

Research Article

Study on Buttresses Distance of Gas Pipelines in the Deviated Well Based on Stress Analysis Method

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Abstract: As the stress is one of the main factors affecting the safe operation of the pipeline in the gas pipeline tunnel crossing project, in order to ensure the safe operation of the pipeline, it is necessary to research the stress conditions of the gas pipelines in the deviated well. In this study, we discuss on these two aspects of the gas pipelines in the deviated well: the necessity of adding buttresses and the distance between buttresses. We do the numerical simulation of China Shaanxi-Beijing III gas pipeline in the Eighth Fort Yellow River tunnel areas using stress analysis software CAESAR II; exploring its secure and economical buttresses distance. Our research shows that the pipeline can be safely run after adding buttresses and it is more reasonable to set buttresses distance of 20 m for the numerical example. Our research provides a reference for the design of the buttresses distance of gas pipelines in the deviated well and has some engineering value.

Keywords: Buttresses distance, CAESAR II, deviated well, gas pipeline, stress analysis, tunnel

INTRODUCTION

With the continuous development of the long-distance pipeline construction, most of the natural gas pipeline through the complex geological environment, the inevitable through obstacles, such as crossing rivers, swamps, climb mountains. Tunnel crossing overcome elevation and terrain obstacles, not only reduces the destruction of vegetation and soil erosion, reduce the difficulty of pipeline construction, but also save the pipe material, reducing construction costs. Increasingly sophisticated pipe tunnel crossing technology is becoming one of the special sections of pipeline construction and reliable method, which deviated well, is one of the tunnel crossing forms.

Pipeline failure has many reasons, besides the construction and material defects, corrosion, third-party damage, design defects, misuse, geological disasters, pipeline fatigue failure and other reasons, there is an important reason is that the stress is higher than the design strength of pipeline requirements arising from the failure of damage.

The general crossing methods are shield method and mining method when crossing the mountains and large rivers, the structural form of tunnel is "deviated well-drift-deviated well". According to the current situation and research data, tunnel uses the form of pipe rack support and import and export will be, respectively installed with fixed buttresses, which are used to block the outside pipelines' effect on the tunnel.

Design of the tunnel crossing pipe installation is divided into three stages: choice of pipeline installation, piping arrangement and pipeline stress analysis. Terrain limitations and maintenance inconvenience lead to more serious the consequences of the accident for the crossing pipeline. Crossing pipeline failure for many reasons, in addition to the unreasonable design, construction quality problems, failure of pipeline corrosion, pipeline fatigue failure and other reasons, there is another important reason is that the bends cannot meet the strength requirements. Pipeline design is the basis of the quality of construction, the reasonableness of pipeline design is directly related to the structural safety of the pipeline (CNPC, 1995).

Currently, scholars did very little research on pipeline stress analysis, so it is necessary to research the stress conditions of the gas pipeline. However, the design of the tunnel crossing structure only rely on empirical parameters, so the pipe stress analysis should be taken seriously in the pipeline design.

Currently, more widely pipe stress analysis software CAESAR II, AutoPIPE and Triflex which CAESAR II's application is the most widely used. COADE developed for the preparation of CAESAR II has a powerful static and dynamic calculation and analysis capabilities. It includes pipeline combined load stress calculation and analysis, container nozzle flexibility and stress check analysis, natural frequency, time history analysis, its theory is one-dimensional beam element finite element method. Its pipe stress

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check method followed by the relevant provisions of the American National Standards B 31., (The American

In this study, we discuss on these two aspects of the gas pipelines in the deviated well: the necessity of adding buttresses and the distance between buttresses. By discussing these two aspects, we can clear the stress distribution of the pipeline in the deviated well and determine safe, economical construction program.

In order to explore the necessity to adding buttresses and the most reasonable distance between buttresses, we analyze the stress conditions of Shaanxi-Beijing III gas pipeline in the eighth Fort Yellow River tunnel areas using stress analysis software CAESAR II. Comparing the stress conditions of pipe without any constraints with the pipe with buttresses, we can draw the necessity of adding buttresses. Discussion on the buttresses distance, we analyze the different buttresses distance of straight pipeline and came to security, economic buttresses distance.

MATERIALS AND METHODS

Pipe stress analysis and calculations: The basic stress of the pipe is axial stress, shear stress, hoop stress and radial stress. Axial stress is the normal stress which is parallel to the tube axis. Shear stress is a variety of load which may make the crystal adjacent planar sliding trend. Hoop stress caused by pressure, parallel to the tangent of the pipe wall circumference. The radial stress caused by the internal pressure, the direction parallel to the radius of the tube. Figure 1 shows the pipeline stress:

Axial stress:

$$\sigma_a = \frac{F_{ax}}{A_m} + \frac{P d_o}{4t} + \frac{M_b}{Z} \quad (1)$$

Shear stress:

- Caused by a shearing force acting in cross-section:

$$\tau_{max} = \frac{VQ}{A_m} \quad (2)$$

- Caused by the torsional load:

Society of Mechanical Engineers, 2010).

$$\tau_{max} = \frac{M_r C}{R} \quad (3)$$

Hoop stress:

$$\sigma_h = P \left(r_i^2 + \frac{r_i^2 r_o^2}{r^2} \right) / (r_o^2 - r_i^2) \quad (4)$$

Radial stress:

$$\sigma_r = P \left(r_i^2 - \frac{r_i^2 r_o^2}{r^2} \right) / (r_o^2 - r_i^2) \quad (5)$$

where,

F_{ax} = The cross-section of the internal force, N

A_m = The cross-sectional area of the wall, m^3

P = Internal pressure, Mpa

d_o = Outer diameter, m

t = Wall thickness, m

M_b = Bending moment acting on the cross-section, N·m

Z = Section modulus in bending, m^3

V = Shearing force, N

Q = Shear coefficient

M_r = Torsional moment acting on the cross-section, N·m

C = Distance of the point of the cross section to the torsion center, m

R = Torsional sectional coefficient

r_i = The inner radius of the pipe, m

r_o = The outer radius of the pipe, m

r = The radial position of the stress calculation point, m

Check criterion of the gas pipelines: According to the basic characteristics of the stress, which fall into three categories, including primary stress, secondary stress and operating stress. Among them, primary stress is normal stress or shear stress in the pipe caused by external load and it does not have characteristic of self limiting and mainly brings about plastic failure.

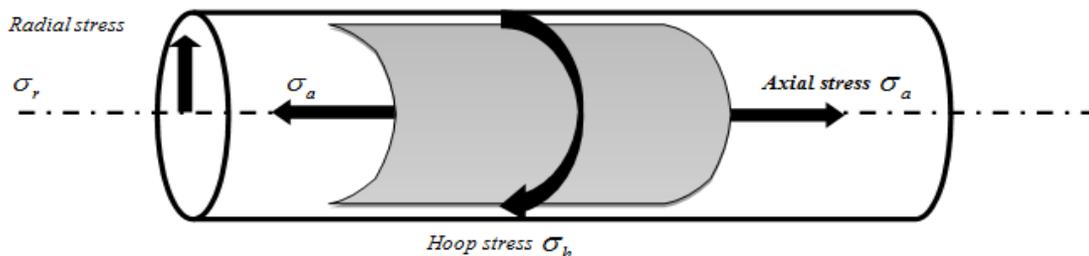


Fig. 1: Pipe stress diagram

Secondary stress is normal stress or shear stress caused by constraints due to the deformation of the pipe and it has characteristic of self-limiting and localization and mainly leads to fatigue failure. Operating stress is the maximum stress value of local stress concentration due to the sudden change of load and abrupt deformation of shape and structure. And it can lead to brittle fracture and fatigue failure.

Therefore, during the design process, it is not feasible to rely only on whether the stress under operating conditions reaches limit value or not to the pipeline safety, but to preset an allowable stress $[\sigma]$ as the criteria to verify the strength requirements within the pipe fittings limit stress range, in which:

$$[\sigma] = F\phi\sigma_s$$

where,

F = Strength design coefficient of different region area

ϕ = Weld coefficient

Due to thermal expansion and contract, curvature mutation, endpoint additional displacements or restraints, pipeline will be loaded with the corresponding axial stress, shear stress, bending moment and moment of torque. Generally, stress calculation needs the checking of primary stress, secondary stress and the operating stress.

Primary stress of pipe should not exceed allowable stress at the pipe design temperature, $\sigma_L \leq [\sigma]$. Secondary stress should not exceed the allowable stress range $\sigma_E \leq \sigma_{allow} = f(1.25\sigma_c + 0.25[\sigma])$. If $\sigma_h > \sigma_L$, the allowable stress range is $\sigma_{allow} = f[1.25(\sigma_c + \sigma_h) - \sigma_L]$. Operating stress σ_{OPE} is the sum of σ_L and σ_E , under the condition that $\sigma_L + \sigma_E \leq \sigma_s$.

where,

σ_h = The allowable stress of the pipe design temperature, Mpa

σ_L = The sum of longitudinal bending stress, which is the sum of loads caused by pressure such as the outside carrier of longitudinal stress, gravity and wind, Mpa

σ_E = Secondary stress, Mpa

σ_{allow} = The allowable stress range

σ_c = The allowable stress in 20°C pipe, Mpa

σ_s = The minimum yield strength of pipe materials standard, Mpa

σ_{OPE} = Operating stress, Mpa

f = Reducing coefficient, considering the allowable stress range influenced by the total cycle time in life expectancy

CAESAR II software checking method is based on the American ASME B31.8 Gas Transportation and

Distribution Piping Systems, it is recommended that pipeline stress should not exceed the 90% of the pipeline allowable stress (Tang, 2003).

The method of modeling: A complete pipeline model includes three parts: Piping input, add constraints and define the load conditions.

Piping input: Piping input is the basis of stress analysis, which includes pipeline parameters (DX, DY, diameter, etc.), pipeline's route in the space (CosX, CosY, etc.), external conditions (temperature, pressure, fluid density, etc.), pipeline material parameters (allowable stress, Poisson's Ratio) and constraints (ANC, Y, etc.).

Add constraints: The actual project, the pipeline system is composed of a variety of devices and supporting accessories, so modeling need to add a variety of constraints to limit the displacement of the pipe. In software, we need to input the constraint node and the type of constraints.

The definition of the conditions:

- **Operating conditions:** (OPE) $L_1 = W + T + P$, the operating condition is the maximum regional concentration stress value caused by load, structure shape.
- **Primary stress calculation condition:** (SUS) $L_2 = W + P$, caused by inner pressure and weight.
- **Secondary stress calculation condition:** (EXP) $L_3 = L_1 - L_2$, caused by the thermal stress.

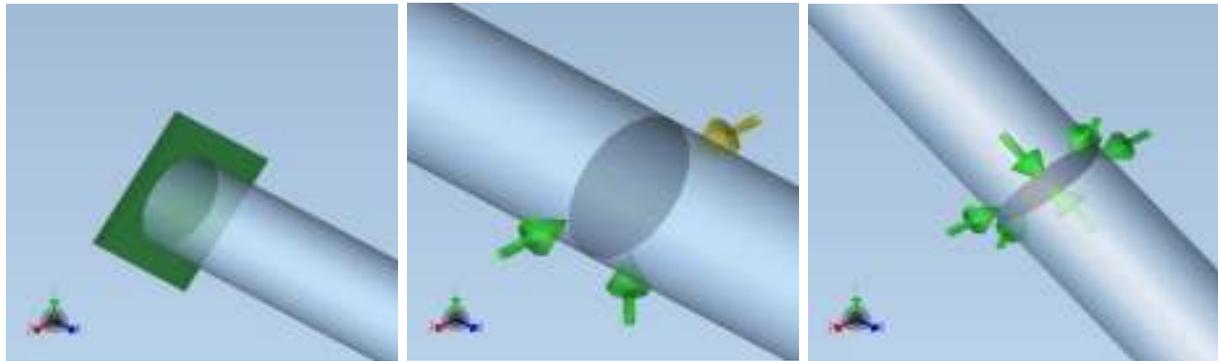
where,

W = Weight load

T = Temperature load

P = Pressure load

Case study of deviated well gas pipelines: China Eighth Fort Yellow River tunnel is located in the junction of Shaanxi and Shanxi. According to the design information, total length of the tunnel is 1598 m, uses the form of pipe rack support (Fig. 2b) and each end of the pipe will be, respectively installed with fixed buttress 1 and 4 (Fig. 2a), which are used to block the outside pipelines' effect on the model. The pipe length along the tunnel entrance is 35 and 20 m-long pipeline deviates from the west side of the tunnel portal about 60°. The length of the west inclined tunnel is 465 m, longitudinal gradient is 28°. The length of the east inclined tunnel is 409 m, longitudinal gradient is 25°. And the length of the drift is 644 m. The pipe length along the tunnel export is 45 and 20 m-long pipeline



(a) Fixed buttress simplify model

(b) Buttress simplified model

(c) Anchor block

Fig. 2: Model simplification diagram

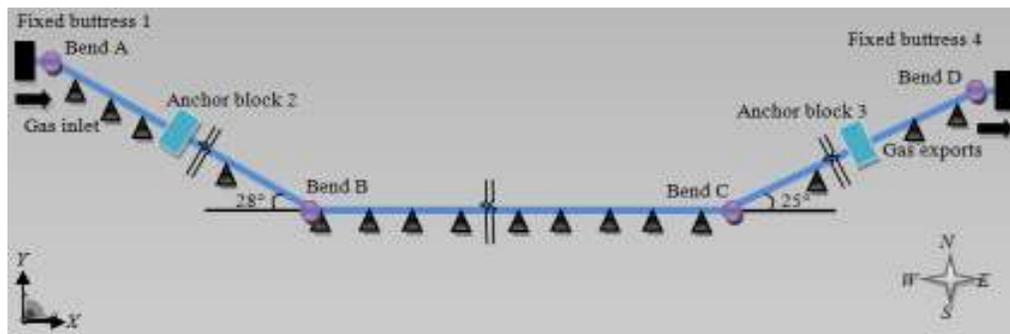


Fig. 3: Pipeline model diagram

Table 1: Pipeline parameters

Material	Diameter (mm)	Wall thickness of straight pipe (mm)	Wall thickness of pipe bend (mm)	Corrosion (mm)
API×70	1016	26.2	33.1	1
Fluid density (kg/m ³)	Insulating layer thickness (mm)	Pressure (MPa)	Temperature (°C)	Allowable stress (MPa)
95	0	10	40	485

Table 2: Bends parameters

Location	Specification	Quantity	Remark
Bend A, bend B	φ1016×33.1, angle is 28°	2	X70 steel, R = 6D
Bend C, bend D	φ1016×33.1, angle is 25°	2	X70 steel, R = 6D

deviates from the east side of the tunnel portal about 60°. Midpoint of the west inclined tunnel and east inclined tunnel will be respectively installed with anchor block 2 and anchor block 3 (Fig. 2c). Curvature radius of the hot-bending bends is $R = 6D$, D is the pipe diameter.

Figure 2 shows the pipeline constraints of simplification model. Figure 3 shows the pipe model. Table 1 show the design data of gas pipelines in deviated well. Table 2 shows the parameters of bends.

RESULTS AND DISCUSSION

Analysis of the necessity to add the buttresses: Design two models, one is the deviated well pipeline doesn't add any support, another is the pipeline add buttresses, the distance between two buttresses is 20 m.

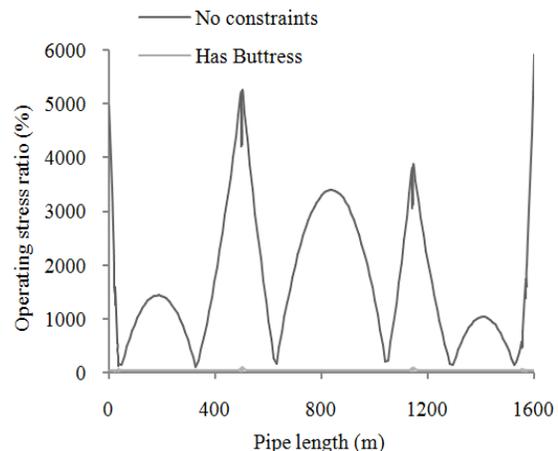


Fig. 4: The operating stress ratio of the two models

Table 3: Buttress distance and quantity

Buttresses distance (m)	10	12	14	16	18	20
Quantity	57	48	41	36	32	29

Table 4: The average stress ratio

Buttresses distance (m)	10	12	14	16	18	20
Average stress ratio (%)	51.69	52.46	53.15	53.91	54.83	55.82

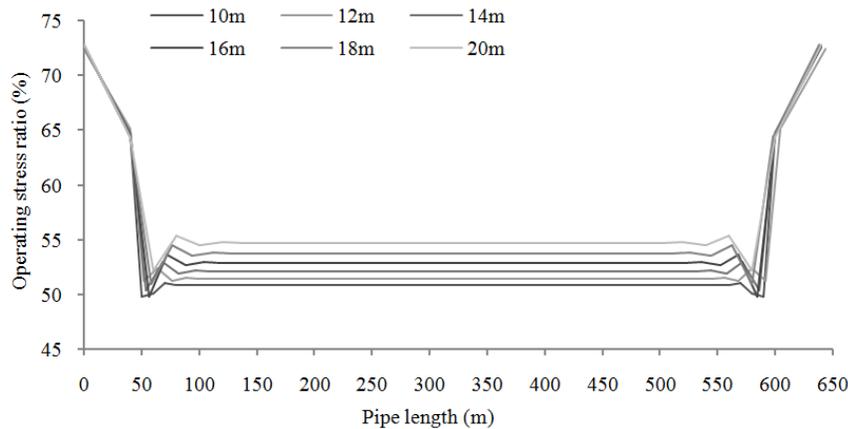


Fig. 5: The operating stress ratio of the six models

We set pipe length as the abscissa, the operating stress ratio as the ordinate, then draw two model's operating stress ratio graphical sheet to make a comparison (Fig. 4).

From Fig. 2 we arrive at that the pipe stress value of the pipeline not added any supporting exceeds the allowable value of the stress and the maximum stress achieves a rate of 5915.87%. The difference is the pipe stress value of the pipeline added the buttresses does not exceed $0.9 [\sigma] = 434369.7000 \text{ MPa}$, so the model meet the strength requirements, the highest operating stress ratio of the pipeline is 97.32%, which happened at the bend B (Huang *et al.*, 2012; Sha *et al.*, 2013; Wang, 2002).

Analysis of the buttresses distance: In order to explore the safety, economic buttress distance, we use the straight pipe intercept method in this study. Select the level of the pipe model straight pipe which is drift and analyze the pipe stress value variation of the different buttresses number. The total length is 644 m, we design different buttresses distance model: 10, 12, 14, 16, 18 and 20 m, respectively. In order to reduce the impact of the fixed buttresses at both ends, the shortest distance between buttresses which are close to fixed buttress is 40 m (Wu *et al.*, 2012).

The same, we set pipe length as the abscissa, the operating stress ratio as the ordinate, then draw these six model's operating stress ratio graphical sheet to make a comparison (Fig. 5). As shown in Table 3, different buttress distance is corresponding to the number of buttress (Liu *et al.*, 2012).

We can be drawn from Fig. 5 and Table 4 that different buttresses distance pipelines' stress value did not exceed $0.9 [\sigma] = 434369.7000 \text{ MPa}$, so these models meet the strength requirements. And with the increase of the number of buttresses, the average stress decreased. The maximum average stress ratio was 55.82% (buttresses distance of 20 m); minimum average stress ratio was 51.69% (buttresses distance of 10 m) (Wu and Tong, 2003).

CONCLUSION

In this study, we analyze the necessity of adding buttresses and the distance between buttresses of the gas pipelines in the deviated well. The analysis showed adding buttresses can greatly reduce the stress value and ensure the safe and stable operation of the pipelines. For buttress distance analysis, from the experimental results, we have come to set buttress distance of 10 m can better ensure the safe operation of the pipeline, its average stress ratio was 51.69%. The pipeline, with 20 m buttresses distance, has the largest average stress ratio, which is 55.82%, but only a difference of 4.13 with 51.69%. Having regarded to the economic and practical, the fewer the number of buttresses, the smaller the investment. Buttresses distance can be set according to the actual situation, it is recommended to set the buttresses distance to 20 m. In this study, our research provides a reference for the design of the buttresses distance of gas pipelines in the deviated well and has certain versatility.

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