investigate any anomaly through dir examination in the ditch. Pipeline excavations require considerable resources and planning. Moreover, excavations may cause disturbance to the land owner as well as the operation of a pipeline. Therefore, it is important to ensure that the excavation decisions are made effectively. While operators do review the key performance indicators on how the integrity programs are performing, currently there is no established definition or measure in the pipeline industry to evaluate the effectiveness of a dig program. Defining and measuring dig effectiveness would allow pipeline operators to identify areas to focus on, such as opportunities for improvement, further research and development, and consequent potential optimization of the integrity dig program, while maintaining safety and reliability. Effectiveness of digs depends on many aspects of the corrosion management program. First, a definition of dig effectiveness that reflects the objectives of the ILI program needs to be established. This paper presents a method developed by TC Energy to evaluate the effectiveness of a dig program. The method was developed using in-house historical dig data obtained from excavations that were selected based on analysis of ILI data. A single dig and its proximity to thresholds (or excavation criteria) depends on many aspects such as ILI measurement error, decision process, etc. The variability of in-ditch results in digs is inevitable and therefore dig effectiveness should be a measure of the population of dig results and not a single dig result. The in-field measurements of metal loss anomalies obtained from digs, completed for leak and rupture threats, were gathered and analyzed to evaluate the bounds in determining dig effectiveness. The advantages of measuring dig program effectiveness using field results as opposed to other metrics such as repair ratio are demonstrated in this paper. Pipeline operators can incorporate this methodology to enhance safety and identify areas of improvement in the ILI based dig program.
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9523	Carly Meena	Third Party Damage Monitoring: Internal Fiber Optic Installation on a Transmission Pipeline Using a Pig, a Disengagement System and a Pack-Off	Fiber optic technology can be leveraged to measure strain, vibration, noise and temperature on pipeline systems. Such technology can enable pipeline operators identify nearby excavations and intervene before third party damage occurs. Acoustic and temperature sensors can quickly identify leaks and strain sensors can identify areas of pipe movement. Transmission pipelines that travel through areas of dense population or areas in development can be at a higher risk for third party damage. The most well-known fiber optic installation method is to perform an external installation, which is typically only economical at the time of construction. The opportunity to use fiber optic technology through retrofit on existing pipelines utilizing internal deployment, if successful, would allow significantly wider use of the technology due to the reduced cost. TransGas Limited has a 1.5 km long NPS 6 sweet natural gas transmission line that travels through the city of Humboldt, Saskatchewan, Canada. A portion of the gas line, totaling 800 m, travels through an area that is under development for businesses and housing. The purpose of this study was to develop and demonstrate a feasible method for installing fiber optics inside of an existing gas line as a proof of concept and to control for the risk of third party damage. In this study, fiber optic sensors were preloaded into steel capillary tubing and coupled to a shear pin disconnect system. The shear pin disconnect system was attached to the back of a pig to carry the fiber optics through the gas line. Nitrogen was used as a gaseous medium and a pack-off was installed at the pig launch location to allow the gas line to maintain pressure during and after the fiber optic installation. The pig travelled through the pipeline to the desired monitoring distance of 800 m and the shear pin disconnect system was engaged. The pig travelled to the receive location and the fiber optics remained in the pipeline for continuous monitoring of third party interferen
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9555	Phat Le	Communication and Mitigation Strategies Related to the Leading Indicator of Pressure Cycle Fatigue	Pressure cycle fatigue has been shown in industry to be a contributing factor to pipeline failure. There are methods for pressure cycle fatigue monitoring that c be used as a leading indicator for the risk of the pipeline to fatigue related failure. Once lines with high cycling are identified, the risk of the cycling to the asset and the mitigation strategies for the cycling can be discussed within the organization. By mitigating the driving force of crack initiation and grow to failure in-service, the pipeline community is safer. Shell Pipeline Company, LP. (SPLC) experienced two in-service failures in under a year where fatigue was a common root cause. Following the investigation of these failures, SPLC management requested communication of the risk of pressure cycle fatigue throughout the organization with the intent to mitigate the levels of pressure cycling across the SPLC system. All pipelines were put on a monthly dashboard of pressure cycling and sent to all SPLC staff for awareness and action. SPLC measures pressure cycling on all pipelines normalized the number of cycles that are 25% of the specified minimum yield strength (SMYS). From January 2016 to December 2019, the number of monthly cycles on the top ten highest cycled segments were reduced from 45,000 cycles per month, to 18,970 cycles. This is a reduction of 58%. The number of Very Aggressively cycled pipelines was reduced from 2 to 0. The number Aggressively cycled pipelines were reduced from 15 to as low as 3. This paper will share the strategies and methodologies SPLC used to achieve these results. SPLC will share how the list of highly cycled pipelines and the monthly communication of status were developed. SPLC will also share how strategies for mitigation were determined in group meetings, by pipeline, with facility engineering, business unit leads, controllers, schedulers, integrity staff. The effectiveness of methods of mitigation such as pressure reduction, installation of back pressure control valves, changing of valve timing on startup and shutdown, changes to the scheduling on the pipeline, utilization of flying switch between tankage, etc. will be discussed. By reducing pressure cycling, the entire risk profile of pipelines subject to pressure cycling has been shifted down for the threat of crack induced failure. This program is continuously being improved because there is both management commitment and ownership of the issue throughout the organization.
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9578	Chris Wood	Getting to Know Your Bends to Support Scc Management	Nova Transportadora do Sudeste (NTS) in Brazil own and operate a relatively young gas transmission system where the confirmed primary integrity threat is axial stre corrosion cracking. The pipelines vary in diameter, weld type, manufacturer and age. One of the pipelines failed in 2015 due to an axial crack. Since the failure, NTS have executed an intense inspection campaign to detect and size axial cracking within their network. The 2015 failure occurred on a field bend. The inspection campaign and follow dig campaign has confirmed that cracking within field bends is the primary integrity threat. Brazil has a challenging terrain and approximately 40% joints within the network is a field bend. The geometrical influences within these areas have resulted in localised elevated stresses where the axial stress corrosion cracking colonies are initiating and growing. To date, no cracking has been verified within their straight pipe sections. Considering the limited information regardi the pipe material and complex stress state, NTS initially took a conservative baseline assessment approach using API 579 Part 9. In addition to hoop stress from internal pressure, the baseline assessment also considered weld residual stress and bending stress due to ovalization to determine immediate and future integrity. NTS have been completing an intensive dig campaign following an EMAT inspection. A large number of deep cracks have been reported by the tool, verified to be deep and repaired with a type B sleeve. However, at one site decided to remove the entire joint it for further analysis. By removing the joint, NTS planned to investigate crack morphology, confirm material properties and refine predictive modelling. This paper outlines how NTS have combined a burst test, mechanical testing, FEA modelling and metallographic examination to further understand the feature morphology and stresses within these areas and how they have been able to strip conservatism from their baseline assessment with confidence and adopt a plastic collapse approach to accurately predict failu

Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9580	Noah Ergezinger	Application of Noise Filtering Techniques for the Quantification of Uncertainty in Dent Strain Calculations	The integrity assessment of dents in pipelines is primarily driven by the dent depths as per the stipulations in current codes and standards. There is a provision for stra based analysis to quantify the severity of dents based on their shapes in the ASME B31.8 non-mandatory Appendix R. In recent years, however, the pipeline industry has also started leveraging more advanced techniques such as Finite Element Analysis (FEA) for dent assessment. These assessments require the detailed deformation profile of dents, which are available from In-line Inspection (ILI) tools. The ILI tools use caliper arms that roll along the inside of the pipeline and scan the inner profile. The measurements recorded by each caliper arm are susceptible to noise due to the vibration of the ILI tool, and as a result, the dent shapes obtained from ILI are not smooth. Strain assessments of dents typically require the calculation of radius of curvature in the longitudinal and circumferential directions. This becomes a complex problem while the ILI data contains noise. For dents that are relatively deep, the depth of the dent can exceed the measurement noise in the inspection tool. For relatively shallow dents, however, the smaller depth approaches the magnitude of the noise in the data, and the radius of curvature estimation can become inaccurate. Furthermore, the amount of noise in the data can vary between dents, and so the accuracy of the estimation varies as well. This paper presents several methods to resolve the above-mentioned issues. To address the issue of data noise itself, a combination of Fast Fourier Transform (FFT) and Gaussian filtering is used to produce a smooth profile that can be used to calculate the maximum radius of curvature of the dent. The smoothed profile also results in a better estimation of dent depth. To estimate the amount of uncertainty in the data, independent iterations of random noise are applied to the smoothed curve. Characteristics required for further reliability analysis, such as dent depth or radius of curvature, are calculated for each iteration. This forms a distribution for each characteristic, effectively quantifying the uncertai
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9616	Bing Liu	Axial Compressive Capacity of Pressurized Pipeline With Corrosion Defect	As the action of geological hazard, the buried steel pipe may bear axial compressive loads and cause buckling instability. At the same time, there will be a large numb of external corrosion defects in long-term buried oil and gas pipelines. Corrosion defects have an important impact on the structural stability of pipelines, which is the ma cause of structural failure of oil and gas pipelines. In order to research the bearing capacity of buried steel pipes with corrosion defects, the numerical simulation model of the buckling of X65 pipeline with corrosion defects under the combined load of internal pressure and axial compressive load is established by using ABAQUS finite element software. Meanwhile, considering the nonlinearity of the material model, the Ramberg-Osgood model is selected as the pipe material model. The bearing capacity analysis of the pipeline with corrosion defects under the combined load of different internal pressure and axial compressive load is carried out. The reliability of the simulation results is verified by the existing test results. The size of corrosion defect and the internal pressure of pipeline have significant influence on the bearing capacity of pipeline under axial compression load. However, there are few studies on the influence of the location of corrosion defects on the bearing capacity of pipelines under Internal pressure-axial compression load. Based on the accurate numerical simulation model, parameter sensitivity analysis is carried out to study the effects of corrosion defect location, defect size and pipeline internal pressure on pipeline bearing capacity. The variation of moment bearing capacity and ultimate strain of pipeline are analyzed quantitatively. The numerical simulation method used in this paper can better reflect the real service state of buried pipelines under the action of geological disasters. The research results have a certain reference value for the safety maintenance of buried pipelines under the action of geological disasters. Key words: corrosion defect, axial compression, X65 pipeline, load capacity, pipe bucklin
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9621	Masoud Baghelani	Microwave Chipless Resonator Strain Sensor for Pipeline Safety Monitoring	Real-time hoop strain monitoring is known as an important parameter for the evaluation of pipeline safety and integrity. Pipeline corrosion could result in internal presst variation which consequently results in strain fluctuation. In addition, leakage causes pressure drop and strain reduction due to negative pressure wave. Due to their promising features such as extremely low cost, relatively high sensitivity, compatibility with harsh environmental conditions, distant and non-contact sensing with negligible power consumption, microwave resonator-based sensors achieved great deals of interest during the last decade. In this work, a chipless flexible microwave sensor for pipeline hoop strain real-time monitoring is presented. The sensor structure comprises a flexible chipless split ring microwave tag resonator attached to the pipeline and electromagnetically coupled to another microwave resonator that forms the reader located at a certain distance from the tag strain sensor. Strain variations the results of the mentioned pipeline defects change the overall length of the attached tag sensor which consequently causes a shift in its resonance frequency. For assuring the tag sensor to mechanically follow the strain variation of the pipeline, the Young modulus of its structural material should be much lower than that of the pipeline. This condition also important for the integrity of the sensor-pipe system because their connection will be accomplished by an adhesive. Since copper as the standard microwave conductive material is relatively highly stiff, it is not an appropriate candidate for such an important application. For addressing this issue, the chipless tag structure is fabricated by a conductive rubber layer in this work with extremely low Young modulus guaranteeing the length of the tag strain sensor to exactly follow the strain variation of the pipeline and forms a reliable and precise pipeline strain sensor. The spectrum of the tag sensor is reflected on the reader structure spectrum which could be measured to monitor the resonance frequency shift of the tag resulted from length variation of the tag sensor directly related to the pipeline str fluctuation.
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9624	Michael Smith	Now You Scc Me, Now You Don't – Using Machine Learning to Find Stress Corrosion Cracking	Electromagnetic Acoustic Transducer (EMAT) is a nor-destructive inspection technology that uses guided acoustic waves to detect planar flaws in a metal structure When deployed via in-line inspection (ILI), it is an effective way to detect cracks in a pipeline. EMAT has thus become a staple of crack management programs throughout the world since its introduction to the market over a decade ago. As with all technologies, challenges remain with the inspection process. One such challenge with EMAT is classification. While it is possible to determine that an anomaly is "cracklike" (a property determined by its tendency to reflect incident waves), it is difficult to determine the nature of the anomaly from the EMAT measurement alone. Indeed, similar reflections are obtained for many different types of anomalies, from relatively benign manufacturing and construction abnormalities, to more concerning defects such as stress corrosion cracking (SCC). To compensate for the difficulties in classification, it is good practice to follow up an EMAT inspection with a number of infield verifications. These investigations allow for a more direct observation of classification and size, and provide valuable information about the nature of cracks. They are, however, expensive – meaning that avoiding unnecessary digs is a top priority. In this paper, we document a developing approach to postILI crack management, where the results of an EMAT run are combined with those from field verifications to maximize the amount of information gained from costly field work. This approach – which relies on supervised machine learning – leads to a marked improvement in the classification of cracklike indications from EMAT, and allows future investigations to be prioritized according to the likelihood of finding a concerning defect. The method was trialed on a pipeline system with extensive SCC, leading to an improved success rate in finding SCC, and a more cc-effective crack
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9655	Zeyanb Shirband	Pipeline Plain Dent Fatigue Assessment: Shedding Light on the Api 579 Level 2 Fatigue Assessment Methodology	For continued safe operation of pipelines, thousands of integrity digs are conducted every year to repair ILI detected defects. Integrity-driven pipeline excavations can quite costly, present significant scheduling challenges with landowner consultation and seasonal access limitations, and an unmitigated defect may have required a pressure reduction or service outage, resulting in a loss of revenue from the asset. Dents are known to be one of the drivers for many integrity excavations, especially for liquid pipelines. A pipeline with a minimal mechanical deformation is not expected to fail immediately, however, severe pressure cycles combined with the geometric distortion can cause a fatigue crack initiation and growth that eventually leads to failure. To account for the possibility of fatigue failure, recent changes to pipeline codes, such as CSA Z662, are requiring pipeline operators to repair any dent susceptible to fatigue failure unless an engineering assessment proves it is fit for service. A widely used dent fatigue assessment methodology is outlined in API RP 579, also known as EPRG model. The assessment methodology uses a stress-life (S-N) curve from D 2413 part 1 with a safety factor of 10, which has been derived from undamaged pressurized pipe sections experiencing pressure cycles with stress ratios of zero, and separate stress enhancement factors for dents and gouges which take into account the shape of dents and gouges. To account for the effect of mean stress, Gerber mean stress correction, which has been developed for pressure cycles with stress ratios of -1 (i.e. for fatigue bar specimens), is also applied on pressure cycles. According to the literature, API 579 Level 2 fatigue assessment methodology results in very conservative estimates of fatigue lives compared to experimental data. This paper will discuss why it does so and propose refinements in the methodology. This will include the safety factor and the mean stress correction model suitable for a pipeline with pressure cycles that have R ratios greater than zero. The acceptable number of cycles obtained using the proposed refinements were compared to experimental data. The comparison revealed that the proposed methodology results in a more realistic safety margin for dented pipelines. The proposed methodology can be used as a part of engineering assessments in mechanical damage integrity management programs to improve the pipeline operator's understanding of a dent's remaining life and enable a more appropriate repair timeline
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9681	Vignesh Shankar	Leveraging Iot Telemetry to Improve the Tracking of Inline Inspection Tools for Oil and Gas Pipelines	To ensure the safe transportation of energy, Canadian pipeline operators spend roughly $1.5 billion every year on pipeline integrity. The most practiced form pipeline integrity is the use of inline inspection (ILI) tools. To ensure that an ILI inspection occurs with minimal to no complications, operators often utilize tracking techniques for the runs. These techniques can be costly and have large safety risks and environmental impacts due to the nature of using manpower to perform the operation. Using advanced Internet of Things (IOT) telemetry devices, the tracking of ILI tools can be completed from remote locations by installing IOT devices semi-permanently along a pipeline right-of-way. This advancement has ensured the efficient, safe and reliable tracking of ILI tools while eliminating risks involved with conventional tracking. Furthermore, the current generation of IOT telemetry devices offers a tailored suite of ILI tracking sensors such as magnetics, ultrasonic frequency, extremely low frequency (22 Hz), and geophone. This multi sensor tracking solution increases an operator's confidence in pig passages and flow rate estimations which allows the operator to optimize pump station bypassing. Finally, the IOT telemetry devices are supported by Global System for Mobile Communications (GSM) and satellite link which has ensured global coverage to remotely track tools. The communication module for the semi-permanent tracking solution is decided based on network availability and endpoints. This paper will present a comprehensive analysis that compares conventional ILI tracking to cutting-edge IOT telemetry ILI tracking and illustrates improvements in operational efficiency, operational risk, overall safety, environmental impact, and cost-effectiveness. In addition, case studies from recent tracking runs will be shared to demonstrate advancements in IOT telemetry, tracking sensor technology, dynamic user interface capabilities, advanced data dissemination methods, and high precision benchmarking. Keywords: Pig Tracking, Inline Inspection, Remote Monitoring, Telemetry, Oil and Gas, Tool Monitoring, Benchmarking, Geophone, Magnetics, Operational Efficiency, Cost Effective, IC
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9683	Miaad Safari	Optimizing the Management of Excavation and Repair Data From Inline Inspection Programs	The pipeline integrity industry is rapidly evolving with advancements in data science and technology in this Information Age. Machine learning, artifici intelligence, and big data are revolutionizing how pipeline companies manage their aging assets. As integrity programs mature over the life of a pipeline, an increasing number of data points are collected from second, third, or further condition monitoring cycles. Types of data include Inline Inspection (ILI) or External Corrosi Direct Assessment (ECDA) inspection data, validation or remediation dig information, and records of various repairs that have been completed on the pipeline system. The diversity and massive quantity of this gathered data proposes a challenge to pipeline operators in managing and maintaining these data sets and records. This paper focuses on how to optimize the management of excavation and repair data from inline inspection programs to enhanced business decisions. A major challenge that pipelines operators currently face is reconciling historical excavation, feature assessment, and repair information with new ILI data sets. Many operators rely on the new inspection to detect repair fittings, in order to conclude whether a feature has been previously repaired. However, there are some shortfalls to relying on this method, as ILI tools may not detect every repair fitting (especially in the case of un-banded Clocksprings) and they would not be able to determine if a feature has been previously inspected, assessed, and deemed to not require a repair. Addressing this gap would save operators significant costs by curbing unnecessary expenditures due to excavating a feature that had been previously excavated and inspected. The following paper describes an excavation data management system that digitizes excavation and repair information, capturing detailed repair specifications from each dig site. Using this system, repairs are assigned to each feature in an excavation, not only to a certain chainage along the pipeline. Subsequently, when a new ILI results report is received, a process of "Repair Matching" is completed to assign pre-existing repairs and assessments to the newly reported features at a feature level. This process is partially automated, whereby pre-determined box-to-box features matched between ILIs are auto-populated for many of the feature repairs. The proposed excavation management system would provide operators a robust approach to managing their repair history and projecting historical repairs and assessments onto new ILI reports, prior to assessing the ILI and issuing further digs on the pipeline. This optimized method is best suited for operators that are embarking on their second or third condition monitoring cycle, with a moderate number of historical repairs

Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9708	Steven Palkovic	Advancements in Nondestructive Methods Using Frictional Sliding for Direct Assessment of Steel Pipelines and Welded Seams	New regulations for gas transmission pipelines in the United States allow for the use of nondestructive evaluation (NDE) techniques to directly measure mater properties in lieu of conservative default values when records are not traceable, verifiable, and complete (TVC). Advanced NDE technologies and processes can used to collect material property data opportunistically when the pipeline is exposed for inspection or repairs, significantly reducing costs compared to traditional cut-outs and laboratory testing. This paper describes recently developed and validated NDE methods based on Hardness, Strength and Ductility (HSD) testing and Nondestructive Toughness Testing (NDTT) to predict conventional laboratory measurements of the mechanical strength, toughness, and quality of pipeline steel and longitudinal welded seams. Both methods are implementations of frictional sliding where a hard stylus deforms a softer substrate and then slides along the sample surface, allowing for hundreds of measurements of the material response to be collected during a single experiment. HSD testing uses multiple spherical styluses of varying size to measure the material hardness at different magnitudes of plastic strain so that a representative stress-strain curve can be constructed, whereas the NDTT uses a wedge-shaped stylus with an internal stretch passage that propagates a shallow tensile crack along the surface. This paper will describe the fundamental basis and test procedures for these methodologies, as well as validation data collected on vintage pipeline materials. Successful case studies describing the application of these techniques within ongoing integrity management programs to perform material verification of steel grade and determination of low frequency or high frequency electric-resistance-welded (ERW) seams are presented for both gas and liquid transmission pipelines. Future possibilities include expanding the use of these techniques to reduce conservatism in dent assessment using a critical strain-based approach, and combining in-situ measurements of metal plasticity and fracture properties to develop more accurate predictive models for fitness for service assessments
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9709	Udayasankar Arumugam	Full-Scale Fatigue Testing of Crack-in-Dent and Framework Development for Life Prediction	Dent containing crack fields (colonies) are often observed in liquid pipelines. The recently completed PRCI research project MD-1N "Study of the Mechanism for Cracki in Dents in a Crude Oil Pipeline" showed evidence of a mechanism for fatigue cracking. The crack growth rate as a function of stress intensity factor was estimated using the measured spacings of fatigue striations from fracture surfaces based on the assumption that the formation of fatigue striations on a cycle-by-cycle basis. However, due to the lack of full-scale fatigue crack growth data, the success was limited. This gap prompted PRCI to launch a full-scale experimental investigation of crack growth rates of cracks-in-dents under cyclic pressure load in the simulated groundwater NS4 environment. The objective of the study is to determine the crack growth rate as a function of stress intensity factor, the number of cycles to failure, and the failure modes of cracks- in-dents. The investigation is aimed at establishing a framework for remaining fatigue life prediction of cracks-in-dents in liquid pipelines. This framework would benefit liquid pipeline Operators to manage bet the integrity of dents associated with corrosion fatigue cracking in groundwater. A total of six pipe samples containing cracks in shallow dents excavated from a 24-inch diameter liquid transmission pipeline were used for the full-scale fatigue tests. The test system developed under the project consisted of (1) a computer-controlled hydraulic pressure cycling system, (2) an environment chamber containing NS4 solution mounted on the dent region to provide a simulated field environment condition, (3) real-time crack growth monitoring systems that included direct current potential drop (DCPD), Clip gage, and Strain gage, and (4) a data acquisition system. The cyclic pressure range used in the fatigue tests is between 78 psig (minimum) to 780 psig (72%SMYS, maximum) with R=0.1, which is based on historical operational pressure data and the Rain flow analysis. A constant frequency of 0.05 Hz was selected for the testing to ensure the frequency requirement for corrosion fatigue is met. In this paper, the test system and results are presented. The fatigue crack growth rate as a function of stress intensity factor is then discussed. The framework developed from this study for the life prediction of cracks in shallow dents is presented. Finally, application of the frame work utilizing inputs from ILI and pipelines historical operational pressure fluctuation data to manage cracks-in-dents is discusse
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9724	Aaron Dinovitzer	Dent Assessment and Management, Api Recommended Practice 1183	Pipeline dents can be developed from the pipe resting on rock, a third party machinery strike, rock strikes during backfilling, amongst other causes. The long-ter integrity of a dented pipeline segment is a complex function of a variety of parameters including pipe geometry, indenter shape, dent depth, indenter support, secondary features, and pipeline operating pressure history at and following indentation. In order to estimate the safe remaining operating life of a dented pipeline, all of these factors must be considered and guidelines for this assessment are not available. US DOT regulations (49 CFR 192 and 195) include dent repair and remediation criteria broadly based upon dent depth, dent location (top or bottom side), pressure cycling (liquid or gas), and dent interaction with secondary features (weld, corrosion, cracks). The criteria defined above are simple to use, however, they may not direct maintenance to higher risk dent features and be overly conservative or, in so cases, unconservative. PRCI, USDOT, CEPA and other full-scale testing, finite element modelling and engineering model development research has been completed to evaluate the integrity of pipeline dents. These results have demonstrated trends and limits in dent behavior and life that can improve on existing codified and traditional treatment of dents. With these research results a guideline for dent management can be developed to support operators develop and implement their pipeline integrity management programs. This paper will provide an overview of the newly developed API recommended practice for assessment and management of dents (RP 1183). The RP considers dentformation strain, failure pressure and fatigue limit states including the effects of coincident features (i.e. welds, corrosion, cracks and gouges). This paper will focus on how pipeline operators can derive value from this step change in integrity management for dents. The paper describes the basis for the dent screeing and integrity assessment tools included it the RP. This RP provides well founded techniques for engineering asessment that may be used to determine the significance and, if require, remedial action schdule required for dent feature
Track 3: Pipeline and Facilities Integrity	On Demand	IPC2020-9781	Chris Alexander	Generation and Monitoring of Synthetic Crack-Like Feature in Pipeline Materials Using Cyclic Pressure Loading	Crack management has become a major focus for many gas and liquid transmission pipeline operators. Failures associated with crack-like features have been a conce for both pipe operators and regulatory agencies. As a result, pipeline operators are excavating large numbers of features for not only in-line inspection validation purposes, but also to make repairs. Additionally, in-line inspection technologies have advanced significantly in recent years and are identifying an increasing number of features with greater levels of accuracy. With increased data generation, operators are faced with an unprecedented amount of information that requires response prioritization. Because of high levels of conservatism associated today's assessment methods, pipeline operators are spending a significant amount of capital excavating crack-like features. There is a need for improved assessment methods that integrates testing simulated / synthetic crack-like features. This paper will provide details on a study funded to systematically generate crack-like features in pipeline materials with the application of cyclic internal pressure loading. Synthetic crack-like features were generated in 12.75-inch x 0.250-inch, Grade X52 pipe material using electronic discharge machining (EDM) to form notches. Notch depths were 10% of the nominal wall and ranged from 1 inch to 3 inches in length. The pipe samples were then pressure cycled to achieve microcracking at the base of each notch. Initial stages of t program involved sectioning features to quantify crack growth levels. Once a systematic process for growing cracks from EDM starter notches had been validated, testing involved cyclic pressure fatigue to failure and burst testing. The advantage with the crack generation methodology used in this study was the ability to generate sharp, crack-like features without altering the microstructure of the pipe material in the vicinity of the feature. Programs such as the one presented in this paper are useful for both generating features in pipeline materials and also quantifying behavior of pipeline materials subjected cyclic pressure and burst loadi
Track 3: Pipeline and Facilities Integrity	Track 3.1	IPC2020-9254	John Kiefner	Peer Review of the Plausible Profiles Corrosion Assessment Model	An enhanced corrosion assessment model has been developed by TC Energy. The new model is called the "Plausible Profiles Model for Corrosion Assessment Psqr for short and is presented in IPC 2020 in a companion paper. The Psqr model uses a statistical approach for creating a number of plausible profiles along a corroded area. The predicted failure pressure for each plausible profile is calculated using RSTRENG, resulting in a statistical distribution of predicted failure pressures. The predicted failure pressure for the corroded area is taken to be the lower 5 th percentile value of the distribution. The Psqr model was validated by means of 30 burst tests. TC Energy showed that using the Psqr model versus using RSTRENG to grade ILI metal loss data results in far fewer excavations. TC Energy has created a Microsoft Excel, VBA-based computer program and user's guide for the execution of Psqr calculations. The progra the user's guide, and a technical report describing the development and validation of the model is available from the Pipeline Research Council International (PRCI). TC Energy requested PRCI to sponsor an independent review of the Psqr model by subject matter experts (SMEs). The PRCI Corrosion Technical Committee and TC Energy jointly selected a team of SMEs to conduct the review. The team was comprised of the following individuals: § Maher Nessim C-FER Technologies § Ming Gao Blade Energy Partners § Ravi Krishnamurthy Blade Energy Partners § Phil Hopkins Independent Consultant § Andrew Cosham Ninth Planet Engineering § Michael Rosenfeld RSI Pipeline Solutions § Bruce Nestleroth Kiefner and Associates, Inc. § John Kiefner RSI Pipeline Solutions The SMEs were provided with TC Energy's technical report and received oral presentations from TC Energy on the model to inform their review. Face-to-face meetings and conference calls were held to facilitate exchanges of information between the SMEs and the TC Energy team. As the result of their work, the SMEs recommended additional validation of the Psqr model using publicly available data and suggested improvements that strengthened the model. In response, TC Energy was able to improve the performance of the model, to show that the model is valid for a wide range of pipeline operating stress levels, to show that ILI tools can provide sufficient data for reliable calculations via the model, and to provide confidence that the model enhances safety in comparison to simpler models such as B31G and Modified B31G when used to evaluate ILI data. This paper describes the work carried out by the SMEs and presents their findings and conclusions. Basically, they found that the model is more accurate and exhibits less scatter than existing models such as RSTRENG, B31G, and Modified B31G. They recommended that the Psqr Model be implemented in conjunction with a high-quality corrosion management plan such as outlined in TC Energy's technical report, and they recommended specific minimum Psqr-predicted failure stress levels for use on pipelines being operated at maximum stress levels ranging from 40% of SMYS to 80% of SMYS.

Track 3: Pipeline and Facilities Integrity	Track 3.1	IPC2020-9470	Mohammad Al-Amin	Achieving Consistent Safety by Using Appropriate Safety Factors in Corrosion Management Program	Metal-loss corrosion anomalies identified by in-line inspection (ILI) or direct examination (e.g., laser scan in the ditch) are assessed by pipeline operators to determin remediation plan which determines the safety of the pipeline. Assessment of metal-loss corrosion anomalies can be performed either by deterministic or probabilistic methods. In deterministic method, the rupture pressure ratio (RPR) for a metal-loss corrosion anomaly is evaluated against a safe limiting RPR value as the rupture criteria, where RPR is defined as the predicted burst pressure of the anomaly divided by the maximum allowable operating pressure (MAOP) or maximum operating pressure (MOP). To prevent ruptures, operators will excavate any anomaly with RPR equal or less than the safe limiting value. The safe limiting RPR value is commonly referred to as the safety factor. In deterministic method, safety factors are used to account for the uncertainties of variables involved in metal-loss corrosion assessment such as measurements of metal-loss, pipe geometry, material properties and assessment model. Safety factors are established in various codes and standards in North America. However, those safety factors are not consistent across codes and standards. For example, ASME B31.8S-04 requires any metal-loss corrosion feature with RPR less than or equal to 1.10 (i.e., a safety factor of 1.10) to be excavated immediately regardless of the class location or design factor of the pipe, whereas the required safety factors in CSA Z662-19 are dependent on class location factor (e.g., a safety factor of 1.25 for Class 1 pipe in gas pipelines). There are also discrepancies in safety factors for metal-loss corrosion assessment between gas and liquid pipelines in North America. For example, the safety factor for immediate response criteria is 1.10 for gas pipelines in the code of federal regulation (CFR) Part 49 Subpart 192, whereas the safety factor for immediate response criteria is 1.0 for liquid pipeline in the CFR Part 49 Subpart 195. Similarly, the safety factors for scheduled response are not consistent. The scheduled response criteria in ASME B31.8S was developed assuming a conservative growth rate which is a function of the wall thickness. CSA Z662-19 uses one set of safety factors for both immediate and scheduled response criteria, but it requires that the growth of metal-loss corrosion features are explicitly accounted for in the scheduled response. Due to such discrepancies, the pipeline systems in North American are not managed to consistent reliability level. This paper describes the fundamentals of how appropriate safety can be assured for pipelines containing metal-loss corrosion by selecting appropriate safety factors. The safety factors required by various codes and standards in North America are compared. The effect of using different safety factors on the reliability level of the pipeline system is examined with case studies. The implications of safety factors for excavation decision based on ILI data versus the repair decision based on in-ditch assessment data is also demonstrated in this paper. Finally, a set of safety factors are proposed to ensure consistent safety level for both gas and liquid pipelines containing metal-loss corrosion for excavation and repair decisi
Track 3: Pipeline and Facilities Integrity	Track 3.1	IPC2020-9690	Shahani Kariyawasam	A Data Driven Validation of a Defect Assessment Model and its Safe Implementation	This paper presents the data analytics performed to ensure safe implementation of the Plausible Profiles (Psqr) corrosion assessment model, (presented in a compan paper at IPC 2020). These analytics were performed during the rigorous review of the model and its implementation by both internal (TC Energy) and external experts. This work addresses key questions posed during the review. As the validation of Psqr model was performed on a unique data set of metal-loss clusters that had ILI measurements, laser measurements (in-ditch measurements), and well monitored burst tests, it provided an unprecedented set of validation data that could represent many perspectives, such as model performance (with all other uncertainties removed), in-ditch decision scenario, and ILI based decision scenario. Moreover, the morphologies of the 30 clusters tested was a good representation of large clusters of corrosion that have failed historically in the pipeline industry. In studying the post-ILI failures due to corrosion in the industry it was found that morphology played a significant role. Previous model validations were mostly performed on simple single anomalies or simple clusters with few features. During the extensive review of Psqr model there was a set of recurring questions that emerged from pipeline integrity engineers, regulators, and consultants. These recurring questions and the ensuing data analytics used to address these questions are presented in this paper. The questions addressed in this paper are: 1. Does the unity plot of ILI-based burst pressure against laser-based burst pressure effectively demonstrate safety? Or can in-di validation verify the safety of a model? 2. Does simple or “conservative” model compensate for ILI error? 3. Does less “conservative” model reduce safety? 4. Do fewer digs lead to less safety? The analysis of this unprecedented and comprehensive set of data led to great learning and revealed how safety can be provided optimally with good understanding of how ILI uncertainties, model errors, in-ditch uncertainties, and safety factors interact and play into integrity. It also revealed the role of common misunderstandings that are barriers to effective pipeline integrity assessment. Overcoming these misunderstandings have helped in developing a more effective ILI based corrosion management program that will avoid more failures and reduce unnecessary integrity actior
Track 3: Pipeline and Facilities Integrity	Track 3.2	IPC2020-9331	David Heaney	A Feature-Specific Probabilistic Assessment of Pipeline Defect Size From Ili Mfl Signal Using Convolutional Neural Network	Uncertainty and measurement error need to be understood to effectively manage the integrity of a pipeline. In-line inspection data are inherently uncertain, which mea the reported dimensions of an anomaly may be higher or lower than the actual values. A pipeline operator will consider specified tool tolerance to ensure conservative assumptions are applied during anomaly dig selection. Actionable anomaly depth criteria, burst pressure calculations, and corrosion growth rate estimates are examples where potential for data uncertainty and bias need to be factored. One of the prevalent sources of uncertainty that needs to be factored is the model error in the estimation of feature depth and length from the in-line inspection tool. Due to modeling technique limitation, as of today, this error can only be reported to operators as an overall error known as the ILI tool tolerance which is usually obtained from samples of excavation data or pull test data. For example, a commonly reported corrosion depth sizing specification is ±10% of pipe wall thickness at 80% confidence. [HD1] This can be interpreted as that the error of each reported depth estimations is assumed to fall in a normal distribution with a mean equal to 0 and standard deviation equal to 7.8% of wall thickness. The shape of the distribution, mean and standard deviation will then be used as constants to factor in the burst pressure calculation. However, these factors are never constant for a sample of defects in reality. In fact, they ought to be variables on an individual feature basis. An example for this a feature specific error tolerance could be the estimated depth of a feature is 36% w.t. in an interval of [30%, 48%] of wall thickness with 80% confidence. This is believed to greatly reduce the level of uncertainty when it comes to failure pressure estimation or other type of pipeline risk assessment. The advancement in Machine Learning today, deep learning with deep neural networks in particular, allows feature-specific error tolerance to be obtained after analyzing visual imagery of MFL signal. In this paper we will describe a novel approach to predict the size of metal loss defe and more importantly the distribution associated with each prediction. We will then discuss the benefits of this approach has with respect to risk assessment such as failure pressure estimation. [HD1]Based on the Pipeline Operator Forum document. This is a standard sizing tolerance specification most commonly adopted I
Track 3: Pipeline and Facilities Integrity	Track 3.2	IPC2020-9386	Thomas Hennig	At the Forefront of In-Line Crack Inspection Services – a Highly Versatile Crack Inspection Platform for Complex Flaw Morphologies and Absolute Depth Sizing	In 2014, Enbridge published a request for proposals to develop and provide a solution on a specific type of long seam cracks in 26" pipeline. In-line inspection technologies available at the time were not able to consistently and accurately characterize the crack threat, although the line was successfully hydrostatically tested in 2015. During the early stages of the project, NDT Global analyzed in detail Enbridge's requirements, including the specific challenges, spool type, seam weld characteristics etc. and provided different proposals to Enbridge. In 2016, both parties signed a development contract to develop and build a 26" Next Generation Crack Detection Robot. The project was divided into various stages to support a successful project that met performance requirements based both on pump tests and a field trial supported by investigative digs and coupon cutouts. The robot developed is a highly versatile crack inspection platform: it allows to be set up in a configuration optimized for the given threat, pipeline conditions, inspection speed and medium characteristics. This optimization of the configuration allows choosing the optimum measurement modes for flaws in the base material and in the seam weld independently. Additionally, the local wall thickness even in the seam weld is measured accurately. These capabilities allow the operator to collect the best data for each situation. Feeding the information into the crack management program allows Enbridge to maintain the target reliability of the asset. The robot was utilized successfully in the 26" pipeline. Processing, data analysis and reporting were performed with pre-agreed periods. Initial field findings and lab tests show high correlation of ILI and real flaws and proof the stated accuracy of the new service. The authors will present in detail some of the specific challenges of the pipeline system and limitations of available crack inspection technologies. Validation results from in-the-ditch non-destructive examination and destructive freeze breaks including cross sections from flaws with complex morphologies will be shown. Performance statistics and comparison to previous inspection results will be used to demonstrate that the new robot can be used as part of an effective crack management program.&nbsr
Track 3: Pipeline and Facilities Integrity	Track 3.2	IPC2020-9495	Doug Dewar	Incorporating Inline Inspection Internal Measurement Unit Data Analysis Into Integrity Management Programs	Inline Inspection Internal Measurement Unit (ILI IMU) data analysis is a well understood but often under-utilized technology for detecting, defining, assessing ar monitoring soil to pipeline interactions caused by construction/maintenance activities, geohazards and buoyancy. The technology has been successfully used to detect landslide interactions since 1996 [1]. ILI Vendors generally provide the option for Operators to purchase an analysis that includes a strain feature summary and plots of individual features (Vendor Analysis). The Vendor Analysis is typically based on a preset curvature threshold across a weld or a run to run movement criteria. Vendor Analysis can identify major soil/pipeline interactions during an initial bending strain and subsequent run to run movement analysis. Additionally, Operators can request the ILI raw data for either internal or third-party analysis (Raw Data Analysis). Raw Data Analysis is typically used to define interactions and provide detailed pipe shapes/responses for modelling in known or suspected interaction features within discrete pipeline segments. Hart [2] defines the calculation methods for converting raw data into curvatures/strains and proposes a standard system of presenting Raw Data Analysis. An approach for determining if and what type(s) of ILI IMU analysis/data is required for individual ILI run segments is presented that can be applied to any size of pipeline system. A process for incorporating the data into an integrity management program is defined when Vendor Analysis and/or Raw Data Analysis would be required. Guidelines are provided for Operators to optimize spend/analysis efforts based on the hazards encountered in individual line segment/systems. The process includes feature screening, integrity/geotechnical specialist review and risk control/mitigation measures, if required. To facilitate the feature screening process, a classification system for ILI IMU features is presented based on type, activity and source modified from the system presented in [3]. The screener incorporates orthophoto/LiDAR, construction/maintenance activities, geohazard, interacting anomaly and company record data into the screening process to identify features that require geotechnical/integrity specialist review. Work flow diagrams are presented for the process. [1] Czyz, J and McClarty, E. 2004. Prevention of Pipeline Failures in Geotechnically Unstable Areas by Monitoring with Internal and Caliper In-Line Inspection. Proceedings of IPC2004 5th International Pipeline Conference , Calgary . [2] Hart, J., 2016. Utilization of IMU Data for Identifying Strain Locations of Interest. In Management of Ground Movement Hazards for Pipelines. Edited by Wang, YY., West, D., Dewar, D., Hart, J., McKenzie-Johnson, A. and Gray, D. J.I.P. report prepared by Center for Reliable Energy Systems, Dublin, Ohio. [3] Dewar, D., Elseify, M., Van Boven, G., Bjorn, P, and Bruce, N. 2018. Operational Experiences with Axial Strain Inline Inspection Tools. Proceedings 11th International Pipeline Conference, Calgar
Track 3: Pipeline and Facilities Integrity	Track 3.3	IPC2020-9486	Jeremiah Konell	A Midstream Pipeline Operator’s Perspective on the Implementation of Api 1183	In preparation for the upcoming (currently in draft) Recommended Practice (RP) on Dent Assessment and Management (API 1183), Explorer Pipeline Company, In (Explorer) has performed an internal procedural review to determine how to effectively implement the methodologies into their Integrity Management Program (IMP). Explorer’s pipeline system transports hazardous liquids and is comprised of over 1,800 miles of pipeline ranging in diameter from 6 to 28 inch. The majority of the system was installed in the 1970s, but parts of the system were also installed as early as the 1940s. The primary focus of this review and implementation into the IMP is in regard to performing and responding to in-line inspection (ILI) based integrity assessments. Prior to the development of API 1183, dent assessment and management consisted of following a set of prescriptive condition assessments outlined in the Code of Federal Regulations (CFR) Title 49, Part 195.452. In order to do this, pipeline operators required basic information, such as dent depth, orientation, and interaction with potential stress risers such as me loss, cracks, gouges, welds, etc. However, in order to fully implement API 1183, additional parameters are needed to define the dent shape, restraint condition, defect interaction, and pipeline operating conditions. Many new and necessary parameters were identified throughout the IMP, from the very initial pre-assessment stage (new ILI vendor requirements as part of the tool/vendor selection process) all the way to defining an appropriate reassessment interval (new process of analyzing dent fatigue life). This paper summarizes the parameters of API 1183 that were not part of Explorer’s current IMP. The parameters are identified, and comments are provided to rank the level of necessity from “must have” to “beneficial” (e.g. can sound and conservative assumptions be made when a parameter is not available). Comments are also provided to explain the impact of applying assumptions in place of parameters. The table of identified parameters should provide a useful tool for other pipeline operators who are considering implementing API 1183 as part of their overall IMP.&nbs

Track 3: Pipeline and Facilities Integrity	Track 3.3	IPC2020-9544	Rogelio Guajardo	Cracks in Dents: How Can I Use an Ultrasonic Crack Ili Robot to Detect Them?	Cracks in dents or linear anomalies interacting with dents are a major threat for the pipelines. These combined anomalies represent challenges to the Mechani Engineers that design the ILI robots as they need to keep the sensor in an optimal position towards the inner pipe wall. Ultrasonic Crack (UC) robots consist in a sensor plate with a fixed incidence angle that depends on the coupling medium. This plate is then attached to the skids; these are in constant contact with the internal pipe wall. When the robot interacts with a dent, the incidence angle is not optimal; therefore, detection of any interacting feature is compromised. By not having the optimum angles in the pipe wall, the amplitudes from the reflections caused by cracks will be attenuated. Depending on the magnitude of the attenuation, these might be below analysis thresholds meaning that an algorithm and/or analyst will not consider them as relevant signals. Up to this point, detection of interacting features sounds like a "guess" or "luck". So, how can we use an UC inspection to detect the interacting features? How can operators manage their assets knowing that they have dents but there is an uncertainty if there are interacting features? To answer these questions, a systematic approach had to be used. It consisted in multiple phases where 1.- the mechanical design of the robot was understood, 2.- simulation campaigns to understand the ultrasonic pulse while interacting with the dent, 3.- pump tests with artificial features, and 4.- pump test with real features. All of the data gathered through the different phases allowed the authors to understand the attributes from the features and conditions that influence detection and identification of cracks in dents. This derived in a performance specification stating the truth capabilities to detect interacting features in a dent. These learnings were applied to commercial inspections where the feedback loop is closed with the field verificatio
Track 3: Pipeline and Facilities Integrity	Track 3.3	IPC2020-9575	Brian Leis	Continuing Development of Criteria to Quantify Metal-Loss Severity, Including Width	The emergence in the early 1970s of what about a decade later became the first release of ASME B31G began the sequence of what became the continued developm and evolution of criteria to assess the severity of metal-loss defects. Motivated by the desire to reduce the conservatism built into B31G, the late 1980s saw the release of Modified B31G. That same report considered the piecewise application of that Modified criterion along the “riverbottom” in a process that was termed RSTRENG. As modern higher-strength, high-toughness line-pipe steels emerged, by the mid-1990s it was clear that application of those just noted criteria to metal-loss in such pipes could lead to quite conservative predictions. Again, motivated by the desire to avoid excessive conservatism in applications involving modern steels, several alternative criteria emerged in quick succession. PCORRC appeared in the spring of 1997, with early versions of DNV RP-F101 and British Gas’ LPC-1 criteria following shortly thereafter. In contrast to the early criteria that relied on empirical fits to test data for various Grades of steel, the effects of the defect for each of these 1990s schemes were quantified by trending results from parametric FEA. The defect-free resistance to failure also differed, as these 1990s criteria defined failure in reference to the UTS, in lieu of the previously used flow stress concept. It has since become evident for isolated smooth-bottomed featu that in addition to feature length, L, and depth, d, its width, W, can be a factor, as can its through-thickness profile, and its in-plane ratio of L to W, herein termed aspect ratio. Since the mid-90s sometimes subtle variations on these approaches have proliferated, with more than 25 such criteria now in the open literature. One of the more significant developments in this context came in 2005 in work by Zhu and Leis. This work showed that the strain-hardening exponent can be a factor the failure pressure of defect-free line pipe, and as such also could be a factor where metal-loss features develop. This paper builds on this wealth of knowledge presenting and validating a Level 1 failure criteria for isolated metal-loss features. The defect-free term in this Level 1 criterion is based on the Zhu-Leis criterion for defect-free pipe response. That defect-free resistance is coupled to a recalibration of the Leis-Stephens defect term in PCORRC, which herein is extended to include the effects of width. The resulting Level 1 criterion is validated in reference to full-scale tests of pipe with metal-loss that include the mix of real corrosion and flat-bottomed machined features. These tests involve line-pipe Grades from Gr B to X100, and consider a wide range of diameters and wall thicknesses. Many of these tests consider the effect of width, in addition to the more commonly studied parameters. Finite element results are introduced to illustrate the role of width in the failure behavior of metal-loss features. Benchmarked against more than 150 full-scale tests it is shown by comparison with other of the often-cited metal-loss criteria that this new approach affects a reduction in conservatism. At the same time, it provides clear benefits in regard to reduced predictive scatter, as well as a reduction in required maintenance and the scope of features that must be considered in field digs.&nb
Track 3: Pipeline and Facilities Integrity	Track 3.4	IPC2020-9231	Hamid Mostaghimi	Dynamic Stress Analysis of an Exposed Pipe Subjected to Moving Ili Tool	Pipelines are one of the most reliable, environmentally responsible, and economical means for transporting oil and gas from production wells to processing a consumption sites. However, pipelines are susceptible to degradation over time due to various types of defects, temperature variations, and boundary conditions. In-line inspection (ILI) is a non-destructive assessment method commonly used for defect analysis of pipelines by using an inspection gauge. The passage of an ILI tool through an exposed section of pipe during an integrity assessment can excite vibrations and exert substantial forces, stress and deflections on the pipe due to weight and speed of the tool. When the excitation frequency due to ILI movements is close to the natural frequency of overall structure, the dynamic stress generated within the pipe can be sufficiently large to impose integrity concerns on the line. This research aims to study effects of the ILI tool passage through floating and partially supported pipes under a variety of boundary and loading conditions. Therefore, a combination of analytical and finite element (FE) methods are used to model the pipe, soil boundaries and mov ILI tool. The model is developed based on 1D Timoshenko beam theory with planar degrees of freedom and differential equations of motion will be solved numerically to predict displacement, strain, and stress as well as frequency response of the pipe. A finite element model in ABAQUS is also developed to verify the proposed model. T model is further validated using a lab-scale experimental setup powered by an electric motor to pull a mass inside an exposed pipe. The setup has been designed and fabricated in such a way to cover a wide range of speeds up to 10 m/sec. The comparison of the simulation and experimental results show that the proposed model is capable of predicting pipe dynamics effectively
Track 3: Pipeline and Facilities Integrity	Track 3.4	IPC2020-9288	Mohamed Elseify	Slope Movement Inspection Using Axial Strain Data Across Multiple Lines and Repeat Inspections	Axial strain inspection using the AXISS TM service is well established as a key tool in the pipeline operator’s toolbox to assess pipeline geotechnical threats and oth strain related events. Over the years, the number of inspections using the axial strain tool has been increasing and there is now a rich set of axial strain data on a large number of different pipelines operating in different environments as well as from multiple inspections at the same geographical locations. The Cheecham slope, located south east of Fort McMurray, Alberta, is a known geohazard site crossed by six individual pipelines. The lines were constructed between 1999 and 2013 with sizes ranging from 10” to 36”. Five out of the six lines, 12” to 36”, have been inspected using the axial strain tools. The pipelines inspected cover a wide range of characteristics including, different vintages, diameters and positions in the ROW. These differences, along with the number of inspection runs, provide an insight into the effect of a landslide event on the strain response of the pipelines. The axial strain measurement of the multiple pipelines in the Cheecham slope’s ROW allows: i) a direct comparison between lines ii) evaluation of the strain profile across the slope iii) assessment of the magnitude of the axial strain in terms of pipe characteristics e.g. pipe vintage and mechanical properties. More importantly, the axial strain data may provide a further tool to assess the effectiveness of strain mitigation steps undertaken by the operators over the years. As the frequency of axial strain ILI runs increases, additional data becomes available and more importantly data from repeat inspections spread over months or sometime years. Whereas a single run captures the strain at the time of inspection, repeat inspections provide an additional comparative tool for the evaluation and monitoring of the pipeline movement. Two out of the five lines inspected have data from repeat runs available. Initially, strain comparison analysis was focussed on specific mitigation projects such as strain relief operations. However, this is now becoming a growing part of the analysis deliverables as more data from repeat inspections becomes available. This paper takes the Cheecham slope as a case study to discuss the benefits of run-to-run analysis of ILI axial strain data either by comparing strain values of repeated runs for one line or by the direct comparison of strain responses of lines in same ROW. The paper aims to demonstrate how run-to-run analysis of ILI axial strain data can be implemented as part of geohazards risk management programs to asses strain risk profiles of these locations and to assess the effectiveness of strain mitigation programs previously used by operators in these high risk are
Track 3: Pipeline and Facilities Integrity	Track 3.4	IPC2020-9478	Shenwei Zhang	Improved Surface Loading Stress Analysis Method Considering Protection Measures	This paper presents a method to evaluate pipe stress induced by the surface vehicle loading at uncased road crossings that are protected by mat or bridging. Wh vehicles cross an existing pipeline, additional circumferential and longitudinal pipe stresses induced by surface vehicle loadings should be comprehensively considered to ensure pipe integrity and safe operation. Surface protection measures are sometimes installed to distribute the surface loading away from pipe centerline and reduce “footprint pressure”. There are two typical protection measures used in practice, namely mat protection or bridging. The protective mats, typically in a format of timber mat, rig mat, steel plate or concrete slab that are laid on the right of way, reduce the footprint pressure by distributing the vehicle load to a larger area and dispersing it away from the pipeline. The pressure reduction depends on the area of mat that effectively contributes to load distribution. CEPA report (Development of a pipeline surface loading screening process and assessment of surface loading dispersing method-Report No. 05-44R1) recommended an approach to evaluate the effective area of protective mat. It has been recognized that the CEPA equation need improvement to consider the effect of footprint of tires. As such, a modified CEPA equation was proposed in this paper and validated by comparing with the results from continuum FEA. The effective length calculated by the modified equation show good consistency with the FEA-predicted effective length. Parametric analyses were carried out to demonstrate the effectiveness of various type of mats in the reduction of surface loading stress. Bridging is another type of protection measure used in the field to mitigate the surface loading stress. The reduction of surface loading stress depends on the free span of bridge. In practice, stress analysis is not typically performed to evaluate the pipe stress with bridging protection. As a result, the free span of bridge is usually specified a standard value (e.g. 2 times depth of cover) that is large enough to reduce the surface loading stress to as low as zero. However, the standard value sometimes might not be feasible due to the restriction of site space, e.g. a tight space with multiple parallel lines or with a challenging terrain. Therefore, an approach was proposed in this paper to evaluate the pipe stress with user-defined free span of bridging, which provide flexibility for optimizing bridging protection in the field. Case studies were presented in the paper to demonstrate the application of the proposed methods. The proposed methods will benefit pipeline operators because they can be used to develop cost-effective protection measures for vehicle crossing while assuring safety of pipeline operatior
Track 3: Pipeline and Facilities Integrity	Track 3.5	IPC2020-9251	Cory Wargacki	Applying Advanced Ultrasonic In-Line Inspections Technologies to Effectively Manage Hook Cracks	Axial cracking inspections have become common place on a global level within pipeline operator’s integrity management programs. As technology continues improve, operators are presented with more accurate assessments of the assets that are in current operation. However as more information is collected more threats are being identified and need to be assessed in a manner that is more applicable to their specific morphology. It is well known that vintage ERW manufacturing techniques can suffer from a wide range of potential threats such as lack of fusion or inclusions within the steel forming hook cracks during the rolling and welding process. Current In-line inspection technologies that are designed to detect, Identify and size crack-like flaws in pipelines are very proficient at doing so. However, due to the physical principals of the Ultrasonic pulse echo technology, deep features approaching, or above pulse echo saturation amplitudes pose challenges in determining accurate depth sizing. In 2015 a Canadian pipeline operator determined the need to inspect one of their 16" assets for axial crack-like indications. During the analysis of this inspection data set a number of saturated crack-like indications were reported. Saturated crack-like signals present a challenge to operators as they have to be considered in a conservative manner as 4mm or deeper which in turn leads to a higher cost associated with their excavation program. The operator approached NDT Global in 2017, after the release of NDT's Enhanced sizing depth algorithm to reevaluate the features that were present in the previous crack inspection data set. Working together with the operator, NDT global applied the Enhanced sizing methodology to all features of significance in the pipeline segment and compared the results to lab measurements and in field NDE measurements from an array of different NDE vendors and technologies. The outcome of the reanalysis using the most up to date software algorithms utilizing enhanced sizing showed great benefits by increasing the accuracy of the crack depth sizing as NDT w now able to report full through wall depth sizing, however there were still some limitations on the ability to accurately size crack-like features as the primary threat is believed to be a result of hook cracks As a final step in this program NDT Global was provided sample spools that were cut out of the pipeline segment to perform a pul testing campaign utilizing the newest crack detection technology that was specifically targeted towards accurately sizing tilted and skewed crack like features. The authors will briefly discuss the pipeline system and inspection campaign and in detail will discuss the benefits to use technology that has been developed to help pipeline operators better understand the threats in their integrity management program and how this approach can benefit the overall efficiencies of managing a pipeline system where critical defects can be present

Track 3: Pipeline and Facilities Integrity	Track 3.5	IPC2020-9465	Chris Davies	Managing the Threat of Selective Seam Weld Corrosion Using a State of the Art Ili System	For many years, pipeline safety regulations in the US have defined prescriptive minimum requirements for integrity management combined with a clear expectation th operators should do more than the minimum where appropriate. The regulations have also provided operators with the flexibility to take a performance based integrity management approach leveraging as much information available to manage threats effectively. One the threats that must be managed is Selective Seam Weld Corrosion (SSWC). SSWC is an environmentally assisted mechanism in which there is increased degree of metal loss in the longitudinal weld in comparison to the surrounding pipe body. An appropriate definition is linear corrosion that is deeper in the longitudinal weld zone than the surrounding pipe body. In some cases, the surrounding pipe body may have limited or no corrosion present, and in other cases the pipe body corrosion may have occurred but at a slower rate than the local corrosion in the longitudinal weld zone. Conventional responses to potential or identified threats focus on in-situ investigations, often resulting in expensive and un-plan repairs for features reported by In-line Inspection (ILI) that when assessed properly demonstrate a remnant life well into the next inspection interval. When ILI identifies metal loss indications co-located with the longitudinal seam weld, the current prescribed response is often a blanket call for remediation. Such a response may not be appropriate if an ILI system is deployed to discriminate feature types and integrity assessment is exercised leveraging a sound understanding of the pipe's material properties. This paper describes the approach taken by a North American Liquid Pipeline operator to manage the threat of SSWC. The foundation of the approach was deployment of an appropriate ILI system incorporating an effective ILI technology, an optimized evaluation process considering the specific threat morphology, material testing and a structured dig program. The evaluation process uses the ILI data and data from the field in combination material properties data and a susceptibility analysis to classify anomalies as "Likely", "Possible" and "Unlikely" SSWC. This is aligned with the guidance in API RP 1176 "Assessment and Management of Cracking in Pipelines" [9] for defining an appropriate response to ILI calls. Approaching the management of SSWC in this way allows operators to define a structured response for excavation activities to verify the process and remediate features as required. By using likelihood classification the risk to pipeline integrity can be reduced by acting on most likely SSWC features as a priority, whilst collecting the data needed to make informed decisions on where to focus resources and efforts on what is a very complicated and difficult to manage threat. The output form this work, including a future plan for managing the remaining metal loss features, was documented in a procedure that was incorporated into the existing Integrity Management Plan.&nbs
Track 3: Pipeline and Facilities Integrity	Track 3.5	IPC2020-9494	Jake Phlipot	Overcoming Challenges of Emat In-Line Inspection Validation for Scc Management in Natural Gas Pipelines - a Practical Approach	Pipeline operators rely on a variety of tools and technologies to manage threats to their pipeline assets. For natural gas pipelines, the management of Stress Corros Cracking (SCC) has benefited from the introduction and evolution of in-line inspection (ILI) technologies, specifically Electro-Magnetic Acoustic Transducer (EMAT) technology, that can reliably detect, identify and size cracking anomalies. Since its introduction in the early 2000's, the performance of EMAT technology has been evaluated and documented through many industry research projects and published articles that describe operational experiences. This paper builds upon that body of shared knowledge to provide an update of observed EMAT performance on a gas transmission system that has undergone extensive EMAT ILI assessments, on a large number of pipeline segments, with a specific focus on the practical strategies employed to overcome the challenges unique to EMAT ILI validation. First discussed is an overview of a practical framework for aligning EMAT ILI validation with API 1163 guidance and establishing a means of tracking program performance within groups of essential variables. Some of the key challenge areas encountered as it relates to EMAT ILI and the solutions employed for overcoming these challenges are discussed for the following: small sample populations, nuances with the EMAT detection and reporting criteria, determining feature types by vendor tool and category to target, selecting validation excavation targets for: 1) no reportable features and 2) too many reportable features and managing manufacturing related findings. This is followed by a discussion of the triggers established to interrogate EMAT ILI data quality for circumstances including overspeed areas, loss of sensor coverage, degraded data or results mis-aligned with historical findings or subject matter expert (SME) understanding. Strategies applied for developing validation excavation targets to interrogate the potential for false negatives using data integration and overlays are presented along with a framework for a root cause analysis process with the vendor for false negative or outlier findings. Opportunities for leveraging additional EMAT ILI inputs such as indications below reportable specification (IBS) feature data, coating condition data and targeted signal reviews/comparisons are highlighted. This will serve to provide an industry update on the observed performance of the latest EMAT ILI technology and the means of overcoming EMAT ILI validation challenges as applied to a recent and extensive SCC assessment program. The paper concludes with a discussion of strategies employed and results obtained from specific, supplemental activities such as hydrotesting of selected segments that have been assessed through EMAT ILI, comparison of consecutive but different vendor EMAT inspections and leveraging data recorded during failed inspections and subsequent re-inspections to validate tool repeatability, and augmentation with additional integrity and ILI data streams, all applied as a means of further validating and quantifying EMAT ILI results. A summary of lessons learned and opportunities for improvement from the overall EMAT ILI validation program is also presente
Track 3: Pipeline and Facilities Integrity	Track 3.6	IPC2020-9572	Thomas Dessein	Characterizing Corrosion Defects With Apparent High Growth Rates on Transmission Pipelines	Multiple in-line inspections of transmission pipelines enable a comparison between inspection results to characterize corrosion growth. Despite the high levels of in-li inspection tool accuracy and detection capabilities, matched defects on consecutive inspections may have a distribution of growth rates that spans from unrealistically lo (negative in some cases) to extremely high. Additionally, corrosion defects with low calculated burst capacities may be detected on a subsequent inspection that were not reported in a previous inspection. These newly reported defects pose a substantial challenge as the apparent growth rates between inspections of these defects can potentially drive unnecessary repair digs. This paper characterizes the contributing factors that can explain these phenomena, including: · Realistic growth rates and their associated statistical frequency · The diminishing detection capability of inspection tools for smaller defects · The inspection tool reporting threshold · The measurement accuracy of inspection tools A statistical analysis was utilized to establish both the probabilities that each of these factors are plausible explanations for the observed unrealistic growth rate distributions, and the number of seemingly "new" defects that were not reported in a previous inspection. For a range of simulated defect sizes, the distribution of measurements that could be reported by the tool was established by considering the tool measurement accuracy. The likelihood that a defect would be reported was determined using both the inspection tool's probability of detection as a function of defect size, and the reporting size threshold. A distribution of realistic growth rates was then applied to grow each defect to the time of a second inspection. After considering the tool measurement accuracy for the second inspecti the observed growth rates were calculated using the reported defect sizes for each inspection and the time between inspections. From the results, the relationship between pipeline inspection interval and the rate of unnecessary repairs was examined. This work provides a methodology to assess the likelihood that unusual corrosion growth rates are present on a pipeline, or instead if the apparent defect population growth rates can be explained by the characteristics of the inspection t
Track 3: Pipeline and Facilities Integrity	Track 3.6	IPC2020-9601	Dongliang Lu	Full-Scale Pull Testing Study of the Mfl-a Performance Within Casings to Improve Ili-Based Corrosion Management of Cased Pipes	High resolution magnetic flux leakage (MFL) in-line inspection (ILI) technology has proven to be one of the most effective approaches to manage corrosion anomalies pipeline industry. However, pipeline casings are suspected of compromising the performance of MFL tools. A research project was carried out by TC Energy with ROSE to better understand the effect of pipeline casings on the performance of the MLF ILI technology. The study involved full-scale pull through testing to investigate effects of various casing conditions and the presence of different types of casing spacers on the tool's sizing and detection performance for corrosion anomalies, including the casing eccentricity, the presence of metallic and electrolytic shorting and the presence of different types of casing spacers. The testing for various eccentricity and shorting scenarios were compared to an uncased baseline scenario. To quantify the effect of various casings conditions and different types of spacers on the MFL tool performance, comprehensive data analytics were performed to analyze the results obtained from the full-scale pull through testing. The analysis identified the dominant factors that influence the tool's detection and sizing performance for cased pipes, including the annulus gaps between the casing and the carrier pipe at the feature location, and the presence of certain type of spacers. Using the full-scale pull through testing data, probabilistic characterizations of the tool's sizing and detection performance corresponding to ranges of these factors were obtained. The probabilistic characterizations of the tool performance within casings obtained from this study can be incorporated in TC Energy's comprehensive probabilistic ILI-based corrosion management program. Case studies demonstrated that with appropriate consideration of the tool performance, TC Energy's probabilistic ILI based corrosion management program would potentially be able to effectively manage corrosion anomalies within cased pipes using ILI and additional research and testing is underway to support this conclusio
Track 3: Pipeline and Facilities Integrity	Track 3.6	IPC2020-9746	Jennifer Sargent	When Metals and Microbes Meet – Preventing Microbial Corrosion in Oil and Gas Transmission Pipelines	Corrosion of carbon steel infrastructure in the oil and gas industry can occur via a variety of chemical, physical, and/or microbiological mechanisms. Althouc microbial corrosion is known to lead to infrastructure failure in many upstream and downstream operations, predicting when and how microorganisms attack metal surfaces remains a challenge. In crude oil transmission pipelines, a kind of aggressive corrosion known as under deposit corrosion (UDC) can occur, wherein mixtures of solids (sands, clays, inorganic minerals), water, oily hydrocarbons, and microorganisms form discreet, (bio)corrosive sludges on the metal surface. To prevent UDC, operators will use physical cleaning methods (e.g., pigging) combined with chemical treatments such as biocides, corrosion inhibitors, and/or biodispersants. As such, it necessary to evaluate the efficacy of these treatments in preventing UDC by monitoring the sludge characteristics and the microorganisms that are potentially involved in the corrosion process. Microorganisms are often monitored in oil and gas systems using growth-based tests, which provide good baselining data for many operations, but do not capture all the kinds of microorganisms that may be involved in UDC. Newer genetic detection techniques for microorganisms (often referred to as next generation sequencing, NGS) are being used more frequently in the oil and gas industry to monitor for and detect potential microbial corrosion and the efficacies of chemical treatments. In this study, we evaluated the efficacies of a biocide and biodispersant being used to prevent microbial corrosion in a large dual diameter crude oil transmission line. Growth-based tests and NGS were used to evaluate the efficacy of the biocide alone, the biodispersant alone, and the combination of both chemicals. The results indicated that the combined treatment was the most effective in preventing metal damage, and both growth-based and NGS approaches provided value towards understanding the effects of the chemical treatments. Sludge samples were collected following pigging operations conducted several months later on the same pipeline segment to demonstrate the importance of repeated sampling and monitoring to ensure ongoing pipeline integrity. The results of this study demonstrate the importance of considering and monitoring for microbial corrosion of crucial metal infrastructure in the oil and gas industry.
Track 3: Pipeline and Facilities Integrity	Track 3.7	IPC2020-9548	Taylor Shie	Integration of Multiple Ili Technologies for Robust Understanding of Unique Anomalies on a Pipeline	Pipeline operators have many choices when selecting in-line inspection (ILI) vendors and technologies. No one technology has a one hundred percent probabi of detection (POD), identification (POI), and sizing (POS) for all anomaly types. Operators must match the threats on their system to the existing capabilities of the ILI technologies to achieve the goals defined by company's integrity management program. It is sometimes necessary for operators to run multiple technologies both at the same time of the integrity management cycle as well as during the lifetime of the pipeline. Shell Pipeline Company, LP (SPLC) has a pipeline that comprised of 83% low frequency electric resistance welded (LF-ERW) pipe from Youngstown Sheet and Tube, 13% seamless pipe from National Tube, and 4% high frequency electric resistance welded (HF-ERW) pipe. The LF-ERW and seamless pipe were installed in 1948 while the HF-ERW was installed during relatively recent replacement projects. From 2015 through 2018, SPLC executed an extensive integrity management program. This included two deformation surveys, two circumferential magnetic flux leakage (CMFL) surveys, an axial magnetic flux leakage survey (AMFL), an ultrasonic wall measurement (UTWM) survey, an ultrasonic crack detection (UTCD) survey, an electro-magnetic acoustic transducer (EMAT) survey, and a hydrotest. A dig campaign of nearly 100 excavations was completed as a result of these surveys. This paper shares some of the unique anomalies found through the dig campaign identifying the effectiveness of each technology and their combination for integrity purposes. The paper shows the benefits of combining ILI technologies to properly characterize, assess and mitigate reported anomalies and ensure there are no blind spots in the integrity management program. Case studies including dent with gouge (e.g. AMFL + Deformation), manufacturing, and cracking anomalies as well as the analytics of ILI versus field findings are presented and discussed in the paper. The paper concludes with the knowledge creation resulting from multiple ILI technology integration assisted with SME experience and analytics to provide a robust understanding of unique anomalies in pipelin

Track 3: Pipeline and Facilities Integrity	Track 3.7	IPC2020-9696	Bo Wang	Burst Pressure Prediction of Pipes With Scc Colonies - Evaluation of Intelligent Flaw Interaction Rules Using Full-Scale Burst Tests	This is the second paper in a two-paper series which cover the work funded by PRCI aimed at developing intelligent flaw interaction rules (termed PRCI-CRE rules). The focus of the first paper was on the development of the rules. This paper covers the full-scale burst tests conducted for the evaluation of the rul The full-scale burst tests involve four pipe segments with SCC colonies. Two pipe segments had 20" OD, 0.25" wall thickness, X60 grade, and DSAW seam welds. The other two pipe segments had 18" OD, 0.25" wall thickness, X60 grade, and spiral seam welds. The SCC colonies were characterized by different NDE methods including MPI, PAUT, IWEX, and Eddy Current Array (ECA). The full-scale burst tests were instrumented with a camera mounting and recording system to record the crack opening and pipe burst failure. For the burst pressure prediction, an equivalent crack size was determined by using the different flaw interaction rules with the inputs from various NDE methods. Then the modified Ln-sec method was used to predict the burst pressure by taking the equivalent crack size and the measured pipe material properties from the small-scale tests. The comparison between the burst pressure from the full-scale burst tests and from the prediction demonstrates that the PRCI-CRES rules are the most accurate and precise for burst pressure prediction, with a mean being close to 1 and small standard deviation in the burst pressure ratio. The burst pressure ratio is defined as the burst pressure from the full-scale burst tests over the burst pressure from the prediction. When the burst pressure predication can be both accurate and precise, appropriate safety factor can be selected to achieve consistent level of conservatism in burst pressure prediction. The FEA and the full-scale burst tests demonstrate that the PRCI-CRES rules capture the fundamental of flaw interaction. Burst failures are mainly driven by the crack driving force at the deepest point of the dominant cracks (i.e., long and deep cracks). During the full-scale burst tests, the deep crack opens and grows through the pipe wall to cause the crack to leak first, then the crack prorogates and grows in the pipe longitudinal direction. The newly developed PRCI-CRES rules provide more consistent burst pressure prediction than the existing flaw interaction rules. The application of the rules is expected to improve the accuracy of burst pressure prediction that can lead to more consistent conservatis
Track 3: Pipeline and Facilities Integrity	Track 3.7	IPC2020-9705	Sanjay Tiku	Full Scale Test Validation of Fatigue Crack Growth Rate of Flaws in Erw Pipe	While the general fracture mechanics methodology for calculating fatigue lives is well documented and validated, its application in the definition of pipeline system fatig lives have differed from field experience. The source and magnitude of the conservatism inherent in the calculated fatigue life estimates are a concern when establishing integrity management programs. Of particular interest are the fatigue life estimates used in the integrity management programs for ERW pipeline systems that are primarily concerned with pipe wall anomalies oriented along the pipe axis. BMT Canada Ltd (BMT) was contracted by Pipeline Research Council International (PRCI) to develop pipeline material fatigue crack growth database and conduct full scale cyclic pressure fatigue tests to validate the use of recommended crack growth rate parameters A pipeline material fatigue crack growth database was developed using 185 fatigue crack growth rate tests carried out on 45 pipeline materials ranging from Grade X46 to Grade X70 from 1937 vintage to 2014. The database included fatigue crack growth rate tests on 18 base materials and 27 ERW weld seam materials at two different stress ratios of R-ratio = 0.1 and R-ratio = 0.6. The sampled crack growth rates observed in the pipeline steels, tested in the present project, are 2 to 3 times lower than the recommendations for fatigue crack growth rates in BS 7910. The report presents proposed power (Paris) law fatigue crack growth equation parameters, C and m, developed for the base material and ERW of steel pipelines tested in the current program. Two full-scale cyclic pressure tests were carried out to validate the use of recommended crack growth rate parameters. Axial flaws were machined in pipe body and weld center line (WCL). Fifty-one (51) flaws of different lengths and depths were machined. The crack growth rates were monitored during the cyclic pressure tests through recording crack mouth opening displacement (CMOD). The calibration curves for correlating CMODs with crack depths were developed and validated against finite element (FE) analysis. The fatigue crack growth rates observed in the full-scale tests were compared with existing BS 7910 and API 579 formulations. The comparisons were carried out using fatigue crack growth rates as recommended by BS 7910 and API 579 as well as using crack growth rate parameters developed in the current project. The comparison showed that BS 7910 approach resulted in very conservative estimates of fatigue crack growth rates of axial flaws. BS 7910 stress intensity factor formulation overestimated the bulging correction for axially oriented flaws. The API 579 fracture mechanics-based fatigue crack growth formulation using crack growth rate parameters developed in the current program (PRCI crack growth rate parameters) provided reasonable estimates for fatigue life. The fatigue crack growth rates for linepipe and ERW weld seams developed in this project are demonstrated to be less conservative and better predicters for fatigue crack growth and represent a valuable tool for pipeline integrity management. The use of this information will focus remedial actions on those features that are most deservin
Track 4: Operations, Monitoring, and Maintenance	On Demand	IPC2020-9247	Fabien Ravet	Sand Dune Migration Monitoring for Pipeline Hazard Risk Mitigation: The Peru Lng Coastal Section Case	Pipelines often cross challenging terrains where natural hazards are the main risk for their integrity. Environmental conditions can also worsen over t infrastructure lifetime. To reduce the risk of disasters, integrity programs are developed and require tools for early detection of threats that can lead to a failure with dramatic social, environmental and economic consequences. Fiber optic (FO) monitoring solutions have been widely used and implemented as one of the most efficient prevention tools of these programs. These solutions include geotechnical monitoring, third party intrusion detection and eventually small or pinhole like leak detection. FO based geotechnical monitoring is successfully in operation to detect landslides and erosion along the Sierra section of the Peru LNG pipeline since 2010. It also has been implemented in along other hydrocarbon transport systems to allow the early detection of such events. However, these natural hazards are not the only ones threatening the pipeline. In fact, the coastal section experiences other phenomenon such as sand dune migration and eolian erosion that put the pipeline at risk. Recently, the monitoring was extended to the coastal region using the existing communication fiber optic cable to sense temperature changes. Very localized events are thermally detected, their spatial and temporal signature analyzed. The comparison of these data with thermal models identified sections that are near to be exposed or whose soil cover is less than 50cm over a spatial extension that does not exceed a couple of meters. Depth of cover of 10 to 30cm are estimated from such analysis. These results are confirmed by past and ongoing site inspections. Such positive result again illustrates the potential value of fiber optic sensing to mitigate geohazard risks. It not only enhances the efficiency of the integrity program detecting and localizing threats, it also improves and rationalizes the maintenance activities as focused surveys can be conducted. &nbs
Track 4: Operations, Monitoring, and Maintenance	On Demand	IPC2020-9260	Peter Song	Enhancing Flooding Monitoring and Response to Improve Geohazard Management	In March 2019, snow melt and heavy rainfall resulted in major flooding at one of Enbridge's (Company) pipeline river crossings. Based on an earlier hydrotechni assessment, it was identified that the estimated scour in the river channel during a flood event of this magnitude could have the potential to create a pipe span of length where vortex induced vibration (VIV) may be initiated. As a precautionary measure, the Company shut down and isolated the pipeline; the two mainline block valves on either side of the river were closed for several days. This un-planned pipeline shut down impacted our customers and resulted in revenue loss. An extended shutdown period would have also impacted downstream refineries. In order to promptly restart of the pipeline, bathymetric surveys were performed in high flow conditions to verify the pipeline burial condition. This crossing had been identified in the Company's long range forecast with a planned remediation completion in 2020. However, the potential residual threat to the integrity of the pipeline due to high flow events exists until the remediation could be completed. Consequently, our Pipeline Integrity group had been closely monitoring this crossing. The Company's Pipeline Integrity Department is on the journey to become a High Reliability Organization (HRO) where there is a strong preoccupation with failure and emphasis on determining the root cause of an incident, with the goal of striving for error free performance. As such, this incident was treated with as much emphasis as a pipeline failure, and several lessons learned from this incident were identified. This paper will discuss the enhancements made to the Company's flood monitoring program including improvement of flood forecast monitoring, formalization of a stakeholder communication strategy, development of shutdown and purge plans, identification of high priority crossings, utilization of new technology for surveying during high flow and the development of a flood response guideline
Track 4: Operations, Monitoring, and Maintenance	On Demand	IPC2020-9270	Bailey Theriault	An Integrated Approach to System-Wide Landslide Monitoring in the Appalachian Basin Region of the Us	Landslides have the potential to adversely affect the integrity of pipelines. Identifying, characterizing, evaluating, and if necessary, mitigating and monitoring landsli hazards have become critical steps to successfully and safely building and operating pipelines in the Appalachian Basin region of the United States. The natural geologic, geographic, and climatic conditions in this region combine to create an area with a high incidence of landslides, where landslide formation and movement are exacerbat by anthropogenic activity. The recent, rapid expansion of pipeline construction and operation in this landslide-prone region along with the ever-decreasing availability of preferred routing options, have resulted in a recent increase in landslide-related incidences both during and post-construction of new pipelines. As such, there is an increasing need to identify, characterize, and closely monitor landslide hazards throughout the construction and operational lifespan of each pipeline system. However, this can prove challenging in an area where a pipeline may be subject to an average of two to five landslides per mile of pipeline, and where new landslide hazards may develop on an annual basis. Typical site-specific monitoring approaches (e.g., strain gauge, inclinometers, monitoring points, etc.) may not be economically feasible to use for all hazards when traversing long distances of such terrain, and such approaches likely do not address the need to identify new hazards that may develop over time (e.g., new or reactivated landslides). A strong monitoring program should seek to identify and use complimentary technologies to balance out the relative strengths and weaknesses of each. Overdependence on a single or select number of tools could lead to overconfidence in understanding and perhaps an unnecessary number of false positives. This paper will provide an overview of monitoring approaches that have proven useful for the long-term monitoring and assessment of high density landslide areas at a system-wide scale, including the use of repeat LiDAR surveys (i.e., LiDAR Change Detection Analysis), in-line inspection (ILI) inertial measurement unit (IMU) data, and aerial reconnaissance. Case studies will be presented from the Appalachian Basin region, including how monitoring techniques were selected based on specific pipeline system configurations and individual Operator objectives, and how they are being used to track existing hazards and to identify hazards as they deve
Track 4: Operations, Monitoring, and Maintenance	On Demand	IPC2020-9332	Rongbin Li	Experimental Investigation of the Difference in Wax Deposition Aging Rate Between Polyethylene and Steel Pipes	Wax deposition is an intrinsic problem existing in the production and transportation of waxy crude oil. In the oilfield, non-metallic pipe especially high-density polyethyle pipe (HDPE) has been widely used to solve corrosion problems due to its excellent performance in intensity and corrosion. However, the wax deposition problem in polyethylene (PE) pipe has never been evaluated using dynamic and systemic apparatus. Only a few studies focus on the wax deposition on the coated polyethylene surface by using the cold finger apparatus in recent decades. In this study, the wax deposition experiments were performed using an in-door flow-loop with detachable PE and stainless steel (SS) test sections under the laminar flow regime at the same time to investigate the difference in wax deposition aging rate between the PE and SS pipes. The wax deposits under different operating conditions in both PE and SS pipes were sampled by three layers to study the aging rate at different radial locations during the wax deposition. The wax precipitation characteristics of the wax deposits were determined by using the differential scanning calorimetry (DSC) method. It was found that the wax contents of the wax deposits in PE pipe were lower than that in the SS pipe. And the difference of the wax content between PE pipe and SS pipe decreases with the depositing duration. Eventually, the wax contents of the wax deposits in PE pipe were almost the same as that in the SS pipe. The heat conduction and heat transfer processes in PE pipe and SS pipe were analyzed. The thermal gradient and the concentration gradient at the boundary were calculated and combined with the heat and mass transfer of wax during the wax deposition to illustrate the difference in wax content. It was found that the variations of the thermal and concentration gradients have significant effects on the diffusion process of wax molecules within the wax deposit layer and thus changing the aging rate. The compariso and findings of wax deposition between the two kinds of pipes have provided a significant reference for the application of non-metallic pipe in the oilfie
Track 4: Operations, Monitoring, and Maintenance	On Demand	IPC2020-9366	Robert Andrews	Leak Rate Testing of a Natural Pipeline Defect	If a stable through-wall defect (leak) occurs in a pipeline, the leak rate is an important factor for both safety (consequence) and environmental assessments as well as determining the performance requirements for a leak detection system. For a "large" leak, estimates of the leak rate can be based on simple idealization as an orifice based on the area of the leak and a discharge factor. For crack-like defects where the opening is much less than the pipe wall thickness this is not appropriate. The flow through a crack is dependent on geometric factors such as the surface roughness, the crack length and opening together with fluid properties such as the viscosity. These issues have been extensively studied for nuclear pipework where the fluid is either pressurized water, steam or CO 2 , and guidance is given in Annex F of BS 7910. However, there is little published work for pipeline geometries and single-phase liquids such as refined hydrocarbons. This paper presents the results of experiments measuring the leak rates through a natural tight axial through-wall crack in an NPS 8 refined-products pipeline. The crack had originated at a gouge and then propagated through the wall. Leak-rate measurements were made using water (for safety reasons) over a range of pressures. The data was fitted to a model for leakage through a tight crack that takes account of the interaction of asperities in the surface roughness. The model gives an approximate square law relationship betw the leak rate and the local pressure. The fitted equation was then adjusted to take account of the different densities and viscosities of the pipeline products. It was concluded that the model was able to give a good prediction of the measured leak rates and that in this case the adjustments for the product properties were sm

Track 4: Operations, Monitoring, and Maintenance	On Demand	IPC2020-9369	R. Peter Weaver	Employing Satellite-Based Hyperspectral Imagery for Pipeline Leak Prevention, Detection & Compliance	Hyperspectral imagery (HSI), collected by micro-satellite, is poised to provide unparalleled daily global pipeline leak prevention, detection and speciation, intrusion a change detection capabilities while replacing conventional DOT pipeline patrol for compliance. In this presentation, Orbital Sidekick will discuss the state-of-the-a including the latest HSI satellite imagery and examples of findings using Spectral Intelligence TM . Technology miniaturization, combined with rapid and pronounced advancements and continual cost reductions for data processing has opened the frontier for applying remote sensing technology for detailed, objective, analytical inspection and leak detection for pipeline assets. Satellite constellations of hyperspectral imaging sensors are now being deployed, augmented by a localized aerial capability, to drive a decrease in the number and magnitude of above- and belowground pipeline leaks. This session will demonstrate how HSI collected from spaceborne assets and aerial platforms is being evaluated for oil, gas and chemical operators. It will also discuss how advanced analytical processes are now being used to detect these threats to pipelines as well as provide low-threshold leak detection and hydrocarbon speciation along pipeline systems and at fixed facilities. Competing technologies, such as infrared and multispectral imagery, collect subsets of the reflected light spectrum. These provide targeted or niche observations. What differentiates the hyperspectral monitoring and analytical capability from other technologies is its robust aggregation of a full spectrum of hyperspectral information, combined with industry-tailored analysis and a reporting mechanism to enable rapid dissemination of actionable findings to operational decisionmakers. Successful deployment of this technology requires frequent, global, high-resolution data collection, rapid and reliable analysis, and immediate reporting of actionable information. This presentation further explores how these combined elements are being applied to midstream asset inspections and integrity management programs, including examples of pipeline and terminal leaks, undetectable by conventional monitoring, that have been found using Spectral Intelligence. It will further demonstrate how this applied technology is meeting compliance obligations for inspection of pipeline Rights-of-Way (ROW). For decades, HSI technology has offered a promise of remote detection of hydrocarbon and other disturbances but has been out of reach for ongoing commercial operations. This very powerful technology has finally become scalable, accessible to, and cost-effective for the pipeline industry. Today's rapid advancements in technology promise a significant advantage to compliance and asset integrity personnel. Satellite-based hyperspectral imaging is now a reality and will be shown to be a powerful, cost-effective and now accessible means for routine data gathering and pipeline stewardshi
Track 4: Operations, Monitoring, and Maintenance	On Demand	IPC2020-9405	Xianwen Cheng	The Study on Non-Heating Transportation of Carbon Dioxide Flooding Gathering and Transportation Pipeline	In the oil field production, carbon dioxide flooding technology has become increasingly common for high water-cut oilfields. It not only reduces carbon emissions, but al greatly improves the efficiency of oil production. In the process of oil field gathering and transportation, most high water-cut crude oil pipelines have achieved in non-heating transportation technique, which means even the temperature drops below the gel point of crude oil, pipelines can still run safely. Especially for carbon dioxide flooding gathering and transportation pipeline, the presence of carbon dioxide can effectively improve the flow characteristics of crude oil and make it easier to achieve non-heating transportation. In the study of non-heating transportation, wall sticking occurrence temperature (WSOT) and quality of the wall-filled congealed oil are the most important research objectives. When the temperature is between the gel point of crude oil and WSOT, the crude oil gel only forms a thin oil layer on the pipe wall, which does not affect the safe operation of the pipeline. Once the temperature drops below WSOT, a large amount of congealed oil will stick to the pipe wall, reducing the inner diameter of the pipe and increasing the risk of plugging. In this paper, two self-developed devices were used to study the changes of viscosity and wax appearance temperature of dissolved carbon dioxide crude oil and the influence of carbon dioxide on WSOT and quality of the wall-filled congealed oil in oil-gas-water system, respectively. It is found that the viscosity and wax appearance temperature of crude oil are reduced after dissolving carbon dioxide, which lead to the less amount of the wall-filled congealed oil in the gathering and transportation process. In addition, the WSOT of dissolved gas-oil-water system is about 10 °C lower than the gel point of the crude oil, which is the same as the oil-water system. What's more, due to the shear action of water current and airflow in actual pipeline, the experimental results are more conservative compared to the operating results of oilfield pipeline. In a word, the research methods mentioned in this paper are suitable for the study of non-heating transportation of carbon dioxide flooding gathering and transportation pipeline, and the development of gathering and transportation scheme can enjoy some benefits from this w
Track 4: Operations, Monitoring, and Maintenance	On Demand	IPC2020-9434	Lei Xu	A Hybrid Method Based on Svm Integrated Improved Pso Algorithm for Electrical Energy Consumption Forecasting of Crude Oil Pipeline	Electrical energy consumption forecasting of crude oil pipeline plays a critical role in energy consumption target setting, batch scheduling, unit commitment. For actua crude oil pipelines, the construction of electrical energy consumption forecasting model is challenging due to its uncertain, nonlinearity, intermittency, fluctuations and complicated characteristics. It is difficult to describe the non-linear characteristics of electrical energy consumption forecasting by traditional methods. Therefore, a novel hybrid electrical energy consumption forecasting system based on the combination of support vector machine (SVM) and improved particle swarm optimization (IPSO) is proposed, which includes four parts: a data preprocessing part, optimization part, forecasting part, and evaluation part. In the preprocessing stage, in order to avoid large deviation caused by sampling stochasticity of small samples, the training set and the test set are divided by the stratified sampling method. During the modeling phase, the non-linear relationship in electrical energy consumption forecasting is efficiently represented by SVM, and the algorithm of IPSO is developed to optimize the parameters of constructed support vector machine regression. According to the established IPSO-SVM electrical energy consumption forecasting model, the evaluation criteria, the hypothesis testing and the stability analysis of the forecasting model are introduced for a comprehensive assessment of the system. To verify the forecasting effectiveness of the system, four forecasting cases are presented in this study, comparing the above evaluation indicators of IPSO-SVM with that of eight state-of-the-art prediction methods of GA-SVM, PSO-SVM, SA-SVM, DE-SVM, FOA-SVM, GSA-SVM, SVM and LR, the effectiveness of IPSO-SVM algorithm is evaluated. For the operation data of four crude oil pipelines in China, the results indicate that the proposed IPSO-SVM hybrid model has the best forecasting accuracy and stability than other benchmark models, and the forecast results most closely match the actual data, which shows its superior ability in terms of forecasting accuracy. As a result, it is concluded that the proposed approach can be an efficient technique for crude oil pipeline electrical energy consumption forecastir
Track 4: Operations, Monitoring, and Maintenance	On Demand	IPC2020-9463	Chris Apps	On-Water Liquid Leak Detection Technology Evaluation	Industry is directing efforts towards reducing the environmental impact of operation through improving pipeline performance, preventing and minimizing releases, a addressing evolving regulatory requirements. An area of interest for these improvement efforts is detecting the presence of liquid hydrocarbons on the surface of water, either inside facilities before leaving the site or on pipeline Right-of-Ways that are associated with waterbody crossings. Many different external leak detection technolog have been recently developed; however, it is challenging to test the effectiveness of these systems with real hydrocarbon products while installed in the field. C-FER, under contract to PRCI, developed a research project to assess the abilities of these external leak detection technologies to identify the presence of liquid hydrocarbon products on the surface of water in a controlled lab environment. The first phase of the project evaluated the performance of six external leak detection systems intended to identify the presence of hydrocarbon products on the surface of water. The scope was limited to an idealized freshwater environment under ambient conditions. Tests were conducted with five hydrocarbon test fluids (gasoline, diesel, Synthetic Sweet Blend, Access Western Blend and Cold Lake Blend), along with three additional test fluids (canola oil, salt water and motor oil). Canola oil was considered as a candidate surrogate fluid and salt water as a possible source of false alarms, while motor oil was considered as a candidate surrogate fluid or a false alarm trigger, depending on the field application. Testing was performed by releasing each test fluid onto the surface of a water basin with six external leak detection systems located equidistant from the release point. Each system's response to contact with the test fluid was monitored and compared based on time to detection and estimated slick thickness at detection. The second phase was expanded to a freshwater environment under freezing conditions, where the surface of the water has frozen over. Five external leak detection systems were evaluated under these conditions (four of which were also tested in Phase 1). Based on results from the first phase, testing was limited to three test fluids (diesel, Synthetic Sweet Blend and Access Western Blend). Testing was performed by releasing each test fluid into basins containing individual external leak detection systems. Releases were performed above the ice surface, below the ice surface, and onto the water surface after freeze/thaw cycles. Each system's response to contact with the test fluid was monitored and compared based on time to detection and estimated slick thickness at detection.
Track 4: Operations, Monitoring, and Maintenance	On Demand	IPC2020-9518	Mathew Bussiere	Establishing a Detection Threshold for Acoustic-Based External Leak Detection Systems	External Leak Detection (ELD) systems are a new generation of pipeline leak detection technologies capable of identifying pipeline leaks by interacting directly with t released fluid or the associated release energy (i.e. acoustic, thermal, or mechanical). They are intended to complement conventional leak detection systems (i.e. internal based systems, such as computational pipeline monitoring systems) by reportedly providing significant improvements in the detection of small leaks. A better understanding of the leak detection sensitivity threshold of such ELD systems will assist pipeline operators in predicting detection performance for a range of leak characteristics, thereby helping them to make more informed decisions regarding procurement and deployment of such systems. The analysis approach described herein was developed to characterize the leak detection sensitivity of select fiber optic cable based systems that employ Distributed Acoustic Sensing (DAS). This work was part a multi-phase Joint Industry Project (JIP) carried out to evaluate the capabilities of a variety of commercially available ELD systems in a controlled laboratory environme The detection sensitivity analysis was based on ELD technology performance data obtained from two full-scale laboratory tests that were carried out as part of the JIP. In each test, the sensors from multiple ELD vendors were installed at various deployment positions and were subjected to multiple release events from a buried test pipe. The release events involved diluted bitumen discharges through circular holes with diameters ranging from 0.79 mm to 4 mm, and driving pressure between 345 and 3450 kPa (50 and 500 psi). The detection sensitivity analysis consisted of two steps. The first step involved identifying a suitable release parameter capable of providing a sound basis for defining detection sensitivity; the second step involved the application of logistic regression analysis to characterize detection sensitivity as a function of the chosen release parameter. The described detection sensitivity analysis provided a means by which to quantitatively determine the leak detection sensitivity threshold for each technology and sensor deployment position evaluated. The chosen sensitivity threshold measure was the release parameter value associated with release events having a 90% probability of being detected. Thresholds associated with a higher probability level of 95% were also established for comparison purposes. The calculated sensitivity thresholds can be interpreted to mean that release events associated with release parameter values above the sensitivity threshold have a very high likelihood (either 90 or 95%) of being detected.
Track 4: Operations, Monitoring, and Maintenance	On Demand	IPC2020-9525	Guohua Li	Evaluation and Acceptability of Pneumatic Pressure Test Results	A pneumatic pressure test can be performed when hydrotesting a pipe is infeasible and/or impracticable. Despite its use throughout the industry, little publishe reference material is available regarding this important and ubiquitous topic with no known industry codes, standards or criteria identified to accept or reject a test. To date, few studies have been performed to evaluate the stabilization time, the appropriate methods for data reduction, and the acceptance criteria. During the gas injection phase of a pneumatic pressure test, pressure and temperature transients are generated, which necessitate that the pressure test should be started only after pressure transients have dissipated. The required stabilization time for dissipation of the transients is dependent on pipe length and volume. Temperature transients often last longer as gas temperature is influenced by heat capacity and thermal conductivity of gas, pipe wall, wrap, and cover soil, by the difference between gas temperature and ambient temperature, and by ambient temperature variation with time. Because temperature transients change slowly with time, pseudo steady-states could be used to assess gas behaviors. This paper provides charts and an evaluation of minimum stabilization time for various pipe lengths and volumes obtained from transient, parametric simulation results. In this study, five parameters were evaluated to accept pneumatic pressure tests, including pressure, temperature, gas mass, compressibility factor, and gas volume. It was concluded that gas mass can be used as the principal acceptability criteria since it is conserved during testing if there is no leak. The other parameters were not considered because they vary with time and/or with different test systems. When there is no leak, gas mass calculated from the gas law equations remains constant or fluctuates with time around an average value. This paper provides additional recommendations for evaluation and acceptance of pneumatic pressure testing results. A test can be accepted if the calculated gas mass, in comparison with the true mass, has an accuracy level less than the measure pressure and temperature accuracy. The paper also discusses suitable confidence levels or reference intervals to accept or reject a test. Finally, several test data from a case study are presented that were used to verify the feasibility and validity of the proposed evaluation and acceptance criteria. The case study is for natural gas mains pneumatically tested with nitrogen at test pressures in the range of 2,100 to 6,200 kPa for nominal pipe sizes between NPS 2 and NPS 2

Track 4: Operations, Monitoring, and Maintenance	On Demand	IPC2020-9532	Chris Holliday	The North Saskatchewan River Valley Landslide – Slope and Pipeline Condition Monitoring	This paper details a case study of an engineering assessment on a pipeline where robust monitoring of continued ground movement and repeat in-line inspection (I supported integrity management decisions and remediation activities. Following a loss of containment incident on a 16-inch diameter pipeline on the south slope of the North Saskatchewan River in July 2016, Husky has undertaken intensive studies to understand and learn from the failure. The cause of the incident was ground movement resulting from a landslide complex on the slope involving two deep-seated compound basal shear slides as well as a near surface translational slide in heavily over consolidated marine clays of the Upper Cretaceous Lea Park Formation. One aspect of the studies has been to undertake structural analysis of the pipeline response to the loading imposed from the ground movement in order to prevent a similar occurrence from happening in the future and determine the integrity of the pipeline at the time of the assessment. Given the scale and complexity of the landslide, slope stabilization measures were not practical to implement, so repeat ILI using caliper and gyro technology, in addition to a robust monitoring program was implemented. Real-time monitoring of ground movements, pipe strain and precipitation levels provided a monitoring and early-detection system combined with documented risk thresholds that identified when to proactively shut-in the pipeline. This paper presents the methodology and findings of the structural analysis that was undertaken to examine the robustness of the pipeline to withstand future landslide movement. The work involved simulation of the pipeline history on the slope including loads that had accumulated in the original pipeline sections based on historical ILI results and slope monitoring. The pipeline orientation was parallel with the ground movement in the landslide complex, so the development of axial strain in the pipeline was the dominant load component which are particularly damaging in the compression zone. The work provided recommendations to ensure the integrity of the pipeline with consideration of continuing ground movement and assisted Husky with decisions over the long-term strategy for pipelines in the south slope of the North Saskatchewan River. The companion paper presents the findings of the geotechnical monitoring
Track 4: Operations, Monitoring, and Maintenance	On Demand	IPC2020-9538	Jianqin Zheng	A Method of Leakage Parameters Estimation for Liquid Pipelines Based on Conditional Generative Adversarial Network	At present, pipeline transportation is a very common mode in the long-distance transportation of liquid materials such as oil. Compared with others transportation way pipeline transportation is not only high-throughput and continuous, it is also reliable and of low energy consumption. Although the probability of pipeline leakage is low, t result of leakage is catastrophic, including economic losses, personal safety, and environmental pollution. Once the liquid pipeline leakage occurs, risk assessment and emergency repair measures are urgent. The key to these is to determine the leakage parameters of the pipeline. The determination of the leakage location is conductive timely maintenance. The leakage coefficient and time affect the leakage volume and leakage range. The current leakage detection methods are quite mature and diverse. However, many popular methods are based on physical mechanism and hydraulic calculations with assumptions (unchanged wave propagation speed, constant pipeline friction coefficient, etc) resulting in poor accuracy and high false alarm rate. Therefore, from the perspective of data driven, the relationship among leakage parameters and the operational flow rate and pressure is mined in this paper. First, due to the limited leakage accidents for one pipeline, a large amount of leakage data is generated through experimental simulation. For every second, the pressure and flow rate in upstream as well as in downstream should be recorded, making it hard for common deep learning algorithms to cope with such a high-dimensional complex dataset. To overcome the dimensionality problem, conditional generative adversarial network (CGAN) is then introduced to treat the dimensional data as labels when the leakage parameters model is trained. It consists of two key components, generative network and discriminative network, which are two powerful neural networks. These two networks explore the distribution of the leakage parameters through continuous adversarial training. After training the leakage data, the leakage parameters can be estimated based on the detected data (upstream and downstream pressure and flow rate) when the leakage occurs. Finally, four cases of pipeline leakage are tested to demonstrate our superiority over two traditional algorithms, i.e. neural network and support vector machine. The computational results show that the errors of four cases are all less than 10% by our approach while more than 12% by the comparison algorithms. Thus, this method has a potential prospect in the estimation of leakage parameters, and can effectively guide site management when the leakage occu
Track 4: Operations, Monitoring, and Maintenance	On Demand	IPC2020-9558	Lei He	Kalman Filter and Model-Free Adaptive Control Theory Applied to the Unsteady Flow State Estimation of Product Pipelines	The accurate online estimation of unsteady flow state provides important operation information for product pipelines real-time scheduling. In practice, affected by t parameter drift and observation noises, traditional estimation methods based on the first principle can hardly provide accurate results within acceptable time. The nonlinear and fast transient characteristics of pipeline flow make it difficult to realize on-line adaptive modification of model parameters. This paper proposes a methodology with multi-level adaptive adjustment to realize the unsteady flow state estimation of product pipelines. In order to meet the requirements of computational efficiency and accuracy simultaneously, we first introduce mode-free adaptive control method as linear compensation of the reduced order unsteady flow model which is obtained by frequency response and difference transforming method. The partial form dynamic linearization method has been adopted to design the adaptive control with minimum deviation between the measured result and the model output result as the objective. To further improve the adaptability of established model, the model parameters are online adjusted by using the recursive least squares with forgetting factor method. The relationship between the two adaptive adjustment methods of adaptive control and model parameter adjustment is achieved by using a two-layer adjustment framework, in which the deviation between the model output and the observed value is used as the threshold. The uncertainty of the model and the interference of observation noise can be eliminated by adopting Kalman filter to the modified state space model and the accuracy flow parameter values can be obtained as new observation of input parameters become available. The effectiveness of the proposed methodology is evaluated through a real pipeline and the robustness of the adaptive model is verified in some unfavorable conditions, including the imprecision of model initial parameters and measurement noise. The results show that the proposed method can obtain the accuracy flow state estimation of a product pipeline even under the interference of parameter drift and observation nois
Track 4: Operations, Monitoring, and Maintenance	On Demand	IPC2020-9565	Dongliang Yu	Numerical Simulation of Petroleum Spreading in a Complex River Channel	Petroleum leaking in rivers may cause serious damages, such as environmental pollution and death of river animals. The petroleum spreading in rivers could be mu faster than that on lands, as the leaking petroleum may flow rapidly downstream with the flowing water. Therefore, accurately estimating the transient petroleum spreading area in rivers is a fatal task for emergency response and disaster rescue. However, the estimating methods in the literature mainly refer to spreading process in ocean and soil, which was commonly happened in the history. The petroleum transportation pipelines in China pass through many rivers with very complex channel geometries, introducing the necessity of estimating of leaking petroleum spreading in actual river channels. In the current study, the petroleum spreading process along an actual river channel is numerically simulated. The river channel geometry is extracted from a map database, which is further treated using image binarization and edge extraction to obtain the discrete river channel data. The river channel data is then smoothed by picking less data representing main geometric characteristics. The smoothed data is used to re-construct the river geometry and generate calculation mesh. The mesh is a two-dimensional structured grid with several possible leaking points along the actual petroleum transportation pipeline passing through the river. A multi-fluid mixture model is used to simulate the petroleum spreading process on t water surface, meaning petroleum blending in the flowing water. A leaking mass flow rate of 240 kg/s and river flow speed of 0.5~2 m/s are simulated for 8 possible leaking sources on the traversing pipeline. The average time for petroleum spreading to 5.5 km downstream the leaking points is 3.3 h with a river flow speed of 1.58 m Different leaking source locations may cause nonsignificant difference between spreading distances downstream. However, the river flow speed affects the spreading velocity significantly. Sudden widening or turning of the river channel may result in vortexes which delays the petroleum spreading process. The simulated data could be used to make the rescue strategy of petroleum leaking in this specific rive
Track 4: Operations, Monitoring, and Maintenance	On Demand	IPC2020-9584	Tianzong (David) Xu	Large Standoff Magnetometry as a Practical Screening and Monitoring Tool for Pipelines Under Geohazard Condtions	Large standoff magnetometry (LSM) as a non-intrusive NDE technology has been used in commercial trial many years for above-ground detection of underground pipel anomalies associated with stress concentration zones (SCZs). As a passive geo-magnetization flux leakage measurement method, it has been mainly targeting common anomalies such as corrosion/metal loss, gouges/dents and cracks that are often very localized in small scale. Insufficient consistency and reliability are still the major concern due to technical challenges in getting high resolutions and signal strength at large standoff distance. In comparison, geohazard related external forces induce much large-scale elevated stresses/strains with stronger stress-magnetization signals. The lack of economically viable solutions for pipeline screening and monitoring under geohazard conditions provides a good opportunity for LSM technology to build up its first market position. This work is part of PG&E’s effort in gaining better fundamental understanding of the current state-of-the-art LSM technology and its potential to enhance the current industrial practices of pipeline assessment under geohazard conditions. Specifically, 3D mapping of pipelines including depth of cover (DOC) measurement, locating girth welds and peak stresses/strains with risk rating, verification of stress/strain relief operation and monitoring afterwards. Inline inspection (ILI) and geotechnical analysis data together with field excavation and strain-gage-on-pipeline data are utilized as references to cross-check the LSM results. All three active LSM technology providers participated in this small-scale field trial that includes a total of 9 field sites subjected to ground movement/landslides or erosion in Northern California. State-of-the-art positioning technologies including total automatic tracking station and real-time GNSS/GPS correction through base station cellular network are tested as well. The outcomes demonstrate LSM technology’s capability of 3D mapping including DOC measurement with reasonable error when high accurate GPS coordinators can be acquired and DOC is 6 feet or less. Capture of significant peak strains (≥ 0.4%) is demonstrated including those associated with major field bends, though monitoring small amount of change may be still a challenge. The locating accuracy is largely dependent on the adopted positioning technologies as well as the on-site satellite and/or cellular network receiving condition, which can be a challenge at remote fields. In comparison to excavation and strain gage data, ILI peak bending strain data have more than expected errors at some of the sites where LSM outcomes show better matching that could have led to better mitigation decision, confirming the value of integrating LSM technology into the current practices
Track 4: Operations, Monitoring, and Maintenance	On Demand	IPC2020-9604	Rui Qiu	A Novel Approach for Two-Stage Uav Path Planning in Pipeline Network Inspection	Unmanned aerial vehicle (UAV) provides the possibility of comprehensive coverage and multi-dimensional visualization of pipeline monitoring. Currently, the research UAV path planning begins to emerge under the encouragement of industry policies in China. The target of UAV path planning in pipeline network inspection is to design flight path with the least cost in advance. The difficulties of this problem lie in the multiple flight mission, the intricate terrain threats, the harsh operational requirements, and the unified optimization for UAV deploy and real-time path planning. Meanwhile, the complex structure and the large scale of pipeline network further complicate this issue. At present, there is still space to improve the optimality and efficiency of model building and solution strategy. Aiming at this problem, this paper proposes a novel two-stage mathematical programming model for UAV path planning in pipeline network inspection. Different from previous researches, the process of path planning is divided into two stages, considering frequent pipeline accidents (e.g. leaks and cracks) and unexpected situations (e.g. meteorological mutations and unknown no-fly restrictions). The first stage is the conventional path planning, in which the requirement for optimality is higher than the calculation time. Thus, a mixed integer linear programming (MILP) model is established and the commercial solver is used to obtain the optimal UAV number, the starting station positions and the detailed flight path. While the second stage is the urgent path planning. After receiving the instruction that danger may occur in a certain area of the pipeline network, the flight path must be timely rearranged to inspect the specific dangerous locations. Thus, the requirement for calculation time is higher than optimality in this stage and the improved genetic algorithm is used for model solution to satisfy the timeliness of decision-making. Finally, the proposed method is applied to a large-scale multi-product pipeline network in China and compared with other methods from optimality and efficiency. From the results, the optimality in the first stage is increased by 10%, the calculation time in the second stage is decreased by 30%, verifying the applicability and superiority of this method in the UAV path planning in pipeline network with complex structu
Track 4: Operations, Monitoring, and Maintenance	On Demand	IPC2020-9636	Zhichao Guo	The Application of Numerical Simulation to Liquid Pipeline Leakage at Lng Terminal in China	In 2018 in China, the natural gas import reached 90.39 million tons, and the liquefied natural gas (LNG) import was 53.78 million tons, accounting for 59.5% of tota natural gas imports. As an important infrastructure for LNG import, 21 LNG terminals have been built in China up to now. With the construction of LNG terminals, more researches on the leakage of LNG storage and transportation facilities have emerged to prevent catastrophic consequences such as explosions and frostbite. However most of previous researches focused on gas pipeline leakage after LNG gasification, and few of those have been done on LNG liquid pipeline leakage. In this paper, the Fluent software is used to numerically simulate the process of LNG liquid pipeline leakage. After the occurrence of LNG leakage, it will suffer the process of endothermic, evaporation, and diffusion, which is considered as a two-phase diffusion process. The Euler-Lagrangian method is introduced to simulate the diffusion process of liquid phase and gas phase separately. In the simulation, the liquid phase is regarded as discrete droplets for discrete processing. The movement trajectory, heat transfer process and evaporation process of each droplet are tracked respectively. Different from the liquid phase, the gas phase is regarded as a continuous phase and the N-S equation is adopted for calculation. To increase the accuracy of simulation, the near ground diffusion process is dealed with a turbulence model. Thereafter, coupling calculations of two phase are performed to determine the concentration field and temperature field of the LNG liquid pipeline leakage. As a supplement to this research, the influence of wind speed on LNG leakage and diffusion process is analyzed in detail. Finally, the numerical simulation method is successfuly applied to a coastal LNG terminal in northern China. The results can provide scientific reference for the establishment of emergency response strategy and the delimitation of risky zon

Track 4: Operations, Monitoring, and Maintenance	On Demand	IPC2020-9641	Joshua Nasrallah	Case Study of Team Approach to Geohazard Identification, Characterization, and Mitigation	This case study summarizes the successful implementation of a team approach to geohazard identification and mitigation. The Owner/Operator worked with Golder establish a system-wide geohazard pipeline integrity management approach. The first part of the program included a phased geohazard assessment along the right-of-way. The second part of the program included office and field-based training provided to the local Pipeline Operations Staff, on how to identify geohazard features. Golder initially identified and delineated a landslide based on February 2018 lidar data (Phase 1). A ground reconnaissance (Phase 2) was completed in November 2018, which showed the landslide had expanded approximately 12 feet downslope since the lidar data had been collected. Local Operations Staff identified possible additional movement in February 2019. Subsequent field-mapping confirmed an additional approximately 15 feet of downslope movement between November 2018 and February 2019. Due to the active movement, additional assessments were completed to further characterize the landslide and the possible threat to the pipeline. A review of historic aerial imagery and Operator data revealed this site had been previously mitigated multiple times. A geotechnical subsurface exploration program consisting of dynamic cone penetration (DCP) tests suggested the landslide depth was such that the pipeline was likely engaged by the ground movement. A comparison of as-built survey versus current pipeline location survey was completed, which showed approximately a 3-foot deviation from the as-built location, indicating possible pipeline stra The Owner/Operator worked with the Center for Reliable Energy Systems (CRES) and Golder to evaluate the threat of observed pipeline strain and the possibility of additional landslide movement. This analysis showed the observed strain to be less than 30-percent of the threshold of concern ("warning level"). Thus, it was opted to postpone implementation of mitigation measures until seasonally drier conditions persisted, in order to avoid the negative impacts and inefficacies of winter or spring construction. Additionally, targeted mitigation along the site was deemed suitable rather than large-scale strain relief excavations. The mitigation measures were implemented in May-June 2019 and Golder worked with the Owner/Operator and Contractor to target site-specific mitigation measures based on the observed ground conditions during construction. The mitigation consisted of excavation below the pipe depth and installation of targeted drains at multiple locations across the site, as well as general grading to control the surface water flows and restore the right-of-way. During the excavations prior to drain installation, vibrating wire strain gauges were installed on the pipe for continued monitoring. Following site restoration, the strain gauges were connected to remote monitoring units to provide real-time strain readings of the pipe. The Owner/Operator continues to monitor this site, post-mitigation
Track 4: Operations, Monitoring, and Maintenance	On Demand	IPC2020-9722	Yuanpeng You	Research Progress of Sand Transport Mechanism and Critical Conditions in Pipelines	Sand deposition and transportation in oil and gas pipelines has become one of the major concerns for flow assurance in petroleum industry. However, research in this f is still in its infancy. This study describes the current development of sand deposition and sand transport in pipeline. The mechanism of particles deposition is described. The effects of particle properties, fluid properties and pipeline structure on the carrying capacity of single - phase and multiphase flow carrying sand are introduced, with emphasis on factors such as particle size, liquid viscosity, flow regime and pipeline inclination. As for modeling studies, the sand transport models can be classified to three categories based on the approach used to develop them: empirical, mechanistic, and semi-mechanistic. The methods for developing and extending models are illustrated in this study. Further researches should focus on the mechanisms and accurate prediction models of sand deposition, figuring out the influencing factors and mechanisms, deciding the major factors, developing predicting models with high accuracy and adaptability with combination of multiphase flow theories. Researches on the sand transport in the single phase flow are more mature against the multiphase flow sand transport. The gas/liquid/solid flow involves the fields of gas/liquid flow, turbulence flow, the velocity distribution in the multiphase flow and the force analysis on the tiny particles. There are quantities of questions waiting for the theoretical solution. Based on the review, the research on the sand transport in the future should focus on the following aspects, 1. Most of literatures describe the macroscopic sand flow regimes and lack the theoretical research on the sand deposition from the point of physical and chemical effects especially in the multiphase flow. 2. The effect of some factors such as viscosity and the interactive influence between the analyzed particle and other particles on the critical velocity should be studied more deeply. In multiphase flow, some parameters have the interactive influences between each other which increases the difficulty of the modeling the critical velocity. Therefore, the mathematical models should consider the experimental results to pay more attention to the main factors. 3. Most of models always introduce the specific value of the particle diameter. However, in actual operation of the pipeline, the solid materials always have the different diameters and sometimes it is unable to regard the solids as a uniform system. Therefore, the diameter of the particles should be adopted from the view of statistics. 4. The measurement of the critical velocity is not based on quantitate method and just under the visual observation or with the help of high-speed camera. As a result, the experimental results would be different from the differe
Track 4: Operations, Monitoring, and Maintenance	On Demand	IPC2020-9743	Alex Mckenzie-Johnson	Identification and Mitigation of a Landslide Threatening an Operating Natural Gas Pipeline	Natural gas pipeline network in the United States spans over 1.6 million miles (USDOT 2018) crossing areas such those susceptible to landslides. The landslides wi excessive ground movement pose a risk of rupture and explosion to the pipeline if not identified and mitigated properly. This paper presents a case study for a pipeline in the southern part of the United States affected by a landslide. This paper covers discussions on various phases of landslide identification and mitigation process, including identification of landslide, geotechnical subsurface investigation, ground movement monitoring, mitigation plan, and construction. This landslide was identified in the area with potential landslide hazard. Review of the Light Detection and Ranging (LIDAR) based Digital Elevation Model (DEM) suggested an indication of ground movements near the pipeline. A real-time remote monitoring program was implemented to monitor the strains on the pipeline induced by landslide movement. The real-time monitoring system provided an early alert for reactivation of the landslide. Immediately after the alert, a preliminary field reconnaissance confirmed significant ground movement and activation of a landslide which has induced strain on the pipeline. A comprehensive field reconnaissance showed that slope toe erosion and upslope progression of head-cut toward the pipeline right of way as well as recent heavy rainfall events have triggered the landslide movement. A geotechnical subsurface investigation within the landslide mass provided additional information which was used to develop the landslide stabilization with a final goal of mitigating the impact of landslide on the pipeline. Various landslide stabilization options including sheet pile wall, soldier beam wall, and soil nail system were considered, however a soldier beam wall was designed and constructed to stabilize the landslide. Upon the construction of the soldier pile wall, a strain relief excavation was performed around the pipeline to partially relieve the pipeline strain/stress induced by previous ground movement
Track 4: Operations, Monitoring, and Maintenance	On Demand	IPC2020-9785	Chantz Denowh	Use of Spoolable Pipe Technologies as a Means for Rehabilitating Small Diameter High Pressure Pipeline Systems	The aging infrastructure of pipeline systems around the world requires operators to explore novel and innovative methods for rehabilitating pipelines. Conventional re methods involve the installation of steel sleeves or composite repair systems. While these repair methods are reliable and provide operators with options for pipeline repair, a major drawback is the requirement that pipelines must be excavated. Activities related to excavation can be expensive and have the potential to further damage the pipeline, including the introduction of additional stresses. If extensive flaws are present in a pipeline system, efforts associated with a comprehensive pipeline repair system is cost-prohibitive. Additionally, the rehabilitation of pipelines that were installed via horizontal direction drilling is impossible using current repair methods. This paper provides an in-depth presentation on a comprehensive study completed to evaluate the use of a spoolable pipeline technology as a means for rehabilitating pipelines. As part of the study, an industry survey was completed that included responses from 15 pipeline operators on the use of spoolable pipe technologies. A Technology Assessment Roadmap was conducted to identify knowledge gaps and lessons learned in the implementation of spoolable pipe technologies. Both the survey and Roadmap contributed to the current study in terms of evaluating areas requiring further consideration. One outcome from the survey was the lack of full-scale test data associated with combined loading, which was a central feature in the current study. The year-long study involved the completion of specific combined loading testing scenarios, which included burst testing, cyclic pressure, torsion, axial tension, and axial compression. More than 50 full-scale test samples were destructively tested usi the combined loading test scenarios, utilizing up to 100,000 pressure cycles to the full operating pressure of the pipeline system. The approach employed in this study, and the associated test results, provide a model for evaluating an spoolable pipeline technologies, additional to the required product qualification standards, prior to implementation as an alterative means for repairing and rehabilitating pipeline
Track 4: Operations, Monitoring, and Maintenance	Track 4.1	IPC2020-9461	Greg Thorwald	Pipe Sleeve Repair Analysis Case Study Examining Axial Surface Cracks With Pressure Reduction and Geometry Factors to Improve Remaining Life	The industry widely uses steel repair sleeves to repair defects in pipes. This paper will focus on the types of repairs used for crack-like defects where there may concerns of crack propagation in service from operating pressure cycles. The length of the repair sleeve, the pressure at the time of the repair and the absence of fillet welds (Type A sleeve) can all affect the future integrity of the repair. Type B sleeves (fillet weld connecting the sleeve to the pipe) are widely used in the pipeline industry to repair crack-like flaws. Current standards require a minimum of two inches of sleeve material past the edge of a defect. A case study will show if this length is adequa under various operating conditions to ensure the defect does not propagate in service to extend beyond the fillet welds. A pipe with a surface crack and the sleeve repair are modeled using finite element analysis to compute the crack front stress intensity. Contact interaction between the pipe's outside surface and the sleeve's inside surface provides the load path from the pipe to the sleeve. The contact interaction is varied from frictionless to fully bonded to vary the amount of crack opening permitted by the sleeve. The stress intensity is compared for each case to quantify the effect of the sleeve repair on reducing the hoop stress and reducing the crack's stress intensity. Operators often take a pressure reduction during an in-service repair both for safety reasons and to assist with obtaining a tight fit-up between the carrier pipe and the steel sleeve. An additional benefit of a pressure reduction can be gained in relation to in-service crack growth. A case study will show how a pressure reduction can extend the fatigue life of a resident defect. Again, comparing the crack front stress intensity shows the effect on the crack of the pressure reduction when the sleeve is applied. Fatigue crack propagation analysis of several cases shows how the pressure reduction affects the crack growth rates. The analysis method can be used to examine trade-offs between the amount of pressure reduction on fatigue life versus operational requirements. Lastly, results will be shown for various operating scenarios to support the use of a Type A sleeve on crack-like defects by varying parameters such as sleeve thickness, sleeve length, repair pressure, sleeve type, crack size and crack location
Track 4: Operations, Monitoring, and Maintenance	Track 4.1	IPC2020-9479	Simon Slater	Maop Reconfirmation for a 20 Inch Gas Pipeline Using the Eca Approach and Enhanced Ili	In light of the revised Federal Pipeline Safety Regulations, active from 1 July 2020, operators of gas transmission pipelines are faced with the task of reconfirming t pipeline MAOP in a prescriptive set of circumstances. This requirement is defined in section 192.624 of 49 CFR 192. An operator of a gas transmission pipeline is operating with an MAOP established using a combination of TVC records and the so-called 'grandfathering' clause and has developed a plan and embarked with the process of reconfirming the MAOP using Method 3 – Engineering Critical Assessment. The pipeline is 20 inch diameter and predominately 0.25 inch wall thickness. It was originally constructed from vintage ERW pipe circa. 1960 to 1970 and is 29.86 miles long. There have been no reportable incidents on the line. There are various HCAs, MCAs, Class 3 and Class 4 locations along the line. The approach taken by the operator is to reconfirm the MAOP along the full pipeline length to cover the possibility of class location changes in the future. MAOP Reconfirmation method 3 is covered in clause 192.632 of 49 CFR 192. A critical aspect of this project was the implementation of various ILI technologies to detect, identify and size anomalies. ROSEN provided a program of enhanced ILI including technologies to assess crack-like and metal-loss features. A critical aspect of method 3 is the use of appropriate material properties in the ECA. The operator used the RoMat PGS ILI service as the foundation for material property verification in line with clause 192.607 of 49 CFR 192. This paper describes the comprehensive work performed by the operator and ROSEN to establish the MAOP reconfirmation process. Such a large ILI program is a significant undertaking with associated operational and engineering issues that ha to be considered. This paper presents the methodologies used for each stage of the process and how the ILI results and material verification were used in feature assessments to determine predicted failure pressures and remaining life. By satisfying the regulations, the operator has established a process to manage the pipeline integrity effectively and reduce risk

Track 4: Operations, Monitoring, and Maintenance	Track 4.1	IPC2020-9757	Chris Alexander	Repair of Leaks in Thin-Wall High Pressure Pipelines Using Composite Reinforcing Technologies	A study was conducted to evaluate two composite repair technologies used to reinforce severe corrosion and thru-wall leaking defects in thin-walled pipe materials whe the welding of conventional steel sleeves cannot be conducted. This program involved the reinforcement of simulated 85% corrosion thru-wall defects in 6.625-inch x 0.157-inch, Grade X52 pipe materials subjected to cyclic pressure and burst testing. The test matrix also included repaired pipe samples with thru-wall defects that were pressurized using nitrogen gas and buried for 90 days. The top performing system achieved high short-term burst pressures, provided high levels of reinforcement to the extremely thin 85% deep corrosion defect, reached up to 4,900 cycles during the pressure fatigue phase of work, and held pressure for 90 days followed by high burst failure pressures. This is the first study ever conducted by a transmission pipeline operator evaluating the performance of competing composite technologies used to reinforce severe corrosion with thru-wall defects. The reinforcement of leaks has not been accepted by regulatory bodies such as the Canadian National Energy Board (NEB) or the U.S. Pipeline and Hazardous Materials Safety Administration (PHMSA). A goal of the current study is to validate composite repair technologies as a precursor to regulatory approval. The program was comprehensive in that it evaluated the following elements: - Corrosion features have a depth of 85% of the pipe's nominal wall thickness in extremely thin-walled pipe material (i.e., 0.157 inches, or 4 mm). - Thru-wall defects having a diameter of 0.125 inches (3 mm). - All testing conducted on pipe material with extremely thin wall thicknesses (0.157 inches, or 4 mm). - One repair made with a leaking defect having 100 psig internal pressure. - Strain gage measurement made in non-leaking 85% corrosion defects; it should be noted that the remaining "15%" ligament was 0.024 inches (0.6 mm); to the authors' knowledge, no high-pressure testing has ever been conducted on such a thin remaining wall. - Long-term 90-day test that included pressurization with nitrogen gas, followed by relatively aggressive pressure cycling up to 80% SMYS followed by burst testing. The results of this study indicate that viable composite repair technologies exist with capabilities for reinforcing leaks in pipelines that experience operating conditions typical for gas transmission systems (i.e., minimal pressure cyclin
Track 4: Operations, Monitoring, and Maintenance	Track 4.2	IPC2020-9233	Chris Minto	Industrial Validation and Verification Approach for External Fiber Optic Based Leak Detection	External Leak Detection systems based on distributed fiber optic sensors (DFOS) offer the exciting potential to significantly reduce the overall amount of spilled prod before a leak is detected and localized. Such systems are not well represented by industrial standards or recommended procedures and as a result most industrial attempts to validate the technology have been research-oriented and whilst these have contributed greatly to the knowledge base they have never been aimed at a full validation of the technology. Additionally, the lack of test facilities that can support the significant scale needed for validation (>500m straight line run) have led to a paucity of attempts to provide a baseline validation of such sensing technology leading to a lack of certainty over performance claims within the industrial user base and no robust method of testing such claims. With a significant customer base of deployed systems, OptaSense have developed a reproducible technology validation approach using full scale, full flow representative leaks at the CTDUT test facility in Brazil which we have used to validate 15 lpm leaks detected and classified via their negative pressure pulse in ~10 seconds and larger 150 lpm leaks detected by our four multiple modes of leak detection in ~1 minute. Valid automated detection of NPP was observed down to 1mm holes in the pipe – a leak rate of only 1.5 lpm. The use of the negative pressure pulse is shown as a compelling rapid detection method but validation needs care to deploy in testing since the use of a valve opening to stimulate a pulse is shown to be significantly inferior in comparison to burst disks due to the increased valve-opening time that gives rise to a reduced amplitude pressure pulse. The conventional external leak detection signals of Orifice Noise, Ground Strain and Temperature Change can all shown to be replicated at the large-scale test facility by these means leading to the potential to establish a valid Probability of Detection for both approaches. With validation now possible, client verification on site has also been addressed with a two-step approach being developed which replicates the validation approach detailed above. Negative Pressure Pulses are used for leak detection stand-alone and can be safely stimulated via accessible valve sites and product release via a burst disc / valve and orifice combination. To stimulate the Multiple Mode behaviour (excluding Negative Pressure Pulse) a controlled fluid release injection mechanisms has been developed which can be introduced at the appropriate offset from the pipeline (mirrored from fibre offset) at any desired location with the minimum of preparation. Ground probe deployment techniques have been created to simulate the creation of a leak at the appropriate point resulting in the similar external signals arising on the fibre. This paper presents the benefits of large-scale validation approaches to performance bound acoustic-based leak detection systems and presents established options for in-field verification on customer owned syste
Track 4: Operations, Monitoring, and Maintenance	Track 4.2	IPC2020-9237	Christopher Macdonald	Pipeline Rupture Detection Using Multiple Artificial Intelligence Classifiers During Steady-State and Transient Operations	The fast and accurate detection of pipeline rupture events is crucial to minimize the harmful environmental and economic effects that they can cause. Pipeline ruptu detection systems need to be able to provide reliable monitoring that minimizes false alarm rates while allowing for detection in both steady-state and transient operational conditions. One of the limitations of existing rupture detection systems is their inability to accurately detect ruptures throughout all operational conditions, as a result of their use of a simple threshold based alert algorithms. This limitation becomes evident during transient operation where false positives can occur, or in extreme cases, events can go completely undetected. To cope with this urgent challenge, in this work we employee multiple machine learning classifiers which rely on pattern recognition instead of traditional operator-set thresholds. Employing multiple classifiers allows a fusion technique to be applied, resulting in greater accuracy over the full range of operational conditions in a pipeline. Two-dimensional (2D) Convolutional Neural Network (CNN) and Adaptive Neuro Fuzzy Interface System (ANFIS) classifiers are chosen to mimic the visualization (using CNN) and decision making (using ANFIS) processes performed by an operator during a leak event. Advanced signal-analysis techniques will be applied to available SCADA data collected at each pump station, consisting of flow rate, suction pressure, and discharge pressure. To allow training and testing of the rupture detection system, a laboratory-scale flow loop consisting of two pump stations and an interjoining pipeline segment was designed and built. This system enables withdrawal tests to be performed in the interjoining segment during both steady-state and transient conditions. The laboratory-collected data will be supplemented through a model built using real-world pipeline data featuring RTTM simulated leaks. Through the use of data sets collected both in the laboratory and real world, the rupture detection system will be developed to ensure non-dimensionality, an essential aspect for the developed system to be applied to ot
Track 4: Operations, Monitoring, and Maintenance	Track 4.2	IPC2020-9333	Sergio Cunha	Pipeline Leak Detection Using a Moderate Gain Nonlinear Observer	Most pipeline control systems use some sort of autonomous leak detection system as a safety feature. Among the pipeline leak detection techniques, state observ stand out as the most sophisticated and promising technique. But its use has been inhibited as the dynamic models employed so far are large and estimating the states of nonlinear systems is not trivial. Pipeline pressure and flow dynamics have been modelled in the literature by means of different numerical solutions to a pair of first order partial differential equations that express mass and linear momentum conservation. The numerical solution requires discretizing the pipeline length in a finite number of segments, resulting in a system of equations with size of twice the number of segments. Although there is nothing wrong with this approach, a smaller system is more convenient if one is concerned exclusively with pressure and flow at the pipeline entrance and exit sections. In this paper, energetic modelling principles are employed to obtain a pair of first order ordinary differential equations representing the dynamics of long liquid pipelines. A recently introduced nonlinear observer enables straight-forward use of linear, constant-gain observers with Lipschitz nonlinear dynamics. This observer gives the designer freedom to choose the observer eigenvalues and enables mathematically proven asymptotic stability with low gains. In this paper this observer, using a second-order model to represent the pipeline dynamics, is used as a pipeline leak detection algorithm. Initially the observer was employed directly as a leak detection algorithm, the leak being indicated by a non-transient difference between the measured and the estimated flows. Afterwards the leak was modeled as a disturbance flow and a disturbance observer was designed. Both algorithms were verified by means of computer simulations. It was found that the two methodologies are capable of detecting and estimating very small leaks, but the disturbance observer seems capable of indicating small holes further way from the measuring point
Track 4: Operations, Monitoring, and Maintenance	Track 4.3	IPC2020-9258	Guoxi He	A Novel Three-Dimensional Non-Contact Pipeline Magnetism-Based Stress Inspection Technology and Its Application on Lng Pipeline	On the bases of the metal-magnetic-memory (MMM) effect, we developed a three-dimensional high-precision non-contact pipeline magnetism-based stress inspecti (PMSI) technology for trenchless inspection of buried pipeline defects. This technology is a new non-destructive testing technology, which can find the possible stress concentration area (SCA) along the buried gas transmission pipeline. Hence, we could further judge the SCA about the overpressure which results from whether the pipeline external load at the potential landslide of the soil or serious metal loss such as corrosion defects. The PMSI was carried out on a 10.3 km target segment of Sinopec Pingdu-Laixi LNG pipeline. We have determined the intensity of the anomaly magnetic area (AMA) along the pipeline and proposed a new comprehensive index F to evaluate the severity and judge the grade of the defect status as well as the sensitive area which are determined by the combined action of metal defect and mechanical stress. Thus, the relative stress and thereby the safety state of the pipeline are assessed, and then the position of the relatively serious section on the pipeline is determined. The PMSI method measures the gradient of B x , B y and B z in the X direction at a certain distance above the pipeline, then the modulus of the gradient vector dB/dx is derived. During the process of analyzing the inspection data, the above-mentioned modulus is integrated versus the distance, which contains the abnormal magnetic signal and background magnetic signal. To sum up, based on the experimental test results, the conclusions are obtained: (1) More than 100000 sets of three-component high-precision anomaly magnetic data were collected from PMSI of the LNG pipeline, and two level-II SCAs were found. (2) The comprehensive index F of the AMA of the two level-II SCAs was 0.28 and 0.26, respectively. The stress concentration degree was 58% and 60% of the yield strength of the pipe, respectively. The F value of the remaining level-III SCAs was between 0.62 and 0.82, and the corresponding stress concentration degree was 14% ~ 30%. (3) The detected signal characteristics of the AMA reveal that the SCA is mostly located at the circumferential weld of the elbow, which becomes a most potential risk factor to the pipeline. (4) The specific repair measures and suggestions, such as installation of epoxy sleeve, are needed after determining the defect type and the safety status of the excavated pipeline. It is also suggested to install an online surveillance system to monitor the strain and thereby the stress of the "II" level stress concentration section when conditions permit, so as to continuously monitor the stress tendency of the pipeline and ensure the safe operatic
Track 4: Operations, Monitoring, and Maintenance	Track 4.3	IPC2020-9599	Benjamin Zand	Surface Loading Analysis: Vehicle Load Distribution Under Timber Mats and Flexible Slab	Pipeline operators commonly use means of temporary crossing such as timber-mat, airbridge, and slab to reduce surface loading induced stresses in a buried pipeline locations where a heavy vehicle crosses a buried pipeline. When a temporary crossing has a continuous contact with the soil, (e.g. timber mat, flexible slab) load distribution over the ground surface is not immediately known. Load distribution under a timber-mat or flexible slab is a function of the slab to soil stiffness ratio. The load distribution tends to become more uniform with increasing timber-mat or slab stiffness. In this work an analytical model using beam-on-elastic-foundation has been developed and Laplace transform is utilized to find the solution and apply free-end boundary conditions. The analytical solution can be used for any arbitrary l distribution over a beam- on-elastic foundation, however in this work the solution for a point load and a uniformly distributed load were employed as these scenarios can accurately represent conventional vehicle foot-prints, while being computationally efficient. The analytical solutions are compared to finite element analysis to validate the model. The model has been programed into Microsoft excel for two different temporary crossing types, namely timber-mat and flexible slab. The end product of the program includes load distributions in form of load matrices for various load cases, each representing a different vehicle location on the slab or timber-mat to represent a moving vehicle. This model can be used in conjunction with the Canadian Energy Pipeline Association (CEPA) surface loading calculator or similar tools to analyze pipeline encroachment problems when means of temporary crossing is utilized to distribute the load more uniformly over the ground surface. This model can help the operators determine dimensions and bending stiffness of timber-mat or flexible slab to assure a desirable load distribution will be achieved. The model can also be used for structural analysis of a timber-mat or flexible slab under vehicular loa

Track 4: Operations, Monitoring, and Maintenance	Track 4.3	IPC2020-9786	Haobin Chen	Operational Modal Response Characterization of a Buried Pipe Structure	Structural health monitoring (SHM) is based on the change in modal characteristics of a mechanical structure when the system undergoes a reduction in mechanic integrity. Modal characteristics are often quantified using vibration signals, with traditional modal analysis performed using either impact-response testing or mechanical-shaker excitation. Both methods, however, are not suitable for a buried pipeline. As a novel non-invasive SHM technique for application to buried pipelines, in-situ vibration-based detection offers an approach for continuous system integrity monitoring. In this research work, the operational modal response of a buried-pipe structure is investigated. Experiments are conducted on a 160-inch horizontal stainless-steel pipe section with an inner diameter of 2-inches that is buried at varying depths of cover, up to a maximum of three-times the pipe diameter. Soil compaction is performed to 95% of the maximum dry density (proctor compaction). During experiments, water flow rate through the pipe (Reynolds number) is increased and turbulent pressure fluctuations provide the varying structural excitation source. Vibration measurements made using wall-mounted accelerometers, one tri-axial and three single-axis, that are positioned along the pipe. The tri-axial and single-axis accelerometer are directly mounted to the pipe (on-pipe measurements) at two pipe locations to examine the operational modal response. Two additional single-axis accelerometers are positioned in the soil (in-soil measurements) at varying distances away from the pipe outer wall. The in-soil accelerometer above the pipe is positioned up to three diameters away, while the in-soil accelerometer on the side is positioned up to ten diameters away. In-soil accelerometers enable the vibration transmission through the soil in both the horizontal and vertical directions to be examined. During experiments, time series records of all vibration signals are collected. Power spectral density (PSD) functions a their integral powers are computed for each flow/position scenario. Visualization of the computed PSD functions with different depths of cover indicate changes in the modal response of the buried-pipe structure. The experimental results reveal that the soil around the pipe acts as a low-pass filter, attenuating vibration signals that propagate both along the pipe wall and away from the pipe wall through the solid medium. Although the lower frequency range is found to contain most of the vibrational power, it is also the range most easily contaminated by other noise sources (e.g., the pump). The operational modal response of in-soil accelerometers in the higher frequency range is examined to determine the distance away from the pipe that vibration signals can still be effectively sensed. Both the operational modal response and the vibration transmission are investigated to examine the feasibility of buried-pipe structure health monitoring using operational vibration measurements, both on pipe a in soil.
Track 4: Operations, Monitoring, and Maintenance	Track 4.4	IPC2020-9230	Gerald Ferris	Lessons Learned From Freespans at Pipeline Watercourse Crossings	Failure (loss of containment) of pipelines buried at watercourse crossings are caused by increased water flow rates that expose (top of pipeline exposed), freespan (bot of the pipeline exposed) and then impart excessive external loading to the pipeline. The erosive power of the water is increased during high flow conditions, which can cause scour of the river bed, erosion of the banks and, in some cases, the formation of a new channel (avulsion), any of these mechanisms can lead to pipeline exposure and/or freespan. For "typical watercourses" the actual pipeline failure mode is either; static loading by water pressure or pressure variations due to vortex induced vibrational (VIV) that causes fatigue failure of the steel. Both of these failure modes require that the pipeline is freespanning, but in the VIV loading scenario there also needs to be enough of a gap under the pipeline to allow the movements caused by the VIV occur to induce fatigue. Over the past 20 years ground inspections (supplemented by boat based surveys or diver surveys) have been completed at nearly 20,000 pipeline watercourse crossings for over 20 different pipeline owners. At many of the watercourse crossings there have been multiple inspections over this period. During this period there have be more than 740 unique locations were an exposed pipeline was found and 150 unique locations where a freespan was encountered. Only one of the freespans resulted in the failure of the pipeline. This record of performance of the exposed pipelines illustrates what is now become widely accepted, that pipeline exposure does not necessa lead to pipeline failure. The relevant question for "water loading caused pipeline failure" is: Does the combination of freespan length and water velocity exceed a combination that would lead to VIV or the exceedance of the static load limit of the pipe? The freespan case history record is used to illustrate that the question posed above is the relevant one. The case histories, however, are dominated by freespans found in smaller watercourses. The records have been supplemented with information from the literature, both with failures and freespans that did not result in failure. These case histories allow for the following: confirmation that sites that do not have a combination of freespan length and water velocity that exceed either VIV or static loading limits do not fail, and creation of a way to estimate what lengths of freespans are typically encountere
Track 4: Operations, Monitoring, and Maintenance	Track 4.4	IPC2020-9452	Richard Guthrie	Using Results of Western Canadian Flood Scour Assessments to Provide a Simple Screening Tool for Pipeline Watercourse Crossings	Pipeline watercourse crossing assessments require river surveys, field investigations, and detailed scour analyses to accurately determine whether a pipeline may subject to scour deeper than their depth of cover (DOC). Typical flood scour algorithms rely on discharge, median grain size, and some measure of channel cross-sectional area to determine the tractive force of water on the stream bed (note: these algorithms are only applied to non-cohesive sediments typical of fluvial systems). To better define pipeline threats at a screening level, reducing unnecessary field and analytical expenses, and focus effort on credible hazards, we developed a flood scour screening tool that uses return period discharge (Q) as the only input requirement. In order to develop the tool, we plotted the results of over 1,200 detailed scour assessments for several grain sizes (6,000 data points) completed in Ontario, Saskatchewan, Alberta, and British Columbia, in 2018 and 2019. The results clearly show the importance of channel variability and grain size, but also showed definable discharge related trends. We compared the results of the National Engineering Handbook (NEH) and the United States Bureau of Reclamation (USBR) methods (both methods use the same algorithms), developed, and provide herein, relationships that can be used to screen out scour assessments at watercourse crossings where DOC is already known, or to support and expedite field programs where DOC is being obtained. If only Q is known, then a single graph, or single equation is used for a given region. This provides the most conservative result. If both Q and median grain size are known, then the user can determine a slightly less conservative result from a series of complimentary equations. In all cases, the result uses the more conservative USBR method, originally intended for design, to fully capture the potential variability in the calculated NEH flood scour. While conservative, the tool is easy to use, and we expe it will substantially reduce the assessment effort on smaller, or less erosive stream
Track 5: Materials and Joining	On Demand	IPC2020-9248	Lyndon Lamborn	Negligible Crack Growth Thresholds	Pipeline operators are often presented with decisions which could be supported with scientifically-vetted and situationally accurate stress thresholds for no crack grow The threshold stress-intensity factor, ΔK_{th} , is the value for ΔK where crack growth, da/dN, approaches the threshold crack growth rate. Stress-intensity factors at or below this value result in crack growth small enough for operators to practically ignore it in pipeline integrity assessment. Previously, a ΔK_{th} value of 2.0 MPa*m 0.5 had been suggested for general use in a PRCI study, these laboratory-determined values appear conservative when compared to industry experience, established ΔK_{th} for similar steel alloys, and conclusions reached in a USDOT report regarding post-hydrostatic test susceptibility. By establishing an on-shore pipeline specific ΔK_{th} which considers a pipeline-specific da/dN threshold and stress ratio effects, operators are afforded the opportunity to: Exclude certain pipelines or portions of pipelines from cr growth susceptibility Identify features with no life limit where loading is known Adjust load and boundary conditions to preclude crack growth Improve computational efficiency by discarding load cycles below threshold A large pipeline operator has researched pipeline crack growth testing and has derived reasonable and prudent negligible crack growth values through a closer examination of ΔK_{th} , including exploration of how different loading scenarios and environments affect ΔK_{th} . A da/dN threshold for when diminishingly small crack growth rates can be neglected for typical pipeline assets was determined based on pressure fluctuation frequency. Applications and value derived from deployment of ΔK_{th} are illustrated for North American pipeline assets, and there are significant implications of determining growth susceptibility of low-pressure pipelines after hydrostatic test. Growth limitations are developed for circumferential cracks based on ΔK_{th} screening for buried pipelines. Establishing threshold ΔK_{th} paves the way toward adoption of next-level fracture mechanics best practice models such as the NASGRO equation; and facilitates crack growth simulations and root-cause analysis
Track 5: Materials and Joining	On Demand	IPC2020-9255	John Kiefner	Estimating Toughness for Lf and Dc Welded Erw Seams	ERW pipe materials, particularly those manufactured prior to 1970, have exhibited higher rates of failures from seam manufacturing defects than other types of pi materials. Typically, the seam bond line regions of low-frequency (LF) and direct-current (DC) welded ERW pipe materials exhibit poor resistance to manufacturi defects. The toughness of the bond line region is difficult to determine, and it is likely to vary for one piece of pipe to another. Pipeline operators must address the risk of ERW seam failures as part of their integrity management plans, but it is unlikely that they will know the toughness levels in the seams of their pipelines comprised of such materials. To avoid having to know the toughness levels in the seams, a pipeline operator can utilize a hydrostatic test to verify the integrity of a vintage ERW pipeline, but there are disadvantages the main one being that the pipeline must be taken out of service. ILI Crack tools offer a means of locating and sizing ERW seam defects without the pipeline having to be removed from service. Even if the seam defects can be located, correctly-sized, and classified, however, the operator may have no idea of the effective toughness that is the key to deciding whether or not a given crack has to be excavated and repaired. Presented herein are some suggestions for improving the effectiveness of an ILI integrity assessment of a pipeline with low toughness ERW seams. First, the operator should choose a suitable model for predicting the failure pressures of defects in a low-toughness material. While several such models exist, the PRCI MAT-8 model is used herein for that purpose. Second, the operator will find it necessary to estimate an appropriate level of toughness to assess the defects identified by the ILI crack tool. Two options for estimating an appropriate level of toughness are described herein for three categories of ERW seam defect: selective seam weld corrosion, cold welds, and hook cracks. Option 1 involves assuming a conservative level of toughness. Some such levels are available in the publicly available documents. Data from a large database of ERW seam failures are used to show the effectiveness of a fixed level of toughness at identifying critical defects while minimizing unnecessary digs. Option 2 consists of back-calculating the toughness levels associated with the known crack sizes and failure pressures of the defects in the database of ERW seam failures and calculating the probability that each type of defect would have been correctly identified at a particular level of confidence using a particular level of toughness. Using either of these options, a pipeline operator can improve the effectiveness of an ILI-crack-tool integrity assessment of a pipeline comprised of LF or DC welded ERW seams by reducing the number of unnecessary excavations while still being able to find the critical defects with an acceptable lev
Track 5: Materials and Joining	On Demand	IPC2020-9354	Philippa Moore	Crack Initiation and Propagation in Static Loaded Fracture Mechanics Tests in Steels Containing Atomic Hydrogen	Hydrogen is well known to have a detrimental influence on the ductility of steels; reducing the fracture toughness. Standard test methods to characterize fractu toughness of steels in terms of ductile tearing resistance curves have not been developed to account for any contribution of hydrogen-driven contribution to the crack extension, Δa. Simply plotting J or CTOD against Δa is not necessarily appropriate for defining the initiation fracture toughness for tests performed in a hydrogen-charging environment. This paper explores a method to further analyse experimental data collected during fracture toughness tests, which allows the contribution of plasticity (i.e. when blunting precedes ductile tearing) to be considered independently from the initiation of crack extension (which could be by stable tearing or by hydrogen-driven crack extension). The principle is based on the assumption that a crack growing by a hydrogen-driven mechanism in a quasi-static fracture mechanics test performed in environment may not be associated with significant ductility in the plastic zone (which would accompany crack growth by stable tearing). Established fracture toughness test methods to define tearing resistance curves presume that all crack extension is by stable tearing, which could lead to over-estimations of fracture toughness when hydrogen-driven crack growth results in an increase in CMOD and thus J without necessarily any plasticity. The analytical method presented in this paper compares the different points of deviation from linear behavior of the components of J, to isolate the effects of ductility within the plastic zone from pure crack extension. In this way, the point of crack initiation can be defined in order to determine the relevant initiation fracture toughness; whether by blunting and stable tearing, or by hydrogen-driven crack growth. This method offers a common testing approach which is illustrated using examples of fracture mechanics specimens tested in environments of varying severity (air, seawater with cathodic protection, and sour service). The initiation fracture toughness can be defined using this method while allowing for a combination of ductile tearing, hydrogen-driven crack extension, or both, to be present during the tes

Track 5: Materials and Joining	On Demand	IPC2020-9403	Brian Leis	The Effects of the Flow Response on the Failure Pressure of Line Pipe Steels	The flow response of modern thermo-mechanically processed structural steels, like those developed for transmission pipelines, reflects the effects of several strengthen mechanisms. Among others, these include refined microstructural size, solid solution strengthening, and precipitation strengthening. While aspects of their effects can be correlated with microstructural metrics, general first-principles models of the flow response based on these metrics can be badly scattered. For this reason engineers in need of flow properties to support their numerical analysis during design, or regarding integrity management decisions, rely on parametric empirical stress-strain models. For many decades engineers doing strength-based design have assessed the post-yield benefits of these strengthening mechanisms in ter of a flow-stress, or by reference to the yield to ratio for the steel. With the advent of strain-based design motivated by concern for ground movement among others, there was a need to also consider the role of the strengthening mechanisms relative to the strain, using for example the strain hardening exponent, n . Recognition that the burst-pressure of pipe also showed a dependence on n further motivated the need to correlate the seldom measured value of n to commonly available metrics like Y/T. This paper begins with a brief review of correlative approaches involving n and Y/T, and then transitions to consider standard practices to quantify n , and their evolution over time. Next the results of about 200 tensile tests carried either to the UTS or beyond are introduced. Results are presented for Grades A25 and A30, and Gr B, for steels removed in rehabilitation as well as those used during the calibration of ASMR B31E. Likewise, X-Grade data that underlie the calibration of B31G are considered in reference to Grades X46 and X52. Flow properties are also considered for vintage X52 through modern X52, with similar results considered for early production of Grades X60, X65, X70, X80 and X100 versus for these same grades in recent to current production. These flow properties are trended relative to Y, T, and n , as well as in reference to the uniform strain corresponding to the UTS. A correlation is developed between Y/T and n that accurately tracks this comprehensive dataset, which shows that these empirical data diverge from existing correlations of n vs Y/T for the lower-strength grades. Further, the results show that within a Grade the value of n is a rather strong function of the ratio of the actual yield stress (AYS) normalized by SMYS, with this dependence indicative of differences in the chemistry and processing used to achieve the Grade. The significant implications of Y/T and its dependence on the ratio AYS/SMYS are illustrated in regard to the predicted failure response of line pipes subject to increasing pressure. These predictions are validated in reference to about 20 full-scale tests on pipe pups for which the corresponding full-range stress-strain response has been developed.&nb
Track 5: Materials and Joining	On Demand	IPC2020-9410	Xin Wang	Application of the Cohesive Zone Model to Crack Tip Opening Angle Design Methodology for Ductile Fracture in Pipeline Steels	The crack tip opening angle (CTOA) has been extensively studied as a fracture propagation parameter with great interest over the past several years. It is particular interest in the gas pipeline industry. ASTM E3039 describes the standard test method for determining the CTOA from a drop weight tear test (DWTT) specimen. This standard was developed to provide a consistent method of determining the CTOA of a DWTT specimen from the load-displacement data. Experimental work has been performed showing that the CTOA determined from ASTM E3039 matches the mid-thickness CTOA of the material (highest constraint). One key aspect to using the CTOA as a design parameter is the idea that it is transferrable from one loading mode to another i.e from a bending loading mode (DWTT) to a tensile loading mode (pipe). In this paper, the ability of the CTOA to be transferred between small-scale test specimens and large-scale structures was examined. This work also compared the results of a cohesive zone model (CZM) to the results of a constant CTOA model. The line pipe steels examined in this work were an American Petroleum Institute (API) Standard X65 steel and a structural steel with the grade designation of STPG370. The commercial finite element code ABAQUS 2017x was used to generate the models and solve the analyses. The surface-based cohesive zone model was used to simulate crack propagation. The CZM parameters were calibrated based on matching the surface CTOA measured from small-scale specimen (DWTT and modified cantilevered beam) finite element models to the experimental surface CTOA of the material. The CZM parameters were then applied to pipe models. A user-subroutine (VDLOAD) was used to model the internal pressure distribution and decay during the fracture process for the pipe models. The transferability of the CTOA between small-scale specimens and the pipe model was demonstrated using the CZM. The results of the analysis demonstrate that the CZM can be used to model fracture propagation and produce results which are very similar to experimental observation. Moreover, the numerical results of the CZM compared well with the results of a constant CTOA model. The experimental results of the STPG370 steel were matched within 10%. These results give confidence to the transferability of the CTOA between small-scale specimens and large-scale structure under different loading mode
Track 5: Materials and Joining	On Demand	IPC2020-9545	Bradley Davis	Separation Characteristics of an X65 Linepipe Steel From Laboratory-Scale to Full-Scale Fracture Tests	Separations are small fissures that form along the rolling plane of line pipe steels as the steel deforms and the stress state reaches the critical value to initiate separation. Separations are often observed on the fracture surfaces of tensile, Charpy, and drop-weight tear test (DWTT) specimens—the key tests for determining the fracture arrest capabilities of line pipe steel. However, when comparing laboratory-scale material tests to a full-scale burst test, the separation appearance on the fracture surface is dissimilar. This indicates that laboratory-scale tests may not capture separations' influence on fracture behaviour compared to full-scale burst tests (FSBT). For this study, the fracture surfaces of Charpy impact and DWTTs specimens were evaluated for their separation characteristics based on the separation index (SI). This was then compared with the separations found of the fracture surfaces of two full-scale burst tests containing a CO 2 /N 2 mixture. Sections at the front, middle, and tail of each fractured full-scale test pipe section were extracted and their surfaces analysed for their separation characteristics. This was then compared with the corresponding Charpy and DWTT specimen fracture surfaces. The methods used in this study revealed several complexities when measuring separations on a fractured surface. The two chief concerns are the effects of lighting and material degradation. For Charpy and DWTT specimens, material degradation is easy to minimise, however, since FSBTs can be exposed to harsh environmental conditions, extra care must be taken to preserve the surfaces for separation analysis. Even with these considerations, the analyses performed here showed a reliable repeatability, providing a trend of separation severity across all fracture faces. With the separations measured across all fracture faces, the SI of the FSBT surfaces consistently fell below those measured on Charpy surfaces but above those measured on DWTT specimens. The closest similarity between FSBT and DWTT surfaces was seen right before fracture arrest, where the fracture velocity was lowest. When comparing the SI between specimen types, only the Charpy and DWTT surfaces showed a strong correlation to each othe
Track 5: Materials and Joining	On Demand	IPC2020-9582	Vitor Adriano	Influence of Small Volumetric Flaws on the Measurement of Crack Growth and Tearing Resistance in Sent Tests.	The clamped Single Edge Notch Tension (SENT) specimen has a crack tip constraint similar to pipes containing a surface breaking defect. For this reason, the SEN test is often applied to characterize the fracture toughness or, by extension, the ductile tearing resistance (R-curve) of pipe girth welds. R-curves can be obtained by testing multiple specimens up to different load levels or testing a single specimen for which crack extension and crack driving force are measured at various instances during the test. The measurement of crack extension is particularly challenging and mostly achieved by means of Unloading Compliance (UC) or Direct Current Potential Drop (DCPD). Due to the challenges inherent to in-the-field arc welding, volumetric flaws such as porosity are often found in pipe girth welds. Within reasonable limits, these flaws are not detrimental to the structural integrity of the full-scale component as a whole. However, they may affect the outcome of an SENT test, given their relatively larger effect on small laboratory test specimens. Prior testing at Soete Laboratory indicated that involved effects on crack extension may be significant. Furthermore, crack sizing techniques such as DCPD and UC might have their accuracy affected as well. Currently, however, there is no guidance in SENT procedures regarding test validity for specimens containing volumetric flaws. This study evaluates and quantifies the influence of volumetric discontinuities on the SENT tearing resistance curve as measured using DCPD and UC techniques. In order to do that, a series of SENT tests were carried out. Specimens containing small drilled holes in different locations to simulate the presence of volumetric weld flaws were used. In addition, porous welds were produced by robotic Gas Metal Arc Welding (GMAW). Welding parameters were fine-tuned in order to obtain specimens with different porosity levels. Afterwards, the porosities were characterized by means of X-ray Computed Tomography (CT) scans and their position, shape and location were determined. SENT tests were performed in a servo-hydraulic machine using a double clip gauge set up to measure crack opening, Digital Image Correlation (DIC) to monitor the strain field and DCPD and UC for crack sizing. The results indicated that volumetric discontinuities can influence the accuracy of crack measurement techniques in particular, and the measured resistance curve as a whole. The outcomes of this study provide a basis for ongoing research, aimed to develop guidance for SENT test validity in presence of volumetric weld flaw
Track 5: Materials and Joining	On Demand	IPC2020-9589	Nathan Switzner	An Approach to Establishing Manufacturing Process and Vintage of Line Pipe Using In-Situ Nondestructive Examination and Historical Manufacturing Data	The October 2019 revisions to US federal rules governing natural gas pipelines establish a focus for operators to determine vintage and manufacturing process for ass with incomplete records. Vintage and manufacturing process information serve as critical inputs to subsequent MAOP reconfirmation, materials verification, and integrity management programs introduced through these revisions. To fulfil these requirements operators will be permitted to use nondestructive examination (NDE) technologies for pipeline materials and attributes verification. Pipeline operators can deploy various state-of-the-art NDE technologies to characterize materials in order to comply with these new rules. The focus of this paper is a methodology utilizing knowledge of historical line pipe manufacturing practices in combination with data gathered nondestructively to re-establish pipe manufacturing process and vintage records. Economic and market demands have driven historical changes in steelmaking technologies and pipe-forming approaches. Knowledge of the relationships between processing, microstructure, mechanical properties have been fundamental to the evolution of steel line pipe product improvements. Standards for manufacturing and testing of pipe products, such as API 5L, have evolved, and performance expectatio have increased. The resulting manufacturing process changes have left a variety of "fingerprints" that can be observed in the NDE data when viewed holistically. The purpose of this work is to enable operators to leverage these fingerprints to illuminate the vintage and manufacturing process of their line pipe assets using the NDE data. PG&E has performed extensive testing of line pipe samples with outside diameters ranging from 4-36 in and vintages from the 1930s to 2010s. Chemical composition was evaluated using NDE and laboratory testing. Microstructures of non-destructive metallographic replicas and destructive cross-sections were analyzed. Hardness testing and instrumented indentation testing were used to estimate mechanical properties and destructive tensile testing was performed for validation. This wo will highlight some pitfalls to assuming that the NDE composition, microstructure and mechanical properties results are equivalent to destructive test results. Variations in chemical composition and microstructure that link to manufacturing processes will be presented. Destructive testing results revealed differences in strength, toughness and mechanical property anisotropy that NDE methods were unable to reveal without considering vintage and manufacturing. The current work harmonizes historical manufacturing knowledge with important findings from NDE and destructive testing of line pipe, which will be crucial in meeting the demands to identify vintage and manufacturing process
Track 5: Materials and Joining	On Demand	IPC2020-9596	Nitin Sharma	Role of Crystallographic Texture on Toughness of Erw Welded and Heat-Treated Api X70 Pipeline Steel	The impact toughness of high frequency electric resistance welded line pipe depends on the steel chemical composition, welding procedure, and post-welding he treatment. Among several microstructural factors that may influence the impact toughness of high frequency electric resistance welded bond line, the crystallographic texture factor is often assumed, but has not been sufficiently studied. The evolution of texture during high frequency electric resistance welding and post-welding heat treatment (PWHT) of API X70 pipeline steel was characterized using X-ray diffraction (XRD) and electron backscatter diffraction (EBSD). Preliminary results of texture factor calculated using the θ/2θ XRD scans indicated that the base metal has a strong preferred crystallographic orientations along the (110) and (211) slip systems of ferrite grains. Following the ERW process, the weld region still shows the same crystallographic orientations, although a strong microstructure texture in the form of flow lines was observed in the hour-glass shaped weld zone and its vicinity. Following post-weld normalizing treatment, the texture factor of the weld bond line along the (100) planes appeared to have increased with the increase in post-weld normalizing temperature, showing the effect of the annealing texture. The texture factor results obtained from θ/2θ XRD scans were further verified using (100) pole figures obtained from EBSD for micro texture in the particular regions of the bond line and the HAZ. The XRD texture factor was also used to correlate the evolution of crystallographic texture and toughness as measured by Charpy V-notch impact testing of PWHTed samples. Based on the observations from both XRD and EBSD, the (110) crystallographic texture seems to correlate with the cleavage fracture planes of the Charpy impact tested samples. Therefore, the post-weld heat treatment should be designed to decrease the (110) texture, for the possible enhancement of ductile fracture, or improved bond line impact toughness at low temperatures

Track 5: Materials and Joining	On Demand	IPC2020-9602	Scott Riccardella	Insight on Fracture Toughness and Predicted Failure Pressure for Vintage Erw Seam Defects	Seam weld anomalies (SWAs) can pose a significant threat to pipeline integrity. Notable longitudinal seam weld failures, such as the 2007 12-inch liquid propane pipelir rupture in Carmichael, MS that resulted in two fatalities, brought this integrity threat to the forefront of industry and regulatory attention. As a result of this accident, the National Transportation Safety Board (NTSB) questioned the effectiveness of In-Line Inspection (ILI), Hydrostatic Pressure Testing (Hydro-testing) and analytical methods used to evaluate the criticality of defects. This paper presents a method for estimating fracture toughness of pipeline seam welds for determination of predicted failure pressure when documented Charpy v-notch toughness values are not available for the pipeline segment. The method determines an inferred toughness distribution from historical pipeline seam failures published in recent PHMSA ERW research projects, a major industry association paper, and a pipeline operator's historical data on seam failures(both operational and during hydrotests). A statistical analysis of these data was performed and recommended fracture toughness values were developed considering different ERW defect types (e.g. Cold Welds/Lack of Fusion, Hook Cracks, Fatigue Enhanced Cracks and Selective Seam Weld Corrosion). The paper also considers different seam types and vintages. Probabilistic Fracture Mechanics methods were then used to compare the resulting probabilities of failure and the economics of dig and repair criteria associated with these fracture toughness recommendations, relative to those that would result using the default toughness values published in recent PHMSA pipeline safety regulations (i.e. 49 CFR Parts 191 and 192, Pipeline Safety: Safety of Gas Transmission Pipelines: MAOP Reconfirmation, Expansion of Assessment Requirements, and Other Related Amendments). The analyses consider typical flaw densities and size distributions from in-line inspections of pipeline seam welds, as well as the impact of uncertainties from common sources, such as ILI tool tolerance, detection threshold, flaw characterization and sizing accuracy, crack growth rates, and PFP accuracy. The paper provides recommendations for remediating ILI anomalies as well as recommended reassessment intervals based on these resul
Track 5: Materials and Joining	On Demand	IPC2020-9649	Muhammad Rashid	The Use of Optimized Erw Techniques to Improve Low Temperature Fracture Toughness of Welded Pipe	Pipes produced using the Electrical Resistance Welding (ERW) process, having good surface finish and consistent dimensional and mechanical properties, are favorable choice for a wide range of pipe and tubular applications. These include pipes for both Line Pipe and Oil Country Tubular (OCTG) products used in standard and low temperature applications (-45 C). During the ERW pipe making process, hot rolled coil skelp edges are heated and then forged (pressed) together to form the ERW weld seam. Subsequently, the welded region in the vicinity of ERW seam is heat treated (normalized). In addition to the actual welding and forming processes, the normalizing step is critical as it contributes to the final microstructure and resulting properties of the ERW seam. It is understood that the bond line can be a zone of weakness in the pipe. In recognition of this, recent changes have been made to CSA and API standards requiring that the notch of the Charpy V-notch tests be placed as close as possible to the bond line. This requirement has made achievement of low temperature requirements particularly challenging. In response to this challenge, several research projects utilizing various line pipe steel grades and welding techniques have been conducted at EVRAZ NA and at an academic research lab. The overall goal of these efforts has been to understand the development of bondline microstructure during the ERW process and improve the weld seam fracture toughness at temperatures below 0°C. These research activities included mill trials using different steel chemistries for different welding parameters and normalizing practices. Gleeble simulation of the as-welded seam was also conducted to evaluate the thermomechanical design. It was realized that a high toughness ERW weld seam is only possible through a tightly controlled combination of weld power, forging pressure, and welding speed. Research studies have indicated that the as-welded seam may not pass standard ERW destructive tests if adequate forging pressure is not applied. For a given weld power level, the ERW weld seam toughness improved with higher forging pressure. Post weld heat treatment (normalizing) practice was also found to be a key element in the development of the appropriate bondline microstructure for higher toughness. Samples from pipes normalized using low and high temperatures produced different bondline microstructures and hence different toughness properties. Detailed charcterization including scanning electron microscopy (SEM) and electron beam back scattered diffraction (EBSD) showed that the time-temperature combination of the normalizing heating and soaking cycles strongly influenced ERW seam microstructure and resultant toughness properties. Results of several mill trials including a full scale DOE trial and detailed charcterization are discussed in this paper. &nbs
Track 5: Materials and Joining	On Demand	IPC2020-9687	Nicolas Romualdi	Austenite Grain Size Control During Welding of Line Pipe Steels	Pipelines are the safest and most cost-effective method of oil and gas transportation to storage and processing facilities. Large diameter API 5L welded pipes fabrical by submerged arc welding (SAW) are the preferred product in many cases for pipeline construction. Furthermore, pipelines are constructed by welding segments of pipe, typically by single or dual torch Gas Metal Arc Welding (GMAW). During welding, both during pipe fabrication and girth welding, the Coarse Grain Heat Affected Zone (CGHAZ) experiences rapid thermal cycles with peak temperatures up to the melting temperature of the base metal. Controlling the microstructure evolution in the heat affected zone (HAZ) during welding of line pipe steels is critical to ensure that these products meet the Charpy impact testing and CTOD requirements by clients and specifications. In particular, the CGHAZ is of concern where austenite grain growth occurs readily due to the combination of high temperature and precipitate dissolution. Controlling the CGHAZ austenite grain size is critical to obtain final microstructures with acceptable impact properties. In this study, austenite grain growth has been measured and modeled for thermal conditions relevant for the CGHAZ in 27 steels including industrial as well as laboratory steels with systematic variations of alloying element content Austenite grain size was measured using a Laser Ultrasonics for Metallurgy (LUMet) sensor attached to a Gleeble, which enables high-throughput in-situ monitoring of austenite grain growth. A classical grain growth model has been developed based on a standard test. The grain growth kinetics are described by combining curvature driven grain growth with pinning due to TiN precipitates. A phenomenological relationship has been developed for the grain boundary mobility that decreases with C, Nb and Mo alloying which is consistent with their expected grain boundary segregation. The pinning parameter is rationalized in terms of volume fraction and size of TiN particles. The proposed model has been validated for CGHAZ heat treatment cycles. The results of this study provide a model that can predict the austenite grain size in the CGHAZ as a function of steel chemistries and heat treatment paths, i.e. welding parameters. Processing maps for austenite grain size control have been constructed as a function of welding parameters and line pipe steel chemistry. Thus, the model can be used both for steel chemistry design and for optimizing welding of steels with known chemical composition to minimize the CGHAZ austenite grain size both during pipe fabrication and girth weldinc
Track 5: Materials and Joining	On Demand	IPC2020-9706	Mitchell Grams	A Quantitative Index to Assess the Influence of Joint Fit-Up on Pipeline Weld Root Discontinuities	This study presents a numerical index to quantify the influence of non-ideal joint geometry on the defect susceptibility of the root pass for circumferential pipeline welc The combination of manufacturing tolerances on component dimensions and thermal distortion during fabrication is known to result in deviations from ideal joint geometry in virtually all welded joints. Although not problematic in many joint geometries, under the unique conditions present during field tie-in welds on pipelines, deviations such as a high-low offset at the inner pipe wall have been correlated with an increased occurrence of root weld defects such as cold cracking. During the deposition of the root weld pass, significant plastic strains are produced in the hoop direction of the pipe as a result of the constrained thermal expansion and shrinkage in the weld fusion zone and surrounding material. After the material has cooled to a uniform temperature, this plastic strain results in a residual tensile hoop stress which will tend to produce local bending across the weld joint. In joints with close to ideal geometry, such as those used for procedure qualification, the material typically has enough capacity to accommodate this bending and the probability of defect occurrence is relatively low. In production welds, the presence of non-ideal joint geometry will create a stress/strain concentration at the weld root which has the potential to produce more severe conditions for defect formation than those present during qualification. Quantifying the effect of non-ideal geometry, necessitates an improved understanding of the interdependence of welding parameters, joint geometry, and the resulting residual stress and strain distribution in circumferential joints. To enable the application of this understanding in industrial practice, it is desirable to simplify the complex multi-physics of residual stress development into a minimal expression which considers only parameters which may be known or estimated prior to welding. Th work utilizes a combination of analytical and numerical methods to identify the dominant material properties and procedural variables that drive defect susceptibili The resulting parameters are synthesized in the form of a quantitative index that allows industrial practitioners to characterize the defect susceptibility of any given weld procedure and joint preparation. In addition, this index represents an enhanced understanding of the interaction between joint geometry and welding residual stresses which is essential to establish improved guidelines for acceptable levels of geometric deviations as well as to guide the development of new and more robust pipeline welding procedures
Track 5: Materials and Joining	On Demand	IPC2020-9710	Aaron Dinovitzer	Heat Affected Zone Softening Susceptibility Test	There have been a number of unexpected girth weld failures in pipelines, both in-service and during pre-service hydrostatic testing. Investigation of these incider indicated that the line pipe met industry standard requirements, such as API 5L and the welding procedures had been qualified to API 1104 and construction welding/inspection had been completed according to industry standards. The investigation of these failures indicated that they were not related to hydrogen cracking or misalignment, however, line pipe chemical composition and tensile properties were identified as having contributed to these failures. Low carbon and low carbon equivalent (CE) higher strength line pipe materials produced with thermo-mechanical controlled processing (TMCP) practice is believed to have contributed to the failures. Higher heat input welding in these lean chemistry steels can result in heat affected zone (HAZ) softening that produces a lower strength zone adjacent to the girth weld, making it susceptible to tensile failure from axial loading. In the presence of thermal or geohaz loading, these softened or lower strength HAZ's become a concern where there has been pipe settlement or in strain-based assessment. To understand the factors that influence the susceptibility to HAZ softening and identify those materials that can be considere at risk, a material testing procedure has been developed. This new testing procedure is a weld bead-in-plate test that was designed to maximize the potential for HAZ softening in an effort to identify those line pipe materials that may be susceptible to HAZ softening in construction or during in-service welding. This paper presents the results of experimental trials comparing the susceptibility of leaner chemistry materials to HAZ softening. The testing procedure is described along with opportunities to enhance the procedure to develop a standardized test for HAZ softening assessment. This test has the potential to be used to identify materials at risk to HAZ softening and may also be used to qualify line pipe to demonstrate its resistance to HAZ softeni
Track 5: Materials and Joining	On Demand	IPC2020-9712	Aaron Dinovitzer	Weld Hydrogen Cracking Susceptibility	Weld hydrogen cracking has been recognised as an issue of concern and a wide range of hardenability criteria and single pass weld testing techniques have be developed to demonstrate material weldability, however, hydrogen cracks continue to be identified in welds. The potential for hydrogen cracking can be related to the presence of hydrogen, the local tensile strain state and the susceptibility of the material microstructure. The weldment slow bend test and hydrogen effusion and cracking model has been used in Pipeline Research Council International (PRCI) research reported in this paper to support the development of an understanding of the interaction of these factors in promoting hydrogen cracking. The slow bend testing procedure is described and examples of the effects of increasing hydrogen and/or strain conditio are used to illustrate hydrogen cracking susceptibility. The slow bend testing procedure was applied to a range of dissimilar weld metals to develop an understanding of the factors which make one material more or less susceptible to hydrogen cracking. Combining the results of slow bend testing, the susceptibility of deposited shielded metal arc weld material to hydrogen cracking is defined using a hydrogen susceptibility curve. The form of the hydrogen susceptibility curve, defining the critical strain and hydrogen concentration to form a crack, has been related to mechanical, chemical and microstructure of properties of the deposited welds through the definition of material ductility and embrittlement indices. This approach is capable of defining hydrogen cracking susceptibility in the absence of slow bend testing. This preliminary model to predict weld metal hydrogen cracking susceptibility was developed to support electrode selection and welding procedure development to preclude hydrogen cracking. The results in this paper will be useful in developing an understanding of the factors influencing the risk of hydrogen cracking and how they can be managed to reduce the risk of cracking and support the development of industry guidance

Track 5: Materials and Joining	On Demand	IPC2020-9766	Gaute Gruben	Pipeline Fracture Control Concepts for Norwegian Offshore Carbon Capture and Storage	The Northern Lights (NL) onshore terminal will initially receive CO2 transported by ship tankers from several industrial source sites located in south-eastern Norw temporarily store liquid CO2 onshore in tanks at the terminal; and finally transport CO2 via a 12 ¾'' OD offshore pipeline for injection into the Johansen storage reservoir, located just south of the Troll field. The CO2 injection pipeline will be laid from the shore terminal to a subsea wellhead structure from where the gas will be injected into the reservoir. Presently, demonstrating arrest of longitudinal propagating shear fracture in CO2 transport pipelines is specifically addressed in two international guidelines, ISO 27913 and DNVGL-RP-F104. The study reported here aims to develop a robust fracture control methodology unique to the Northern Lights pipeline that confirms a strengthens the fracture arrest criteria available in these guideline documents The important loading of concern for fracture propagation control of pipelines transporting liquid CO2 stems from the fluid saturation pressure. For the NL pipeline concept study, the highest expected CO2 saturation pressure will occur by depressurization from onshore/shallow water conditions. This pressure is 55.8 bar, which gives an effective loading pressure of 54.8 bar. Application of the Battelle method without correction led to an arrest pressure of the baseline pipe that is near insensitive to the linepipe material Charpy impact energy (CVN) value. The estimated arrest pressure is ~140 bar for CVN values in the range 100-200 J, or more than 2.5 times the estimated maximum load. Applying factors in accordance with ISO 27913 and DNVGL-RP-F104, here 1.2 on the estimated arrest pressure and 1.3 on the estimated load pressure, a wall thickness of ~10 mm is sufficient to arrest a propagating crack. Thus, the baseline pipe with a wall thickness of 15.9 mm has abundant capacity to arrest a propagating crack following the Battelle method. The Battelle analyses were supplemented by numerical simulations. The numerical models applied in this study are based on SINTEF's coupled FE-CFD model. The FE-CFD model is built within the framework of the commercial FE software LS-DYNA. The pipe is discretized using shell elements and the surrounding soil or water is discretized using smoothed particle hydrodynamics. The depressurization upstream of the crack-tip and the pressure of the escaping fluid downstream of the crack-tip are calculated using an in-house, one-dimensional CFD solver. The results from the CFD simulation are used to estimate the pressure profiles in the cross-sections both upstream of the crack-tip and on the flaring flaps downstream the crack-tip. The numerical simulations of the baseline pipe positioned on rigid ground with no trench or backfill also resulted in a minimum wall thickness of ~10 mm for a CVN value of 200 J. However, the numerical analysis is more sensitive to the CVN value than the Battelle analysis, and the minimum wall thickness for CVN=100 J is ~11.5 mm. When accounting for soft soil, and especially for cases where the pipe is submerged under water, trenched or backfilled, the capacity is further increased so that the minimum required wall thickness of ~11.5 mm for the 100 J material is conservative. The main conclusion is that with the given pipe material and diameter, and the given loading conditions, a wall thickness of 15.9 mm, or potentially a wall thickness of 14.4 mm accounting for a 1.5 mm reduction due to corrosion, is enough for arresting a propagating crack. In addition, it is concluded that the BTCM with ISO 27913 or DNVGL-RP-F104 correction factors can provide a good first estimate in pipe design. In this study, however, the arrest pressure saturates for low CVN values indicating limited accuracy. For t NL pipeline, the analyses lead to a robust arrest assessment with significant margin to a critical wall thickness. With these factors now verified for this specific case, the otherwise straightforward fracture arrest methodology is considered fit for use in subsequent FEED and detail desig
Track 5: Materials and Joining	Track 1.1 / Track 5.1	IPC2020-9407	William Walsh	Ring Expansion Testing Innovations – Hydraulic Clamping and Strain Measurement Methods	Ring expansion testing is one of the three accepted methods in API 5L for the measurement of yield strength for line pipe. The other two are flattened-strap tens testing and round-bar tensile testing. A novel-concept ring expansion test machine has recently been commissioned which uses hydraulic pressure to clamp the top and bottom pressure-reacting plates rather than a traditional bolting arrangement. The benefit of hydraulic clamping is vastly reduced set-up times. This paper describes the design approach and the pitfalls that were overcome in commissioning the ring expansion test unit. Expansion measurements are taken using two different methods: a chain extensometer and an LVDT with a band wrapping the circumference of the pipe. Both approaches are used simultaneously to generate and compare two stress-strain curves for one pressure test. In addition, a 3-Point contact approach is developed to determine the hoop strain during pipe expansion. The 3-point contact approach is an attempt to infer the full hoop expansion behavior by measuring the radius change over a segment of the circumference. The device has two rollers which contact the pipe surface while a dial indicator midway between measures the radius change. As the pipe expands, the rollers maintain contact with the pipe surface while the dial indicator records the change in radius. Tests are performed on HFI, SAWL, and SAWH pipes ranging in outer diameter from 20-inch (508 mm) to 48-inch (1219 mm) and wall thicknesses from 0.375-inch (9.5 mm) to 0.969-inch (24.4 mm). The differences in the stress-strain behavior of these pipe forms are described and related to the residual-stress profiles generated by their respective manufacturing operations. The comparison to flattened-strap and round-bar tensile results are presented in a companion paper. The results of the 3-Point contact approach show that the radius change during early stages of expansion are not uniform around the pipe circumference and different patterns are observed in the HFI, SAWL, and SAWH pipe forn
Track 5: Materials and Joining	Track 5.2	IPC2020-9444	Harpreet Sidhar	Improving Reliability of Carbon Steel Girth Welds in Sour Environment	The oil and gas industry has seen unexpected failures of sour service carbon steel pipelines in the recent past. Below par performance of girth welds and line pipe mate have been identified as the root causes of such failures. Although mechanized welding can achieve good consistency, the weld region is more heterogeneous as compared to base material, which can lead to inconsistencies and poor weld performance. Overall, the effects of welding parameters on performance of carbon steel pipeline girth welds for sour service are not well understood. Furthermore, industry is moving towards more challenging environments, such as production of hydrocarbons from ultra-deepwater, which further necessitates the need to improve welding practices for sour service applications. So, there is a clear need to understa the effects of various welding parameters on weld properties and performance. This effort aims at assessing the effects of key welding parameters on performance of girth welds to develop improved welding practice guidelines for sour service pipeline applications. In this study, several API X65 grade line pipe girth welds were made using commercially available welding consumables. The effects on weld root performance of preheat, wire consumable chemistry, hot pass tempering, single vs. dual torch, copper backing, root pass heat input, metal transfer mode, pipe fit-up (root gap, misalignment) were studied. Generally, carbon steel welds with hardness 250HV or bel are considered acceptable for sour service. So, detailed microhardness mapping and microstructural characterization were conducted to evaluate the performance and reliability of welds. It was evident that the welding parameters studied have a significant impact on root performance. Preheat and pipe fit-up showed the most significant impact on weld root performance. Based on the results and understanding developed with this study, recommendations for industry are provided through this paper to improve reliability of pipeline girth welds in sour service applicatior
Track 5: Materials and Joining	Track 5.2	IPC2020-9497	Liam Hagel	Electromagnetic Induction Post Heating to Reduce Nde Delay Times of Welded In-Service Repairs	When a pipeline requires a repair, a pressure-containing steel sleeve or an emergency repair fitting is often fillet welded to the in-service pipe to return the pipeline normal service conditions. During welding, the flowing product rapidly quenches the fillet weld, promoting the formation of high hardness and low ductility microstructures in the heat affected zone. The rapid cooling rates also limit the mobility of diffusible hydrogen introduced from the welding electrodes. The hydrogen can be trapped in the weld metal and heat affected zone and concentrated in specific locations throughout the weld based on the welding deposition sequence. Fillet welds also contain inherent locations of geometric stress concentration at the weld toes and root locations. The elevated hydrogen concentration in the in-service weld, combined with the geometrical stress concentrations at the location of crack-susceptible microstructures, can increase the likelihood of forming a hydrogen-induced crack. Delayed non-destructive examination (NDE) is often employed to wait a sufficient time for any cracks to form so they can be detected. To reduce hydrogen concentration at the locations of stress concentration and NDE delay times, post heating can be applied to the in-service weld. Elevating the temperature within the weld can enable hydrogen diffusion and reducing the cracking propensity. The rapid heat removal of flowing product requires post heating techniques with high energy outputs that will not overheat the steel surfaces. Electromagnetic induced current (induction heating) methods can produce sufficient thermal energy in the electrically conductive steel pipe and sleev Coupled numerical finite element analysis (FEA) models were utilized to simulate various induction cable arrangements and thermal convection coefficients, representative of various pipeline products. The analysis of the induction heating arrangements for the studied thermal convection coefficient was conducted to achieve a minimum temperature of 120 °C in the fillet weld root and toes to enable sufficient thermal driving force for hydrogen diffusion, while ensuring the pipe and sleeve surface temperature does not exceed 200 °C.. An optimal induction heating procedure was found to that could achieve the target temperatures within a reasonable heating time such that NDE delay times of in-service welds can be reduced by 5-6 times.
Track 5: Materials and Joining	Track 5.2	IPC2020-9721	Mohsen Mohammadijoo	Influence of Steel Chemistry and Field Girth Welding Procedure on Performance of Api X70 Pipelines	Owing to the recent concerns regarding the pipeline field girth weld performance, particularly heat affected zone (HAZ) softening and toughness, EVRAZ North Ameri has initiated a research program to evaluate the response of API grade line pipe to the current field girth welding procedures. In particular, this study aims to elucidate the role of steel alloy design as well as the welding procedure on the field girth weld and HAZ properties. This understanding is critical to balance the detrimental effects of HAZ softening on the joint overall strength against factors affecting the HAZ toughness. A selection of several different steels with varying alloying levels of C, Mn, Mo, Ni, Ti, N, Ceq and Pcm have been subjected to the welding trials to assess the effects of chemistry on joint performance. Furthermore, an analysis of the effect of welding process parameters on the joint properties has been made. The welds, fabricated via a manual shielded metal arc welding (M-SMAW) process, were evaluated in terms of toughness, local vs global strain distribution using digital image correlation (DIC) technique, and hardness contour mapping of the weld and HAZ regions. The results explicitly show that the extent of HAZ softening decreased as the amount of C, Mo, Mn and Ti/N ratio increased. However, this alloying addition resulted in a relatively detrimental effect on the HAZ toughness, particularly towards the cap and fill passes. The analysis of the HAZ properties as a function of the welding process parameters indicated that the HAZ softening increased as the interpass temperature and the welding heat input increased. In addition, the DIC strain distribution analysis along the weld and HAZ regions confirmed the weld passes towards the root, hot and first fill passes are more prone to the HAZ softening compared with the upper weld cap and fill passes.
Track 5: Materials and Joining	Track 5.3	IPC2020-9290	Paul Hill	Repair and Reinforcement of Blunt Defects on Pipeline Bends Using Composite Materials	The focus of research on the use of composite repair systems to date has been on the repair of damage on straight pipe sections. However, pipeline systems a comprise other components such as bends and tees and there has been very little work to demonstrate whether or not the more complex loading in these components can be accommodated by the repair systems. Experience in use of composite repairs on bends to date has primarily been on low pressure systems in chemical plants and refineries where the design concept is markedly different to that utilised for high pressure pipe systems. This paper reports work completed in the UK DNV GL and TEAM, on behalf of the main gas pipeline operators (Cadent, SGN, National Grid, Northern Gas Networks and Wales & West Utilities) to determine how to specify composite repairs for pipeline bends in a safe and controlled manner that will ensure a consistent approach and equal level of performance is maintained over the entire system. Bends were selected that were considered bounding examples of those used within the UK gas transmission and distribution network. A series of finite element analyses were completed to consider the effects of bend size (diameter and wall thickness), material grade and bend radius and angle. From this work 90° bends of 1.5 x diameter radius were selected for test, manufactured from 12" diameter, X52 material. Rather than just consider restoration of design pressure the main interest was whether or not the repairs would restore fatigue life under cyclic pressurisation to acceptable levels. Defects were machined into the intrados of the bend of dimensions equal to 0.5 times the diameter axially and 0.25 times the diameter radially. Wall losses of 20% and 80% were replicated. This meant that both thick and thin repairs were tested to identify whether the change in stiffness, due to repair thickness, at the repair location would have an influence on the life achieved. The pressure cycles were selected to be aggressive with the hoop stress range in the steel pipe being either 125N/mm 2 or 90N/mm 2 with the lower stress range loaded for a higher number of cycles. A successful test was defined as one which exceeded the target number of cycles by a factor of 10 AND for which there was no visual sign of repair degradation. The results enabled the slope of the S-N curve for the repaired samples to be verified as matching that of an undamaged steel pipeline and confirm that the repair approach would maintain the required margin of safety within the system. The work demonstrated a design approach for repairs to be proposed that differs slightly from that in ISO 24817 and ASME PCC-2 Article 401 in that it is based on restoring the f strength of the pipe spool rather than just restoring to a design pressure. It is shown that this method is necessary and it is proposed that this be adopted by the standards when considering repairs on high pressure gas transmission pipeline systems to ensure equality of performance of the repaired sections with undamag

Track 5: Materials and Joining	Track 5.3	IPC2020-9421	Guillaume Michal	An Empirical Fracture Control Model for Dense-Phase Co2 Carrying Pipelines	All other pipe properties being equal, the control of a running ductile fracture in dense-phase CO2 carrying pipelines requires noticeably better fracture resistance th typically required for the transport of lean or rich natural gas. The long decompression's saturation plateau sustains a significant pressure, even at low fracture propagat velocities; the fracture's driving force is more severe as a result. At least four independent projects published data since 2012 to support a better understanding of the applicability of the Battelle Two-Curve Method for dense-phase CO 2 transportation and provide insight on how to estimate the minimum required toughness with sufficient margins of safety: CO2PIPESTRANS, COOLTRANS, SARCO2 and CO2Safe-Arrest. A total of 9 full-scale propagation tests were executed across these projects. About 50 pipes had interactions with a running ductile fracture: 33 supported the propagation of the fracture over their entire length, the fracture stopped in the other 17. The conclusions gained from these tests is that the original Battelle Two-Curve Method (BTCM) is not applicable with dense-phase CO 2 . Despite the saturation plateau presenting a decreasing slope as function of velocity, despite the pressure at the crack tip being typically 8 bar lower than predicted, the model can be significantly non-conservative. Correction factors on toughness and arrest pressure are required to predict the required toughness conservatively. The industrial concern is ultimately to guarantee the safety of the environment, the surrounding community and that of the asset in a cost-effective manner. Despite not providing a physical understanding of the failure mechanism, an empirical arrest equation fits this purpose. The proposed model is supported by the data from the four aforementioned projects. The details and the limitations of the database are presented. The arrest boundary is expressed graphically in the frame of the non-dimensional resistance to fracture and driving force axes, commonly used to present the NG18 arrest pressure boundary. A discussion on the location of the experimental data points relative to the arrest-propagation boundary is given. It supports the definition of three regions of interest: a region of likely propagation, a region of likely arrest, and a transition region between these two, where the boundary resides. All current standard and recommended practices have seemingly similar gaps with respect to the control of a running ductile fracture. The empirical model brings along a set of recommendations and requirements to consider in the context of dense-phase CC
Track 5: Materials and Joining	Track 5.3	IPC2020-9787	J. Barry Wiskel	Evaluation of Hydrogen Induced Cracking Resistance of X70 Pipeline Steel Under Severe and Mild Sour Service Conditions Using Ultrasonic Analysis	A standard NACE hydrogen induced crack test was used to evaluate the resistance of two compositions of X70 steel (X70-X and X70-B) under severe (pH = 2.7 ar 100% H 2 S) and mild (pH = 5.5 and 100% H 2 S) sour service conditions. An ultrasonic technique was developed to quantify the severity of hydrogen cracking in both steels as a function of test conditions, steel type and time. In this procedure, a series of local ultrasonic measurements were taken for each test sample to determine a local crack to backwall signal ratio (LCBR). The local LCBR values were integrated over the entire sample to give a global crack to backwall ratio (GCBR). The larger the value of GCBR, the greater the severity of hydrogen cracking in the sample. Energy dispersive X-ray spectroscopy (EDX) and glancing angle X-ray diffraction (XRD) were used to characterize the surface corrosion products that formed during testing. For severe sour service conditions, the GCBR value reached an asymptotic value of approximately 0.4 and 0.5 for X70-X and X70-B steels, respectively, after 2 days of testing. For mild sour service conditions, the GCBR value reach an asymptotic value of approximately 0.2 for X70-B steel after 32 days of testing. The onset of cracking of X70-X steel occurred between 32 and 64 days. XRD measurements showed the formation of FeS deposits on both steels tested under mild sour service after 8 days of testing. EDX mapping confirmed the presence of high sulfur content over a significant fraction of the surface. XRD measurements of X70-B steel under severe sour service after 8 days did not show the presence of FeS. The surface FeS is believed to alter hydrogen ingress into the steel making it difficult to directly compare the measured GCBR values obtained under mild and severe sour service
Track 5: Materials and Joining	Track 5.4	IPC2020-9323	Taro Kizu	Effects of Niobium on Microstructure and Hardness of Coarse Grained Haz of High Strength X70 Grade Uoe Linepipe Steel	The use of higher strength pipeline steel grades has enabled the economic development of oil and gas fields in hostile and remote locations. Steel alloy design these steels are the subject of continual debate in terms of cost of production and the mechanical properties afforded to the base pipe and weld heat affected zone. Debate continues in the use of various alloying combination. Niobium is indispensable in terms of austenite grain size control during steel fabrication and following weld fabrication during pipe production and field construction. Contradictory evidence exists as the role of small concentrations of niobium in the control of weld HAZ properties, primarily because of the influence of other alloying additions as the pipe strength grade increases. The present study systematically evaluated the controlled addition of increasing levels of niobium in comparison with other alloying combinations of Mn, Ni, Mo and V using laboratory melts and processed under standard production conditions It is demonstrated that niobium additions up to 0.1mass% in a low carbon steel design provide opportunities to improve pipeline mechanical properties, service performance and safety. For the hot-rolled plates, increasing niobium content resulted in grain refinement with a concomitant increase in YS and TS. Charpy impact toughness was also improved. Bainite and small volume fractions of secondary phase was a characteristic feature of all steels, irrespective of chemical composition and also niobium content. For the coarse grained HAZ, austenite grain size was limited as the niobium content increased. Weld HAZ microstructures were relatively similar with little influence of niobium content on MA character, although the hardness was noted to increase with increasing niobium content, which would be beneficial to ensure adequate resistance to weld zone softening. The results of these laboratory trials were confirmed with comparison of niobium bearing production pipe steels. In summary, the effects of niobium and other elements on the mechanical properties and microstructural development, including hardness has been quantified. The role of martensite and austenite in terms of size, shape and chemical composition has also been assess
Track 5: Materials and Joining	Track 5.4	IPC2020-9404	Douglas Stalheim	Cross-Sectional Grain Size Homogeneity Effect on Structural Steel Fatigue Performance in Air and Hydrogen Environments	Structural steel mechanical properties of strength and ductility for a given microstructure are predominately driven by the average ferrite grain/packet size and by the cro sectional homogeneity of the ferrite grain/packet size in the final product. Fatigue performance, a ductility property, in air for applications of wind towers, bridges or high-rise buildings along within environments of high-pressure gaseous hydrogen for various pipeline systems is critical to the end-use design. Fracture and fatigue testing of a commercially produced low carbon 20 mm API X60 Sour Service had been completed which showed very good stable performance when compared to other commercially produced pipeline and structural steel microstructures. This commercially produced API steel was reported as "Alloy D" in prior published work. The microstructure was predominately polygonal ferrite with industrial quality of steel cleanliness, microstructural banding and cross-sectional grain size/homogeneity required for a successful API X60 Sour Service specification/application. Based on the initial fatigue performance reported for the "Alloy D" cross-sectional microstructure a more comprehensive study on the effect of the cross-sectional grain size/homogeneity on fatigue was initiated. To isolate and study the effect of the cross-sectional ferrite grain size/homogeneity only on fatigue performance, laboratory developed samples of a low carbon API X60 Sour Service with the same alloy design as "Alloy D", predominately single-phase polygonal ferrite microstructure with excellent cleanliness and no microstructural banding with having the only difference of variations in average cross-sectional and homogeneity of the final ferrite grain size were produced. To create the desired cross-sectional grain size differences, per pass reduction strategies and austenite recrystallization behaviors were modified. The processing conditions were considered as "optimized" and "non-optimized" for the alloy design and processing capabilities of the laboratory pilot rolling mill. The cross-sectional microstructure (optically, LAGB, HAGB, averages, distributions, kernel mapping, etc.) of each processing conditions, "optimized" and "non-optimized" were fully characterized prior to fatigue testing in air and high-pressure gaseous hydrogen. The characterization analyses show that there is a strong correlation between the "optimized" and "non-optimized" processing conditions and the homogeneity in the final microstructure. The mean grain size value is reduced in the "optimized" condition to 3.2 μm from 4.7 μm. Also, the degree of homogeneity, evaluated as the Dc20% value, which gives an idea of the extension of the distribution tail, is reduced from 16.5 μm in the "non-optimized" to 8.5 μm in the "optimized" condition. Therefore, a convenient process design provides a finer and more homogeneous final microstructure. In addition, MicroSim® austenite evolution modeling of the pilot mill was conducted which also confirmed the differences noted in the cross-sectional microstructural characterization average and heterogeneity differences. Traditional mechanical property testing of the "optimized" and "non-optimized" showed expected slight strength differences from the cross-sectional ferrite grain size/homogeneity. Ductility properties of elongation and transverse charpy toughness transition temperature also showed expected differences with elongation decreased by 5.4% and charpy transition temperature increased by 25 °C for the "non-optimized" steel. For fatigue comparison purposes to the original "Alloy D" along with other pipeline/structural steel microstructures completed by NIST and others, hydrogen pressures of 800 and 3000 psi will be used at NIST. NIST Initial fatigue testing in air has been completed while fatigue testing in hydrogen is currently on-going. Pre-cracking the samples for fatigue testing showed the "optimized" condition took 2-7 times the number of cycles to pre-crack (1 -3.5 million vs. 0.5 million) which illustrates the strong effect on the cross-sectional microstructure homogeneity on the ductility properties of toughness. Fatigue testing in air showed that "optimized" had improved fatigue performance than that of the "non-optimized" and when compared to some previously tested API X70. This paper will detail the trial design, cross-sectional microstructure created, mechanical properties and fatigue test results generated to date of the effect of cross-sectional ferrite grain size/homogeneit
Track 5: Materials and Joining	Track 5.4	IPC2020-9725	Yong-Yi Wang	Improved Linepipe Specifications and Welding Practice for Resilent Pipelines	At least 10 girth weld incidents in newly constructed pipelines are known to have occurred. The main contributing factors to the incidents are: (1 weld strength undermatching, (2) heat-affected zone softening, (3) weld bevel geometries of manual stick welding processes that favor plastic straining along the softened HAZ, and (4) elevated stresses/strains from normal settlement and other loads. In addition to the girth weld incidents, there are some indications that some features of modern linepipe steels may lead to under-performance in comparison with vintage steels when anomalies are present in pipelines. This paper covers the development of improved linepipe specifications aimed at reducing the risk of similar girth weld incidents in newly constructed pipelines and to increase the long-term resilience of the pipelines to anomalies such as mechanical damage, corrosion, etc. A companion paper covers possible improvements to welding processes to reduce the risk of similar incidents. The linepipe specifications have been developed through extensive work in the following areas: Reviewing the characteristics of the linepipes involved in the girth weld incidents, Reviewing the history and trends of linepipe properties and comparing them with the properties of the linepipes involved in the incidents, Correlating failure processes with characteristics of linepipes through numerical analysis and experimental testing, Understanding the evolution of metallurgical and material properties of linepipe steels when subjected to welding thermal cycles, and Understanding the interaction between linepipes and pipeline service conditions. The improved specifications include (1) limiting the upper-bound strength for a given pipe grade, (2) having optional testing of longitudinal tensile properties, (3) alternative tensile test methods, (4) alternative definitions of yield strength, (5) the need to maintain a certain level of strain hardening, and (6) potential ways to quantify a linepipe steel's susceptibility to HAZ softening. The linepipe specifications were developed with a full account of current practices and the history associated with the practices. The improved specifications are expected to be adopted by pipeline operators in stages that are most suitable to their circumstances. The specifications are written in a tiered structure meant for different stages of a pipeline construction project.

Track 6: Strain Based Design	On Demand	IPC2020-9310	Junfang Lu	A Case Study of Predicting Tensile Strain Capacity of In-Service Pipelines	Strain-based design (SBD) method has evolved over the years for use in the construction of large-diameter, high pressure gas and liquid transmission pipelines. It has been widely materialized for major construction projects because of the technical complexity which requires multidisciplinary expertise including, but not limited to, pipeline material properties, welding processes, mechanical testing, field construction, and weld inspection. The industry is growing more interest in using this methodology for strain capacity assessment of in-service stress-based pipelines, especially those that are subjected to ground movement. The strain capacity assessm of the stress-based pipelines is essential to ensure structural integrity and operational safety of the pipeline. This has become more apparent due to recent incidents in pipeline industry caused by geotechnical hazards. This paper provides a case study of assessing the tensile strain capacity (TSC) of existing modern pipelines manufactured through thermomechanical controlled process (TMCP). The TSC was predicted using two main methodologies in the public domain: CSA Z662-11 Annex C approach and PRCI-ABD-1 model. Actual pipeline information and construction data are used to perform TSC assessment. This includes pipe material properties, welding procedures qualified on the project pipe, and the resulting test weld properties. Key mechanical testing results including cross weld tensile, pipe longitudinal tensile, weld tensile, Charpy-V notch, 3PB CTOD and hardness survey are presented in this paper. The predicted tensile strain capacity and the estimated strain demand will allow for effective remediation decisions. This work helps to enhance pipeline strain management systems in response to the geotechnical and hydrotechnical issues and therefore fills the gaps in present day's pipeline threat management programs in addition to crack, corrosion and mechanical damage threats. Through such a program, prevention, monitoring and mitigation strategies can be deployed to existing stress-based pipelines, especially in areas where pipeline strain is identified as a potential risk
Track 6: Strain Based Design	On Demand	IPC2020-9319	Kanako Asano	Effects of Profile Data Grid on Deformation Capacity of Line Pipes	A sensitivity study of the density of initial profile data on the deformation capacity of line pipes is represented in this paper, which profile data are used for finite eleme analysis (FEA). An X65 line pipe with outside diameter of 610mm and wall thickness of 12.2mm and an X80, 1220mm, 22.5mm line pipe are used for the sensitivity study. The surface profiles and thickness distributions are measured by using grids of 25 and 50mm squares drawn on the surfaces of 610 and 1220mm line pipes, respectively. The initial profiles of the 610mm line pipe are employed for FEA by changing the grid size as 600, 400, 300, 200, 100, 50, or 25mm squares. Those of the 1220mm line pipe are considered varying the grid size as 1200, 800, 600, 400, 200, 100, or 50mm squares. The line pipes unpressurized or pressurized to 40 or 60% SMYS are used to discuss the compression capacity, and those pressurized to 40 or 60% SMYS are employed to investigate the bending capacity. The compression capacity is discussed with respect to the critical compressive strain. The results of FEA clarifies that the critical compressive strain of the unpressurized 610mm line pipe becomes 0.94 to 1.05 times as large as that calculated without initial profile data. In case the line pipe is pressurized, the critical compressive strain varies from 0.94 to 1.02 times as large as that obtained without initial profile data. It is recognized from the results that the critical compressive strain is independent of the grid size of initia profile data. The results of the 1220mm line pipe represent almost the same tendency as those of the 610mm line pipe. The bending capacity is discussed with respect the global bending strain. The results explain that the global bending strain values of the 610mm pressurized line pipe become 0.34 to 0.58 times as large as that calculated without initial profile data. In addition, in case the 1220mm line pipe is pressurized, the global bending strain values become 0.46 to 0.75 times as large as that obtained without initial profile data. Consequently, it is recognized that the effects of the grid size of initial profile data on bending capacity are significant compared to those on compression capacity
Track 6: Strain Based Design	On Demand	IPC2020-9341	Xiaoben Liu	An Improved Analytical Strain Analysis Method for Buried Steel Pipelines Subjected to Permanent Ground Displacement	Abrupt permanent ground displacement is a typical loading condition for pipelines crossing geotechnical hazard areas. An improved analytical method for calculati longitudinal strain of buried pipeline under tension combined with bending load induced by permanent ground displacement (PGD) was proposed, in which, the pipe steel was considered as a bilinear material and the soil constraint on pipe was considered as a series of elastic-plastic nonlinear soil springs. Effects of elastic deformation of axial soil springs on pipe strain was derived accurately. Effects of axial force in pipe on pipe's bending deformation was considered directly in the governing equation of pipe. Equilibrium between the section stresses in the large deformed pipe sections near fault trace and the section force and moment at the same position derived by the beam theory was used to obtain the nonlinear stress distributions in the pipe section and furtherly to obtain the equivalent modulus describing the locally decreased pipe stiffness. This method makes it possible to accurately derive the pipe longitudinal strain considering the effects of pipe material nonlinearity induced locally decreased p stiffness in large bending deformed pipe segments. A three dimensional nonlinear finite element model was also established by general software package ABAQUS to serve as a benchmark to validate the accuracy of proposed analytical method. Shell and pipe elements were employed to simulate pipes in large deformation and small deformation regions respectively. Distributed nonlinear soil spring elements were employed to simulate nonlinear soil constraints on pipe. Various loading conditions were performed to compare the efficiency and accuracy of the proposed analytical method comparing with the FE method. Results show the proposed analytical method can predict accurate longitudinal strain results even large plastic deformation appears in pipe. And comparing with FE method, analytical method has advantages in calculating efficiency, which is more suitable for application in engineering practice
Track 6: Strain Based Design	On Demand	IPC2020-9376	Mario Macia	Papua New Guinea Earthquake Proves the Value of Robust Pipeline Materials Selection and Construction	The Papua New Guinea Liquefied Natural Gas (PNG LNG) project is a joint venture with participation by ExxonMobil, Oil Search Limited (OSL), Kumul Petroleun Santos, JX Nippon Oil and Gas Exploration and Mineral Resources Development Company, and began production in 2014. As described in a previous IPC paper, the PNG LNG project in 2018 sustained a M7.5 earthquake, and ca. 300 aftershocks, epicentered directly under key facilities. Around 150 km of high-pressure gas and condensate pipelines were affected. In anticipation of such an earthquake event and due to the challenging terrain that the pipeline traverses, two design methodologies were used in specifying the pipe and welds for the onshore pipelines: strain based design and allowable stress design with robust materials selection. The strain based design approach was used for segments crossing faults and was the subject of IPC2014-33550. In this paper, the robust allowable stress design that was used for the remainder of the onshore pipeline route will be discussed along with the performance of the pipeline designed with this methodology when it was subjected to the earthquake. Robust allowable stress design involved the selection of line pipe and welding procedures that would reduce the risk of failure during unanticipated ground movements. Lower grade, thicker wall pipe was selected, and enhanced weld properties were specified to increase weld strength overmatch and toughness. Additionally, enhanced testing of pipe and weld properties was performed in order to enable prediction of pipeline strain capacity and assessment of fitness for service of any portion of the pipeline that experienced plastic strains due to ground movement. These efforts enabled the pipeline to safely sustain the ground movement experienced during the earthquake and allowed safe project operations to be rapidly restored. This paper and accompanying oral presentation provide details of the selection of pipe grade and wall thickness and the specification of material properties for pipe and girth welds for the natural gas and condensate pipelines. The property distributions achieved and the impact on strain capacity are presented along with estimates of the strain experienced by the pipeline due to the earthquake. The performance of the pipeline during the earthquake illustrate the benefits of the robust allowable stress design approach for pipelines in challenging environments
Track 6: Strain Based Design	On Demand	IPC2020-9471	Christoph Ladenhauf	Earthquake in Papua New Guinea Results in New Concept for Securing Pipelines in Ridgeline Right-of-Way: the Micropile Contiguous Wall	The Papua New Guinea Liquefied Natural Gas (PNG LNG) project is a joint venture with participation by ExxonMobil, Oil Search Limited (OSL), Kumul Petroleun Santos, JX Nippon Oil and Gas Exploration and Mineral Resources Development Company, and began production in 2014. As described in a previous IPC paper, the project sustained a M7.5 earthquake, and ca. 300 aftershocks in 2018, epicentered directly under key facilities. Around 150 km of high-pressure gas and condensate pipelines were affected. A number of design and construction decisions protected the pipelines, and prevented serious damage. However, the earthquake disturbed several sections of the pipeline Right of Way (RoW), which subsequently required intervention and stabilization. The challenges of re-occupying remote, mountainous, disturbed RoW and safely installing stabilization structures led to the development of a new pipeline stabilization concept: the Micropile Contiguous Wall. The concept, leveraging tools and techniques from the tunneling industry and practices from the Alpine region, consists of 139 mm micro piles, installed in 3 m joints, in rows along either side of the pipeline. Once installed, opposing rows of these micropiles are attached to each other at ground level with steel tendons. This new concept can be installed with light equipment with minimal vibration and ground disturbance, is designed to sustain significant earthquake loads, does not retain groundwater, and is resistant to corrosion and third-party damage. This concept was developed and selected in order to repair parts of damaged ROW and ensure pipe integrity taking into account future deterioration of adjacent slopes but without considering slope stabilization for several dozens of landslides, which would have been too large an effort considering the remoteness of the terrain, climatic conditions, safety considerations and other constraints. This paper and accompanying oral presentation present details of the concept's genesis, design refinement, field testing, and installation, and shows the value of collaborating across different industries. "NOTE: This abstract, together with three others submitted to the IPC 2020 Strain Based Design track, provide a comprehensive view of the design, construction, operation, post-earthquake recovery and post-earthquake restoration of the PNG LNG onshore pipelines." &nbs
Track 6: Strain Based Design	On Demand	IPC2020-9492	Bob Albrecht	Returning Pipelines to Service Following a M 7.5 Earthquake: Papua New Guinea Experience	The Papua New Guinea Liquefied Natural Gas (PNG LNG) project is a joint venture with participation by ExxonMobil, Oil Search Limited (OSL), Kumul Petroleun Santos, JX Nippon Oil and Gas Exploration and Mineral Resources Development Company, and began production in 2014. As described in a previous IPC paper, the project, operated by ExxonMobil PNG Limited (EMPNG) sustained a M7.5 earthquake and ca. 300 aftershocks in 2018, epicentered directly under key facilities. Around 150 km of high-pressure gas and condensate pipelines in the rugged PNG highlands were affected but did not lose containment or pressure. Immediately following the M7.5 event. EMPNG began efforts to assess and inspect the pipelines in order to ensure public safety, and, at the appropriate time, restore LNG production. The technical efforts took place along the pipeline Right of Way (RoW) in a remote jungle environment, which, following the earthquake, was also a disaster zone in which the few available resources were prioritized towards humanitarian relief. Due to resource constraints, the pipeline field inspection team typically numbered only two or three specialists. The inspection team drew heavily on analysis work, ongoing since project startup in 2014 and in progress when the earthquake occurred, that simulated the condition of the RoW and pipe stress state following earthquake events similar in magnitude to what actually occurred. The body of existing analysis work allowed the field team to compare aerially observed RoW ground movements to previously modeled cases, and rapidly infer pipe str state without actually measuring pipe deformation on the ground. Due to resource constraints, that latter activity, if required before startup, would have significantly delayed project restart. The worldwide network of technical resources that had been assisting with ongoing simulations was quickly re-directed to analyzing actual observed ground deformations, efficiently supporting the small field team from outside the disaster zone. After restart, field inspection activities continued, observations were categorized, and an Earthquake Recovery (EQR) organization was initiated to execute RoW repairs. Just as the initial inspection work was aided by pre-earthquake analyses, EQR activities have been expedited by the extensive RoW maintenance program that had been ongoing prior to the earthquake. This paper and accompanying oral presentation present details of the inspection and recovery, and show that the extensive simulations, preparations and maintenance programs supported by EMPNG during project operations prior to the earthquake enabled a rapid and efficient response when the earthquake actually occurred, and thus provided enormous value to the business. NOTE: This abstract, together with three others submitted to the IPC 2020 Strain Based Design track, provide a comprehensive view of the design, construction, operation, post-earthquake recovery and post-earthquake restoration of the PNG LNG onshore pipelin

Track 6: Strain Based Design	On Demand	IPC2020-9546	Jinxu JIANG	Failure Analysis of Buried X65 Steel Pipeline Under the Influence of Permafrost Thawing Settlement Based on Moisture-Heat-Stress Coupled Method	The China-Russia oil pipeline can't avoid crossing large permafrost zone in northeast China. Permafrost is extremely sensitive to changes in temperature. The hot oil \ lead to the increase of soil temperature around the pipeline, and the formation of thaw bulb will lead to soil settlement. The differential thawing settlement displacement loading may cause pipeline failure, by producing a large axial strain due to bending and geometric deformation. With the increase of oil temperature, Permafrost thawing settlement has become a major threat to the safe operation of buried pipeline in permafrost region. In this paper, considering the case of parallel laying of double pipes in the China-Russia crude oil pipeline route from Mo'he to Daqing, northeastern China, the numerical simulation model of buried pipeline in permafrost zone is established by using ABAQUS finite element software. The calculation of temperature field of soil around the pipeline was conducted, considering the ice-water phase change. Then, the permafrost thawing settlement based on moisture-heat-stress coupled will be used for stress-strain analysis of X65 steel pipeline, by considering pipe-soil interaction. The failure analysis of pipe by using the strain-based design criterion, and the maximum differential thawing settlement displacement allowed for the safe operation of the pipeline is given. Parameter sensitivity analysis will be conducted. The effects of oil temperature, internal pressure, the geometric size of pipe and the distribution of soil on the safe operation of the pipeline are studied. The numerical simulation method used in this paper can well reflect the real process of permafrost thawing settlement. Compared with soil spring model, 3D solid model may describe pipe-soil interaction and predict strain of pipeline accurately. The research results have a certain referen value for the optimization of design parameters of buried pipeline in permafrost region and the safety maintenance of in-service pipeline route from Mo'he to Daqing. Key words: permafrost, thawing settlement, coupled method, X65 pipeline, pipe-soil interaction, strain-based desic
Track 6: Strain Based Design	On Demand	IPC2020-9617	Shoma Onuki	Theoretical Formula for Determining the Maximum Straight Length of a Buried Pipeline That Can Prevent Seismic Buckling	Buried pipelines must exhibit an appropriate seismic performance to be applied practically and securely. One of pipeline failure mode is buckling, which is caused l seismic motion and it typically occurs in straight pipeline sections because seismic axial loads accumulate along straight lines. A simplified formula for calculating the maximum straight pipeline length that can avoid buckling was previously proposed; however, its applicability was limited to pipelines with a diameter of 100 A or smaller. Therefore, it must be generalized for an expanded range of pipe specifications. In this study, a theoretical formula is proposed to estimate the maximum straight length of the pipe for which the axial stress remains below the yield stress of the pipe material. Because this formula is based on theoretical calculations, it can be readily applied pipelines with bigger diameters. The pipeline model includes the main straight pipe, two bent pipes connected to both ends of the main straight pipe, and sub straight pipes connected to the bent pipes. Taking soil-structure interaction into account, static sinusoidal ground displacement caused by seismic motion is applied to the pipeline model. Using this pipeline model, the axial stress in the main straight pipe is evaluated. The proposed theoretical formula is derived using an analytical pipeline model with soil springs of elastic-perfectly plastic solid under seismic ground displacement and validated through finite element analysis. The required inputs include the straight pipe cross-section dimensions, bending angles at both ends of the pipe, yield stress of the pipe material, and soil–pipe interaction properties. The theoretical formula underestimates the maximum straight length compared with the finite element analysis result, because it is intentionally established to be conservatively. Using the formula, The axial stress in an actual pipeline can be reduced using this formula to be less than the yield stress of the pipe material;, thus, preventing buckling failures. This work may be useful in designing buried pipelines to prevent buckling failures; thus, enabling safer and more viable pipelin
Track 6: Strain Based Design	Track 6.1	IPC2020-9259	Ali Fathi	Rapid Strain Demand Estimation of Pipelines Deformed by Lateral Gourd Movements	In strain-based design and assessment, accurate measurement of pipe longitudinal strain demand is a key element in performing proper strain assessments. Qui pipeline strain assessments are usually needed after widespread natural disasters such as earthquakes or rainfalls that affect multiple lines at several sites. Finite Element Analyses (FEA) and In-line Inspection (ILI) tools are the most common methods to estimate /measure the longitudinal strain demand of in-service pipelines. However, since they are rather time-consuming methods, they cannot be relied on when a quick fitness-for-service evaluations of pipelines is needed. ILI needs considerable amount of time for planning and preparation as well as post-run analyses, and FEA needs extensive effort to gather geotechnical and geological input data which might not be readily available for all sites. Enbridge recently used a method of strain demand estimation during a rapid response process for several sites affected by lateral landslides after a major weather event. This method involves surveying the deformed shape of the pipe from surface by identifying the lateral and vertical shifts of the po of maximum deflection, and its distance to the ends of the displaced span. Then, a proper sinusoidal function is curve-fitted to the measured deformed shape of the pipe. Having the shape function, the bending and uniform axial strains can be analytically calculated via the curvature and change of the arch-length throughout the deformed span. Like other methods, this process has its own advantages and limitations that makes it a better fit for certain areas of geohazard management. This paper describes this method, its key elements, and the assumptions on which it is based. It also presents the evaluation of its performance via FEA of several pipes, soil conditions, and landslides scenarios. And finally, it concludes on the applicability of this method for different cases of pipes and landslide
Track 6: Strain Based Design	Track 6.1	IPC2020-9473	Bob Albrecht	High-Pressure Natural Gas Pipeline in Geohazardous Region of Papua New Guinea Sustains M 7.5 Earthquake: Key Factors of Successful Outcome	ExxonMobil PNG Limited (EMPNG) operates the Papua New Guinea Liquefied Natural Gas Project (PNG LNG), an integrated LNG project comprising wellpad gathering lines, gas conditioning plant, onshore and offshore export pipelines, liquefaction plant and marine terminal in Papua New Guinea (PNG). The PNG LNG project is a joint venture with participation by ExxonMobil, Oil Search Limited (OSL), Kumul Petroleum, Santos, JX Nippon Oil and Gas Exploration and Mineral Resources Development Company, and began production in 2014. The highlands of PNG presents a challenging physical environment, with high rainfall, steep terrain, active tectonics and seismicity, and ongoing landsliding and erosion. The PNG LNG onshore gas and condensate pipelines confront these physical challenges by having to traverse approximately 150 km of steep volcanic, mudstone and Karstic highlands along the PNG Range Front, the modern leading edge of active mountain-building, plus an additional 150 km in Karstic lowlands. During design, construction and operations of the pipelines, ExxonMobil has addressed these challenges in partnership with the engineering, construction and specialist consulting communities. On February 25 th , 2018 (UTC) a Magnitude 7.5 earthquake struck the PNG highlands. The event, along with its approximately 300 aftershocks, caused widespread community impact, landsliding and damage to over 1000s of km 2 , and was centered directly under the highlands portion of the PNG LNG pipelines. The pipeline however, did not lose containment or pressure, and, following inspections and repairs to the PNG LNG gas conditioning plant, PNG LNG production was restored within seven weeks of the main shock. This technical paper and companion oral presentation discuss the key factors of this successful outcome, in particular the sustained condition of the gas and condensate pipelines. Contributing factors to the pipeline's success include route selection, pipe material specification, early commitment to field studies, careful assessment of geohazards, high awareness of off-RoW community impacts, micro-routing during construction, and active geohazard management during startup and operations. The paper demonstrates that, with respect for the host community, thoughtful engineering, careful construction and ongoing surveillance, pipelines can be safely and successfully designed, constructed and operated in remote and extreme geohazardous environments. NOTE: This abstract, together with three others submitted to the IPC 2020 Strain Based Design track, provide a comprehensive view of the design, construction, operation, post-earthquake recovery and post-earthquake restoration of the P
Track 6: Strain Based Design	Track 6.1	IPC2020-9664	Banglin Liu	Estimation of Tensile Strain Capacity of Vintage Girth Welds	Being able to estimate the tensile strain capacity (TSC) of vintage girth welds is sometimes necessary in the integrity management of vintage pipelines. F instance, assessing the girth weld integrity could be a top priority after a confirmed ground movement event. Decisions may also be needed about the disposition of a girth weld when weld anomalies are found. Typical fitness-for-service (FFS) procedures, such as API 1104 Annex A and API 579/ASME FFS-1, generally target materials under nominally elastic conditions and strain demands less than 0.2%. These procedures can produce overall conservative results when the strain demand exceeds 0.2%. This paper summarizes the development and validation of a TSC estimation tool for vintage girth welds. The tool development process generally follows the Level 4a procedures of the PRCI-CRES tensile strain models. Finite element analysis (FEA) was performed to develop a crack-driving force database with consideration of the salient features of vintage girth welds, such as larger weld caps and weld strength mismatch levels. A TSC model was then derived from the crack-driving force database and representative apparent toughness of vintage girth welds based on an initiation-controlled limit state. A graphical user interface (GUI) was developed to facilitate the application of the TSC model. The tool produces TSC estimates based on given geometry and material characteristics of a girth weld, such as pipe strain hardening capacity, weld strength mismatch, heat-affected zone (HAZ) softening, girth weld high-low misalignment, girth weld flaw dimensions, and operating pressure. For inputs that might not have readily available values, recommended values are provided. The tool allows the evaluation of the impact of various input parameters on TSC. The TSC tool is evaluated against eight purposely-designed curved-wide plate (CWP) tests. Accompanying small-scale material characterization tests, including chemical composition, round bar tensile, microhardness, and Charpy impact tests, were performed to provide inputs for the evaluation of the tool. The tool is shown to provide reasonably conservative estimates of TSC. Gaps and future work to refine the assessment of vintage girth welds are highlighted at the end of the pape
Track 6: Strain Based Design	Track 6.2	IPC2020-9739	Yong-Yi Wang	Management of Ground Movement Hazards – an Overview of a Jip	Ground movements, such as landslides and subsidence/settlement, can pose serious threats to the integrity of pipelines. The consequences of a grou movement event can vary greatly. Certain types of ground movements are slow moving and can be monitored and mitigated before a catastrophic failure. Other forms of ground movements can be difficult to predict. The most effective approach could be hazard avoidance, proactive means to reduce strain demand pipelines, and/or building sufficiently robust pipeline segments that have a high tolerance to the strain demand. This paper provides an overview of a Joint Industry Project (JIP) aimed at developing a best-practices document on managing ground movement hazards. The hazards being focused on are landslides and ground settlement, including mine subsidence. This document attempts to address nearly all major elements necessary for the management of such hazards, including: •Methods of Identification and Assessment •Characterization of Stresses and Strains Affecting Girth Welds •Utilization of IMU Data •Mechanical Properties of Pipe and Girth Welds •Detection and Sizing of Girth Weld Anomalies •Fitness-For-Service Assessment •Mitigation and Monitoring Methods, and, •Overall Management of Landslide and Subsidence Hazards The most unique feature of the JIP is that the scope included the hazard management approach often practiced by geotechnical engineers and the fitness-for-service assessment of pipelines often practiced by pipeline integrity engineers. The document developed in the JIP provides a technical background of various existing and emerging technologies. The recommendations were developed based on solid fundamental understanding of these technologies and a wide array of actual field experiences. In addition to the various elements involved in the management of ground movement hazards, the document from JIP addresses some common misconceptions about the adequacy of codes and standards, including •The adequacy of design requirements in ASME B31.4 and B31.8 with respect to ground movement hazards, •The adequacy of linepipe standards such as API 5L and welding standards such as API 1104 for producing strain-resistant pipelines, •The proper interpretation of the longitudinal strain design limit of 2% strain in ASME B31.4 and B31.8, and •The effectiveness of hydrostatic testing in "weeding out" low strain tolerance girth welds.

Track 7: Risk and Reliability	On Demand	IPC2020-9261	MD Anthony Payoe	Application of Risk and Reliability in Designing Facility Site Containment	Enbridge is North America's premier energy infrastructure company delivering the energy people need and want. Enbridge's business value is asset intensive. With ov 200 onshore liquid pipeline facility assets, operational safety and environmental protection are always top priorities. The embedment of risk management practices in business decisions is an effective way to appropriately optimize asset performance while avoiding catastrophic impacts to people and the environment. This would inclu understanding and managing the events that could lead to impacting people and the environment and barriers in place to prevent this impact. Facility site containment is one such barrier as it is a secondary containment structure and a passive, independent protection layer that mitigates the consequences of a potential hazardous event. Part 112 in the Code of Federal Regulations (CFR) by the United States Environmental Protection Agency's (EPA) describes the requirements for Oil Pollution Preventi at onshore hazardous liquid pipeline facilities. Additionally, the National Fire Code of Canada (NFC) 4.1.6 provides requirements to contain overland flow of a spill from pipeline facilities. However, there are no specific volumetric requirements for spill containment as there are with spill protection for tanks. Industry typically emplo an index-based approach using catastrophic rupture volumes and facility location, which has several short-comings including design inadequacy, consistency, and scalability. A risk-based approach is an appropriate methodology in determining the required site containment volume based on oil spill history, facility assets and environmental sensitivities. A probabilistic model was created using historical facility oil spill data based on Pipeline Hazardous Materials Safety Administration's (PHMSAs) facility incident database to estimate the likelihood of a release occurring. This was combined with the estimated consequence by accounting for the volume of a release and the environmental sensitivity at the release location to evaluate the risk of a release. This estimation of the risk was then leveraged to support facility site containment design to manage the risk to an acceptable level. By informing facility site containment with volumetric requirements using reliability and consequence models and risk management principles, an organization can prudently balance between pipeline safety and capital constraints and to comply with federal regulations. This paper demonstrates this approach and describes: · The value of available data and model development · Reliability modelling & consequence assessment · Risk-informed decision making · Future model enhancement
Track 7: Risk and Reliability	On Demand	IPC2020-9314	Lyndon Lamborn	Surviving Population Reliability Projection Methods	Uncertain environments demand the use of probabilistic methods to assess pipeline safety, but a realistic and validated probabilistic method to demonstrate pc hydrostatic test (PHT) integrity has eluded the pipeline industry. Traditionally, deterministic methods grow a 'just-surviving flaw' (JSF) under worst-case pressure cycling to predict the remaining life of the most severe imperfection which could have survived a pressure test. The limitations of deterministic JSF are self-evident as they routinely produce unreasonable results and even with attempts to include probabilistically modeled material variabilities they have failed to match known historical PHT reliability. A pipeline operator has now developed a novel approach to the task of quantifying marginal pipeline reliability after hydrostatic test. Rather than limiting random variables to only material properties, potential defects are assigned size and pressure cycling values, randomly sampled from validated distributions of defect size and pressure cycling severity (equivalent to location). The number of generated defects is determined by a validated defect density, and defect size remains limited to what could have physically survived the hydrostatic test. The question posed is no longer "what possible sizes of JSF close to discharge survive to time = t under known load conditions", but rather "what proportion of pipeline segments with similar defect populations would survive to time=t under defined loading conditions?" This represents a fundamental paradigm shift away from considering only a worst-case scenario to quantification of pipeline condition. Monte Carlo simulation time is kept practical by usi an equivalent load integral method to compute crack growth. This proposed methodology has been applied to a selection of pipeline segments with historic fatigue fractures following hydrostatic tests and quantifies the predictability of station reliability over time. Surprisingly, uncalibrated initial results were reasonably predictive of past incidents. Essential input parameters are discussed, including detailed methods for assigning defect size distributions and densities based on extrapolations of field and in-line inspection data, and a minimum defect density floor established based on the PHT fatigue failure of a newly constructed pipeline. While the method originally targets PHT pipeline segments, development of an analogous method managed exclusively by in-line inspection (ILI) tools is under way, the largest potential flaw for ILI-managed assets then dictated by what could have evaded ILI tool detection rather than survived a hydrostatic test. Progress on this development and future suggested research are discussed
Track 7: Risk and Reliability	On Demand	IPC2020-9367	Thomas Dessein	Reliability Performance Benchmarks for Low Vapor Pressure Liquid Pipelines	The pipeline industry is increasingly utilizing reliability methods as a basis for decision-making when managing the integrity of pipeline systems. In this paper we prese a methodology for developing reliability benchmarks for onshore low vapour pressure (LVP) transmission pipelines to enable an operator to evaluate the performance of their pipelines relative to their industry peers. A goal of this methodology is to use approach that is calibrated to historical performance, that remains interpretable, that c readily be adjusted over time, and that reflects the increased sensitivity of High Consequence Areas (HCAs). On this basis, the Top Quartile (Q 1) and Average historical environmental performance of the top 20 largest liquid pipelines operators were identified as two primary benchmarks of interest. Top Quartile environmental performance represents an industry leading benchmark performance while the Average historical environmental performance is representative of typical pipelines. This group of operators was selected on the basis that these major companies operate pipeline networks with comparable complexity, similar integrity challenges and a diverse range operating environments (urban, rural, etc.). In addition, the length of their respective systems decreases the impact of small sample size issues. The dataset used for calculating the historical environmental performance of these operators was the 2010-2018 PHMSA Hazardous Liquids Incidents and Annual Mileage datasets. The framework presented in this paper, allows specific reliability benchmarks to be calculated for a given pipeline dependent on the environmental consequences associated with failure of the line. Consequences are considered in order to be risk-consistent between pipelines with different outflow potentials and different land use surroundings (HCA vs. Non-HCA). The heightened sensitivity of HCA areas is considered by including an impact ratio in calculating the reliability benchmarks. These benchmarks can be used to identify pipelines for additional scrutiny when the expected environmental performance is below benchmark levels and to flag areas for additional evaluation. Quantifying the failure potential of pipeline segments gives operators insights into which maintenance actions will make the most effective use of the available resources to improve reliability. These benchmarks are calculated directly from historical data using a simple methodology and are easily recalibrated in the future as the performance of the pipeline industry continuously improves to meet increasing societal expectation
Track 7: Risk and Reliability	On Demand	IPC2020-9459	Alex Nemeth	Quantifying Risk to Optimize Facility Integrity Management	Effective asset integrity management is supported through the understanding of the condition of the asset, and the quantification of the safety and uncertainty of properties. Risk based and risk informed decision making can help operators prioritize inspections and repairs on mainline pipe, as well as within operator facilities. Setting operator system specific targets for reliability and risk can help operators better understand the condition of their system and provide one means of determining whether integrity action is required or not on a specific asset, either on the mainline pipe system or on a facility asset system, to mitigate integrity threat drivers. While mainline pipe condition is better understood through the use of inline inspection technology and non destructive examination in the field, facility piping and storage condition is more difficult to understand due to the complexity and sheer number of assets within an operator's station fence, as well as the unpiggable nature of the majority of facility piping. To help resolve this issue, a risk quantification can be done for each segmented asset within a facility. A relative ranking of asset risks can help prioritize facility integrity activities and drive the optimization of executing these activities, as well as the execution timing of these activities. However, simply looking at a relative ranking of asset risks may not be enough to maximize risk reduction for operators to optimize integrity management for a group of assets. This paper looks to expand on the implementation of Risk Based Inspection (RBI) standard in API 581 and explore more broadly how facility asset risk results can be used in integ decision making. The paper also examines the application of using finance principals to better quantify risk and carry out a meaningful cost benefit analysis to optimize integrity programs. Interpreting a quantified risk dollar amount is an industry challenge, and shedding light onto the value of applying reliability and risk models beyond the safety of an operator's system can be extremely beneficial for operators to remain competitive and cost efficient. The quantification of risk helps support the optimizatio spend and resource allocation to bring efficiencies into integrity management systems while focusing on the right risk mitigation across an operator's syste
Track 7: Risk and Reliability	On Demand	IPC2020-9483	Shawn Smith	Recommendations for Jet Fire Model Selection When Performing Consequence Assessments of Onshore Natural Gas Pipelines and Facilities	When an accidental release occurs from a natural gas asset, there is potential for ignition leading to a jet fire. Jet fires can pose a significant hazard to both people a equipment, leading to injury, equipment damage, or cascading failures of nearby pressure containing assets. Therefore, the accuracy of the model used to assess the jet fire hazard and resulting consequences can have a significant impact on the assessed risk. The purpose of this paper is to outline a process to select a jet fire model to perform consequence assessments on natural gas assets. The selection process is structured as a decision tree that recommends the simplest model that will produce accurate results for a given scenario, only proceeding to more complex models when required. Generally, jet fire models can be categorized as a single point, multi-point, solid flame, or CFD model. For natural gas pipelines, the Potential Impact Radius (PIR) model, a single point model, is commonly used (Stephens et al. 2002); a modifie version of this model was used to develop the reliability targets that have been incorporated into Annex O of the Canadian pipeline regulations, CSA Z662 (Nessim et al. 2009). The PIR model has been found to produce reasonable results, with slight conservatism, when compared to the far-field effects of a jet fire such as burn extent and injury (Stephens et al. 2002). However, in the near-field where damage to equipment can occur, single point models can be overly conservative (Hankinson and Lowesmith, 2012). Additionally, the PIR model only applies to vertical releases while non-vertical releases are common for above ground assets. Other models, such as a multi-point or solid flame model can be more accurate for non-vertical releases, and can incorporate the effects of receiver orientation, lift-off, buoyancy, wind, topography, and obstructions. Selected case studies are presented in this paper that illustrate the conditions under which each model is suitable and scenarios where the limitations the simpler models affect the accuracy of the predicted hazard areas. This assessment was repeated for several radiation thresholds associated with human injury and equipment damage. With these results a decision-tree was developed to provide recommendations on the selection of the simplest jet fire model that provides accurate and reasonably conservative results for a given release scenario from a natural gas pipeline or facility components such as aboveground facility piping or compressor station equipment
Track 7: Risk and Reliability	On Demand	IPC2020-9484	Jason Yan	Reliability-Based Crack Threat Assessment and Management	Crack or crack-like anomaly is one of the major threats to the safety and structural integrity of oil and gas transmission pipelines. The crack threat is usually managed hydrostatic test or regular in-line inspection (ILI) using electromagnetic acoustic transducer (EMAT) or ultrasonic crack detection (UTCD) tools. For a given crack ILI pipeline tally, operators need to identify the critical anomalies, determine the time of mitigation, and whether pressure restriction (derate) is required. Traditionally, a deterministic approach is used to determine the mitigation plan based on characteristic values of pipe properties, conservative crack sizing and crack growth rate, and considering a minimum required safety factor (e.g. 1.25). This study introduces a reliability-based approach to make the mitigation decision. The annual conditional probability of failure (POF) is evaluated for each reported crack anomaly by Monte Carlo simulation technique considering all the uncertainties associated with the pipe geometry, material properties, crack size measurement, and assessment model error explicitly. Both environmental and cyclic fatigue load driven crack growth are considered following API RP 1176. A reliability-based mitigation threshold is proposed and calibrated against the deterministic minimum required safety factor for maintaining the system to a consistent safety level. Two case studies were conducted to demonstrate the advantage of reliability-based assessment approach in this paper. Case Study 1 considers an NPS 20 transmission gas pipeline with more than 2000 ILI reported crack anomalies. Compared to the deterministic approach using conservative characteristic values, the reliability-based approach can reduce the number of required mitigation activities by approximately 20% without compromising safety. Case Study 2 considers an NPS 30 liquid pipeline to illustrate the impact of environmental and cyclic fatigue load driven crack growth on the POF. The POF for crack anomalies can be compared and combined with other threats, e.g. external corrosion, to evaluate the quantitative risk of the pipeline system. The proposed framework in this study can also be used by other operators to improve their crack assessment progran

Track 7: Risk and Reliability	On Demand	IPC2020-9500	Dan Williams	Stress Corrosion Cracking "Like-in-Kind" Reliability Approach for Pipelines Without Crack Tool In-Line Inspection	Gas pipeline operators increasingly rely on Electro-Magnetic Acoustic Transducer (EMAT) technology to reliably detect, identify and size stress corrosion cracking (SC anomalies in their pipeline system. However, scheduling EMAT in-line inspection (ILI) on every pipeline in the system is not always practicable or achievable in an expeditious manner. A means of conducting a preliminary assessment of the SCC threat on pipelines without EMAT ILI data in an objective and quantifiable manner is useful for understanding the threat level and for prioritizing or deciding on outstanding EMAT inspections. A wealth of system-specific SCC field data from historical integrity excavations across the pipeline system typically exists in a pipeline operator's dataset and can be readily leveraged for quantitatively estimating SCC threat reliability in other, similar ("like-in-kind") parts of the pipeline system. This system-specific data, based on actual SCC findings from integrity excavations, is an improved and more granular alternative to applying industry-wide SCC statistics to estimates of SCC reliability levels on pipelines without EMAT ILI data. This paper presents a robust and direct approach for estimating the SCC reliability level in pipelines that have not yet had an EMAT ILI completed by leveraging system-wide SCC field findings from historical integrity excavations. A software tool is utilized to dynamically segment the entire pipeline system into "like-in-kind" groups based on SCC relevant attributes such as age, pipe size, coating type and operating stress level. This produces unique 4-factor, "like-in-kind" segments throughout the pipeline system. All past SCC excavation findings are then overlaid onto the applicable "like-in-kind" segments based on excavation chainage and location. Based on the true in-field measurements of SCC features, probability of rupture failure (PoF R in ruptures/yr) values are generated, aggregated and normalized for each "like-in-kind" group by modeling SCC features as "existing features" assuming they were not detected, have been left in place and have continued to grow as SCC. This simulates how severe such features "could be" if left unattended without assessment or remediation. Having developed normalized PoF R values for each like-in-kind group within the pipeline system, it is now possible to "port" these results to similar "like-in-kind" segments that exist within any pipelines in the system, in particular, thos that have not been inspected with EMAT ILI. The results of the analysis can then be used to compare against quantitative acceptance criteria and to prioritize, decide on and schedule EMAT ILI for un-inspected pipelines. Alternatively, the results could be used to develop SCC-focused excavation assessment targets for pipeline segments where EMAT ILI is currently not possible and/or to confirm the need to commit to an EMAT ILI program for certain pipeline segments. The paper concludes by summarizing opportunities for enhancements in the approach from lessons learned through applicatio
Track 7: Risk and Reliability	On Demand	IPC2020-9517	Riski Adianto	Demonstration of Limit States Design Method for Assessment of Corrosion and Crack Features	A reliability-based Limit State Design (LSD) method for assessment of corrosion and crack features has been developed for onshore transmission pipelines as part o joint industry project. The rule-based LSD approach is a simplified form of the reliability-based approach that reduces the latter to a set of deterministic checks. The LSD corrosion assessment method and a comparison of its performance against one operator's reliability approach were published in previous IPC papers. This paper describes the application of the LSD corrosion and crack assessment methods to four Enbridge liquid pipelines and provides a comparison of the results to those of Enbridge's internally developed Level I reliability analysis method. Enbridge's reliability analysis (published in a previous IPC paper) is staged into three levels, where Level I analysis is also a simplified form of the reliability-based approach where the probability of failures of predefined features' sizes are precalculated using conservative assumptions for a fast turnaround screening analysis of the entire pipeline system in order to identify areas requiring more in-depth Level II or III analysis. The comparative analysis was based on the number of feature repairs required according to each method. Out of the four pipelines considered, two have corrosion and the other two have cracks as the dominant threat. The results show that there are significant differences between the output of the two methods. The root cause of these differences was investigated by conducting a sensitivity analysis on the input parameters, including: pipeline segmentation procedure, segment reliability target, wall thickness distribution, feature depth distribution, feature length distribution, and the usage of model error (which is used in the LSD method but not Enbridge's Level I method). For cracks, differences between the Modified Ln-Secant model used in the LSD method and the CorLAS model used by Enbridge were also considered. It was observed that the discrepancies in the required repairs resulting from the two methods can be mostly attributed to the inclusion of model error in the LSD method and the method used to define the wall thickness and feature depth distributions. This observation was confirmed by comparing the LSD results with the results of Enbridge's more in-depth Level II reliability analysis. For cracks, the burst pressure model selection also had a significant impact on the results. Comments are provided on the implications of using each approach to define the key inputs for the assessment, and recommendations are made for continued development of a viable and practical reliability-based feature assessment approacl
Track 7: Risk and Reliability	On Demand	IPC2020-9556	Jiatong Ling	Intelligent Prevention Method for Third-Party Damage of Long-Distance Pipeline Based on Mobile Devices Location Information	As one of the main risks of long-distance oil and gas pipelines, the third-party damage has a huge impact on the consequences of the accident. At present, tl third-party damage prevention mainly adopts the safety early warning technologies such as line patrol, fiber-optical vibration and UAV line patrol, but there are many problems such as untimely warning, false alarm and missed report. As the location technology of mobile device matures, the huge user group provides massive data sources for the collection of location data, with which the activity track and activity characteristics of the third party along the pipeline can be directly obtained. Therefore, this paper proposes a method to identify the third-party damage behavior based on the location data of mobile devices. Firstly, according to the type of the third-party damage, the corresponding characteristics of the third-party damage are extracted from the relevant historical spatiotemporal location data, including time characteristics, number characteristics and location characteristics. Then, the location information of the third party activity near the target pipeline is obtained and the data is processed to remove the influence of noise, so as to reduce the computational burden of the subsequent identification process. Calculate the similarity with the third-party damage feature and the difference degree of neighborhood trajectory based on the data feature grouping (Similarity feature and Difference feature) to identify the type of the third-party activity, so as to realize the intelligent prediction of the third-party damage accident and improve the intelligent management level of the pipeline. Finally, taking a 10km pipeline section as an example on the basis of theoretical research, 52,994 pieces of valid data were obtained by collecting nearby mobile devices location information for 10 days. The method of this paper is used to preprocess the collected data and calculate their similarity and difference, and 232 third-party damage events are identified, including 196 suspected private excavation damage events, 28 engineering construction damage events, and 8 stolen oil and gas damage events. After the on-site verification of the suspected damage by the line patrol, the results show that the method can better identify the the third-party personnel activities of the pipeli
Track 7: Risk and Reliability	On Demand	IPC2020-9609	Qian Zhen	Reliability-Based Assessment Method for Pipelines Buried at Fault Crossings	The tectonic fault is one of the most common geo-hazards for buried pipelines. A pipe segment buried near the fault plane will undergo longitudinal strain due to seism movements and rupture or buckling could occur with continuously increased fault displacements. Therefore, safety analysis of pipelines located in seismic areas is of great significance to pipeline design and maintenance. In this study, a reliability-based assessment procedure based on hybrid method of finite element method and artificial neural network is provided to conduct safety analysis of pipelines subjected to fault displacement loads. The strain-based limit state function is established at the first stage where the resistance including tensile strain capacity considered as deterministic and compressive strain capacity which is calculated by a simplified engineering equation of pipe diameter and wall thickness. Strain demand is of highly non-linear relationship with influencing parameters like pipe geometrical size (diameter and wall thickness), operational pressure, magnitude of fault displacement, intersection angle between pipeline and fault plane, and the characteristic mechanic's value of the backfill. Then the Back Propagation (BP) artificial neural network with double hidden layers is alternatively applied to develop the strain demand prediction model, which possesses bilateral advantages of accuracy and efficiency. Training data is obtained by comprehensive calculation of the finite element model with consideration of influencing parameters mentioned above. After several trainings, a relatively accurate prediction model will be achieved and it can be used as the strain demand item in foregoing limit state function. Subsequently, the probability of failure can be calculated by Monte Carlo simulation to quantitatively assess the safety level of pipeline segments induced by permanent fault displacements. Finally, practicability of this reliability-based assessment method is validated by applying it on a case study in which basic variables are referred to the Second West-to-East natural gas transmission pipeline projec
Track 7: Risk and Reliability	On Demand	IPC2020-9726	Mona Abdolrazaghi	Into Multi-Parameter Decision Making Scenarios: A New Look at Optimizing Utility Functions	Pipeline operators face multiple challenges in executing both capital and operational projects. Decision making analysis could assert a framework in devising an optimu solution to such multi-parameter decision challenges. A favorable option would be the one with the least amount of cost and the highest benefit. However, there could exist multiple constraints in ensuring the safety and reliability of pipelines for the given scenario that add complications to operation regimes. Addressing the challenge of arriving at an optimum decision for a multi-parameter problem is the core discussion of this paper. This includes comparing potential solution scenarios in terms of costs, benefits, risks, and utility. Risk estimation of every scenario captures a safety measure (e.g. probability of failure or factor of safety) along with the associated consequences. Cost-benefit analysis (CBA) investigates the gain in monetary values in comparison to the cost of exercising the scenario. While utility measures the decision maker's behavior/preference (e.g. risk-averse, -neutral, or -prone). The new-look herein is in balancing the parameters within conflicting objective functions (i.e. costs as a function of utility and risk). Optimization is based on the presumption of reducing the costs of the pipeline operation and maintenance or maximizing its benefits. To analyze the decision making under uncertainty, a balance of the costs of different parameters becomes significant for a decision-maker. The trade-off betw cost and benefit in any options would be quantified based on the level of risk recipient of the decision-maker. This level of risk aversion by the pipeline operators could be shown in risk and reliability targets. Moreover, this paper introduces a new concept for the pipeline industry in terms of setting safety targets constraint as a function of the Life Quality Index (LQI). LQI provides a rationale for determining the acceptability of decisions especially the ones involving life safety ris
Track 7: Risk and Reliability	On Demand	IPC2020-9738	Martin Di Blasi	Asset Complexity Based Benchmarks in Support of Reliability Improvement Program	Tackling reliability improvement programs for complex asset network tends to be challenging as understanding the factors that impact reliability performance usua involves aspects of culture, asset strategy, resource allocations, reliability and maintenance strategy and maintenance execution. Very often the focus of attention drift to detailed reliability metrics on equipment performance (i.e. benchmarking reliability at the asset level) because they tend to be easier to understand and address, when some of the key factors impacting reliability may be at the asset strategy or resource allocation level but where measuring and benchmarking can be more challenging. In this sense, being able to benchmark different operating areas in terms of maintenance, reliability or resources performance can help understand higher level factors driving less than ideal asset reliability performance. As part of an asset reliability improvement program on a liquid pipeline network, multi-attribute decision making (MADM) concepts were used to create several assessment models and metrics used then to measure complexity from different perspectives and for different areas of operations. This complexity metrics were then used to benchmark reliability and resource allocation across those regions on a common basis or unit. From this type of benchmarks, metrics like maintenance technicians per equivalent complexity or maintenance budget per equivalent complexity were produced and used in support of preliminary resource allocation discussions. The paper will describe the usage of a MADM methodology like the Analytical Hierarchy Model, discuss how different complexity models were developed working in collaboration with multiple maintenance SMEs, discuss some of the analysis and findings of different regional benchmarks and also comment on some of the cultural challenges encountered when using and communicating quantitative benchmarks to influence and drive reliability improvements. Hopefully the paper will help other professionals in the industry understand how SME experience can be captured and transformed into assessm tools with which benchmarks can be done
Track 7: Risk and Reliability	Track 7.1	IPC2020-9240	Francois Ayello	Probabilistic Digital Twin for Risk Assessment Transmission Pipelines	Digitalization in the oil and gas industry has led to the formation of digital twins, which are software representations of assets that are used to understand, predict, a optimize performance. Digital twins bring closer the physical and virtual world as data is transmitted seamlessly between real time sensors, databases and models. The strength of the digital twin concept is the interconnectivity of data and models. Any model can use any combination of inputs (e.g. operator owned data sets and sensors, third-party databases such as soil composition or weather data or even results from other models such as flow assurance modeling, threat modeling or risk modeling). Consequently, the results of one model may become the input of another. This strength is also a weakness, as uncertain (or missing) data will lead to a great source of uncertainty, and may lead to incorrect risk results. Worst case scenarios have been used to resolve this issue, however worst case scenarios may lead to undesired outcomes such as a lack of differentiation in risk results. This paper presents a new concept: probabilistic digital twins for pipelines. Probabilistic digital twins use probability density functions instead of deterministic values. Therefore, they do not lose uncertainty as results pass from one model to another, thus providing greater confidence in the results. First, this publication compares deterministic digital twins versus probabilistic digital twins. Second, data from West Pipeline Company (CNPC) is used to demonstrate how probabilistic digital twins can be implemented in two different scenarios. The methodology is used to predict the evolution of pipeline integrity for the 30 years following installation. Multiple threat models interact with CNPC's probabilistic data to predict corrosion rates, flaw depth and failure rate. Finally, this publication shows how this methodology could be used for real time risk assessments and real time learnin

Track 7: Risk and Reliability	Track 7.1	IPC2020-9504	Smitha Koduru	Comparison of a Standard Reliability-Based Approach and a Bayesian Network Approach for Integrity Management of a Northern Canadian Liquids Pipeline	Multiple investigations have been conducted to assess the integrity of a northern Canadian liquids pipeline (IPC 2014-33033, IPC2014-33037, IPC 2014-33092) wi respect to methanol-induced axial stress corrosion cracking (SCC), which has previously resulted in leaks. The investigations included cyclic fatigue laboratory testing, field data from bell-hole excavations and non-destructive examinations (NDE), and in-line inspections (ILI) for crack detection. From these investigations, methanol-induced SCC was observed to be short, axially-oriented, adjacent to girth welds and intergranular in nature. Managing this threat to pipeline integrity is challenging due to the short, axially-oriented nature of the cracks and their proximity to the girth weld, which result in reduced accuracy of detection and sizing by crack ILI tools. Therefore has been determined that this threat would be best managed using a probabilistic integrity management tool that enables systematic treatment of the uncertainties regarding susceptibility of a given pipe joint to methanol-induced internal axial SCC, detection by ILI or other indirect inspection methods, crack growth rate, and possibility of leakage due to opening of a through-wall crack. Such a tool must be able to use all available data regarding the pipeline to estimate the probability of leaks or through-wall cracks occurring on any given segment, which can then be used as a basis for identifying and ranking potential locations for mitigation action. Two possible probabilistic approaches to develop such an integrity management tool have been considered: a Standard reliability-based approach and a Bayesian Networks approach. In this paper, both approaches are described and the two approaches are compared based on a number of criteria, including: 1) direct and effective use of the available data, 2) ability to incorporate repeated observations, 3) ability to expand the approach to other threats, 4) effort required to use the tool and interpret the results, and 5) ability to improve the tool over time
Track 7: Risk and Reliability	Track 7.1	IPC2020-9586	Daryl Bandstra	Subset Simulation for Structural Reliability Analysis of Pipeline Corrosion Defects	One of the leading threats to the integrity of oil and gas transmission pipeline systems is metal-loss corrosion. This threat is commonly managed by evaluati measurements obtained with in-line inspection tools, which locate and size individual metal-loss defects. Both deterministic and probabilistic methods are used in the pipeline industry to evaluate the severity of these defects. Probabilistic evaluations typically utilize structural reliability, which is an approach to designing and assessing structures that focuses on the calculation of the probability that a structure may fail. Reliability methods have been applied to pipeline corrosion defects since the 1990's, and have continually remained an active area of research and development. The basic equations of the structural reliability approach involve a multi-dimensional integral which must be solved in order to obtain the probability of failure. This solution can be obtained using either analytical or numerical methods. While complex analytical methods such as the First-Order Reliability Method (FORM) have been successfully applied to pipeline corrosion, the most common and straight-forward approach is to use Monte Carlo simulation. While Monte Carlo simulation is robust, it is also computationally intensive and therefore can be time-consuming to obtain stable estimates at small probability levels (ex. less than 10 -6) . To deal with this issue, many variance-reduction approaches have been utilized such as importance sampling, however this approach is not always robust for time-dependent reliability problems with multiple limit states. An alternative varianc reduction approach, called Subset Simulation, views the rare failure probability as the product of a series of larger, conditional failure probabilities by introducing intermediate events. These conditional failure probabilities cannot be estimated using simple Monte Carlo, so a Markov Chain Monte Carlo methodology called the Modified Metropolis algorithm is utilized instead. Subset Simulation provides an efficient solution to reliability problems without the need for prior information about the system's behavior, other than an input-output model. Subset simulation has proven so effective, that it has been applied to rare-event reliability problems in disciplines such as geotechnical, aerospace, fire and nuclear engineering. This paper presents comparisons between the probability of failure estimates generated by Monte Carlo simulation and Subset Simulation, for various pipeline corrosion defect cases. These cases illustrate the increased accuracy and decreased computational effort required for Subset Simulation. By significantly reducing the computational effort required to obtain stable estimates of small failure probabilities, this methodology reduces one of the major barriers to the use of reliability methods for system-wide pipeline reliability assessme
Track 7: Risk and Reliability	Track 7.2	IPC2020-9274	Maher Nessim	Safety Risk Acceptance Criteria for Pipelines	The lack of established acceptance criteria has been one of the key challenges to the application of quantitative risk assessment (QRA) techniques in the Canad pipeline industry. While a wide range of such criteria have been developed and published, it remains difficult for most operators to commit to specific criteria because such criteria may not be acceptable to other stakeholders, such as regulators and the public. Recognizing this limitation, the Canadian Standards Association formed a Risk Management Task Force (RMTF) under the Technical Committee for the Z662 Standard on the Oil and Gas Pipeline Systems to propose criteria for potential inclusion in its non-mandatory Annex on Risk Assessment. This paper describes the criteria that have been developed by the RMTF and provides the background information needed for users to understand and use them correctly. The discussion includes: a summary of the measures used to quantify the safety risk associated with an ignited product release; a summary of established international and Canadian criteria that have been considered; a description and interpretation of the ALARP (As Low As Reasonably Practicable) principle used as a basis; and the rationale used by the RMTF to select specific individual risk and societal risk criteria for CSA Z662. The proposed criteria are also compared to the criteria underpinning other risk-based parts of the Standard, including Annexes C and O. Guidance is also provided on the analysis assumptions, methods and parameters required to ensure that the risk calculations produce results that are consistent with the definition and intent of the criter Key issues addressed by the guidance include the definition of individual risk (i.e. location risk versus personal risk), the pipeline length over which the frequency versus number of fatalities (F-N) relationship representing societal risk is calculated, and the effect of population density averaging over the pipeline lenc
Track 7: Risk and Reliability	Track 7.2	IPC2020-9278	Mark Stephens	Hazardous Liquid Pipeline Spill Volumes	For pipelines transporting hydrocarbon products that remain in a liquid state after release, where the dominant concern is environmental damage and socioeconon impact on people in the area affected by the release, there is general agreement that the magnitude of impact is, at least in part, a function of the volume of product released. Analytical models exist for estimating the release volume from pipelines as a function of the physical and operational parameters of the line (e.g. product flow rate, elevation profile, block valve spacing and closure times), and the effective size of the opening at the point of line break. While the line- and location-specific estima of spill volumes obtained from such models are an important component of line-specific risk assessments and serve to inform emergency response planning activities, i also useful to understand what historical data indicates in terms of actual release volumes and how they are affected by key pipeline attributes. This paper summarizes the findings of an analysis of product release events associated with the US hazardous liquid pipeline network, as obtained from reportable incident data publicly available from the Pipeline and Hazardous Materials Safety Administration (PHMSA). The findings of the study suggest that, for major releases resulting from pipeline rupture, spill volumes are correlated with line diameter, whereas releases as the result of a leak are largely independent of line diameter. Based on this, simple models have been developed from which both the average release volume and the range of likely release volumes can be estimated as a function of the pipeline diameter and mode of fai (i.e. leak versus rupture). These simple models are useful for benchmarking more complex, line-specific release volume estimation models, and for the calibration of pipeline risk acceptance criteria and reliability targets based on average or expected release volume
Track 7: Risk and Reliability	Track 7.2	IPC2020-9788	Rodolfo Sancio	Model for Estimating the Probability of Failure at River Crossings	Pipeline river crossings are typically managed through a process of flood monitoring, ground inspections, risk assessments, and conducting of remediations. T assessments conducted within this management approach require simplifications within the data that is collected during monitoring. For example, the measured depth of cover is a timestamp that may vary with flow conditions; river bed soil type is often estimated based on bank observations; and software default values are often used during allowable span length calculations. Moreover, assessments are often based on the current observations at the crossing, opposed to the potential conditions during flooding events. Thus while conservative assumptions are usually applied, there would be benefit in developing a model that considers the potential ranges in crossing assessment inputs. A probabilistic model would enable combined consideration of all factors that contribute to the span failure threat, provide site rankings to support discrete mitigation prioritizations, allow for evaluation of whether a crossing is acceptable in regards to a risk target, and provide a 'check' to the hydrotechnical engineers visually based assessments. This paper describes two models for estimating the pipeline probability of failure at river crossings. The first model is a qualitative scoring-based model that is readily implementable by operators and consultants. This model employs a weightings factor approach to consider the multiple factors that contribute to pipeline exposures and overstress. A unique score for each crossing was established, and a relationship between score and probability of failure was determined by using the historical failure rates of similar crossings. The second model is a more complex quantitative model that required: 1) Generation of a semi-quantitative model that estimates the likelihood of a crossing exposure occurring, 2) Identification of scour depth equations that may be applied to pipeline integrity management, 3) Development of a method for estimating scour lengths, 4) Updating of the Pipeline Research Council International (PRCI) model that assesses the allowable pipeline span length at river crossings, and 5) Development of a model that quantifies the probability that a span length longer than the critical span length could form. The results from this project demonstrated that the site rankings correlated reasonably with those estimated by program managers, the scour depth and length prediction results were consistent with measured historical scours, and the pipeline probability of failure at the assessed river crossings were within expected ranges
Track 8: Northern, Offshore and Production Pipelines	On Demand	IPC2020-9346	Baodong Wang	Numerical Analysis of the Mechanical Behaviors of Nonmetal Unbonded Flexible Pipe Under Combined Load	Unbonded flexible pipe is widely used in the oil and gas industry for its good flexibility, especially in deep-water oil and gas production and transportation. And t nonmetal unbouded flexible pipe has excellent corrosion resistance and wear resistance. However, they are subject to internal pressure, external pressure and tension loads during the operation and service phases, which are important aspects affecting the integrity and security of the flexible pipe. In this paper, the mechanical behaviors of 8 inches nonmetal unbonded flexible pipe which consists of internal layer, internal pressure layer, anti-friction layer, carcass, tensile layer and external layer is investigated by numerical methods. The internal layer is high performance thermoplastic polymer material, the internal pressure layer and tensile layer is aramid fiber winding structure, and the carcass is high strength carbon fiber/resin composites. A rigorous three-dimensional solid finite element model of flexible pipe that considers the real material parameters, structural nonlinearity as well as the nonlinear contact behavior between components was created using ABAQUS. The material parameters of each functional layer were obtained by experiments. ABAQUS/Explicit quasi-static simulation is adopted to study the mechanical behaviors of the unbonded flexible pipe under combined load. And the accuracy of the simulation method for the internal pressure layer and tensile layer is verified by comparing with the small-scale internal pressure burst test of 1 inch flexible pipe. The mechanical behavior of flexible pipe subjected to internal pressure, external pressure and tension load was investigated in detail. The failure model and failure loads of flexible pipe were analyzed. Effects of the structure parameters such as the braided angle of aramid fiber braid layers, and the thickness of each layer were investigated. Based on the parametric study, some practical conclusions have been obtained which may be use for the practical design and production of flexible pipe. This study can be referenced for the applications of nonmetal unbonded flexible pipe marine oil and gas production
Track 8: Northern, Offshore and Production Pipelines	On Demand	IPC2020-9350	Dongxu Zhang	Hydrate Formation in Water-in-Oil Emulsions in the Presence of Resins	Gas hydrate is one of the main concerns in the flow assurance issues for under water multiphase pipelines. Hydrate nucleation and growth in the water-in-oil emulsion a not completely understood due to the complex factors, such as the composition of crude oil. Resins, as a common component in crude oil, can pose great influence on hydrate formation, which is still lack of investigation. This paper aims to bridge this gap with a custom-designed high pressure autoclave. Different with other hydrate investigation apparatus, an online viscometer was equipped for the real time viscosity measurement. Resins were separated from the Venezuelan residue for the purpose, following the saturates, aromatics, resins, and asphaltenes (SARA) fractionation method. A series of experiments for hydrate formation were carried out in the emulsions in the presence different resin contents, under the condition of 2.7 °C, 2.6 MPa, and 20 vol. % water cut. It was observed that resins hindered hydrate formation in water-in-oil emulsions, and the induction time increased with the increasing of resin content, for example, the induction time in the emulsion in the presence of 1 wt. % resin content was almost 200 min longer than that in the emulsion without resins. It was also found that the increase in resin concentration led to the significant reduction in peak value of temperature. In addition, a time delay phenomenon in temperature and pressure of the nucleation onset was found in the system with 0.5 or 1 wt. % resin content, by virtue of the online viscometer, reflecting the slower formation rate in the system with higher resin content. Moreover, the microphotographs of water-in-oil emulsions were obtained. It was demonstrated that the resins can adsorb on the water droplet surface, and hence may occupy the hydrate nucleation sites and form a barrier for the further penetration of guest gas molecules, which can account for the inhibit effect of resins on hydrate formation. It provides a scientific understanding for the effect of resins on hydrate formation in water-in-oil emulsions, excluding the interference of wax and other components, which would be useful to an appropriate flow assurance strategy making in the under-water multiphase pipelines

Track 8: Northern, Offshore and Production Pipelines	On Demand	IPC2020-9351	Xun Zhang	The Coarse Particle Influence on the Strength of Wax Deposition	Wax deposition has always been an important issue for flow assurance, especially in subsea pipelines. The coarse particles, which are usually measured in millimete will be carried out by oil flow during the deep-water oil fields production. However, due to insufficient understanding of the structure of wax deposition and the complexity of sandy crude oil deposits, the interaction between coarse particles and wax deposition in pipeline have rarely been investigated. In this paper, the mass fraction and size distribution of coarse particles effect on the yield stress of wax deposition has been studied. The sample was mixed at reversible structure temperature so that the impact of shear history could be eliminated and the rapid particle settlement at high temperature could be avoided. Experimental results have found that there is a limit fraction in coarse particle influences, below which a small amount of coarse particles added will led to a slightly increase in bulk yield stress. On the contrary, a dramatic decrease yield stress when exceed the limit and increasingly marked enhancement of yield stress as the fraction increases. This phenomenon has been explicated microscopically by the structural interaction between coarse particles and wax deposition. The interlock between wax crystals is the major contribution of structure as the less particle fraction contains. In spite of the silica sand is a typical non-colloidal particle, however, the asphaltene and resin could be absorbed in surface of particles that forming a cluster of colloidal particles. As the fraction of particles slightly increased, the slip between colloidal particles and wax crystal interlock accelerates structural failure. Nevertheless, more particles involved the overall yield stress may depend on the friction and the adhesive force between solid particles. The subtle changes induced by coarse particles would have a harder deposition which can hinder pig passing and affect pipeline pigging operatior
Track 8: Northern, Offshore and Production Pipelines	On Demand	IPC2020-9436	Mohamed Odan	Investigation Four-Phase Multi-Component Flow Techniques in Horizontal and Sub-Sea Pipelines	Offshore drilling projects can be as complex as they are costly, and many problems can arise during the drilling and extraction of sub-sea pipelines petroleum, includi environmental issues. The oil and gas industry relies on multi-phase, multi-component flow techniques to transport substances such as gas, oil and water through horizontal and sub-sea pipelines. Artic and offshore drill sites can be particularly challenging due to hydrate formation in the transport horizontal and sub-sea pipelines. This study investigates the feasibility of using a four-phase, four-fluid flow Multi-Component through horizontal pipelines to move a four-phase multi-component flow (oil gas, water, and sand particles) through submerged pipelines. In order to accurately gauge the multi-component mixtures' hydro- and thermo-dynamic properties, fluid equilibrium and phase-behavior models are constructed. As well, to examine various interrelated factors such as momentum, mass and heat transfer occurring between pipelines walls and flow, a series of equations are developed. In the present work, the effect of pressure and temperature on multi-phase flows in horizontal and sub-sea pipelines is investigated. As well, models of flow patterns and pressure drops are created specifically for horizontal and sub-sea pipeline environments. Note that the ter "Four-Phase and Multi-Component flow" are used interchangeably in this study. And Create pressure drops and flow behavior models of multi-phase flows for horizontal and sub-sea pipelines. Furthermore, multi-phase flows may occur in any one of the following combinations: gas-liquid, gas-liquid- solid, gas-liquid-liquid-solid, An examp of a , gas-liquid-liquid-solid flow is four immiscible fluids and component (e.g., gas, water, oil and solid), immiscible liquids being those which do not form a homogeneou mixture when added together. In terms of practical applications of multi-phase and multi-component flows, water injected into an oil pipelines helps to decreases both the pressure gradient and flow resistance. Keywords: Four-Phase Flow, Multi- Component, Three-Phase Flow, Sub-sea Pipelines, phase-behavior, &nb
Track 8: Northern, Offshore and Production Pipelines	On Demand	IPC2020-9542	Zonghan Bai	Research on Virtual Metering System of Offshore Oilfield Based on Multi-Level Electrical Submersible Pump	With the increasing demand for offshore oil and gas resources, exploitation moves from single point to multi-point, from shallow sea to deep sea. Flow parameters play important role in the safe and reliable production of offshore oil and gas, so real time measurement of flow parameters is an crucial problem we need to solve. The trend of increasing number and complexity of offshore oil and gas wells bring some challenges to multiphase flow measurement in wells. Traditional single well multiphase flow measurement includes multiphase flowmeter and complex test manifold. The cost and maintenance of multiphase flowmeters as well as the single well measurement of operation test manifold will increase the production cost and greatly reduce the economic benefits of production. As early as in the late 1980s, scholars put forward the virtual metering system (VMS). After continuous development, the virtual metering technology has been relatively mature. Virtual metering system can calculate the flow parameters of the whole submarine pipeline operation process based on some measured data and some formed algorithm models without occupying the physical space of the offshore platform. Compared with traditional single well measurement, virtual metering system has many advantages and is widely used in different offshore oil and gas fields by major oil companies. The calculation models of virtual metering system include reservoir model, nozzle model, wellbore model, electrical submersible pump (ESP) model and so on. Among them, the nozzle model and wellbore model have been well applied to the virtual measurement of some offshore gas fields. However, in the production process of oil wells, the nozzle will not be adjusted, and the speed and accuracy of the calculation using the wellbore model are affected by the length and complexity of the wellbore, so the calculation of flow rate by ESP model can solve the above problems to a certain extent. In this paper, based on the measured operating data of ESP in an offshore oil field, by analyzing the characteristics of fluid and ESP structure, a method for establishing the model of ESP operation characteristics in every stage is proposed. From the view of energy loss, the inter-stage utility parameters are defined for multi-stage ESP, and the ANN (artificial neural network) method is used to regress 260 data set. By using this regression method, the calculation model of inter-stage utility parameters is obtained, which is based on fluid viscosity, total pump efficiency, pump frequency and Q/Q bep . The algorithm is applied to the field data, and the relative error between the calculated flow rate and the field measured data is less than 5%, which meets the needs of Engineering applicatio
Track 8: Northern, Offshore and Production Pipelines	On Demand	IPC2020-9547	Jianping Liu	Establishment and Application of the Pipeline Monitoring System in Permafrost Regions in China	Buried pipelines in permafrost regions are inevitably subjected to some typical geohazards, such as frost heave, thaw settlement and thaw slumping. Under these typ ground movement, bending or/and longitudinal strains will be induced in pipe in the potential of leading to weld joint rupture. Thus, in order to prevent pipe failure, a comprehensive monitoring system was designed and used in the Mohe-Daqing oil pipeline in the permafrost region in northeast China. The Mohe-Daqing oil pipeline is built for importing oil from Russia and its north part of 440km lays in permafrost. The monitoring system includes a soil temperature field monitoring system, a ground displacement monitoring system and a pipe strain monitoring system. The soil temperature field monitoring system, which uses fiber brag grating sensors, can monitor the distribution of surrounding soil temperature in radial direction of pipe in order to detect the change of active ring of permafrost. The ground displacement monitoring system, which is based on a total station, can discover any subsidence or heave of the pipe itself and the embankment along the pipeline. The pipe strain monitoring system, which includes pipe stress monitoring system based on fiber brag grating sensors and inertial measurement unit (IMU) mapping, can inspect the real-time change of pipe stress and the bending strain periodically respectively. Using the comprehensive monitoring system, the important parameters that affect pipeline integrity such as pipeline temperature, stress, strain and displacement of Mohe-Daqing oil pipeline can be supervised timely and effectively. And the accuracy and reliability of the monitoring system have been verified in practical application. In this paper, detail about how these systems are designed and installed on the Mohe-daqing oil pipeline is elucidated and the monitoring data is analyzed. Through these data, the present mechanical situation of Mohe-Daqing oil pipeline is safe, but the long-term change is critical because of the soaring oil temperature that is far high than the design temperature. The monitoring system is of great significance to ensure the safe operation of Mohe-Daqing pipeline and can provide reference for the pipeline operation in permafrost are
Track 8: Northern, Offshore and Production Pipelines	On Demand	IPC2020-9567	Sijia Chen	Study on the Distribution of Submarine Pipeline Corrosion Defects Based on Internal Inspection Data and Data Mining Method	Pipelines are applied for oil, gas, water and mixed transportation, accounting for 9%, 10%, 16% and 65% in Bohai Sea respectively. Among them, 91% of the pipe contain CO_2 . The service life is 1 to 30 years and 31% is 6 to 10 years. In this paper, based on the existing pipeline internal inspection data (PIID) of submarine pipelir the Apriori algorithm and least-square-support-vector-machine (LSSVM) are applied to analyze the distribution rule and defect characteristics of internal defects along the pipeline with different transmission media. The contents include the analysis of the characteristics and types of defects, the size characteristics of defects, the distribution of defects along the pipe, the severity of defects, and the comparison of the data detected in multiple rounds. We divide the corrosion types into axial grooving, axial slotting, circular grooving, circular slotting, general, pinhole, pitting. Taking 1 hour as an interval, the pipeline section is divided into 12 intervals. Along the pipeline mileage, we have defined the pipe body, the weld joint and the location closed to the weld as J, W and C respectively. The variation of the severity of defects was studied by the percentage distribution of corrosion depth. We found that the defect depth of four kinds of pipelines is mainly 10% - 20%. This kind of defect accounted for 94.4%, 90.5%, 88.9%, 90.3% of the total number of defects. The density of 10% - 20% defects is 301.16, 226.11, 6.25 and 2514.32 one per km, respectively. The number of defects with the defect depth exceeding 50% accounts for 4.9%, 8.0%, 2.5% and 9.7% of the total number of defects in these four types of pipes respectively. We also get the maximum corrosion rate of each pipe. We found that 45% of the submarine pipelines are seriously corroded, and 58% of the severely corroded pipelines are mixed pipelines. About 15% of the submarine pipelines are heavy corrosive pipelines, 69% of which are mixed pipelines. We count the defects in different clock positions along the line in each 1km, where the corrosion concentrated in the first third of the pipe length and the corrosion defects mainly occurred in the 4:00-7:00 clock position. The relationship between corrosion location and defect type is as follows. The JCW of mixed transportation pipeline is mainly pitting and circular slotting, and tl confidence degrees are greater than 0.95, 0.86, and 0.72 respectively. In addition, there is a certain degree of axial or circular grooving at the weld joint with a confidence of 23%. The JCW of gas transmission pipeline is mainly pitting and circular slotting, and the confidence degree of JCW is greater than 0.96, 0.90, and 0.87 respectively. The confidence of JCW of oil pipeline is 0.995, 0.95, and 0.99. However, the corrosion of water transmission pipeline is different from that of the former three. The water pipelines' JCW mainly have circular grooving and general corrosion, and the confidence degrees are greater than 0.96, 0.99, and 0.96 respectively. In conclusion, we determined the corrosion type and used LSSVM to analyze the length, width and depth of the corrosion defects. The accuracy is over 96%. We used Apriori to mine the distribution rule of clock position and mileage location of corrosion defects. The corrosion severity of different transmission media was determined, and the clock orientation, corrosion distribution along the pipeline, and multiple inspection data were visualized. Mixed, gas and oil transportation were mainly pitting corrosion and circular slotting, while water transmission pipeline was mainly circular grooving and general corrosion. The mixed transportation pipeline had the fastest and the most serious corrosion, while the density of the corrosion of the water pipeline was the largest. The research methods and results in this paper can be employed to predict the most likely mileage location, clock position, defect type, and shape size of submarine pipeline corrosion. This is helpful to the integrity management of submarine pipeli
Track 8: Northern, Offshore and Production Pipelines	On Demand	IPC2020-9695	Babafemi Olugunwa	The Influence of Burial Depth and Soil Thermal Conductivity on Heat Transfer in Buried Co2 Pipelines for Ccs: A Parametric Study	Pipeline heat transfer modelling of buried pipelines is integral to the design and operation of onshore pipelines to aid the reduction of flow assurance challenges such carbon dioxide (CO_2) gas hydrate formation during pipeline transportation of dense phase CO_2 in carbon capture and storage (CCS) applications. In CO_2 pipelines for CCS, there are still challenges and gaps in knowledge in the pipeline transportation of supercritical CO_2 due to its unique thermo-physical properties as a single, dense phase liquid above its critical point. Although the design and operation of pipelines for bulk fluid transport is well established, the design stage is incomplete without the heat transfer calculations as part of the steady state hydraulic and flow assurance design stages. This paper investigates the steady state heat transfer in a buried onshore dense phase CO_2 pipelines analytically using the conduction shape factor and thermal resistance method to evaluate for the heat loss from an uninsulated pipeline. A parametric study that critically analyses the effect of variation in pipeline burial depth and soil thermal conductivity on the heat transfer rate, soil thermal resistance and t overall heat transfer coefficient (OHTC) of the one-dimensional heat conduction model at constant CO_2 fluid temperature and average constant ambient temperatures investigated. The results presented show that the influence of soil thermal conductivity and pipeline burial depth on the rate of heat transfer, soil thermal resistance and OHTC is dependent on the average constant ambient temperature in buried dense phase CO_2 onshore pipelines. Modelling results show that there are significant effects of the ambient natural convection on the soil temperature distribution which creates a thermal influence region in the soil along the pipeline that cannot be ignored in the steady state modelling and as such should be modelled as a conjugate heat transfer problem during pipeline desic

Track 8: Northern, Offshore and Production Pipelines	Track 6.2 / Track 8.1	IPC2020-9597	SeonHong Na	A Coupled Thermo-Hydro-Mechanical Model for Capturing Frost Heave Under Chilled Gas Pipelines	Transmission pipelines are large-diameter pipelines that transport 97% of Canada's daily natural gas and onshore crude oil production from producing regions to mark within provinces and across provincial or international boundaries. In fact, Canada has a huge network of transmission pipelines that can wrap the world almost 20 times. Many of these pipelines traverse through seasonally frozen soil regions, where frost heave effect of frozen soil can impose a significant threat to pipeline integrity. The frost heave is often referred to as the upward movement of the ground surface due to the formation of ice lenses in the underlying soils. It is a complex process involving a combined effect of heat transfer, pore water pressure variation, deformation, and evolution of strength. For example, during the freezing period, water in the unfrozen area rapidly migrates to the frozen area, and the total moisture content abruptly changes at the vicinity of the freezing front. Therefore, a typical mechanical or thermal assessment is not enough to study the effect of frost heave on the pipelines. In other words, a coupled thermo-hydro-mechanical assessment including an advanced soil constitutive model is necessary to assess the pipeline integrity against the frost heave. However, a limited number of previous studies are available in the literature that considers this combined effect. Among this limited literature, many approaches have been proposed to analyze the potential risks of frost have in soils by estimating the maximum depth of frost penetration in soils. This paper introduces a computational framework that accounts for coupled thermo-hydro-mechanical mechanisms of frost heave and associated preferential formation of ice lenses around the chilled pipelines. Based on the mixture theory, frost-susceptible soils are formulated as unsaturated porous media to capture the Darcy flux and thermal extractions around the pipelines. A constitutive model that combines the cryo-suction and temperature is also presented to reproduce changes in volume and strength of frozen soils. Numerical examples for pipeline applications are designed to analyze the influence of the overburden pressures from the pipelines and the rate of water flux and thermal gradient associated with ice lenses on frost heave. Furthermore, a parametric study is also carried out for a wide range of pipe diameters and soil propertie