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

Design, Operation, and Maintenance, Nominal Process

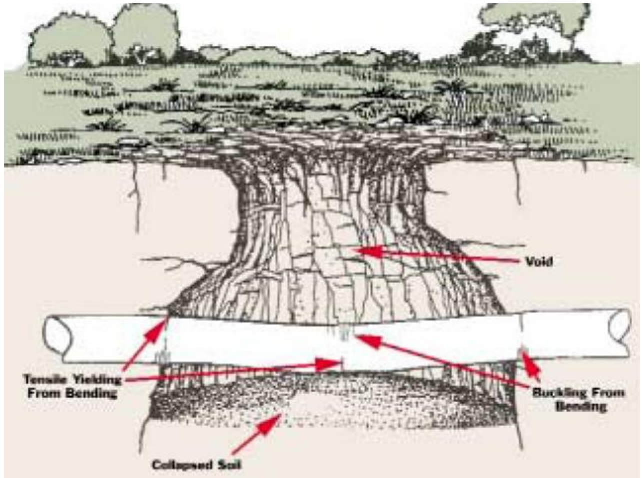
- Historically pipelines were constructed to contain content and maintain pressure. So design against hoop stress is the primary criterion.
- Other design consideration includes:
  - External interference (e.g., mechanical damage, road crossings)
  - Corrosion
  - Collapse from external pressure (offshore)
  - Manufacturing defects (e.g., seam and girth welds)
- Materials remain elastic under normal operating conditions.

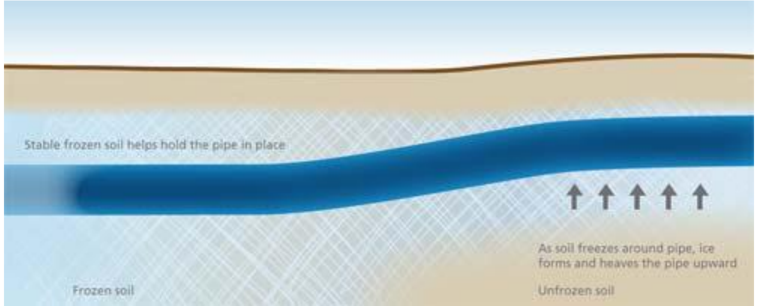
What is Strain-Based Design and Assessment

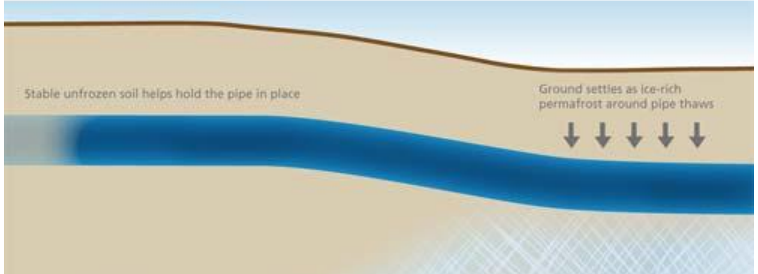
- Strain-based design and assessment (SBDA) falls under the general framework of fitness-for-service assessment
- FFS correlate the following key parameters
  - Pipe dimensions
    - Diameter, wall thickness
  - Material properties
    - Strength and toughness
  - Anomalies
  - Loads/stress/strain on 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







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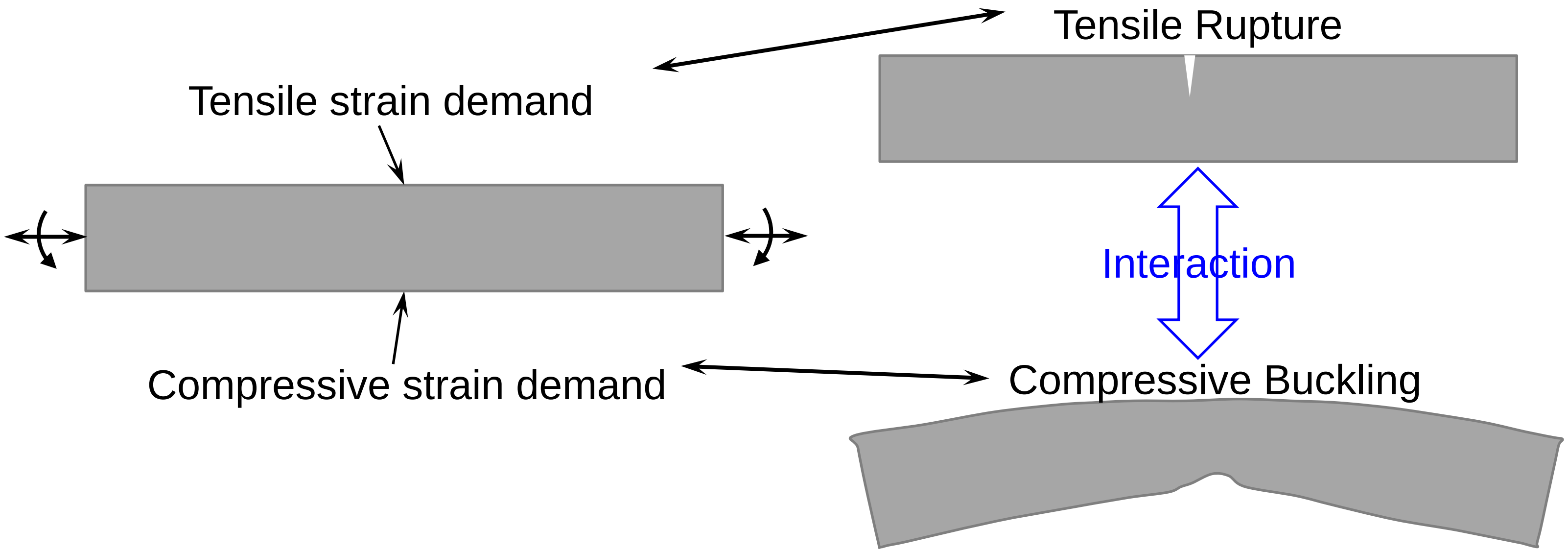
Applications of SBDA - Offshore

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

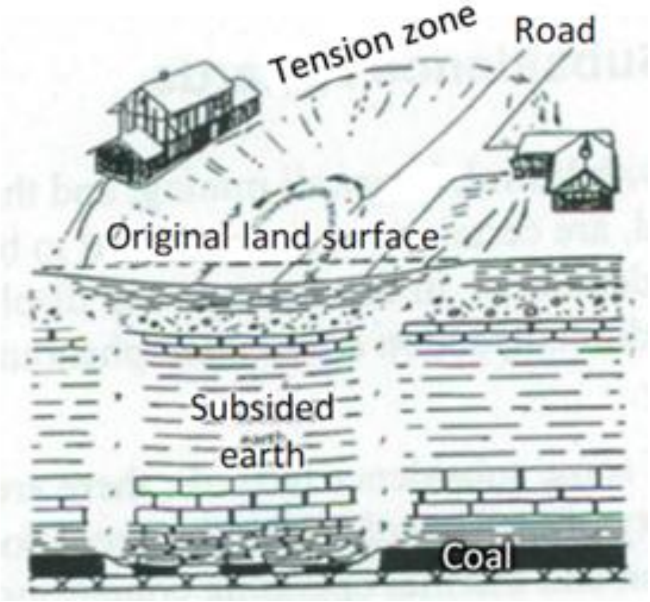
Approach to SBDA

- Components of SBD
  - Strain demand: tensile or compressive
  - Strain capacity: tensile or compressive.
- Design conditions
  - ε_d (strain demand) < f (safety factor) × ε_c (strain capacity)

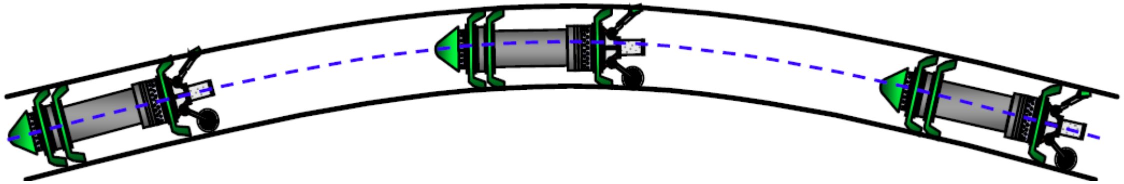


Strain Demand

❑ Soil movement → pipe/soil interaction



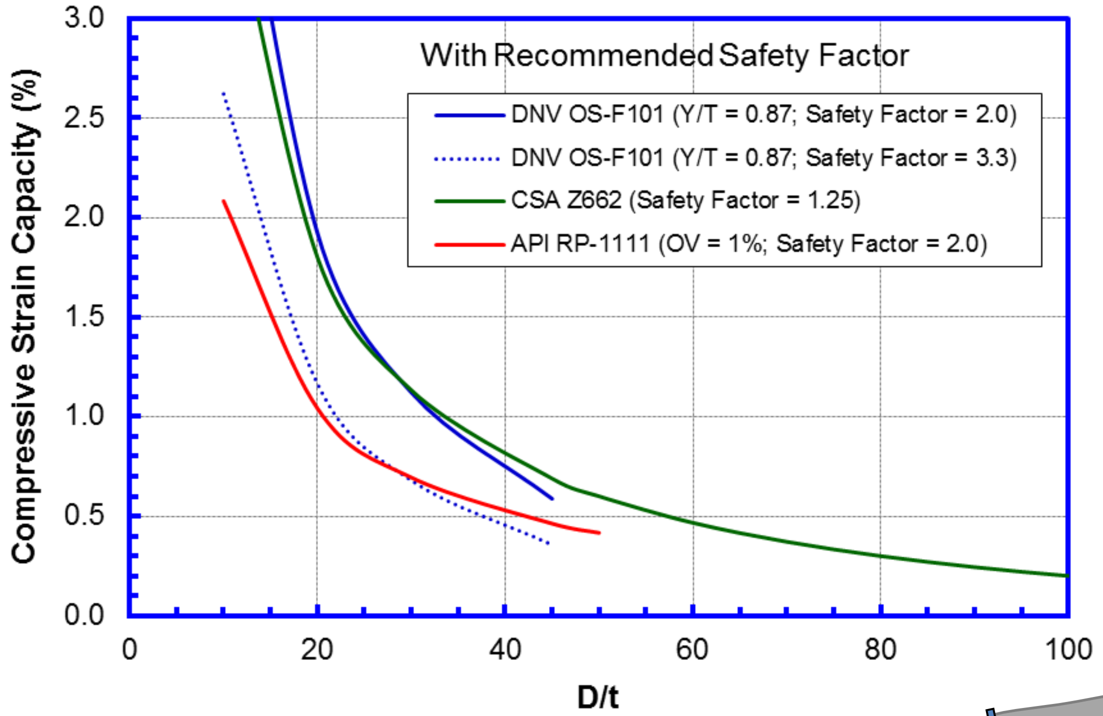
❑ Inertial measurement unit (IMU)

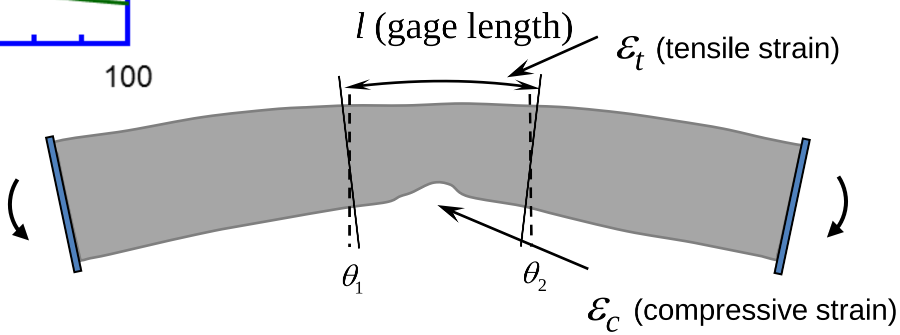


❑ Direct stress measurement

Compressive Strain Capacity (CSC)

- Compressive strain capacity

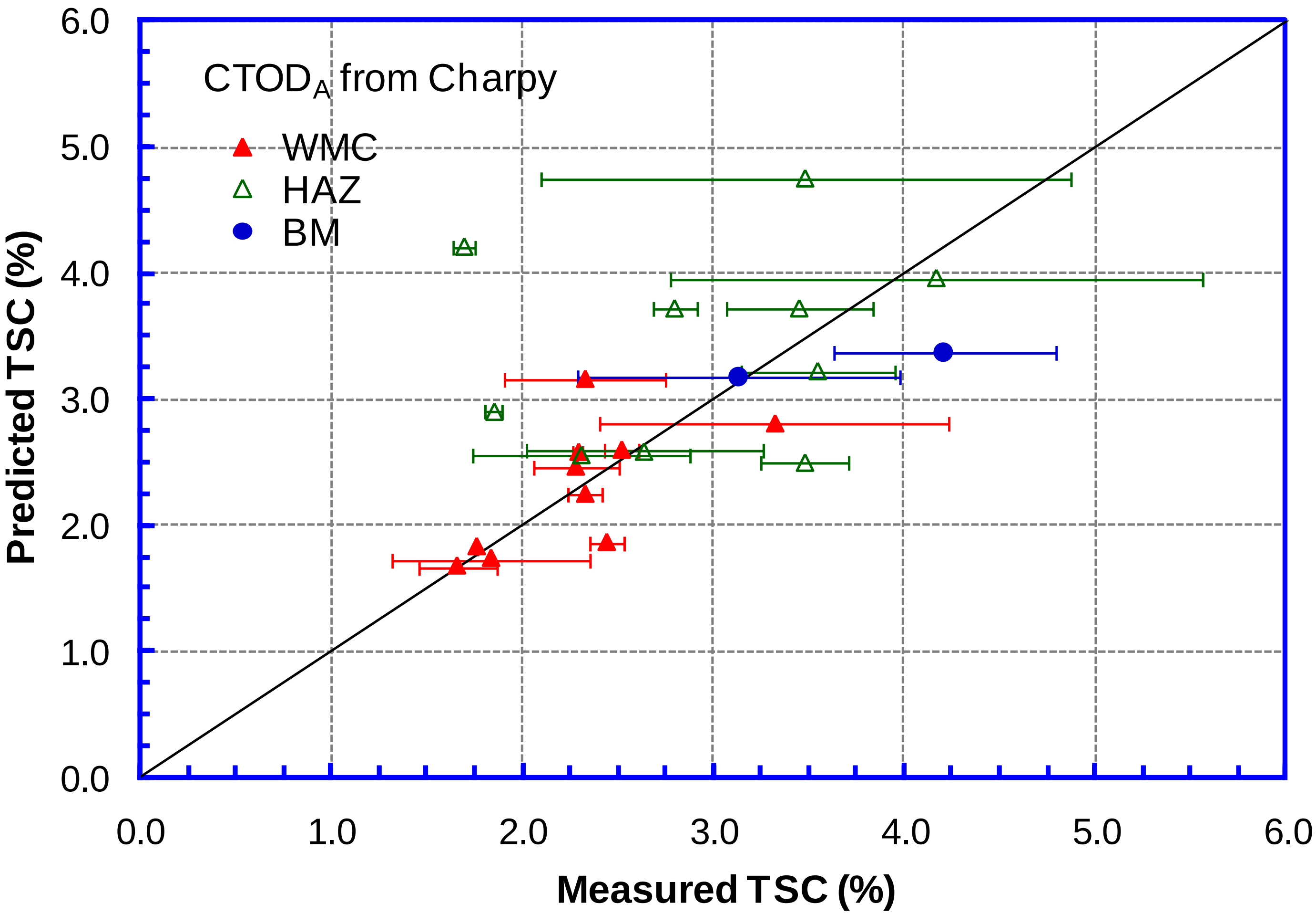




$$\varepsilon_c = \varepsilon_t - D^*(\theta_2 - \theta_1)/l$$

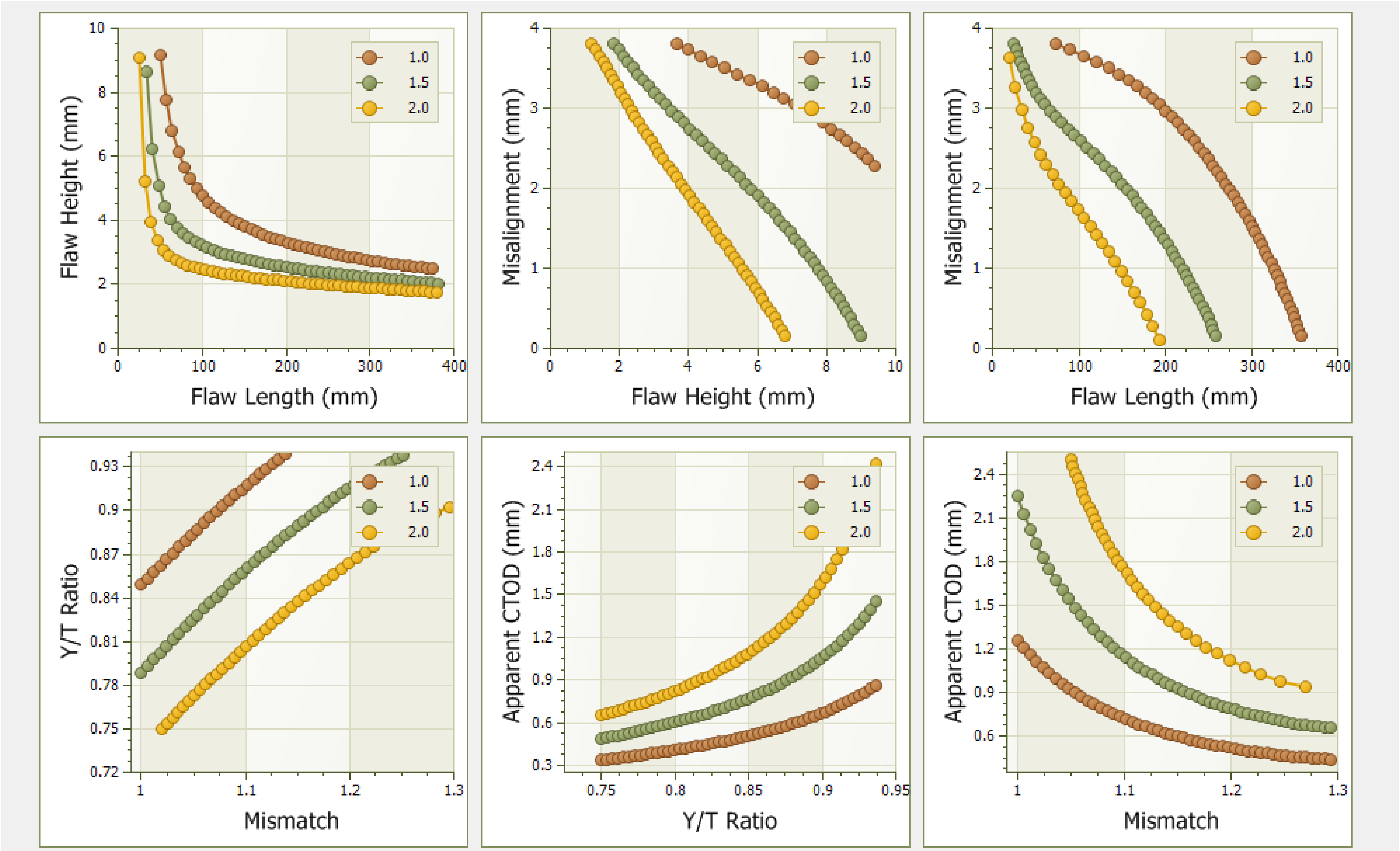
Tensile Strain Capacity (TSC)

- The bars are the test data spread between two sides of the curved wide plate (CWP) specimens.



TSC vs. Material Property, Flaw Size, Misalignment

- Three curves represent three levels of target tensile strain capacity (1.0%, 1.5% and 2.0%).

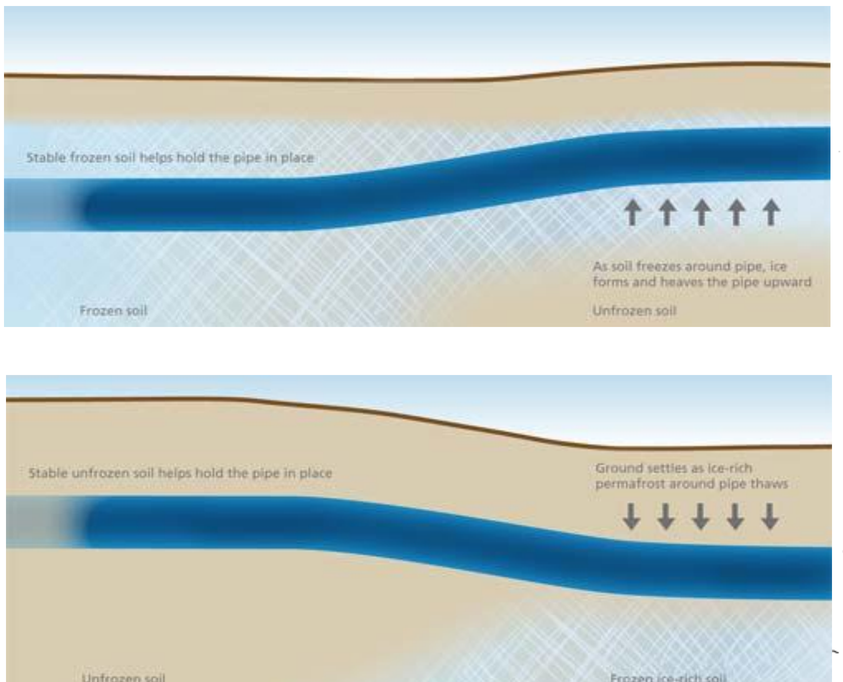


Role of SBDA in Pipeline Life Cycle

- 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



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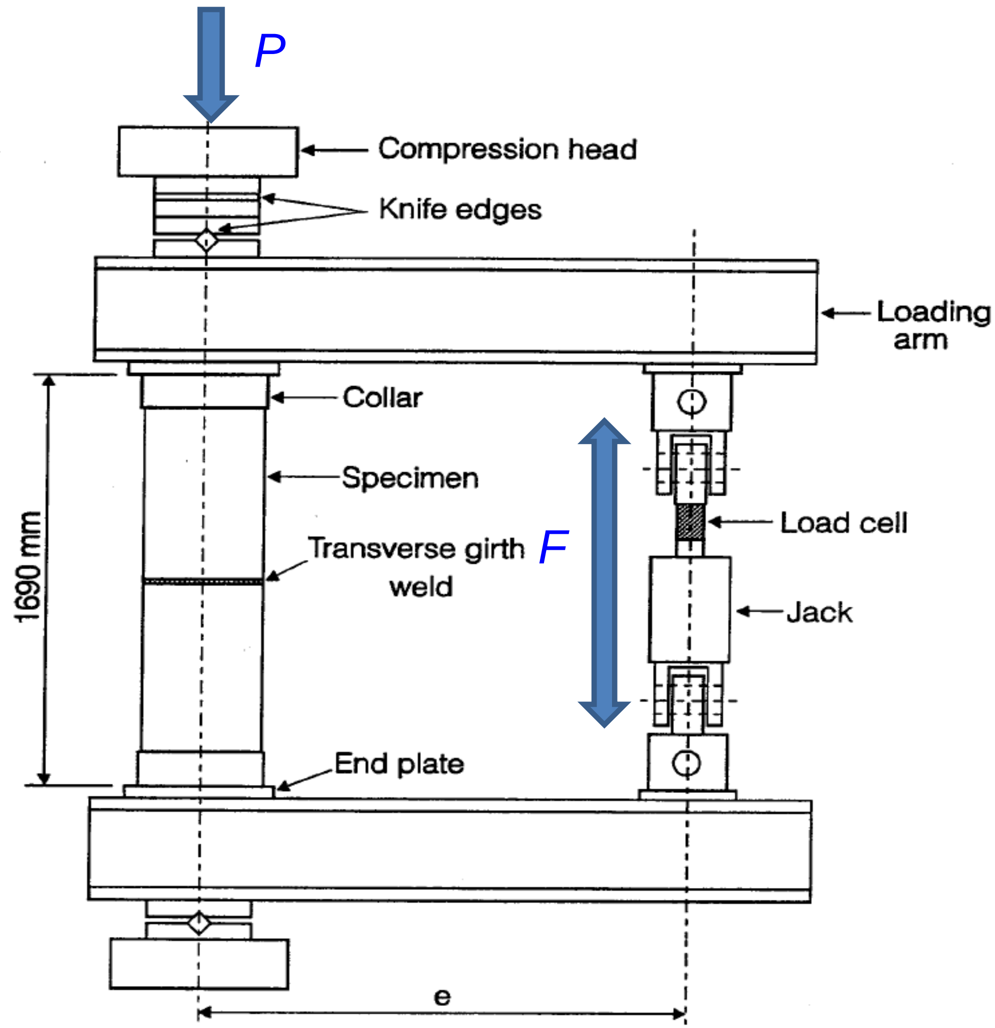
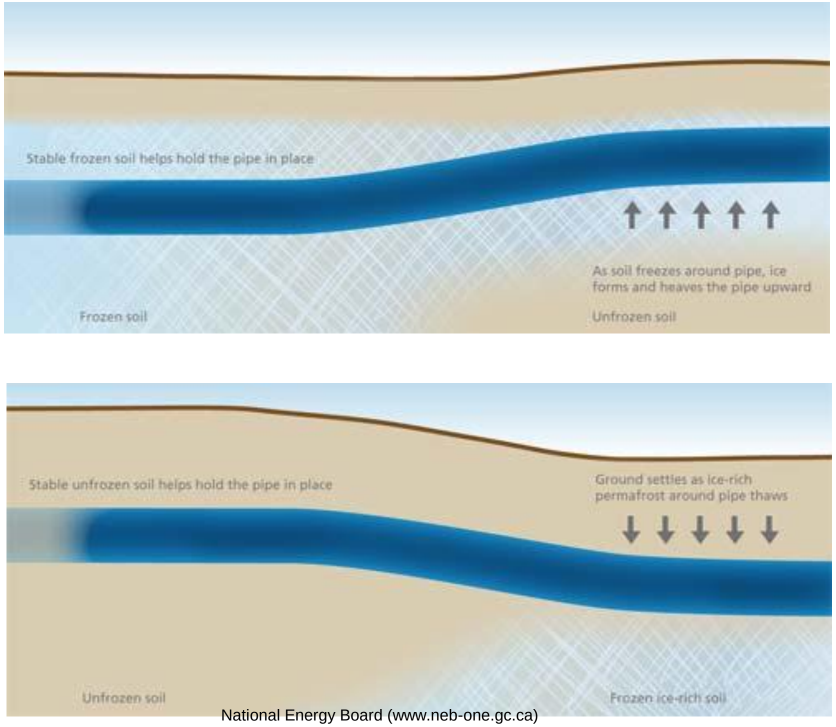
- ❑ Test condition



Understanding Gaps - TSC

- ❑ Field condition



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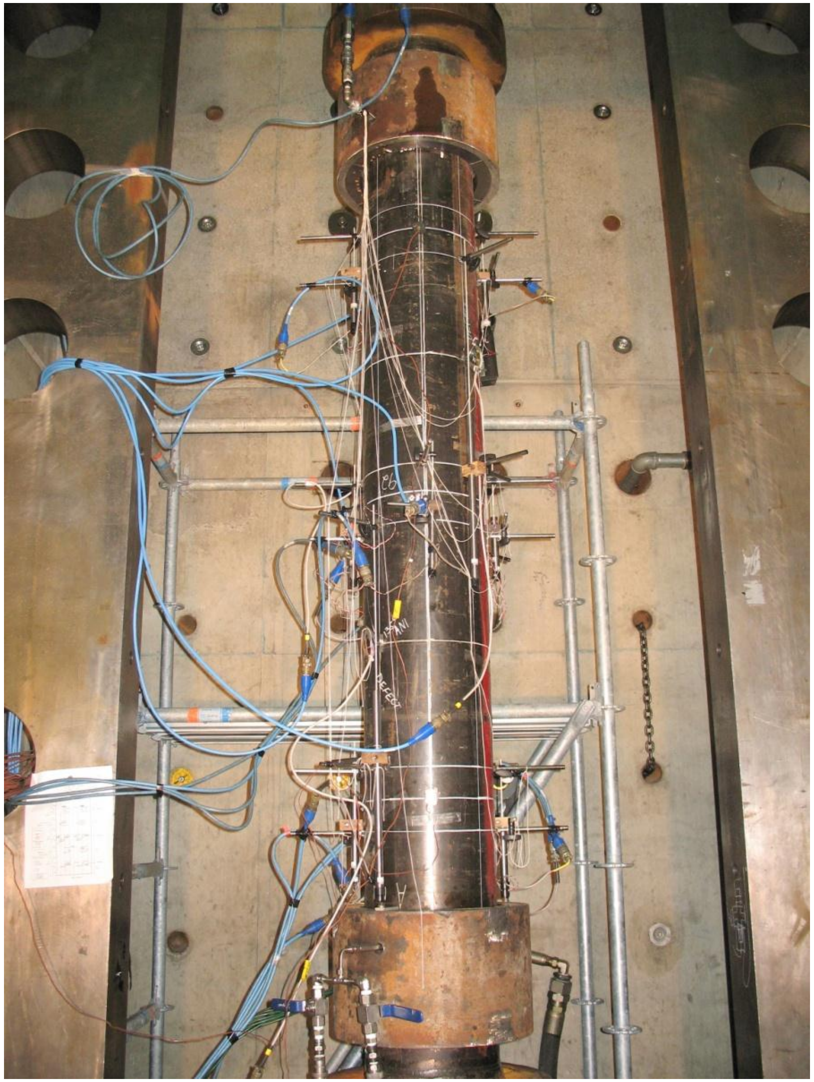
- ❑ Test condition



Strain-Based Design and Assessment and 0.8 Design Factor

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)
    - http://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=361
  - Project-specific equations
- Tensile strain capacity (TSC)
  - Procedures from a DOT/PRCI co-funded project (CRES and C-FER)
    - http://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=201
    - http://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=200
  - Procedures from other organizations

SBDA for In-Service Pipelines

- JIP: <u>Risk-Informed Fitness-For-Service Assessment of Pipelines Subjected to Ground Settlement and Movement Hazards</u>
- 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 <u>interacting defects</u>
  - 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