Effects of High-Low Misalignment on Girth Weld Integrity

PRCI Research Update
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Overview of this Presentation

- Background and incentives
- Objectives and work scope
- Work completed so far
  - Experimental tests
  - Numerical analysis
- Observations from the work completed
- Recommendations
- Concluding remarks / implementation issues
Background and Incentives

- Some newly constructed pipelines in the US experienced
  - Hydrostatic failures
  - In-service leaks soon after lines were put in service
- PHMSA issued ADB-10-03 (Mar 18, 2010)
  - Girth weld quality issues were identified.
  - Some of the contributing factors:
    - Improper transitioning,
    - Misalignment,
    - Improper welding practice and/or not following qualified welding procedure, and
    - Hydrogen-assisted cracking and high stress.
- Misalignment is not new in pipelines
  - Girth welds with high degrees of misalignment have provided satisfactory service
- Questions
  - Why some fail and others are OK?
  - Is the current practice (including codes and standards) adequate?

Possible negative impact of high-low misalignment

- Difficulty in making high-quality root pass
- Local stress concentration at the geometric discontinuities
  - May contribute to the formation of hydrogen cracks
- Gross stress concentration due to reduced load-bearing cross-sectional area
- Increased difficulty in interpreting NDT results?
- Contributors to the performance of welds with misalignment
  - Weld transition profile
  - Ratio of misalignment over pipe wall thickness
  - Weld strength mismatch
  - Existence of indications/flaws
Background and Incentives

- Current language in API 1104
  - "Misalignment should be limited to 1/8". Misalignment greater than 1/8" is permitted when the misalignment is evenly distributed around the circumference."

- Deficiency in the code language
  - The impact of the level of misalignment is inadequately addressed
    - e.g., the same 1/8" misalignment can have different impact on 3/8" vs. ¾" WT welds.
  - Does not address the impact of
    - Weld profile
    - Weld strength mismatch

- How is misalignment managed in the fields?
  - More on implementation issue later

Objectives and Work Scope of PRCI Project

- Objectives
  - Better understanding of the impact of high-low misalignment
  - Provide practical guidelines on the management of misalignment

- This work does not address
  - Reduction of misalignment through pipe specifications
  - Use of clamps to deform pipes to reduce misalignment
  - Rotation of pipes (issues related to practicality, safety, etc.)
  - Welding practice aimed at reducing the possibility of HAC

- This work addresses consequence of misalignment
  - Divided into two parts
    - Nominally defect-free welds → workmanship criteria
    - Weld with planar flaws → ECA criteria
Overall Approach

- Fabricate welds
- Test welds
  - Cross-weld tensile specimens of welds with misalignment
  - Tests to characterize basic material properties
- Finite element analysis
  - Sensitivity analysis was conducted to determine factors that have major impact on load capacity
  - Refined analysis to determine the quantitative impact of major influencing factors
  - Correlation of small-scale specimen with full-scale pipe
- Recommendations

Test Materials

- Mechanized GMAW weld
  - Made under the direction of TransCanada at CRC-Evans
  - UOE pipe
  - 36" OD
  - 0.372" WT
  - Grade X70
  - Target maximum misalignment of 3.2 mm
  - Welding wire: ER70S-6
- SMAW weld
  - Made under the direction of Spectra Energy
  - ERW pipe
  - 24" OD
  - 0.500" WT
  - Grade X70
  - Target maximum misalignment up to 6.4 mm (50% WT) if possible
  - Welding rod: E8045-P2 H4R
High-Low Misalignment around the Circumference

- Maximum high-low misalignment is 2.1 and 5.0 mm for the 36 inch and 24 inch pipe, respectively.

The high-low misalignment shown is magnified by a factor of 20.

Test Setup

- Upper Crosshead
- Support Column
- Load Cell
- Upper Grip
- Lower Grip
- Hydraulic Actuator
- Laser Extensometer
Deformation Pattern of Specimens from 36” Pipe

- Necking of a specimen during and after test

Response of Specimens from 36” Pipe

- Maximum stress is essentially an indication of the maximum tensile strength of the pipe.
- The UTS variation is about 5%.
Deformation Pattern of Specimens from 24" Pipe

- At small misalignment (specimen Nos. 1 and 12), base metal necking was the final failure mode, although large plastic deformation occurred in the weld region at the point.

Specimen No. 1
Specimen No. 12 is similar

Response of Specimens from 24" Pipe

- Other than specimen Nos. 1 and 12 which “failed” by necking in the base metal, all other specimens “failed” by shearing through the welds.
Iso-Load-Capacity Curves from FEA

- Load capacity (LC) factor
  - $\text{LC} = \text{LC of welds with misalignment} / \text{LC of welds with zero misalignment}$
- Have conservative assumption about the weld transition profile

![Load Capacity Curves](image)

Effects of the Circumferential Extent of Misalignment

- Load capacity decreases with increasing extent of misalignment
- Even with 40% normalized misalignment, the load capacity reduction is only 6.5-7.5% when the local misalignment extends to 12.5% circumference.

![Misalignment Curves](image)
Measured Misalignment

- OD=48", WT=15.9mm, spiral pipe
- The magnitude if the misalignment is magnified by X20.
- Misalignment is local.

Response of Specimens from 24" Pipe

- Case-specific analysis: using the profiles of current test welds
- Generic analysis: using generic (conservative) weld profiles. These profiles are used in the recommendation of misalignment limits.
Main Observations

- **GMAW welds**
  - High-low misalignment between 0.0 and 2.1 mm (misalignment / WT = 0.00-0.22)
  - All “failures” occurred in the base metal.
  - The “UTS” variation of approximately 5% was observed.
  - There is a dependence UTS on o’clock position.
  - Weld strength mismatch ratio = ~1.05 (5% overmatching).

- **SMAW welds**
  - High-low misalignment between 0.0 and 5.0 mm (misalignment / WT = 0.00-0.39)
  - Weld strength mismatch ratio = 0.95 (5% undermatching)
  - There is a load capacity reduction of 9.5% for misalignment up to 39% of wall thickness.

- For SMAW welds, the iso-load capacity relation of CRES models captures the highest load capacity reduction.

Guidelines on Misalignment

- **Factors affecting the performance of girth welds with misalignment**
  - Weld profile
  - Ratio of misalignment / pipe WT
  - Weld strength mismatch
  - Applied longitudinal stress
  - Indications/flaws

- **Challenges**
  - No one-size-fits-all criteria on misalignment limit.
  - Other factors have influence on the tolerance of misalignment.

- **Approaches adopted** – use reasonably conservative estimates
  - Weld strength mismatch ratio = 0.90 (10% undermatch)
  - Applied stress = 70-90% SMYS (consistent with ASME B31 allowable stress)
Use of Iso-Load-Capacity Factor

- Relative allowable misalignment is given as a function of mismatch and applied stress level.
- Weld profile is handled through the requirements of weld dimensions.

Welds with Smooth ID Transition (with Back Welds)

- Applied stress = 90% SMYS, allowable misalignment is the larger of
  - 1/3 of pipe wall
  - 1/8”
- Applied stress = 80% SMYS, allowable misalignment is the larger of
  - 1/2 of pipe wall
  - 1/8”

\[ W_{OD} \geq 1.15 \times t_p + 1/8” \]
\[ W_{ID} \geq h_{MS} + 1/8” \]
Welds without back welds

- Applied stress = 90% SMYS, allowable misalignment is the larger of
  - 15% of pipe wall
  - 1/8"
- Applied stress = 80% SMYS, allowable misalignment is the larger of
  - 25% of pipe wall
  - 1/8"

- These are upper limits when cross-weld strength is considered

- Other factors may dictate smaller allowance
  - Feasibility of welding
  - Quality control of field welds
  - Local stress concentration
    - HAC
    - Fatigue

Concluding Remarks

- High levels of misalignment can be tolerated in pipeline girth welds with minimal negative impact on their integrity if
  - (1) welds can be made without "large" planar flaws and
  - (2) welds have sufficient toughness and ductility to avoid the initiation of brittle fracture.
    - The second condition is generally met with modern welding practice.

- The misalignment management should therefore focus on
  - minimizing the likelihood of having planar flaws
  - detecting and repairing such flaws,
  - having smooth weld profiles with sufficient width
  - Having overly-undermatched weld metal

- High levels of misalignment, by themselves, are not an integrity concern.
  - static loading
  - Fatigue is a separate topic that is not covered in this project.
Concluding Remarks

- Management of misalignment requires collective across-department actions.
  - Have a strategy at the start of a project. Consider all contributing factors.
- Thoughts about API 5L and 1104 joint task group
  - Limiting pipe dimensional tolerance alone is not a practical solution to the possible negative impact of misalignment.
  - Scientifically justifiable one-size-fits-all misalignment limits don’t exist.
- Generally-accepted procedures for the measurement and documentation of misalignment in the fields don’t exist.
- Process of mitigation is not clear.
  - What to do if misalignment limit is exceeded? Could you weld with stronger consumable?

Special caution
- Very-thin-walled pipes