Comparison for Through-wall Cracks

Developed by Central Engineering Programs, Entergy Operations Inc

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References :

1) ASME PVP paper PVP-350, Page 143; 1997 {Fracture Mechanics Model}
2) Crack Growth of Alloy 600 Base Metal in PWR Environments; EPRI MRP Report MRP 55 Rev. 1, 2002

Purpose :- This worksheet is used to compare the results from the conventional model, edge crack model and the current model. The SIF comparison is made between the conventional model and the current model. The crack growth and SIF comparisons are made between the edge crack and current model. The SIF equations for the conventional model are included in the current model's recursive loop structure. The edge crack is modeled separately in a recursive loop immediately following the loop for the current model. Graphical results show the comparisons at the end.

The salient differences between the three models considered are:

1) Current model is based on λ, which is limited to 20. The closed form solutions are based on a thick wall cylinder. The applied stresses are based on a moving average. Therefore an increase in the stress field as the crack advances is considered in the analyses
2) The conventional model is based on a Center Cracked Panel with a SICF of 1.0 . The applied stresses are at the initial flaw location and remain constant over the entire crack growth regime.
3) The edge crack model uses the plate height (b) equal to the nozzle length from the bottom of the nozzle to below the weld. The initial flaw length (a) is equal to the blind zone (1.544 inches). When this is done the ratio a/b (crack-length/plate-height) is larger than the validity limit of 0.6. Therefore, the estimated SIF is considered non-representative.

Waterford Steam Electric Station Unit 3

Component : Reactor Vessel CEDM -"8.8"degree Nozzle, "0" Degree Azimuth 1.3 inch above Nozzle Bottom

Calculation Reference: MRP 75 th Percentile and Flaw Pressurized

Note : ***Used the Metric form of the equation from EPRI MRP 55-Rev. 1*** .
The correction is applied in the determination of the crack extension to obtain the value in inch/hr .

Through Wall Axial Flaw

C01

The first Input is to locate the Reference Line (eg. top of the Blind Zone). The through-wall flaw "Upper Tip" is located at the Reference Line.

Enter the elevation of the Reference Line (eg.Blind Zone) above the nozzle bottom in inches.

$BZ := 1.3$ Location of Blind Zone above nozzle bottom (inch)

The Second Input is the Upper Limit for the evaluation, which is the bottom of the fillet weld leg. This is shown on the Excel spread sheet as weld bottom. Enter this dimension (measured from nozzle bottom) below.

$UL_{Strs.Dist} := 1.786$ Upper axial Extent for Stress Distribution to be used in the analysis (Axial distance above nozzle bottom)

Input Data :-

$L := .794$	Initial Flaw Length TW axial
$OD := 4.05$	Tube OD
$ID := 2.728$	Tube ID
$P_{Int} := 2.235$	Design Operating Pressure (internal)
$Years := 4$	Number of Operating Years
$I_{lim} := 1500$	Iteration limit for Crack Growth loop
$T := 604$	Estimate of Operating Temperature
$\nu := 0.307$	Poissons ratio @ 600 F
$\alpha_{0c} := 2.67 \cdot 10^{-12}$	Constant in MRP PWSCC Model for I-600 Wrought @ 617 deg. F
$Q_g := 31.0$	Thermal activation Energy for Crack Growth {MRP)
$T_{ref} := 617$	Reference Temperature for normalizing Data deg. F

$$C_0 := e^{\left[\frac{-Q_g}{1.103 \cdot 10^{-3}} \cdot \left(\frac{1}{T+459.67} - \frac{1}{T_{ref}+459.67}\right)\right]} \cdot \alpha_{0c} \qquad Tim_{opr} := Years \cdot 365 \cdot 24$$

$$R_o := \frac{OD}{2}$$

$$R_i := \frac{ID}{2} \qquad t := R_o - R_i \qquad R_m := R_i + \frac{t}{2} \qquad CF_{inhr} := 1.417 \cdot 10^5$$

$$C_{blk} := \frac{Tim_{opr}}{I_{lim}} \qquad Prnt_{blk} := \left|\frac{I_{lim}}{50}\right| \qquad l := \frac{L}{2} \qquad L_l := BZ$$

Stress Distribution in the tube. The outside surface is the reference surface for all analysis in accordance with the reference.

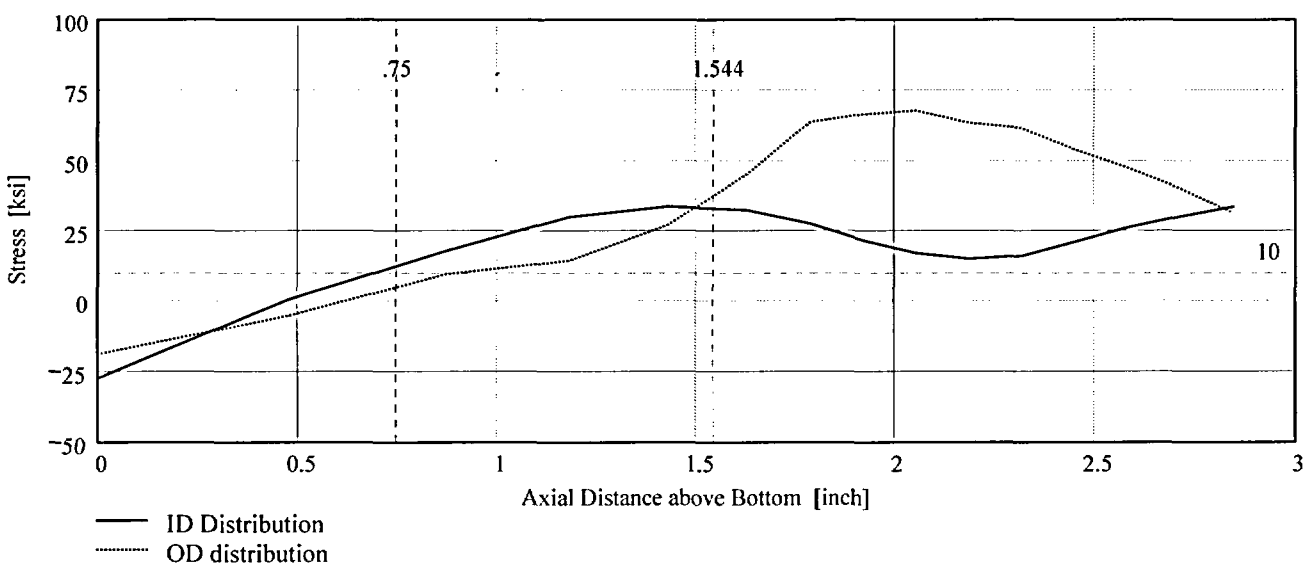
Stress Input Data

Import the Required data from applicable Excel spread Sheet. The column designations are as follows:
Column "0" = Axial distance from Minimum to Maximum recorded on the data sheet (inches)
Column "1" = ID Stress data at each Elevation (ksi)
Column "5" = OD Stress data at each Elevation (ksi)

$Data_{All} :=$

	0	1	2	3	4	5
0	0	-27.4	-24.36	-22.21	-20.41	-18.98
1	0.48	0.63	-1.49	-3.6	-4.44	-5.27
2	0.87	17.66	16.42	14.61	12.41	9.38
3	1.18	29.8	26.05	22.72	18.95	14.2
4	1.43	33.62	27.79	24.8	24.32	26.99
5	1.63	32.36	28.47	27.59	34.28	45.1
6	1.79	27.39	28.92	31.39	43.88	63.72
7	1.92	21.5	25.56	33.55	48.09	66.36
8	2.05	16.94	23.79	34.06	49.47	67.67
9	2.18	14.83	22.26	34.78	49.05	63.38

$AllAxl := Data_{All}^{\langle 0 \rangle}$ $AllID := Data_{All}^{\langle 1 \rangle}$ $AllOD := Data_{All}^{\langle 5 \rangle}$



Observing the stress distribution select the region in the table above labeled $Data_{All}$ that represents the region of interest. This needs to be done especially for distributions that have a large compressive stress at the nozzle bottom and high tensile stresses at the J-weld location. Copy the selection in the above table , click on the "Data" statement below and delete it from the edit menu. Type "Data and the Mathcad "equal" sign (Shift-Colon) then insert the same to the right of the Mathcad Equals sign below (paste symbol).

$$Data := \begin{pmatrix} 0 & -27.404 & -24.356 & -22.209 & -20.407 & -18.978 \\ 0.483 & 0.633 & -1.486 & -3.599 & -4.44 & -5.268 \\ 0.87 & 17.665 & 16.422 & 14.61 & 12.415 & 9.376 \\ 1.18 & 29.798 & 26.049 & 22.723 & 18.95 & 14.201 \\ 1.428 & 33.623 & 27.792 & 24.8 & 24.321 & 26.989 \\ 1.627 & 32.364 & 28.469 & 27.591 & 34.284 & 45.104 \\ 1.786 & 27.394 & 28.918 & 31.388 & 43.882 & 63.718 \end{pmatrix}$$

$Axl := Data^{\langle 0 \rangle}$ $ID := Data^{\langle 1 \rangle}$ $OD := Data^{\langle 5 \rangle}$

$R_{ID} := regress(Axl, ID, 3)$ $R_{OD} := regress(Axl, OD, 3)$

$FL_{Cntr} := BZ - 1$ Flaw Center above Nozzle Bottom

$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - BZ}{20}$$

$$Incr_{Edg} := \frac{UL_{Strs.Dist} - BZ}{20}$$

$RID_{All} := regress(AllAxl, AllID, 3)$ $ROD_{All} := regress(AllAxl, AllOD, 3)$

No User Input required beyond this Point

Calculation to develop Stress Profiles for Analysis

Hoop Stress Profile in the axial direction of the tube for ID and OD locations

$N := 20$ Number of locations for stress profiles

$Loc_0 := FL_{Cntr} - L$

$i := 1 .. N + 3$

$$Incr_i := \begin{cases} 1 & \text{if } i < 4 \\ Inc_{Strs.avg} & \text{otherwise} \end{cases}$$

$$Incr_{edg_i} := \begin{cases} \frac{L_1}{2} & \text{if } i < 4 \\ Incr_{Edg} & \text{otherwise} \end{cases}$$

$$Loc_i := Loc_{i-1} + Incr_i$$

$$Loc1_i := \begin{cases} 0 & \text{if } i = 1 \\ Loc1_{i-1} + Incr_{edg_i} & \text{otherwise} \end{cases}$$

$$SID_i := R_{ID_3} + R_{ID_4} \cdot Loc_i + R_{ID_5} \cdot (Loc_i)^2 + R_{ID_6} \cdot (Loc_i)^3$$

$$SOD_i := R_{OD_3} + R_{OD_4} \cdot Loc_i + R_{OD_5} \cdot (Loc_i)^2 + R_{OD_6} \cdot (Loc_i)^3$$

$$SID_{All_i} := RID_{All_3} + RID_{All_4} \cdot Loc1_i + RID_{All_5} \cdot (Loc1_i)^2 + RID_{All_6} \cdot (Loc1_i)^3$$

$$SOD_{All_i} := ROD_{All_3} + ROD_{All_4} \cdot Loc1_i + ROD_{All_5} \cdot (Loc1_i)^2 + ROD_{All_6} \cdot (Loc1_i)^3$$

Development of Elevation-Averaged stresses at 20 elevations along the tube for use in Fracture Mechanics Model

$$j := 1..N$$

$$S_{id_j} := \begin{cases} \dfrac{SID_j + SID_{j+1} + SID_{j+2}}{3} & \text{if } j = 1 \\ \dfrac{S_{id_{j-1}} \cdot (j+1) + SID_{j+2}}{j+2} & \text{otherwise} \end{cases}$$

$$S_{od_j} := \begin{cases} \dfrac{SOD_j + SOD_{j+1} + SOD_{j+2}}{3} & \text{if } j = 1 \\ \dfrac{S_{od_{j-1}} \cdot (j+1) + SOD_{j+2}}{j+2} & \text{otherwise} \end{cases}$$

$$S_{id.all_j} := \begin{cases} \dfrac{SIDAll_j + SIDAll_{j+1} + SIDAll_{j+2}}{3} & \text{if } j = 1 \\ \dfrac{S_{id.all_{j-1}} \cdot (j+1) + SIDAll_{j+2}}{j+2} & \text{otherwise} \end{cases}$$

$$S_{od.all_j} := \begin{cases} \dfrac{SODAll_j + SODAll_{j+1} + SODAll_{j+2}}{3} & \text{if } j = 1 \\ \dfrac{S_{od.all_{j-1}} \cdot (j+1) + SODAll_{j+2}}{j+2} & \text{otherwise} \end{cases}$$

$$\sigma_{m_j} := \frac{S_{od_j} + S_{id_j}}{2} + P_{Int} \qquad \sigma_{b_j} := \frac{S_{od_j} - S_{id_j}}{2} \qquad \sigma_{m.all_j} := \frac{S_{od.all_j} + S_{id.all_j}}{2} + P_{Int}$$

Stress Distributions for use in Fracture Mechanics Analysis

	Membrane Stress σ_m	Bending Stress σ_b	OD Stress S_{od}	ID Stress S_{id}	Membrane stress (Edge Crack) $\sigma_{m.all}$
0	0	0	0	0	0
1	15.27	-4.731	8.303	17.766	5.53
2	18.819	-4.823	11.761	21.408	12.037
3	21.119	-4.766	14.117	23.65	16.08
4	22.794	-4.625	15.934	25.184	18.889
5	24.115	-4.426	17.454	26.306	20.99
6	25.215	-4.184	18.796	27.164	22.646
7	26.169	-3.905	20.029	27.839	24.005
8	27.022	-3.594	21.193	28.381	25.153
9	27.802	-3.254	22.314	28.821	26.146
10	28.53	-2.885	23.41	29.18	27.022
11	29.217	-2.489	24.493	29.471	27.807
12	29.874	-2.066	25.572	29.705	28.518
13	30.507	-1.617	26.655	29.889	29.169
14	31.122	-1.142	27.745	30.029	29.77
15	31.723	-0.64	28.848	30.128	30.329

$Prop_{Length} := UL_{Strs.Dist} - (FL_{Cntr} + 1)$

$Prop_{Length} = 0.486$

Calculations : Recursive calculations to estimate flaw growth

Recursive loop for Entergy Model and Industry Model

$TWC_{pwscc} :=$

$i \leftarrow 0$

$l_0 \leftarrow l$

$NCB_0 \leftarrow C_{blk}$

while $i \le I_{lim}$

$\sigma_{m.appld} \leftarrow$

σ_{m_1} if $l_i \le l_0$

σ_{m_2} if $l_0 < l_i \le l_0 + Inc_{Strs.avg}$

σ_{m_3} if $l_0 + Inc_{Strs.avg} < l_i \le l_0 + 2 \cdot Inc_{Strs.avg}$

σ_{m_4} if $l_0 + 2 \cdot Inc_{Strs.avg} < l_i \le l_0 + 3 \cdot Inc_{Strs.avg}$

σ_{m_5} if $l_0 + 3 \cdot Inc_{Strs.avg} < l_i \le l_0 + 4 \cdot Inc_{Strs.avg}$

σ_{m_6} if $l_0 + 4 \cdot Inc_{Strs.avg} < l_i \le l_0 + 5 \cdot Inc_{Strs.avg}$

σ_{m_7} if $l_0 + 5 \cdot Inc_{Strs.avg} < l_i \le l_0 + 6 \cdot Inc_{Strs.avg}$

σ_{m_8} if $l_0 + 6 \cdot Inc_{Strs.avg} < l_i \le l_0 + 7 \cdot Inc_{Strs.avg}$

σ_{m_9} if $l_0 + 7 \cdot Inc_{Strs.avg} < l_i \le l_0 + 8 \cdot Inc_{Strs.avg}$

$\sigma_{m_{10}}$ if $l_0 + 8 \cdot Inc_{Strs.avg} < l_i \le l_0 + 9 \cdot Inc_{Strs.avg}$

$\sigma_{m_{11}}$ if $l_0 + 9 \cdot Inc_{Strs.avg} < l_i \le l_0 + 10 \cdot Inc_{Strs.avg}$

$\sigma_{m_{12}}$ if $l_0 + 10 \cdot Inc_{Strs.avg} < l_i \le l_0 + 11 \cdot Inc_{Strs.avg}$

$\sigma_{m_{13}}$ if $l_0 + 11 \cdot Inc_{Strs.avg} < l_i \le l_0 + 12 \cdot Inc_{Strs.avg}$

$\sigma_{m_{14}}$ if $l_0 + 12 \cdot Inc_{Strs.avg} < l_i \le l_0 + 13 \cdot Inc_{Strs.avg}$

$\sigma_{m_{15}}$ if $l_0 + 13 \cdot Inc_{Strs.avg} < l_i \le l_0 + 14 \cdot Inc_{Strs.avg}$

$\sigma_{m_{16}}$ if $l_0 + 14 \cdot Inc_{Strs.avg} < l_i \le l_0 + 15 \cdot Inc_{Strs.avg}$

$\sigma_{m_{17}}$ if $l_0 + 15 \cdot Inc_{Strs.avg} < l_i \le l_0 + 16 \cdot Inc_{Strs.avg}$

$\sigma_{m_{18}}$ if $l_0 + 16 \cdot Inc_{Strs.avg} < l_i \le l_0 + 17 \cdot Inc_{Strs.avg}$

$\sigma_{m_{19}}$ if $l_0 + 17 \cdot Inc_{Strs.avg} < l_i \le l_0 + 18 \cdot Inc_{Strs.avg}$

$\sigma_{m_{20}}$ otherwise

$$\sigma_{b.appld} \leftarrow \begin{cases} \sigma_{b_1} & \text{if } l_i \le l_0 \\ \sigma_{b_2} & \text{if } l_0 < l_i \le l_0 + Inc_{Strs.avg} \\ \sigma_{b_3} & \text{if } l_0 + Inc_{Strs.avg} < l_i \le l_0 + 2 \cdot Inc_{Strs.avg} \\ \sigma_{b_4} & \text{if } l_0 + 2 \cdot Inc_{Strs.avg} < l_i \le l_0 + 3 \cdot Inc_{Strs.avg} \\ \sigma_{b_5} & \text{if } l_0 + 3 \cdot Inc_{Strs.avg} < l_i \le l_0 + 4 \cdot Inc_{Strs.avg} \\ \sigma_{b_6} & \text{if } l_0 + 4 \cdot Inc_{Strs.avg} < l_i \le l_0 + 5 \cdot Inc_{Strs.avg} \\ \sigma_{b_7} & \text{if } l_0 + 5 \cdot Inc_{Strs.avg} < l_i \le l_0 + 6 \cdot Inc_{Strs.avg} \\ \sigma_{b_8} & \text{if } l_0 + 6 \cdot Inc_{Strs.avg} < l_i \le l_0 + 7 \cdot Inc_{Strs.avg} \\ \sigma_{b_9} & \text{if } l_0 + 7 \cdot Inc_{Strs.avg} < l_i \le l_0 + 8 \cdot Inc_{Strs.avg} \\ \sigma_{b_{10}} & \text{if } l_0 + 8 \cdot Inc_{Strs.avg} < l_i \le l_0 + 9 \cdot Inc_{Strs.avg} \\ \sigma_{b_{11}} & \text{if } l_0 + 9 \cdot Inc_{Strs.avg} < l_i \le l_0 + 10 \cdot Inc_{Strs.avg} \\ \sigma_{b_{12}} & \text{if } l_0 + 10 \cdot Inc_{Strs.avg} < l_i \le l_0 + 11 \cdot Inc_{Strs.avg} \\ \sigma_{b_{13}} & \text{if } l_0 + 11 \cdot Inc_{Strs.avg} < l_i \le l_0 + 12 \cdot Inc_{Strs.avg} \\ \sigma_{b_{14}} & \text{if } l_0 + 12 \cdot Inc_{Strs.avg} < l_i \le l_0 + 13 \cdot Inc_{Strs.avg} \\ \sigma_{b_{15}} & \text{if } l_0 + 13 \cdot Inc_{Strs.avg} < l_i \le l_0 + 14 \cdot Inc_{Strs.avg} \\ \sigma_{b_{16}} & \text{if } l_0 + 14 \cdot Inc_{Strs.avg} < l_i \le l_0 + 15 \cdot Inc_{Strs.avg} \\ \sigma_{b_{17}} & \text{if } l_0 + 15 \cdot Inc_{Strs.avg} < l_i \le l_0 + 16 \cdot Inc_{Strs.avg} \\ \sigma_{b_{18}} & \text{if } l_0 + 16 \cdot Inc_{Strs.avg} < l_i \le l_0 + 17 \cdot Inc_{Strs.avg} \\ \sigma_{b_{19}} & \text{if } l_0 + 17 \cdot Inc_{Strs.avg} < l_i \le l_0 + 18 \cdot Inc_{Strs.avg} \\ \sigma_{b_{20}} & \text{otherwise} \end{cases}$$

$$\lambda_i \leftarrow \left[12 \cdot \left(1 - \nu^2\right)\right]^{0.25} \cdot \frac{l_i}{\left(R_m \cdot t\right)^{0.5}}$$

$$A_{em_i} \leftarrow 1.0090 + 0.3621 \cdot \lambda_i + 0.0565 \cdot (\lambda_i)^2 - 0.0082 \cdot (\lambda_i)^3 + 0.0004 \cdot (\lambda_i)^4 - 8.326 \cdot 10^{-6} \cdot (\lambda_i)^5$$

$$A_{bm_i} \leftarrow -0.0063 + 0.0919 \cdot \lambda_i - 0.0168 \cdot (\lambda_i)^2 - 0.0052 \cdot (\lambda_i)^3 + 0.0008 \cdot (\lambda_i)^4 - 2.9701 \cdot 10^{-5} \cdot (\lambda_i)^5$$

$$A_{eb_i} \leftarrow 0.0029 + 0.0707 \cdot \lambda_i - 0.0197 \cdot (\lambda_i)^2 + 0.0034 \cdot (\lambda_i)^3 - 0.0003 \cdot (\lambda_i)^4 + 8.8052 \cdot 10^{-6} \cdot (\lambda_i)^5$$

$$A_{bb_i} \leftarrow 0.9961 - 0.3806 \cdot \lambda_i + 0.1239 \cdot (\lambda_i)^2 - 0.0211 \cdot (\lambda_i)^3 + 0.0017 \cdot (\lambda_i)^4 - 4.9939 \cdot 10^{-5} \cdot (\lambda_i)^5$$

$K_{pm_i} \leftarrow \sigma_{m.appld} \cdot (\pi \cdot l_i)^{0.5}$

$K_{pb_i} \leftarrow \sigma_{b.appld} \cdot (\pi \cdot l_i)^{0.5}$

$K_{membrnOD_i} \leftarrow (A_{em_i} + A_{bm_i}) \cdot K_{pm_i}$

$K_{membrnID_i} \leftarrow (A_{em_i} - A_{bm_i}) \cdot K_{pm_i}$

$K_{bendOD_i} \leftarrow (A_{eb_i} + A_{bb_i}) \cdot K_{pb_i}$

$K_{bendID_i} \leftarrow (A_{eb_i} - A_{bb_i}) \cdot K_{pb_i}$

$K_{AppOD_i} \leftarrow K_{membrnOD_i} + K_{bendOD_i}$

$K_{AppID_i} \leftarrow K_{membrnID_i} + K_{bendID_i}$

$K_{WH_i} \leftarrow \sigma_{m_i} \cdot (\pi \cdot l_i)^{0.5}$

$K_{App_i} \leftarrow \dfrac{K_{AppOD_i} + K_{AppID_i}}{2}$

$K_{WH.lcnr.Strs_i} \leftarrow \sigma_{m.appld} \cdot (\pi \cdot l_i)^{0.5}$

$K_{\alpha_i} \leftarrow K_{App_i} \cdot 1.099$

$K_{\alpha_i} \leftarrow \begin{cases} 9.0 & \text{if } K_{\alpha_i} \le 9.0 \\ K_{\alpha_i} & \text{otherwise} \end{cases}$

$D_{len_i} \leftarrow C_0 \cdot (K_{\alpha_i} - 9.0)^{1.16}$

$D_{lengrth_i} \leftarrow \begin{cases} D_{len_i} \cdot CF_{inhr} \cdot C_{blk} & \text{if } K_{\alpha_i} \le 80.0 \\ 4 \cdot 10^{-10} \cdot CF_{inhr} \cdot C_{blk} & \text{otherwise} \end{cases}$

$output_{(i,0)} \leftarrow i$

$output_{(i,1)} \leftarrow \dfrac{NCB_i}{365 \cdot 24}$

$output_{(i,2)} \leftarrow \lambda_i$

$output_{(i,3)} \leftarrow l_i - l_0$

$output_{(i,4)} \leftarrow l_i$

$output_{(i,5)} \leftarrow K_{App_i}$

$output_{(i,6)} \leftarrow K_{AppOD_i}$

$output_{(i,7)} \leftarrow K_{AppID_i}$

$output_{(i,8)} \leftarrow K_{membrnOD_i}$

$output_{(i,8)} \leftarrow K_{membrnOD_i}$

$output_{(i,9)} \leftarrow K_{membrnID_i}$

$output_{(i,10)} \leftarrow K_{bendOD_i}$

$output_{(i,11)} \leftarrow K_{bendID_i}$

$output_{(i,12)} \leftarrow K_{WH_i}$

$output_{(i,13)} \leftarrow K_{WH.Icnr.Strs_i}$

$i \leftarrow i + 1$

$l_i \leftarrow l_{i-1} + D_{lengrth_{i-1}}$

$NCB_i \leftarrow NCB_{i-1} + C_{blk}$

output

Recursive Loop For Edge Crack Model

$TWCEDG_{pwscc} :=$

$i \leftarrow 0$

$L1_0 \leftarrow |L_1|$

$NCB_0 \leftarrow C_{blk}$

$\text{while } i \le I_{lim}$

$\sigma_{m.appld} \leftarrow$
- $\sigma_{m.all_1}$ if $L1_i \le L1_0$
- $\sigma_{m.all_2}$ if $L1_0 < L1_i \le L1_0 + Incr_{Edg}$
- $\sigma_{m.all_3}$ if $L1_0 + Incr_{Edg} < L1_i \le L1_i + 2 \cdot Incr_{Edg}$
- $\sigma_{m.all_4}$ if $L1_0 + 2 \cdot Incr_{Edg} < L1_i \le L1_0 + 3 \cdot Incr_{Edg}$
- $\sigma_{m.all_5}$ if $L1_0 + 3 \cdot Incr_{Edg} < L1_i \le L1_0 + 4 \cdot Incr_{Edg}$
- $\sigma_{m.all_6}$ if $L1_0 + 4 \cdot Incr_{Edg} < L1_i \le L1_0 + 5 \cdot Incr_{Edg}$
- $\sigma_{m.all_7}$ if $L1_0 + 5 \cdot Incr_{Edg} < L1_i \le L1_0 + 6 \cdot Incr_{Edg}$
- $\sigma_{m.all_8}$ if $L1_0 + 6 \cdot Incr_{Edg} < L1_i \le L1_0 + 7 \cdot Incr_{Edg}$
- $\sigma_{m.all_9}$ if $L1_0 + 7 \cdot Incr_{Edg} < L1_i \le L1_0 + 8 \cdot Incr_{Edg}$
- $\sigma_{m.all_{10}}$ if $L1_0 + 8 \cdot Incr_{Edg} < L1_i \le L1_0 + 9 \cdot Incr_{Edg}$
- $\sigma_{m.all_{11}}$ if $L1_0 + 9 \cdot Incr_{Edg} < L1_i \le L1_0 + 10 \cdot Incr_{Edg}$
- $\sigma_{m.all_{12}}$ if $L1_0 + 10 \cdot Incr_{Edg} < L1_i \le L1_0 + 11 \cdot Incr_{Edg}$
- $\sigma_{m.all_{13}}$ if $L1_0 + 11 \cdot Incr_{Edg} < L1_i \le L1_0 + 12 \cdot Incr_{Edg}$
- $\sigma_{m.all_{14}}$ if $L1_0 + 12 \cdot Incr_{Edg} < L1_i \le L1_0 + 13 \cdot Incr_{Edg}$
- $\sigma_{m.all_{15}}$ if $L1_0 + 13 \cdot Incr_{Edg} < L1_i \le L1_0 + 14 \cdot Incr_{Edg}$
- $\sigma_{m.all_{16}}$ if $L1_0 + 14 \cdot Incr_{Edg} < L1_i \le L1_0 + 15 \cdot Incr_{Edg}$
- $\sigma_{m.all_{17}}$ if $L1_0 + 15 \cdot Incr_{Edg} < L1_i \le L1_0 + 16 \cdot Incr_{Edg}$
- $\sigma_{m.all_{18}}$ if $L1_0 + 16 \cdot Incr_{Edg} < L1_i \le L1_0 + 17 \cdot Incr_{Edg}$
- $\sigma_{m.all_{19}}$ if $L1_0 + 17 \cdot Incr_{Edg} < L1_i \le L1_0 + 18 \cdot Incr_{Edg}$
- $\sigma_{m.all_{20}}$ otherwise

$b \leftarrow UL_{Strs.Dist}$

$$Z_i \leftarrow \begin{cases} 0.99 & \text{if } \frac{L1_i}{b} \geq 1.0 \\ \frac{L1_i}{b} & \text{otherwise} \end{cases}$$

$$F_{a.b_i} \leftarrow 1.12 - 0.231 \cdot (Z_i) + 10.55 \cdot (Z_i)^2 - 21.72 \cdot (Z_i)^3 + 30.39 \cdot (Z_i)^4$$

$$K_{edg.Crk_i} \leftarrow \begin{cases} \sigma_{m.appld} \cdot \sqrt{\pi \cdot L1_i} & \text{if } \left(\sigma_{m.appld} \cdot \sqrt{\pi \cdot L1_i}\right) \leq 0 \\ \sigma_{m.appld} \cdot \left(\pi \cdot L1_i\right)^{0.5} \cdot F_{a.b_i} & \text{otherwise} \end{cases}$$

$$K_{A_i} \leftarrow K_{edg.Crk_i} \cdot 1.099$$

$$K_{\alpha_i} \leftarrow \begin{cases} 9.0 & \text{if } K_{A_i} \leq 9.0 \\ K_{A_i} & \text{otherwise} \end{cases}$$

$$D_{len_i} \leftarrow C_0 \cdot \left(K_{\alpha_i} - 9.0\right)^{1.16}$$

$$D_{lengrth_i} \leftarrow \begin{cases} D_{len_i} \cdot CF_{inhr} \cdot C_{blk} & \text{if } K_{\alpha_i} \leq 80.0 \\ 4 \cdot 10^{-10} \cdot CF_{inhr} \cdot C_{blk} & \text{otherwise} \end{cases}$$

$$output_{(i,0)} \leftarrow i$$

$$output_{(i,1)} \leftarrow \frac{NCB_i}{365 \cdot 24}$$

$$output_{(i,2)} \leftarrow L1_i - L1_0$$

$$output_{(i,3)} \leftarrow D_{lengrth_i}$$

$$output_{(i,4)} \leftarrow K_{edg.Crk_i}$$

$$output_{(i,5)} \leftarrow F_{a.b_i}$$

$$i \leftarrow i + 1$$

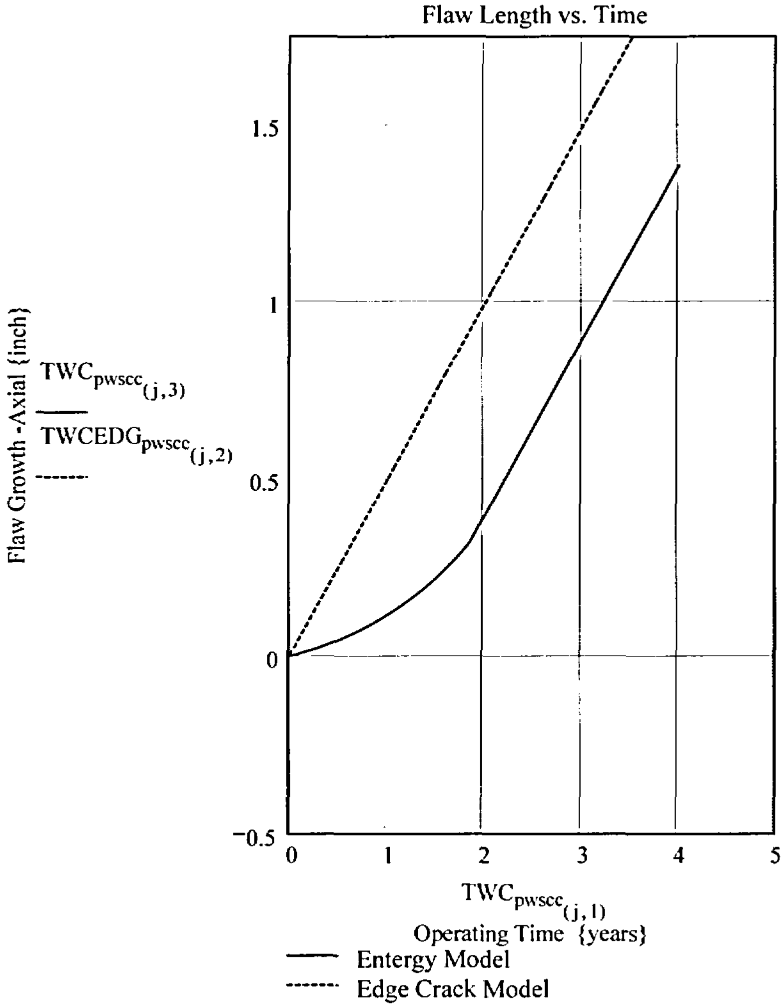
$$L1_i \leftarrow L1_{i-1} + D_{lengrth_{i-1}}$$

$$NCB_i \leftarrow NCB_{i-1} + C_{blk}$$

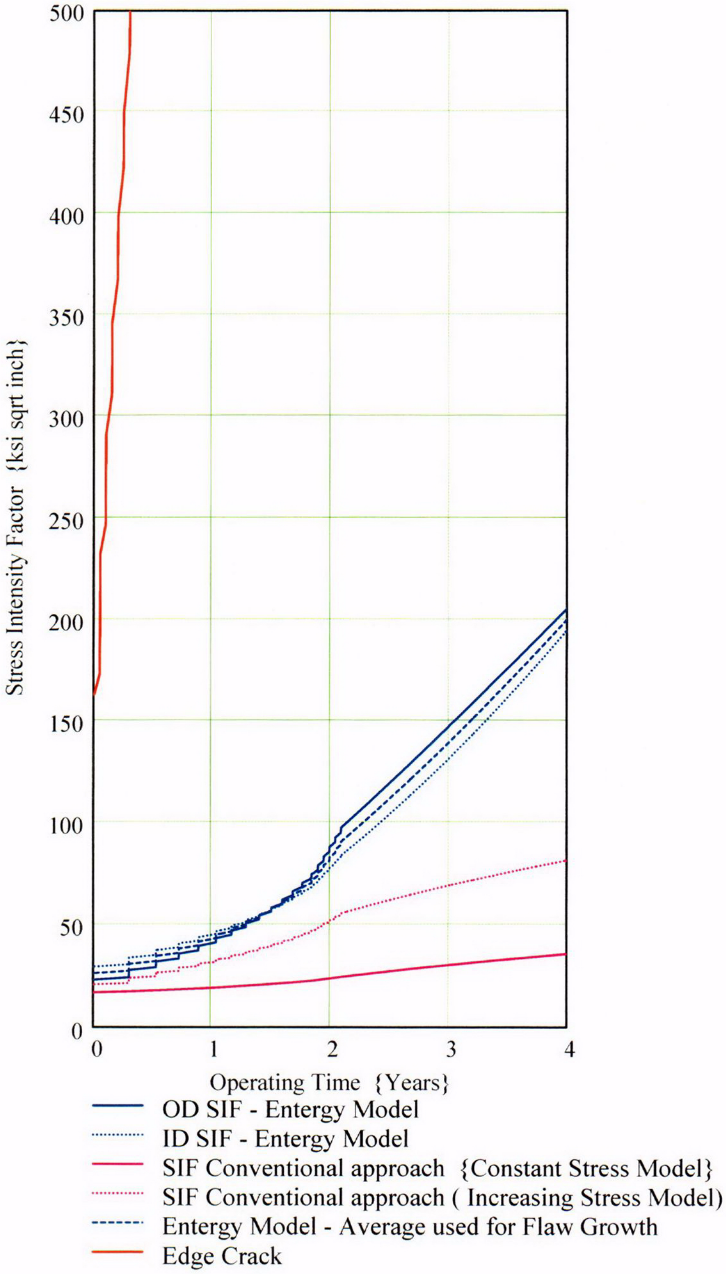
output

$$j := 1 .. l_{lim}$$

$Prop_{Length} = 0.486$



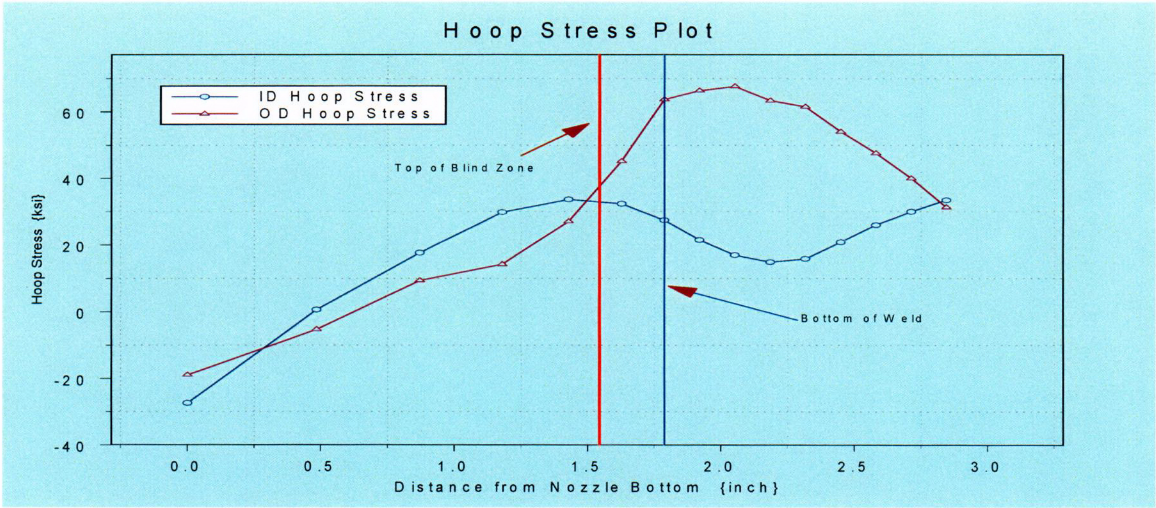
Comparison for crack growth between Edge Crack and Current Model. The edge crack model provides a constant crack growth rate equal to the asymptotic growth rate of about 05. inch/year. The edge crack model produces a SIF much greater than the asymptotic value of 90 ksi* in^0.5 or 80 Mpa*m^0.5. This is because the "a/b" ratio (crack-length/plate-height) is significantly greater than the validity limit of 0.6. In order to meet the "a/b" ratio validity limit of 0.6 the crack length, for the assumed plate height cannot be greater than 1.073 inches, which is lower than the blind zone length of 1.544 inches. As shown in attachment 3 of this appendix, assuming a longer plate height produces SICF that can be lower than the membrane component SICF. Therefore, the SICF for the modeled edge crack configuration is considered incorrect because the validity regime is violated (since a/b ratio is in excess of 0.6).



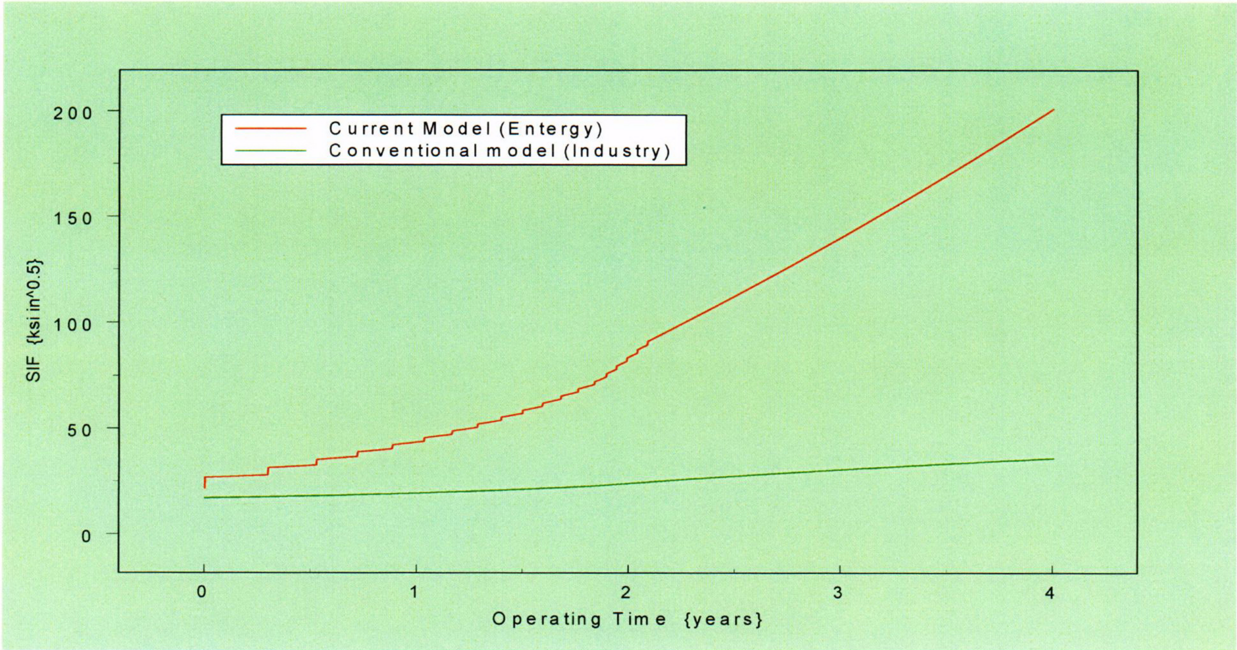
The SIF for the current model is always higher than the conventional model. Hence the estimated crack growth produced by the current model will be higher than that produced by the conventional model. Hence the current model is shown to be more conservative than the conventional model. The SIF for the edge crack is very high owing to the large SICF produce by a large a/b ratio, which is beyond the validity limit for the determination of the SICF (discussed in the previous figure).

C02

Axum Plot for the ID and OD Stress distribution along nozzle length used in the comparison



Axum plot showing the comparison for the SIF between the Current and Conventional Models.



Evaluation of Curve fit for Stress Profile Generation along the Tube Axis

In this worksheet the effect of data set selection for curve fitting, using a third order polynomial is evaluated. The data table below is form a data set used in the CEDM analyses. This data set is imported directly from the Excel spreadsheet provided by Dominion Engineering for the CEDM. The evaluation considers the full data set and a limited data set spanning the region of interest.
The purpose of this evaluation is to demonstrate the need for the proper selection of a subset of nodal stress data (in the region of interest) to ensure the accuracy of the analysis.

Data set imported from Excel spreadsheet.

AllData :=

	0	1	2	3	4	5
0	0	19.02	9.58	3.37	-2.08	-7.96
1	1.35	4.88	-0.01	-3.32	-6.54	-9.39
2	2.43	4.12	-0.78	-2.08	-2.21	-2.99
3	3.29	11.59	9.74	9.09	5.5	1.99
4	3.99	15.7	11.01	11.9	12.48	10.55
5	4.54	1	3.69	8.87	18.84	26.6
6	4.99	-19.25	-7.47	4.61	28	35.85
7	5.16	-28.8	-16.47	1.4	28.03	40.15
8	5.33	-31.34	-20.97	-0.5	28.53	38.49
9	5.5	-32.98	-22.94	-2.56	28.32	38
10	5.68	-34.3	-23.31	-2.31	25.93	41.38
11	5.85	-35.44	-22.61	-1.59	23.03	31.35
12	6.02	-33.28	-18.55	-0.38	19.78	39.55
13	6.2	-27.73	-13.19	2.94	18.4	35.15
14	6.37	-18.45	-7.65	5.99	18.87	29.93
15	6.54	-6.28	-1.9	9.27	20.26	23.73
16	6.72	5.11	4.63	13.32	22.66	23.44
17	6.89	15.03	11.24	16.3	22.16	22.62
18	7.06	25.53	19.11	20.22	23.17	20.07

$AxlLen := AllData^{\langle 0 \rangle}$ $\qquad IDAll := AllData^{\langle 1 \rangle}$ $\qquad MidWall := AllData^{\langle 3 \rangle}$ $\qquad ODAll := AllData^{\langle 5 \rangle}$

$$\text{Data} := \begin{pmatrix} 0 & 19.022 & 9.579 & 3.372 & -2.08 & -7.96 \\ 1.348 & 4.884 & -0.011 & -3.322 & -6.536 & -9.387 \\ 2.427 & 4.116 & -0.784 & -2.075 & -2.213 & -2.987 \\ 3.292 & 11.593 & 9.74 & 9.093 & 5.504 & 1.989 \\ 3.985 & 15.695 & 11.005 & 11.902 & 12.478 & 10.549 \\ 4.54 & 0.999 & 3.689 & 8.873 & 18.835 & 26.599 \\ 4.985 & -19.249 & -7.467 & 4.613 & 28.003 & 35.847 \\ 5.158 & -28.802 & -16.466 & 1.395 & 28.031 & 40.149 \end{pmatrix}$$

Selected subset from the data table above

$\text{ALen} := \text{Data}^{\langle 0 \rangle}$ $\quad ID_{lim} := \text{Data}^{\langle 1 \rangle}$ $\quad MW_{lim} := \text{Data}^{\langle 3 \rangle}$ $\quad OD_{lim} := \text{Data}^{\langle 5 \rangle}$

Regression for the full data set

$RID_{All} := \text{regress}(\text{AxlLen}, \text{IDAll}, 3)$

$RMW_{All} := \text{regress}(\text{AxlLen}, \text{MidWall}, 3)$

$ROD_{All} := \text{regress}(\text{AxlLen}, \text{ODAll}, 3)$

Regression for selected data set

$RID_{data} := \text{regress}(\text{ALen}, ID_{lim}, 3)$

$RMW_{data} := \text{regress}(\text{ALen}, MW_{lim}, 3)$

$ROD_{data} := \text{regress}(\text{ALen}, OD_{lim}, 3)$

$\text{Bottom} := 0 \quad \text{Top} := 7.0 \quad WB := 4$

$\text{Dist} := \text{Top} - \text{Bottom} \quad \text{Incr} := \dfrac{\text{Dist}}{20} \quad D := WB - \text{Bottom} \quad \text{Incr1} := \dfrac{D}{20}$

$L_0 := 0 - \text{Incr}$

$\text{Len}_0 := 0 - \text{Incr1}$

$i := 1..20$

$L_i := L_{i-1} + \text{Incr}$

$\text{Len}_i := \text{Len}_{i-1} + \text{Incr1}$

Determination of Stresses at three locations across wall thickness, using the full data set

$$ID_{all_i} := RID_{All_3} + RID_{All_4} \cdot L_i + RID_{All_5} \cdot \left(L_i\right)^2 + RID_{All_6} \cdot \left(L_i\right)^3$$

$$MW_{all_i} := RMW_{All_3} + RMW_{All_4} \cdot L_i + RMW_{All_5} \cdot \left(L_i\right)^2 + RMW_{All_6} \cdot \left(L_i\right)^3$$

$$OD_{all_i} := ROD_{All_3} + ROD_{All_4} \cdot L_i + ROD_{All_5} \cdot \left(L_i\right)^2 + ROD_{All_6} \cdot \left(L_i\right)^3$$

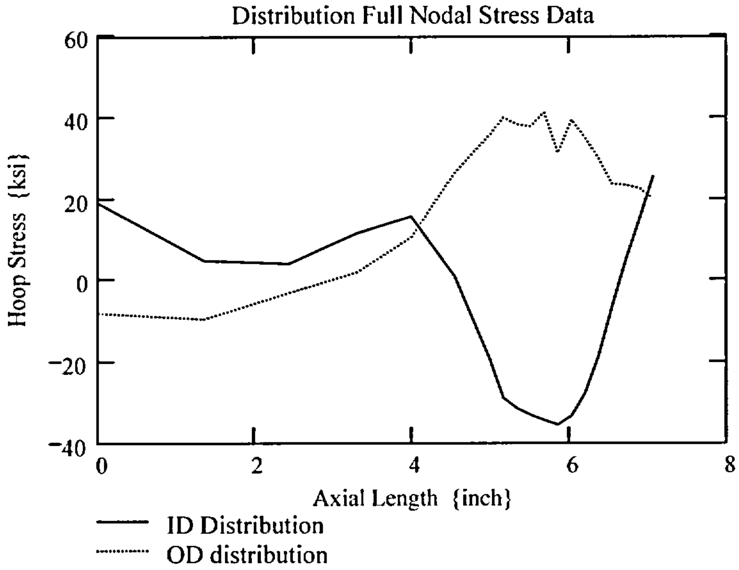
Determination of Stresses at three locations across wall thickness, using the selected data set

$$ID_{data_i} := RID_{data_3} + RID_{data_4} \cdot Len_i + RID_{data_5} \cdot \left(Len_i\right)^2 + RID_{data_6} \cdot \left(Len_i\right)^3$$

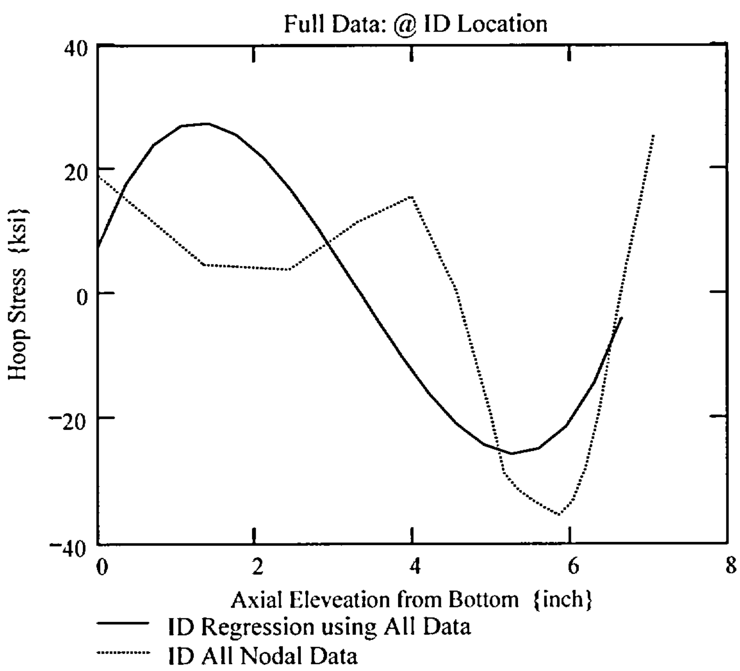
$$MW_{data_i} := RMW_{data_3} + RMW_{data_4} \cdot Len_i + RMW_{data_5} \cdot \left(Len_i\right)^2 + \left(RMW_{data_6}\right) \cdot \left(Len_i\right)^3$$

$$OD_{data_i} := ROD_{data_3} + ROD_{data_4} \cdot Len_i + ROD_{data_5} \cdot \left(Len_i\right)^2 + ROD_{data_6} \cdot \left(Len_i\right)^3$$

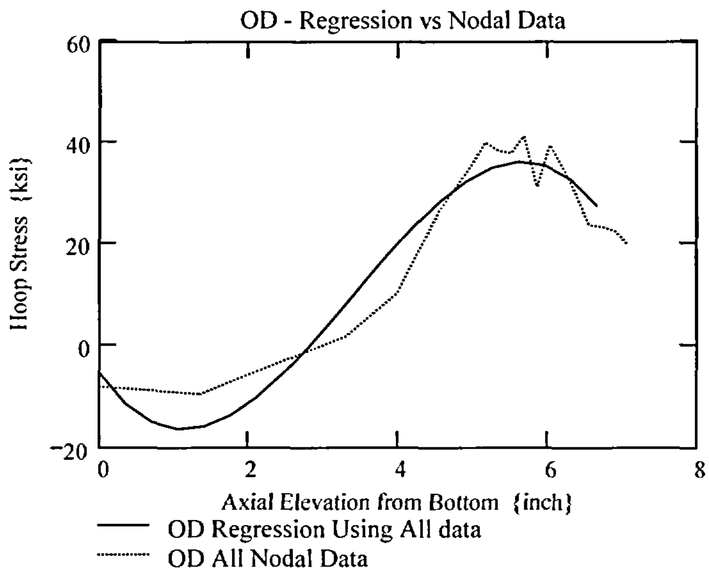
Graphical Display of Results



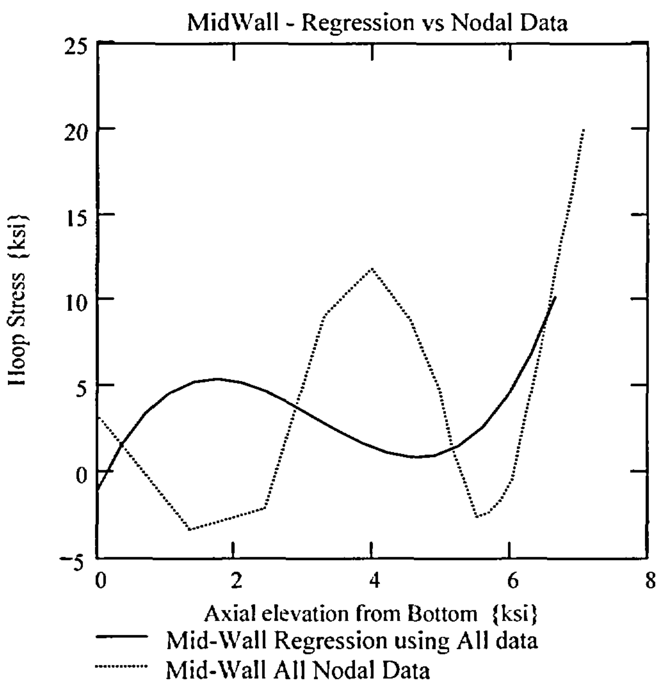
Nodal stress data plotted for the ID and the OD distribution. This plot is based on the full data set.



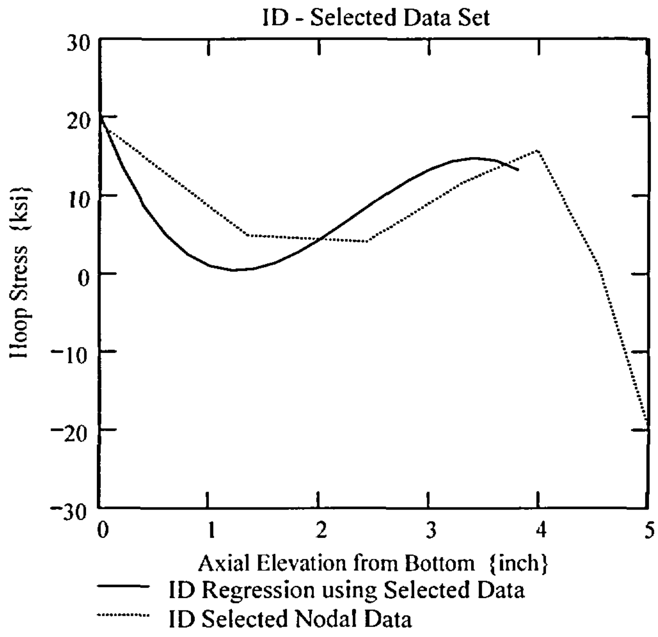
ID Stress Distribution:-
Comparison of regression fit versus the full data set. The third-order polynomial does not provide an accurate fit. The trend in the data is captured.



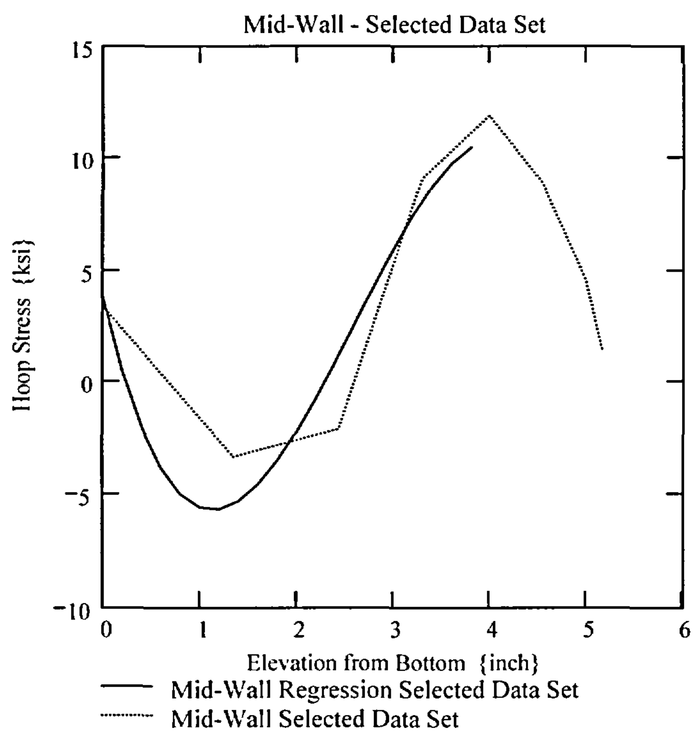
OD Stress Distribution:-
Comparison of regression fit versus the full data set. The third-order polynomial does not provide an accurate fit. The trend in the data is captured.



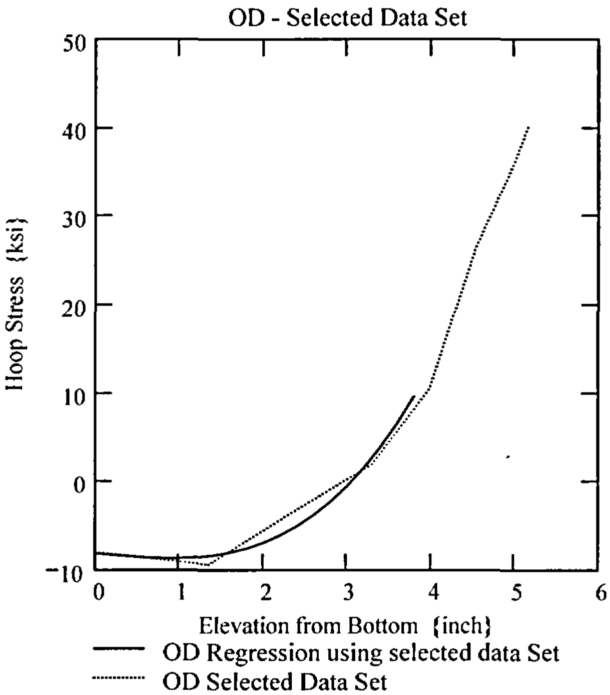
Mid-Wall Stress Distribution:-
Comparison of regression fit versus the full data set. The third-order polynomial does not provide an accurate fit. The trend in the data is captured.



ID Stress Distribution (Selected Data Set):-
Comparison of regression fit versus the selected data set. The third-order polynomial provides an accurate fit.

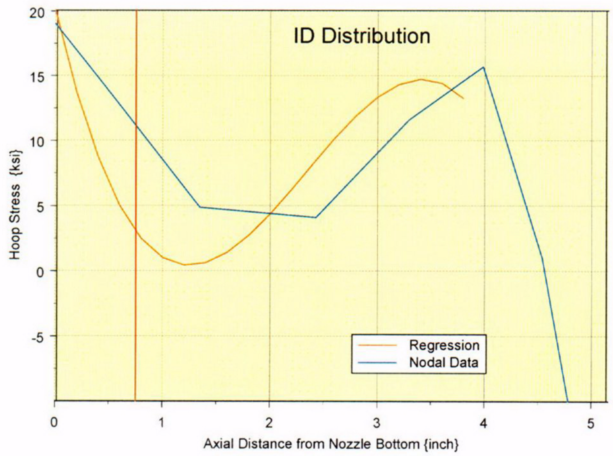


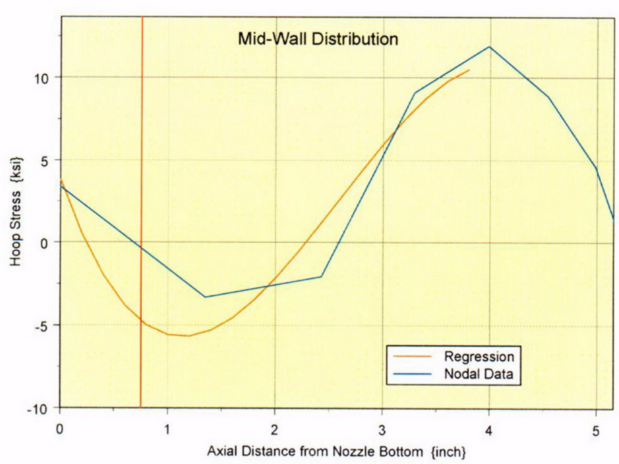
Mid-Wall Stress Distribution (Selected Data Set):-
Comparison of regression fit versus the selected data set. The third-order polynomial provides an accurate fit.

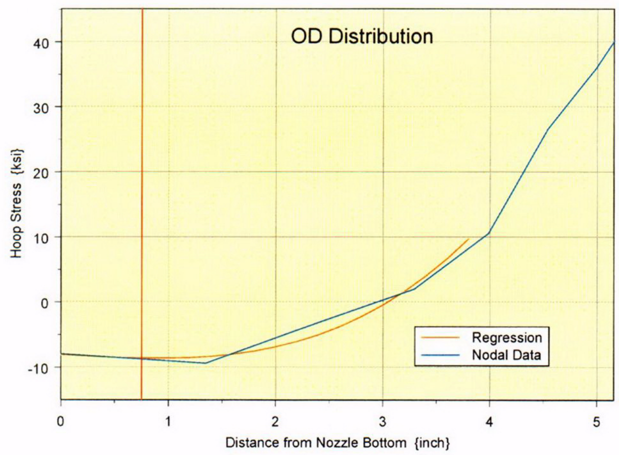


OD Stress Distribution (Selected Data Set):- Comparison of regression fit versus the selected data set. The third-order polynomial provides an accurate fit.

Conclusion :- By selecting the data judiciously, in the region of interest, facilitates an accurate regression fit of the data.


ID Distribution
Hoop Stress {ksi}
Axial Distance from Nozzle Bottom {inch}
Regression
Nodal Data
20
15
10
5
0
-5
0
1
2
3
4
5


Mid-Wall Distribution
Hoop Stress {ksi}
Axial Distance from Nozzle Bottom {inch}
Regression
Nodal Data
10
5
0
-5
-10
0
1
2
3
4
5


OD Distribution
Hoop Stress {ksi}
40
30
20
10
0
-10
0
1
2
3
4
5
Distance from Nozzle Bottom {inch}
Regression
Nodal Data

ENCLOSURE 5

CNRO-2003-00038

LICENSEE-IDENTIFIED COMMITMENTS

LICENSEE-IDENTIFIED COMMITMENTS

COMMITMENT	TYPE (Check one) ONE-TIME ACTION	CONTINUING COMPLIANCE	SCHEDULED COMPLETION DATE
1. The final results of the inspections will be included in the 60-day report submitted to the NRC in accordance with Section IV.E of the Order.	X		60 days after startup from the next refueling outage
2. If the NRC staff finds that the crack-growth formula in MRP-55 is unacceptable, Entergy shall revise its analysis that justifies relaxation of the Order within 30 days after the NRC informs Entergy of an NRC-approved crack-growth formula.	X		Within 30 days after the NRC informs Entergy of an NRC-approved crack-growth formula.
3. If Entergy's revised analysis (#2, above) shows that the crack growth acceptance criteria are exceeded prior to the end of Operating Cycle 13 following the upcoming refueling outage), Entergy will, within 72 hours, submit to the NRC written justification for continued operation.	X		Within 72 hours from completing the revised analysis in #2, above.
4. If the revised analysis (#2, above) shows that the crack growth acceptance criteria are exceeded during the subsequent operating cycle, Entergy shall, within 30 days, submit the revised analysis for NRC review.	X		Within 30 days from completing the revised analysis in #2, above.
5. If the revised analysis (#2, above) shows that the crack growth acceptance criteria are not exceeded during either Operating Cycle 13 or the subsequent operating cycle, Entergy shall, within 30 days, submit a letter to the NRC confirming that its analysis has been revised.	X		Within 30 days from completing the revised analysis in #2, above.
6. Any future crack-growth analyses performed for Operating Cycle 13 and future cycles for RPV head penetrations will be based on an acceptable crack growth rate formula.		X	N/A