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COMPARISON OF THE ACCURACY OF NINE METHODS FOR DETERMINING THE REMAINING STRENGTH OF CORRODED PIPE

to

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COMPARISON OF THE ACCURACY OF NINE METHODS FOR DETERMINING THE REMAINING STRENGTH OF CORRODED PIPE

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INTRODUCTION

This report summarizes the results of a comparison of the accuracy of nine methods of determining the remaining strength of corroded pipe. The nine methods are

- ASME B31G
- Modified ASME B31G
- API RP 579 (Level 1)
- DNV 2000
- RAM 1 (SMYS)
- RAM 2 (SMTS)
- RAM 3 (UTS)
- ABS 2000
- PCORRC.

All nine methods provide estimates of the burst pressure of pipes affected by corrosion-caused metal loss. All nine considered the depth of penetration of the corrosion as a percentage of the wall thickness and the strength of the material. Some consider the axial length of the metal loss while others do not. In this report, the nine methods are evaluated for accuracy on the basis of results of corroded pipe burst tests obtained from the A.G.A./ PRC Database of Corroded Pipe Burst Tests. This database was created and used during the Continued Validation of RSTRENG(1). Of the 215 incidents contained in the database, 48 were not used in the Continued Validation of RSTRENG(1) or in this comparison for the following reasons

1 – Through-wall defect
7 – Spiral orientation of corroded area
14 – Obvious interaction of corroded areas
2 – Defect free burst test
1 – Fatigue crack in pit caused premature leak
12 – No failure
4 – Cut, removed, rewelded

2 – Circumferential failure
3 – Actual failure pressure >1.5 times predicted values probably because actual yield strength was not measured
2 – Brittle behavior.

Each assessment method is compared to the actual failure pressures recorded for the remaining 167 tests. Actual yield strength, tensile strength, and wall thickness values were used in the calculations whenever they were available. If actual values were unavailable, then the API 5L nominal values for the particular pipe were used.

All nine methods apply strictly to pipe materials that behave in the ductile manner. Thus, they should be applied only to pipelines with operating temperatures sufficiently high to assure ductile fracture initiation. This temperature is difficult to measure directly but can be estimated as approximately 60°F below the fracture propagation transition temperature (FPTT) of the material. The FPTT can be estimated using Charpy V-notch testing.

BACKGROUND

The remaining strength of corroded pipe can be calculated by a number of methods, some more accurate than others. The oldest and one of the most commonly used methods, the ASME B31G criterion(2), though it was not called that until 1984, was established in the late 1960s as an offshoot of Maxey's "NG-18 Surface-Flaw Equation"(3). Maxey's work, supported by the American Gas Association's Pipeline Research Committee resulted in an extremely versatile equation that has been and is still used for a wide variety of pipeline applications. In any case, the simple criterion that later became known as the ASME B31G criterion was part of a more rigorous calculation method known and used in the late 1960s and early 1970s to provide more exact calculations of remaining strength. At a time when the only choices for complex calculations were either slide rules, cumbersome and slow electric calculators, or mainframe digital computers, the use of the more rigorous technique, later to be embodied in PC-software versions as RSTRENG(1) and KAPA, was limited to analyzing failures of corroded pipe and evaluating research burst tests.

Interest in computing the remaining strength of corroded pipe remained low until the mid 1980s when significant improvements in in-line-inspection technologies made possible accurate characterization of both external and internal corrosion-caused metal loss in buried natural gas and petroleum pipelines. With the mushrooming of interest in methods for evaluating corroded pipe, several new evaluation methods emerged throughout the late 1980s and the 1990s (e.g., $PCORR_C$[4], API RP579[5], and DNV 2000[6]). More recently, at least to the authors' knowledge, additional methods called RAM 1, RAM 2, RAM 3, and ABS 2000, have appeared. Aside from the last four, the other methods mentioned above all have several things in common. They all involve calculating the remaining strength of corroded pipe on the basis of the depth of penetration of the metal loss, the axial length of the metal loss, a material-strength parameter (either flow stress or ultimate tensile strength), and a variation of the "Folias" factor. The Folias factor was first proposed in the public domain in 1964[7] as a shell-theory-based factor to describe the elastic stress field and deformation pattern that surrounds an axially oriented through-wall crack in an internally pressurized cylinder. Maxey quickly recognized the value of this factor with respect to evaluating defects in pressured pipe, and used it to develop the semi-empirical NG-18 surface-flaw equation. The latter was validated by means of nearly 150 burst tests of pressured pipes containing axially oriented through-wall and part-through flaws[8]. By 1971, the method had been adapted to use for predicting the remaining strength of corroded pipe and validated by burst tests of 47 samples of corroded pipe. The original database of 47 tests[9] was expanded over the years and used to validate the RSTRENG[10, 11, 1] and "modified" B31G methods. By 1995, the database contained 215 experiments, 167 of which can be used to qualify and validate any method for evaluating the burst strength of corroded pipe. The database has been used by others to validate the alternative Folias-based evaluation methods: PCORR, API RP579, and DNV 2000. Past comparisons of all of the five Folias-based methods have shown that all five give reasonably safe predictions of remaining strength and that the differences between the five are relatively minor when each is used in its most rigorous form wherein variations in depth along the "effective" length of the metal loss are taken into account. When each is used in its "two-parameter-defect-geometry" format (i.e., using only overall length and the maximum depth of the defect), the predictions contain more scatter but usually give conservative estimates. The usefulness of the two-parameter format for assessing in-line-inspection data leads to keen interest in the accuracy of each method. The same incentive applies to the need to assess the newer methods RAM 1, RAM 2, RAM 3, and ABS 2000. Pipeline operators will no doubt opt to rely on the method or methods that result in the most correct selection of the areas of metal loss that need to be remediated.

DESCRIPTIONS OF THE CRITERIA

The equations for the nine criteria for evaluating the remaining strength of corroded pipe are presented below. To make the terminology as simple as possible, the formats of the criteria are presented in terms of the following parameters. As a result, the formats shown for some of the criteria may appear different from those presented in the referenced documents.

$$
\begin{aligned}
&P_f = \text{burst pressure of corroded pipe}\\
&SMYS = \text{Specified Minimum Yield Strength}\\
&UTS = \text{Ultimate Tensile Strength}\\
&\overline{UTS} = \text{mean longitudinal tensile strength}\\
&D = \text{outside diamter of pipe}\\
&d = \text{maximum depth of flaw}\\
&t = \text{nominal pipe wall thickness}\\
&L = \text{total axial extent of the flaw}\\
&SCF = \text{Stress Concentration Factor}
\end{aligned}
$$

ASME B31G

When

$L \le \sqrt{20Dt}$

$$P_f = 1.1\left(\frac{2 \cdot t \cdot SMYS}{D}\right)\left(\frac{1-\left(\frac{2}{3}\right)\left(\frac{d}{t}\right)}{1-\left(\frac{2}{3}\right)\left(\frac{d}{t}\right)\left(1+\frac{0.8L^2}{Dt}\right)^{-0.5}}\right)$$

When

$L > \sqrt{20Dt}$

$$P_f = 1.1\left(\frac{2 \cdot t \cdot SMYS}{D}\right)\left(1-\frac{d}{t}\right)$$

Modified B31G

$$P_f = \frac{2 \cdot t \cdot (SMYS + 10{,}000)}{D}\left[\frac{1-0.85(d/t)}{1-0.85(d/t)M_{T2}^{-1}}\right]$$

For $\frac{L^2}{Dt} \le 50$: $M_{T2} = \sqrt{1+0.6275\frac{L^2}{Dt}-0.003375\frac{L^4}{D^2t^2}}$

For $\frac{L^2}{Dt} > 50$: $M_{T2} = 0.032\frac{L^2}{Dt}+3.3$

API RP579 Level 1

$$P_f = \left(\frac{2 \cdot t \cdot SMYS}{0.9 \cdot D}\right)\left(\frac{1-d/t}{1-(d/t)\left(M_{T1}^{-1}\right)}\right)$$

$$M_{T1} = \sqrt{1+0.8\left(\frac{L^2}{Dt}\right)}$$

DNV 2000

$$P_f = \frac{2 \cdot t \cdot UTS}{(D - t)} \left[\frac{1 - (d/t)}{1 - (d/t)(1/Q)} \right]$$

$$Q = \sqrt{1 + 0.31 \left(\frac{L^2}{Dt} \right)}$$

RAM 1 (SMYS)

$$P_f = \frac{3.2 \cdot t \cdot SMYS}{(D - t) \cdot SCF}$$

$$SCF = 1 + 2 \left(\frac{2 \cdot d}{(D - t)} \right)^{0.5}$$

RAM 2 (SMTS)

$$P_f = \left(\frac{2.4 \cdot UTS \cdot t}{SCF \cdot (D - t)} \right)$$

$$SCF = 1 + 2 \left(\frac{2d}{D - t} \right)^{0.5}$$

RAM 3 (UTS)

$$P_f = \left(\frac{2 \cdot \overline{UTS} \cdot t}{SCF \cdot (D - t)} \right)$$

$$SCF = 1 + 2 \left(\frac{2d}{D - t} \right)^{0.5}$$

ABS 2000

$$P_f = 0.5(SMYS + UTS)\left(\frac{2 \cdot t}{D}\right)\left(\frac{1 - d/t}{1 - (d/t)(M_{T1}^{-1})}\right)$$

$$M_{T1} = \sqrt{1 + 0.8\left(\frac{L^2}{Dt}\right)}$$

PCORRC – Pipeline CORRosion Criterion

$$P_f = \left(\frac{2 \cdot t \cdot UTS}{D}\right)\left(1 - \frac{d}{t}\left(1 - \exp\left(-0.157\frac{L}{\sqrt{(D/2)(t-d)}}\right)\right)\right)$$

COMPARISONS OF THE CRITERIA TO THE DATA

The calculations of failure pressures via the criteria are compared to burst test results (actual failure pressures) in Table 1. Each burst test is identified by its "Index Number" in the database (References 9, 10, 11, and 1). Results obtained through burst tests of corroded pipe removed from pipelines are highlighted in orange in the "Defect Type" column. Results obtained through burst tests of pipes containing corrosion-simulating machined flaws are highlighted in yellow, and results obtained from in-service pipeline ruptures and hydrostatic test breaks are highlighted in green. The red-highlighted numbers in the "Actual Tensile Strength" column are the specified minimum ultimate tensile strengths given in the API Specification 5L, Line Pipe, for the particular grade of material. Non-highlighted values in the same column are values obtained by means of tensile tests on the particular piece of pipe.

The failure pressures calculated via each criterion are compared individually to the actual failure pressures via Figures 1 through 9. The figures present the results via each criterion in relation to the "one-to-one" line. (If agreement were perfect, all compared calculations would lie on the one-to-one line.) Note in Figures 1 through 9 that the orange "plus" symbols represent burst tests of corroded pipe, the yellow circles represent burst tests of pipes containing machined corrosion-simulating defects, and the green triangles represent in-service failures and hydrostatic test breaks. Figures 1 through 9 also present the results with a "best-fit" trend line. The latter permits a "goodness-of-fit" calculation in terms of the number R^2. The closer R^2 is to 1, the better the fit.

On the basis of the table and the figures, one can assess the accuracies of the various criteria. The levels of accuracy from several standpoints are summarized in Table 2. The values presented in Table 2 were calculated based on the ratios of predicted, P_c , to actual, P_a , failure pressures. The average, standard deviation, and percent of values where the predicted level is expected to be below the actual level are presented for each criterion based on the assumption that the P_c/P_a ratios follow a normal distribution. Also shown in Table 2 are the minimum and maximum values for each criterion. Lastly, the "best-fit" trend line for each criterion is used to test the "goodness-of-fit" in terms of R^2. (An R^2 if 1 indicates a perfect fit.) The results are discussed below for each criterion.

ASME B31G

Calculations of P_c/P_a via the ASME B31G method resulted in an average ratio of predicted to actual failure pressure of 0.785 with a standard deviation of 0.218. Overall, 83.9 percent of the calculations that were performed using this method resulted in predictions of failure pressures that were below the actual failure pressures. The calculations using ASME B31G resulted in a minimum failure pressure calculation of 3.4 percent of the actual failure pressure and maximum of 123.8 percent of the actual failure pressure. The R^2 value for this method is 0.70.

Modified B31G

Calculations of P_c/P_a via the Modified B31G method resulted in an average ratio of predicted to actual failure pressure of 0.826 with a standard deviation of 0.187. Based on a normal distribution, 82.4 percent of the calculations that were performed on corroded pipe would result in predictions of a failure pressure that were below the actual failure pressure. The calculations using Modified B31G resulted in a minimum failure pressure calculation of 24.4

percent of the actual failure pressure and maximum of 134.8 percent of the actual failure pressure. The R^2 value for this method is 0.74.

API Recommended Practice 579 (Level 1)

Calculations of P_c/P_a via the API RP 579 method resulted in an average ratio of predicted to actual failure pressure of 0.639 with a standard deviation of 0.202. Based on a normal distribution, 96.3 percent of the calculations that were performed on corroded pipe would result in predictions of a failure pressure that were below the actual failure pressure. The calculations using the API RP 579 method resulted in a minimum failure pressure calculation of 3.8 percent of the actual failure pressure and maximum of 108.0 percent of the actual failure pressure. The R^2 value for this method is 0.71.

Det Norske Veritas

Calculations of P_c/P_a via the Det Norske Veritas method resulted in an average ratio of predicted to actual failure pressure of 0.835with a standard deviation of 0.278. Based on a normal distribution, 72.3 percent of the calculations that were performed on corroded pipe would result in predictions of a failure pressure that were below the actual failure pressure. The calculations using DNV 2000 resulted in a minimum failure pressure calculation of 5.9 percent of the actual failure pressure and maximum of 177.4 percent of the actual failure pressure. The R^2 value for this method is 0.55.

RAM 1

Calculations of P_c/P_a via the RAM-1 method resulted in an average ratio of predicted to actual failure pressure of 1.355 with a standard deviation of 0.368. Based on a normal distribution, 16.7 percent of the calculations that were performed on corroded pipe would result in predictions of a failure pressure that were below the actual failure pressure. The calculations using RAM 1 resulted in a minimum failure pressure calculation of 80.3 percent of the actual failure pressure and maximum of 279.8 percent of the actual failure pressure. The R^2 value for this method is 0.64.

RAM 2

Calculations of P_c/P_a via the RAM-2 method resulted in an average ratio of predicted to actual failure pressure of 1.289 with a standard deviation of 0.377. Based on a normal distribution, 22.2 percent of the calculations that were performed on corroded pipe would result in predictions of a failure pressure that were below the actual failure pressure. The calculations using RAM 2 resulted in a minimum failure pressure calculation of 75.7 percent of the actual failure pressure and maximum of 268.0 percent of the actual failure pressure. The R^2 value for this method is 0.46.

RAM 3

Calculations of P_c/P_a via the RAM-3 method resulted in an average ratio of predicted to actual failure pressure of 1.074 with a standard deviation of 0.314. Based on a normal distribution, 40.7 percent of the calculations that were performed on corroded pipe would result in predictions of a failure pressure that were below the actual failure pressure. The calculations using RAM 3 resulted in a minimum failure pressure calculation of 63.1 percent of the actual failure pressure and maximum of 223.3 percent of the actual failure pressure. The R^2 value for this method is 0.46.

ABS 2000

Calculations of P_c/P_a via the ABS 2000 method resulted in an average ratio of predicted to actual failure pressure of 0.648 with a standard deviation of 0.205. Based on a normal distribution, 95.7 percent of the calculations that were performed on corroded pipe would result in predictions of a failure pressure that were below the actual failure pressure. The calculations using ABS 2000 resulted in a minimum failure pressure calculation of 4.5 percent of the actual failure pressure and maximum of 125.3 percent of the actual failure pressure.
The R^2 value for this method is 0.64.

Pipeline CORRosion Criteria

Calculations of P_c/P_a via the PCORRC method resulted in an average ratio of predicted to actual failure pressure of 0.827 with a standard deviation of 0.264. Based on a normal distribution, 72.1 percent of the calculations that were performed on corroded pipe would result in predictions of a failure pressure that were below the actual failure pressure. The calculations using PCORR resulted in a minimum failure pressure calculation of 5.0 percent of the actual failure pressure and maximum of 165.9 percent of the actual failure pressure.
The R^2 value for this method is 0.56.

COMMENTS

The results of the comparisons show that all of the "Folias-factor-based" methods, ASME B31G, Modified B31G, API RP 579 (Level 1), DNV 2000, ABS 2000, and PCORR, give reasonable predictions of the remaining pressure-carrying capacity of corroded pipe. It is particularly important to note that all six of these methods provided reasonably conservative predictions (nearly 100 percent of the time) for the in-service failures and the burst tests of pipe containing the machined defects. The fact that they do not look quite as good on the basis of the results of burst tests of corroded pipe is at least partly due to erroneous wall-thickness measurements in some of the early tests as described in Reference 1. The authors have no reservations about anyone using any of these methods to evaluate either corroded pipe or to prioritize in-line-inspection data, though it is noted that the discontinuity in the ASME B31G at $L = \sqrt{20Dt}$ creates a tendency toward excessive conservatism for long defects. It is hoped that the ASME B31G approach will be replaced by the modified B31G method by all potential users and that the ASME code committees will adopt the latter as well. In any case, U.S. DOT regulations, Parts 192 and 195, permit the use of Modified B31G.

In contrast to the Folias-based methods, the RAM methods appear to have characteristics that cause concern on the part of the authors. The characteristics that cause concern are

- Length of the anomaly is not included as a variable.

The difficulty this creates is perhaps best illustrated by considering the burst test results Index 126 and Index 129 within the group of pipes with machined defects. The only difference between the defects in the two samples of the same pipe was the defect length. Index 126 with a 24-inch-long defect has a burst pressure of 2,030 psig, whereas Index 129 with a 6-inch-long defect had a burst pressure of 2,683 psig. The RAM methods show no difference in predicted burst pressures for these samples because defect length is not considered.

- Failure pressure does not go to zero when the depth of the defect penetrates the wall thickness.

The depth of the defect is considered only in the stress-concentration factor on the RAM methods. This assures that the failure pressure would not approach zero even if no wall thickness were remaining over a length of several feet (recalling that length is not included).

- The predictions are unconservative and the trend lines in Figures 5 through 7 diverge from the origin.

This strongly suggests that the methods are inappropriately representing the behavior of corroded pipe.

On the basis of these characteristics, the authors have serious reservations about the use of the RAM techniques for predicting the remaining strength of corroded pipe.

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Table 1. Actual Failure Pressure Compared to Predicted Failure Pressure

	Index Number	Diameter	Actual Wall Thickness	Actual Yield Strength	Actual Tensile Strength	Maximum Pit Depth	Length of Defect	Actual Failure Pressure	Calculated Failure Pressure									Ratio: calculated / actual								
		Dia	WTA	Yield	UTS	d	L	Pf	B31G	B31G Mod	RP579 Level 1	DVN 2000	RAM Pipe 1	RAM Pipe 2	RAM Pipe 3	ABS 2000	PCORRC	B31G	B31G Mod	RP579 Level 1	DVN 2000	RAM Pipe 1	RAM Pipe 2	RAM Pipe 3	ABS 2000	PCORRC
Defect Type		inch	inch	psi	psi	inch	inch	psi	psi	psi	psi	psi	psi	psi	psi	psi	psi									
Burst Test	1	30	0.382	58,700	76,100	0.146	2.50	1,623	1,556	1,642	1,507	1,876	2,021	1,965	1,638	1,557	1,799	0.9590	1.0115	0.9283	1.1558	1.2454	1.2109	1.0091	0.9593	1.1082
Burst Test	2	30	0.382	58,700	76,100	0.146	2.25	1,620	1,569	1,658	1,528	1,890	2,021	1,965	1,638	1,579	1,811	0.9687	1.0234	0.9434	1.1669	1.2477	1.2132	1.0110	0.9749	1.1180
Burst Test	3	30	0.382	58,700	76,100	0.157	4.25	1,700	1,460	1,514	1,346	1,744	2,009	1,953	1,628	1,391	1,695	0.8589	0.8907	0.7920	1.0256	1.1817	1.1490	0.9575	0.8184	0.9973
Burst Test	4	30	0.375	63,800	80,600	0.240	5.50	1,670	1,325	1,262	998	1,393	2,060	1,952	1,626	1,016	1,428	0.7932	0.7557	0.5974	0.8341	1.2335	1.1687	0.9739	0.6085	0.8553
Burst Test	5	30	0.380	58,800	75,300	0.209	4.75	1,525	1,345	1,351	1,132	1,533	1,951	1,873	1,561	1,162	1,517	0.8819	0.8861	0.7425	1.0055	1.2790	1.2285	1.0237	0.7620	0.9948
Burst Test	6	24	0.377	40,500	66,000	0.271	3.00	1,100	1,135	1,187	857	1,594	1,587	1,940	1,617	1,015	1,565	1.0319	1.0788	0.7795	1.4492	1.4431	1.7638	1.4698	0.9224	1.4224
Burst Test	7	24	0.377	40,500	66,000	0.251	4.75	1,165	1,047	1,067	768	1,408	1,601	1,957	1,631	909	1,446	0.8989	0.9163	0.6592	1.2087	1.3746	1.6801	1.4000	0.7800	1.2410
Burst Test	8	24	0.377	40,500	66,000	0.251	5.25	1,220	1,024	1,033	737	1,347	1,601	1,957	1,631	872	1,399	0.8392	0.8469	0.6043	1.1044	1.3126	1.6043	1.3369	0.7151	1.1469
Burst Test	9	24	0.370	41,800	65,900	0.261	1.75	1,040	1,287	1,402	1,123	1,845	1,614	1,909	1,591	1,303	1,726	1.2375	1.3477	1.0803	1.7740	1.5524	1.8356	1.5297	1.2525	1.6594
Burst Test	10	24	0.375	41,800	65,900	0.282	4.25	1,165	1,040	1,018	674	1,267	1,622	1,918	1,598	781	1,334	0.8925	0.8742	0.5784	1.0874	1.3922	1.6462	1.3718	0.6707	1.1452
Burst Test	11	24	0.365	41,800	65,900	0.261	2.00	1,020	1,237	1,332	1,037	1,754	1,592	1,883	1,569	1,203	1,653	1.2123	1.3057	1.0170	1.7192	1.5612	1.8459	1.5383	1.1792	1.6208
Burst Test	12	24	0.365	41,800	65,900	0.219	2.25	1,215	1,254	1,371	1,122	1,820	1,624	1,920	1,600	1,300	1,723	1.0323	1.1288	0.9231	1.4976	1.3363	1.5801	1.3167	1.0703	1.4179
Burst Test	13	24	0.365	41,800	65,900	0.230	2.50	1,320	1,220	1,319	1,051	1,752	1,615	1,910	1,591	1,218	1,669	0.9245	0.9995	0.7961	1.3270	1.2235	1.4467	1.2056	0.9230	1.2646
Burst Test	14	24	0.365	41,800	65,900	0.261	2.75	1,320	1,156	1,211	894	1,589	1,592	1,883	1,569	1,037	1,545	0.8757	0.9177	0.6776	1.2041	1.2064	1.4264	1.1887	0.7856	1.1705
Burst Test	15	24	0.380	41,800	65,900	0.251	3.75	1,335	1,156	1,201	895	1,576	1,666	1,970	1,642	1,037	1,567	0.8657	0.8997	0.6702	1.1807	1.2480	1.4757	1.2298	0.7771	1.1739
Burst Test	16	24	0.370	41,800	65,900	0.188	2.00	1,350	1,321	1,467	1,248	1,937	1,672	1,978	1,648	1,447	1,834	0.9788	1.0866	0.9246	1.4349	1.2389	1.4649	1.2207	1.0720	1.3587
Burst Test	17	24	0.370	41,800	65,900	0.240	3.00	1,375	1,186	1,260	971	1,670	1,630	1,927	1,606	1,126	1,618	0.8626	0.9167	0.7065	1.2146	1.1853	1.4016	1.1680	0.8191	1.1766
Burst Test	18	24	0.375	41,800	65,900	0.240	3.75	1,438	1,152	1,205	911	1,587	1,652	1,954	1,628	1,057	1,571	0.8009	0.8379	0.6338	1.1033	1.1489	1.3585	1.1321	0.7348	1.0927
Burst Test	19	24	0.365	41,800	65,900	0.261	1.75	1,450	1,265	1,375	1,094	1,808	1,592	1,883	1,569	1,269	1,692	0.8726	0.9481	0.7546	1.2468	1.0982	1.2985	1.0821	0.8749	1.1669
Burst Test	20	24	0.375	41,800	65,900	0.251	2.25	1,200	1,265	1,366	1,081	1,809	1,644	1,944	1,620	1,253	1,713	1.0538	1.1387	0.9005	1.5077	1.3699	1.6198	1.3499	1.0440	1.4273
Burst Test	21	24	0.375	41,800	65,900	0.292	2.25	1,490	1,215	1,271	909	1,645	1,615	1,910	1,592	1,054	1,581	0.8155	0.8528	0.6101	1.1041	1.0841	1.2818	1.0682	0.7074	1.0613
Burst Test	22	24	0.375	41,800	65,900	0.219	2.50	1,520	1,276	1,392	1,135	1,851	1,669	1,973	1,644	1,316	1,759	0.8395	0.9160	0.7470	1.2176	1.0979	1.2981	1.0818	0.8661	1.1575
Burst Test	23	24	0.375	41,800	65,900	0.188	2.00	1,520	1,342	1,491	1,271	1,968	1,695	2,005	1,671	1,474	1,864	0.8829	0.9808	0.8362	1.2950	1.1154	1.3189	1.0991	0.9696	1.2264
Burst Test	24	24	0.375	41,800	65,900	0.177	2.25	1,520	1,333	1,480	1,260	1,957	1,706	2,017	1,681	1,461	1,860	0.8772	0.9737	0.8292	1.2875	1.1221	1.3268	1.1057	0.9614	1.2239
Burst Test	25	24	0.375	41,800	65,900	0.271	5.00	1,510	1,018	995	674	1,234	1,630	1,927	1,606	781	1,308	0.6743	0.6592	0.4462	0.8171	1.0792	1.2760	1.0634	0.5174	0.8664
Burst Test	27	30	0.375	60,100	66,000	0.146	5.50	1,840	1,434	1,471	1,306	1,432	2,031	1,673	1,394	1,233	1,411	0.7791	0.7994	0.7097	0.7783	1.1039	0.9092	0.7577	0.6701	0.7667
Burst Test	28	30	0.375	60,800	66,000	0.115	4.50	1,895	1,531	1,594	1,457	1,536	2,094	1,705	1,421	1,367	1,498	0.8078	0.8412	0.7689	0.8105	1.1049	0.8996	0.7496	0.7216	0.7904
Burst Test	29	30	0.375	64,800	66,000	0.230	4.00	1,775	1,463	1,443	1,199	1,321	2,101	1,605	1,338	1,089	1,299	0.8241	0.8129	0.6755	0.7443	1.1838	0.9043	0.7535	0.6135	0.7319
Burst Test	30	30	0.375	69,200	66,000	0.209	1.60	2,140	1,817	1,871	1,746	1,603	2,265	1,620	1,350	1,535	1,515	0.8491	0.8745	0.8158	0.7492	1.0584	0.7571	0.6309	0.7173	0.7078
Burst Test	31	30	0.375	65,200	66,000	0.209	2.00	2,000	1,677	1,731	1,577	1,570	2,134	1,620	1,350	1,428	1,484	0.8383	0.8655	0.7887	0.7851	1.0670	0.8101	0.6751	0.7142	0.7420
Burst Test	32	20	0.325	41,000	60,100	0.209	5.75	1,150	1,035	1,029	740	1,182	1,678	1,845	1,537	821	1,240	0.8997	0.8949	0.6432	1.0281	1.4592	1.6042	1.3368	0.7138	1.0786
Burst Test	33	20	0.325	41,000	60,100	0.219	6.50	1,695	985	954	662	1,058	1,669	1,835	1,529	735	1,126	0.5813	0.5629	0.3906	0.6244	0.9847	1.0826	0.9022	0.4334	0.6640
Burst Test	34	16	0.310	28,600	47,500	0.230	4.50	1,100	810	833	496	955	1,347	1,678	1,398	594	1,040	0.7367	0.7573	0.4508	0.8684	1.2245	1.5253	1.2711	0.5398	0.9452
Burst Test	35	16	0.310	28,600	47,500	0.240	5.00	1,270	766	759	425	821	1,340	1,669	1,391	508	915	0.6035	0.5974	0.3343	0.6463	1.0548	1.3139	1.0949	0.4003	0.7203
Burst Test	36	16	0.310	28,600	47,500	0.282	6.00	820	625	509	171	342	1,311	1,633	1,361	204	395	0.7626	0.6206	0.2082	0.4173	1.5989	1.9916	1.6597	0.2494	0.4818
Burst Test	37	16	0.310	28,600	47,500	0.272	2.75	890	834	816	367	831	1,318	1,641	1,368	440	964	0.9365	0.9172	0.4126	0.9334	1.4804	1.8440	1.5367	0.4940	1.0828
Burst Test	38	16	0.310	28,400	40,200	0.199	6.25	1,290	823	876	574	870	1,362	1,446	1,205	624	911	0.6380	0.6788	0.4452	0.6742	1.0557	1.1207	0.9339	0.4839	0.7060
Burst Test	39	24	0.417	50,200	79,000	0.290	13.00	1,395	1,172	1,045	722	1,179	2,162	2,552	2,127	836	1,202	0.8402	0.7489	0.5177	0.8454	1.5500	1.8295	1.5245	0.5996	0.8613
Burst Test	40	24	0.410	46,800	81,300	0.380	8.00	1,660	894	638	207	443	1,915	2,495	2,080	255	521	0.5387	0.3843	0.1247	0.2671	1.1538	1.5033	1.2527	0.1536	0.3136
Burst Test	41	24	0.396	50,200	79,000	0.360	5.75	930	1,043	800	314	652	1,997	2,357	1,965	364	837	1.1219	0.8607	0.3378	0.7014	2.1477	2.5349	2.1124	0.3913	0.9001
Burst Test	42	24	0.444	50,200	79,000	0.220	8.25	1,900	1,580	1,593	1,302	2,107	2,378	2,807	2,339	1,508	2,132	0.8314	0.8386	0.6854	1.1091	1.2515	1.4771	1.2309	0.7938	1.1221
Burst Test	43	24	0.366	53,900	60,000	0.275	15.00	1,476	450	844	542	617	2,047	1,709	1,424	515	599	0.3046	0.5719	0.3672	0.4181	1.3866	1.1576	0.9647	0.3492	0.4061
Burst Test	44	24	0.364	52,000	60,000	0.254	13.00	1,265	1,048	924	640	759	1,982	1,715	1,429	620	765	0.8286	0.7306	0.5056	0.5997	1.5665	1.3556	1.1297	0.4900	0.6047
Burst Test	45	24	0.355	52,000	60,000	0.289	6.50	1,505	1,023	862	501	685	1,903	1,647	1,372	485	789	0.6799	0.5729	0.3327	0.4552	1.2646	1.0943	0.9119	0.3224	0.5243
Burst Test	46	24	0.319	47,500	60,000	0.216	5.50	1,732	979	942	678	956	1,612	1,527	1,273	691	1,012	0.5652	0.5436	0.3915	0.5519	0.9308	0.8818	0.7348	0.3987	0.5841
Burst Test	47	24	0.332	45,000	60,000	0.220	4.50	1,752	1,025	1,024	753	1,126	1,587	1,587	1,323	791	1,158	0.5849	0.5846	0.4300	0.6426	0.9059	0.9059	0.7549	0.4515	0.6610
Burst Test	52	24	0.361	47,400	64,100	0.319	10.50	1,290	783	580	251	378	1,744	1,768	1,474	265	391	0.6067	0.4494	0.1942	0.2930	1.3516	1.3708	1.1423	0.2056	0.3035
Burst Test	53	24	0.361	41,200	67,200	0.285	12.50	1,475	746	634	363	624	1,536	1,879	1,566	430	630	0.5057	0.4296	0.2460	0.4230	1.0415	1.2741	1.0618	0.2913	0.4271
Burst Test	54	24	0.355	50,300	63,900	0.243	8.50	1,741	1,064	976	691	945	1,878	1,789	1,491	706	1,006	0.6113	0.5608	0.3970	0.5427	1.0787	1.0278	0.8565	0.4056	0.5776
Burst Test	55	24	0.371	45,000	65,600	0.276	10.50	1,357	908	802	511	797	1,732	1,893	1,578	565	842	0.6691	0.5907	0.3765	0.5874	1.2761	1.3952	1.1626	0.4164	0.6201
Burst Test	56	24	0.371	45,000	65,600	0.291	10.50	1,357	868	738	437	690	1,721	1,881	1,568	484	733	0.6394	0.5439	0.3222	0.5088	1.2681	1.3865	1.1554	0.3563	0.5402
Burst Test	57	24	0.372	48,200	63,300	0.284	22.00	1,599	389	727	444	576	1,854	1,826	1,521	462	516	0.2432	0.4547	0.2774	0.3600	1.1592	1.1418	0.9515	0.2888	0.3228
Burst Test	58	24	0.364	48,100	62,000	0.224	8.50	1,645	1,112	1,070	802	1,090	1,859	1,797	1,497	827	1,137	0.6760	0.6503	0.4878	0.6624	1.1299	1.0923	0.9102	0.5025	0.6910
Burst Test	59	24	0.366	43,000	59,000	0.242	12.50	1,808	910	852	594	836	1,657	1,705	1,421	635	848	0.5031	0.4711	0.3288	0.4622	0.9163	0.9430	0.7858	0.3509	0.4689
Burst Test	60	24	0.366	51,500	70,000	0.191	4.00	1,583	1,448	1,499	1,251	1,779	2,035	2,074	1,729	1,328	1,743	0.9150	0.9470	0.7902	1.1236	1.2854	1.3103	1.0919	0.8390	1.1012
Burst Test	61	24	0.368	47,700	67,300	0.288	28.00	1,530	350	664	389	534	1,811	1,917	1,597	422	467	0.2286	0.4342	0.2544	0.3490	1.1839	1.2528	1.0440	0.2760	0.3051
Burst Test	62	20	0.283	37,900	60,800	0.274	30.00	1,090	38	266	41	64	1,305	1,571	1,309	49	55	0.0344	0.2441	0.0380	0.0590	1.1977	1.4410	1.2008	0.0446	0.0502

Table 1 (Cont)

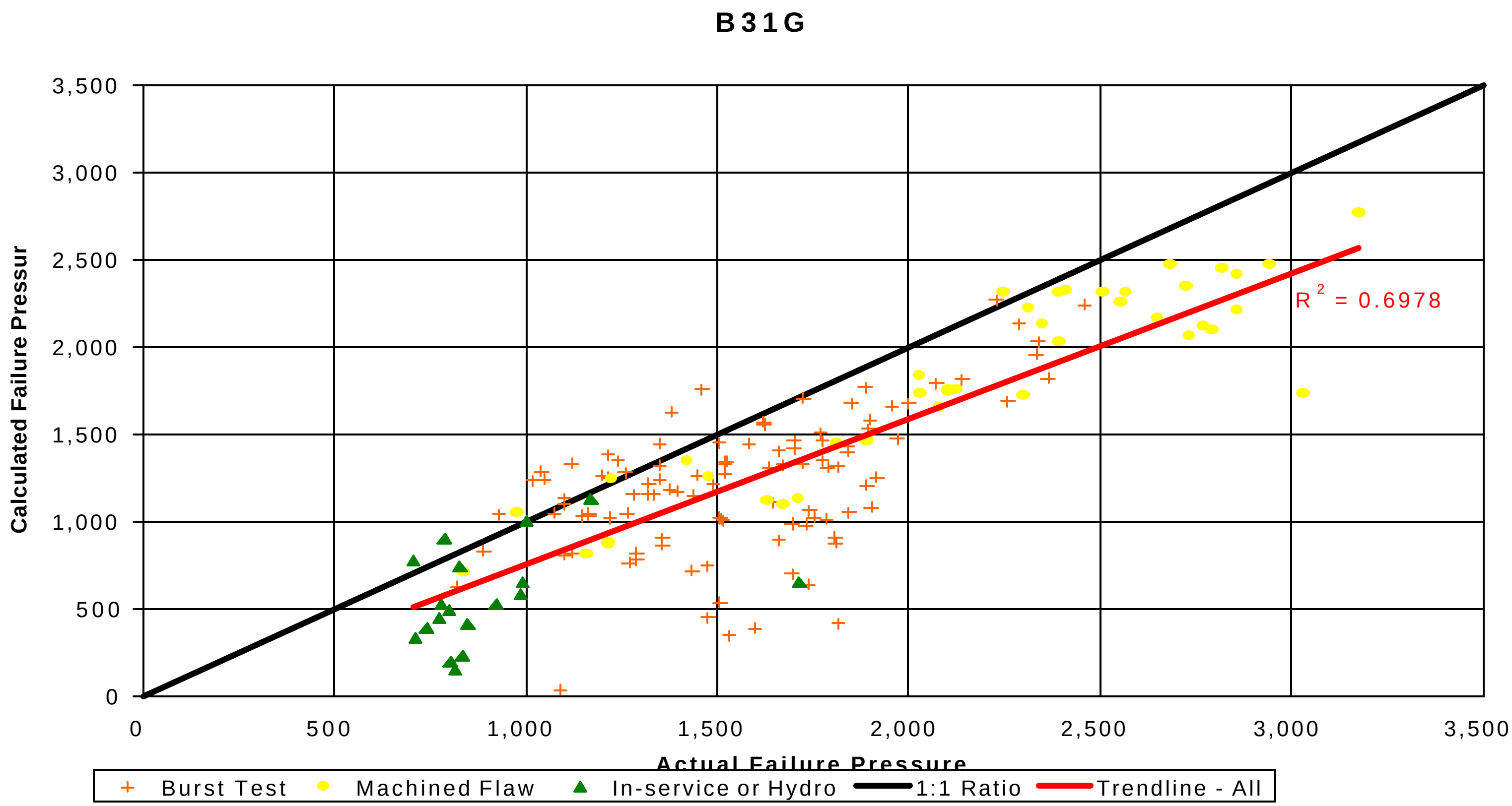
	Index Number	Diameter	Actual Wall Thickness	Actual Yield Strength	Actual Tensile Strength	Maximum Pit Depth	Length of Defect	Actual Failure Pressure	Calculated Failure Pressure									Ratio: calculated / actual								
		Dia	WTA	Yield	UTS	d	L	Pf	B31G	B31G Mod	RP579 Level 1	DVN 2000	RAM Pipe 1	RAM Pipe 2	RAM Pipe 3	ABS 2000	PCORRC	B31G	B31G Mod	RP579 Level 1	DVN 2000	RAM Pipe 1	RAM Pipe 2	RAM Pipe 3	ABS 2000	PCORRC
Defect Type		inch	inch	psi	psi	inch	inch	psi	psi	psi	psi	psi	psi	psi	psi	psi	psi									
Burst Test	63	20	0.274	40,500	64,100	0.130	12.00	1,739	642	921	721	1,110	1,464	1,738	1,448	838	1,096	0.3689	0.5297	0.4145	0.6383	0.8419	0.9993	0.8328	0.4818	0.6305
Burst Test	64	20	0.311	35,300	56,900	0.239	8.50	1,694	701	637	371	648	1,360	1,645	1,370	436	692	0.4138	0.3762	0.2192	0.3828	0.8030	0.9708	0.8090	0.2577	0.4084
Burst Test	65	20	0.311	35,300	56,900	0.105	11.00	1,694	991	1,096	881	1,364	1,479	1,788	1,490	1,036	1,352	0.5848	0.6467	0.5201	0.8054	0.8730	1.0554	0.8795	0.6113	0.7978
Burst Test	66	20	0.266	40,200	61,000	0.144	15.50	1,507	539	798	598	877	1,397	1,589	1,324	678	841	0.3580	0.5298	0.3969	0.5818	0.9267	1.0547	0.8789	0.4496	0.5582
Burst Test	67	20	0.309	41,900	64,900	0.218	12.00	1,816	419	766	504	796	1,621	1,884	1,570	578	787	0.2310	0.4216	0.2775	0.4381	0.8929	1.0373	0.8644	0.3183	0.4333
Burst Test	68	30	0.372	59,400	66,000	0.130	36.00	1,844	1,054	1,263	1,105	1,144	2,010	1,675	1,396	1,049	1,094	0.5717	0.6851	0.5990	0.6203	1.0900	0.9084	0.7570	0.5691	0.5934
Burst Test	69	30	0.376	54,100	66,000	0.230	12.00	1,515	1,006	939	716	897	1,759	1,609	1,341	715	926	0.6641	0.6200	0.4725	0.5921	1.1610	1.0623	0.8852	0.4720	0.6110
Burst Test	70	30	0.375	59,000	66,000	0.140	12.00	1,815	1,317	1,322	1,156	1,258	2,001	1,679	1,399	1,102	1,260	0.7254	0.7282	0.6368	0.6930	1.1024	0.9249	0.7707	0.6071	0.6941
Burst Test	71	30	0.382	62,200	66,000	0.145	20.00	1,902	1,081	1,346	1,175	1,187	2,143	1,705	1,421	1,090	1,163	0.5684	0.7075	0.6177	0.6243	1.1267	0.8967	0.7472	0.5729	0.6117
Burst Test	72	30	0.376	56,200	66,000	0.130	20.00	1,785	1,014	1,256	1,094	1,218	1,922	1,693	1,411	1,070	1,194	0.5680	0.7039	0.6128	0.6822	1.0770	0.9486	0.7905	0.5996	0.6689
Burst Test	73	30	0.378	63,700	66,000	0.110	33.00	1,916	1,252	1,454	1,308	1,260	2,219	1,724	1,437	1,198	1,216	0.6534	0.7590	0.6825	0.6578	1.1580	0.8999	0.7499	0.6254	0.6345
Burst Test	74	30	0.379	63,900	66,000	0.170	14.00	1,775	1,350	1,307	1,120	1,133	2,155	1,669	1,391	1,024	1,136	0.7606	0.7362	0.6309	0.6384	1.2139	0.9403	0.7836	0.5772	0.6399
Burst Test	75	30	0.381	52,000	66,000	0.300	12.00	1,120	820	678	409	560	1,666	1,586	1,322	417	595	0.7318	0.6050	0.3649	0.5001	1.4877	1.4161	1.1801	0.3726	0.5315
Burst Test	76	30	0.378	59,900	66,000	0.170	8.00	1,720	1,333	1,329	1,142	1,272	2,014	1,665	1,387	1,080	1,283	0.7750	0.7729	0.6637	0.7394	1.1711	0.9678	0.8065	0.6277	0.7457
Burst Test	77	30	0.377	60,500	66,000	0.160	12.00	1,789	1,310	1,293	1,114	1,195	2,040	1,669	1,391	1,048	1,203	0.7325	0.7229	0.6226	0.6680	1.1402	0.9329	0.7774	0.5858	0.6722
Burst Test	78	30	0.373	58,900	66,000	0.110	9.00	1,840	1,400	1,440	1,294	1,401	2,024	1,701	1,418	1,235	1,395	0.7609	0.7824	0.7032	0.7615	1.1001	0.9245	0.7704	0.6710	0.7581
Burst Test	82	30	0.375	64,400	93,700	0.150	7.50	1,970	1,475	1,477	1,307	1,899	2,172	2,370	1,975	1,444	1,899	0.7487	0.7498	0.6635	0.9639	1.1023	1.2029	1.0024	0.7330	0.9640
Burst Test	87	36	0.381	74,769	88,737	0.280	2.70	1,770	1,507	1,468	1,213	1,577	2,046	1,821	1,518	1,193	1,506	0.8511	0.8292	0.6851	0.8911	1.1560	1.0290	0.8575	0.6742	0.8508
Burst Test	88	30	0.363	61,812	79,993	0.120	7.80	1,700	1,416	1,443	1,296	1,640	2,053	1,993	1,661	1,338	1,633	0.8332	0.8487	0.7622	0.9645	1.2077	1.1722	0.9769	0.7869	0.9605
Burst Test	89	24	0.270	73,035	89,150	0.200	3.70	1,635	1,310	1,181	863	1,240	2,111	1,933	1,611	863	1,308	0.8010	0.7225	0.5280	0.7584	1.2911	1.1820	0.9850	0.5276	0.8002
Burst Test	90	36	0.400	73,440	95,500	0.270	1.60	1,724	1,706	1,734	1,600	2,034	2,119	2,066	1,722	1,656	1,905	0.9894	1.0059	0.9279	1.1800	1.2289	1.1986	0.9988	0.9605	1.1052
Burst Test	91	36	0.393	73,765	92,203	0.310	1.40	1,850	1,677	1,689	1,502	1,889	2,061	1,932	1,610	1,521	1,752	0.9063	0.9128	0.8120	1.0208	1.1142	1.0445	0.8705	0.8222	0.9469
Burst Test	92	24	0.319	57,500	76,600	0.090	19.00	1,891	1,207	1,436	1,277	1,595	2,111	2,109	1,757	1,340	1,557	0.6383	0.7592	0.6754	0.8437	1.1161	1.1152	0.9293	0.7088	0.8233
Burst Test	106	12.75	0.233	55,112	63,000	0.184	1.96	1,957	1,664	1,563	1,054	1,482	2,445	2,096	1,747	1,017	1,533	0.8502	0.7988	0.5388	0.7574	1.2491	1.0709	0.8924	0.5196	0.7832
Burst Test	108	12.75	0.239	55,693	63,000	0.157	2.36	2,072	1,791	1,760	1,369	1,738	2,585	2,193	1,828	1,313	1,740	0.8645	0.8495	0.6608	0.8388	1.2478	1.0586	0.8822	0.6337	0.8396
Burst Test	109	12.75	0.230	55,547	63,000	0.153	1.76	2,363	1,822	1,832	1,461	1,834	2,488	2,116	1,763	1,403	1,780	0.7711	0.7752	0.6183	0.7759	1.0527	0.8955	0.7462	0.5938	0.7533
Burst Test	110	12.75	0.236	64,394	63,000	0.185	1.16	2,228	2,271	2,236	1,749	1,935	2,892	2,122	1,768	1,557	1,832	1.0191	1.0035	0.7850	0.8685	1.2979	0.9523	0.7936	0.6989	0.8224
Burst Test	111	12.75	0.236	58,738	63,000	0.177	1.56	2,333	1,960	1,920	1,453	1,804	2,652	2,134	1,778	1,355	1,756	0.8402	0.8230	0.6230	0.7731	1.1369	0.9146	0.7622	0.5810	0.7528
Burst Test	112	12.75	0.239	60,914	63,000	0.115	1.76	2,458	2,240	2,310	2,048	2,152	2,929	2,272	1,894	1,875	2,058	0.9114	0.9399	0.8334	0.8753	1.1918	0.9244	0.7704	0.7629	0.8374
Burst Test	113	12.75	0.259	50,326	63,000	0.204	1.76	1,886	1,772	1,730	1,192	1,809	2,453	2,303	1,919	1,208	1,808	0.9394	0.9171	0.6321	0.9590	1.3005	1.2210	1.0175	0.6405	0.9585
Burst Test	114	12.75	0.242	53,662	63,000	0.095	1.16	2,288	2,136	2,286	2,077	2,345	2,665	2,347	1,956	2,032	2,231	0.9335	0.9993	0.9077	1.0248	1.1649	1.0257	0.8548	0.8880	0.9749
Burst Test	115	12.75	0.243	51,487	63,000	0.178	1.56	2,072	1,790	1,805	1,369	1,909	2,393	2,197	1,830	1,370	1,845	0.8639	0.8710	0.6609	0.9211	1.1552	1.0601	0.8834	0.6613	0.8903
Burst Test	116	12.75	0.234	51,632	63,000	0.164	1.80	2,258	1,688	1,694	1,293	1,790	2,333	2,135	1,780	1,291	1,753	0.7476	0.7500	0.5725	0.7925	1.0334	0.9457	0.7881	0.5720	0.7765
Burst Test	117	12.75	0.237	53,952	63,000	0.074	2.16	2,338	2,030	2,155	1,937	2,208	2,686	2,352	1,960	1,890	2,135	0.8682	0.9217	0.8286	0.9446	1.1488	1.0061	0.8384	0.8083	0.9132
Burst Test	198	24	0.39	57,100	66,000	0.297	3	1380	1,626	1,575	1,150	1,568	2,291	1,986	1,655	1,116	1,557	1.1783	1.1414	0.8335	1.1363	1.6604	1.4394	1.1995	0.8086	1.1285
Burst Test	199	24	0.39	57,100	66,000	0.203	3.5	1460	1,760	1,810	1,554	1,864	2,391	2,073	1,727	1,508	1,802	1.2056	1.2400	1.0644	1.2765	1.6378	1.4198	1.1831	1.0326	1.2344
Burst Test	200	24	0.37	52,200	66,000	0.327	5.5	1075	1,047	832	383	626	1,963	1,861	1,551	391	777	0.9744	0.7743	0.3566	0.5824	1.8256	1.7312	1.4427	0.3634	0.7229
Burst Test	201	24	0.37	52,200	66,000	0.324	2.5	1215	1,383	1,291	742	1,244	1,965	1,863	1,553	756	1,304	1.1383	1.0628	0.6108	1.0236	1.6171	1.5335	1.2779	0.6224	1.0730
Burst Test	202	24	0.37	52,200	66,000	0.26	3	1350	1,444	1,450	1,113	1,588	2,017	1,913	1,594	1,134	1,554	1.0698	1.0743	0.8242	1.1761	1.4941	1.4169	1.1807	0.8399	1.1512
Burst Test	203	24	0.335	52,200	66,000	0.215	3	1120	1,331	1,357	1,086	1,497	1,862	1,766	1,472	1,107	1,459	1.1885	1.2120	0.9700	1.3369	1.6629	1.5769	1.3141	0.9884	1.3023
Burst Test	204	24	0.37	52,200	66,000	0.22	14	1435	718	1,102	841	1,064	2,055	1,948	1,624	857	1,060	0.5002	0.7678	0.5859	0.7413	1.4319	1.3578	1.1315	0.5970	0.7388
Burst Test	205	24	0.33	53,400	66,000	0.24	3.4	1050	1,241	1,205	879	1,266	1,854	1,719	1,432	885	1,285	1.1822	1.1474	0.8375	1.2054	1.7660	1.6370	1.3642	0.8427	1.2236
Burst Test	206	24	0.33	53,400	66,000	0.21	8	1100	1,101	1,031	773	1,014	1,881	1,744	1,453	778	1,066	1.0012	0.9373	0.7032	0.9216	1.7102	1.5853	1.3211	0.7075	0.9687
Burst Test	207	24	0.33	53,400	66,000	0.23	2.6	1240	1,348	1,363	1,069	1,467	1,863	1,727	1,439	1,075	1,421	1.0870	1.0988	0.8617	1.1828	1.5024	1.3927	1.1605	0.8671	1.1464
Burst Test	208	24	0.33	53,400	66,000	0.24	3	1260	1,283	1,263	940	1,340	1,854	1,719	1,432	945	1,334	1.0179	1.0024	0.7457	1.0634	1.4716	1.3642	1.1368	0.7503	1.0587
Burst Test	209	24	0.33	53,400	66,000	0.24	4.5	1280	1,153	1,082	763	1,099	1,854	1,719	1,432	768	1,164	0.9006	0.8452	0.5961	0.8584	1.4486	1.3428	1.1190	0.5997	0.9093
Burst Test	210	24	0.33	53,400	66,000	0.2	4.7	1350	1,242	1,229	970	1,304	1,891	1,753	1,461	976	1,324	0.9201	0.9103	0.7183	0.9656	1.4006	1.2983	1.0819	0.7228	0.9809
Burst Test	211	24	0.33	53,400	66,000	0.23	1.8	1505	1,450	1,507	1,252	1,624	1,863	1,727	1,439	1,259	1,527	0.9633	1.0016	0.8317	1.0790	1.2378	1.1474	0.9562	0.8368	1.0149
Burst Test	212	12.75	0.197	58,570	66,000	0.13	3.33	1660	1,406	1,313	991	1,233	2,284	1,930	1,609	949	1,298	0.8470	0.7910	0.5971	0.7430	1.3759	1.1628	0.9690	0.5715	0.7822
Burst Test	213	12.75	0.197	58,570	66,000	0.11	15	1810	879	1,206	950	1,021	2,326	1,965	1,638	910	949	0.4858	0.6663	0.5251	0.5642	1.2849	1.0859	0.9049	0.5025	0.5243
Machined Flaw	97	20	0.261	64,360	86,800	0.103	15.00	1,631	1,119	1,390	1,210	1,551	2,261	2,287	1,906	1,279	1,509	0.6858	0.8520	0.7419	0.9510	1.3864	1.4023	1.1686	0.7841	0.9250
Machined Flaw	98	20	0.262	62,000	87,100	0.101	40.00	1,674	1,098	1,301	1,137	1,479	2,190	2,308	1,923	1,231	1,409	0.6559	0.7771	0.6793	0.8836	1.3085	1.3786	1.1489	0.7351	0.8414
Machined Flaw	99	20	0.256	63,440	82,800	0.101	6.00	1,892	1,467	1,464	1,290	1,669	2,189	2,143	1,786	1,339	1,676	0.7752	0.7738	0.6820	0.8823	1.1571	1.1327	0.9439	0.7075	0.8857
Machined Flaw	100	20	0.256	63,400	85,700	0.101	6.00	1,892	1,466	1,463	1,290	1,728	2,188	2,218	1,848	1,365	1,735	0.7747	0.7733	0.6816	0.9133	1.1564	1.1724	0.9770	0.7213	0.9168
Machined Flaw	101	20	0.256	63,400	85,200	0.101	6.00	1,892	1,466	1,463	1,290	1,718	2,188	2,205	1,838	1,360	1,724	0.7747	0.7733	0.6816	0.9079	1.1564	1.1655	0.9713	0.7189	0.9114
Machined Flaw	119	20	0.252	62,350	75,000	0.134	39.00	1,160	809	1,035	846	948	2,065	1,863	1,552	839	889	0.6977	0.8925	0.7296	0.8174	1.7801	1.6060	1.3383	0.7233	0.7660
Machined Flaw	120	20	0.252	62,350	75,000	0.087	40.00	1,712	1,132	1,317	1,168	1,298	2,144	1,934	1,612	1,158	1,242	0.6610	0.7692	0.6824	0.7583	1.2521	1.1296	0.9413	0.6765	0.7257

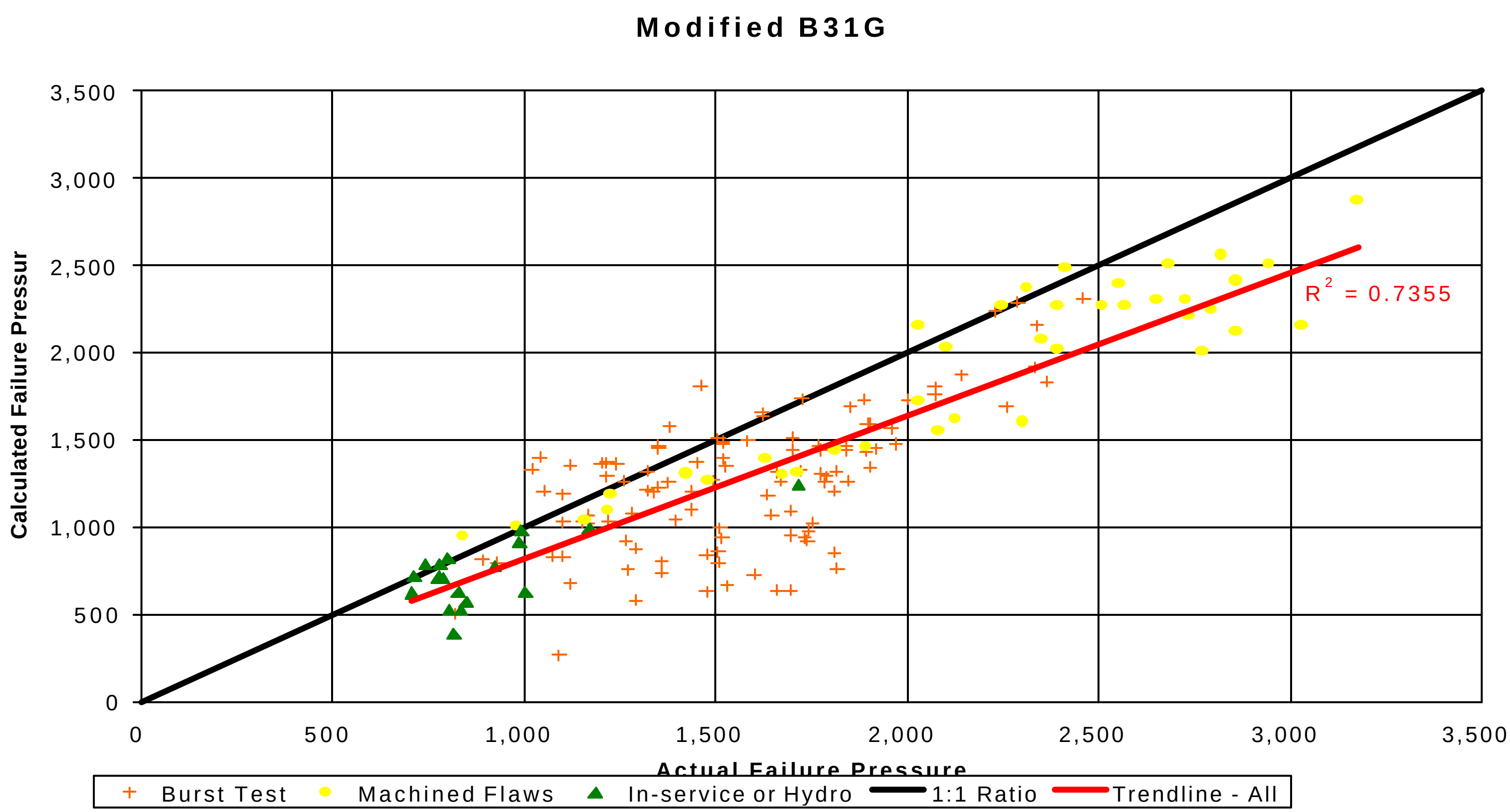
Table 1 (Concluded)

	Index Number	Diameter	Actual Wall Thickness	Actual Yield Strength	Actual Tensile Strength	Maximum Pit Depth	Length of Defect	Actual Failure Pressure	Calculated Failure Pressure									Ratio: calculated / actual								
		Dia	WTA	Yield	UTS	d	L	Pf	B31G	B31G Mod	RP579 Level 1	DVN 2000	RAM Pipe 1	RAM Pipe 2	RAM Pipe 3	ABS 2000	PCORRC	B31G	B31G Mod	RP579 Level 1	DVN 2000	RAM Pipe 1	RAM Pipe 2	RAM Pipe 3	ABS 2000	PCORRC
Defect Type		inch	inch	psi	psi	inch	inch	psi	psi	psi	psi	psi	psi	psi	psi	psi	psi									
Machined Flaw	121	20	0.252	63,075	75,000	0.118	4.00	1,813	1,442	1,442	1,250	1,525	2,114	1,885	1,571	1,232	1,519	0.7955	0.7955	0.6896	0.8410	1.1658	1.0396	0.8664	0.6793	0.8381
Machined Flaw	122	20	0.252	63,075	75,000	0.114	8.00	1,422	1,343	1,306	1,119	1,316	2,120	1,891	1,576	1,102	1,329	0.9441	0.9188	0.7867	0.9256	1.4909	1.3296	1.1080	0.7749	0.9343
Machined Flaw	123	20	0.252	62,350	75,000	0.134	8.07	1,226	1,247	1,182	971	1,176	2,065	1,863	1,552	962	1,198	1.0172	0.9640	0.7918	0.9590	1.6843	1.5195	1.2662	0.7849	0.9772
Machined Flaw	124	20	0.252	63,100	75,000	0.126	39.37	1,218	875	1,095	912	1,008	2,102	1,874	1,561	899	949	0.7180	0.8987	0.7491	0.8279	1.7256	1.5383	1.2819	0.7378	0.7790
Machined Flaw	125	24	0.486	65,400	66,000	0.194	120	2103	1,751	2,034	1,791	1,673	3,441	2,605	2,171	1,619	1,606	0.8324	0.9670	0.8516	0.7957	1.6364	1.2386	1.0321	0.7700	0.7637
Machined Flaw	126	24	0.486	64,900	66,000	0.194	24	2030	1,737	2,154	1,872	1,819	3,415	2,605	2,171	1,699	1,749	0.8557	1.0612	0.9222	0.8961	1.6823	1.2831	1.0693	0.8370	0.8614
Machined Flaw	127	24	0.486	64,900	66,000	0.194	12	2248	2,308	2,273	1,996	2,003	3,415	2,605	2,171	1,812	1,996	1.0269	1.0111	0.8880	0.8911	1.5192	1.1587	0.9656	0.8060	0.8879
Machined Flaw	128	24	0.486	64,900	66,000	0.194	12	2393	2,308	2,273	1,996	2,003	3,415	2,605	2,171	1,812	1,996	0.9647	0.9498	0.8342	0.8371	1.4271	1.0885	0.9071	0.7572	0.8341
Machined Flaw	129	24	0.486	64,900	66,000	0.194	6	2683	2,476	2,502	2,233	2,294	3,415	2,605	2,171	2,027	2,251	0.9229	0.9327	0.8324	0.8549	1.2729	0.9708	0.8090	0.7555	0.8390
Machined Flaw	133	24	0.486	64,900	66,000	0.194	12	2509	2,308	2,273	1,996	2,003	3,415	2,605	2,171	1,812	1,996	0.9201	0.9059	0.7957	0.7984	1.3611	1.0381	0.8651	0.7222	0.7955
Machined Flaw	136	24	0.486	64,900	66,000	0.291	1.5	3176	2,764	2,869	2,647	2,616	3,265	2,490	2,075	2,402	2,445	0.8704	0.9032	0.8334	0.8238	1.0280	0.7841	0.6534	0.7564	0.7697
Machined Flaw	142	24	0.486	64,900	66,000	0.291	4.5	2726	2,343	2,302	1,913	2,116	3,265	2,490	2,075	1,736	2,081	0.8594	0.8445	0.7017	0.7764	1.1978	0.9135	0.7613	0.6369	0.7634
Machined Flaw	144	24	0.486	64,900	66,000	0.194	12	2567	2,308	2,273	1,996	2,003	3,415	2,605	2,171	1,812	1,996	0.8993	0.8855	0.7777	0.7803	1.3304	1.0147	0.8456	0.7059	0.7776
Machined Flaw	147	24	0.486	64,900	66,000	0.194	6	2944	2,476	2,502	2,233	2,294	3,415	2,605	2,171	2,027	2,251	0.8410	0.8500	0.7586	0.7791	1.1600	0.8848	0.7373	0.6885	0.7646
Machined Flaw	151	24	0.486	64,900	66,000	0.291	7.5	2770	2,122	2,003	1,609	1,763	3,265	2,490	2,075	1,460	1,814	0.7660	0.7229	0.5808	0.6364	1.1787	0.8990	0.7492	0.5272	0.6548
Machined Flaw	152	24	0.486	64,900	66,000	0.292	6	2857	2,209	2,119	1,721	1,909	3,264	2,489	2,074	1,562	1,933	0.7731	0.7418	0.6024	0.6682	1.1424	0.8713	0.7261	0.5467	0.6767
Machined Flaw	153	24	0.486	64,900	66,000	0.22	6	2857	2,410	2,410	2,112	2,208	3,370	2,571	2,142	1,917	2,177	0.8434	0.8437	0.7391	0.7727	1.1797	0.8998	0.7498	0.6709	0.7620
Machined Flaw	154	24	0.486	64,900	66,000	0.291	6	2857	2,212	2,124	1,727	1,914	3,265	2,490	2,075	1,567	1,937	0.7741	0.7434	0.6045	0.6699	1.1428	0.8717	0.7264	0.5486	0.6780
Machined Flaw	157	24	0.486	64,900	66,000	0.194	24	3031	1,737	2,154	1,872	1,819	3,415	2,605	2,171	1,699	1,749	0.5731	0.7107	0.6177	0.6001	1.1267	0.8594	0.7161	0.5606	0.5769
Machined Flaw	158	48	0.48	65,000	66,000	0.12	18	1480	1,251	1,270	1,167	1,121	1,840	1,401	1,167	1,058	1,116	0.8455	0.8584	0.7883	0.7575	1.2429	0.9465	0.7888	0.7149	0.7542
Machined Flaw	160	48	0.48	65,000	66,000	0.24	18	980	1,054	1,003	843	850	1,749	1,332	1,110	764	863	1.0754	1.0239	0.8598	0.8677	1.7851	1.3594	1.1328	0.7798	0.8809
Machined Flaw	161	48	0.48	65,000	66,000	0.24	30	840	715	952	792	773	1,749	1,332	1,110	718	753	0.8512	1.1335	0.9428	0.9208	2.0826	1.5860	1.3216	0.8550	0.8961
Machined Flaw	163	12.75	0.243	51,600	63,000	0.147	0.79	2734	2,063	2,213	1,968	2,341	2,455	2,248	1,874	1,967	2,188	0.7547	0.8094	0.7200	0.8563	0.8980	0.8223	0.6853	0.7196	0.8004
Machined Flaw	165	12.75	0.246	51,600	63,000	0.149	0.78	2795	2,092	2,244	1,999	2,374	2,482	2,273	1,894	1,998	2,219	0.7485	0.8029	0.7151	0.8494	0.8881	0.8132	0.6777	0.7147	0.7938
Machined Flaw	166	12.75	0.243	61,200	63,000	0.148	0.78	2819	2,449	2,559	2,336	2,342	2,910	2,246	1,872	2,133	2,188	0.8686	0.9078	0.8286	0.8307	1.0322	0.7969	0.6641	0.7567	0.7763
Machined Flaw	167	12.75	0.252	55,400	63,000	0.127	0.79	2413	2,327	2,481	2,272	2,468	2,781	2,372	1,977	2,185	2,328	0.9644	1.0283	0.9417	1.0229	1.1527	0.9831	0.8193	0.9057	0.9646
Machined Flaw	168	12.75	0.237	55,400	63,000	0.141	0.76	2652	2,168	2,302	2,079	2,291	2,582	2,202	1,835	1,999	2,145	0.8175	0.8679	0.7838	0.8639	0.9738	0.8305	0.6921	0.7538	0.8088
Machined Flaw	169	12.75	0.248	54,100	63,000	0.141	0.78	2313	2,222	2,371	2,143	2,409	2,641	2,307	1,922	2,088	2,259	0.9605	1.0250	0.9266	1.0414	1.1418	0.9972	0.8310	0.9026	0.9766
Machined Flaw	171	12.75	0.247	55,300	63,000	0.148	0.78	2554	2,253	2,392	2,157	2,387	2,673	2,284	1,903	2,077	2,232	0.8822	0.9366	0.8446	0.9346	1.0467	0.8943	0.7453	0.8131	0.8739
Machined Flaw	182	12.75	0.27	54,100	63,000	0.178	2.2	2393	2,023	2,020	1,584	2,065	2,800	2,445	2,038	1,543	2,030	0.8455	0.8442	0.6618	0.8629	1.1699	1.0218	0.8515	0.6447	0.8482
Machined Flaw	183	12.75	0.261	55,300	63,000	0.174	4.17	2302	1,720	1,602	1,186	1,492	2,773	2,369	1,974	1,142	1,574	0.7471	0.6960	0.5152	0.6483	1.2044	1.0291	0.8576	0.4959	0.6836
Machined Flaw	184	12.75	0.268	55,300	63,000	0.183	4.11	2126	1,752	1,621	1,182	1,503	2,830	2,418	2,015	1,138	1,593	0.8240	0.7625	0.5559	0.7069	1.3312	1.1375	0.9479	0.5351	0.7491
Machined Flaw	185	12.75	0.267	58,400	63,000	0.183	2.2	2350	2,126	2,077	1,610	1,976	2,978	2,409	2,008	1,506	1,958	0.9048	0.8839	0.6849	0.8410	1.2670	1.0251	0.8543	0.6407	0.8333
Machined Flaw	186	12.75	0.265	52,100	63,000	0.175	4.25	2081	1,650	1,556	1,147	1,527	2,651	2,404	2,004	1,140	1,606	0.7930	0.7475	0.5512	0.7337	1.2739	1.1553	0.9628	0.5479	0.7718
Machined Flaw	187	12.75	0.259	58,400	63,000	0.166	4.19	2028	1,838	1,720	1,314	1,548	2,922	2,364	1,970	1,229	1,617	0.9062	0.8481	0.6480	0.7632	1.4409	1.1658	0.9715	0.6061	0.7974
Service or Hydro	48	24	0.375	53,800	68,700	0.295	16.00	742	395	793	475	621	2,076	1,989	1,657	487	588	0.5317	1.0682	0.6405	0.8373	2.7984	2.6801	2.2334	0.6562	0.7925
Service or Hydro	49	24	0.375	48,800	60,000	0.320	9.00	788	903	708	354	497	1,865	1,720	1,433	355	556	1.1457	0.8987	0.4493	0.6312	2.3666	2.1823	1.8186	0.4507	0.7056
Service or Hydro	50	20	0.312	50,000	60,000	0.252	12.00	713	330	721	408	510	1,921	1,729	1,441	404	493	0.4628	1.0106	0.5723	0.7152	2.6941	2.4247	2.0206	0.5666	0.6912
Service or Hydro	51	20	0.305	55,100	75,600	0.210	10.50	1,170	1,132	998	705	996	2,113	2,175	1,812	753	1,011	0.9679	0.8527	0.6026	0.8515	1.8062	1.8587	1.5489	0.6433	0.8639
Service or Hydro	79	24	0.375	42,000	62,600	0.322	16.75	804	204	532	248	381	1,604	1,793	1,494	278	339	0.2538	0.6622	0.3083	0.4740	1.9947	2.2298	1.8582	0.3456	0.4211
Service or Hydro	80	30	0.365	58,600	75,500	0.229	16.00	987	584	910	688	887	1,850	1,787	1,489	708	883	0.5921	0.9215	0.6966	0.8983	1.8741	1.8109	1.5091	0.7173	0.8947
Service or Hydro	81	30	0.375	68,770	84,100	0.245	27.00	992	656	977	728	861	2,216	2,032	1,694	728	795	0.6609	0.9845	0.7335	0.8675	2.2336	2.0486	1.7072	0.7337	0.8013
Service or Hydro	83	20	0.260	50,700	59,800	0.218	16.00	835	234	531	273	321	1,647	1,457	1,214	267	278	0.2805	0.6361	0.3264	0.3848	1.9728	1.7452	1.4543	0.3201	0.3332
Service or Hydro	84	36	0.330	65,000	77,000	0.218	16.00	775	445	714	532	635	1,576	1,400	1,167	523	638	0.5741	0.9218	0.6860	0.8192	2.0334	1.8066	1.5055	0.6743	0.8233
Service or Hydro	85	30	0.298	71,000	75,000	0.269	63.00	815	151	392	160	159	1,796	1,423	1,186	148	145	0.1853	0.4806	0.1965	0.1946	2.2037	1.7459	1.4549	0.1819	0.1779
Service or Hydro	86	22	0.198	60,967	66,000	0.148	6.00	828	739	630	422	501	1,437	1,167	972	396	549	0.8929	0.7606	0.5101	0.6054	1.7354	1.4090	1.1742	0.4780	0.6634
Service or Hydro	188	34	0.261	49,250	66,000	0.132	17	848	411	577	460	595	1,036	1,041	868	484	585	0.4848	0.6808	0.5424	0.7017	1.2216	1.2278	1.0232	0.5712	0.6903
Service or Hydro	189	30	0.5	62,000	75,000	0.47	17	1003	1,004	628	179	237	2,478	2,248	1,874	178	194	1.0013	0.6264	0.1789	0.2362	2.4706	2.2415	1.8679	0.1779	0.1934
Service or Hydro	190	26	0.29	58,600	66,000	0.184	23	922	526	781	580	628	1,707	1,442	1,201	555	581	0.5701	0.8470	0.6286	0.6808	1.8512	1.5637	1.3031	0.6014	0.6304
Service or Hydro	191	18	0.25	58,800	66,000	0.181	19	800	496	821	550	598	2,061	1,735	1,446	526	536	0.6199	1.0264	0.6878	0.7479	2.5767	2.1692	1.8076	0.6569	0.6702
Service or Hydro	195	20	0.312	42,800	60,000	0.262	9	707	775	623	317	487	1,636	1,721	1,434	342	513	1.0968	0.8818	0.4478	0.6893	2.3147	2.4337	2.0280	0.4840	0.7258
Service or Hydro	214	10.75	0.265	49,000	63,000	0.2	8.75	1715	652	1,246	783	1,037	2,850	2,748	2,290	805	991	0.3801	0.7267	0.4565	0.6049	1.6617	1.6023	1.3353	0.4696	0.5780
Service or Hydro	215	26	0.281	62,000	66,000	0.181	19	779	525	793	590	611	1,752	1,399	1,166	548	575	0.6734	1.0184	0.7568	0.7838	2.2490	1.7956	1.4963	0.7031	0.7379

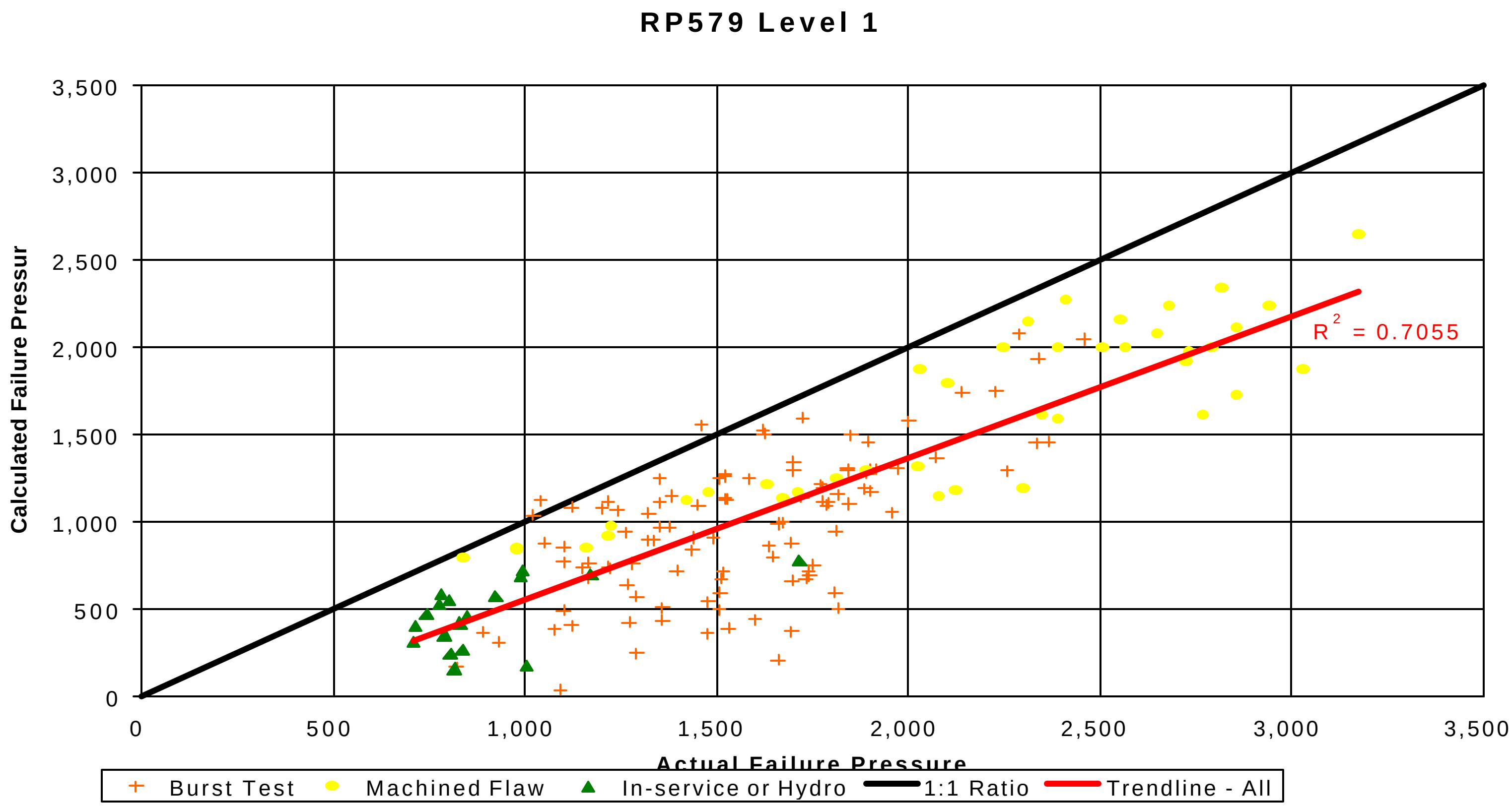
Table 2. Evaluation of Calculated Failure Pressure to Actual Failure Pressure Ratio

	B31G	B31G Mod	RP579 Level 1	DVN 2000	RAM Pipe 1	RAM Pipe 2	RAM Pipe 3	ABS 2000	PCORRC
Average	0.7845	0.8260	0.6387	0.8353	1.3553	1.2889	1.0740	0.6480	0.8270
Standard Deviation	0.2177	0.1869	0.2017	0.2778	0.3675	0.3773	0.3145	0.2050	0.2638
Minimum	0.0344	0.2441	0.0380	0.0590	0.8030	0.7571	0.6309	0.0446	0.0502
Maximum	1.2375	1.3477	1.0803	1.7740	2.7984	2.6801	2.2334	1.2525	1.6594
Normal Distribution	83.89%	82.40%	96.34%	72.34%	16.68%	22.20%	40.69%	95.70%	74.40%
R^2	0.6978	0.7355	0.7055	0.5470	0.6339	0.4621	0.4621	0.6444	0.5562

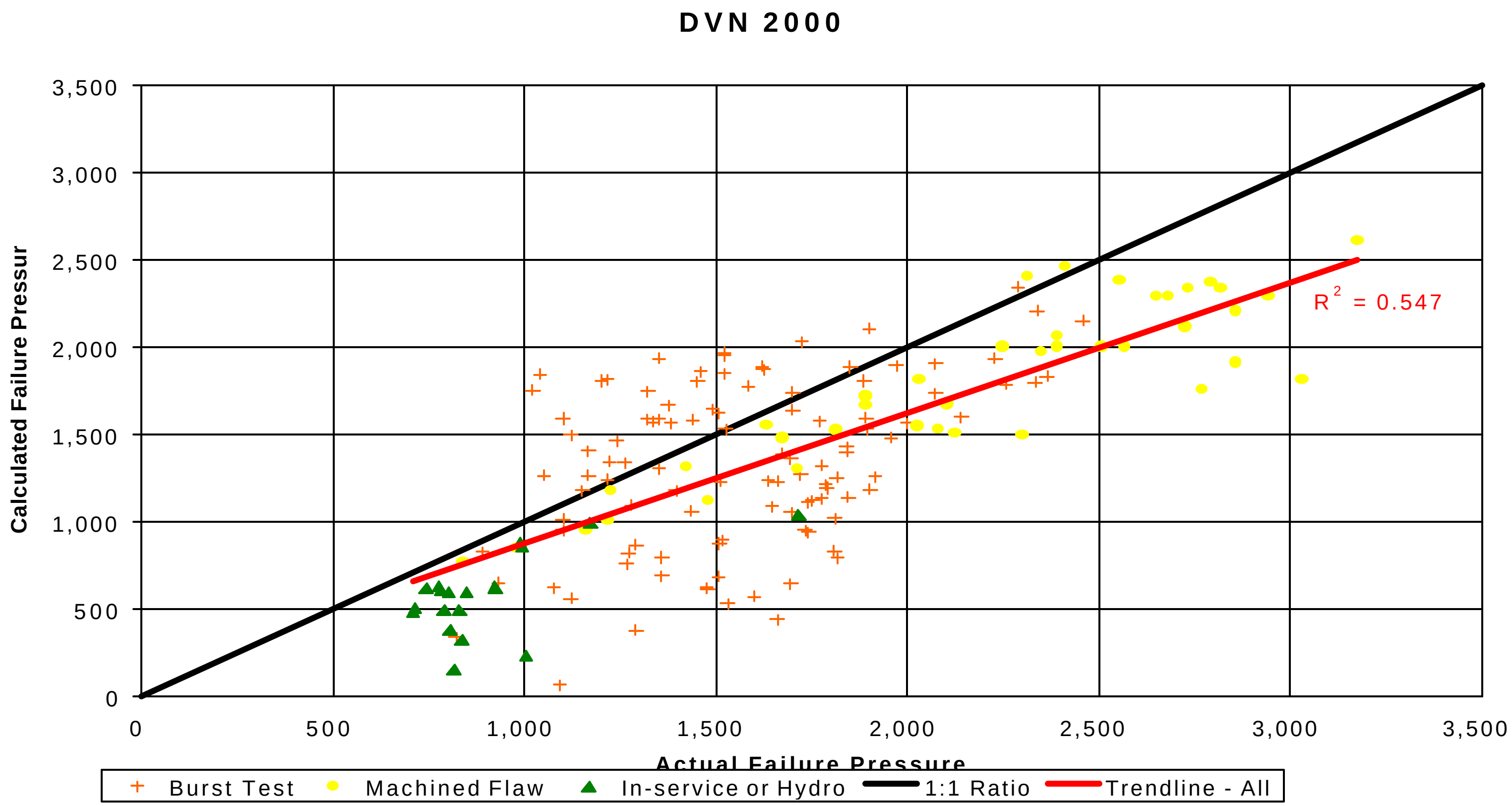

B31G
Calculated Failure Pressur
Actual Failure Pressure
0
500
1,000
1,500
2,000
2,500
3,000
3,500
$R^2 = 0.6978$
Burst Test
Machined Flaw
In-service or Hydro
1:1 Ratio
Trendline - All



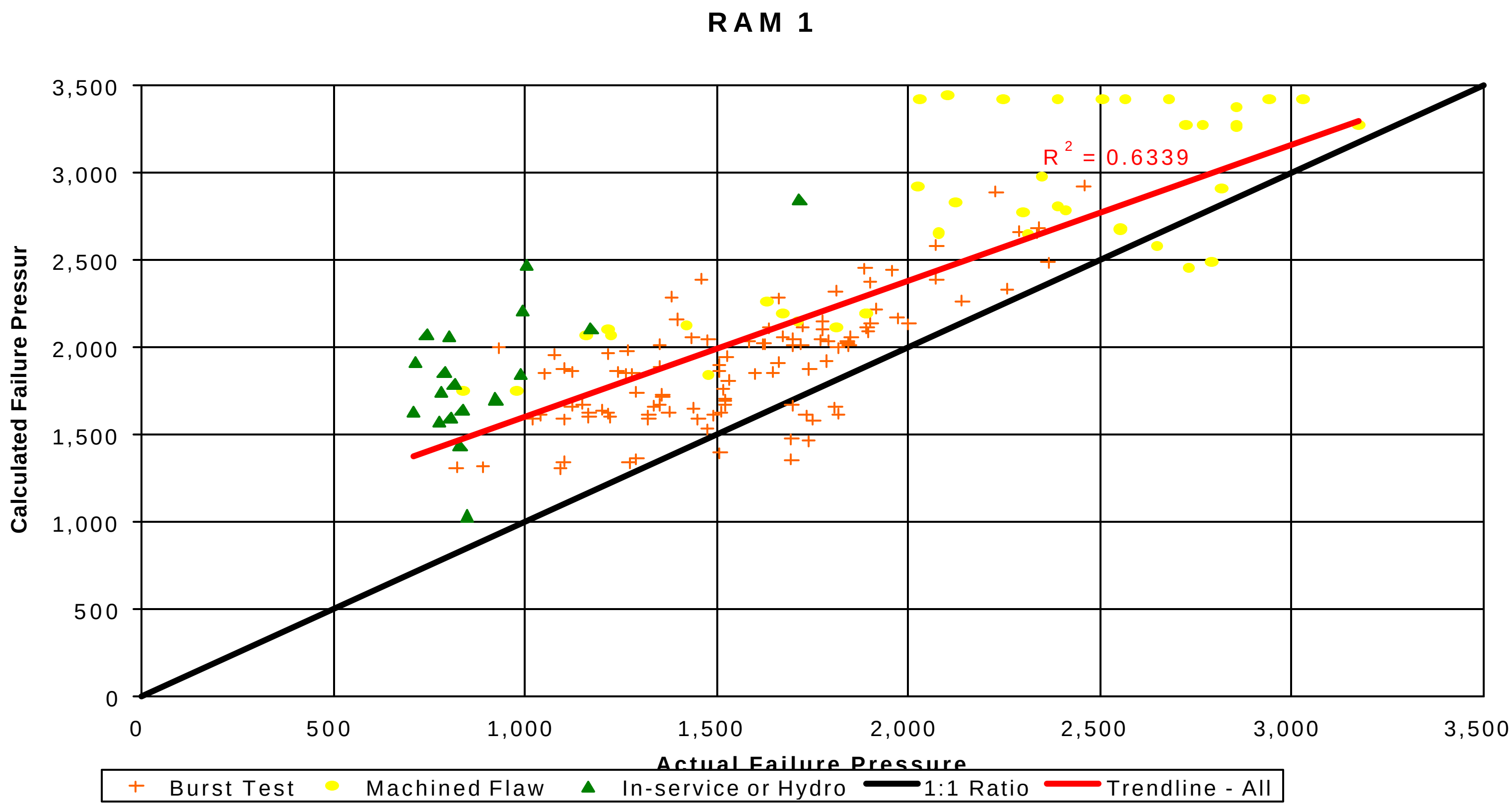
Modified B31G
Calculated Failure Pressur
Actual Failure Pressure
0
500
1,000
1,500
2,000
2,500
3,000
3,500
$R^2 = 0.7355$
Burst Test
Machined Flaws
In-service or Hydro
1:1 Ratio
Trendline - All

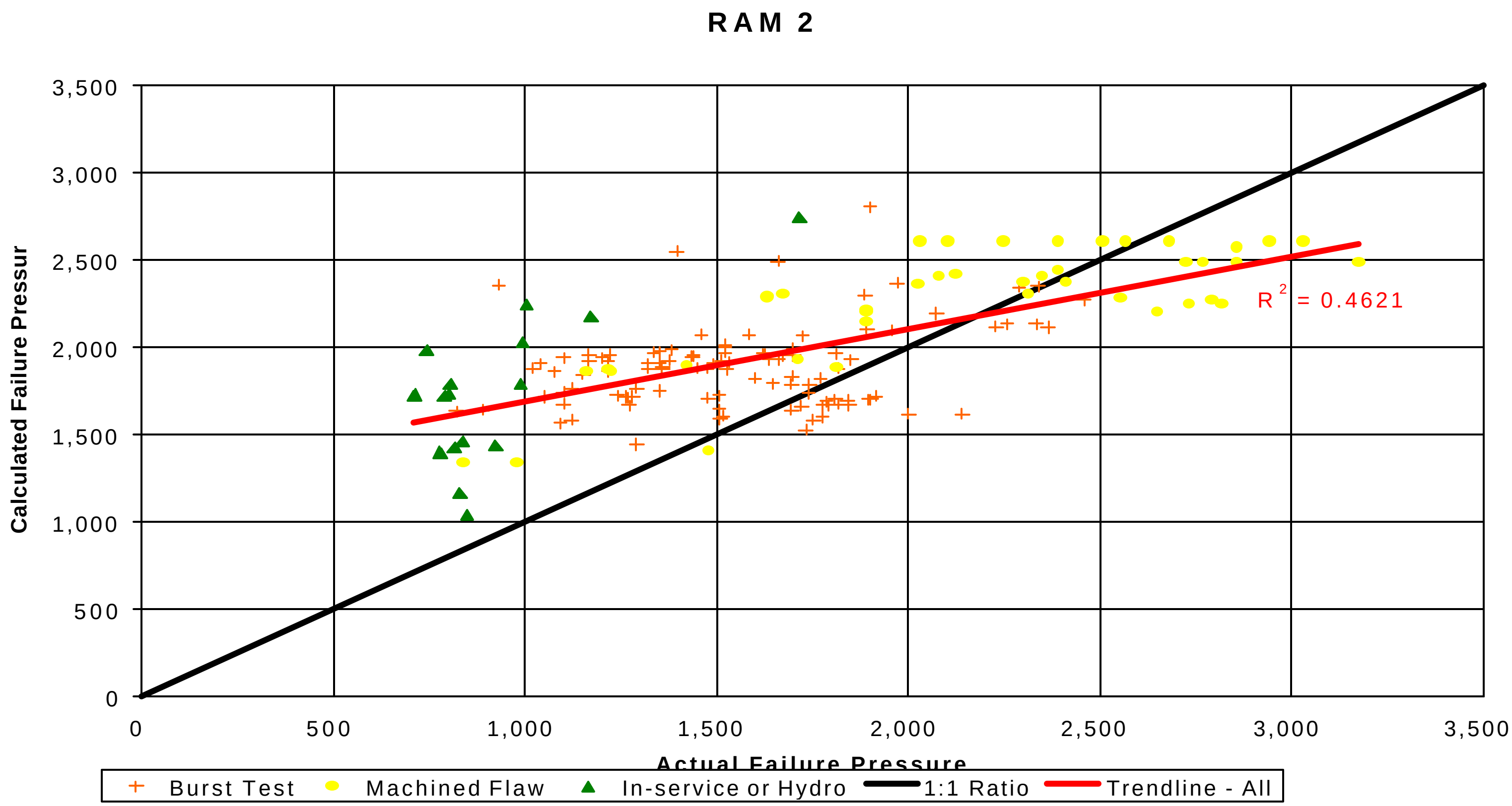


RP579 Level 1
Calculated Failure Pressur
Actual Failure Pressure
0
500
1,000
1,500
2,000
2,500
3,000
3,500
$R^2 = 0.7055$
Burst Test
Machined Flaw
In-service or Hydro
1:1 Ratio
Trendline - All

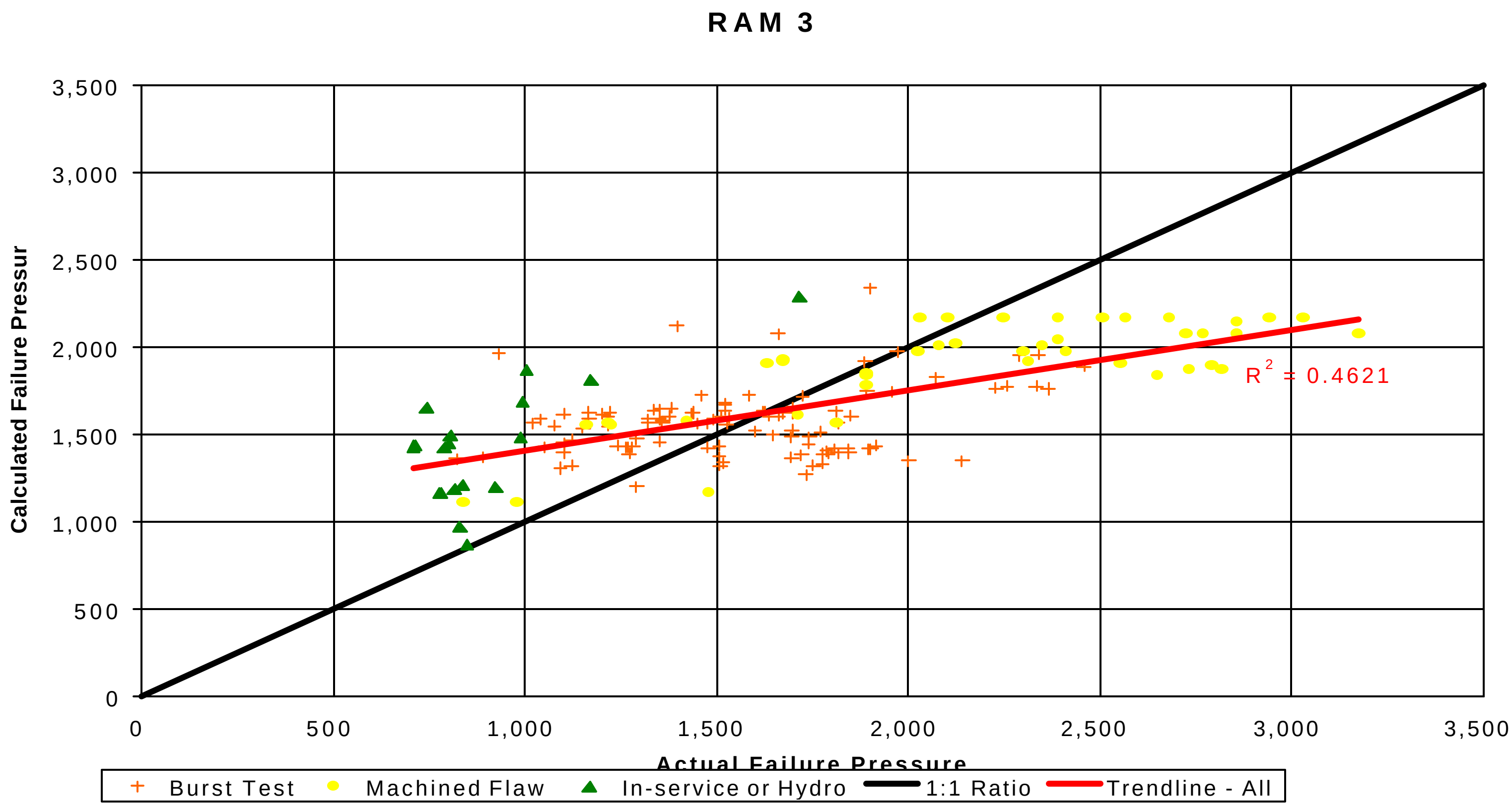


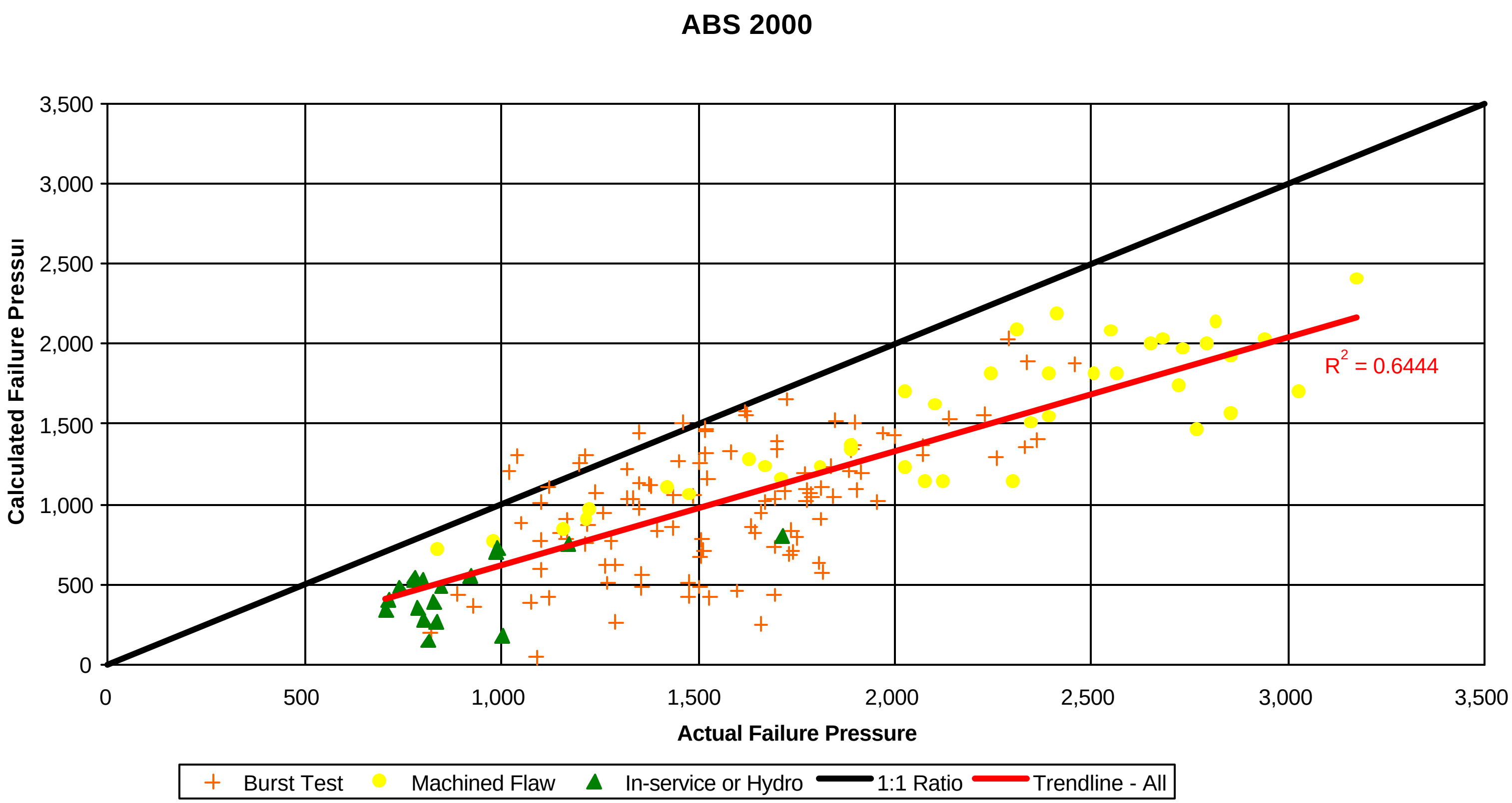
DVN 2000
Calculated Failure Pressur
Actual Failure Pressure
3,500
3,000
2,500
2,000
1,500
1,000
500
0
0
500
1,000
1,500
2,000
2,500
3,000
3,500
R2 = 0.547
Burst Test
Machined Flaw
In-service or Hydro
1:1 Ratio
Trendline - All


RAM 1
R 2 = 0.6339
Calculated Failure Pressur
Actual Failure Pressure
0
500
1,000
1,500
2,000
2,500
3,000
3,500
Burst Test
Machined Flaw
In-service or Hydro
1:1 Ratio
Trendline - All

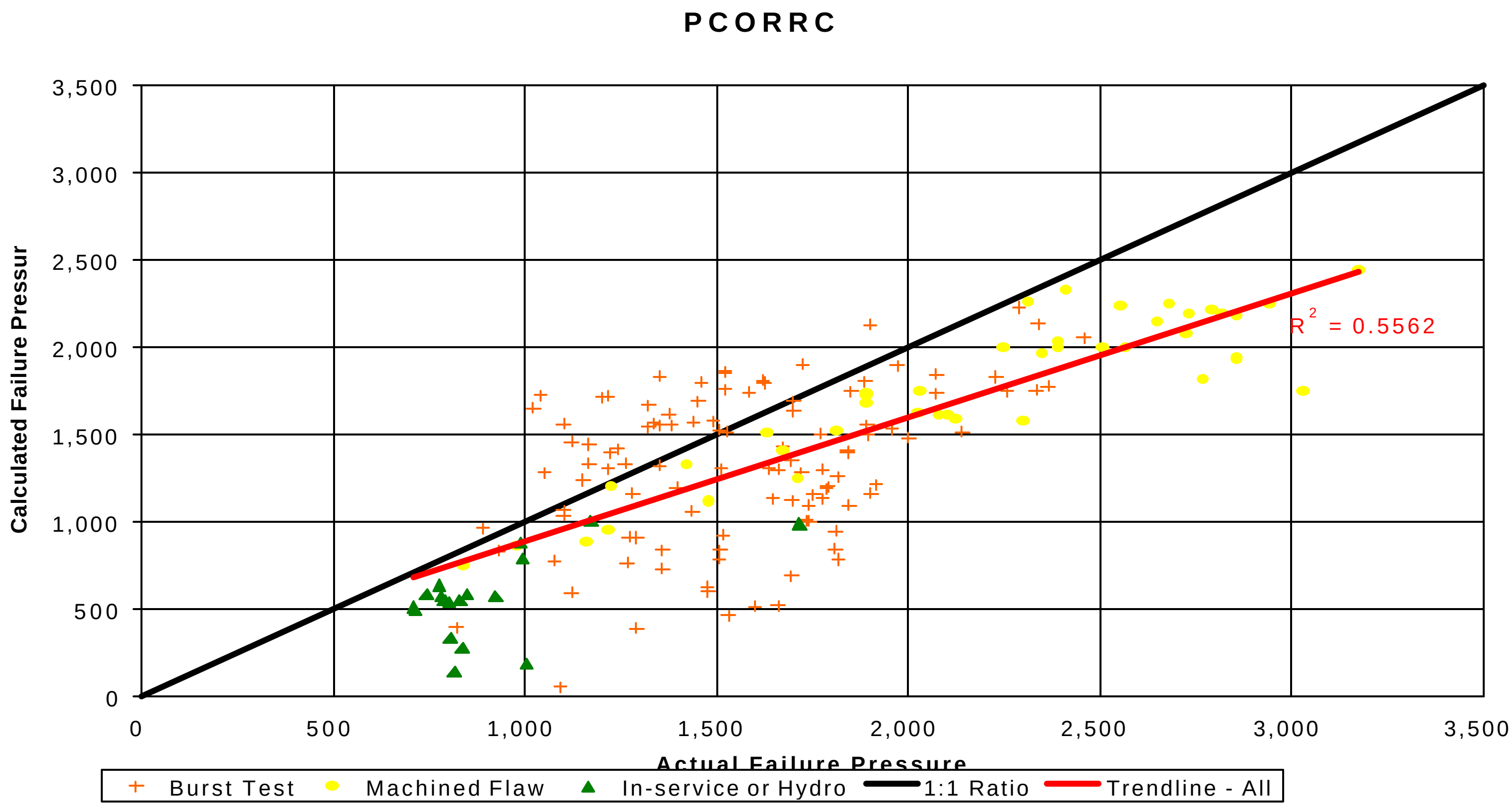


RAM 2
Calculated Failure Pressur
Actual Failure Pressure
3,500
3,000
2,500
2,000
1,500
1,000
500
0
0
500
1,000
1,500
2,000
2,500
3,000
3,500
$R^2 = 0.4621$
Burst Test
Machined Flaw
In-service or Hydro
1:1 Ratio
Trendline - All


RAM 3
Calculated Failure Pressur
Actual Failure Pressure
0
500
1,000
1,500
2,000
2,500
3,000
3,500
$R^2 = 0.4621$
Burst Test
Machined Flaw
In-service or Hydro
1:1 Ratio
Trendline - All



ABS 2000
Calculated Failure Pressur
Actual Failure Pressure
3,500
3,000
2,500
2,000
1,500
1,000
500
0
0
500
1,000
1,500
2,000
2,500
3,000
3,500
$R^2 = 0.6444$
Burst Test
Machined Flaw
In-service or Hydro
1:1 Ratio
Trendline - All



PCORRC
Calculated Failure Pressur
3,500
3,000
2,500
2,000
1,500
1,000
500
0
0
500
1,000
1,500
2,000
2,500
3,000
3,500
Actual Failure Pressure
R 2 = 0.5562
Burst Test
Machined Flaw
In-service or Hydro
1:1 Ratio
Trendline - All