Safety Assessment of Gas Pipeline Body and Weld Stress in High Fill Area

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Abstract. Gas pipeline is occupied by high-filled soil and a large amount of soil has caused long-lasting additional stress on the pipeline. Under the action of the additional stress of the high fill soil, the pipeline may undergo relatively large displacement and deformation, which will cause harm to the safe operation of the pipeline. In order to clarify the stress and deformation state of gas pipeline body and weld in the high fill area, this paper preliminarily calculated the radial stability of gas pipeline under the action of the high-fill soil and the stress state of the weld under the ovality deformation. According to the actual parameters, boundary conditions and deformation of pipeline, a finite element model is established to calculate and check the stress state of the pipeline in the high fill area. Analyzed the serviceability of the pipeline according to the requirements of gas pipeline integrity management specification. Finally, according to the analysis results, a comprehensive assessment of the high fill area of the pipeline is carried out, and recommendations for the next treatment measures are put forward.

1. Introduction
After the gas pipeline was built and put into operation, it was occupied by a large amount of high fill soil. The pipe was found by pipe probe and on-site pit excavation. Compared with the buried depth of the completed pipeline before, the buried depth of this section of the pipeline is now about 11m. A large amount of high-filled soil has caused lasting additional stress on the natural gas pipeline. The pipeline may be displaced and deformed under the action of the additional stress of the high fill soil, causing potential hazards to the safe operation of the pipeline [1-2]. According to the information provided by the pipeline operator, a total of five ball passing operations were carried out during the internal inspection of the pipeline, and three callipers ball jams occurred. Since the amount of deformation has exceeded the passing capacity of the detector, subsequent inspections in the pipeline have been suspended [3-6]. Afterwards, we organized and implemented the excavation of the suspected deformation point, and used the digging method to excavate and find the pipe [7-9]. When the excavation depth was 10.8m, the pipe top was found, but then it was found that the pipe was displaced upward (the side of the pipe top was about 2cm from the soil), then stop the excavation work and backfill. In order to ensure the safety of the gas pipeline during the operation period and reduce the risk of damage to the pipeline by the high filling, it is urgent to conduct a safety assessment of the gas pipeline body and weld stress.

2. Assessment content
The gas pipeline has a diameter of 711mm, a wall thickness of 10.3mm, a design pressure of 4MPa, and L415M steel grade. In order to clarify the stress and deformation state of the natural gas pipeline...
body and the weld seam in the high fill area (Fig. 1), the following evaluation work needs to be carried out: Using theoretical calculation methods, preliminary calculation of the radial stability and deformation of the natural gas pipeline under the action of high fill soil stress state of girth weld under ovality deformation. According to the pipeline burying depth and pipeline coordinate data provided by the operating unit after the high fill soil is under pressure, compare and fit the completed coordinate data to calculate the deformation of the pipeline. According to the actual pipeline parameters, boundary conditions and deformation, establish a finite element model to calculate and check the stress state of the pipeline in the high overburden section. Analysed the serviceability of the pipeline in accordance with the requirements of the oil and gas pipeline integrity management specification; Based on the above analysis results, conduct a comprehensive assessment of the high-overburden section of the pipeline, and make recommendations for the next treatment measures.

![Figure 1. Schematic diagram of the location of the gas pipeline in the high fill area](image)

### 3. Stability and safety assessment of weld stress

#### 3.1 Stability check calculation

According to the requirements of GB 50251-2015 (Code for design of gas transmission pipeline engineering), when the gas pipeline is buried deeply or the external load is large, the stability should be checked according to the state of no internal pressure. In this calculation, the pile load height of the soil above the pipeline is taken as 10m, the design buried depth of the pipeline is taken as 1.5m, the buried depth of the pipe top is 11.5m, and the bulk density of the soil is taken as 18 KN/m³. The main variable parameters are the bed coefficient \( k \) and the soil deformation modulus \( E_s \) is selected by GB 50251-2015. According to the above parameters and calculation formula, the calculation results of the pipe radial stability are shown in Table 1.

| Operating pressure (MPa) | \( E_s \) (MN/m²) | \( K \) | \( \Delta x \) (mm) | \( \Delta x/D \) | Check result |
|--------------------------|------------------|-------|------------------|-----------------|--------------|
| 0                        | 1                | 0.108 | 83.4             | 11.71%          | Not satisfied|
| 1                        | 1                | 0.108 | 58.1             | 8.18%           | Not satisfied|
| 2                        | 1                | 0.108 | 44.6             | 6.28%           | Not satisfied|
| 3                        | 1                | 0.108 | 36.2             | 5.09%           | Not satisfied|
| 4                        | 1                | 0.108 | 30.5             | 4.29%           | Not satisfied|

#### 3.2 Calculation of weld stress

The stress concentration factor \( k \) under ovality deformation of the pipeline can be calculated by the calculation methods provided by BS 7910 (Guide on methods for assessing the acceptability of flaws in fusion welded structures) and PD 5500 (Specification for unfired fusion welded pressure vessels),
which is specific to different pipes. The calculation results of the pipe weld stress under different types and operating pressures are shown in Table 2.

Table 2. Calculation table of weld stress of pipeline under different operating pressure

| Operating pressure (MPa) | Ovality | $\sigma_S/\sigma_0$ | $k$ | $\sigma_h$ (MPa) | $\sigma_e$ (MPa) | $0.9\sigma_e$ (MPa) | Check result |
|-------------------------|---------|--------------------|-----|------------------|------------------|---------------------|-------------|
| 0                       | 11.71%  | 1.70               | 2.70| 0                | 0                | 373.5               | satisfied    |
| 1                       | 8.18%   | 0.98               | 1.98| 35               | 68.2             | 373.5               | satisfied    |
| 2                       | 6.28%   | 0.68               | 1.68| 69               | 116.2            | 373.5               | satisfied    |
| 3                       | 5.09%   | 0.53               | 1.53| 104              | 158.1            | 373.5               | satisfied    |
| 4                       | 4.29%   | 0.43               | 1.43| 138              | 197.2            | 373.5               | satisfied    |

The preliminary calculation results show that the radial stability of the pipeline cannot meet the requirements of the specification, and the stress of the circumferential weld of the pipeline can meet the requirements of the specification under different pipe types and different operating pressures. The preliminary calculation result only considers the vertical earth pressure of the pipeline subjected to the high-filled soil, and cannot consider the effect of the squeezing displacement load on the pipeline. The real pipeline should be vertical on the high-filled soil. Deformation occurs under the combined action of soil pressure and squeeze displacement load, so it is necessary to use finite element analysis software to establish a true pipe force model for calculation and analysis.

4. Pipeline strength check

In this paper, we used ANSYS 19.1 software to carry out the stress analysis and verification of the gas pipeline body and weld. In finite element analysis, the engineering problem needs to be abstracted and simplified into a mechanical model, and then the finite element method is used for analysis. Refer to GB/T 50470-2017 (Seismic technical code for oil and gas transmission pipeline engineering) Appendix E and ASCE standards to calculate the three-way soil spring parameters.

4.1 Load and loading method

The high-fill area of gas pipeline is mainly affected by internal pressure, temperature difference, self-weight, high-fill soil weight, and displacement load. The pipeline displacement load applied in the model is shown in Figure 2 and Table 3. The displacement of each point along the pipeline is applied to the finite element model to calculate the deformation and stress state of the buried pipeline under the action of surface displacement.

![Figure 2. Comparing the pipeline's completed line position and actual measured line position](image-url)
Table 3. Pipe displacement load applied

| Location       | △X/m  | △Y/m  | △Z/m  |
|----------------|-------|-------|-------|
| GB042          | 0.000 | 0.000 | 0.000 |
| GB043+10m      | -0.125| -0.355| 0.000 |
| GB043+60m      | -0.110| -0.288| 0.000 |
| GB044+10m      | 0.135 | 0.340 | 0.000 |
| GB044+40m      | 0.000 | 0.000 | 0.000 |

4.2 Stress check standard

GB50251-2015 has the equivalent stress check requirements for buried pipelines. The equivalent stress of the calculated pipe section is checked according to this code. However, there is no check requirement for axial stress in GB50251-2015. But when the pipeline is displaced, the axial stress will also change, and the axial stress needs to be checked. Therefore, the axial allowable additional stress can be checked and calculated with reference to the formula in Gas Transmission and Distribution Piping Systems (ASME B31.8-2018).

4.3 Pipeline stress state

Calculate the stress state of the pipeline under the above displacement conditions, and use the stress check specification of the buried pipeline to check, it can be seen that the most unfavourable axial stress of the pipeline (Fig. 3) does not exceed the allowable value. To meet the specification requirements, the equivalent stress ((Fig. 4) has exceeded the allowable value and does not meet the specification requirements. The most unfavourable axial stress and equivalent stress of the pipeline and their locations are shown in Table 4.

Figure 3. Axial stress cloud diagram under operating pressure of 3.2MPa
Figure 4. Equivalent stress cloud diagram under operating pressure of 3.2MPa

| Internal pressure (MPa) | Maximum axial stress (MPa) | Maximum equivalent stress (MPa) | Allowable stress (MPa) | Check result | The most unfavorable position |
|------------------------|---------------------------|-------------------------------|------------------------|--------------|------------------------------|
| 3.2                    | 162.0                     | 444.0                         | 373.5                  | Not satisfied | Near GB043 Elbow             |

5. Pipeline serviceability analysis

The gas pipe diameter is D711mm, wall thickness 10.3mm, inner diameter 690.4mm, the original size of the caliper plate is 621.5mm in diameter. After operation, the diameter of the caliper plate is 585mm, and the deformation is 14.8% of the D711 pipeline. Such a large deformation indicates that the pipeline has been in the plastic deformation stage, after unloading the overlying soil layer in time, the ovality of the pipeline cannot be restored to the normal value. At the same time, in accordance with the relevant regulations and requirements of GB 32167-2015 (Oil and gas pipeline integrity management specification) integrity evaluation for internal inspection, the pass ability of the inner detector should be guaranteed during the in-service pipeline inspection work, and the maximum allowable inner diameter change is regarded as the passable inner detector. One of the main factors that need to be considered for performance is that the deformation of the pipeline being tested should not exceed the passing performance index of the detector. Judging from the measured pipeline deformation, it has obviously exceeded the passing performance index of the detector. Therefore, the current section of the pipeline cannot meet the passing requirements of the normal internal detector, cannot carry out internal inspection work, and cannot meet the normal service requirements.
6. Conclusions and recommendations

In order to clarify the stress and deformation state of gas pipeline body and weld in the high fill area, this paper preliminarily calculated the radial stability of gas pipeline under the action of the high-fill soil and the stress state of the weld under the ovality deformation. According to the actual parameters, boundary conditions and deformation of pipeline, a finite element model is established to calculate and check the stress state of the pipeline in the high fill area. In this paper, we can draw conclusions and recommendations are as follows:

(1) After analysis and evaluation, it can be seen that the radial stability of the gas pipeline cannot meet the requirements of the specification. Although the axial stress of the pipe meets the specification requirements, the equivalent stress cannot meet the specification requirements. Therefore, neither the stability check nor the strength check meets the specification requirements.

(2) Based on the deformation of the caliper plate, the gas pipeline in this section has undergone large ovality deformation and is in the plastic deformation stage, which cannot meet the normal internal detector passing requirements, cannot carry out internal inspection work, and cannot meet normal service requirements.

(3) According to conclusions, in order to ensure the safety of the gas pipeline during operation and reduce the risk of pipeline damage, we recommend that pipeline operators carry out repair work as soon as possible.

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