# *SMiRT-16 LBB Workshop*

## Effects of Secondary Stresses on Pipe Fracture


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# *Secondary Stresses are Handled in Different Ways in Pipe Flaw Evaluations*

- For ASME Section XI in-service pipe flaw evaluation
  - Uses Safety Factor of 1.0 for stainless steel welds and ferritic base metal and welds.
  - Does not include secondary stresses for wrought stainless steel base metals and austenitic TIG welds, and
  - Originally included only thermal expansion ($P_e$) as a secondary stress, but seismic anchor motion (SAM) included recently.

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# *Secondary Stresses are Handled in Different Ways in Pipe Flaw Evaluations*

- For LBB, NRC's draft SRP 3.6.3 included primary and secondary stresses together with same safety factor on stress or flaw size for all cases except for (wrought) austenitic base metal or austenitic TIG welds, where the thermal expansion stresses are not included.
- New suggested technical basis approach for an NRC LBB Regulatory Guide has three options:
  - Option 1 – Include secondary stress as a primary stress and conduct simple analyses with conservative safety factors.
  - Option 2 – Include secondary stress as a primary stress and conduct more complex leak-rate and fracture analysis with possible lower safety factors.
  - Option 3 – Conduct nonlinear time-history stress analysis, secondary stress contributions may be less important for fracture. Probably same applied safety factors on crack size as Option 2 analysis.

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## *Experimental Assessment of Secondary Stresses*

- Pipe-system experiment conducted in Battelle Integrity of Nuclear Piping (BINP) program to assess secondary stress effects on fracture
  - Identical to several full-scale pipe tests, including pipe-system test in IPIRG-1 program with circumferential surface crack in center of stainless steel SAW.
  - Pipe-system test includes stresses from:  pressure, thermal expansion, inertial loading from dynamic excitation, and seismic anchor motion from dynamic excitation.
    - Dynamic loading in IPIRG-1 and BINP tests were single-frequency excitation at ~90-percent of first natural frequency.

## *Tests on Same 16-inch-Diameter, Schedule 100, TP304, Pipe (Pipe A-8) at 288C with Circumferential Cracks in Center of Stainless Steel SAW*

| Program | Exp't Number | Type of Experiments | Test Pressure, MPa | a/t | Circumferential length, % |
|---|---|---|---|---|---|
| DP3II | 4141-4 | QS bend | 11.03 | 0.633 | 50.0 |
| IPIRG-2 | 1-6 | QS bend | 15.51 | 0.649 | 27.0 |
| IPIRG-1 | 1.3-5 | single frequency | 15.51 | 0.574 | 53.2 |
| IPIRG-2 | 1-5 | single frequency | 15.51 | 0.427 | 26.7 |
| BINP | B-1 | single frequency | 15.51 | 0.606 | 47.6 |

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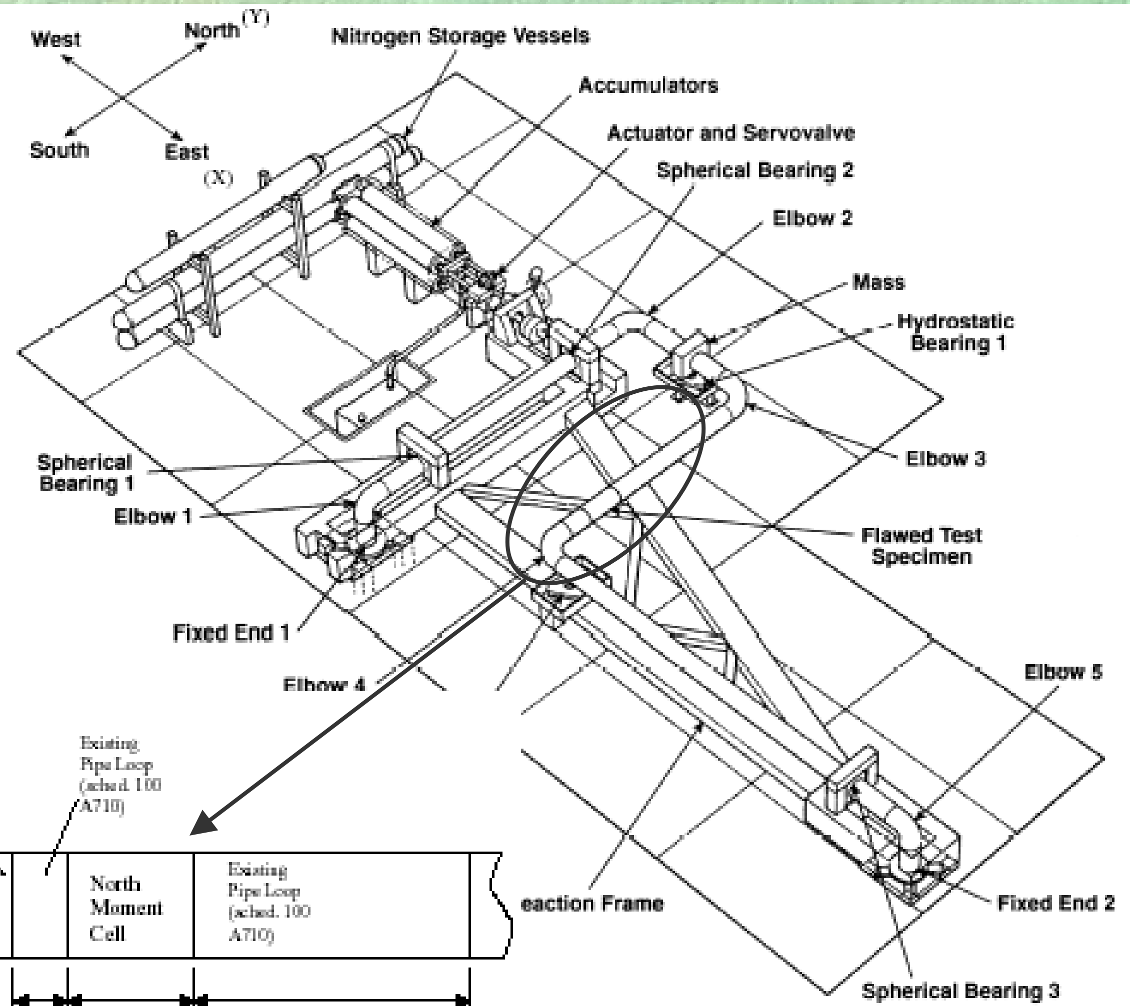
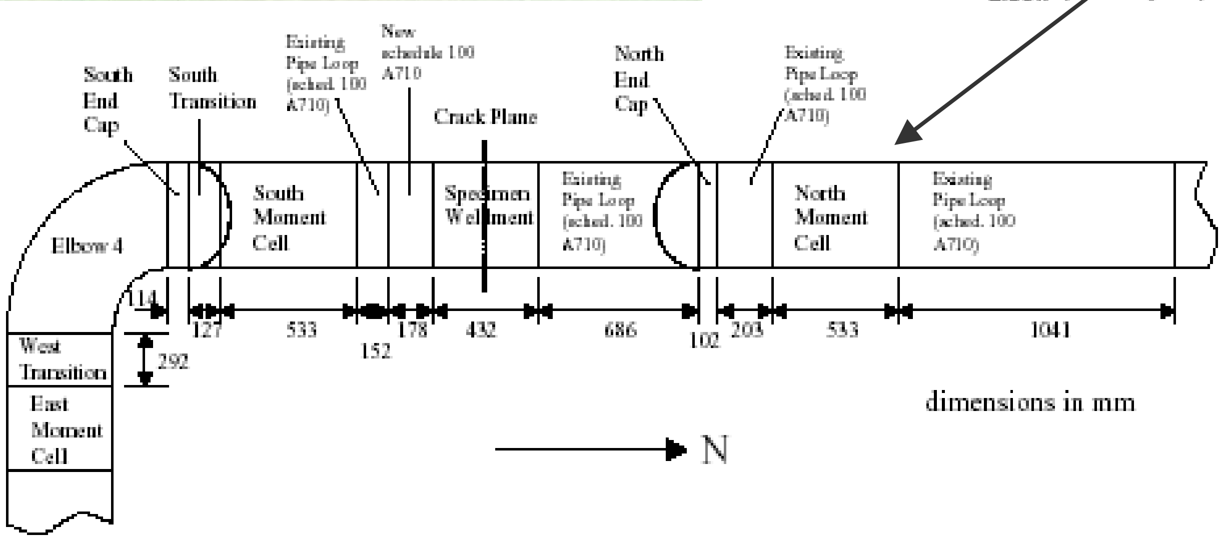
# IPIRG Pipe Loop

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# IPIRG Pipe-System Test 1.3-7

(Endcaps removed to allow for full jet forces after fracture)

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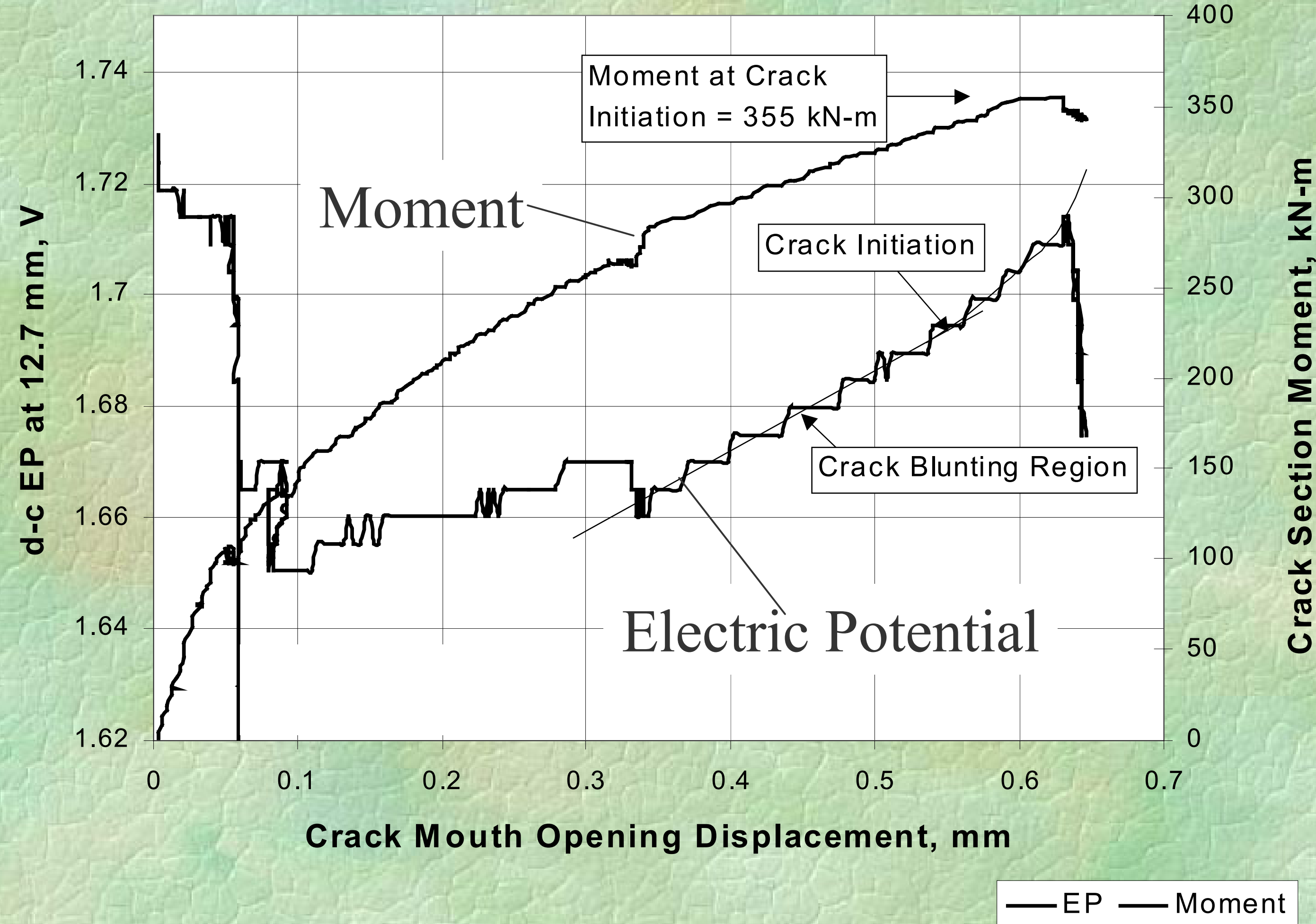
# Static Offset Displacements to Induce Secondary Stresses in BINP-1

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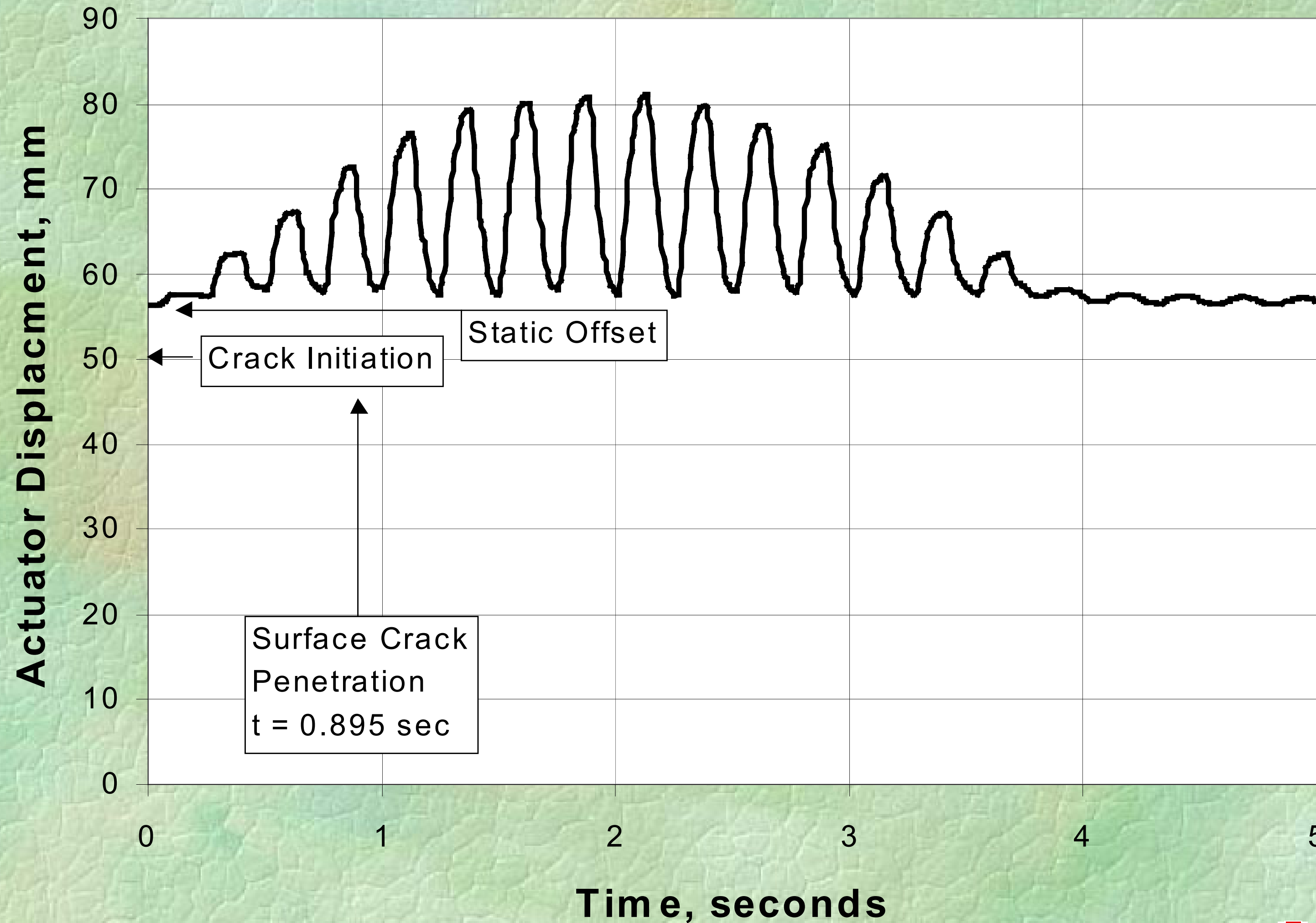
# BINP Test 1 Dynamic Loading

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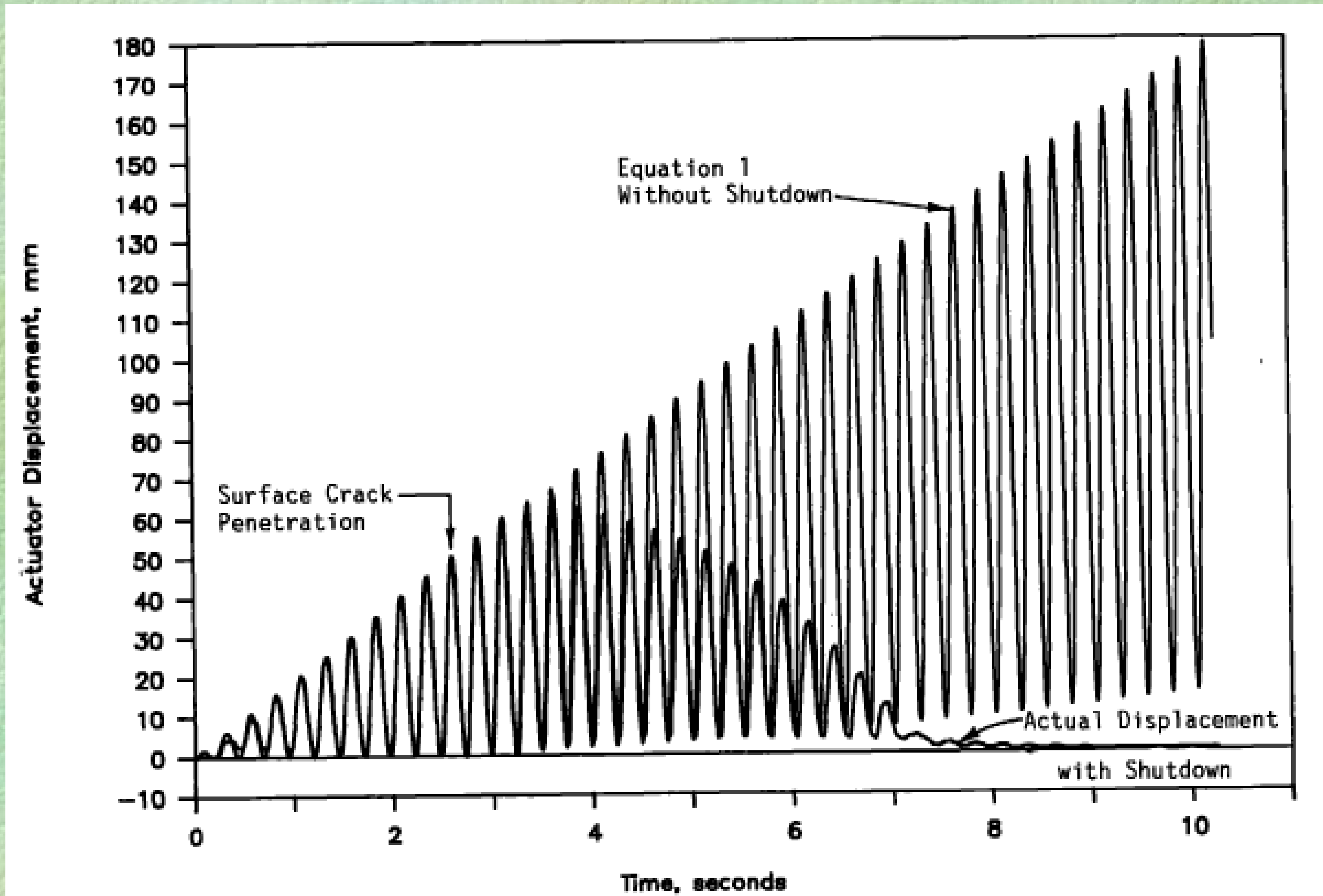
$\mathcal{E}mc^2$

# IPIRG-1 Test 1.3-5 Dynamic Loading

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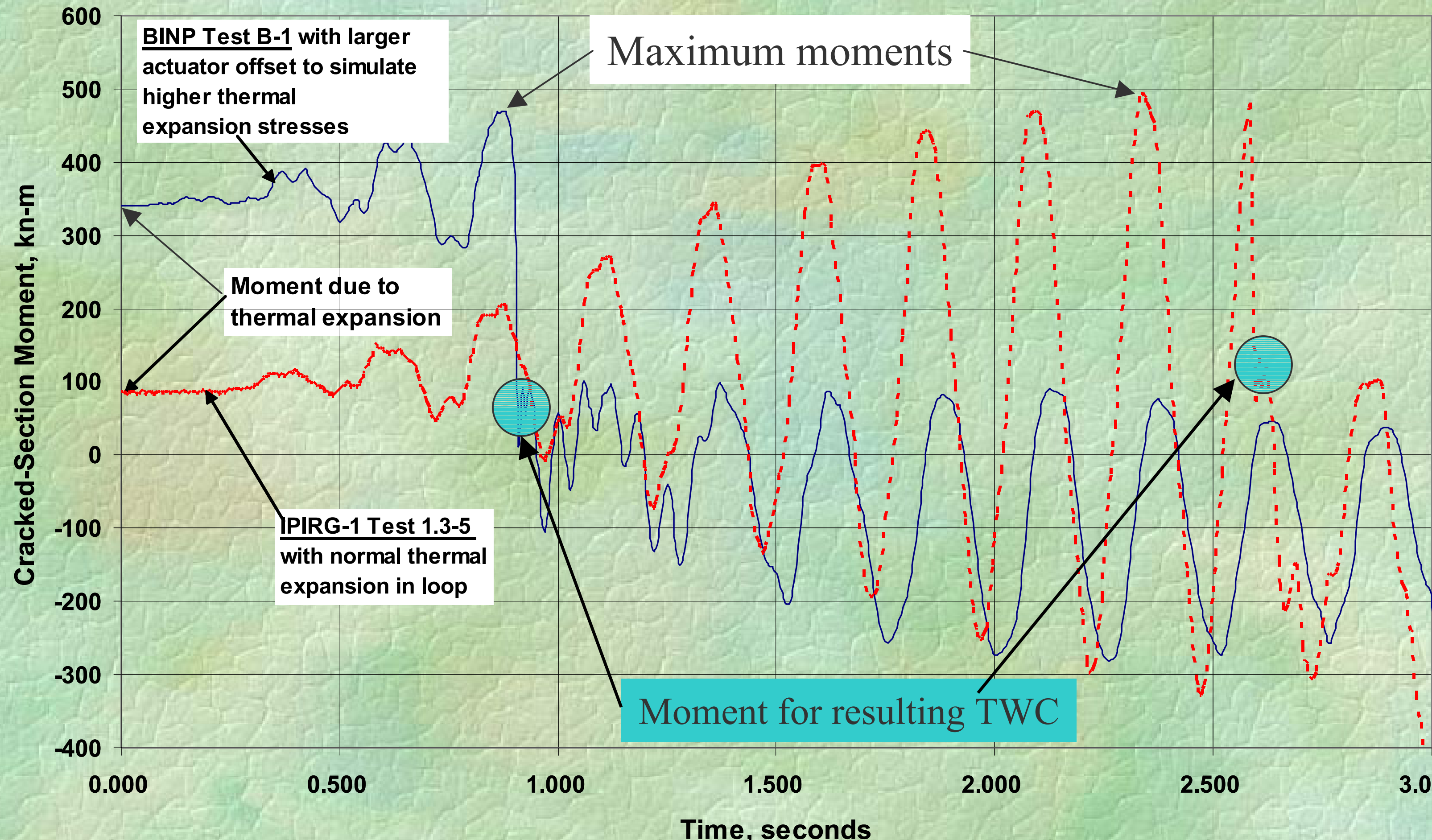
# Comparison of IPIRG-1 and BINP-1 Pipe System Test Results

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# Comparison of BINP-1 and IPIRG-1 Pipe System Results

- Maximum moments were about the same, independent of thermal expansion stress.
- Crack initiation occurred during displacement-controlled loading in high secondary stress test.
- Resulting through-wall crack after surface flaw penetration perhaps slightly longer for higher thermal expansion test.
- Number of cycles to reach maximum load much lower for higher "thermal expansion" test.
- Higher thermal expansion (secondary) stresses <u>not</u> less detrimental than inertial (primary) stresses.

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# Secondary Stress Aspects

- Important consideration also comes from ASME Code efforts to evaluate acceptance criteria for erosion-corrosion flaws.

NC-3672.6 1998 SECTION III, DIVISION 1 — NC NC-3673.2

**(b) Local Overstrain**. All the commonly used methods of piping flexibility analysis assume elastic behavior of the entire piping system. This assumption is sufficiently accurate for systems in which plastic straining occurs at many points or over relatively wide regions but fails to reflect the actual strain distribution in unbalanced systems in which only a small portion of the piping undergoes plastic strain or in which, for piping operating in the creep range, the strain distribution is very uneven. *In these cases, the weaker or higher stressed portions will be subjected to strain concentrations due to elastic follow-up of the stiffer or lower stressed portions*. Unbalance can be produced:

(1) …

(2) by local reduction in size or cross section, or local use of a weaker material;

(3) …

(c) Conditions of this type shall be avoided where materials of relatively low ductility are used; if unavoidable…

# Secondary Stress Considerations

- Original pipe system Code writers recognized that global secondary stresses (not through-thickness stresses, i.e., weld residual stresses) can act as a primary stress under certain conditions.
  - Those conditions were difficult to quantify.

- One condition is if surface crack in the pipe has a failure stress below yield.
  - The displacements from the local crack tip plasticity for a surface crack, are much smaller than the pipe-system global displacements, so the secondary stresses are not relieved by yielding.
  - Different for through-wall crack?

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# Secondary Stress Considerations

- Implication is that the safety factor for secondary stresses should be a function of the failure stress/yield strength of the pipe.

  - If failure/yield stress < 1.0 then global secondary stress same as primary stress for fracture.

  - If failure stress/yield stress > 1.0, then global secondary stress become less important with some nonlinear function.

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# Conclusions

- Battelle pipe-system tests illustrate that secondary stresses for a deeply surface-cracked pipe can behave like a primary stress (actually higher $P_e$ stresses may be more detrimental since the number of cycles to failure were less).

- Through-wall-cracked pipe-system might behave different since the through-wall crack will allow for more rotation to relieve thermal expansion stresses than a surface crack.
  - Validation of this needed.

- Applied safety factor for secondary stresses for surface-flawed pipe should depend on the predicted failure stress relative to the yield strength.  Crack size could also be used rather than stress ratio if easier.

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