Copyright © 2010 Tech Science Press SDHM, vol.6, no.2, pp.101-111, 2010

Application of GB/T 19426-2004 "Safety Assessment for In-Service Pressure Vessels Containing Defects" to the Long-Distance Oil Pipeline

Zihua Zhao[1], Yu Zhou, Zheng Zhang and Qunpeng Zhong

Abstract: Annex H"Safety assessment method for straight pressure pipeline with local thinning area" of "Safety assessment for in-service pressure vessels containing defects"(GB/T 19426-2004) is briefly introduced. The maximum allowable hanging (unsupported) length of straight pressure pipeline with a local thinning area (LTA) is then determined by using this assessment method. This is the first time that the assessment method has been applied to the long-distance oil pipeline. As a typical case, we have analyzed a length of straight pressure pipeline with LTA and gave the relationship of maximum allowable unsupported length, operating pressure and the depth of LTA.

Keywords: GB/T 19426-2004; pressure pipeline; LTA; safety assessment

1 Introduction

Most of the long-distance oil pipelines in China have been in-service for more than 30 years. The pipelines are faced with a lot of problems such as anticorrosion insulation ageing, serious corrosion and material property degradation. So the industry has entered a period of frequent accidents and the pipelines have to be excavated and repaired. If the unsupported length of straight pressure pipeline is too long, the piping will fail because of excessive bending moment. Thus, it is of significance to determine the maximum unsupported length of pipeline under the combined internal pressure and bending moment.

The structural integrity analysis of the pipeline has been performed using the Chinese national standard GB/T 19426-2004, i.e. Safety assessment for in-service pressure vessels containing defects. The standard was formulated based on the latest research achievements and engineering experience in the domain of safety

[1] School of Material Science and Engineering, Beihang University, Beijing 100083, China. E-Mail: Zhzh@buaa.edu.cn

assessment for pressure vessels and pressure pipes in China. [GB/T 19624-2004 (2004); Zhong et al. (2006)]

There were a lot of safety assessment procedures such as R6 and BS 7910 in UK, SINTAP and FITNET FFS in Europe, API 579 and ASME XI in USA, JSME in Japan. Though these procedures were widely used in industry, there was no specific assessment procedure to assess the pressure piping with LTA under combined internal pressure and bending moment.

Annex H"Safety assessment method for straight pressure pipeline with local thinning area" of GB/T 19426-2004 adopted the innovative research achievement of the state key research project in the period of the ninth five-year-plan, i.e. the "engineering assessment method of plastic limit loads for LTA pressure piping". [Chen et al. (2006)] Based on more than 2500 calculation examples and a large number of full scale pipe testing results, the effects of shape, size of internal pressure and bending moment were studied. An engineering fitting formula for plastic limit loads of pressure piping with LTA was presented. Then, a safety assessment procedure was proposed for pressure piping with LTA under combined action of internal pressure and bending moment.

2 Background to "Safety Assessment Method for Straight Pressure Pipeline with Local Thinning Area"

2.1 Applicability

This annex can be applied to in-service steel pressure piping, with the following conditions:

(a) In the operating condition, pipe material has good ductility and has no degradation or degradation tendency.

(b) The lowest operating temperature is not lower than -20˚C, or the lowest operating temperature is lower than -20˚C, but material is austenitic stainless steel.

(c) The ratio of outer diameter to inner diameter is not higher than 1.4.

(d) The LTA depth is less than 70% of the original (i.e. not corroded) wall thickness and the minimum wall thickness at the bottom of the LTA is not less than 2mm.

2.2 Characterisation of LTA (regularisation and dimensionless process)

An irregular LTA on external surface can be regularised as a surface flaw with longitudinal half-length A, circumferential half-length B and depth C. This is shown in Figure 1.

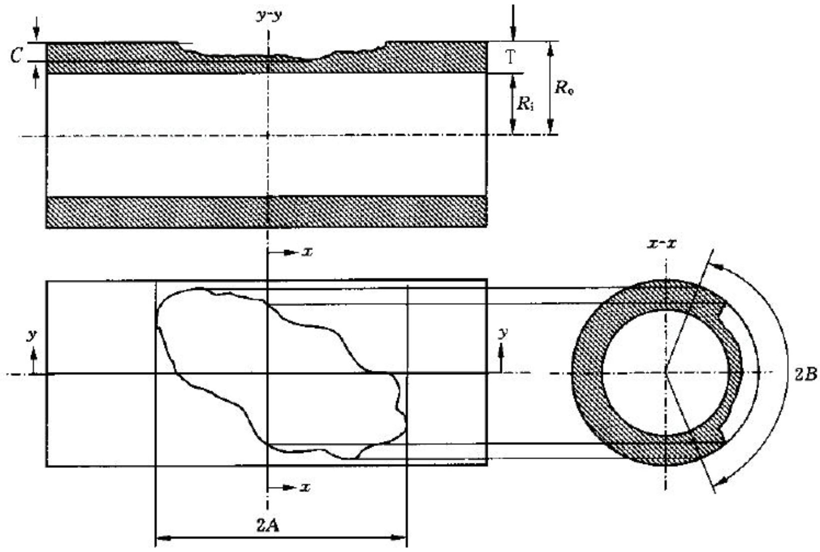

Figure 1: Regularisation of LTA on external surface

For the convenience of assessment, the dimensionless dimensions of LTA are used. The dimensionless parameters describing relative longitudinal length a, relative circumferential length b and relative thickness c are calculated from the following equations:

$$a = A/\sqrt{R_o T} \tag{1}$$

$$b = B/(\pi R_o) \tag{2}$$

$$c = C/T \tag{3}$$

where
R_o is the external radius of the piping assessed.
T is the calculated wall thickness of the piping assessed.

2.3 Plastic limit internal pressure P_{L0} under the single load of internal pressure and plastic limit bending moment M_{L0} under the single load of bending moment of flawless piping

The von Mises limit internal pressure P_{L0} under the single load of internal pressure of flawless piping is calculated from the following equation[1][11]:

$$P_{L0} = \frac{2}{\sqrt{3}} \bar{\sigma}' \ln \frac{R_o}{R_i} \tag{4}$$

where
$\bar{\sigma}'$ is the flow stress of piping material.
R_i is the internal radius of piping.

The plastic limit bending moment M_{L0} under the single load of bending moment of flawless piping is calculated from the following equation [GB/T 19624-2004 (2004)]:

$$M_{L0} = 4\bar{\sigma}'\frac{R_o^3 - R_i^3}{3} \tag{5}$$

2.4 Plastic limit internal pressure P_{LS} and plastic limit bending moment M_{LS} of pressure piping with LTA

The plastic limit internal pressure P_{LS} of pressure piping with LTA is determined using the following equation [1][12]:

$$P_{LS} = p_{LS} \times P_{L0} \tag{6}$$

where

$$p_{LS} = \begin{array}{ll} 0.95 - 0.85A_e & a/b \le 7.0 \\ 0.95 - 1.04A_e & 7.0 < a/b \le 25.0 \\ 0.95 - 1.47A_e & a/b > 25.0 \end{array} \tag{7}$$

$$A_e = c\sqrt[3]{a_e bc} \tag{8}$$

$$a_e = \min(3.0, a) \tag{9}$$

The plastic limit bending moment M_{LS} of pressure piping with LTA is determined using the following equation [GB/T 19624-2004 (2004); Chen et al. (2006)]:

$$M_{LS} = m_{LS} \times M_{L0} \tag{10}$$

where

$$m_{LS} = \begin{array}{ll} \cos\left(\frac{c\pi b}{2}\right) - \frac{c\sin(\pi b)}{2} & c < \frac{1-b}{b} \\ (1-c)\sin\left[\frac{\pi(1-bc)}{2(1-c)}\right] + \frac{c\sin(\pi b)}{2} & c \ge \frac{1-b}{b} \end{array} \tag{11}$$

2.5 Safety evaluation

If the following formula [GB/T 19624-2004 (2004)] is established, the pressure piping with LTA is safe or acceptable. Otherwise, the pressure piping with LTA is unsafe or unacceptable. Herein, the safety factor is 1.5.

$$\left(\frac{P}{P_{LS}}\right)^2 + \left(\frac{M}{M_{LS}}\right)^2 \le 0.44 \tag{12}$$

where
P is the operating internal pressure.
M is the bending moment on the location of LTA¡£

3 Application of "Safety Assessment Method for Straight Pressure Pipeline with Local Thinning Area"

3.1 Application background

As mentioned above, the straight pressure pipeline with LTA was excavated and repaired. Figure 2 is the schematic illustration diagram of the pipeline.

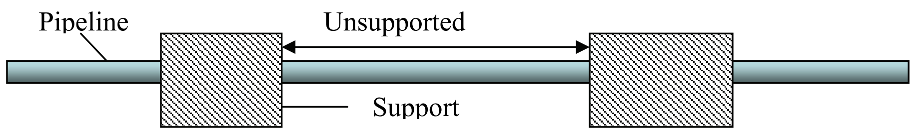

Figure 2: Schematic illustration diagram of the pipeline

The unsupported straight pressure piping is mainly under the loads of internal pressure and bending moment caused by deadweight of piping. Thus, the unsupported pipeline could be considered as beam. The end conditions of piping is near to fixed ended if the supporting soil was treated to rigid body. Considered for conservative, the piping was assumed to be simple supported.

The results of internal inspections have shown that the flaws in the piping are mainly LTA. The piping material is low alloy steel (16Mn) with good toughness and no degradation found. The lowest operating temperature is about 35°. The ratio of outer diameter to inner diameter is 1.023. This is within the range considered acceptable for annex H "Safety assessment method for straight pressure pipeline with local thinning area" of GB/T 19624-2004 and hence this can be used to evaluate the piping with LTA.

3.2 Application principle

Suppose a region of LTA is located at the midpoint of a length of unsupported piping (i.e. at the location with maximum bending moment).

Known from equation (12), the critical condition is

$$\left(\frac{P}{P_{LS}}\right)^2 + \left(\frac{M}{M_{LS}}\right)^2 = 0.44 \tag{13}$$

Suppose that,

$$f = \left(\frac{P}{P_{LS}}\right)^2 + \left(\frac{M}{M_{LS}}\right)^2 - 0.44 \tag{14}$$

On the condition that piping dimensions, flaw parameters and piping material properties are constant, variable f is the function of internal P and bending moment M, i.e. $f = f(P,M)$.

Because the maximum bending moment $M_{\max}$ is the function of unsupported length x, i.e.

$$M_{\max}(x) = -\frac{1}{8}w \cdot x^2 \tag{15}$$

where w is the weight of piping per unit length (including weight of conveyed medium and anticorrosion coating).

So f is also the function of internal pressure P and unsupported length x , i.e. $f = f(P,x)$. If $f(P,x) \leq 0$, the piping with LTA is safe; otherwise, it is unsafe. $f(P,x) = 0$ is the critical state of safety. Under the critical state, the internal pressure value P_i and the critical unsupported length x_i (i.e. maximum allowable unsupported length) is one to one correspondence. Thus the maximum allowable unsupported length can be obtained by solve the safety evaluation equation $f(P,x) = 0$.

The unsupported straight piping is not only under the load of internal pressure and bending moment, but also under the load of thermal stress originating from temperature differences and residual stresses in the piping. During safety evaluation, thermal stress and residual stress should also be considered. Therefore, an equivalent internal pressure P_e is introduced to represent the applied internal pressure P.

The equivalent internal pressure P_e is determined using the following equation:

$$P_e = \frac{2\sigma_L \cdot T}{R} \tag{16}$$

where

σ_L is the longitudinal stress of piping and calculated by the following equation (assuming that there was no interaction between longitudinal forces):

$$\sigma_L = \sigma_L^P + \sigma_L^T + \sigma_L^R \tag{17}$$

where

σ_L^P is the longitudinal stress caused by internal pressure; σ_L^T is the longitudinal thermal stress caused by temperature difference;
σ_L^R is the longitudinal residual stress and was measured by hole-drilling method.

$$\sigma_L^P = \frac{PR}{2T} \tag{18}$$

where, R is the average radius of piping.

$$\sigma_L^T = -E\alpha \cdot \Delta T \tag{19}$$

where, E is the Young's modulus of material; α is the linear expansion coefficient; ΔT is the temperature variation.

Thus, the maximum allowable unsupported length can be obtained given that parameters such as piping size, piping properties, flaw dimensions, internal pressure, temperature difference and residual stress of piping are known.

The piping internal pressure and depth of LTA are the two dominant factors affecting safe running. So the assessment equation can also be expressed as $f = f(P,C,x)$. Given that parameters such as piping size, piping properties, flaw dimensions, internal pressure, temperature difference and residual stress of piping, the relationship of internal pressure, flaw depth and maximum allowable hanging length can be obtained by solving equation $f(P,C,x) = 0$.

3.3 Application example

The example piping (16Mn) lies on the Qing-Tie east new line pipeline network. Characteristic parameters of an example piping with LTA are given in Table 1.

The maximum allowable unsupported lengths when the internal pressure is 0.1∼3MPa and depth of LTA is 0.1∼5.6mm are obtained by solving the equation $f(P,C,x) = 0$. The results are given in figure 3. The curved surface in figure 3 is $f(P,C,x) = 0$. The zone inside the curved surface is safe; otherwise, the zone outside the curved surface is unsafe.

$$f(P,C,x) = 0$$

A series of charts of relationship between maximum allowable unsupported length and depth of LTA when internal pressure values are fixed are given considering the engineering application. The relationships between maximum allowable unsupported length and depth of LTA (given that ΔT=2°, A=150mm, B=100mm) at different internal pressures are given figure 4.

It is obvious that maximum allowable unsupported length decreases more rapidly with increasing depth of LTA when the internal pressure value is fixed. And with

Table 1: Characteristic parameters of example piping

Piping size		Material properties			LTA dimensions			Loads			
R_o	T	σ_s	E	α	A	B	C	w	P	ΔT	σ_L^R
mm	mm	MPa	GPa	10^{-6}	mm	mm	mm	N/m	MPa	$\circ$	MPa
360	8	333	212	12.8	150	100	0.1∼5.6	4849	0.1∼3	2	15

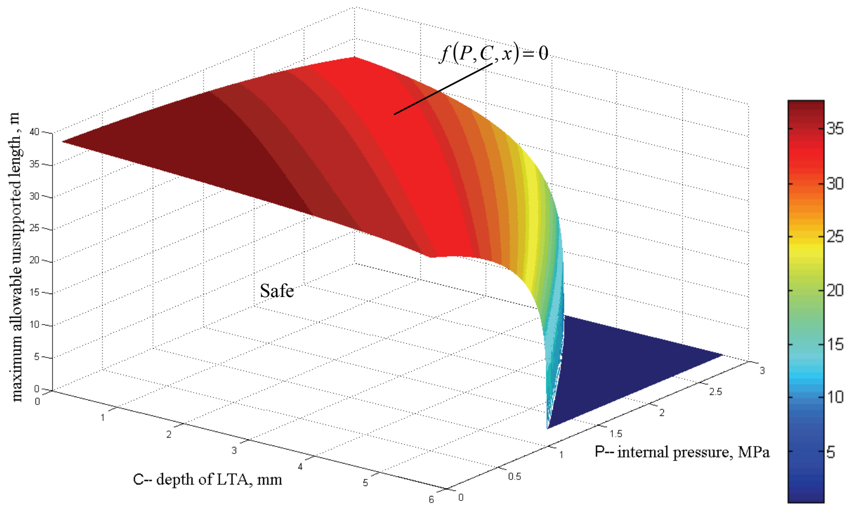

Figure 3: Graph of relationship of internal pressure, flaw depth and maximum allowable unsupported length (the colors represent the values of the maximum allowable unsupported length)

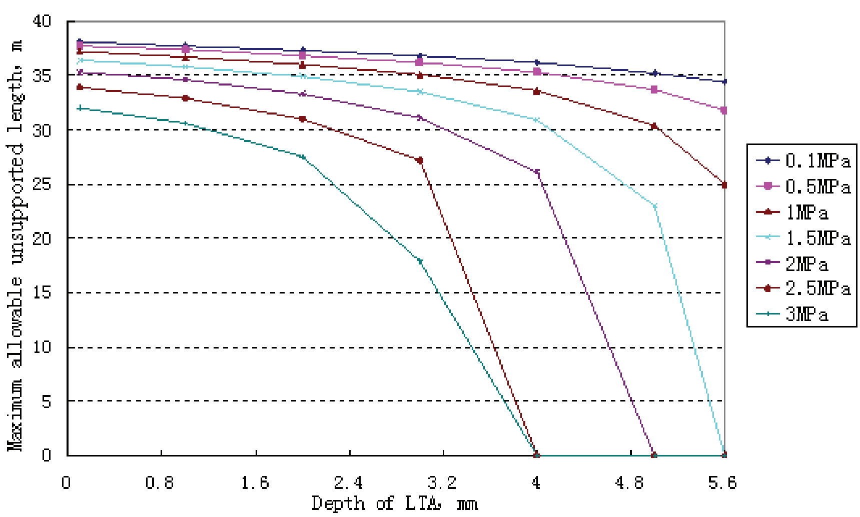

Figure 4: Graph of relation between maximum allowable unsupported length and depth of LTA at different internal pressures

the increasing of internal pressure, the influence of degree of depth of LTA on maximum allowable unsupported length is greater. When the internal pressure reaches to 2.5MPa, LTA with depth 4mm is already unsafe.

It should be pointed out that piping welds and other factors such as execution machines, adjacent environment and weather conditions are not considered during the evaluations. In practice, we should conservatively determine the limiting unsupported length of piping based on each specific situation.

4 Conclusions

1. Annex H"Safety assessment method for straight pressure pipeline with local thinning area" of GB/T 19426-2004 adopted engineering assessment method based on theory of plastic limit loads and fitting formula for plastic limit loads of pressure piping with LTA. The method is of preciseness and simple. Its generalization and application has great benefit.

2. It is the first time that "Safety assessment for in-service pressure vessels containing defects"(GB/T 19426-2004) is applied to pipeline network of oil field.

3. It provides theoretical basement for safe excavation of pressure piping with LTA and is important to engineering application.

References

GB/T 19624-2004 Safety assessment for in-service pressure vessels containing defects.

Zhong Qunpeng, Li Peining, Li Xueren, Chen Gang (2006): The summarization of the features and creative ideas of Safety assessment for in-service pressure vessels containing defects. *Pipeline technique and equipment*, 1: 2-5.

R6, revision 4 (2001): Assessment of the integrity of structures containing defects. British Energy Generation.

BS7910 (2000): Guide to methods for assessing the acceptability of flaws in metallic structures. London: BSI.

SINTAP (1999): Structural integrity assessment procedure for European industry. SINTAP BRITE-EURAM Project BRPR-CT95-0024; 1999.

European fitness-for-service network. EU's framework 5, proposal no. GTC1-2001-43049, contract no. G1RT-CT-2001-05071.

API 579 (1996): Recommended practice for fitness for service. Draft issue 4. American Petroleum Institute.

ASME XI (1995): rules for in-service inspection of nuclear power plant components. ASME.

JSME (2001): Codes for nuclear power generation facilities-rules on design and construction for nuclear power plants. JSME S NC1.

Chen Gang, Jia Guodong, Sun Liang, Zuo Shangzhi (2006): Numerical analyses of plastic limit loads and conditions exempting from assessment of local wall-thinning pressure piping. In: *Integrality technology for pressure vessel and pressure pipeline.* Beijing: China machine press, 601-613.

Xu Bingye, Chen Sencan (1981): Simple plastic theory tutorial. Qsinghua University Press, Beijing.

Miller A.G. (1988): Review of limit loads of structure containing defects. I*nternational Journal of Pressure Vessel and Piping*. 32: 197-327.