A Comprehensive Update in the Evaluation of Pipeline Weld Defects

Project Background

Yong-Yi Wang

Engineering Mechanics Corporation of Columbus

614-459-3200 ext. 230

ywang@emc-sq.com

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Overview

- Benefits of alternative acceptance criteria
- How did the project get started? The procedural issues
- Recent work funded by PRCI to facilitate the revision of alternative acceptance criteria
- Why this work is necessary?
  - Historical evidence
  - New issues faced by the industry
  - World wide development in ECA (Engineering Critical Assessment)

Alternative Acceptance Criteria

- **The alternative acceptance criteria are relative to the traditional workmanship acceptance criteria.**
- **The alternative acceptance criteria have their fundamental basis on fracture mechanics.**
- **The process of developing alternative acceptance criteria is often referred to as ECA (*Engineering critical assessment)* or FFS (*fitness for service)* assessment.**
- **The philosophy of ECA is to set defect acceptance level based on the need of a particular job.**

Why ECA?

- Effective use of your resources
- Consistent safety level
- Be able to work with continuously evolving material, welding, construction, and loading conditions
- Work effectively with AUT and mechanized welding
- Cut down unnecessary repairs
- ECA methodology can be an effective tool in assessing the weld integrity of existing facilities therefore enables prioritizing repair and maintenance schedule.
- The focus of this work is alternative acceptance criteria for new constructions.

How Did this Project Get Started?

- DOT Solicitation
  - DOT requested white papers on Improved Materials Performance and Other Pipeline Safety Improvements. The white papers were due on January 31, 2003.
  - Emc^2 responded to the solicitation with support from PRCI.
  - The white paper was selected by DOT. A full proposal was submitted.
  - The full proposal was reviewed by DOT and the project was funded.
- This project is a convergence of interests of DOT, PRCI, and the primary researcher.

> **Comments**: Mr. Jim Merritt of OPS noted at the meeting that the proposal was reviewed and the funding was recommended by representatives of several government agencies and industries beyond the staff of DOT.

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PRCI Interests in Alternative Defect Acceptance Criteria

- PRCI has been developing girth weld defect assessment procedures for its member companies for many years.
- In 2000 a project was commissioned to review API 1104 Appendix A and provide technical basis for its revision.
- The project was initiated due to the recognition by PRCI members, some were also on the API 1104 committee,
  - that significant advances have been made in understanding weld behavior since the adoption of Appendix A.
  - That those advances have not been incorporated in Appendix A.

PRCI Interests in Alternative Defect Acceptance Criteria (continued)

- The project was expanded later to include recommendations to the revision of CSA Z662 Appendix K.
- The results of the project have been presented at API 1104 committee meetings.
- A summary paper of the project was presented at IPC 2002 in Calgary. The paper is available in public domain.
- CSA committee has since adopted the recommended plastic collapse criterion in its latest revision.

Why is the Work Necessary?

- Historical perspective
- New materials and processes
- Other developments around the world

Development of API 1104 Appendix A

- Appendix A should be technically referred to as “the Appendix” to API 1104 until the recent addition of Appendix B to API 1104.
- We will refer it as “Appendix A” throughout this meeting.
- The Appendix A was first published by API in 1983 in the Sixteenth Edition of API 1104.
- DOT did not adopt the Appendix A initially.

Significant Historical Work Related to Appendix A

- **API funded work:**
  - **University of Kansas**
  - **The Welding Institute of Canada (WIC)**
- **DOT funded work**
  - **Lehigh University**
  - **National Bureau of Standard (NBS)**
  - **Arthur D. Little, Inc. (ADL)**
- **PRCI/AGA funded Work**
  - **Battelle**

Technology Basis at the Time of Initial Publication

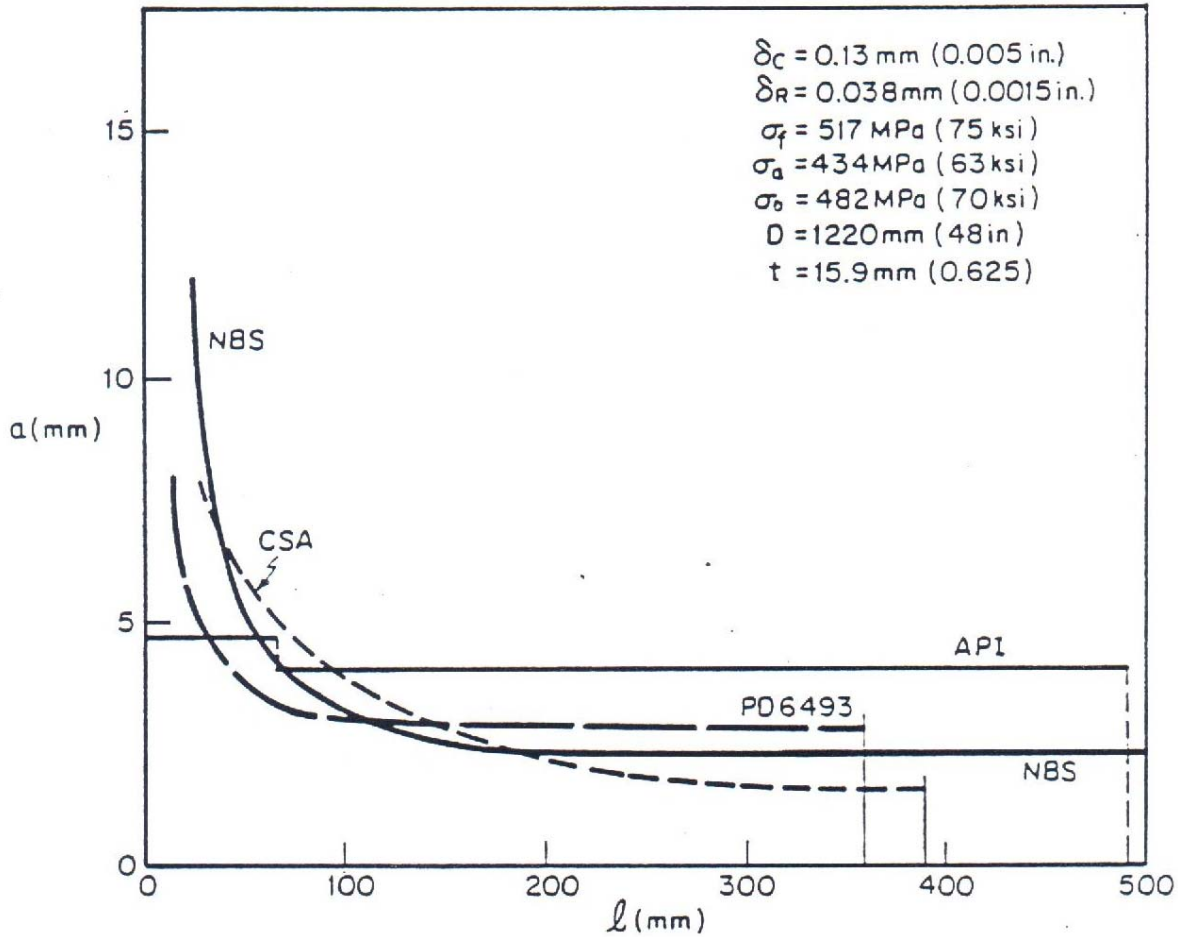
- CSA Z184 (predecessor of CSA Z662) had a draft alternative acceptance criteria in 1984, i.e., Appendix K.
- A large number of full-scale tests were done in support of the CSA alternative acceptance criteria.
- Both Appendix A and Appendix K are partially based on PD 6493:1980.
- A key component of PD 6493:1980 is the CTOD Design Curve, which was published in 1971 by Burdekin and Dawes.
- The idea of CTOD design curve originate from Wells work which was published in 1963.
- CTOD toughness testing was performed by TWI in late 1960's in support of the North Sea development.

Fracture Mechanics in Pipeline Construction

- **The need for an alternative acceptance criterion arose in the construction of the Trans-Alaska Pipeline.**
  - **Defects were not identified in the initial radiography examination.**
  - **Non-compliant defects were found in later audits after the pipes had been backfilled.**
  - **A waiver was filed with DOT based on fracture mechanics principles and environmental justifications.**
  - **The waiver was granted based on extensive review and testing led by NBS and a blue ribbon team of experts.**
- **The decision document concluded that "Fracture mechanics analysis is acceptable as a basis for granting exemptions from existing standards in appropriate circumstances, if such analysis produces a convincing and conservative estimate of structure integrity."**

Comparison with other Codes in ADL Work

- **The allowable defect length of 0.4*D* (*D* being pipe diameter) per Appendix A is greater than those of all other codes.**

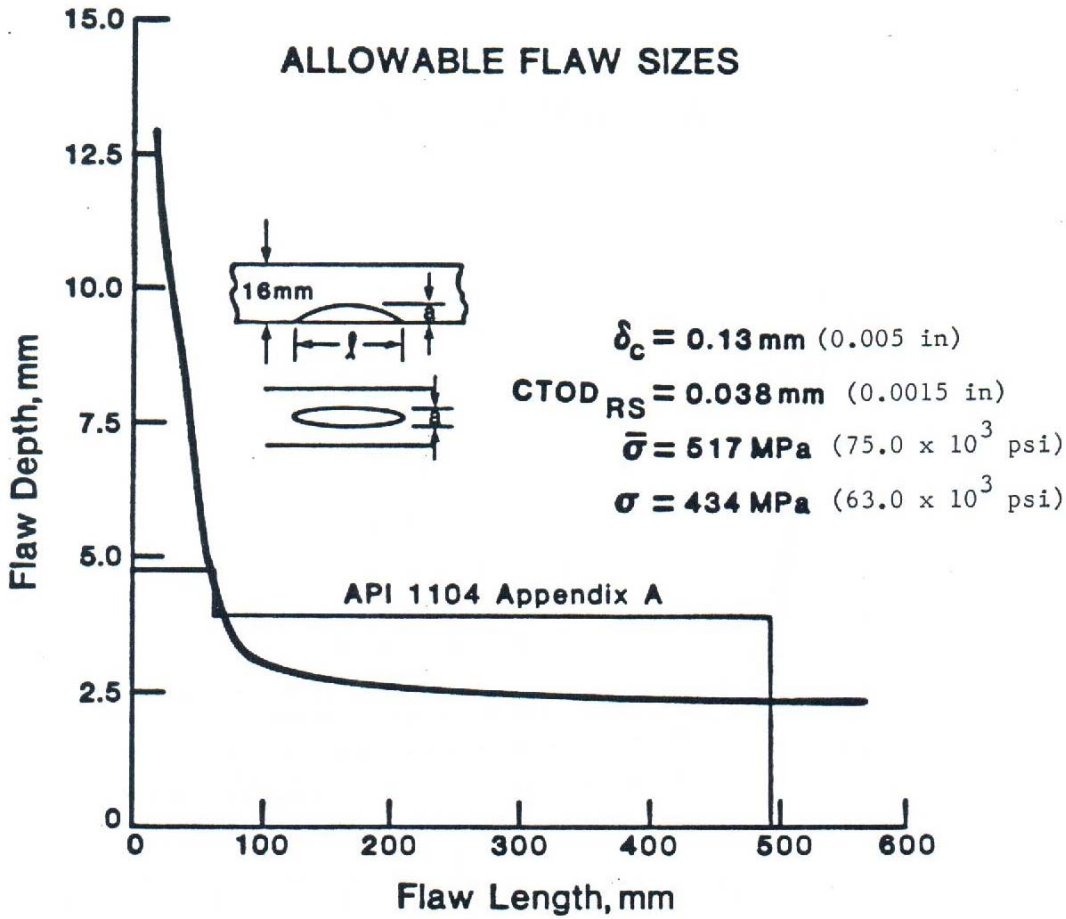


Conclusion from ADL Work

- **"We recommend that API 1104 Appendix A be altered in two areas prior to usage as a girth weld defect tolerance standard for pipeline service conditions. First, it should be made consistent with the base standard on the topic of allowable longitudinal pipeline stresses. In addition, the standard should be altered (or new data provided) to address the apparent lack of conservatism in its application to the long flaw problem. Possible approaches for altering the standard in this area include, but not limited to, further restriction on allowable defect length, inclusion of a plastic collapse limit, and/or inclusion of a crack geometry correction to the CTOD Design curve."**

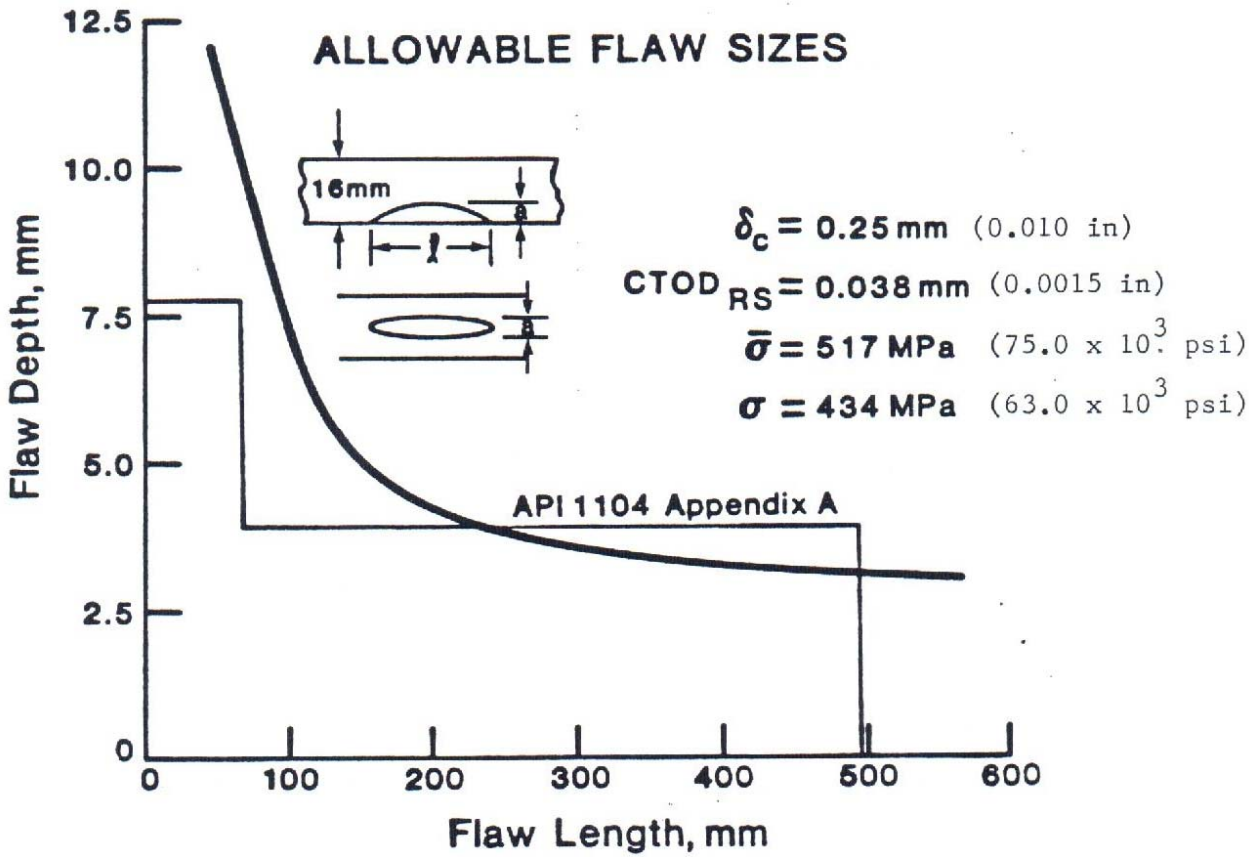
Comparison with NBS Criterion

- NBS allowable flaw size is smaller than that of Appendix A.



Comparison with NBS Criteria (continued)

- Even at CTOD=0.010 inch, the NBS allowable flaw size is smaller than that of Appendix A.



Comparison with Other WIC Tests

- The final report by the University of Kansas cited 47 full-scale tests conducted jointly by the University of Waterloo and WIC.
- None of the tests strictly satisfied API 1104 Appendix condition on CTOD toughness.
- However there were a few tests with flaws close to largest allowable long flaw that failed at strain levels below the maximum allowable value of 0.5% in Appendix A.
- The material and flaw conditions were close to the required values that the test data suggested probability of non-conservatism for the long allowable defects in Appendix A.

Comparison with Other WIC Tests (Cont'd)

- The ADL study using the same test data concluded that
  - "Application of the Methodology 1, on which the standard is base, to the available data resulted in wide range of safety margins or failure strains and nonconservative predictions for allowable strains for some data points associated with long flaws."
- The "standard" here referred to Appendix A. The "Methodology 1 referred to the CTOD Design Curve.

CSA Appendix K Approach

- The full-scale tests by Glover, etc., found low safety margins for long defects in the original PD 6493:1980 method.
- Appendix K took the following action:
  - The allowable flaw length chart for the brittle fracture evaluation was modified from PD 6493:1980 to maintain consistent conservatism.
  - Plastic collapse criterion was added, in addition to the brittle fracture criterion.
- In contrast, the basis of the allowable defect length in Appendix A was not well documented.

Conclusion from Reviewing Historical Work

- **Questions have been raised by a number of research organizations on the conservatism of the long allowable defect length at the high end of the applicable strain range.**
- **At low to moderate strain levels (<0.25%), the long allowable defect length (0.4*D*) was justified for the materials at that time.**
- **When considered with other contributing factors, such as the constraint effect on fracture toughness and weld strength overmatch, the current Appendix A is probably safe. But the safety margin may not be as high as one might expect from a code, particularly at the high end of the applicable strain range.**
- **Due to the step change in allowable defect length, the safety margin can have very large variation for large diameter pipes.**

New Challenges

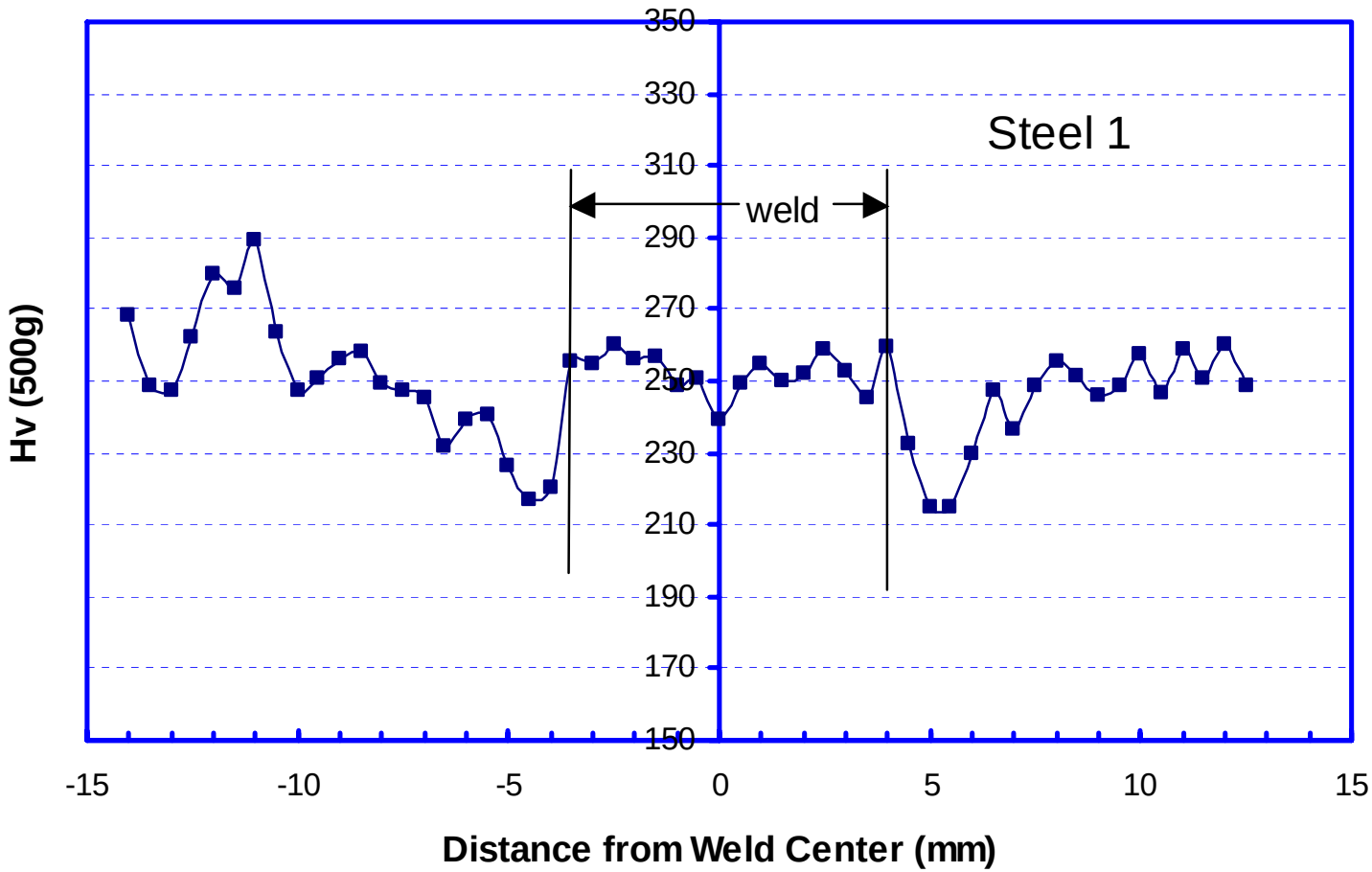
- Different materials from those of 20 years ago
  - Good toughness
  - High Y/T (Yield / UTS) ratio
  - Anisotropy (through thickness, circumferential vs. longitudinal)
  - Lean chemistry
  - Possibility of HAZ softening
- Welding and NDT
  - Mechanized welding
  - High productivity welding
  - AUT
  - Possibility of weld strength undermatching
- Service environment
  - Deep water offshore
  - Arctic area
- Justification to operate old pipelines

New X60 vs. Old X60

- **X60 material tested by Glover for API (draft report dated June 25, 1987)**
  - **Yield (at 0.5% strain) = 63.85 ksi, UTS = 89.9 ksi, *Y/T*=0.71**
- **A recent X60 pipe**
  - **Yield=74.9 ksi, UTS=84.5 ksi, *Y/T*=0.89**

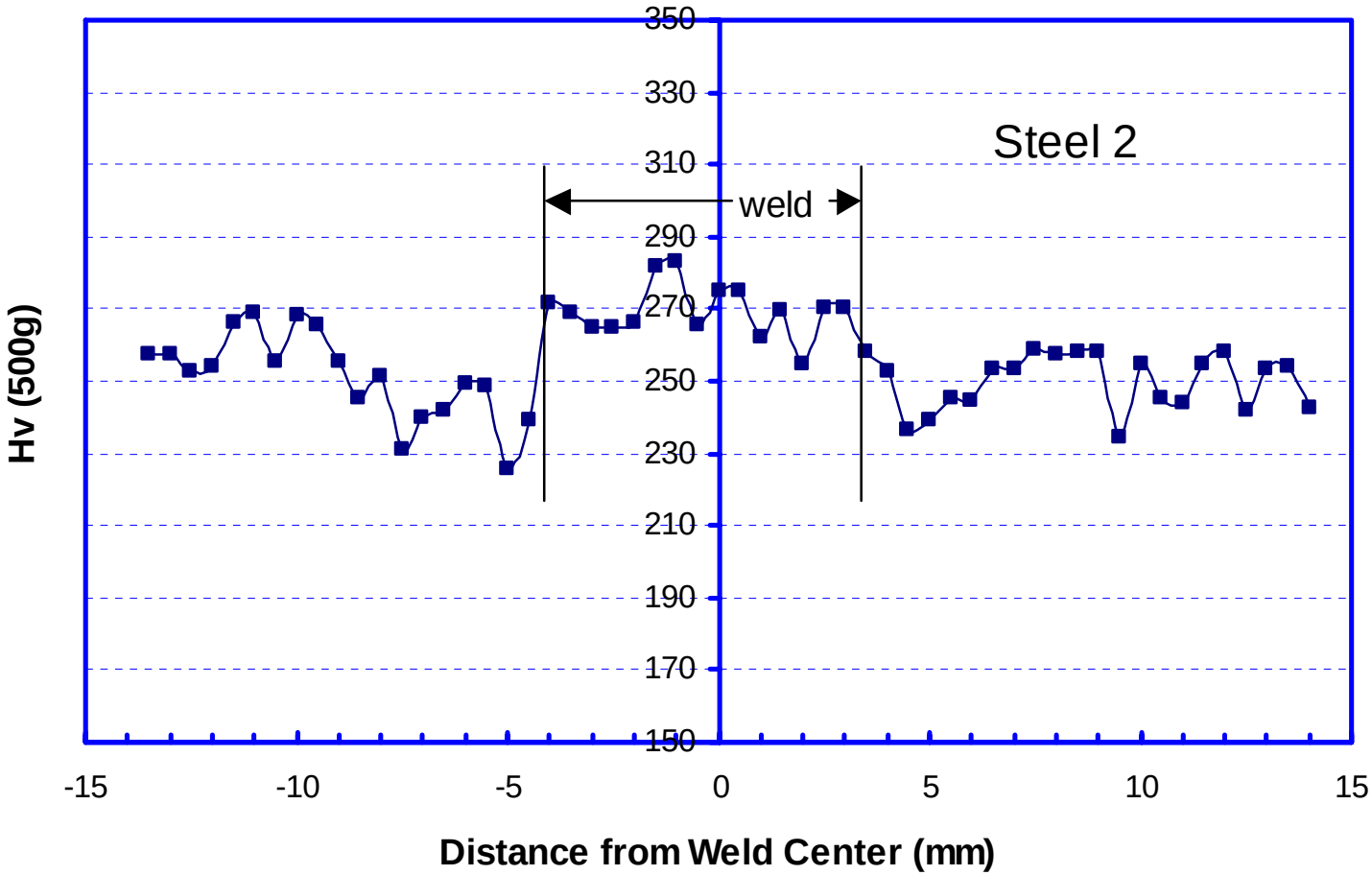
HAZ Softening

- A trial heat of X100. HAZ softening and some weld strength undermatching



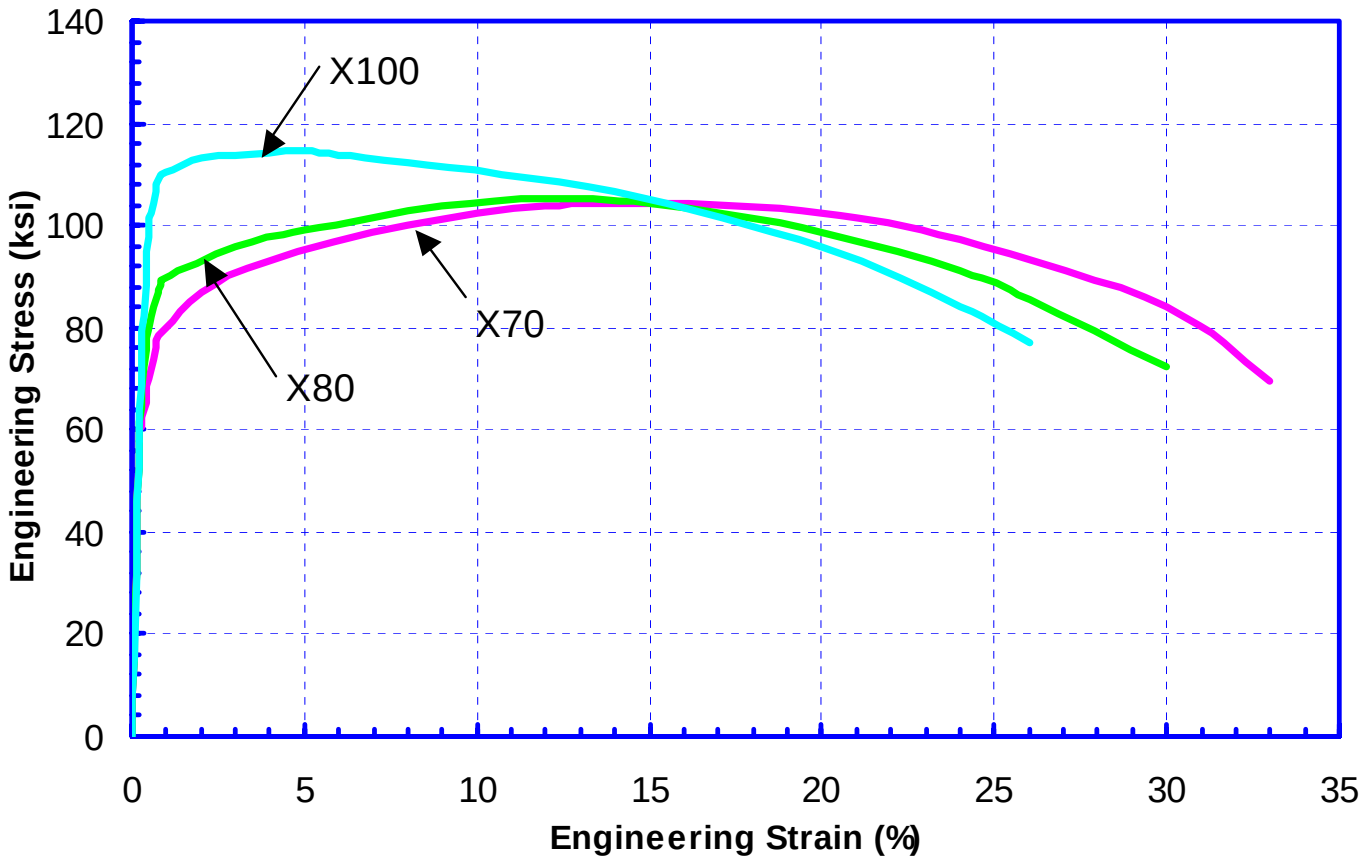
HAZ Softening (continued)

- A trial heat of X80



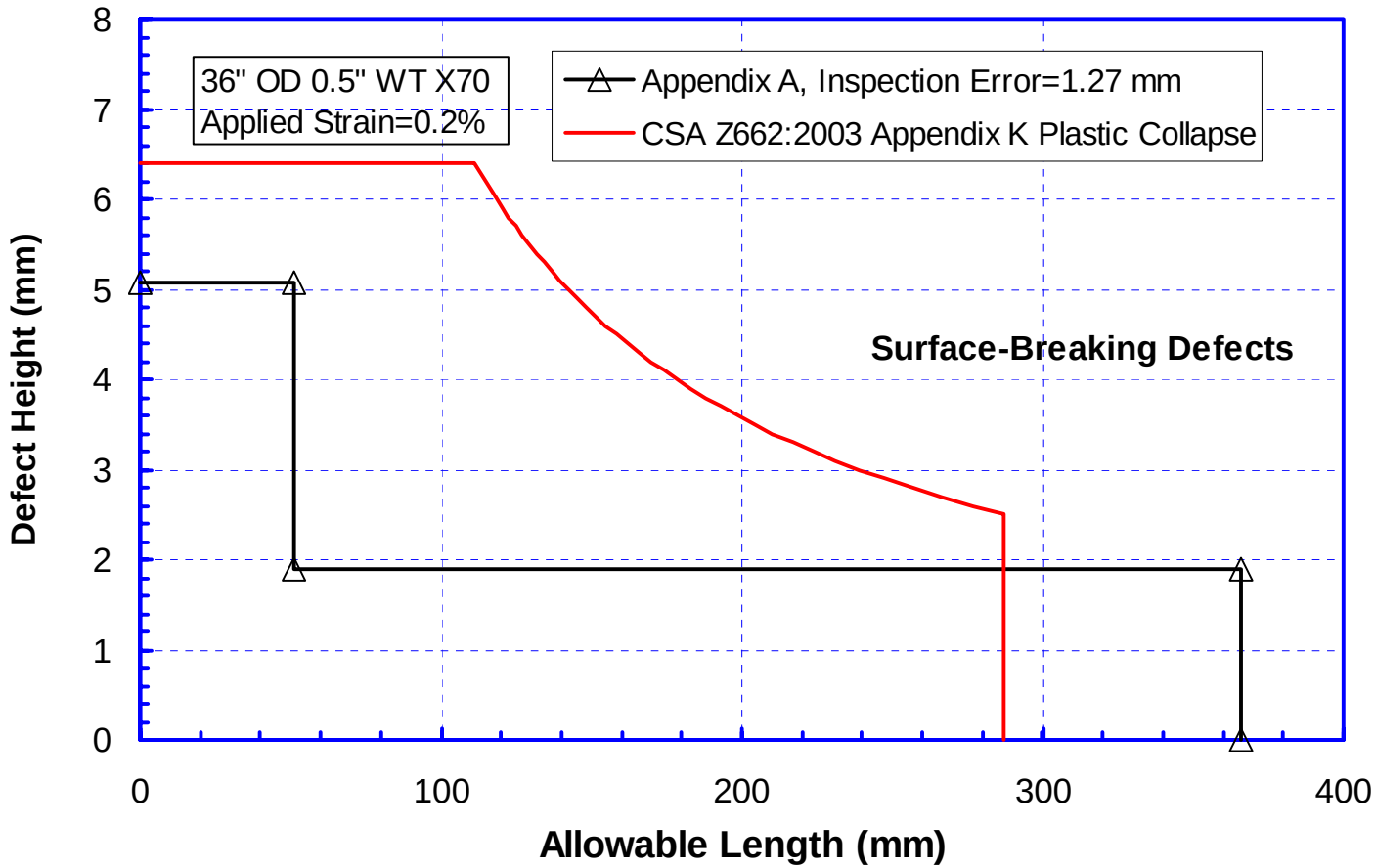
Tensile Behavior vs. Pipe Grade (Schematic)

- The tensile properties of X100 are quite different from X70 of the past.
- New X60-X70 materials can have high Y/T ratio and low uniform strain.



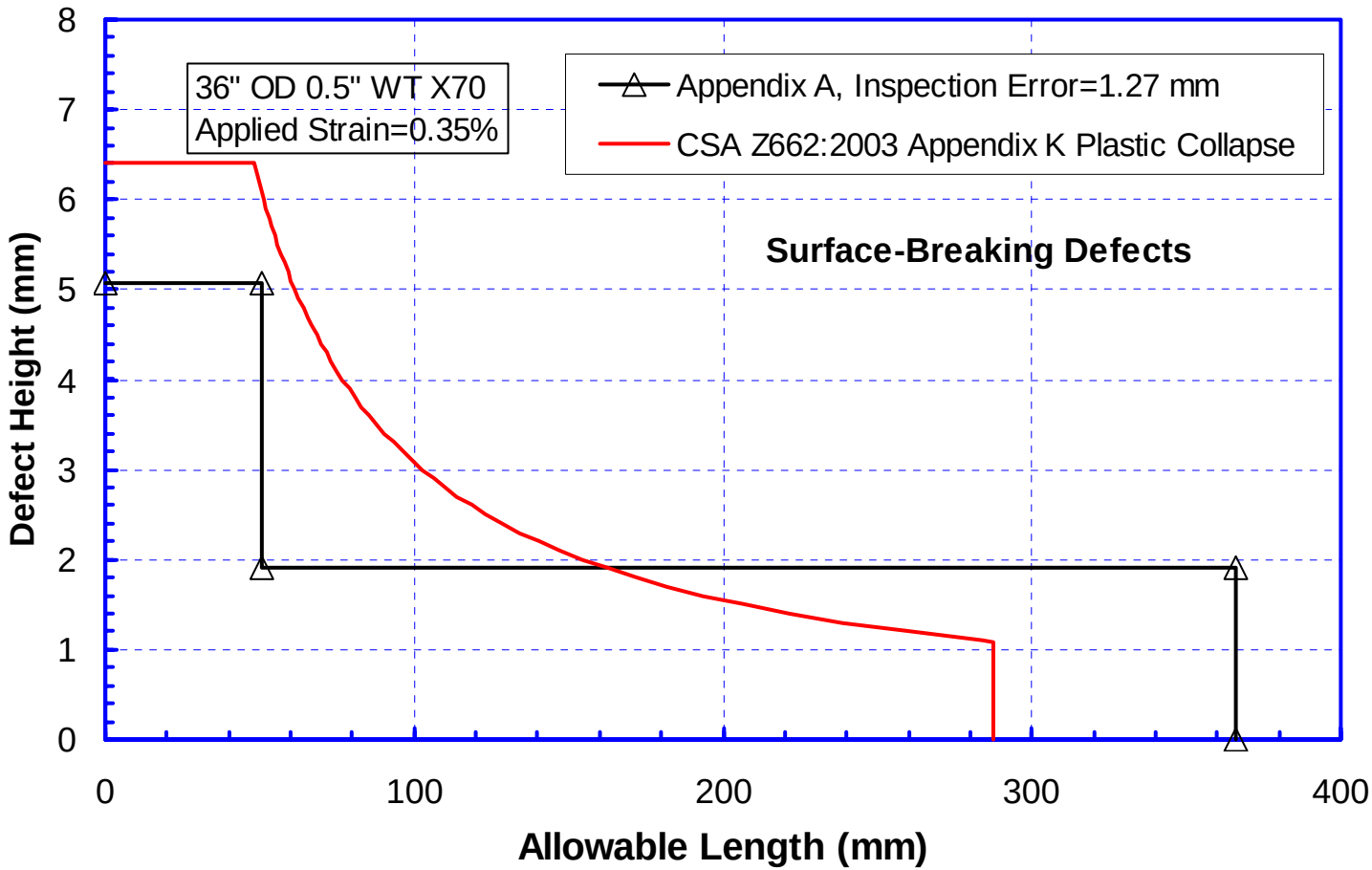
Appendix A and Plastic Collapse

- There is no plastic collapse criterion in Appendix A.
- <u>The CSA Z662:2003's plastic collapse criterion has a safety factor of 2 on defect length. This safety factor is consistent with some historical codes.</u>



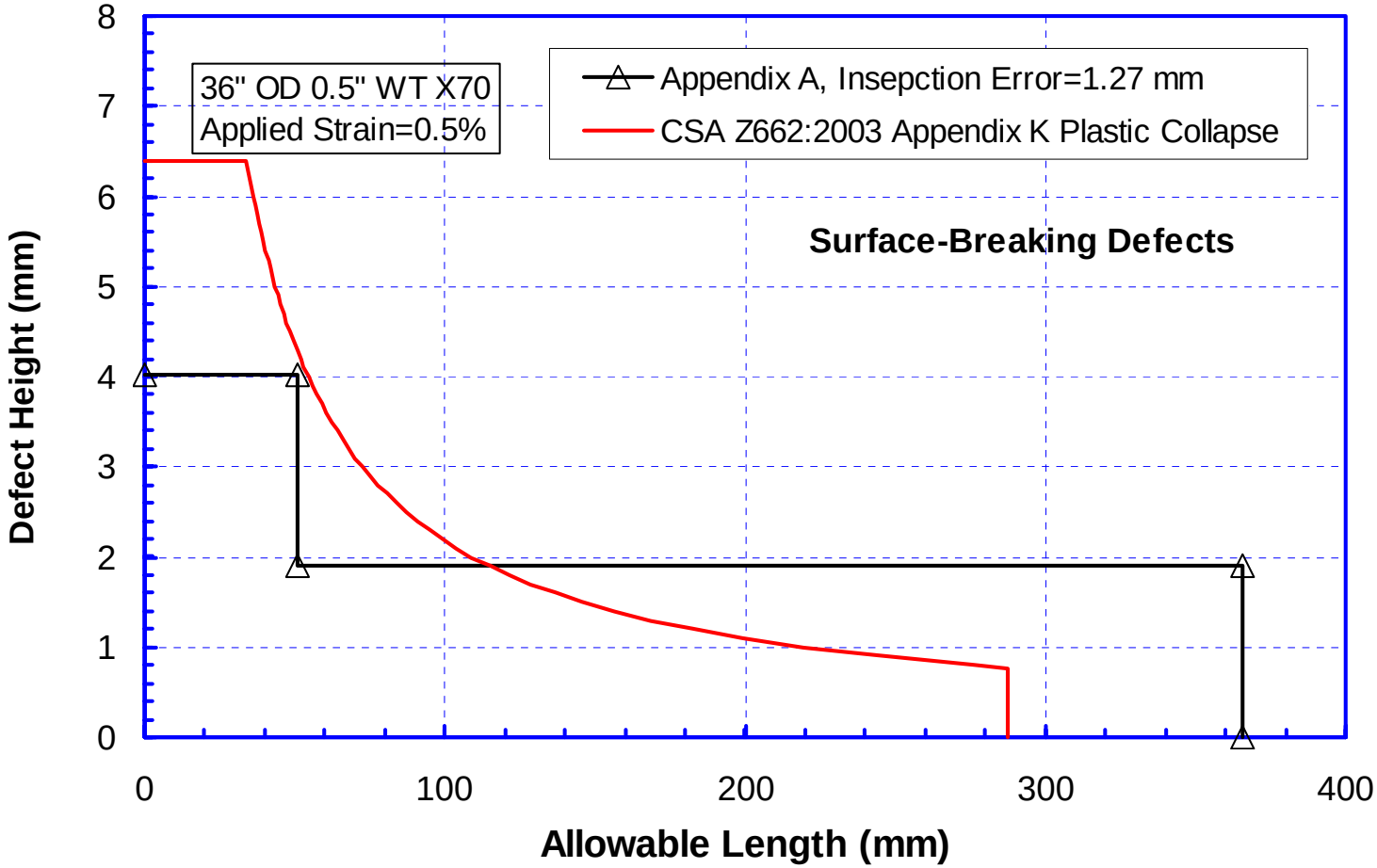
Appendix A and Plastic Collapse (Cont'd)

- At higher applied strain of 0.35%. There is a safety factor of 2 on defect length in the CSA Z662:2003's plastic collapse criterion.



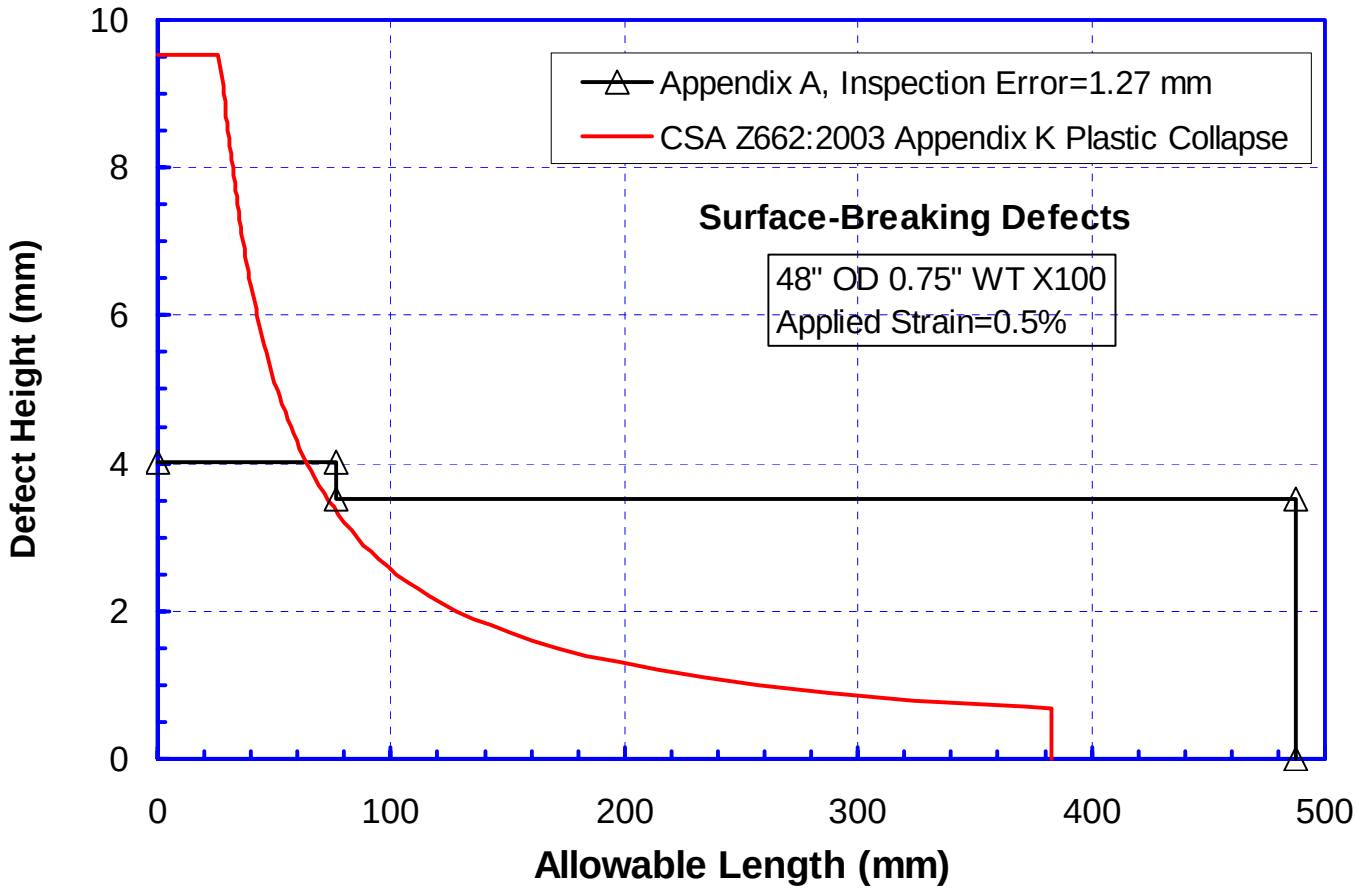
Appendix A and Plastic Collapse (Cont'd)

- **At the maximum allowed applied strain of 0.50%. There is a safety factor of 2 on defect length in the CSA Z662:2003's plastic collapse criterion.**



Appendix A vs. Newer Code (Cont'd)

- There is a safety factor of 2 on defect length in the CSA Z662:2003's plastic collapse criterion.
- Appendix A can be problematic particularly with large diameter, high *Y/T* materials, and high end of applicable longitudinal strain range.



ECA Code Development around World

- PD 6493:1980 -> PD 6493: 1991 -> BS 7910:1999
- BS 7910 has procedures for
  - Fracture
  - Fatigue
  - Creep crack growth
  - Other failure modes (corrosion, buckling, leakage, erosion, etc.)
- BS 7910 incorporated many of the features developed in R6, which is an ECA procedure primarily used in nuclear power generation.
- In fossil energy industries, BS 7910 is still considered the standard of standards.

Other ECA/FFS Codes

- DNV Offshore Standard OD-F101 (1999-2000?)
- EPRG (European Pipeline Research Group) Guidelines
- AS (Australian Standards) 2885.2
- SINTAP
- API RP 579

Contrasting App. A with Other ECA Codes

- **Appendix A is prescriptive.**
  - **Pro: less prone to error from unqualified analysts**
  - **Con: not adaptive to new materials and construction practices**
- **BS 7910 is descriptive.**
  - **Pro: more adaptive to new conditions**
  - **Con: depend on analysts making assumptions and sound judgments**
- **Appendix A is two revisions behind its base document.**

Comments on App. A Criteria

- Degree of conservatism is reduced towards its high end of the allowable strain range, particularly for large diameter pipes.
- The lack of plastic collapse criteria is a significant shortcoming.
- The reduced conservatism at high applied strain is caused by:
  - Allowable defect length independent of applied strain
  - Lack of plastic collapse criteria.
- The use of Appendix A in ultra-high strength materials at its high end of allowable strain range is very much questionable.

Limitations of the Current Worldwide Alternative Acceptance Criteria

- Almost all ECA codes are based on the premises of "stress-based" design. They tend to work well if the nominal applied stress is in the elastic range.
- Pipelines may experience high longitudinal strains (>0.5%)
  - offshore reeling
  - Ground movements (seismic events, slope instability, washout, mine subsidence)
  - Pipelines going through discontinuous permafrost
- The ability to develop alternative acceptance criteria for such high strain conditions are largely within the domain of research organizations and perhaps large corporations.

$E=mc^2$

Need for Conservatism

- NDT sizing accuracy
- Actual property versus specified minimum property
- Scatter in toughness
- Uncertainty in loading
- Weld metal property mismatch
- Prior strain effects on material properties
- Seismic loading

Why is this Work Needed?

- We are dealing with new materials, welding processes, and potentially more challenging loads on the pipelines.
- High longitudinal strain loading beyond 0.5% strain is not covered by the current standard.
- Even when the applied strain is less than 0.5%, current acceptance criteria per Appendix A can be overly optimistic for the new high *Y*/*T* materials.
- <u>The new environment and historical evidence all point to the need for the development of revised and expanded alternative acceptance criteria.</u>