Journal of Civil Engineering and Urban Planning (2023) DOI: 10.23977/jceup.2023.050809
Clausius Scientific Press, Canada ISSN 2616-3969 Vol. 5 Num. 8

Analysis of Uneven Settlement and Deformation of the Existing Railway under the Condition of Mined-out Area after Mining

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Keywords: Deformation, wireless timely monitoring, goaf, transition area, stable area, existing railways

Abstract: Due to the railway construction being ahead and the mining work being behind, it is inevitable for some mining areas to pass under the railway. However, at present, for the mining work face passes across under the railway there is a lack of research and evaluation on the deformation of the existing railway roadbed after the upper strata of the goaf were reinforced and repaired. Based on the deformation monitoring of roadbed after the 5301 mining face passed under the section form milepost DK1 290 to milepost DK2 755 of Gucheng Special Railway, the variation law of the uneven deformation of the existing railway roadbed on the goaf was studied. The research results indicated that the deformation in the transition area and the stable area of the existing railway roadbed was very small, while the subgrade deformation of the existing railway above the goaf was relatively large, and the maximum vertical displacement of railway subgrade was 7.8 cm within 3 months. According to the analysis of monitoring data, the deformation distribution law of existing railway subgrade above goaf was in shape of "V".

1. Introduction

The problem of mined-out area is a difficult problem in the world, when it cannot be avoided, it must be rectified and monitored by reasonable methods to achieve the goal of engineering safety. As the railway construction in front, mining work in the later, so some mining work face inevitably goes under the railway. The mined-out area is the area and range affected by ground deformation and failure due to surrounding rock instability, such as displacement, breakage and collapse, whole subsidence and bending of overlying strata after the mining [1]. Because of the high speed of some special railway and the high requirement of foundation stability, it is very important to analyze and evaluate the deformation and stability of railway subgrade when the mining face crosses under the railway [2,3].

Many engineers have studied the influence of the mining area on the adjacent engineering buildings, and obtained some useful research results. According to the requirement of deformation monitoring, Jiang and Xu. monitored the deformation of the existing expressway on a goaf for 4 times, and analyzed the influence of goaf collapse deformation on expressway deformation [4]. Peng. used Insar technology to explore and evaluate the deformation monitoring of mined-out areas near the expressway [5]. Fu. evaluated the risk and deformation prediction of the goaf through the monitoring results of the goaf in the Nanqin Railway coal mine, and pointed out that the ground above the goaf would produce cracks and collapse, which would lead to the disaster risk of the whole subsidence [6]. Xu et al. analyzed and evaluated the stability time, safety depth, maximum subsidence amount and maximum subsidence velocity of goaf subsidence in several large goaf [7]. Li. analyzed the actual situation of the large-area water-saturated mined-out area formed underground in the salt mine area which has been exploited for more than 20 years, and studied the main engineering treatment measures of the proposed railway project on the mined-out area, the methods include widening roadbed, adopting simply supported bridge, adjustable bearing, and grouting reinforcement of soil layer [8]. Fan. took the Goaf of a gold mine as an example, the distribution of goaf of was found out by means of geological survey, geophysical survey and Insar subsidence monitoring [9]. Wang. studied the classification and deformation characteristics of the mined-out area of the coal mine along the Baoxian railway, and put forward feasible engineering measures and treatment schemes [10]. Zhang. discussed the layout, data acquisition and data processing of deformation monitoring of mined-out area [11].

It is worth noting that for the Goaf, because of the Goaf overlying strata repair, rock deformation stability needs a process, however, the evaluation of the influence of the deformation of the goaf on the deformation of the existing railway roadbed is still lack of research.

Therefore, after the Goaf strata were repaired, through the real-time wireless monitoring system of subgrade deformation of Gucheng Special Railway form DK1 290 to DK2 755, this paper will analyze the subgrade deformation law of the existing railway above goaf based on the monitoring of subgrade settlement in section form DK1 290 to DK2 755, and further evaluate the future stability trend of the existing railway subgrade on goaf, and provide technical basis for making scientific and reasonable early warning measures and railway maintenance to ensure the safety of railway operation.

2. Wireless Monitoring Layout

Since the Gucheng Special Railway was built before the mining 5301 working face mining in the later, so the 5301 working face can not avoid from the railway through the lower. In order to ensure the operation safety of the railway after mining, the overburden separated layer grouting technique was used to reinforce the area to be mined before the 5301 working face passes under the section from DK1 290 to DK2 755 in the existing Gucheng Special Railway. After the mined-out area was mined, the existing railway subgrade above the mined-out area should be monitored in real time. The safety monitoring mileage was form DK1 000 to DK2 860, of which DK1 000-DK899 was the bridge section (Jiang River Bridge), DK1 899 - DK2 365 was the embankment section, and DK2 365 - DK2 860 was the cutting section. According to the subsidence characteristics of mined-out area, the railway monitoring area was divided into mined-out area, transition area and relatively stable area.

A real-time wireless monitoring and analysis system for railway roadbed deformation was established based on GNSS deformation monitoring equipment located by Beidou positioning Satellite, and the real-time deformation data of existing railway roadbed above goaf were collected. The layout of GNSS monitoring equipment and actual influence area were designed, and the layout of measuring points was shown in Figure 1.

In this monitoring project, 14 GNSS monitoring stations are built in Jianghe Bridge (DK1 280 - DK1 899), which were numbered M01 - M14 respectively.

In this monitoring project, 14 GNSS monitoring stations were constructed on both sides of the embankment section from DK1 899 to DK2 365. During the layout, the monitoring stations were arranged at every 30m interval between left and right, and the corresponding numbers were M15 - M28 respectively.

In this monitoring project, 10 GNSS monitoring stations were constructed on both sides of the roadbed within the cutting section from DK2 365 to DK2 860. During the monitoring, the GNSS monitoring stations are to be laid at a 50m interval within the monitored roadbed section with left and right cross positions adjusted according to the site conditions. The corresponding numbers are M29 to M36.

In this monitoring project, 6 GNSS monitoring stations were planned to be built symmetrically on the slope top platform on both sides of the cutting section from DK2 365 to DK2 860, and the corresponding numbers were M37 - M44.

In addition, two GNSS monitoring base stations were constructed in stable locations within a 3 km radius of the stations.

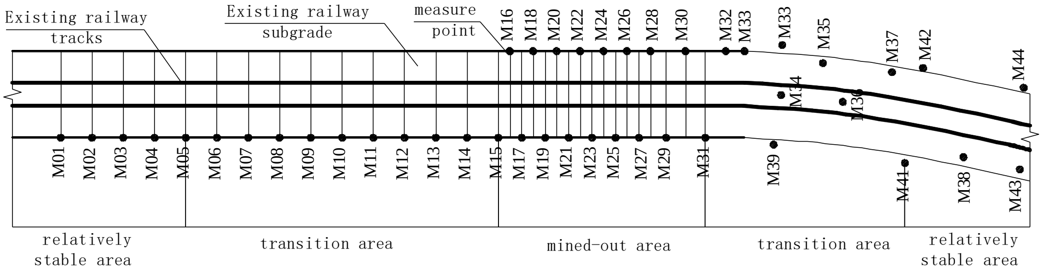

Figure 1: Schematic diagram of measurement point layout.

3. Analysis of Monitoring Data

When the 5301 working face passed under the section from DK1 290 to DK2 755 in the existing Gucheng Special Railway, according to the deformation monitoring data of M01, M07, M13, M17, M23, M29, M34, M37 at the typical locations of the existing railway subgrade on the goaf, transition area and relative stable area for about 3 months, the settlement displacement of the typical measuring points above the mined-out area, the transition area and the relative stable area were arranged as shown in Figure 2, where M01 was the measuring point of relatively stable area, M07, M13, M34, M37 were the measuring points of transition area, M17, M23, M29 were the measuring points of goaf.

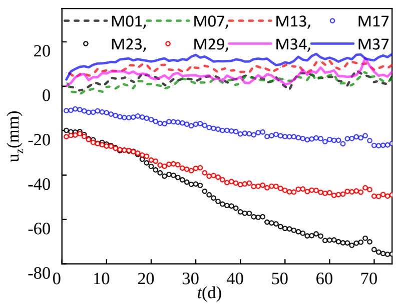

Figure 2: Displacement of Typical Measurement Points.

Through the analysis of Figure 2, it can be seen that after the 5301 working face passed under the

Gucheng Special Railway, the change rate of settlement displacement of the railway subgrade measuring point M01 in the stable area and the measuring point M07 and M34 in the transition area were basically 0, the change rate of the settlement displacement of M13, M37 in the relative stable area increased slightly, and the settlement deformation of M17, M23, M29 in the goaf increased nonlinearly at first and then slowly, the rate of change tended to flatten slightly. It is worth noting that the settlement displacement of M23 was relatively large, and the cumulative displacement was 7.8 cm, the settlement displacement of each measuring point decreased from goaf to transition area and relative stable area.

The analysis of the settlement displacement curve of measuring point M17, M23 and M29 above the mined-out area during the 3-month monitoring were shown in Figure 3- Figure 5.

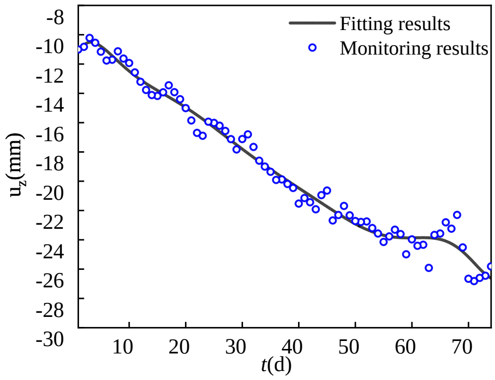

Figure 3: Displacement monitoring curves and fitting results of M17 measurement point.

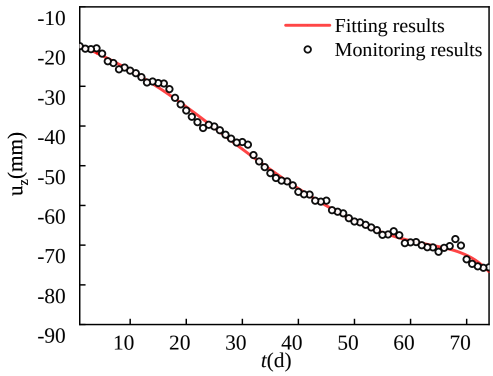

Figure 4: Displacement monitoring curves and fitting results of M23 measurement point.

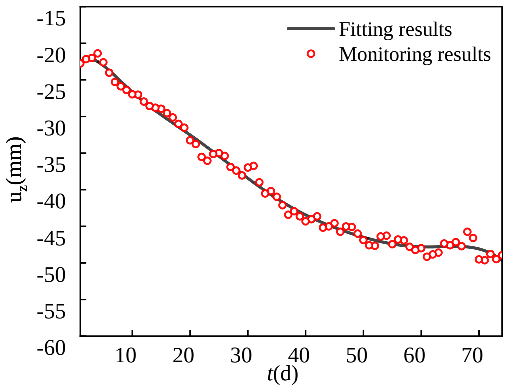

Figure 5: Displacement monitoring curves and fitting results of M29 measurement point.

By analyzing the monitoring data of the settlement and displacement of M17, M23 and M29 above the goaf, the trend of the monitoring curve of the settlement and displacement was in accordance with the high order polynomial:

$$u_z = k_9 t^9 + k_8 t^8 + k_7 t^7 + k_6 t^6 + k_5 t^5 + k_4 t^4 + k_3 t^3 + k_2 t^2 + kt + b \tag{1}$$

Where T was time (day) and b、k_i were fitting constants. The fitting parameters of measuring points M17, M23 and M29 were detailed in Table 1.

Through this fitting equation, the settlement deformation of railway subgrade above goaf in the future could be predicted.

Table 1: Fitting Parameter Parameters.

name	M17	M23	M29
b	-12.25204	-19.08922	-23.52284
k_1	1.39245	-0.54959	1.42004
k_2	-0.36259	-0.0275	-0.42416
k_3	0.03798	0.00295	0.04159
k_4	-0.00222	-2.45E-04	-0.00225
k_5	7.71E-05	1.05E-05	7.19E-05
k_6	-1.64E-06	-2.48E-07	-1.40E-06
k_7	2.08E-08	3.26E-09	1.62E-08
k_8	-1.45E-10	-2.24E-11	-1.03E-10
k_9	4.25E-13	6.22E-14	2.76E-13
R^2(COD)	0.98024	0.99724	0.99179

After the 5301 working face passed under the section form milepost DK1 290 to milepost DK2 755 of Gucheng Special Railway, the displacement distribution of typical measuring points M06, M12, M18, M24, M30, M36, M42 along the railway line was shown in Figure 6. According to the curve in Figure 6, the settlement displacement of the roadbed along the railway line presents the distribution law of “V” shape.

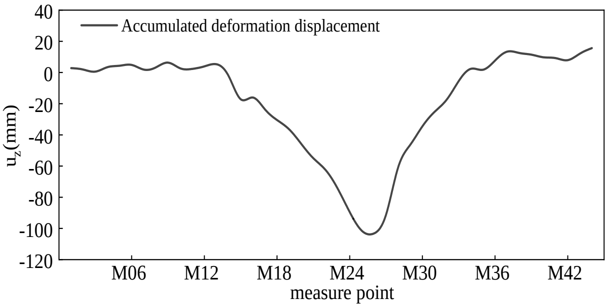

Figure 6: Statistical analysis results of cumulative deformation displacement.

One of the reasons why the roadbed settlement along the railway line presented a “V” shape distribution law was that the deformation of the roadbed above the goaf was obvious, secondly, the deformation of the railway subgrade above the transition area was relatively small, and the deformation of the railway subgrade was smaller the closer to the stable area, it was because the railway subgrade above the stable area hardly deformed.

4. Conclusion

Based on the monitoring data of railway subgrade deformation after the 5301 working face passed under the railway, this paper analyzed the subgrade deformation law of the existing railway above goaf based on the monitoring of subgrade settlement in section form DK1 290 to DK2 755 of

Gucheng Special Railway. The analysis of continuous monitoring data over a three-month period led to the following main conclusions:

(1) The subgrade deformation in the transition and stable areas was very small, the subgrade deformation in the goaf was large, and the vertical displacement of measuring point M26 in the middle of the goaf was large, the displacement was 7.8 cm.

(2) The settlement displacement of each measuring point decreased from goaf to transition area and relative stable area.

(3) According to the analysis of monitoring data, the deformation distribution law of existing railway subgrade above goaf was in shape of "V" along the railway line.

(4) The relationship between the settlement deformation and the time accorded with the high-order polynomial fitting, through which the settlement deformation of the existing railway roadbed above the goaf could be predicted in the future in a certain time.

The Research can guide the early warning measures to ensure the safety of railway operation in future.

Acknowledgment

This work was supported in part by a grant from the Science and technology project of Shanxi Lu'an Mining Industry (Group) Co., Ltd. (No.2022B2101183), the Science and Technology Project of China Railway Xi'an Institute of Investigation, design and research Co., Ltd (No.XKY-2022-10(23-119)).

References

[1] Ren L.W., Ning H., Zou Y.F., Dun Z.L., Guo W.B. and Tian Z.B. (2021) Research status and prospect on deformation control of high-speed railway subgrade in goaf site. Journal of China Coal Society, 46(08): 2534-2547.

[2] Zhang X.D., Sun Q., Du D.N. and Wei X. (2011) Numerical simulate research on the Benxi section of Shenyang to Dandong railway passenger dedicated line. The Chinese Journal of Geological Hazard and Control, 22(02): 104-107.

[3] Duan Y., Zhao P., Ning Q.Y. and Zhao, Y.S. (2014) Research on Instability Mechanism and Stability Numerical Simulation of Mined-out Areas of Non-coal Mines. Safety and Environmental Engineering, 21(06): 29-35.

[4] Jiang T.G. and Xu S.N. (2019) Monitoring and Analysis of Deformation in Underlying Goaf of Expressway. Inner Mongolia Coal Economy, 277(08): 117-125.

[5] Peng X.H. (2022) Deformation monitoring of goaf of Lüliang Ring Expressway based on InSAR technology. Transport Construction and Management, 488(03): 132-133.

[6] Fu Y.J. (2013) Deformation Prediction and Hazard Assessment for Mined-out Area along Nanning-Qinzhou Railway. Subgrade Engineering, 171(06): 208-212.

[7] Xu Y.M., Zhang R.K. and Li G.H. (2004) Stability Analysing of Railway Subgrade in the Large Coal Pits District. Railway Surveying and Surveying, (02): 75-77.

[8] Li S.P. (2022) Study on the Prediction of Ground Subsidence Induced by Solution Mining and the Engineering Treatment Measures for Railways Passing Through the Mine Field. Railway Construction Technology, 354(09): 169-173.

[9] Fan J.P. (2021) Analysis of the lnfluence of Goaf of a Gold Mine on Railway Stability. Engineering Design of the Ground, 454(08): 19-20+23.

[10] Wang S.R. (2007) Deformed Characteristics of Coal Mining Area along Baoxi Railway and Treatment Principle. Railway Surveying and Surveying, 131(04): 76-78.

[11] Zhang G.J. (2009) Exploration for Technical Scheme on Mined Areas Deformation Survey in Railway. Urban Survey, (02): 127-129.