STRAIN-BASED DESIGN AND ASSESSMENT AND 0.8 DESIGN FACTOR

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Outline

- Three parts: (1) intro, (2) status, and (3) gaps
- Introduction to strain-based design and assessment (SBDA)
  - What is SBDA?
  - Practical applications of SBDA
- Current approach to SBDA
- Elements of SBDA
  - Strain demand
  - Compressive strain capacity
  - Tensile strain capacity
- Role of SBDA in pipeline life cycle
- Gaps in SBDA
- Concluding remarks
Historically pipelines were constructed to contain content and maintain pressure. So design against hoop stress is the primary criterion.

Other design consideration includes:
- External interference (e.g., mechanical damage, road crossings)
- Corrosion
- Collapse from external pressure (offshore)
- Manufacturing defects (e.g., seam and girth welds)

Materials remain elastic under normal operating conditions.
What is Strain-Based Design and Assessment

- Strain-based design and assessment (SBDA) falls under the general framework of fitness-for-service assessment.

- FFS correlate the following key parameters:
  - Pipe dimensions
    - Diameter, wall thickness
  - Material properties
    - Strength and toughness
  - Anomalies
  - Loads/stress/strain on the pipelines

- **Strain based design**
  - Pipeline design with a specific goal of servicing/surviving under longitudinal plastic deformation (strain > 0.5%)

- **Strain-based assessment**
  - Using the same approach to assess the condition of in-service pipelines
Applications of SBDA – Onshore

- Frost heave and thaw settlement
- Slope movement
- Mining settlement
- Earthquake
Applications of SBDA - Offshore

- Pipe laying by reeling
- Lateral or upheaval buckling from pipe expansion
Approach to SBDA

- **Components of SBD**
  - Strain demand: tensile or compressive
  - Strain capacity: tensile or compressive.

- **Design conditions**
  - $\varepsilon_d$ (strain demand) < $f$ (safety factor) $\times \varepsilon_c$ (strain capacity)
Strain Demand

- Soil movement → pipe/soil interaction

- Inertial measurement unit (IMU)

- Direct stress measurement
Compressive Strain Capacity (CSC)

Compressive strain capacity

\[ \varepsilon_c = \varepsilon_t - D^* \frac{\theta_2 - \theta_1}{l} \]

With Recommended Safety Factor

- DNV OS-F101 (Y/T = 0.87; Safety Factor = 2.0)
- DNV OS-F101 (Y/T = 0.87; Safety Factor = 3.3)
- CSA Z662 (Safety Factor = 1.25)
- API RP-1111 (OV = 1%; Safety Factor = 2.0)
Tensile Strain Capacity (TSC)

- The bars are the test data spread between two sides of the curved wide plate (CWP) specimens.
Three curves represent three levels of target tensile strain capacity (1.0%, 1.5% and 2.0%).
Role of SBDA in Pipeline Life Cycle

- **Design**
  - Route selection, understanding strain demand and possible strain capacity
  - Ductile fracture control / design of crack arrestor

- **Materials**
  - Linepipe material specification

- **Construction**
  - Welding procedure qualification
    - Weld strength
    - Toughness
  - Flaw acceptance criteria in field welding
  - Basis for the control of weld profile and misalignment

- **Operation and maintenance**
  - Assess the margin of safety for possible threats to pipelines
  - Help to establish intervention criteria
  - Facilitate decisions on mitigation options
Understanding Gaps - CSC

- Field condition

![Diagram](https://www.neb-one.gc.ca)

**Test condition**

- Compression head
- Knife edges
- Loading arm
- Specimen
- Transverse girth weld
- Load cell
- Jack
- End plate

Strain-Based Design and Assessment and 0.8 Design Factor

National Energy Board (www.neb-one.gc.ca)
Understanding Gaps - TSC

- Field condition

- Test condition

Strain-Based Design and Assessment and 0.8 Design Factor

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State of Art in SBDA

- Strain demand
  - IMU to pick up strains from pipe bending
  - Use pipe/soil interaction model to estimate strain/stress on pipes from soil movement
- Compressive strain capacity (CSC)
  - Various equations from standards (e.g., CSA, DNV, and API) and published document (U. of Alberta)
  - More refined equations are being developed (PHMSA funded project at CRES)
  - Project-specific equations
- Tensile strain capacity (TSC)
  - Procedures from a DOT/PRCI co-funded project (CRES and C-FER)
  - Procedures from other organizations
SBDA for In-Service Pipelines

- JIP: Risk-Informed Fitness-For-Service Assessment of Pipelines Subjected to Ground Settlement and Movement Hazards

- Philosophy
  - Focus on technology deployment
  - Certain areas will need to be refined over time

- Led by operators and technology leaders
  - Kinder Morgan, Spectra, and CRES

- Intend to deliver “complete solutions”
  - Identification of geotechnical hazards
  - Proper use of inspection tools (ILI and other tools)
  - FFS and associated input parameters (material properties and flaw characteristics)
  - Mitigation (repair, stress relief) and monitoring
  - Risk ranking and intervention

- Key team members
  - Operators
  - Geotechnical experts
  - Inspection companies
  - Experts in materials, welding, and mechanics
Gaps – Overall Observations

- Strain capacity models are relatively advanced, but
  - Developed under laboratory test conditions
    - Straight pipes without any damage
    - Application of loads could be different from field conditions.
  - Without considering interacting defects
  - Material (linepipe and girth welds) qualification procedures, requirements, and test methods do not have the necessary precision for SBDA.
  - Data on the material properties and flaw characteristics of in-service pipelines are limited.

- The gaps identified below are applicable, in general, to new constructions and in-service pipelines.
Gaps

- Gap 1: Interaction of high longitudinal strain and anomalies from corrosion or mechanical damage
  - Present assessment methodology on those anomalies was established
    - under the condition of small longitudinal strain
    - Hoop stress level is higher than longitudinal stress level
  - Would the behavior of those anomalies change under high longitudinal strain?
  - How would the strain capacity change with the presence of those anomalies?

- Gap 2: SBDA in the presence of fittings (hot bends, elbows, tees, valves)
  - Transition zones can be points of strain concentration
  - Qualification, flaw detection, and monitoring of manual welds
  - Heat treatment of large diameter high pressure (thick) fittings
Thank You!

- Questions