GIRTH WELD DEFECT ACCEPTANCE
WORKMANSHIP, REPAIR OR ECA?

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Scope of Presentation

✓ Girth weld (pipeline) integrity
  • Stress based design (“Stable soil”)
  • Strain based design (Earthquakes, soil settlement, land slides, ..)

✓ Defect acceptance
  • Workmanship
  • Fitness-for-purpose (ECA)
  • Major codes
  • Comparison

✓ Issues
  • Toughness testing
  • Weld strength mismatch
  • Non-destructive inspection

✓ Final observations
Stress vs strain based design – 1/2

Stress-based design

Remote stress > YS
- Remote yielding

Strain-based design

Remote stress < YS
- NSY

Threshold toughness

Need strain hardening (Y/T ratio)

Defect (3 % max)

X %. SMYS

Applied stress

REMOTE Straining capacity
Stress vs strain based design – 2/2

Today: SMYS and SMTS
Future: Actual properties

“Very safe”
Girth weld (pipeline) integrity – Stress based design

- Girth welds failure is prevented by using:
  - Design codes (Max. hoop stress – x % of SMYS)
  - Material selection codes
    - Material properties (Yield strength, Y/T ratio*, )
    - Adequate toughness (Charpy V or CTOD requirements)
    - Matching welding consumables (transverse tensile test)
    - Good weldability (prevention of cold cracking)
    - Hardness restriction (sour service)
  - Non-destructive inspection
    - X-ray (film) and / or ultrasonic testing

- However, … girth welds are a possible weak link in a pipeline string when flaws/defects occur.

* Axial tensile properties are “neglected” (Longitudinal vs Spiral welded pipe)
Girth weld defect/flaw acceptance - 1/2

- Girth welds might contain non-planar and/or planar defects
- To avoid unnecessary repairs*, welding standards allow some defects

Acceptance criteria:

✓ Workmanship levels
  • Are based on experience

✓ Engineering Critical Assessment (ECA) methods
  • Based on Fracture Mechanics and Plastic Collapse theories (stress based design)
  • Under development (strain based design)

✓ UGent approach
  • Curved wide plate test (stress based design)
  • Full scale tensile test

* Repair of rejected (“small”) defects can be harmful (undermatch weld/new anomalies)
Girth weld defect acceptance - 2/2

Flaw/defect acceptance criteria

Workmanship criteria
Compliance with known (API, CEN, ..) or new criteria
Yes
ACCEPTABLE

Engineering Critical Assessment (ECA)
Compliance with "ad-hoc" criteria
No
No
REPAIR or CUT OUT
Yes
Curved Wide Plate Testing

ACCEPTABLE
CWP and FST tensile testing

Full Scale Pipe Testing
(Effect of internal pressure)
Comparison of full-scale bend / CWP test results

CWP test provides conservative estimates
Tolerable flaw size for stress/strain based design

- Flaw size limits (via CWP / FST)
- Predicted (tolerable) dimensions (ECA)
  (EPRG or other methodologies)
- Acceptable dimensions (sizing error)
  Height and length!!
- Workmanship
  \((l = 25/50 \text{ mm} \times h = \text{variable})\)
- WM vs ECA limits: significant safety margin

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Workmanship codes – Facts 1/2

- Based on what can be seen on the film (length)
  - Are in use since 1938 (Pressure Vessels)
  - Go / no go acceptance levels (API 1st Ed. - 1953)

- Various requirements (API, BS, CSA, CEN...)
  - Toughness requirements ?
  - Strength mismatch (transverse / all-weld metal tension tests)
  - Specify/limit allowable length (planar flaws)

- High level of safety which is not known
  - Ensure safe (girth) welds
  - WMS are conservative

- Developed for manual welding

WMS criteria for GMAW welds?
UGent - CWP data base (X60/X70 results)

Data base has been used to develop the EPRG guidelines.

Remote strain at failure, $e$ (%)

Defect area ratio $d_r$ ($= l_h/st$)

- Remote strain $= 0.50 \%$
- Overmatched welds
- Undermatched welds
- Plain pipe

Y/Tpipe $\leq 0.90$
CVN $\geq 30/40 \, J$
and / or
CTOD $\geq 0/10/0.15 \, mm$

50 x 3 mm²

Scatter?
Workmanship codes – Facts 2/2

- **Issues**
  - WMS have no relationship to applied stress (Max ? – Hydro test / MAOP)
  - WMS don’t refer to pipe grade
  - WMS do not incorporate effect of the thickness effect
  - WMS assume matching welds

- **Progress in welding technology**
  - Manual versus mechanized welding
  - Type of flaws: Non-planar (SMAW/FCAW) versus planar flaws (GMAW/SAW)

- **Progress in NDE**
  - Past: X-ray inspection (film)
  - Today: Automated Ultrasonic Inspection (AUT)
Fitness-for-purpose (ECA) codes (stress based design)

- Require information on:
  - Applied strain (stress)
  - Strength, weld strength mismatch and toughness
  - Defect length, height and depth (location)
  - Can NDE procedure detect the significant flaws?

- Assessment methodology (failure conditions)
  - Brittle fracture (low toughness)
  - Plastic collapse
  - Different approaches are available

- Determine tolerable (≠ critical) defect dimensions
Input parameters - Stress vs Strain Based Design

STRESS based design

STANDARD INPUT FACTORS
- Applied (remote) stress
- Toughness
- Defect size (length, height, location)
- Tensile properties

Specified values

Variability of input parameters

Supplementary input parameters

STRAIN based design

- Applied / remote strain (STRAIN DEMAND)
- Actual Pipe and Weld Metal Tensile Properties
- Full stress-strain curves (Uniform elongation capacity)
- Y/T ratio pipe and weld metal
- Level of weld strength mismatch
- Tearing resistance
- Internal pressure
- Wall thickness variations, etc.,
Flaw acceptance limit for strain based design?

Flaw acceptance limit for high plastic strains

TIER 1
Workmanship Criteria

TIER 2
Fitness-for-Purpose (ECA)

Validate their applicability for Strain-based designs

Use existing (API / CEN) criteria

Methodology?

Under development
Options:

Traditional pipe/weld qualification procedures provide insufficient information.

Numerical / FAD

Experimental
Failure conditions (stress based design)

- Brittle fracture
  - Toughness = defect size x applied stress
    - Brittle fracture is possible if CVN < 27 J
    - EPRG excludes BF if CVN > 30/40 J (min./avg.)
    - CTOD requirements? – Can vary from 0.05 up to 0.25 mm

- Plastic collapse
  - Applied stress = Flow stress x Defect size
    - Toughness threshold: 30 J / 40 J at design temperature (EPRG)
    - Flow stress = f(Y/T) becomes a key variable
    - Overmatching is a beneficial factor !!!!

- FAD diagram (combines BF and PC assessments)
  - API, CSA, BS, ...
Major ECA (pipeline specific) codes

■ Semi-empirical (numerical + limited validation)
  ✓ API 1104 Appendix A
  ✓ CSA Z 184 Appendix K (and J)
  ✓ Others: (BS7910, DnV RP F101, …..)
  ✓ FAD diagram / various options (Level 1, Level 2, … )

■ Empirical
  ✓ EPRG Tier 2 guidelines – 2010 / AS 2805 / CEN 12732

■ Each of these codes have **different** requirements as to
  ✓ Applicability
  ✓ Weld procedure qualification (property requirements)
  ✓ Mechanical and toughness properties of weld and pipe material
  ✓ Inspection (sizing error)

■ Predictions are **not consistent** (different approach / provisions)
ECA vs workmanship

- EPRG philosophy towards ECA based defect (anomalies) acceptance limits:
  - Unless pipe and weld materials are fully documented, defect acceptance should be based on workmanship standards such as API 1104 or EPRG-Tier 1.
  - ECA defect size limits should only be used when defects exceeding the workmanship limit are identified during a post construction audit.
  - ECA based defect size limits are not intended to be used to justify poor workmanship.
  - The presence of a larger defect, or many defects in a single weld, indicates poor quality control of the welding, and remedial action to maintain good workmanship is required.

- However, EPRG:
  - Accepts that defects exceeding workmanship levels do not necessarily affect the fitness-for-purpose of a girth weld.
## API vs EPRG

### API 1104 Appendix A Option 1 (2007) vs EPRG - Tier 2 (2009)

#### PIPE PROPERTIES
- **Pipe grade**
  - Not mentioned
- **Y/T ratio**
  - 0.95 / unlimited
- **Pipe grade**
  - up to L555 (X80)
- **Y/T ratio**
  - 0.90

#### PIPE DIMENSIONS
- **Pipe diameter**
  - D ≥ 30 inch
- **Wall thickness t**
  - 7.5 < t ≤ 25.4 mm

#### APPLIED STRESS / STRAIN
- **User input (max. 0.5 %)**
  - Stress or strain
- **0.5 % (default value)**
  - Strain

#### EXPERIMENTAL VALIDATION
- **Full-scale bend tests**
  - 69
- **Curved wide plate tests**
  - 31 (Grade X60 pipe)
  - 485 (upto Grade X80)

#### TOUGHNESS REQUIREMENTS
- **CVN (Min/Ave.) at minimum design temp.**
  - 30/40 J
  - Close to weld crown
  - 30/40 J
  - Root region
- **Sampling position**
  - Close to weld crown
  - Root region
- **Shear area**
  - 50%
  - No requirement
- **CTOD - Bx2B (Min) at minimum design temp.**
  - 0.10 or 0.25 mm
  - Not required

#### WELD METAL REQUIREMENTS
- **Cross tensile**
  - Yes
  - Yes
- **Reinforcement in place**
  - TS > SMTS Pipe
  - Yes
- **Test requirement**
  - TS > SMTS Pipe
  - Yes
- **All weld metal tensile**
  - Not specified
  - SMYS + 100 MPa
- **YS matching requirement**
  - No gross undermatching

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**Plastic collapse solution needs to be revised!**
Toughness testing

- **API 1104 and CSA Z186**
  - Toughness obtained from **CTOD** testing

- **DnV RP F101**
  - Toughness obtained from **CTOD / SENT** testing

- **EPRG**
  - Toughness obtained from **Charpy V** testing

CVN test can be used to ensure failure by plastic collapse
Toughness

- CTOD testing can produce disquieting low results, suggesting that only very small flaws would be acceptable

- API / CSA assumes that CTOD is the key variable in fitness-for-purpose based girth weld defect acceptance;

- If, the EPRG (30/40 J) toughness requirement is met, EPRG concludes that:

  ✓ Y/T ratio (strain hardening capacity) and,
  ✓ weld strength mismatch

  have a greater effect on the allowable defect size than CTOD toughness has.
EPRG Guidelines 2001/2010 - $\frac{Y}{T} \leq 0.90$

Remote stress < YS  
Remote stress > YS

<table>
<thead>
<tr>
<th>Pipe Grade (SMYS)</th>
<th>Flaw height</th>
<th>Allowable flaw length per 300 mm (12”) length of weld</th>
<th>Predicted lengths</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\leq X80$ + 120 MPa</td>
<td>$h$ (mm)</td>
<td>$\leq 3$</td>
<td>$l$ (mm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\leq 4$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\leq 5$</td>
<td></td>
</tr>
<tr>
<td>$&gt; X80$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Wall thickness range*: 7 mm $\leq t \leq 30$ mm

* Wall thickness, $t > 8$ mm for $h = 4$ mm and $t > 10$ mm for $h = 5$ mm

Predicted length formula: \[ l = \frac{300 t (1-R)}{h (1+R)} \]

Remote yielding: Remote stress > YS

Remote stress < YS

Remote stress > YS

Remote stress > YS

Remote stress > YS

Remote stress > YS
API vs EPRG

"Denys" collapse model
(W = 300)

API 1104 collapse solution level 1
(CTOD > 0.25 mm)

API 1104 collapse solution level 1
(CTOD > 0.10 mm)

Without length correction

D_t = 40" x 0.7"
D/t = 57
Y/T = 0.90 (P_f = 0.95)

WMS

EPRG limits
CVN = 30/40 J
EPRG vs API 1104 (with and without length correction)

**API 1104**

Y/T = 0,90

(CTOD > 0.10 mm)

**API 1104**

Y/T = 0,90

(CTOD > 0.25 mm)

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**Denys - 300 mm collapse**

**EPRG 2009**

**API 2008 - CTOD = 0,10 mm - NC**

**With length correction**

**API 2008 - CTOD = 0.25 mm - NC**

**With length correction**

**Dt = 40” x 0,62” (15.7 mm)**

D/t = 57

Y/T = 0.90

**WMS**

**CVN = 30/40 J**
Tensile properties ("X80") – Specimen geometry effects

Pipe Wall: 18 mm

Engineering stress (MPa)

Engineering strain (%)

YS\textsubscript{max} = 617

YS\textsubscript{min} = 579

Luders plateau

Representative stress-strain curve ??
Effect strain hardening (Y/T ratio) – Can be an issue!!

Surface breaking flaw: 75 mm x 3 mm

- Net Section Yielding: $Y/T = 0.92$
- Gross Section Yielding: $Y/T = 0.86$

Low Y/T ratio steels perform better
Weld Strength Requirements – Strain based design

Matching / Over-matching is a minimum requirement!
Factors affecting level of mismatch

Incorporate effect of:
- Sampling position
- Specimen size
- Sampling direction (trans vs axial)

BASE Metal Yield Strength

WELD Metal Yield Strength

Level of Weld Metal Yield Strength Mismatch

VARIABILITY: Cannot be avoided
Weld strength mismatch (Stress BD)

Pipe - SMYS+120/150 MPa
EPRG - MYS+100 MPa

Pipe metal Yield strength distribution (Hoop direction)
WM Yield strength distribution (EPRG TIER 2 req.)
Tail Overlap EPRG Tier 2 (Undermatching)

SMYS (X80) + 120 MPa

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Weld metal yield strength requirement (Strain BD)

Plate/pipe and weld metal yield strength distributions

- 1.18 SMYS
- 34% on SMYS
- 10% on Y_max

Tentative
All weld metal testing

- Specimen geometry
- Cross section
- Sampling position
  - Low/high strength root
  - High/low strength fill
Effect of sampling on YS and YS/TS ratio

Verify sampling position!
Variation of weld metal tensile properties - 1

- SMAW weld
- Pipe: X70

General average: 536 MPa
Flaw treatment

WELD FLAW(S)

VERIFY

FLAW dimensions

Flaw Treatment

Interaction (Multiple flaws)

Re-categorisation (Near surface breaking flaws)

Type

Surface breaking

Embedded

Depth

Length

Height

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Surface breaking vs embedded defects

Inspection accuracy
- Focus inspection on root flaws
- Height and LENGTH inspection errors
- The inspection error for embedded defects is a minor problem
- Flaw treatment (re-categorization)

Suggestion
- Eliminate ALL workmanship root flaws
- This measure is very effective if plastic straining capacity of flawed welds is a design requirement
Defect sizing – defect geometry effect

Weld defects

Surface breaking defect

"Salami"

Low temperature tensile test

Buried defect of variable height

Verification of defect dimensions:
Macro sectioning (salami technique) vs low temperature tensile testing
Final UGent recommendations

- Level 1: Workmanship criteria
- Level 2: Pipe yielding (< 0.5 % strain)
  - EPRG criteria
- Level 3: Full ECA
  - Are input parameters available?
  - Which methodology (API, BS, CSA,...) is best?
- Level 4: Model (wide) plate testing
  - Sub-standard welds
  - Non-elastic design

Pipeline industry does not have yet generally accepted guidelines for strain based designs