Based on Finite Element Method Research on Treatment Measures of Crossing Gas Pipeline

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Abstract. The finite element method is used to analyze the stress and deformation of the crossing gas pipeline. The evaluation results show that the current pipeline stress and displacement cannot meet the allowable values specified in the specification. In order to ensure the safety of pipeline operation, it is necessary to treat the crossing gas pipeline. By investigating the pipeline construction period and operation period data, the deformation data collection and analysis of the pipeline has been carried out. It is speculated that the direct cause of the pipeline deformation is the temperature difference and the internal pressure and gravity. The indirect cause is that no appropriate compensation structure or sufficient restraint measures have been taken across the two ends. Cracking of the protective wall across the ends is a secondary failure of displacement. The finite element method is used to check the proposed governance measures, and finally determine more reasonable control measures. After the implementation of the treatment measures on the site, the better results were achieved. The pipeline stress and deformation were all within the requirements of the specification. The pipeline was in a safe state and the treatment measures were feasible and practical. The engineering application results show that the feasibility of checking the cross-section pipeline control measures by the finite element method has certain effectiveness and economic rationality, and can achieve the purpose of engineering governance.

1. Introduction

Oil and gas pipelines are linear projects, during the construction period, pipelines often pass through rivers and valleys. At present, when pipeline engineering passes such obstacles, in addition to tunnels, cross-passing is usually adopted [1-3]. For example, the China-Myanmar oil and gas pipeline spans the Lancang River, and the West-East Gas Pipeline crosses the Yellow River. These straddle methods often require the use of compensators and additional measures such as fixing piers to ensure that the sections of the pipeline do not deform. However, in some small spans, it is not excluded that the set compensator is not in place, and the purpose of anchoring at both ends is not achieved, so that the deformation of the pipe across the section is excessively large. Once the pipeline is deformed too much and causes failure and damage, it will lead to oil and gas leakage, causing fire and explosion and other safety accidents. Therefore, it is necessary to find a fast, effective and economical method to evaluate the stress and deformation of the spanning pipeline. This method can reasonably check the governance measures of the spanning pipeline and achieve the purpose of engineering governance. In this paper, the finite element method [4-9] is used to establish the spanning section pipeline model. The engineering application results show that the finite element method is feasible for checking the
cross-section pipeline control measures, which has certain effectiveness and economic rationality, and can achieve the purpose of engineering governance.

2. Background and deformation analysis
A gas pipeline spans 45m in Zichang County. The bolts on the support piers have been pulled off, and the support on both sides is about 200 mm away from the pipe support pier (Fig. 1), and the masonry protection wall is cracked. There is an urgent need for a risk assessment of this segment of the pipeline. There is no other external load in the span, it is presumed that the direct cause of such a large deformation at the span is the large temperature difference of the pipeline, the internal pressure and the gravity. The indirect cause is that no appropriate compensation structure or sufficient constraints are adopted across the two ends. Cracking of the protective walls at both ends is a secondary failure of the above-mentioned larger displacement.

3. Analysis model and guidelines
There are many horizontal elbows, vertical elbows and superimposed elbows in the span. The model is more complicated. In order to reflect the force of the pipeline more realistically, the three-dimensional finite element model is used for analysis. The pipeline adopts the ELBOW290 pipe unit, and the soil constraints across the buried pipelines on both sides are simulated by discrete nonlinear springs[10-12]. The outer diameter of the gas pipeline is 1016mm, the wall thickness of the pipeline is 26.2mm (straight pipe section) and 32.2mm (hot bend pipe), X70M steel pipe, installation temperature -10 °C. The soil spring unit is used to simulate the pipe-soil interaction, including axial, horizontal lateral, vertical earth springs. The loading and unloading curves of the soil are considered according to different soil types and laying conditions[13-18]. The soil spring parameters in three directions are calculated according to the formula provided in Appendix E of the code GB/T 50470-2017, and the calculation results are shown in Table 1.

| Direction             | Ultimate resistance (N/m) | Displacement (m) |
|-----------------------|---------------------------|------------------|
| Axial spring          | 57667                     | 0.008            |
| Lateral spring        | 246565                    | 0.101            |
| Vertical upward spring| 83046                     | 0.201            |
| Vertical down spring  | 743620                    | 0.203            |

The stress and deformation of the spanning pipe are evaluated using the following guidelines: (1) According to article 6.2.5 of GB/T 50459-2017, the strength check should meet the following requirements:
Where: $\sigma_e$ is equivalent stress, MPa; $\sigma_s$ is the minimum yield strength of the pipe material; F is strength design factor.

(2) According to article 3.5.1 of GB/T 50459-2017, under the action of permanent load and variable load standard value, the mid-span deflection of the truss in the beam-type straight span and the truss span is less than 1/400 of the span of the flexural member.

4. Overall stress analysis

Based on the above model settings, we have established a finite element model of the spanning pipe. Through our investigation, we found that the pipe on the two piers was lifted up to 200 mm. So we initially judge that the buried anchor pier on the right side has no effect. Therefore, the boundary conditions of the model are set such that the anchor piers at both ends do not have sufficient constraint on the axial displacement of the pipeline, and do not constrain the spanning of the buttress. In the analysis we considered the combined effects of gravity, operating temperature and internal pressure. The deformation and stress distribution along the pipeline are shown in Figure 2 and Figure 3.

The maximum displacement point along the line is located near the center of the mid-span, with a maximum displacement of 258 mm. The displacement at the buttress is extracted, 201 mm on the left side (N173) and 207 mm on the right side (N219). The analysis and prediction of the lifting distance at the buttress is basically the same as the actual displacement of 200 mm. It can be inferred that the analysis result is basically consistent with the actual force of the pipeline.

From the above figure, it can be concluded that the maximum equivalent stress of the pipe is 316 MPa, which occurs at the elbow at the corner position.

According to the calibration criteria in Section 2, the pipeline strength check and deflection check are shown in Tables 2 and 3. According to the results of the check, the current stress and deformation of the spanning section pipeline do not meet the requirements of the specification and need to be treated.

### Table 2. Calculation results of pipe stress across spans

| Calculating equivalent stress $\sigma_e$ (MPa) | Yield stress $\sigma_s$ (MPa) | Allowable stress $F \sigma_s$ (MPa) | Result  |
|-----------------------------------------------|-----------------------------|-------------------------------------|---------|
| 316                                          | 485                         | 291                                 | Not satisfied |

### Table 3. Calculation results of pipe displacement across spans

| Calculate the maximum deflection (mm) | Span length (mm) | Allowable deformation value (mm) | Result  |
|--------------------------------------|------------------|----------------------------------|---------|
| 258                                  | 45100            | 112.75                           | Not satisfied |
5. Treatment measures analysis
The treatment measures we intend to adopt are as follows: firstly reduce the operating pressure of the pipeline, using the operating parameters of 2005, the pressure is 6.5MPa, the temperature difference is 30°C; then re-create the anchor piers at both ends (size 4m*4m*4m, resistance 230t, yield displacement 50mm), and finally gradually increase the pressure operation. We calculate and verify the scheme by the finite element method. The deformation and stress distribution along the pipeline are shown in Figure 4 and Figure 5.

![Figure 4. Cross-section pipe deformation map](image)

The maximum displacement point along the line is located near the left side of the mid-span, the maximum displacement is 178mm. The displacement at the buttress is extracted, 173 mm on the left side (N173) and 152 mm on the right side (N219). At the same time, the pipe will produce a displacement of 62 mm to the right in the horizontal direction.

![Figure 5. Equivalent stress diagram of the spanning section pipe](image)

The analysis results show that after the treatment measures, the maximum equivalent stress of the pipeline is 280 MPa, which occurs at the corner elbow. Compared with the original working condition (316 MPa), the equivalent stress of the pipeline decreases greatly, the effect is ideal, and the displacement change is also obvious. In the end, we can conclude that the measure is feasible and can achieve the effect of governance.

6. Conclusion and suggestion
(1) By investigating the pipeline construction period and operation period data, the deformation data collection and analysis of the pipeline have been carried out, it is presumed that the direct cause of such a large deformation at the span is the large temperature difference of the pipeline, the internal
pressure and the gravity. The indirect cause is that no appropriate compensation structure or sufficient constraints are adopted across the two ends. Cracking of the protective walls at both ends is a secondary failure of the above-mentioned larger displacement.

(2) The finite element method is used to check the proposed governance measures, and finally determine the reasonable control measures. After the implementation of the treatment measures, the good results have been achieved. The pipeline stress and deformation are all within the requirements of the code. The pipeline is in a safe state and the treatment measures are feasible and practical.

(3) The engineering application results show that the feasibility of checking the cross-section pipeline control measures by the finite element method has certain effectiveness and economic rationality, and can achieve the purpose of engineering governance.

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