Research on Emergency Treatment Measures for Oil and Gas Pipeline Passing Though Mining Subsidence Area

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Abstract. With the continuous increase in the mileage of long-distance oil and gas pipelines in China, more and more pipelines need to pass through prospecting areas, mining areas and mined-out areas. In these areas, underground subsidence and surface cracking may occur due to over-exploitation of underground minerals, which may cause damage to buried oil and gas pipelines. In order to ensure the safety of the pipelines in these areas, it is necessary to put forward appropriate measures for the management of different mined-out areas. This is a new topic that needs further study for the mined-out area pipelines. This paper takes the geological disasters of the collapsible subsidence suffered by the Puxian-Hejin gas pipeline as an example, through the establishment of a settlement monitoring system for mined-out area and the analysis and verification of pipeline stress status, comprehensive physical survey, on-site monitoring data analysis, expert experience, calculation and analysis of pipeline stress, evaluation of geological safety in mined-out area, and emergency measures such as trench excavation, interception and drainage, weld protection, timely pipe lift, decompression and gas transmission, and monitoring and early warning measures to effectively reduce the risk of pipeline damage and ensure the safe operation of pipelines. The treatment measures have reference and reference significance for the treatment of oil and gas pipelines in mined-out areas.

1. Introduction

The mining of underground mineral resources will lead to the emergence of mined-out area. if the surrounding rock instability occurs in the mined-out area, geological disasters such as earth's surface cracking, subsidence or collapse will be caused, which will bring great safety risks to the surface and underground buildings [1-3]. Data shows that China’s coal resources are relatively abundant and widely distributed, with the most dense coal resources in Shanxi [4-6]. Due to the excessive mining of coal mines, geological disasters such as surface cracking and ground subsidence often occur, which not only threaten people's production and life safety, but also put forward new issues for the prevention and treatment of geological disasters in the mined-out area [7]. In the meanwhile, with the continuous increase of construction mileage of long-distance oil and gas pipelines in our country, more and more pipelines need to pass through the exploration area, mining area and mined-out area. In the future, these areas may have different degrees of ground subsidence and surface cracks due to the over-exploitation of underground minerals, and then damage the oil and gas pipelines [8-9]. In order to ensure the safety of pipelines in these areas, the appropriate treatment measures need to be put forward according to different mined-out areas conditions, which is a new topic that requires further study for mined-out area pipelines.
Puxian-Hejin gas pipeline undertakes the gas supply task of 700000 people and more than 2000 industrial and commercial users in Yuncheng City, with a heating area of $300 \times 10^4 \text{ m}^2$, which is a key construction project in Shanxi Province. In June 2015, the mined-out ground subsidence disaster occurred in 610+820–611+370 section of Puxian-Hejin gas pipeline project due to coal mining under the pipeline. After field investigation, it was found that under the influence of mined-out subsidence, fissures were very developed in the field. There are 5 first-level ground fissures, 21 second-level ground fissures and 55 third-level ground fissures in the field, of which 14 were first-level and second-level ground fissures run through the pipe trench with large dislocations. It seriously threatens the safety of gas pipeline project (Fig. 1). This article will take this as an project case to explore and study the emergency treatment measures for pipelines passing through the mined-out area, and the experience and method of mined-out area governance will strive to be promoted and applied in other mined-out area pipeline projects.

2. Emergency Treatment Measures

2.1 Establish mined-out area subsidence monitoring system
In order to timely grasp the development trend of mined-out area ground subsidence and deformation in 610 + 820-611+370 section of Puxian-Hejin gas pipeline project and the degree of damage to the pipeline, Establish monitoring system according to the building deformation measurement specification (JG J 8-2016), and combined with actual situation of the site and the requirements of emergency treatment measures. The main content of the monitoring work is to monitor the surface movement and deformation on east and west sides of the pipeline, so as to provide data support for whether further subsidence occurs in the mined-out area.

2.2 Carry out pipeline stress state analysis
Based on the comprehensive collection, collation and analysis of the existing achievement data (including engineering geology, mining design, production and excavation, etc.) in the study area, we use the probability integral method to predict the deformation situation of the mined-out area. In this paper we compare the maximum predicted value of the mined-out area deformation with the measured data, and analyse residual surface movement and deformation to comprehensively evaluate the stability of the mined-out area. Based on the above data, simulation analysis and calculation check of the pipeline stress situation are carried out based on the pipe top deformation monitoring and the pipeline body strain monitoring data. According to the analysis results, it is determined whether pipe lifting measures are needed to implement to reduce the risk of pipeline damage.

2.3 Carry out emergency treatment measures
Comprehensive physical survey, on-site monitoring data analysis, expert experience, pipeline stress calculation and analysis, and geological safety assessment of mined-out areas, and emergency measures such as pipe trench excavation, interception and drainage, weld protection, timely pipe lifting, and decompression gas transmission are taken to effectively reduce the risk of pipeline damage and ensure the safe operation of pipelines.

2.3.1 Pipe trench excavation
In the case of cracks and surface deformation in the mined-out area, in order to reduce the force of the overlying soil layer on the pipeline to the pipeline, it is necessary to peel off the soil layer on the pipeline where mined-out subsidence occurred as soon as possible. According to the pipe trench excavation plan (Fig. 1), the buried depth of the pipeline is about 2m, the width of the upper excavation opening is 2.2m, and the width of the lower part is 1.5m, which can be appropriately adjusted according to the actual situation. According to the width of coal mining face, the influence range of ground subsidence and monitoring data, the total length of pipe trench excavation is about 560m (Fig. 1).
2.3.2 Interception and drainage measures and Weld protection

The trench, excavation and filling soil formed by the pipe trench excavation shall be protected against rainfall and surface water infiltration and erosion. First, the trench walls dug out on both sides of the pipe trench should be trimmed, and the soil on both sides of the pipe trench should be covered with plastic cloth for waterproofing. The width of each piece of plastic cloth should be repeated 0.5m, and the upper part of the plastic cloth should be configured appropriate weight to prevent wind blowing. Second, completely cover the bottom of the excavated pipe trench with plastic cloth (Fig. 2). Set drainage ditch at the bottom of the excavated trench. Set shallow water collecting well every 40m. The size of drainage ditch and water collecting well is determined by the size of the excavation section. The plastic cloth covered at the bottom of the pipe trench is fixed under the plastic cloth covered on the trench wall, and reset more than 30cm. Third, configure a sewage pump for each collection well, set a filter at the pump port, and have a dedicated person on duty when pumping water. Fourth, set up drainage hoses along the outer ground of the pipe trenches and connect them with the sewage pump drainage pipes, so as to drain the rainwater drawn from the drainage wells at the bottom of the trenches into the trenches outside the mined-out subsidence area.

2.3.3 Timely pipe lifting and Depressurized gas transmission

On the basis of comprehensive consideration of engineering geological survey, geophysical prospecting, mined-out subsidence prediction, pipeline strain monitoring and stress calculation, pipeline and ground subsidence monitoring and other factors, we carried out a total of six times of pipe lifting operations during the emergency period by using large-scale, equal proportion and collaborative pipe lifting, which ensured the safety of the pipeline in the stage of large mined-out deformation. In order to effectively reduce the risk of pipeline damage, the gas transmission pressure is reduced to the minimum under the condition of ensuring the minimum amount of gas consumption of residents.
Analysed the pipeline stress in the mined-out area by using the finite element analysis software, combined with the analysis of the pressure in the analysis of the maximum allowable subsidence of the pipeline. During the period of emergency disposal, the gas transmission pressure of the pipeline decreases from normal 3.2Mpa to the minimum 1.6Mpa, and the average is 2.5MPa. The commissioner observes the gas transmission pressure every two hours, then records and reports it.

2.3.4 Analysis of pipe lifting effect
According to the pipeline coordinate data after pipe lifting, we checked the pipeline stress state. The check results are shown in Table 1.

| Pipeline pressure | Part   | Axial stress /MPa | Allowable stress/MPa | Check results | Results of the first stress check | Results of the second stress check |
|-------------------|--------|-------------------|---------------------|--------------|----------------------------------|----------------------------------|
| Operation pressure | Elbow 1 | 81.42             | 270                 | Meet         | 265.91                           | 294 Meet                         |
| 2.5MPa            | Elbow 2 | 75.51             | 270                 | Meet         | 76.29                            | 304 Meet                         |
|                   | Elbow 3 | 87.98             | 270                 | Meet         | 85.09                            | 293 Meet                         |
| Design pressure   | Elbow 1 | 126.47            | 270                 | Meet         | 89.71                            | 255 Meet                         |
| 4.0MPa            | Elbow 2 | 118.55            | 270                 | Meet         | 129.24                           | 260 Meet                         |
|                   | Elbow 3 | 142.80            | 270                 | Meet         | 160.86                           | 240 Meet                         |

The relationship between the displacement calculated by finite element method and the measured displacement is shown in Fig.3. It can be seen from the figure that the calculated horizontal and vertical displacement of the pipeline is basically equal to the measured value. The deformation trend is the same, and the error is small. The calculation result of pipeline stress can reflect the real stress state of the pipeline.

![Figure 3. The relationship between the calculated value and the measured value of horizontal displacement and vertical displacement](image)

According to the check results, we know that under 2.5MPa operating pressure, the pipeline stress cannot meet the stress requirements about unconstrained pipeline in ASME B31.8 regulation; when the pipeline operates at the design pressure higher than 2.5MPa to 4MPa, the pipeline stress state is more disadvantageous. So the pipeline should operate at a low pressure during the subsidence active period of mined-out area.

2.4 Monitoring and early warning
During the implementation of the treatment measures, in addition to requiring the pipeline operation unit to communicate with the local meteorological bureau in time to release the next 24-hour weather forecast of the ground subsidence area, the most important thing is to monitor the stress and strain of the pipeline body, and monitor the top of the pipeline and surface deformation. In the later stage of operation, it is suggested to continue monitoring and early warning work of the pipeline.
2.4.1 Stress and strain monitoring of the pipeline body

According to the monitoring data of surface movement and deformation and the experience of experts, we analysed the trend of surface movement and its impact on the pipeline and select the typical points and sections of pipeline deformation caused by press (elbows and parts with large deformation) for strain monitoring of the pipeline body (Fig.4). Master the stress and strain conditions of the pipeline in time. According to the design regulation for gas pipeline engineering (GB 50251-2015), design regulation for geological disasters prevention and control of oil and gas pipeline engineering (SY/T7040-2016) and technical regulation for risk management of oil and gas pipeline geological disasters (SY/T6828-2011), the threshold value of axial stress warning is set as 80% of the minimum yield strength of the pipeline. During the emergency disposal, the strain gauges of 4 sections of the pipeline should be installed. Monitor a total of 24 strain gauges, 6 strain gauges in each section by using Bgk-micro40-24 data acquisition equipment, so as to master the pipeline stress and strain situation in real time, and provide quantitative basis for pipeline emergency disposal decision.

2.4.2 Stress and strain monitoring of the pipeline body

Select the top of the pipeline and the typical points and sections of surface deformation to carry out surface deformation monitoring. Grasp the development trend of mined-out subsidence and deformation and the degree of damage to the pipeline in time. The threshold of surface movement and deformation monitoring is set according to the actual situation of the site. Generally, it will give an early warning based on the actual situation of the site when the monitoring curve has an obvious jump or a dramatic change.

In view of the deformation of the top of the pipeline, arrange a monitoring point every 10~15m from north to south along the direction of the pipe top, and the number them. The position and elevation of the measurement point are measured daily to grasp the displacement and settlement deformation of the pipeline. In view of the surface deformation, select 36 monitoring points and 33 monitoring points from west to field within the range of 12~15m from the pipeline center along the pipeline axis direction to carry out the surface movement and deformation monitoring. The distance between each two monitoring points is 12~15m. Measure the movement and deformation of the surface by using the total station every day, so as to grasp the movement and deformation of the surface in time.

3. Conclusion

In order to effectively deal with the effect of geological disasters of mined-out subsidence in 610+820~611+370 section of Puxian-Hejin gas pipeline, we established mined-out area settlement monitoring system and carry out the analysis and verification of pipeline stress state, combined the methods of physical survey, field monitoring data analysis, expert experience, pipeline stress calculation and analysis, and geological safety assessment of mined-out areas and took the emergency measures of pipe trench excavation, interception and drainage, weld protection, timely pipe lifting, decompression gas transmission, monitoring and early warning to reduce the risk of pipeline damage and ensure the safe operation of the pipeline.
A series of measures for emergency disposal of mined-out subsidence were put forward timely, accurately and effectively, which ensured the safe operation of the pipeline. It not only greatly reduced the economic loss, but also ensured the industry reputation of the pipeline management company.

The experience and methods of this disposal of mining subsidence area can be popularized and applied in other pipeline mining subsidence areas. At the same time, it is suggested that continue to carry out strain monitoring and ground subsidence observation on the mining subsidence section pipeline in the later operation period, so as to do early warning well.

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References
[1] Zarnani S, Bathurst R J. (2009) Numerical parametric study of expanded polystyrene (EPS) geofoam seismic buffers [J]. Canadian Geotechnical Journal, 46(3): 318-338.
[2] ZHAO L, FENG Q M. (2011) Research on methods for establishing FEM model of buried pipelines [J]. Earthquake Engineering And Engineering Vibration, 21(2): 53-57.
[3] Wang Z L, Li Y C, Wang J G. (2006) Numerical analysis of attenuation effect of EPS geofoam on stress-waves in civil defense engineering [J]. Geotextiles and Geomembranes, 24: 265-273.
[4] XIA Mengying, ZHANG Hong, WANG Baodong, et al. (2018) Strain analysis of buried pipelines in continuous mining subsidence areas based on shell element [J]. Oil & Gas Storage and Transportation, 37(3): 256-262.
[5] WANG Teng, DU Bao-ping. (2018) Analytical solution for penetration response of steel catenary riser at touchdown zone on bilinear seabed[J]. Chinese Journal of Geotechnical Engineering, 840(9):1676-1683.
[6] HE Xu, WANG Yongxue, LI Xiaochoao. (2011) Analysis of VIV for Free Spanning Pipelines Considering Pipe-soil Interaction [J]. China Offshore Platform, 26(6):21-26.
[7] Xu Wan-hai, XIE Wu-de, GAO Xi-feng, et al. (2018) Study on vortex-induced vibrations(VIV)of free spanning pipeline considering pipe-soil interaction boundary conditions [J]. Journal of Ship Mechanics, 22(4): 446-453.
[8] Lucy L. (1995) A numerical approach to testing the fission hypothesis[J]. Astron J, 82: 1013-1024.
[9] QING Longbang, WANG Miao, HAO Bingjuan. (2018) Research on cohesive laws of concrete and crack propagation process based on a series-parallel spring model[J]. Advances in Science and Technology of Water Resources, 38(4): 38-43.