Arbitrary Surface Crack Growth due to PWSCC and its Inclusion in PFM Codes

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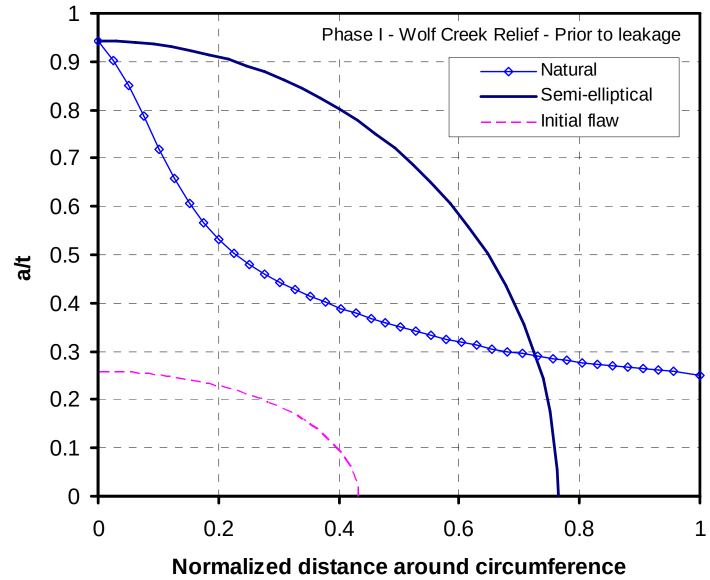
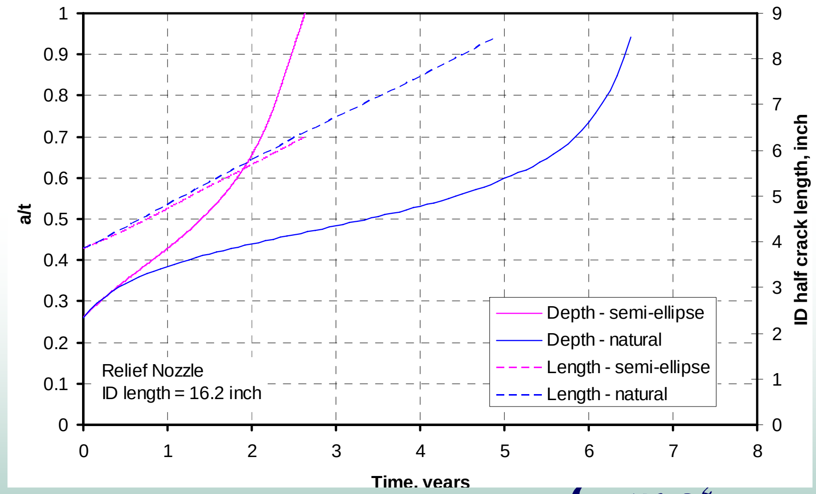
Rationale

- **_Through work on Wolf Creek issue (MRP-216 and NRC confirmatory effort), PWSCC surface crack growth is arbitrary in nature._**
- **_PFM codes use pre-defined, semi-elliptical surface crack influence functions for making crack growth predictions._**
- **_In some cases this assumption can be very conservative – for both crack growth and stability._**
- **_Can this behavior be modeled for use in PFM codes?_**





Objective

- ***Conduct sensitivity analyses using PipeFracCAE code to determine the conditions where a surface crack will not grow with a semi-elliptical profile.***

- ***Compare the crack size/time behavior of the arbitrary and idealized (semi-elliptical) surface crack at the deepest and surface locations along the crack front.***

- ***Determine if correction factors to published influence functions can be used to make more accurate leakage time predictions in PFM codes***

Sensitivity Matrix

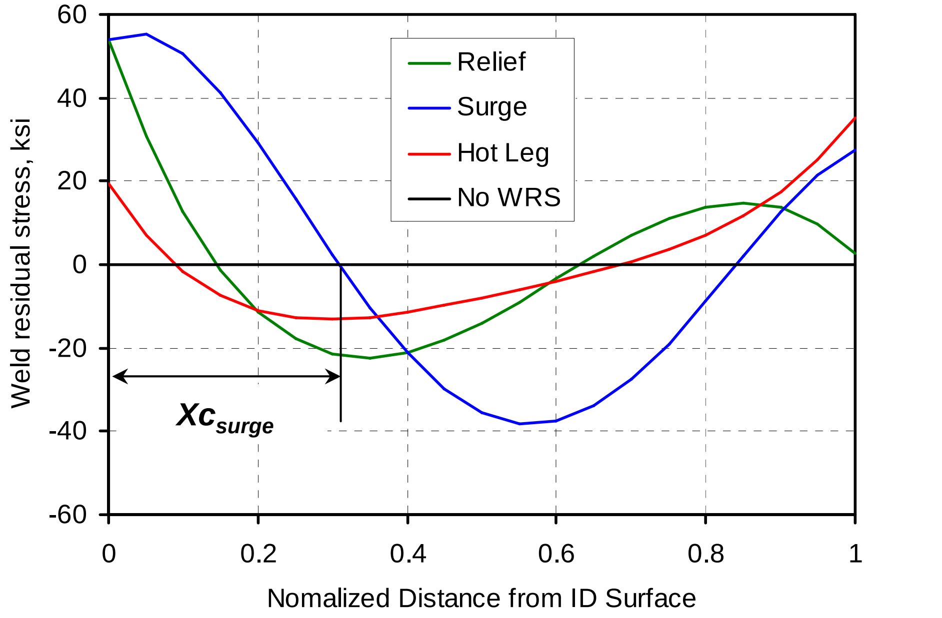
- ***Three pipe diameters***
- ***Four weld residual stresses (including no WRS)***
- ***Two levels of bending stresses (6.31 ksi and 14.26 ksi)***
- ***Two initial crack lengths (12.5% and 40% of pipe circum.)***
- ***Initial crack depth (26% of wall thickness) – Fixed***
- ***Axial tension (4 ksi), Internal pressure (2.235 ksi) – Fixed***
- ***Total of 48 cases (24 cases completed so far)***

Sensitivity Matrix (cont'd)

- ***Three pipe diameters***

Pipe geometry	D_o (in)	t (in)	R_i / t
Small (Relief line)	7.75	1.29	2.00
Medium (Surge line)	15.00	1.58	3.75
Large (Hot leg)	33.94	2.37	6.16

- ***Four weld residual stresses (including no WRS)***



Xc = Distance where stress field crosses into compression

$$Xc_{surge} > Xc_{relief} > Xc_{hotleg}$$

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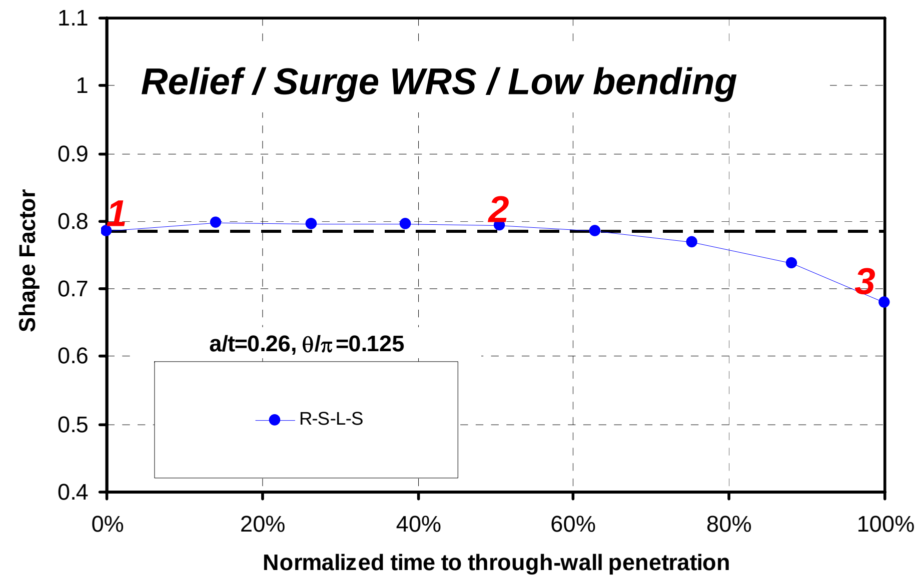
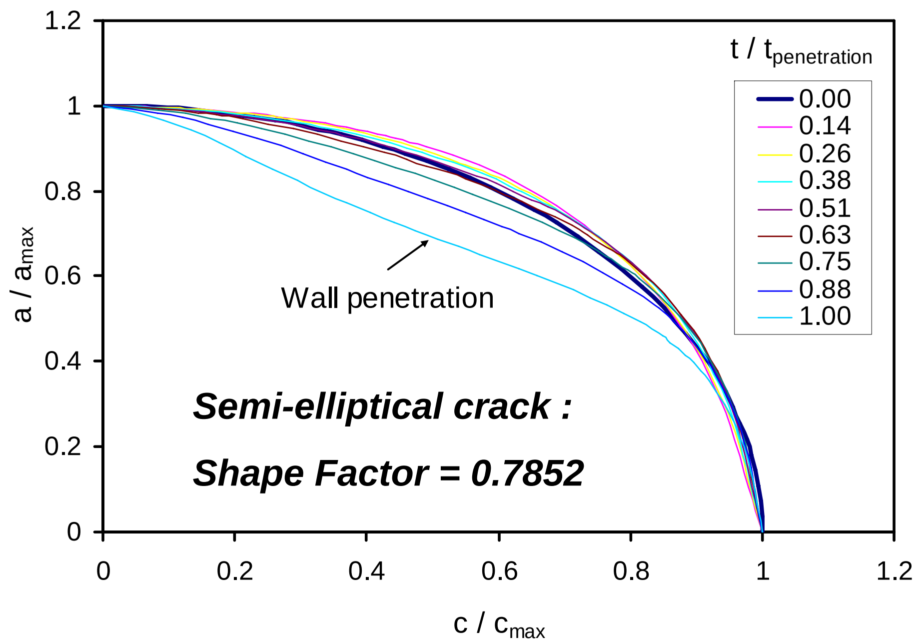
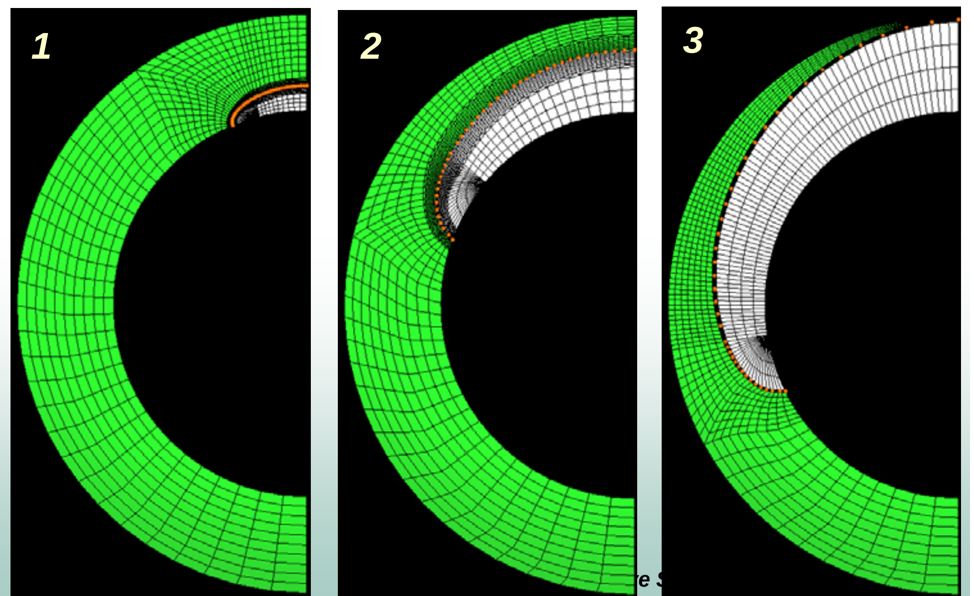
Shape Factor

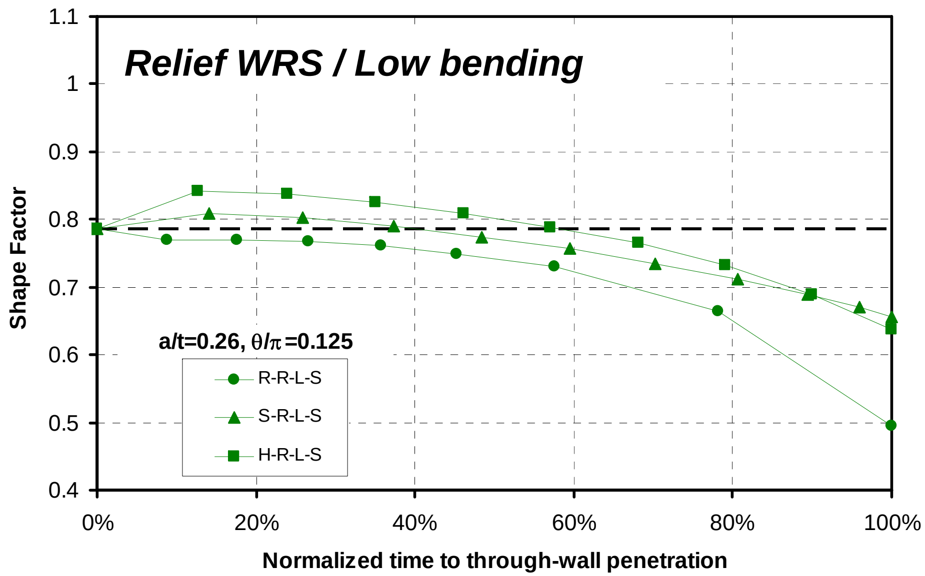
- ***Shape factor is defined as the area under the normalized crack shape***
- ***Shape factor indicates how the crack shape is changing relative to a semi-elliptical shape***

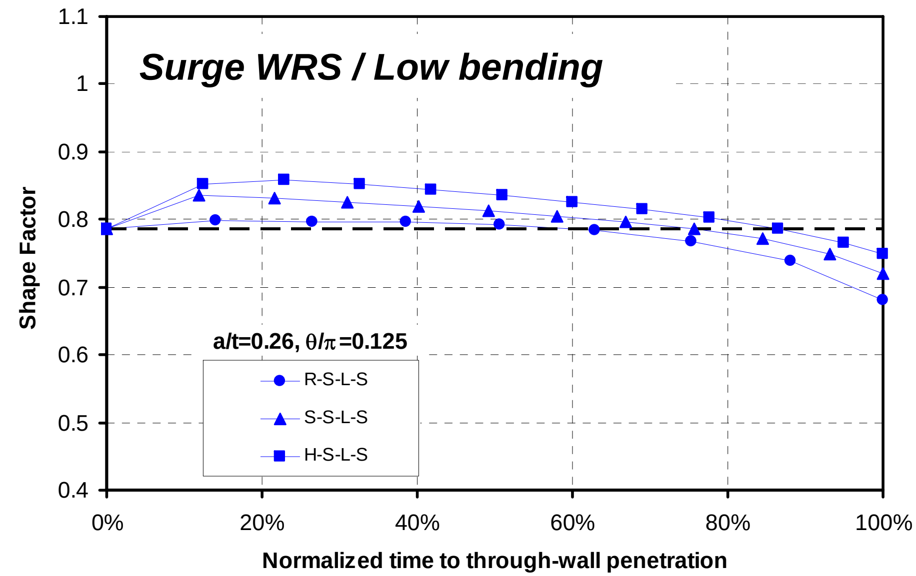


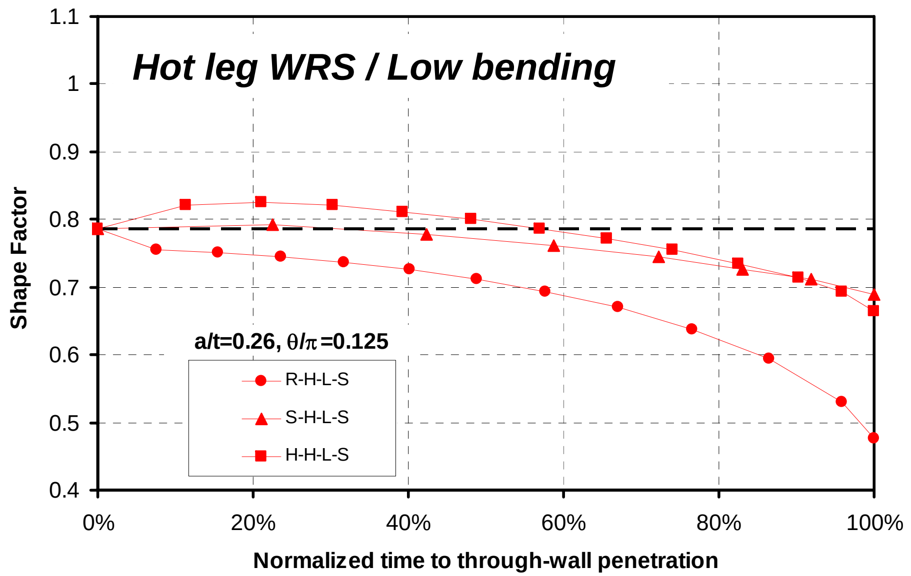


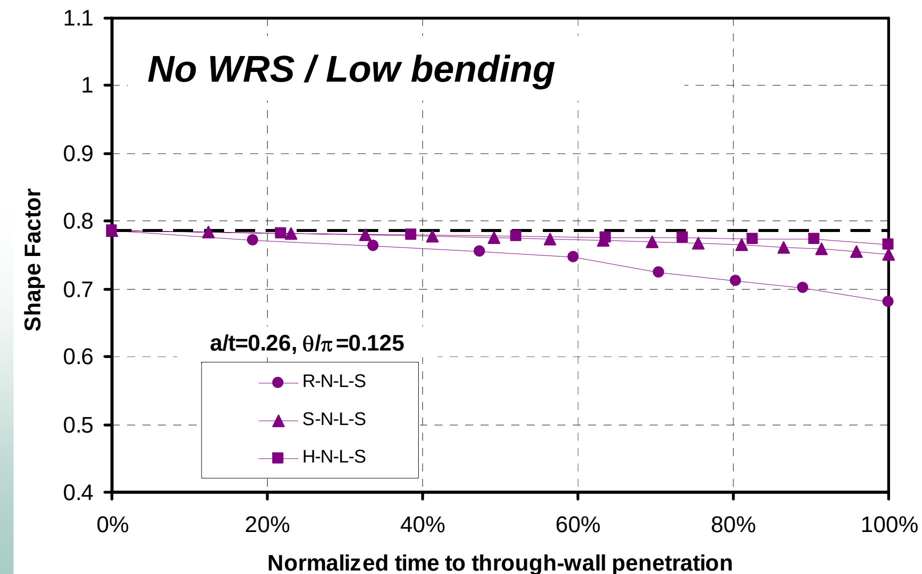


Results – Effect of pipe diameter

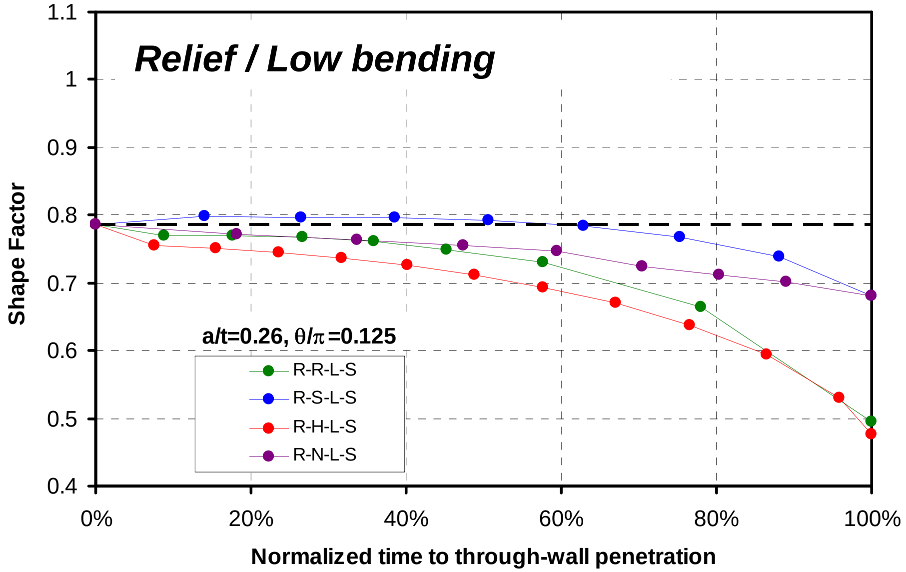


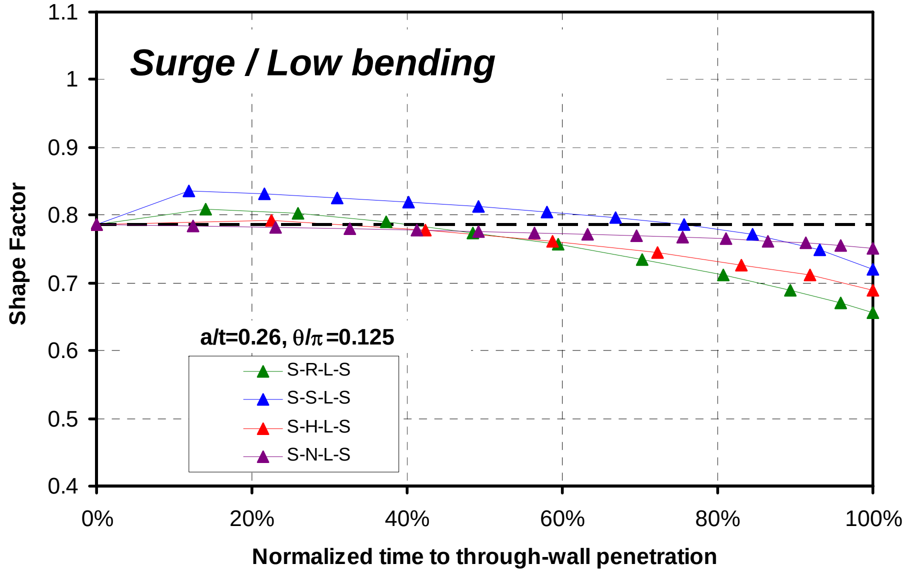


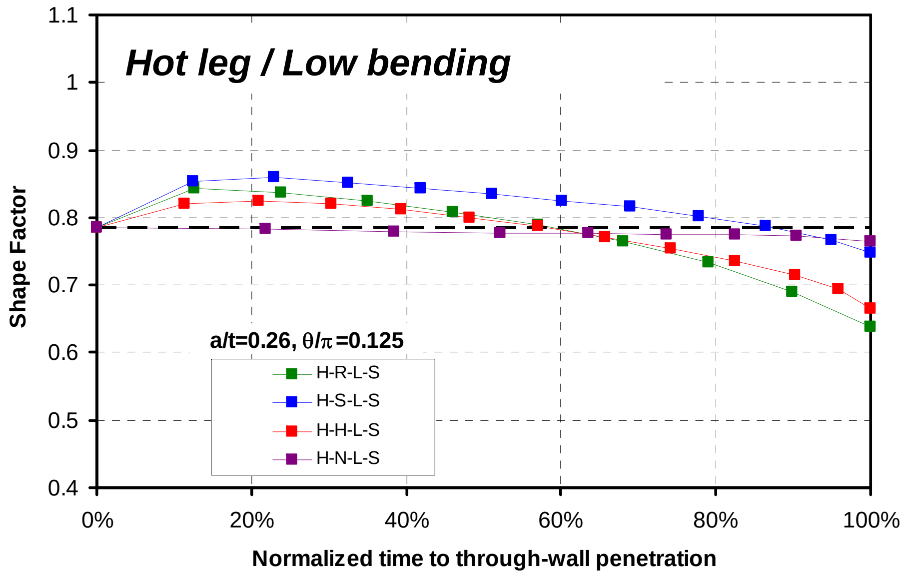




Results – Effect of WRS







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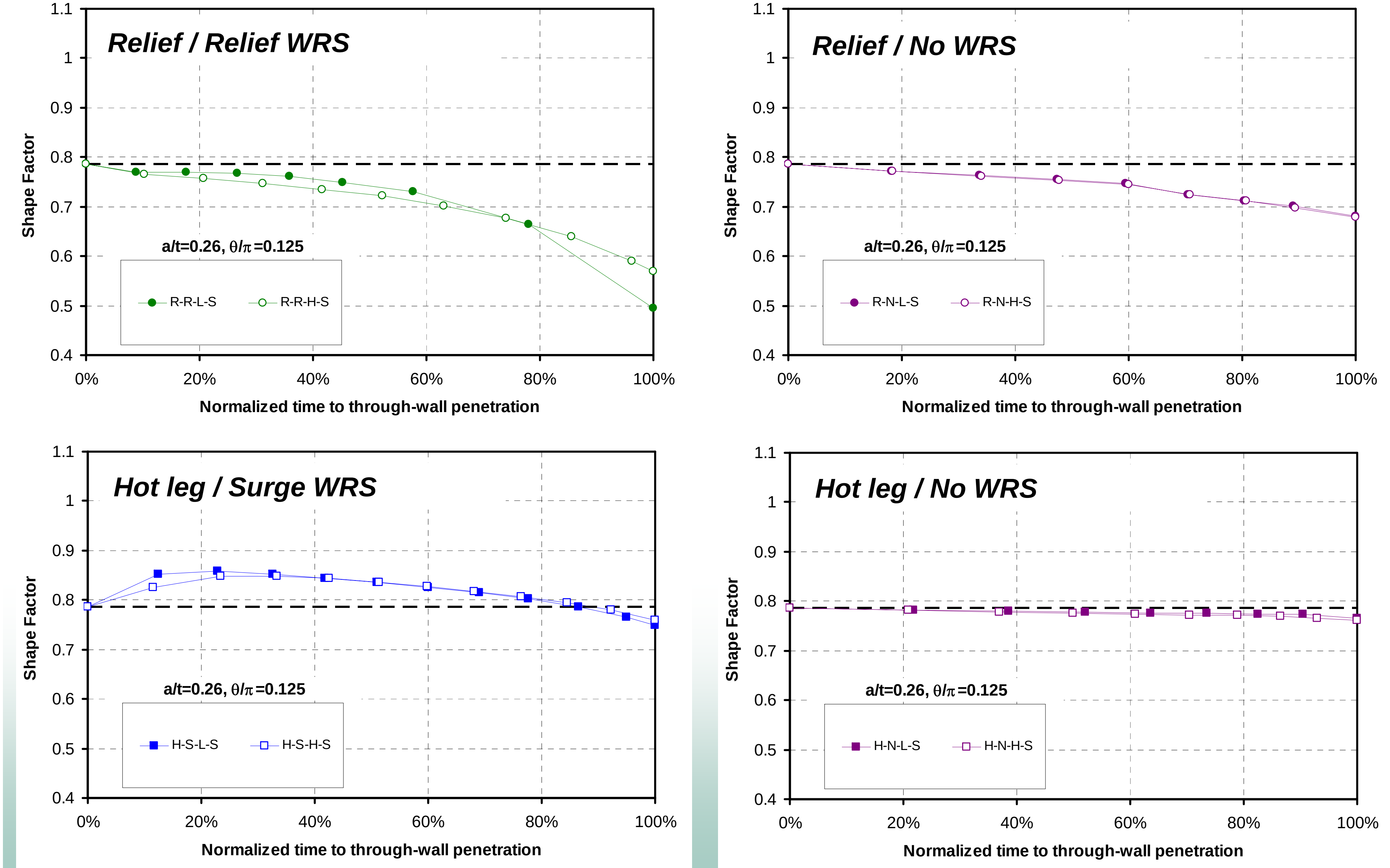
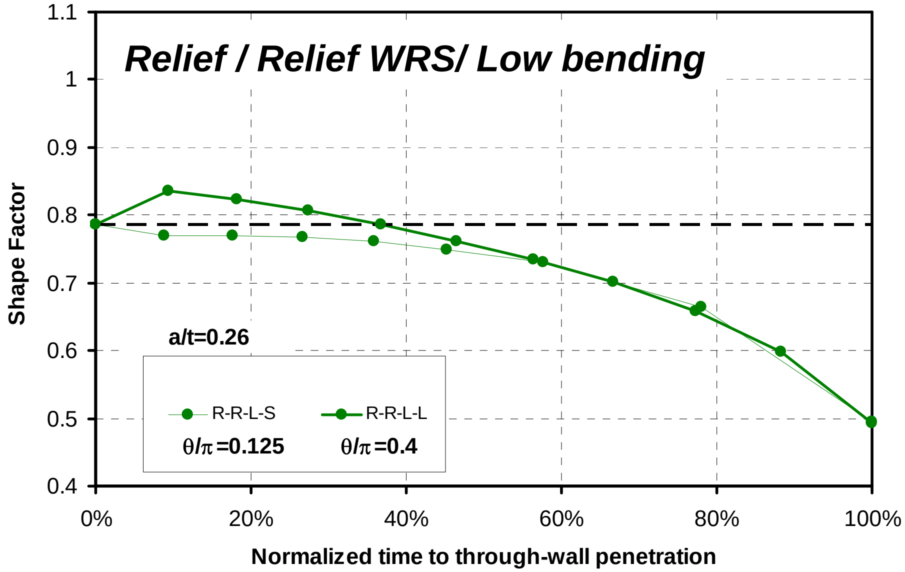
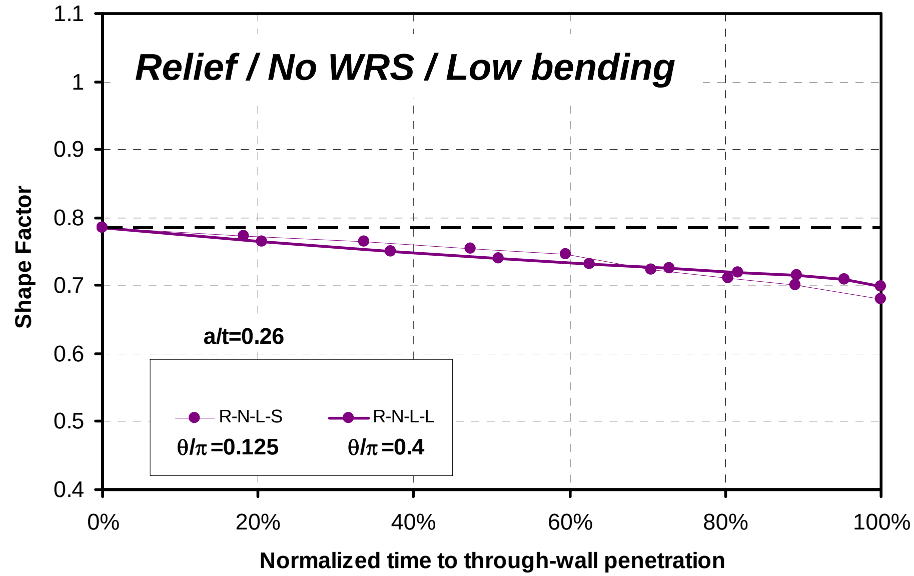
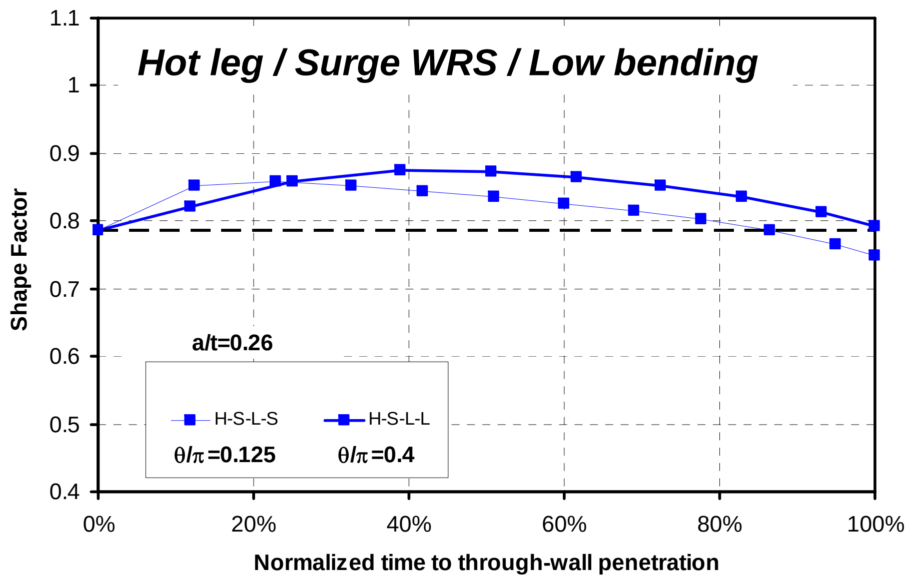
Results – Effect of bending stress

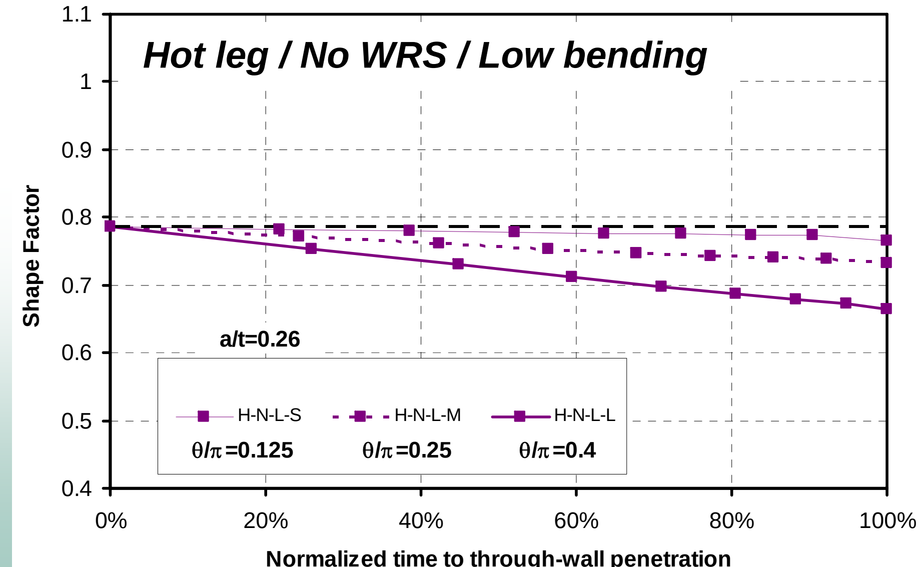


Results – Effect of initial crack length



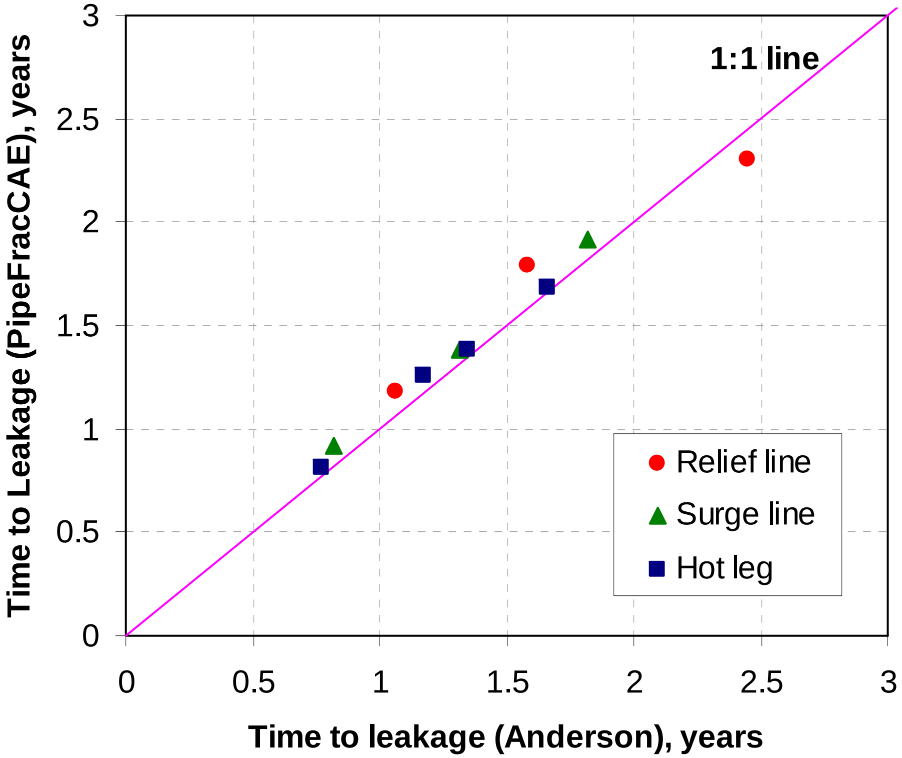


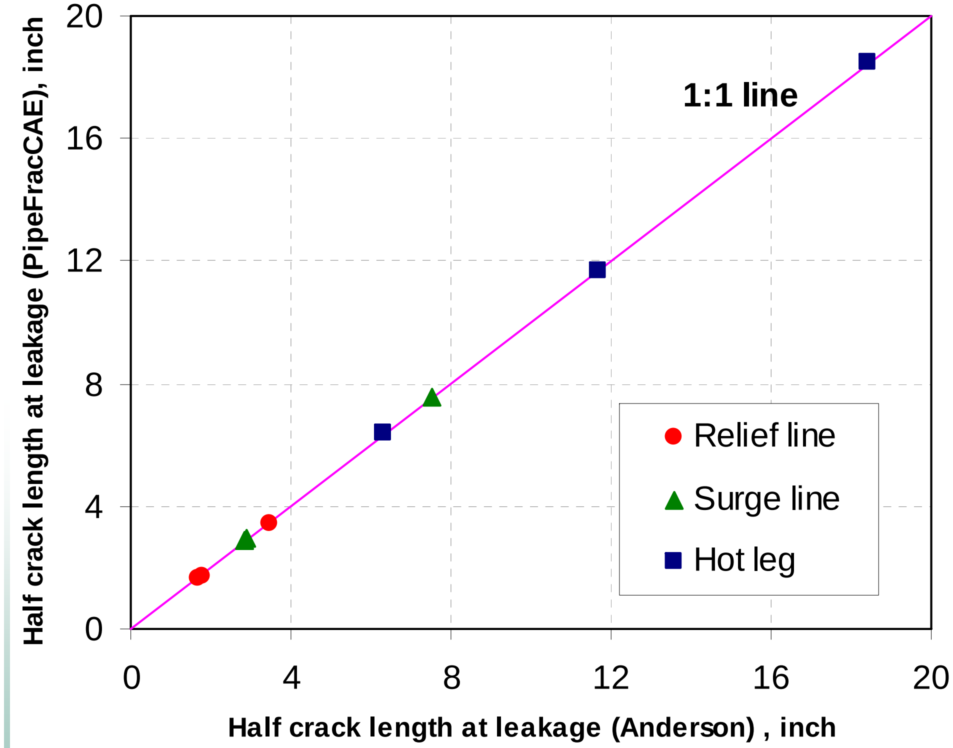




Comparison with Idealized Solution

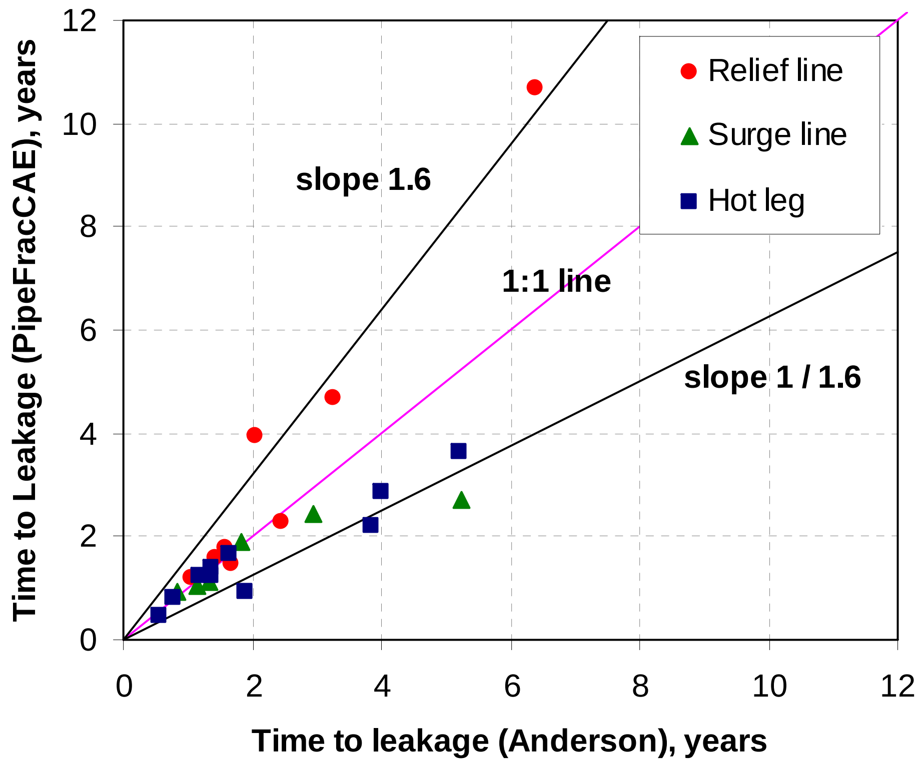
- ***Idealized (semi-elliptical) crack growth using Anderson solution***
  - K values at deepest and surface points
- ***Compare crack growth at deepest and surface points***
- ***Comparison for all 'no WRS' case results***

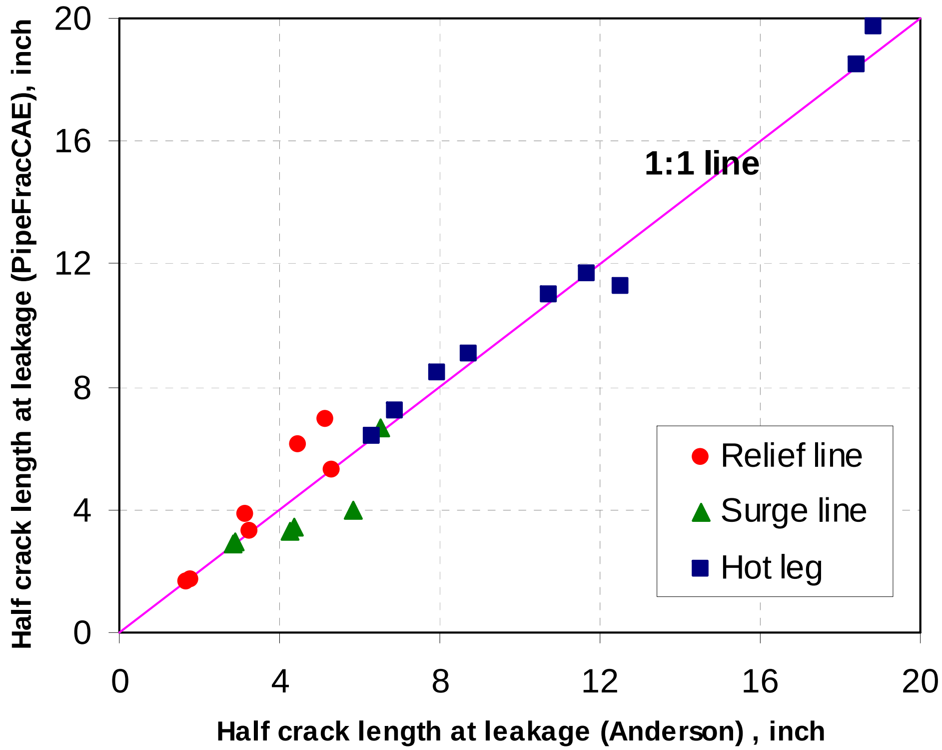




Comparison with Idealized Solution (cont'd)

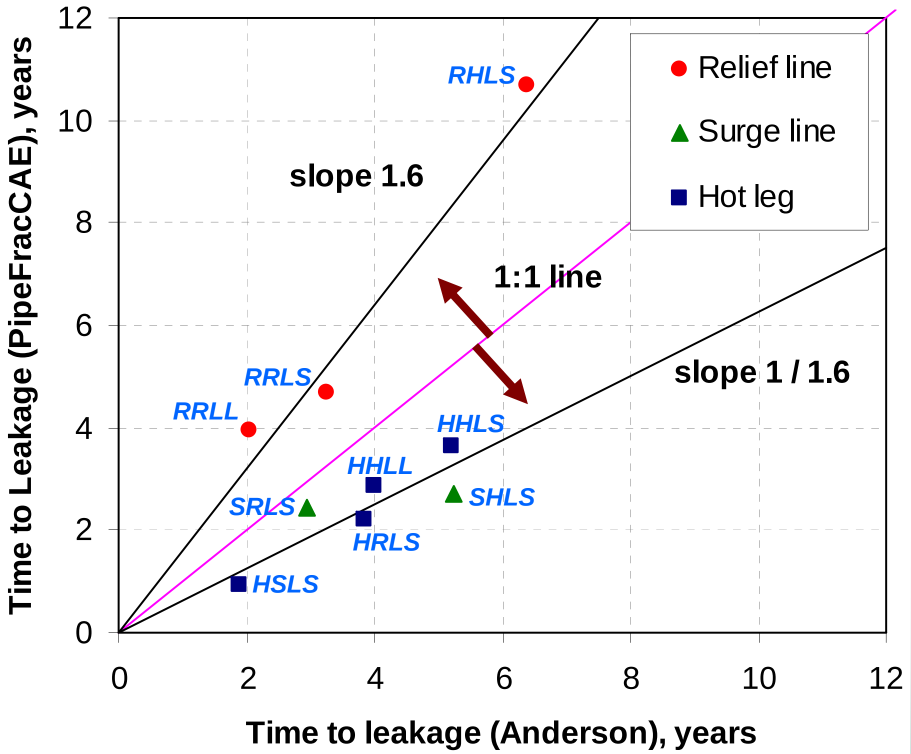
- Comparison for all 24 cases
- Time to leakage showed some difference for certain cases
- However, crack depth and crack length at leakage show relatively good agreement

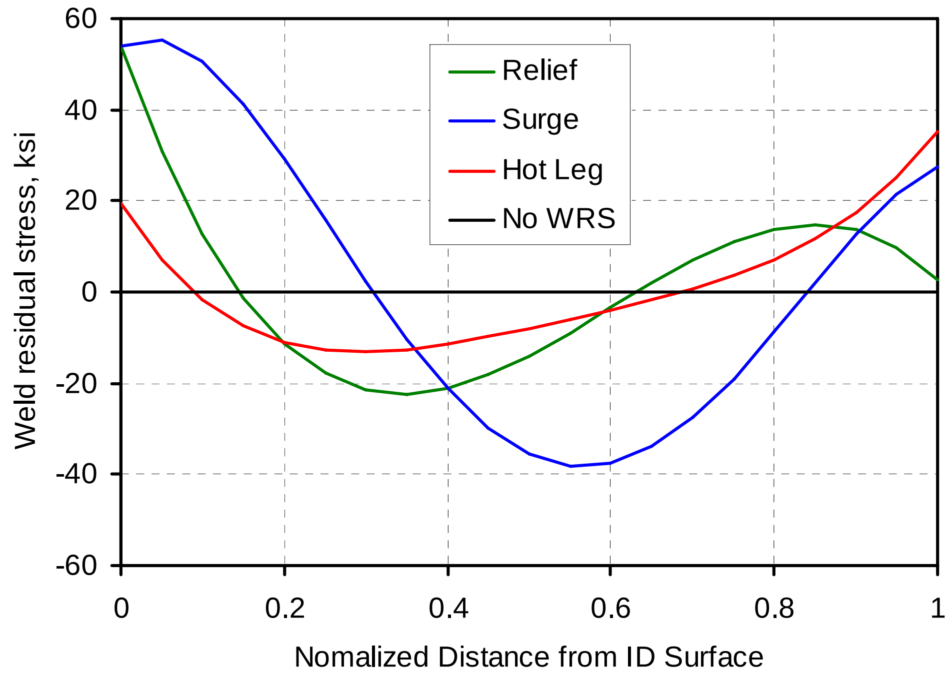




Cases Showing Difference in Time to Leakage

- *Cases with low bending (6.31 ksi) with Relief or Hot leg WRS*
- *Relatively small K values near the compressive WRS*





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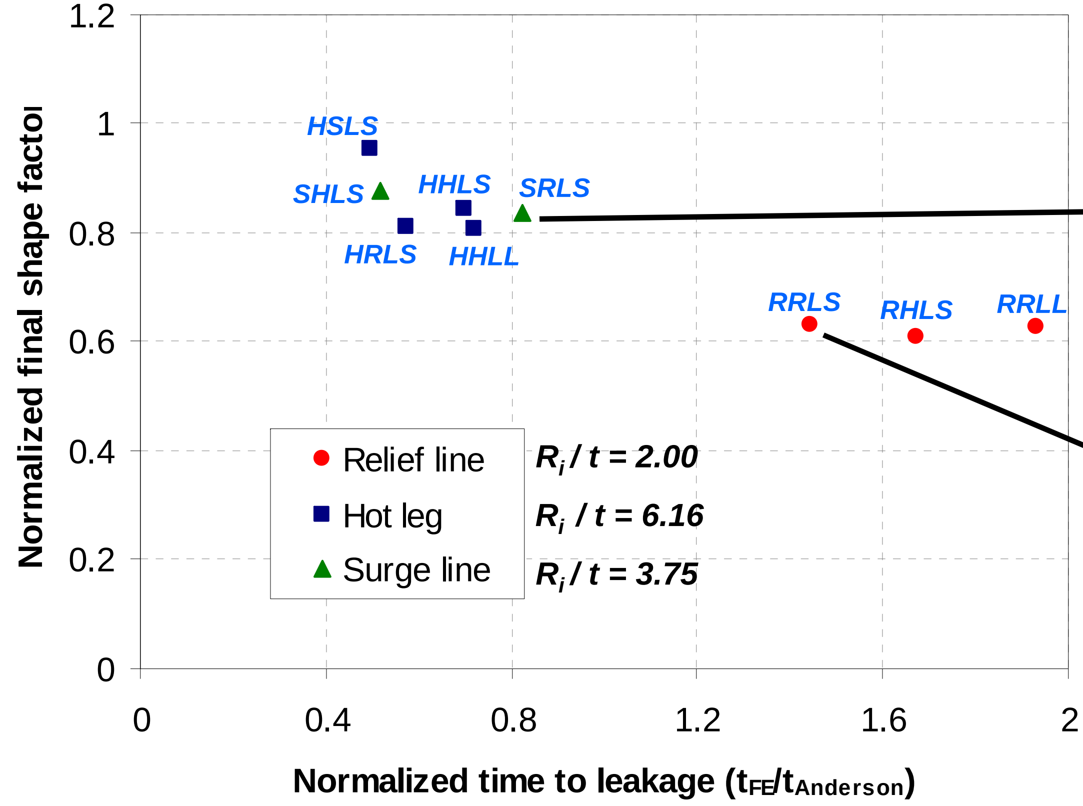
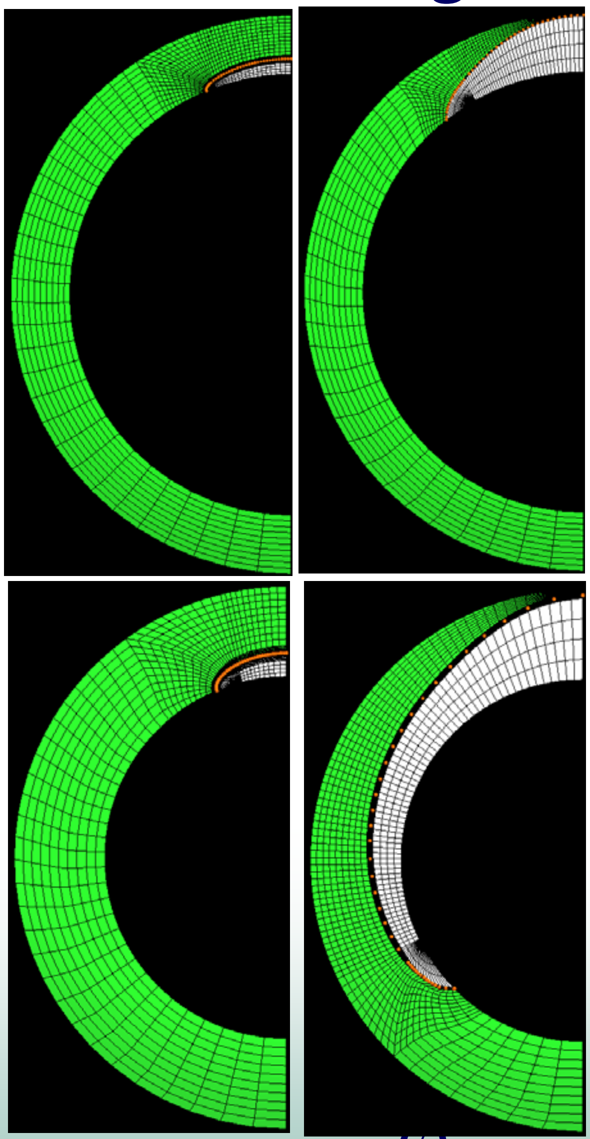
Cases Showing Difference in Time to Leakage

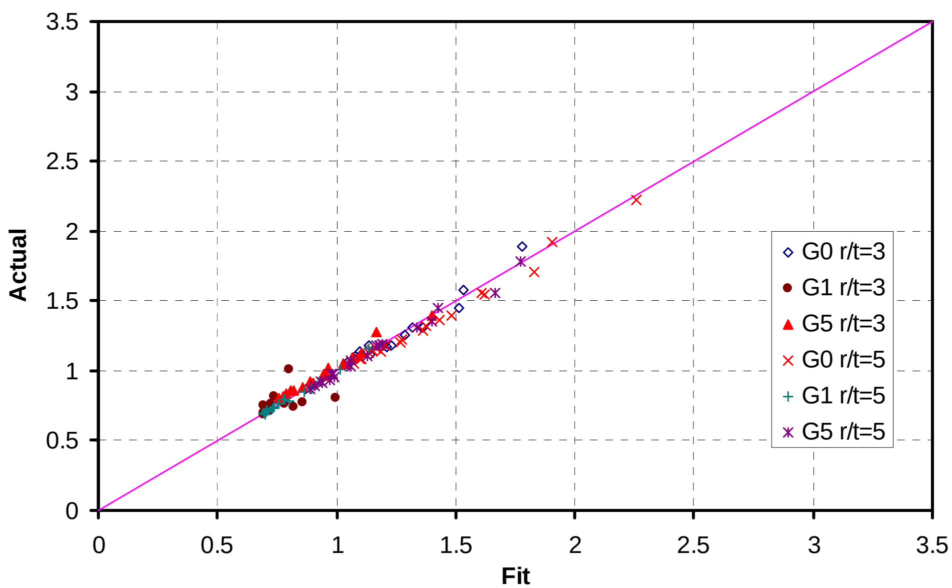
- ***Comparison of final shape factor***

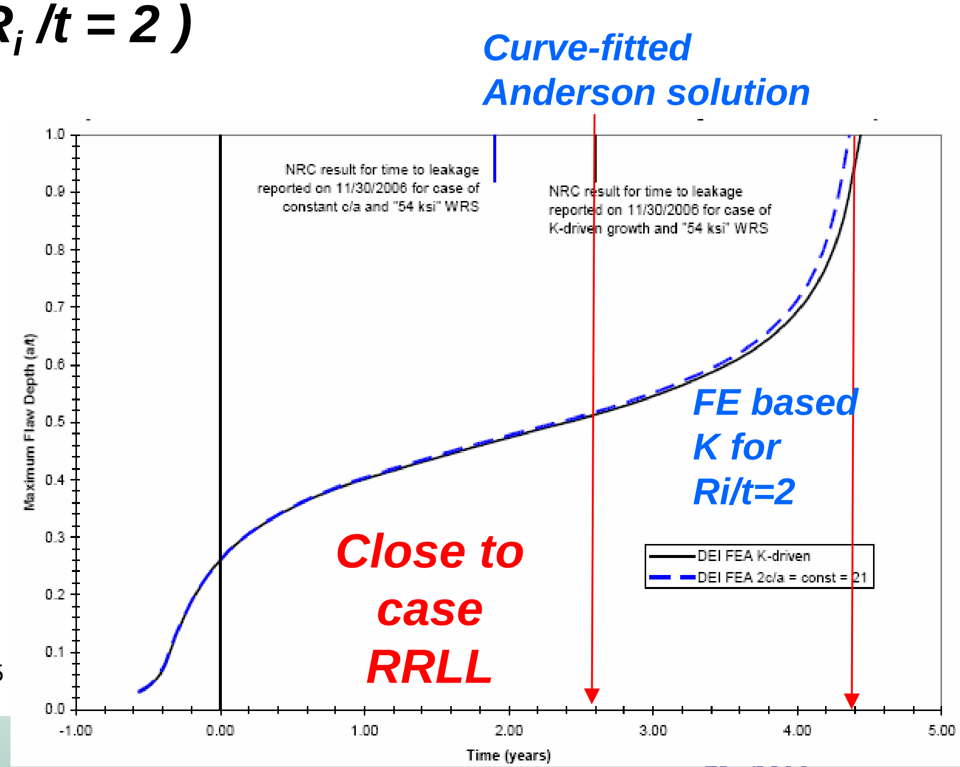




Effect of Influence Functions

- *Curve-fitted influence functions used in the present work*
- *Slight difference shown between actual and curve-fitted results*
- *Range of R_i/t in Anderson solution : from 3 to 100*
- *Results from Wolf Creek demonstrated the effect of influence function on time to leakage ($R_i/t = 2$)*





Effect of Influence Functions (cont'd)

- *Need to compare the crack growth results using the actual influence functions versus the curve-fitted values.*

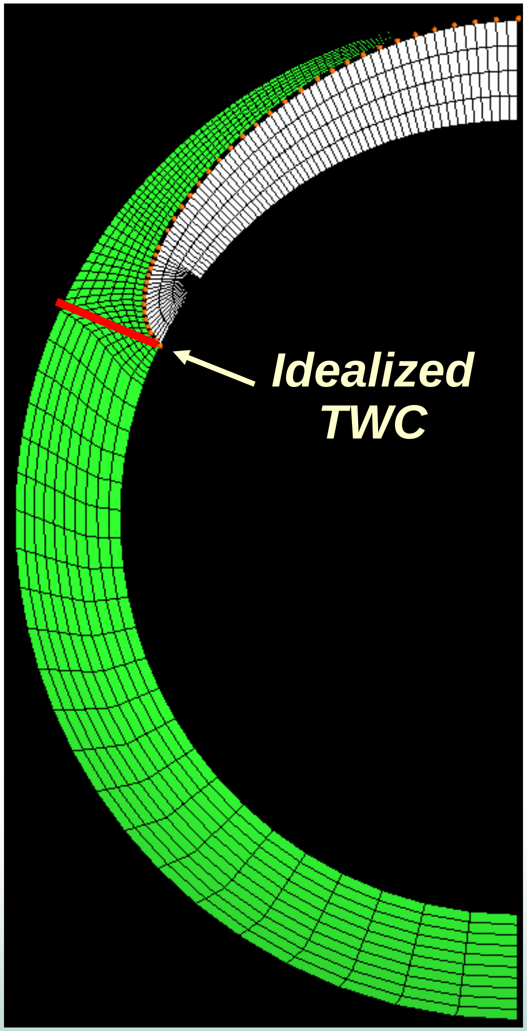
- *Also need to investigate the applicability of the influence functions for high-order stress distribution.*

  - Anderson solution uses FE based G_0 and G_1 values along with weight functions to calculate G_2-G_4 which are used for K calculation for high-order stress distribution

Transition from surface crack to TWC

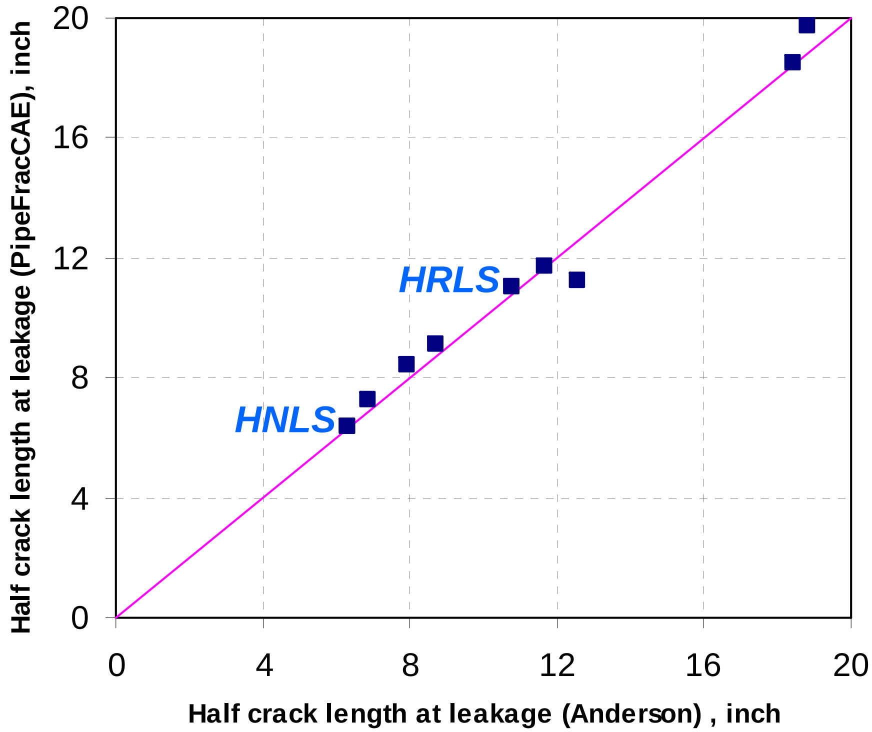
- ***Generally, when a surface crack penetrates the wall-thickness, the resulting ID TWC length is assumed to be same as the final ID length of the surface crack.***

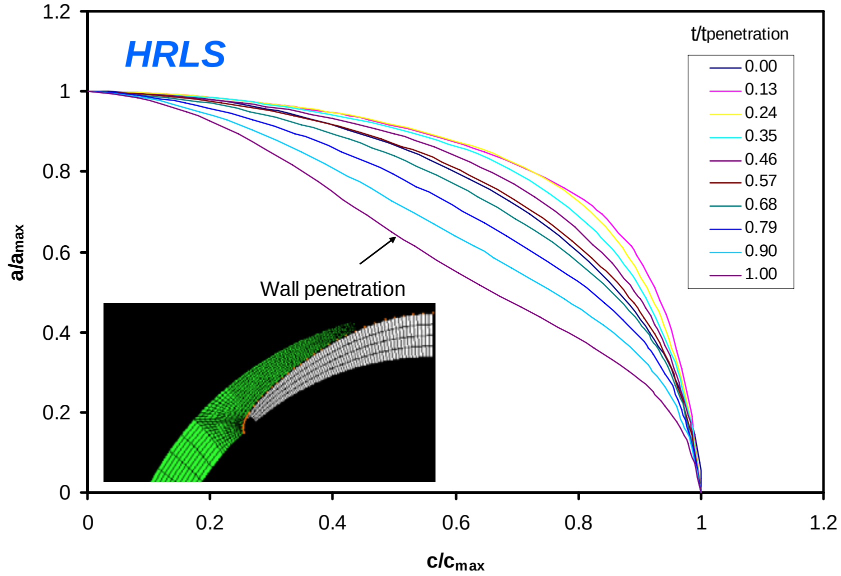
- ***In some cases, this assumption may be overly conservative, since it ignores the time from leaking surface crack to idealized TWC.***

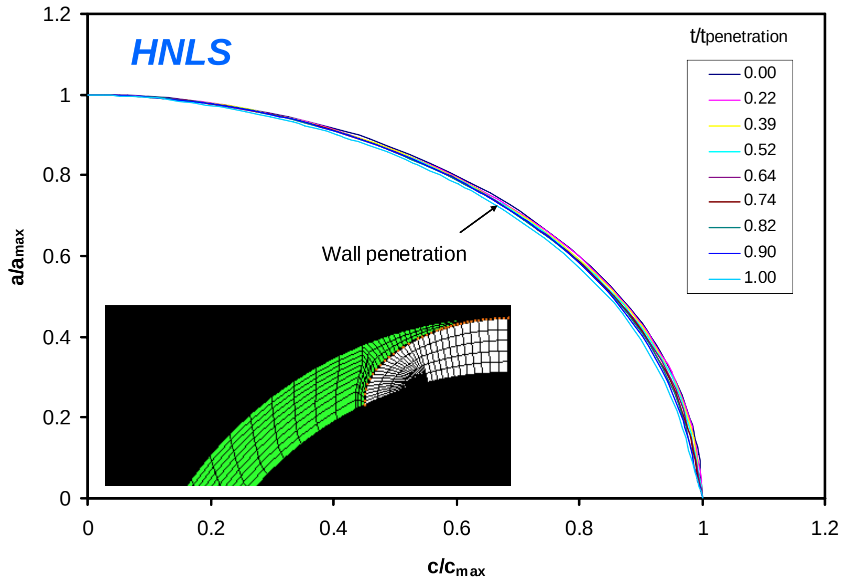


Transition from surface crack to TWC (cont'd)

- *Different shape factor at leakage (even for cases on 1:1 line)*
- *Equivalent idealized TWC may be defined using the shape factor (crack area) at leakage*







Summary

- ***From the sensitivity analyses performed using PipeFracCAE, the effects of each parameter on crack growth behavior were investigated.***
- ***The results demonstrate that for the cases with relatively low bending stress and WRSs with small values of Xc, the PipeFracCAE and Anderson solution showed difference in time to leakage.***
- ***However, the crack lengths at leakage showed relatively good agreement.***
- ***The inaccuracy (curve-fit, weight function) of the influence function may be causing the difference.***
- ***Need to further investigate the applicability of the influence functions.***
- ***Transition from surface crack to TWC may be made by using the shape factor.***