Mechanical Damage Characterization - Existing Technology in Gas Transmission Pipelines

Todd D. Kedzie, P.E.
Manager of Laboratory Services
El Paso Corporation

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Mechanical Damage Characterization

- Coating
  - holidays, disbondment
- Denting
  - smooth dents, sharp dents, rerounding, top side-bottom side
- Metal Loss
  - associated corrosion, removed metal
- Metal Deformation
  - smeared metal, scrapes, pipewall creasing
- Cracking
  - sheer cracks, ductile tearing, fatigue cracks, SCC

Coating (holidays, disbondment)

- DCVG/ACVG – DC/AC Voltage Gradient
- AC Current Attenuation Survey

Coating (holidays, disbondment)

DCVG/ACVG – DC/AC Voltage Gradient - Surface survey techniques to locate holidays in protective coatings of buried pipelines. (CL = M)

Advantages:

- May be relatively accurate in pinpointing location (tedious)
- May be used under rivers, marshland and city streets (DC)
- May identify the extent of effectiveness of CP system (DC)

Coating (holidays, disbondment)

DCVG/ACVG – DC/AC Voltage Gradient - Surface survey techniques to locate holidays in protective coatings of buried pipelines. (CL = M)

Challenges:

- Cannot confirm existence of mechanical defects. Likelihood of mechanical damage may be inferred only with combined technology assessment techniques (encroachment, land use, river dredging, ditch crossings)
- Survey operator must be experienced in the survey technique to interpret
- Sacrificial anodes, cross bonds etc often must be disconnected (AC)
- Accuracy may be affected by resistivity of soils, electrical interference such as overhead power lines, buried power cables

Coating (holidays, disbondment)

<u>**AC Current Attenuation Survey**</u> - Surface survey technique to ascertain condition of protective coatings of buried pipelines. (CL = M)

Advantages:

- Provides broad analysis of coating integrity
- Does not require "connection" to the pipeline. May be used for pipe in congested areas (such as city streets)
- May identify the extent of effectiveness of CP system

Coating (holidays, disbondment)

AC Current Attenuation Survey - Surface survey technique to ascertain condition of protective coatings of buried pipelines. (CL = M)

Challenges:

- Fast general results – best when used in conjunction with CIS or DCVG/ACVG
- Cannot confirm existence of mechanical defects. Likelihood of mechanical damage may be narrowed down with DCVG/ACVG and when combined technology assessment techniques (encroachment, land use, river dredging, ditch crossings)
- Survey operator must be experienced in the survey technique to interpret
- Accuracy may be affected by resistivity of soils, electrical interference, proximity to transmitter

Denting (smooth dents, sharp dents, rerounding, top side-bottom side)

- ILI Hi-Res Geometry Tool
- Direct visual examination
- API RP 579

Denting (smooth dents, sharp dents, rerounding, top side-bottom side)

ILI Hi-Res Geometry Tool – Combined technology intelligent pig - Magnetic Flux Leakage and Caliper Geometry tool technology utilizing multiple channels. (CL = M)

Advantages:

- Accuracy of sizing – good (1-2 %) – before excavation (rebounding).
- Orientation (top vs. bottom side) – good (clock position).
- Geometry (sharp vs. shallow) – good.

Denting (smooth dents, sharp dents, rerounding, top side-bottom side)

ILI Hi-Res Geometry tool – Combined technology intelligent pig - Magnetic Flux Leakage and Caliper Geometry tool technology utilizing multiple channels. (CL = M)

Challenges:

- MFL ILI tools that are designed to detect metal-loss corrosion are not optimized for detecting mechanical damage (thus combined technology presented above).
- Tool operator must be experienced in the results to interpret
- Metal loss accuracy – may be poor due to geometry
- Can not reliably detect corrosion vs. gouge in all dent profiles
- Cracks (shear) – poor (unless specifically se up)
- Strain (cold working) – poor (unless specifically set up)

Denting (smooth dents, sharp dents, rerounding, top side-bottom side)

<u>**Direct Visual Examination**</u> – excavation and measurement. (CL = H)

Advantages:

- Accuracy of sizing – excellent after excavation (rebounding)
- Orientation (top vs. bottom side) – excellent (clock position)
- Geometry characterization (sharp vs. shallow) – excellent.
- Metal loss accuracy – excellent (corrosion vs. gouge in dent)
- Cracks (shear) – good (requires UT for ID)
- Strain (cold working) – poor (w/o grinding and etching)
- Determination of plain dents = little effect on pipe strength

Denting (smooth dents, sharp dents, rerounding, top side-bottom side)

<u>**Direct Visual Examination**</u> – excavation and measurement. (CL = H)

Challenges:

- Requires access (cased pipe, river crossings, marsh, offshore)
- Original depth – unknown after rebounding
- No prescriptive guidelines (after construction, outside HCAs)
- Unrestrained dents in welds require additional assessment/caution
- Unrestrained dent defect combinations difficult to quantify remaining life - Requires other assessment methodology

Denting (smooth dents, sharp dents, rerounding, top side-bottom side)

API RP 579 – Fitness for service engineering assessment adapted from petrochemical industry, applicable to code design pipes. Section 8 smooth, Section 5 gouged. (CL = M)

Advantages:

- Relies on a three level assessment technique
- May accommodate: smooth dents, dents with grooves, dents with gouges, and secondary loading conditions
- Provisions for bends, elbows, tees
- Suitable for determining a safe operating pressure

Denting (smooth dents, sharp dents, rerounding, top side-bottom side)

API RP 579 – Fitness for service engineering assessment adapted from petrochemical industry, applicable to code design pipes. Section 8 smooth, Section 5 gouged. (CL = M)

Challenges:

- Comprehensive calculations may not be field friendly, more suitable for engineering analysis requiring competent personnel
- May require charpy-impact data
- May require depth before rebounding (can estimate)
- May require actual yield strength of material (can estimate with SMYS)
- Requires "blend" grinding of dents with defects
- Not for cyclic service (fatigue not considered)
- "…a dent [gouge] represents the most damaging flaw….unless the condition of the material can be adequately evaluated repair or replacement is recommended."

Metal Loss (associated corrosion, removed metal)

- RSTRENG
- DNV RP F101
- API RP 579

Metal Loss (associated corrosion, removed metal)

RSTRENG – Semi empirical procedure based on burst test data, defect size and yield strength. (CL= H)

Advantages:

- Most widely used corrosion analysis in US - field friendly commercial computer programs available
- Utilizes multi-tiered assessment techniques
- Requires only commonly available pipe property data (OD, WT, SMYS)
- May be used for internal corrosion, erosion, “blended” defects removed by grinding, and some smooth bends, DSAW long seams
- Suitable for determining safe operating pressure

Metal Loss (associated corrosion, removed metal)

RSTRENG – Semi empirical procedure based on burst test data, defect size and yield strength. (CL= H)

Challenges:

- Not applicable to stress concentrations or brittle material (mechanical damage, most weld seams, girth welds, hard spots)
- Not applicable to secondary loading conditions (bending stresses, spans)
- Not applicable to complex geometrical shapes (tees, dents, wrinkle bends)
- Conservatism decreases as corrosion length increases

Metal Loss (associated corrosion, removed metal)

DNV RP F101 – First internationally recognized comprehensive recommended practice for assessing pipelines containing corrosion defects. (CL= H)

Advantages:

- Utilizes multi-tiered assessment techniques (based on allowable stress or partial safety factor)
- Accommodates various levels of inspection accuracy (relative measurements - ILI, absolute measurements -UT)
- Applicable to secondary loading and interacting corrosion defects
- May be used for internal corrosion, and “blended” OD defects removed by grinding
- Suitable for determining safe operating pressure

Metal Loss (associated corrosion, removed metal)

DNV RP F101 – First internationally recognized comprehensive recommended practice for assessing pipelines containing corrosion defects. (CL= H)

Challenges:

- Comprehensive calculations may not be field friendly, more suitable for engineering analysis requiring competent personnel
- Not applicable to stress concentrations or brittle material (mechanical damage, most weld seams, girth welds, hard spots)
- Requires ultimate tensile strength (UTS)
- More conservative than Rstreng (however less variation)

Metal Loss (associated corrosion, removed metal)
API RP 579 – Fitness for service engineering assessment adapted from petrochemical industry, applicable to code design pipes. Sections 4, 5, 6. (CL = M)

Advantages:

- Addresses uniform, local and pitting corrosion separately
- Relies on a three level assessment technique
- Suitable for local metal loss and mechanical damage, and "blend" grinding crack-like flaws
- Provisions for bends, elbows, tees, secondary loading and two sided pitting
- Suitable for determining safe operating pressure or rerating
- Corrosion rate and remaining life can be predicted

Metal Loss (associated corrosion, removed metal)

API RP 579 – Fitness for service engineering assessment adapted from petrochemical industry, applicable to code design pipes. Sections 4, 5, 6. (CL = M)

Challenges:

- Comprehensive calculations may not be field friendly, more suitable for engineering analysis requiring competent personnel
- May require charpy-impact data
- May require depth before rebounding (can estimate)
- May require actual yield strength of material (can estimate with SMYS)
- Requires estimation of pitting propagation rate or in-service monitoring
- Requires access for “blend” grinding of mechanical damage
- Complex shapes require detailed numerical stress analysis

Metal Deformation (smeared metal, scrapes, pipewall creasing)

- Direct visual examination
- API RP 579

Metal Deformation (smeared metal, scrapes, pipewall creasing)

<u>Direct Visual Examination</u> – excavation and measurement. (CL = H)

Advantages:

- Accuracy of sizing – excellent after excavation
- Metal loss accuracy – excellent
- Surface cracks – good (requires UT for ID)
- Strain (cold working) – poor (w/o grinding and etching)

Metal Deformation (smeared metal, scrapes, pipewall creasing)
Direct Visual Examination – excavation and measurement. (CL = H)

Challenges:

- Requires access (cased pipe, river crossings, marsh, offshore)
- No prescriptive guidelines (after construction, *outside HCAs*)
- Deformations of welds require additional assessment/caution
- Requires other assessment methodology and acceptance criteria

Metal Deformation (smeared metal, scrapes, pipewall creasing)

API RP 579 – Fitness for service engineering assessment adapted from petrochemical industry, applicable to code design pipes. Section 5 (CL = M)

Advantages:

- Relies on a three level assessment technique
- Suitable for local metal loss and mechanical damage, and "blend" grinding crack-like flaws
- Provisions for bends, elbows, tees, secondary loading
- Suitable for determining safe operating pressure or rerating

Metal Deformation (smeared metal, scrapes, pipewall creasing)

API RP 579 – Fitness for service engineering assessment adapted from petrochemical industry, applicable to code design pipes. Section 5 (CL = M)

Challenges:

- Comprehensive calculations may not be field friendly, more suitable for engineering analysis requiring competent personnel
- May require charpy-impact data
- May require actual yield strength of material (can estimate with SMYS)
- Requires access for "blend" grinding of mechanical damage
- Complex shapes require detailed numerical stress analysis

Metal Deformation (smeared metal, scrapes, pipewall creasing)
API B31.8 – Semi empirical procedure specifically developed for metal deformation (CL= NR)

Advantages:

- Similar to Rstreng single point analysis
- Requires only commonly available pipe property data (OD, WT, SMYS)
- Designed for "blended" defects removed by grinding
- Provides pass/fail criteria for determining safe operating pressure

Metal Deformation (smeared metal, scrapes, pipewall creasing)

API B31.8 – Semi empirical procedure specifically developed for metal deformation. (CL= NR)

Challenges:

- No commercially available field friendly computer programs available
- Not applicable to stress concentrations or brittle material (mechanical damage, most weld seams, girth welds, hard spots)
- Not applicable to secondary loading conditions (bending stresses, spans)
- Not applicable to complex geometrical shapes (tees, dents, wrinkle bends)
- Requires physical access to defect
- Maximum after-ground defect depth limited to < 40%
- Requires magnetic particle or dye penetrant inspection to verify crack removal
- Requires acid etch for verification of complete removal of cold worked surface
- Requires UT inspection for wall thick ness verification
- Slightly more conservative than Rstreng

Cracking (sheer cracks, ductile tearing, fatigue cracks, SCC)

- **API RP 579** (CL = M)

Fracture mechanics models combined. All assessment methodology predict relationship between critical defect size and failure pressure. (CL = M)

Models are most accurate when used for the original developed guidelines (i.e. Cracks or metal loss). Generally, arranged in order of conservatism (accuracy):

- **NG-18 In-secant Formula** (CL = M)
- **Level 2 Strip Yield Model** (CL = M)
- **PAFFC Pipe Axial Flaw** (CL = M)
- **CorLAS** (CL = M)

Cracking (sheer cracks, ductile tearing, fatigue cracks, SCC)
API RP 579 – Fitness for service engineering assessment adapted from petrochemical industry, applicable to code design pipes. Section 9 (CL = M)

Advantages:

- Relies on a three level assessment technique
- May allow cracks to remain in service after assessment
- Provisions for secondary stresses from welding
- Suitable for determining safe operating pressure or rerating

Cracking (sheer cracks, ductile tearing, fatigue cracks, SCC)

API RP 579 – Fitness for service engineering assessment adapted from petrochemical industry, applicable to code design pipes. Section 9 (CL = M)

Challenges:

- Comprehensive calculations may not be field friendly, more suitable for engineering analysis requiring competent personnel
- Requires identification of predominant crack to predict behavior
- May require charpy-impact data
- May require actual yield strength of material (can estimate with SMYS)
- Complex shapes require detailed numerical stress analysis
- May require crack growth monitoring
- May require remaining life assessment
- Requires reassessment after each hydrotest

Cracking (sheer cracks, ductile tearing, fatigue cracks, SCC)

NG-18 ln-secant Formula- Based on a strip yield model and empirically derived for single crack surface axial flaws. Oldest, widely used. (CL = M)

- Requires flow stress (approximated by yield + 10 ksi)
- Requires Charpy v-notch impact toughness at temperature
- Not applicable to flaw growth (in-service or hydro)
- Overly conservative for SCC failure pressure predictions
- Not applicable to multiple crack colonies
- Very (overly?) consistently conservative

Cracking (sheer cracks, ductile tearing, fatigue cracks, SCC)
Level 2 Strip Yield Model – Collapse-modified strip yield model for axial surface cracks in pipelines. (CL = M)

- Requires toughness properties
- Provides leak vs. rupture a various pressures
- Very conservative poor consistency

Cracking (sheer cracks, ductile tearing, fatigue cracks, SCC)
P**<u>AFFC - Pipe Axial Flaw Failure Criterion</u>** - Update to ln-secant Formula (CL = M)

- Requires flow stress (approximated by yield + 10 ksi)
- Requires upper shelf Charpy v-notch impact toughness
- Accommodates stable flaw growth of newer steels
- Complex calculations required (commercially available software)
- Not applicable to multiple crack colonies
- Adequate predictability and conservatism

Cracking (sheer cracks, ductile tearing, fatigue cracks, SCC)

CorLAS - An iterative assessment of interacting crack-like flaws and other defects to determine critical flaw size and remaining life predictions. (CL = M)

- Requires material properties (yield and tensile strength, toughness testing (or default), strain hardening exponent).
- Requires detailed flaw characterization - detailed profile, or assume semi elliptical shape (direct measurement or infer from hydrotest)
- Complex calculations required (commercially available software) assumes steel has good toughness properties (not applicable to older lines)
- Requires a flaw growth rate resulting in limited range of applicability.
- Most accurate least conservative analysis technique