Analysis and Research on Safety Evaluation of Oil and Gas Pipelines in Goaf

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Abstract. Through the analysis of the subsidence of the mined-out area of the mine, the characteristics and laws of the subsidence can be mastered. According to different subsidence types and subsidence, a reasonable calculation model is used to calculate and analyse the stress of the pipeline, and the stress and strain values at different points of the pipeline are obtained. At the same time, by studying different pipeline laying methods, a reasonable pipeline laying method is selected from them to meet the adaptability of the pipeline to the ground subsidence of the goaf. When optimizing the laying method of the pipeline, the design concept and method based on the strain are used to put forward requirements for the strain of the pipeline, formulate reasonable design guidelines, and finally determine reasonable countermeasures according to the design guidelines, thereby improving the design level of the mine's goaf pipeline, and ensure the intrinsic safety of the pipeline and coordinate the relationship between pipeline construction and mineral exploration.

1. Introduction
The mining of underground mineral resources will cause goafs. If the surrounding rock instability occurs in the goafs, it will cause geological disasters such as surface cracking, subsidence or subsidence, which will bring great security risks to surface buildings[1]. Data show that China's coal resources are relatively abundant and widely distributed, with Shanxi being the dense. Geological disasters such as surface cracking and ground subsidence often occur due to excessive mining of coal mines. This not only threatens the safety of people's production and life, but also raises new issues for the prevention and treatment of geological disasters in goafs[2]. As the mileage of China’s long-distance oil and gas pipelines continues to increase, more and more pipelines need to pass through prospecting areas, mining areas and goafs of mineral deposits. These areas may cause ground subsidence and surface cracking to varying degrees due to the over-exploitation of underground minerals[3-7]. Through the analysis of the subsidence of the mined-out area of the mine, the characteristics and laws of its subsidence can be mastered. According to different subsidence types and subsidences, a reasonable calculation model is used to calculate and analyze the stress of the pipeline, and the stress and strain values at different points of the pipeline are obtained[8]. At the same time, by studying different pipeline laying methods, a reasonable pipeline laying method is selected from them to meet the adaptability of the pipeline to the ground subsidence of the goaf.

2. Background of research
The coal-bearing stratum in the mining area is the Upper Permian Longtan Formation (P3l), which belongs to the sea-land interactive facies deposition. The stratum thickness is 62.77 ~ 90.54m, with an average thickness of 83.78m. There are 9 to 12 layers of coal and coal line, generally 10 layers. The...
total thickness of coal is 8.20 to 15.85m, the average is 12.69m, and the coal content is 15.14%. Contains 4 coal seams, which are 5, 7, 8, 12 coal seams. The total thickness of the recoverable coal seam is 6.56m, and the coal content of the recoverable coal seam is 7.83%.

The mining area contains 4 mineable coal seams, which are 5, 7, 8, 12 coal seams. The 5, 8 and 12 coal seams are mineable seams in the whole area, and the 7 coal seams are local mineable seams. According to the stratum conditions of the above mining areas, the basic mining parameters used in this paper are shown in Table 1.

| Mine name | Fu-ping coal mine | Subsidence coefficient | 0.55 |
|-----------|-------------------|------------------------|------|
| Mining process | longwall full collapse management of roof mining | Time factor | 2.5 |
| Mining range | reference survey report | Horizontal movement factor | 0.30 |
| Mining depth | 0-455m | Bedrock moving angle | 75 |
| Mining thickness | 6.6m | Loose layer moving angle | 75 |

This mine belongs to inclined coal seams, and the planned mining technology is long-wall full collapse method to manage roof mining. From the depth map of the coal seam along the pipeline, it can be seen that the surface of the coal seam is exposed near the left ore boundary (large pile number side), and the deepest seam near the right ore boundary (small pile number side) is about 455m. In this analysis, the coal seam section is divided according to the depth of the coal seam along the pipeline. The surface displacement prediction of the coal seam in each section is assumed to be a horizontal coal seam, and subsequent pipeline stress analysis is performed. Finally, laying measures along the pipeline are proposed.

3. Goaf subsidence prediction

In order to ensure the safety and reliability of the prediction results of the surface subsidence and the results of subsequent pipeline stress analysis, a sufficient mining range is considered in the prediction of the surface displacement of the mining area to ensure that the mining area reaches an ultra-full mining state. This paper uses the probability integral method to predict the surface displacement of the mining area. The axial displacement, lateral displacement and vertical displacement of the surface movement of the goaf along the pipeline are predicted. According to the different depths of the mining layer (different mining depth / mining thickness), the prediction results are shown in Figure 1, the mining depth=455m.

![Fig 1. Distribution of surface displacement along the pipeline](image)

4. Pipeline stress analysis

4.1. Soil spring and pipe parameter data

In this paper, a calculation model of the buried pipeline stress is used, the backfill soil is compacted clay, and the discrete nonlinear spring is used to simulate the soil restraint effect on the pipeline. The
soil parameters in the calculation model are shown in Table 2 and the calculation results of the three-way soil spring are shown in Table 3.

### Table 2. Parameters of soil spring

| Direction                  | Ultimate resistance (N/m) | Displacement (m) |
|----------------------------|---------------------------|------------------|
| Axial spring               | 19904                     | 0.008            |
| Lateral spring             | 74237                     | 0.061            |
| Vertical upward spring     | 57799                     | 0.081            |
| Vertical downward spring   | 144489                    | 0.081            |

### Table 3. Pipeline and laying parameters

| Parameter                  | Value          |
|----------------------------|----------------|
| Pipe outer diameter        | 406.4mm        |
| Design pressure            | 6.3MPa         |
| Pipe wall thickness        | 7.9 mm         |
| Buried depth               | 1.5m           |
| Pipe steel grade           | L360           |
| Backfill soil              | dense clay     |
| Elastic Modulus            | 2.01E11 Pa     |
| Laying direction           | cross in the middle |

4.2. Pipe Stress Analysis

In this paper, the pipe element, shell element and spring element in ANSYS are used to analyze the stress of the pipeline in the goaf. The model can simulate the interaction between the pipeline and the soil given the surface deformation (the prediction of the surface displacement of the mining area as input). At the same time, the coupling between the internal pressure of the pipeline and the temperature difference load can be considered, which can reflect the mechanical response along the pipeline under mining conditions, and provide a basic judgment for the pipeline's stress in the mining area. In the analysis, the mining depth and the thickness ratio of 40 are taken as the boundaries. Continuity deformation is analyzed by tube element, and for discontinuous type, shell element is used to check with the maximum predicted sinking amount. When the check fails, measures such as reserving coal pillars are proposed.

4.2.1. Analysis of continuous surface deformation in goaf

The pipe element and the spring element in ANSYS are used to analyze the stress of the pipeline under the continuous surface deformation of the goaf. The model can simulate the interaction between the pipeline and the soil under a given continuous surface displacement, and determine the pipeline in the working condition. Under the mechanical response, the calculation accuracy can meet the engineering requirements. It can be seen from Table 4 that under the laying conditions in this example, the mechanical check of the pipeline meets the requirements under the condition of continuous surface displacement.

### Table 4. Stress check table for continuous surface deformation and displacement

| wall thickness | Compressive strain | Tensile strain | Meets conditions |
|----------------|--------------------|----------------|-----------------|
|                | Calculated value   | Allowable value| Calculated value| Allowable value |                  |
| 7.9 mm         | 0.067%             | 0.69%          | 0.1%            | 0.83%           | yes              |

4.2.2. Analysis of Discontinuous Surface Deformation in Goaf

For discontinuous ground surface displacement and deformation, the pipeline stress check should consider the most unfavorable load state possible. This article assumes that the ground surface sinks once in a step, and the sinking value is considered according to the possible maximum. The shell element and spring element in ANSYS were used to analyze the stress of the pipeline under the discontinuous surface deformation in the goaf. The model can simulate the interaction between the
pipeline and the soil under a given discontinuous surface dislocation, and determine the mechanical response of the pipeline under this condition. The calculation accuracy can meet the engineering requirements. It can be seen from Table 5 that under the laying conditions in this calculation example, under the condition of discontinuous ground displacement, when the wall thickness is 7.9mm, the pipe stress check cannot meet the requirements of the code. The check passed by increasing the wall thickness to 11.1mm.

Table 5. Stress check table for non-continuous surface deformation and displacement

| Pipe outer diameter | Pipe wall thickness | Compressive strain | Tensile strain | Meets conditions |
|---------------------|--------------------|--------------------|----------------|-----------------
| 406.4mm             | 7.9mm              | 1.44%              | 0.69%          | no              |
|                     |                    | 1.01%              | 0.83%          |                 |
| 406.4mm             | 11.1 mm            | 0.80%              | 0.97%          | yes             |
|                     |                    | 0.61%              | 1.17%          |                 |

5. Conclusion

The analysis conclusions are as follows:

(1) In the continuous deformation area, given the mining conditions and pipeline laying conditions in the mining area, the current wall thickness (7.9mm) can be used, and the pipeline stress check meets the design requirements. The pipeline safety can be ensured after the routine safety measures of the pipelines in the goaf are adopted in the pipeline laying.

(2) In the area of non-continuous deformation, under the existing wall thickness of 7.9mm, the pipeline force check failed, and after adjusting the wall thickness, the pipe force check passed. Therefore, it is recommended to increase the pipe wall thickness in this section, and the adjusted wall thickness should not be less than 11.1mm.

(3) The surface where the coal seam is exposed may form a localized centralized sinking during surface mining in the future, so increasing the possibility of pipeline maintenance in this section. Therefore, it is recommended that the near surface area near the pipeline (the depth of the mine layer is less than 50m) be consulted with the coal mine owner not to carry out mining activities.

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