

A decorative pattern of white-outlined squares of various sizes is scattered across the blue background, primarily on the left side and top.

Mechanical Damage Characterization - Existing Technology in Gas Transmission Pipelines

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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
 - shear cracks, ductile tearing, fatigue cracks, SCC

A decorative pattern of white-outlined squares of various sizes is scattered across the blue background. Some squares are arranged in vertical columns, while others are isolated. The squares vary in size, with some being quite small and others being larger.

Coating (holidays, disbondment)

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

A series of white-outlined squares of various sizes arranged in a horizontal line across the top of the slide.



Coating (holidays, disbondment)

A vertical column of white-outlined squares on the left side of the slide.

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

A single white-outlined square on the left side of the slide.

Advantages:

- 
- A single white-outlined square on the left side of the slide.
- 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)
- 
- A vertical column of white-outlined squares on the left side of the slide.








Coating (holidays, disbondment)



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

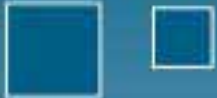


Challenges:

- 
- 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
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Coating (holidays, disbondment)



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



Advantages:

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- 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
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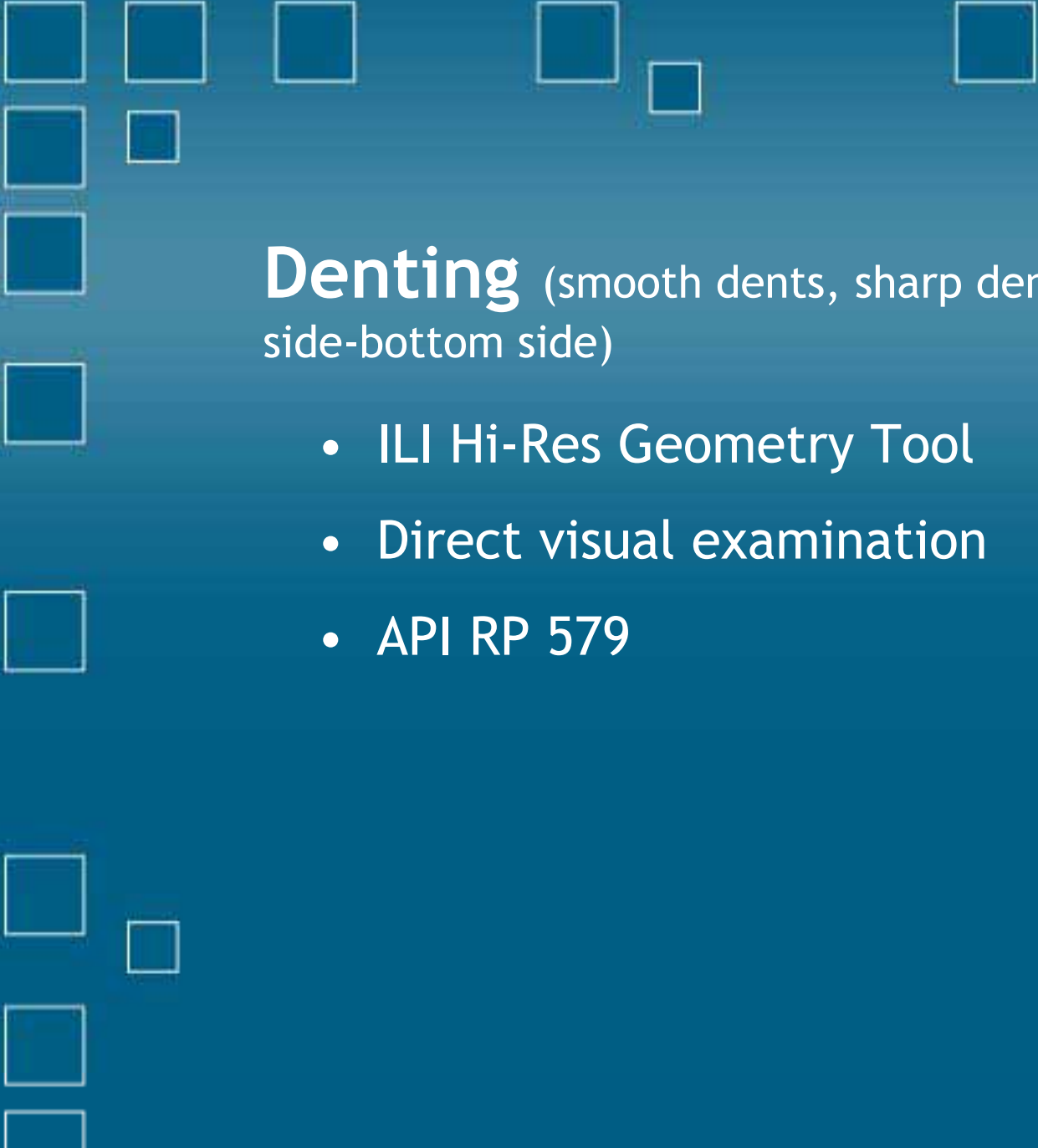
A decorative pattern of white squares of various sizes is scattered across the left side of the slide. Some squares are solid white, while others are hollow outlines. They are arranged in a somewhat vertical column, with some appearing in pairs or small groups.

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

A decorative pattern of white-outlined squares of various sizes is scattered across the blue background. Some squares are arranged in vertical columns, while others are isolated. The squares vary in size, with some being quite small and others being larger.

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


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

A series of white-outlined squares of various sizes and orientations are arranged in a pattern on the left side of the slide. Some are solid white, while others are hollow outlines. They are scattered across the top and middle sections of the slide.

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:


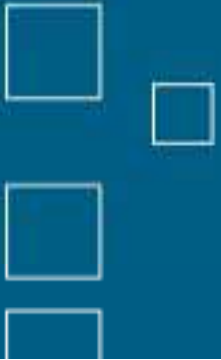
- Accuracy of sizing - good (1-2 %) - before excavation (rebounding).
 - Orientation (top vs. bottom side) - good (clock position).
 - Geometry (sharp vs. shallow) - good.
- 
- A series of white-outlined squares of various sizes and orientations are arranged in a pattern on the left side of the slide, continuing from the top section. Some are solid white, while others are hollow outlines. They are scattered across the bottom section of the slide.



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 set up)
 - Strain (cold working) - poor (unless specifically set up)
- 



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

Direct Visual Examination - 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


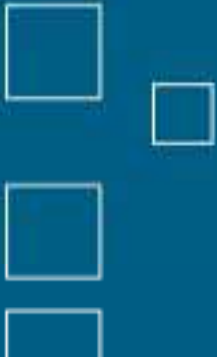


Denting (smooth dents, sharp dents, rerounding, top side-bottom side)

Direct Visual Examination - 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
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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.”

A vertical column of white-outlined squares of varying sizes is positioned on the left side of the slide, serving as a decorative element.

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:

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- 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)

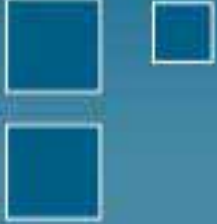


Challenges:

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- 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:


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- 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
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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

A vertical column of white-outlined squares of varying sizes is positioned on the left side of the slide. Some squares are larger and more prominent, while others are smaller and more subtle, creating a decorative border.

Metal Deformation (smearing metal, scrapes, pipewall creasing)

- Direct visual examination
- API RP 579


A decorative pattern of white-outlined squares of various sizes is scattered across the blue background. Some squares are solid white, while others are just outlines. They are arranged in a somewhat random pattern, with some appearing in vertical columns and others isolated.

Metal Deformation (smearing metal, scrapes, pipewall creasing)

Direct Visual Examination - 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 (smear 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
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Metal Deformation (smear 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 (smear 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
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Metal Deformation (smearred metal, scrapes, pipewall creasing)

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

Advantages:

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- 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
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Metal Deformation (smear 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 thickness verification
 - Slightly more conservative than Rstreng
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Cracking (shear 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):

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- NG-18 In-secant Formula (CL = M)
 - Level 2 Strip Yield Model (CL = M)
 - PAFFC Pipe Axial Flaw (CL = M)
 - CorLAS (CL = M)
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Cracking (shear 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 (shear cracks, ductile tearing, fatigue cracks, SCC)
NG-18 In-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

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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 at various pressures
- Very conservative poor consistency






Cracking (sheer cracks, ductile tearing, fatigue cracks, SCC)
PAFFC - Pipe Axial Flaw Failure Criterion - Update to In-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

A decorative pattern of white squares of various sizes is arranged in a grid-like fashion on the left side of the slide. Some squares are larger than others, and they are scattered across the vertical space.

Cracking (shear 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)

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- 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