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TECHNICAL ARTICLE—PEER-REVIEWED

Analysis on the Latest Assessment Criteria of ASME B31G-2009 for the Remaining Strength of Corroded Pipelines

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Abstract ASME B31G provides the most basic and widespread method in assessing the remaining strength of corroded pipelines. The third edition B31G (ASME B31G-2009) is the latest revision issued by the American National Standards Institute (ANSI) and is used as the basis for this study. This article discusses the development process of ASME B31G, and presents the comparative analysis of ASME B31G, RSTRENG, and DNV RP-F101. The predicted failure pressures are calculated by each standard mentioned above, based on 35 groups of data for full-size pipe tests collected from the literature. The deviations between the predicted values and the actual experiment results are discussed. Finally, practical applications are compared among the assessment methods. The investigation showed that predictions based on ASME B31G-2009 are much more accurate than predictions based on the previous editions of B31G. The applications of ASME B31G-2009 and RSTRENG 0.85 dL effectively improve the pipe's conveying efficiency and optimize the cost of managing the piping system. However, they both are applicable only for evaluating the medium- and low-strength pipe steels. In contrast, DNV RP-F101 is applicable to the medium- and high-strength pipe steels, but its results are often not safe for application to the lower-strength pipe steels.

Keywords Remaining strength · Evaluation criteria · Corrosion · Pipeline · Defect

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Introduction

In the pipeline industry, some sections of high-pressure pipelines, particularly those with long service histories, may experience corrosion. A little amount of metal loss due to corrosion can be tolerated without impairing the ability of the pipeline to operate safely. The objectives of the remaining strength assessment of long-distance corroded pipelines for crude oil and gas is to establish the maximum allowable working pressure in the presence of certain defects, and to confirm if the corroded pipeline can service under a normal operation pressure. Ultimately, the remaining strength assessments guide the pipeline maintenance plans and ensure safety in production management schemes.

Since the 1960s, many countries have started studying the assessment methods to determine the remaining strength of corroded pipelines and have issued relevant evaluation standards and specifications. Early in 1984, the ASME published the first edition of the B31G Manual for Determining the Remaining Strength of Corroded Pipelines [1]. The B31G document provides pipeline operators with a simplified evaluation method based on the results of analysis and tests. This document continues to be reissued by ASME with only minor revisions over time, although other corrosion evaluation methods had evolved since B31G's initial publication. A majority of these other methods are based on the same theoretical model from which the original B31G method was derived, but may offer some refinement in accuracy. ASME B31G-2009 is the third edition approved by the American National Standards Institute (ANSI) and released on July 10, 2009. An effort was undertaken to update the B31G document to adapt to the development of modern industry.

This article introduces the development process of ASME B31G. By the comparisons of the calculated values for the remaining strength obtained using three versions of ASME B31G and other methods, the advancements of ASME B31G-2009 are presented.

The Development Process of ASME B31G

At present, ASME B31G is the most widely and basic standard used in the remaining strength assessment of pipeline. This standard provides the capability to consider pipeline corrosion defects as part of the assessment method and is based on actual full size, semi-empirical test results. The potential for pipeline failure caused by corrosion depends on the amount of corrosion (sizes of defects), and the material flow stress or yield stress. According to B31G, metal loss having a maximum depth exceeding 80% of the nominal pipe wall thickness shall not be evaluated, and metal loss having a maximum depth of 10% of the nominal pipe wall thickness or less is not limited as to allowable length.

ASME B31G-1984

The calculation formula of NG-18 surface defect in fracture mechanics is initially utilized to determine burst pressure of pipeline with corrosion defect which for NG-18 is as follows:

$$P = \frac{\sigma_{\text{flow}} \cdot 2 \cdot t}{D}\left[\frac{1 - \frac{A}{A_0}}{1 - \frac{A}{A_0} \cdot \frac{1}{M_1}}\right] \quad \text{(Eq 1)}$$

where

$$M_1 = \sqrt{1 + 0.6275\frac{L^2}{Dt} - 0.003375\left(\frac{L^2}{Dt}\right)^2} \quad \text{(Eq 2)}$$

The input parameters include burst pressure, P; flow pressure; pipe outer diameter D; wall thickness, t; local area of metal loss in the longitudinal plane, A; local original metal area ($A_0 = L \cdot t$); and bulging stress magnification factor M—which in standards ASME B31G-1984, -1991 and -2009 are represented by M_1, M_2, and M_3, respectively. Defect area definition is as shown in Fig. 1.

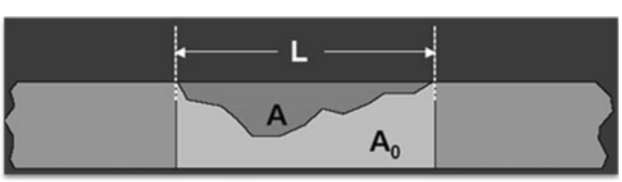

Fig. 1 Defect area

This formula can also be employed to assess the remaining strength of corroded pipeline. The original B31G issued in 1984 was based on the formula of NG-18. It has the following hypotheses:

(1) Maximum circumference stress is equal to yield strength.
(2) Flow stress is equal to 1.1*SMYS.
(3) Use the equivalent area A to express the metal loss area: for short defects, the equivalent area is equal to parabolic area, 2/3 dL; and for long defects, the equivalent area is equal to rectangular area, dL. The value of L^2/Dt is utilized to determine whether the defects is short or long, when $L^2/Dt < 20$, the defect is short; and when $L^2/Dt > 20$, the defect is long.

The failure pressure can be obtained as

$$P = \frac{\sigma_{\text{flow}} \cdot 2 \cdot t}{D}\left[\frac{1 - \frac{2}{3} \cdot \frac{d}{t}}{1 - \frac{2}{3} \cdot \frac{d}{t} \cdot \frac{1}{M_1}}\right] \quad \text{(short defects)} \quad \text{(Eq 3)}$$

$$P = \frac{\sigma_{\text{flow}} \cdot 2 \cdot t}{D}\left[\frac{1 - \frac{d}{t}}{1 - \frac{d}{t} \cdot \frac{1}{M_1}}\right] \quad \text{(long defects)} \quad \text{(Eq 4)}$$

where

$$\sigma_{\text{flow}} = 1.1 * \text{SMYS} \quad \text{(Eq 5)}$$

ASME B31G-1991

In the practical applications, researchers gradually found that ASME B31G-1984 is too conservative, and that the predicted failure pressure is much higher than the actual value. This prediction results are safe in engineering applications but cause unnecessary economic waste. In view of the conservative nature of the original B31G-1984, the revised B31G-1991 was made with the following alterations [2]:

(1) The expression for M is given by

$$M_2 = \left(1 + 0.8\frac{L^2}{Dt}\right)^{1/2} \quad \text{(Eq 6)}$$

(2) The failure pressure expression for long defects is given by

$$P = \frac{\sigma_{\text{flow}} \cdot 2 \cdot t}{D}\left[1 - \frac{d}{t}\right] \quad \text{(Eq 7)}$$

ASME B31G-2009

The two previous editions of B31G both use the parabolic or rectangular area to express the short or long defects, respectively. This use too is conservative, and thus, a new edition of B31G-2009 proposed the following revisions:

(1) Redefine the value of L^2/Dt to enable one distinguish the defect types as follows: when $L^2/Dt < 50$, the

defect is short; and when $L^2/Dt > 50$, the defect is long.

(2) Use different bulging factors of M to reflect short or long defects; the expression of M can be written as below [3]:

For $L^2/Dt < 50$,

$$M_3 = \sqrt{1 + 0.6275\frac{L^2}{Dt} - 0.003375\left(\frac{L^2}{Dt}\right)^2} \quad \text{(Eq 8)}$$

For $L^2/Dt > 50$,

$$M_3 = 0.032\frac{L^2}{Dt} + 3.3 \quad \text{(Eq 9)}$$

Defect area:

$$A = 0.85\,\text{dL} \quad \text{(Eq 10)}$$

This value lies between those of parabolic and rectangular areas.

(3) Failure pressure is denoted uniformly as

$$P = \frac{\sigma_{\text{flow}} \cdot 2 \cdot t}{D}\left[\frac{1 - 0.85 \cdot \frac{d}{t}}{1 - 0.85 \cdot \frac{d}{t} \cdot \frac{1}{M_3}}\right] \quad \text{(Eq 11)}$$

The application scope of B31G-2009 has been extended to (1) metal loss that incidentally affects longitudinal or helical electric seam welds or circumferential electric welds, (2) metal loss in new pipe where it is allowed by the applicable code of construction, (3) metal loss in pipe material having ductile fracture initiation characteristics, and (4) metal loss in pipe operating at temperatures above ambient within the range of operating temperature.

Based on the experimental data collected by Ref. [4], the failure pressures are calculated using the criteria of the three editions of ASME B31G. The deviations are obtained by the comparison between the predicted results and the actual values (see Fig. 2). It is shown that the conservatism of ASME B31G-1991 has been decreased, but there is still quite a safety allowance. However, the results of ASME B31G-2009 are much more accurate than the former editions (see Table 1).

RSTRENG Method

RSTRENG method has improved the conservatism of original ASME B31G, which includes RSTRENG 0.85 dL and RSTRENG effective area methods. RSTRENG tries to enhance the accuracy by improving ASME B31G and focus on isolated defects [5]. RSTRENG 0.85 dL method uses 0.85 dL as the defect area, and RSTRENG effective area method uses the PC program to calculate the effective area by measuring the actual size of the defect. The expressions for the bulging stress magnification factor M and failure pressure P in RSTRENG method are the same as with ASME B31G-2009. However, the former assumes that flow stress is underestimated by ASME B31G and defines the flow stress as SMYS + 68.95 MPa. Thus, the failure pressure of RSTRENG 0.85 dL method can be obtained as per the expression:

$$P = \frac{\sigma_{\text{flow}} \cdot 2 \cdot t}{D}\left[\frac{1 - 0.85 \cdot \frac{d}{t}}{1 - 0.85 \cdot \frac{d}{t} \cdot \frac{1}{M_3}}\right] \quad \text{(Eq 12)}$$

where

$$\sigma_{\text{flow}} = \text{SMYS} + 68.95\,\text{MPa} = \text{SMYS} + 10000\,\text{psi} \quad \text{(Eq 13)}$$

For $L^2/Dt < 50$,

$$M_3 = \sqrt{1 + 0.6275\frac{L^2}{Dt} - 0.003375\left(\frac{L^2}{Dt}\right)^2} \quad \text{(Eq 14)}$$

For $L^2/Dt > 50$,

Table 1 The analysis of the deviations among B31G-1984, B31G-1991, and B31G-2009

	Deviation of calculation, %		
Item	Maximum	Minimum	Average
ASME B31G-1984	90	2	59.58
ASME B31G-1991	78	10	35.13
ASME B31G-2009	60	5	21.79

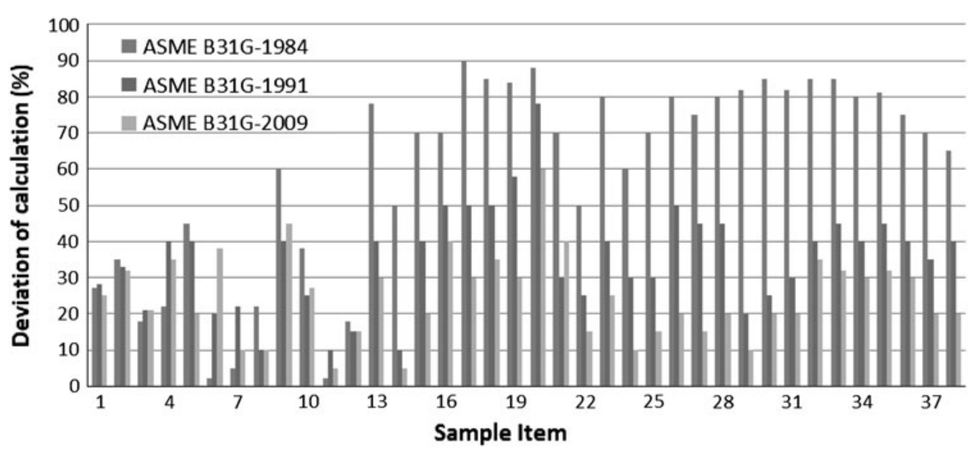

Fig. 2 The comparison of deviations among B31G-1984, B31G-1991, and B31G-2009

Table 2 Comparison between RSTRENG and ASME B31G

Criterion	B31G-1984	B31G-1991	B31G-2009	RSTRENG 0.85 dL	RSTRENG effective area
Flow stress	1.1*SMYS	1.1*SMYS	1.1*SMYS	SMYS + 68.95 MPa	SMYS + 68.95 MPa
Defect area	dL or 2/3 dL	dL or 2/3 dL	0.85 dL	0.85 dL	Effective area
Value of L^2/Dt	20	20	50	50	50
Kinds of M	1	1	2	2	2
Kinds of failure stress	2	2	1	1	1

$$M_3 = 0.032\frac{L^2}{Dt} + 3.3 \quad \text{(Eq 15)}$$

Table 2 summarizes the relationship and the difference among ASME B31G criteria and RSTRENG method.

Comparison with Other Commonly Used Criterion

In this section, the author compares the previous calculations to those made using the other commonly criterion, namely, DNV RP-F101, which also assesses the remaining strength of corroded pipelines.

DNV RP-F101

This Recommended Practice [6] is based on a project guideline developed in collaboration between BG Technology and DNV. The results from their respective Joint Industry Projects (JIP) have been merged, which formed the technical basis for this Recommended Practice. Its evaluation objects include single defects subjected to internal pressure and complicated defects under the action of composite load in multiple factors.

This article concentrates on the remaining strength assessment for the single defects of pipeline subjected to internal pressure. Therefore, we only present the calculation formula of failure pressure due to allowable stress subjected to internal pressure:

$$P = \frac{2t\mathrm{UTS}\left(1 - \frac{d}{t}\right)}{(D - t)\left(1 - \frac{d}{tQ}\right)} \quad \text{(Eq 16)}$$

where

$$Q = \sqrt{1 + 0.31\left(\frac{l}{\sqrt{Dt}}\right)^2} \quad \text{(Eq 17)}$$

where UTS is the ultimate tensile strength, and Q is the length correction factor.

It is shown that DNV RP-F101 replaced σ_{flow} (usually, $E > \sigma_{\mathrm{flow}}$) with UTS and Q ($Q < M$) with M. Thus, the value of failure pressure calculated by DNV

Table 3 The data of blasting experiment

Item	D, mm	t, mm	L, mm	D, mm	UTS, MPa	SMYS, MPa	Burst pressure, MPa
1	272.97	4.67	2.62	48.26	350.62	453.86	13.79
2	273.1	4.88	2.18	101.6	350.62	453.86	15.18
3	273.89	4.93	1.6	45.72	350.62	453.86	14.99
4	274.14	5	2.16	124.46	350.62	453.86	13.35
5	274.12	4.98	2.72	38.1	350.62	453.86	14.8
6	529	9	4.7	350	285	415	8.83
7	323.6	8.51	0	0	356.4	469.29	25.06
8	323.34	8.64	2.16	63.5	356.4	469.29	24.37
9	323.6	8.64	0	0	356.4	469.29	24.44
10	324.1	8.53	0	0	356.4	469.29	25.01
11	323.09	8.64	2.69	60.96	356.4	469.29	25.23
12	321.56	8.33	0	0	356.4	469.29	22.46
13	323.6	8.74	0	0	356.4	469.29	23.92
14	324.1	8.43	0	0	356.4	469.29	23.27
15	323.6	8.64	2.67	127	356.4	469.29	21.75
16	323.09	8.53	2.18	50.8	356.4	469.29	21.56
17	323.85	8.64	0	0	356.4	469.29	24.52
18	863.6	9.63	3.63	213.36	400.26	508.02	10.8
19	863.6	9.47	3	185.42	400.26	508.02	10.56
20	273.05	8.26	3.96	241.3	409.32	481.13	21.21
21	273.05	5.28	0	0	388.71	502.27	17.24
22	612.55	6.43	3.56	1432.56	402.54	534.53	7.88
23	611.51	6.4	2.57	1371.6	402.54	534.53	9.81
24	506.73	5.74	3.02	132.08	462.34	587.34	10.73
25	504.95	5.66	3.25	462.28	462.34	587.34	8.05
26	508	5.69	3.76	619.76	462.34	587.34	8.58
27	508	5.61	3.35	596.9	462.34	587.34	8.05
28	508	5.64	2.46	170.18	462.34	587.34	11.51
29	323.9	9.8	7.08	255.6	452	542	14.4
30	323.9	9.71	6.91	394.5	452	542	12.84
31	323.9	9.91	7.31	433.4	452	542	12.13
32	323.9	9.74	7.02	466.7	452	542	11.92
33	323.9	9.79	6.99	488.7	452	542	11.91
34	323.9	9.79	6.99	500	452	542	11.99
35	323.9	9.74	7.14	527.8	452	542	11.3

RP-F101 is larger than B31G, and the conservatism of DNV RP-F101 is lower than that of B31G.

Examples Validation

The failure pressures are calculated by means of ASME B31G-2009, RSTRENG 0.85 dL, and DNV-RP-F101 methods based on 35 groups of experimental data summarized in Table 3 [7–10]. The comparisons of their reliability and accuracy are shown in Table 4.

According to the comparisons of calculation results summarized in Fig. 3, we come to the following conclusions: ASME B31G-2009 and RSTRENG 0.85 dL are suitable for evaluation of the medium- and low-strength steels, and are often not conservative for the remaining strength assessment of high strength steels. The conservatism of ASME B31G-2009 is a little more than RSTRENG 0.85 dL. DNV RP-F101 is suitable for assessing high-strength steels, but not suitable for medium- and low-strength steels.

The analytic comparison of application for the three methods is shown in Table 5.

Table 4 The analysis of the deviations among ASME B31G-2009, RSTRENG 0.85 dL, and DNV RP-F101

Item	Deviation of calculation, %		
	Maximum	Minimum	Average
ASME B31G-2009	51.89	0.06	20.84
RSTRENG 0.85 dL	45.68	0.10	17.00
DNV RP-F101	61.35	0.50	27.20

Conclusions and Recommendations

(1) Compared with the previous two versions, the latest edition ASME B31G-2009 has shown much improved accuracy. Predicted failure pressures are closer to the actual value and greatly reduce the conservatism in the calculations. However, this standard only applies to medium- and low-strength steels (below X65) and is non-conservative for the high-strength steels.

(2) The conservatism of ASME B31G-2009 is almost the same with RSTRENG 0.85 dL. They can effectively improve the pipe-conveying efficiency and optimize the cost efficiency.

(3) DNV RP-F101 is suitable for the high-strength steels, and its conservatism is lower. However, assessment results by this method are often not reliable for the medium- and low-strength steels.

(4) ASME B31G-2009 should extend the application scope in assessing high-strength grade and large diameter steels.

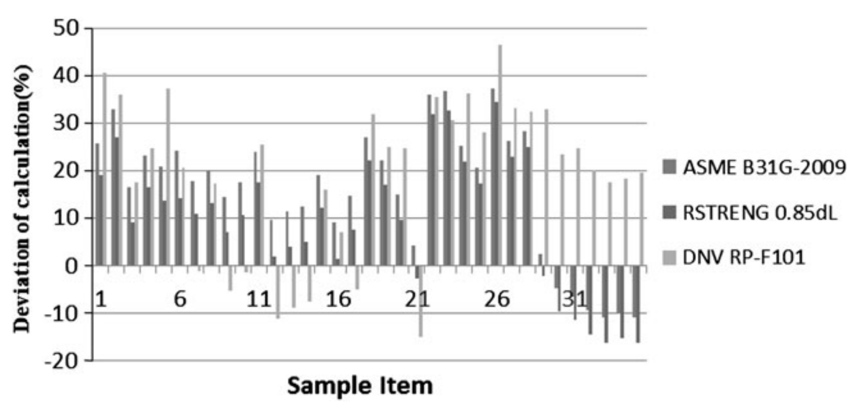

Fig. 3 The comparison of deviations among B31G-2009, RSTRENG 0.85 dL, and DNV RP-F101

Table 5 Application comparison among ASME B31G-2009, RSTRENG 0.85 dL, and DNV RP-F101

Compared item	ASME B31G-2009	RSTRENG 0.85 dL	DNV RP-F101
Safety criterion	SMYS, flow stress	SMYS, flow stress	UTS
Best applicable materials range	Medium and low strength steels	Medium and low strength steels	Medium and high strength steels
Defects types	Isolated defects or adjacent defects as an isolated defect	Isolated defects	Isolated defects or interactive defects, complicate defects
Load range	Internal pressure	Internal pressure	Internal pressure and axial pressure
Defect models uncertainty	No consideration	No consideration	Partial coefficient method

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