2011 International Conference on Information Management and Engineering (ICIME 2011)
IPCSIT vol. 52 (2012) © (2012) IACSIT Press, Singapore
DOI: 10.7763/IPCSIT.2012.V52.37

Research on Improved Calculation Method for Vertically Installing Pressure Pipes' Wall Thickness

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Abstract—Because hanging deadweight and vertically installing error for the vertically installing pressure pipes, the pressure within pipes will increase, and this installing error must be considered when the wall thickness is calculated for vertically installing draining pipe. According to the vertically installing error, the empirical design formula for the pipes' wall thickness was improved when the eccentric installing error's maximum is 0.191° . According to the fourth strength theory, the pipe's circumferential stress and radial stress are obtained based on the unit length pipe's weight's orthogonal component force, then the wall thickness' improved design formula is derived. Comparing equivalent stress's finite element calculation results, there are some conclusions that the maximum stress calculated from the improved design formula is closer to the finite element calculation results, and the relative error is less than the calculation results from the empirical design formula; vertically installing error's effect on calculation results is larger.

Keywords-pipe; vertially installing; wall thickness calculation; strength design; finite element

1. Introduction

Pipeline transportation is widely used as fluid transportation method for modern industrial enterprise, especially for gas enterprise, the city gas network is the biggest and most basic asset [1~4]. Because most of pipes bear certain transfer pressure, the pipe's wall thickness is an important index for pipe's strength and the pipe's wall thickness design and calculation are important contents for pipe's strength calculation [5~7]. Recent years, for china's petroleum and natural gas enterprise, the improvements of transportation pipeline's manufacturing technology and normative standard can offer powerful technical support, computation basis and lots of empirical design data for transportation pipeline's wall thickness's optimization design [8~9]. But generally, these empirical design data and design formula are only suitable for limited applications. So the empirical design formula is not suitable for mine drainage pipe's wall thickness calculation [10~12]. With respect to installing pipe on the ground, mine drainage pipe's application situation is special and mine drainage pipe is often installed vertically [13, 14]. Because hanging deadweight and vertically installing error for the vertically installing pressure pipes, the pressure within pipes will increase, and this installing error must be considered while calculating wall thickness [15]. Although the existing empirical formula can design and calculate the wall thickness, the empirical formula does not take the vertically installing error into account [16], [17]. According to force analysis and calculation, we found that there would be bigger calculation error if the vertically installing error was neglected. So the vertically installing error must be taken into account to improve the pipe's wall thickness' calculation formula.

2. Empirical design and calculation formula for vertically installing pipe's wall thickness

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$$\delta = \frac{pd}{2.3([\sigma]-6.3)-p}+c \tag{1}$$

Expression (1) is the design and calculation formula for the vertically installing pipe's wall thickness.   is the pipe's design wall thickness (mm). *p* is pressure within pipe. *d* is the pipe's inner diameter. $[\sigma]$ is pipe's allowable stress. *c* is pipe's additional wall thickness because of corrosion, generally $c = 0.5\text{mm}$. The expression (1) is suitable for vertical pipe that is held up by two points. And the distance between the two points does not exceed 150m.

From expression (1), we know that pressure *p* within pipe and pipe's inner diameter *d* are two important parameters for pipe's wall thickness design when pipe's material's allowable stress $[\sigma]$ is determined. The effect laws of pressure *p* within pipe and inner diameter *d* are showing in (a), (b) and (c) of figure 1. In figure 1, (b) is pressure within pipe *p*'s section and (c) is pine's inner diameter *d*'s section. And the material's allowable stress $[\sigma]$ is 230MPa, and the additional wall thickness *c* is 0.5mm. From figure 1, we can see that the wall thickness δ will linearly increase with *p*'s increasing and *d*'s increasing. But, the pipe's vertically installing error is not considered in expression (1).

3. Improved design and calculation method for vertically installing pipe's wall thickness

We still take expression (1) into account, and make assumption that intermediate pipe saddle should be installed every 150m. In figure 2, we consider vertically installing error, namely the pipe deviates vertical line. The deviation angle is α, and α is called eccentricity degree and vertically installing error. For the pipe *AB*, *A* is up fixed

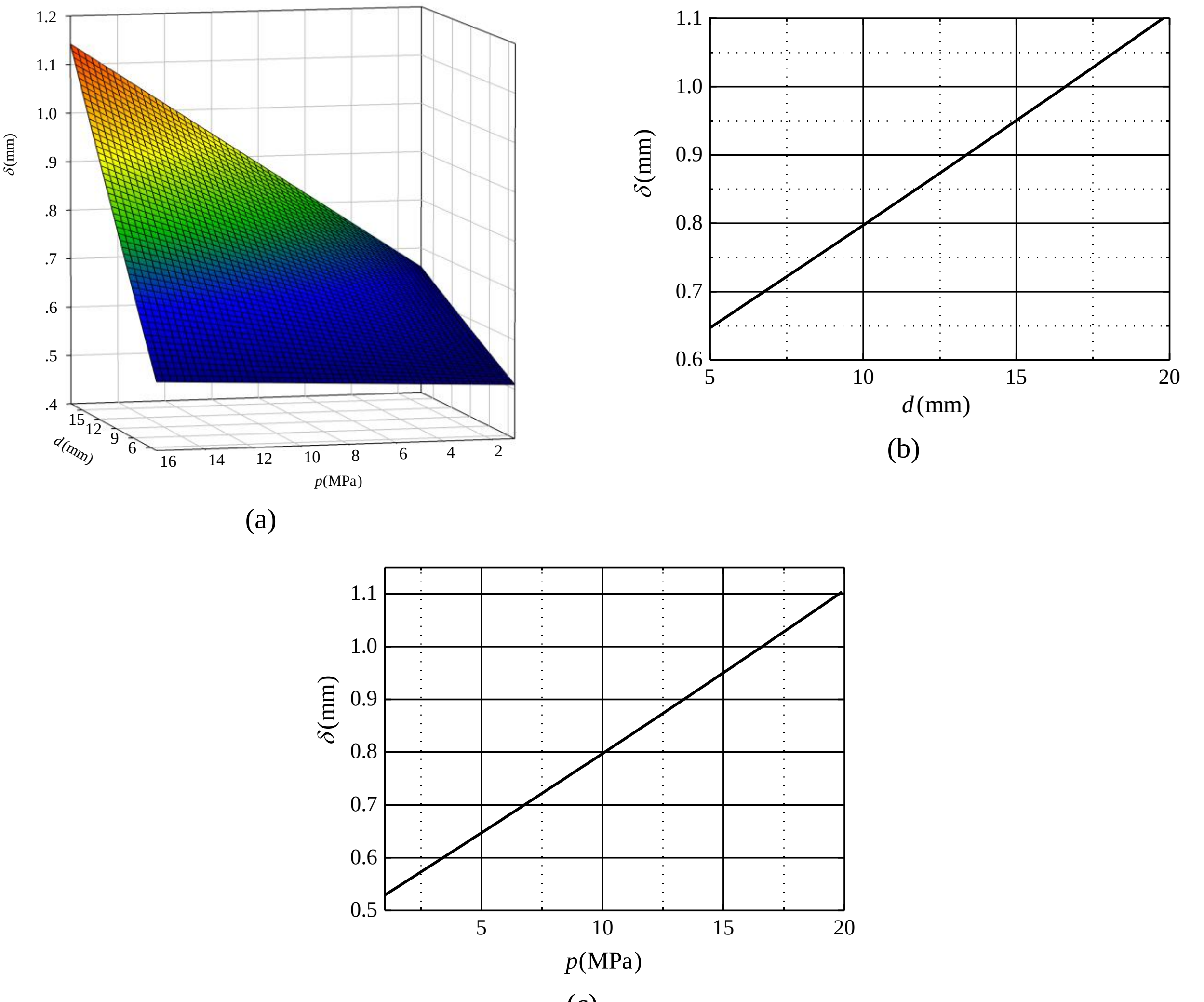

Figure 1. Effect of pipe pressure and inner diameter on wall thickness

bearing, B is down freely movable bearing and C is AB's mass center. Now, the coordinate system showing in figure 2 is established, and A is the origin of coordinates, x axis is the straight line along AB.

The pipe's total gravity of 150m is undertaken by the up fixed bearing A. There is pipe's lateral offset yy because of the vertically installing error. According to the pipeline's installation requirement, the offset's maximum value will not exceed 0.5m. So the maximum eccentricity degree can be expressed as

$$\alpha_{\max} = \arctan \frac{yy}{H} \tag{2}$$

where: H is pipe's length and H is 150m, the vertical height approximates H because the vertically installing error is small. $\alpha_{\max}$ is 0.191° because yy is 0.5m.

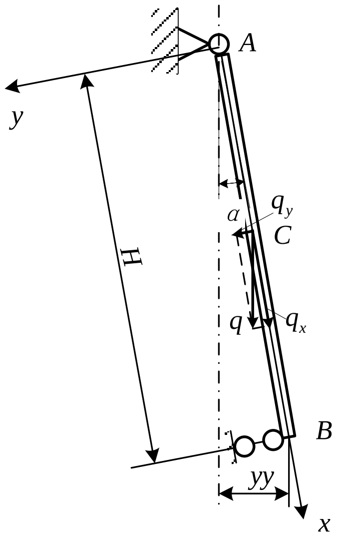

Figure 2. Schematic diagram of pipe's vertically installing

According to above assumptions, the pipe AB is equivalent to a simply supported beam. Let q is unit length pipe's gravity and q's dimension is N/m. q_x and q_y are q's orthogonal decomposition respectively along x direction and y direction when $\alpha = \alpha_{\max}$, we have the following expression

$$\begin{cases} q_x = q\cos\alpha_{\max} \approx q \\ q_y = q\sin\alpha_{\max} \approx 0.0033q \end{cases} \tag{3}$$

The beam AB's maximum bending moment is $M_{\max}$, and $M_{\max}$ occurs on the AB's intermediate cross section, and

$$M_{\max} = \frac{1}{8} q_y H^2 \tag{4}$$

So, maximum bending positive stress is

$$\sigma_{\max} = \frac{3236}{D} \tag{5}$$

where: D is pipe's inner diameter, and the wall thickness δ can be expressed as $0.5(D-d)$.

According to pipe's force condition, pipe's maximum pulling force $N_{\max}$ occurs on the cross section A. For pipes with deferent diameter, maximum pulling stress $\sigma_{l\max}$ can be regarded as constant and $\sigma_{l\max}$ is only connected with pipe's length. The pulling stress because of pipe's self weight is half of maximum pulling stress, namely,

$$\sigma_l = \frac{1}{2}\sigma_{l\max} = 6\text{MPa} \tag{6}$$

According to treatment method of thin-walled vessel, when pipe's pressure within pipe is p, axial stress can be expressed as

$$\sigma_2^* = \frac{pD}{4\delta} \tag{7}$$

where: D is pipe's external diameter, δ is pipe's wall thickness, and $\delta = 0.5(D-d)$.

We take the pipe's offset and dead weight , when $\alpha = \alpha_{\max}$, the pipes axial stress can be expressed as

$$\sigma_2 = \sigma_2^* + \sigma_{\max} + \sigma_l \tag{8}$$

Let σ_N is $\sigma_{\max} + \sigma_l$, then expression (8) can be expressed as

$$\sigma_2 = \frac{pD}{4\delta} + \sigma_N \tag{9}$$

For the thin-walled vessel, circumferential stress σ_1 and radial stress σ_3 can respectively expressed as

$$\begin{cases} \sigma_1 = \dfrac{pD}{2\delta} \\ \sigma_3 = p \end{cases} \tag{10}$$

Generally, the radial stress σ_3 is relatively small, and can be neglected. So according to the fourth strength theory, we have

$$\sigma_{xd4} = \sqrt{\frac{1}{2}[(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_3 - \sigma_2)^2]} \le [\sigma] \tag{11}$$

Now, we take σ_1 , σ_2 and σ_3 into the expression (11), and obtain the following expression

$$\sqrt{\sigma_1^2 - \sigma_1\sigma_2 + \sigma_2^2} \le [\sigma] \tag{12}$$

We regard pipe's external diameter as pipe's average diameter D_P . The following expression about the vertically installing pipe's wall thickness calculation can be obtained through settling.

$$\delta = \frac{pd}{2.3[\sigma]\sqrt{1 - (\frac{\sigma_N}{[\sigma]})^2} - p} + c \tag{13}$$

Obviously, there is certain difference for the form between expression (1) and expression (3). Comparing the expression (1), expression (3) more accord with practical engineering because the pipe's vertically installing error is considered based on the expression (1). So the pipe's wall thickness's calculation method based on expression (13) is improved, and calculation result is more reasonable and effective than the empirical formula (1).

4. Finite element calculation for pipe section's equivalent stress

In order to prove expression (13)'s rationality and validity, analyze and calculate the pipe's stress state with finite element calculation method according to practical state of pipe's stress distribution.

We take pipe's axial section as object of study, take pipe's dead weight and stalling eccentricity degree into account and make section's force analysis and displacement constraints analysis. See figure 3, pipe's inner wall element is densely divided when the section is divided to unit grid because the stress does not uniformly distribute along pipe's wall thickness. And the stress' distribution is that inner wall's stress is bigger and external wall's stress is smaller. In figure 3, *p* is pressure within pipe (MPa), δ_L is pipe's wall thickness of theoretical calculation, *d* is pipe's inner diameter and *D* is pipe's external diameter. Take the grid information, load information, displacement constraints as inputs; solve every unit grid's stress value according to compiled program.

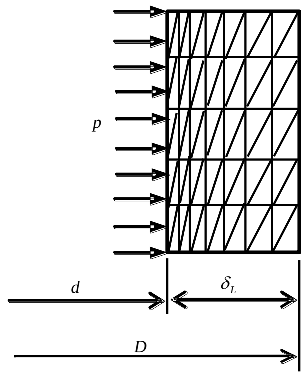

Figure 3. Finite element unit grid's division of pipe's section

We obtain section's equivalent stress σ 's function cure $\sigma-\delta_L$ through above analyzing and data processing. Obviously, the equivalent stress does not uniformly distribute along section's wall thickness. Take average value of equivalent stress as the basis of pipe's strength calculation for the thin-walled vessel. The equivalent stress's average value δ_L can be expressed as

$$\sigma_d = \frac{\int_0^{\delta_L} \sigma \mathrm{d}\delta}{\delta_L} \tag{14}$$

The pipe is safe if $\sigma_d \le [\sigma]$. Let design parameters are $d = 300\text{mm}$, $\delta_L = 14\text{mm}$, $p = 10\text{MPa}$. The curve $\sigma-\delta_L$ can be drawn based on calculation results. See figure 4, and the average equivalent stress σ_d is 97.5MPa.

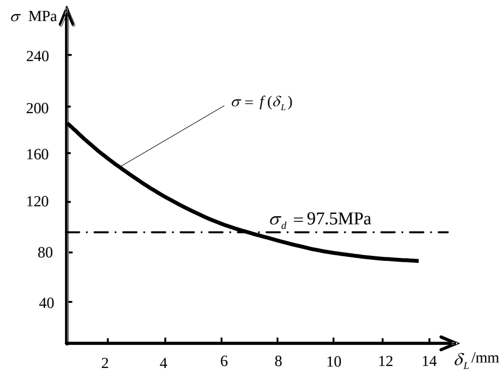

Figure 4. $\sigma-\delta_L$ curve and σ_d

5. Comparison of calculation formula for pipe wall thicknes

In order to conveniently compare, we change pipe wall thickness' calculation into pipe' section's maximum working stress $\sigma_{\max}$. Let $\sigma_{\max} = [\sigma]$, the expression (1) and expression (13) can be respectively expressed as

$$\sigma_{\max} = \frac{p(d+\delta)}{2.3\delta} + 6.3 \tag{15}$$

and

$$\sigma_{\max} = \sqrt{[\frac{p(d+\delta)}{2.3\delta}]^2 + \sigma_N^2} \tag{16}$$

Now, we take three group theoretical calculation data and calculate equivalent stress and maximum working stress with expression (15) and expression (16), respectively. Compare these results with finite element calculation results and obtain equivalent error $\Delta\sigma\%$. See table 1.

From table 1, we know that the maximum stress calculated by expression (16) more approximates to the finite element calculation results than the maximum stress calculated by expression (15). Especially when the pipe's inner diameter is smaller, the equivalent error $\Delta\sigma\%$ calculated by expression (15) is negative. Negative equivalent error shows that section's strength does not meet practical demand and the pipe can not reliably and safely work. When the pipe's inner diameter is smaller, vertically installing error's effect on calculation results is bigger.

6. Conclusion

Because hanging deadweight and vertically installing error for the vertically installing pressure pipes, the pressure within pipes will increase, and this installing error must be considered when the wall thickness is calculated for vertically installing draining pipe. According to the vertically installing error, the empirical design formula for the pipes' wall thickness was improved when the eccentric installing error's maximum is 0.191° . According to the fourth strength theory, the pipe's circumferential stress and radial stress are obtained based on the unit length pipe's weight's orthogonal component force, then the wall thickness' improved design formula is derived.

Through comparing equivalent stress's finite element calculation results, we draw the following conclusions:

(1) The maximum stress calculated by the improved calculation method in this paper more approximates to the finite element calculation results, and the equivalent error is smaller.

(2) When the pipe's inner diameter is smaller, vertically installing error's effect on calculation results is bigger.

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TABLE I. COMPARISON OF CALCULATION RESULTS

Pipe's parameters	$p = 10\text{MPa}$ $D = 328\text{mm}$ $\delta_L = 14\text{mm}$		$p = 6.4\text{MPa}$ $D = 265\text{mm}$ $\delta_L = 7.5\text{mm}$		$p = 10\text{MPa}$ $D = 57\text{mm}$ $\delta_L = 3.5\text{mm}$	
σ_d (MPa)	98.3		95.6		86.4	
	σ_{max}	$\Delta\sigma$%	σ_{max}	$\Delta\sigma$%	σ_{max}	$\Delta\sigma$%
Calculated by expression (14)	103.8	+5.6	101.8	+6.5	72.8	-15.8
Calculated by expression (15)	98.8	+0.5	97.3	+1.8	91.4	+5.8