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Assessment of Pipeline Integrity with Circumferential Corrosion Using ASME B31.G and BS 7910

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Abstract

Pipeline integrity is essential for ensuring the safe and reliable transportation of hydrocarbons. Corrosion is one of major cause of pipeline failure and requires regular assessment. The ASME B31.G method is commonly used in Indonesia to evaluate pipeline integrity based on hoop stress due to internal pressure. However, this method does not account for axial stress, which can become significant in the presence of circumferential corrosion defects. This study assesses a pipeline with 19 corrosion defects using ASME B31.G and compares the results with BS 7910, which considers both hoop and axial stresses. Future defect growth is predicted using DNV RP F101. Results show that two circumferential defects are governed by axial stress in 2027 and 2030, and that ASME B31.G significantly overestimates safe operating pressure in such cases. A simulation further reveals that axial stress tends to dominate when corrosion depth exceeds 50% of wall thickness. This study recommends identifying defect orientation and using BS 7910 for a more conservative assessment when axial stress is likely to govern.

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Abstrak

Integritas pipa sangat penting untuk menjamin transportasi hidrokarbon yang aman dan andal. Korosi merupakan salah satu penyebab utama kegagalan pipa dan memerlukan evaluasi secara berkala. Metode ASME B31.G umum digunakan di Indonesia untuk menilai integritas pipa berdasarkan tegangan lingkar akibat tekanan internal. Namun, metode ini tidak mempertimbangkan tegangan aksial, yang dapat menjadi dominan pada cacat korosi sirkumferensial. Studi ini mengevaluasi pipa dengan 19 cacat korosi menggunakan metode ASME B31.G dan membandingkan hasilnya dengan BS 7910, yang mempertimbangkan baik tegangan lingkar maupun aksial. Pertumbuhan cacat diprediksi dengan menggunakan DNV RP F101. Hasil menunjukkan bahwa dua cacat sirkumferensial didominasi oleh tegangan aksial pada tahun 2027 dan 2030, dan bahwa ASME B31.G secara signifikan melebihestimasi tekanan operasi aman dalam kasus tersebut. Simulasi tambahan menunjukkan bahwa tegangan aksial cenderung menjadi dominan ketika kedalaman korosi melebihi 50% dari ketebalan dinding. Studi ini merekomendasikan identifikasi orientasi cacat dan penggunaan BS 7910 untuk penilaian yang lebih konservatif ketika tegangan aksial berpotensi mendominasi.

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1. BACKGROUND

Oil and gas transmission pipelines must maintain integrity to ensure the safe and reliable transportation of hydrocarbons. Pipeline integrity is achieved through a combination of sound design, appropriate material selection, and effective operating practices. The materials used in pipeline construction are selected to withstand severe stress conditions. However, certain unavoidable factors may still lead to pipeline failure when the material's stress limits are exceeded. One of the primary causes of failure is corrosion. UKOPA stated that around 22% of failure is caused by corrosion, external corrosion and external corrosion (Goodfellow, Lyons and Haswell, 2021).

Pipelines may experience both external and internal corrosion due to interactions between the pipe material and the surrounding environment, both internally and externally. Corrosion in pipelines reduces structural strength and increases the risk of failure. In practice, pipelines with corrosion defects are assessed periodically. For pipelines inspected using Inline Inspection (ILI) technology, several references are commonly used to assess pipeline integrity with corrosion defects, such as ASME B31.G, DNV RP F101, and BS 7910. Among these, ASME B31.G is the most used standard in Indonesia. These assessments primarily consider the stress in the pipeline caused by internal pressure. Pressurized pipelines are subject to various types of stress, including hoop stress, axial stress, and radial stress. Hoop stress is typically the highest due to internal pressure. However, in some cases, axial stress can become more dominant, particularly when corrosion occurs in the circumferential direction i.e. weld corrosion. It is important to note that ASME B31.G only considers hoop stress. Therefore, it is recommended to take axial stress into account when evaluating pipelines with circumferential corrosion defects, as failure may occur due to axial loading.

This paper presents a recommendation for the integrity assessment of pipelines, with a specific focus on circumferential corrosion defects. This study aims to evaluate the limitations of ASME B31.G in assessing circumferential corrosion and to propose the inclusion of axial stress effects using BS 7910 for a more accurate integrity evaluation.

2. METHODOLOGY

A pipeline with 19 corrosion defects is taken as a case study for the assessment. The pipeline has the following properties:

- Maximum Operating Pressure, 740 psi
- Material, API 5L Gr B
- Fluid, crude oil
- Outside Diameter, 16in
- Nominal Thickness, 0.5in

The pipeline is checked against the construction code minimum required thickness specified in the construction code ASME B31.4. Then, the assessment procedure based on ASME B31.G is conducted using the formula in Table 1 (ASME B31.G, 2022)

Table 1.
ASME B31.G Formula

Original ASME B31.G	Modified ASME B31.G
For z ≤ 20 $S_F = S_{flow}\left[\frac{1-{}^{2}/_{3}(d/t)}{1-{}^{2}/_{3}{}^{(d/t)}/_{M}}\right]$ For z >20 $S_F = S_{flow}(1-d/t)$ Where, $M = (1+0.8z)^{1/2}$ $z = {}^{L^2}/_{Dt}$	$S_F = S_{flow}\left[\frac{1-0.85(d/t)}{1-0.85\,{}^{(d/t)}/_{M}}\right]$ For z ≤ 50 $M = (1+0.6275z - 0.003375z^2)^{1/2}$ For z >50 $M = 0.032z + 3.3$ $z = {}^{L^2}/_{Dt}$
S_F = estimate failure stress level P_F = estimated failure pressure = ${}^{2S_F t}/_{D}$	S_{flow} =flow stress P_s = safe operating pressure = ${}^{P_F}/_{SF}$

The lowest P_s result from original and modified ASME B31.G is taken as safe operating pressure. The formula is rearranged to determine the maximum allowable defect size (depth and length) due to internal pressure, as shown in **Error! Reference source not found.**. It should be noted that when pipeline corrosion depth higher than 80% of nominal thickness, repair is usually recommended regardless of P_s obtained from the calculation.

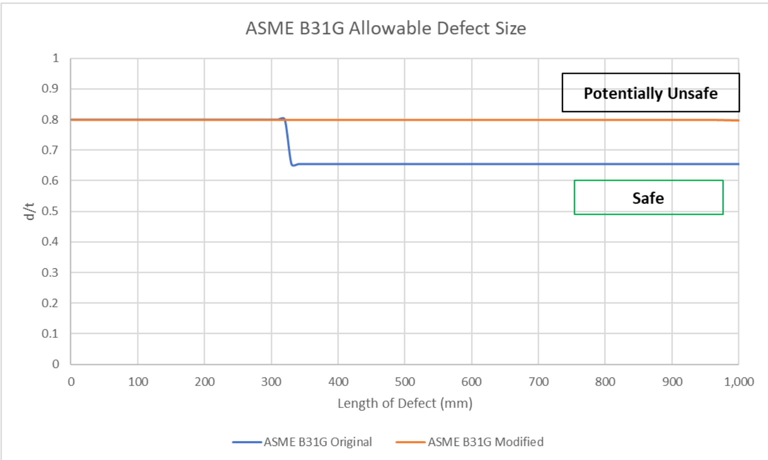

Figure 1.
ASME B31.G Allowable Defect Size

Since ASME B31.G only considers failure due to hoop stress, an additional assessment based on BS 7910 is also conducted as a comparison. Hoop (σ_{ref2}) and axial reference stress (σ_{ref1}) due to metal loss is defined in BS 7910 as follow (BS 7910, 2019):

$$\sigma_{ref1}=\frac{\pi(1-\frac{a}{B})+2\frac{a}{B}\sin(\frac{c2}{r})}{(1-\frac{a}{B})(\pi-(\frac{c2}{r})(\frac{a}{B})}\sigma_1$$

$$\sigma_{ref2}=\left(\frac{1-(\frac{a}{B})\frac{1}{Q}}{1-(\frac{a}{B})}\right)\sigma_2$$

$$Q=\sqrt{1+0.62(\frac{C1^2}{rB})}$$

The load ratio L_r is calculated from the following equation:

$$L_r = \frac{f_c \sigma_{\text{ref}}}{\sigma_Y}$$

The cut-off is to prevent local plastic collapse, it is set at the point at which $L_r = L_{r,max}$ where

$$L_{r,max} = \frac{\sigma_Y + \sigma_U}{2\sigma_Y}$$

Hence, the corrosion defect is acceptable when $L_r < L_{r,max}$. The procedure outlined in BS 7910 enables users to determine the predicted stress that may cause pipeline failure, whether it is due to hoop stress or axial stress.

As corrosion defects tend to grow over time in depth, length, and width, the future integrity of the pipeline can be assessed by predicting defect growth using the methodology outlined in DNV RP F101 (DNV RP F101, 2017). The predicted corrosion growth is then evaluated using both the ASME B31.G and BS 7910 assessment procedures.

3. RESULT AND DISCUSSION

The corrosion defect found during the ILI in 2014 is projected to the years 2027 and 2030. The results are presented in Table 2. Out of the 19 defects, 7 are circumferential corrosion defects located near the weld which potentially fail due to axial stress.

Table 2.
Corrosion defect size prediction

No	Nominal Thickness (mm)	2024 Defect Size			2027 Defect Size Prediction			2030 Defect Size Prediction		
		Depth /Nominal	Length (mm)	Width (mm)	Depth /Nominal	Length (mm)	Width (mm)	Depth /Nominal	Length (mm)	Width (mm)
1	12.7	0.18	18	18	0.24	23.89	23.89	0.3	29.79	29.79
2	12.7	0.16	24	39	0.21	32.21	52.34	0.27	40.42	65.68
3	12.7	0.24	31	21	0.31	40.25	27.26	0.38	49.49	33.53
4	12.7	0.31	40	293	0.4	51.14	374.58	0.48	62.28	456.16
5	12.7	0.11	29	96	0.15	40.66	134.58	0.2	52.31	173.17
6	12.7	0.12	39	32	0.17	54.05	44.35	0.21	69.11	56.7
7	12.7	0.35	16	73	0.44	20.33	92.76	0.54	24.66	112.52
8	12.7	0.16	14	39	0.21	18.79	52.34	0.27	23.58	65.68
9	12.7	0.58	82	394	0.72	102.24	491.25	0.87	122.48	588.5
10	12.7	0.12	11	19	0.17	15.25	26.33	0.21	19.49	33.67
11	12.7	0.3	12	35	0.38	15.37	44.82	0.47	18.74	54.65
12	12.7	0.1	13	21	0.14	18.47	29.84	0.18	23.95	38.68
13	12.7	0.18	16	49	0.24	21.24	65.05	0.3	26.48	81.09
14	12.7	0.48	35	387	0.6	43.9	485.45	0.72	52.81	583.89
15	12.7	0.29	35	298	0.37	44.91	382.37	0.45	54.82	466.74
16	12.7	0.22	33	160	0.29	43.11	209	0.35	53.21	257.99
17	12.7	0.13	45	267	0.18	61.76	366.45	0.23	78.52	465.9
18	12.7	0.1	12	44	0.14	17.05	62.53	0.18	22.11	81.05
19	12.7	0.13	19	330	0.18	26.08	452.91	0.23	33.15	575.83

Acceptability of defect based on the ASME B31.G in year 2024, 2027 and 2030 procedure are shown in **Error! Reference source not found.**

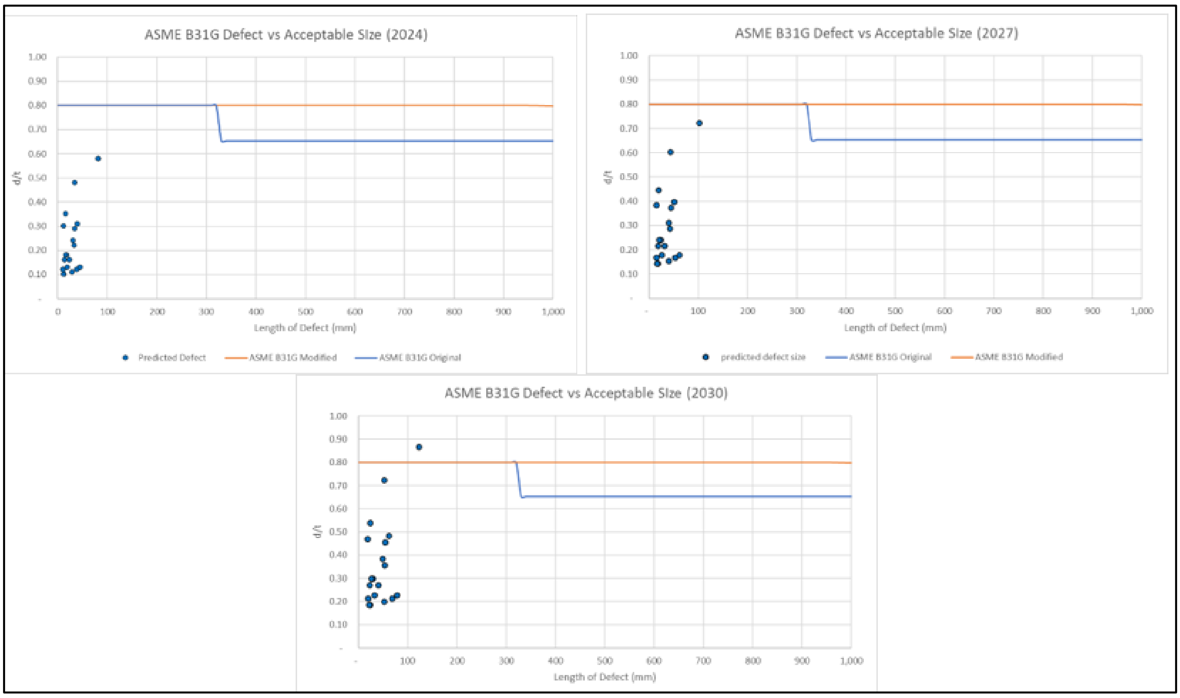

Figure 2.
Defect Acceptability based on ASME B31.G Procedure

The depth of Defect No. 9 is predicted to exceed 80% of the wall thickness (retirement thickness). However, the safe operating pressure (Ps) for this defect can still be calculated. The calculated Ps values for the years 2024, 2027, and 2030 are 1710 psi, 1394 psi, and 1007 psi, respectively. It is important to note that the ASME B31.G method for calculating Ps considers failure due only to hoop stress. If axial stress becomes the dominant stress in the pipeline, these results may no longer be valid and could underestimate the risk of failure.

To evaluate the potential dominance of axial stress resulting from internal pressure, the assessment procedure provided in BS 7910 was implemented. Table 3 presents the results of this evaluation. Among the 7 circumferential defects analyzed, 2 are predicted to exhibit axial stress dominance in the years 2027 and 2030. Consequently, the calculated safe operating pressures (Ps) for these defects are notably lower than those obtained using methods that consider hoop stress alone.

Table 3.
Assessment Result based on BS 7910

No	2024 Defect Size			2024 Result		2027 Result		2030 Result	
	Depth /Nominal	Length (mm)	Width (mm)	Psafe	Stress Govern	Psafe	Stress Govern	Psafe	Stress Govern
1	0.18	18	18	2,131	hoop	2,124	hoop	2,113	hoop
2	0.16	24	39	2,129	hoop	2,118	hoop	2,100	hoop
3	0.24	31	21	2,117	hoop	2,093	hoop	2,051	hoop
4	0.31	40	293	2,093	hoop	2,041	hoop	1,954	hoop
5	0.11	29	96	2,129	hoop	2,118	hoop	2,098	hoop
6	0.12	39	32	2,123	hoop	2,103	hoop	2,069	hoop
7	0.35	16	73	2,127	hoop	2,115	hoop	2,092	hoop
8	0.16	14	39	2,133	hoop	2,129	hoop	2,123	hoop
9	0.58	82	394	1,757	hoop	1,206	axial	503	axial
10	0.12	11	19	2,135	hoop	2,133	hoop	2,129	hoop

Table 4.
Assessment Result based on BS 7910 (Lanjutan)

No	2024 Defect Size			2024 Result		2027 Result		2030 Result	
	Depth /Nominal	Length (mm)	Width (mm)	Psafe	Stress Govern	Psafe	Stress Govern	Psafe	Stress Govern
11	0.3	12	35	2,132	hoop	2,126	hoop	2,116	hoop
12	0.1	13	21	2,134	hoop	2,132	hoop	2,128	hoop
13	0.18	16	49	2,132	hoop	2,127	hoop	2,117	hoop
14	0.48	35	387	2,069	hoop	1,736	axial	1,075	axial
15	0.29	35	298	2,106	hoop	2,067	hoop	2,003	hoop
16	0.22	33	160	2,117	hoop	2,092	hoop	2,050	hoop
17	0.13	45	267	2,118	hoop	2,091	hoop	2,048	hoop
18	0.1	12	44	2,135	hoop	2,133	hoop	2,129	hoop
19	0.13	19	330	2,132	hoop	2,126	hoop	2,116	hoop

Table 5.
Comparison Lowest Ps between ASME B31.G and

Lowest Ps	ASME B31.G	BS 7910	Stress Govern (BS7910)
2024	1,710	1,757	hoop
2027	1,394	1,206	axial
2030	1,007	503	axial

The lowest safe operating pressure (Ps) among all identified defects is typically used as the basis for determining the pipeline's maximum allowable operating pressure (MAOP). As shown in Table 4, when hoop stress governs the failure mode, the Ps values calculated using ASME B31.G and BS 7910 are relatively similar. However, due to the ASME B31.G methodology considering only hoop stress, it tends to overestimate Ps in scenarios where axial stress becomes dominant.

In the years 2027 and 2030, when axial stress is expected to be the dominant stress, the calculated Ps is significantly lower. For instance, in 2030, ASME B31.G predicts a Ps of 1007 psi. However, when assessed using BS 7910—which accounts for axial stress—the Ps is only 503 psi. This significant difference highlights the potential risk of relying solely on ASME B31.G for defects influenced by axial stress. Therefore, when assessing pipeline integrity due to corrosion, it is strongly recommended to first identify the orientation of the defect—whether it is longitudinal or circumferential. Circumferential defects are more likely to result in elevated axial stress, making ASME B31.G assessments potentially invalid or non-conservative in such cases. Similarly, predictions of remaining pipeline life using ASME B31.G tend to be non-conservative when compared to BS 7910, which accounts for both hoop and axial stress effects.

For the assessed pipeline, a simple simulation was performed to evaluate the effect of defect size on the governing stress type. The objective was to identify conditions under which axial stress becomes dominant. As shown in Table 6, the deeper the corrosion defect, the more likely axial stress is to govern. The simulation indicates that axial stress may become dominant when the corrosion depth exceeds approximately 50% of the wall thickness.

Based on the construction code, the minimum required wall thickness for the pipeline is 5.97 mm, which permits corrosion up to approximately 53% of the nominal wall thickness, regardless of defect length or width. However, the simulation results suggest that when the defect depth approaches or exceeds this allowable limit—especially for circumferentially oriented defects—axial stress might become a critical factor. Therefore, axial stress evaluation becomes increasingly important when corrosion depth nears or surpasses the minimum required thickness as per the construction code. Other reference such as API 579 requires user to check axial stress when width of defect more than twice length of defect (API 579, 2021).

Table 6.
Simulation various corrosion depth and width effect to stress govern

Width (mm)	Depth 30%	Depth 40%	Depth 50%	Depth 60%	Depth 70%	Depth 80%
	Stress Govern	Stress Govern	Stress Govern	Stress Govern	Stress Govern	Stress Govern
120	hoop	hoop	hoop	hoop	hoop	hoop
239	hoop	hoop	hoop	hoop	hoop	axial
359	hoop	hoop	hoop	axial	axial	axial
479	hoop	hoop	hoop	axial	axial	axial
599	hoop	hoop	axial	axial	axial	axial

4. CONCLUSION AND RECOMMENDATION

The integrity assessment of oil transmission pipelines with axial corrosion defects reveals that the ASME B31.G method, which considers only hoop stress, may overestimate the safe operating pressure (Ps), especially in the presence of circumferential defects. The comparative assessment using BS 7910 demonstrates that in the years 2027 and 2030, two out of seven circumferential defects are governed by axial stress, resulting in significantly lower Ps values compared to those calculated using ASME B31.G. Further simulations indicate that axial stress tends to become the governing stress when corrosion depth exceeds approximately 50% of the pipe wall thickness. Based on the findings, when assessing the integrity of pipeline, it is recommended that:

- Identify Defect Orientation: The orientation of corrosion defects (longitudinal vs. circumferential) should be identified prior to integrity assessment, as it significantly influences the dominant stress type in the pipeline.
- Apply Supplementary Methods for Circumferential Defects: For circumferential defects, reliance on ASME B31.G alone is not recommended. It is strongly advised to include BS 7910 in the evaluation to obtain a more conservative and comprehensive estimate of safe operating pressure, accounting for potential axial stress failure.
- Perform Periodic Assessments and Defect Growth Predictions: Ongoing monitoring and prediction of corrosion growth, as outlined in DNV RP F101, should be implemented to ensure long-term pipeline integrity, especially for defects nearing the minimum required wall thickness as specified in construction codes.

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