Study on Stability Evaluation and Protection Technology of Newly Built Large Coal Bunker Above Goaf

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Abstract. To ensure the safety of constructing large coal bunkers above the goaf of coal mines, the probability integral method was used to predict the residual settlement deformation of the ground surface, and the foundation stability of the newly built large coal bunkers was evaluated. The evaluation concluded that the new coal bunkers would cause the further activation of the goaf, and necessary safety protection technical measures should be taken for the new coal bunkers. According to the structural type of coal bunker, the specific safety monitoring methods, anti-deformation technical measures, and maintenance and reinforcement measures were proposed, providing the technical guarantee for the safe and stable operation and use of coal bunker in the future.

Keywords: Goaf; Large coal bunker; Stability evaluation; Protection technology

1 Introduction

With the rapid development of cities and engineering construction in China, construction land was becoming increasingly scarce [1], especially in some resource-based cities; many buildings (structures) had to be built above the coal mining (dynamic) goaf. In recent years, with the increasing coal mining volume year by year, large-scale constructions of various large buildings (structures) began to be built above the coal mining subsidence area including factories, schools, large office buildings, etc. These buildings generally had characteristics such as high floors, large spans, and heavy loads, which were affected by coal mining in mines and certain safety hazards. This had also become a major safety issue to restrict urban development.

After years of practice, rich experience had been gained in the study of mining damage to buildings (structures), and the theory had become more mature in China. Certain systems had also been established. However, most of the building protection technologies were proposed for brick and wood, brick and concrete structure bungalows, or multi-story buildings, and technical measures were mainly absorbed or resisted mining deformation [2]. There were few engineering examples of constructing large coal bunkers above goaf areas, and there had been no systematic research conducted domestically or internationally. Coal bunkers had the characteristics of high

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height, large volume, and heavy load, which required higher stability of the foundation, especially for coal bunkers built above the goaf of coal mines. To ensure safe and stable use, certain protective technical measures must be adopted.

In this article, the constructions of the large coal bunkers above Pingmei No.7 Mine were taken as examples to analyze the mining impact under the influence of multi-layer goaf, and the anti-deformation and safety protection technical measures were proposed for the large coal bunker providing the scientific basis for the stability analysis and protection technology of the similar engineering foundations.

2 Engineering situations

The project site was located at the location of the original Pingmei Gangue dumping site on the south side of Ping'an Avenue in Pingdingshan City, and it was planned to construct four 10000 t grade coal bunkers, with a diameter of 23 m and a height of 50 m. Coal bunkers were the integral cast-in-place concrete structure, and the entire area covered the area of approximately 3360 m^2. The project was located within the coal mining subsidence area of the No. 7 Coal Mine of Pingmei Group. The No. 7 Coal Mine had successively mined three groups of coal seams, namely, the Group Wu, the Group Ji, and the Group Gen. Mining depth was 70-323 m, the cumulative mining thickness was 11.3 m and the mining period was from 1961 to 2008. In addition, small coal mines such as Hualian Mine, Wenji Mine, and Xinhua No.1 Mine had conducted mining activities near the site and had now ceased production. Affected by faults and small associated folds, the coal seams were discontinuous along strike and dip, with large thickness changes, fragmented coal seams, and the tectonics were relatively complex. The thickness of the Quaternary topsoil layer in the overlying strata of the region was 23.14 meters, and the bedrock was composed of shale, sandstone, sandy shale, etc. Overall lithology of the overlying rock was medium hard.

3 Surface deformation prediction

Experts had proposed a variety of methods for the prediction of surface subsidence deformation at home and abroad. Currently, the probability integral method, negative exponential function method, Weibull function method, and typical curve method were the most used methods for the calculation of surface movement deformation in China [3]. Among them, the probability integral method was widely used in various mining areas, the parameters were easy to determine, and the practicability was strong. The estimation of residual subsidence deformation on the local surface was calculated using the probability integration method for the residual deformation of the entire area. Surface movement estimating parameters were shown in Table 1.

Table 1. Selection of technical parameters for mining subsidence

Sinking coefficient q	Horizontal displacement factor b	Tangent of major influence angle $tg\beta$	Propagation coefficient of extraction k	Deviation of inflection point s/H
0.03 ~ 0.15	0.30	2.0	0.7	0.05

After calculation, the maximum subsidence value of the surface in the area was 295 mm, the maximum inclination value was 4.7 mm/m, and the maximum horizontal deformation value was -1.3 mm/m.

At the same time, one calculation point was taken from each of the four coal bunkers to calculate the deformation of the coal bunkers. Calculation results were shown in Table 2. Referencing "Buildings, water bodies, railways and main roadway coal pillar setting and coal mining regulations" (Referred to as the "Three Lower" Mining Regulations) formulated by the National coal industry Bureau [4], the allowable value of inclined deformation of coal bunkers was 8 mm/m, the maximum value of inclined deformation was 4.7 mm/m in the project site, and the maximum value of inclined deformation of coal bunkers was 2.0 mm/m, which did not exceed the allowable value of inclined deformation of coal bunkers. Surface movement and deformation values of four coal bunkers in X-direction were shown in Table 2.

Table 2. Surface movement and deformation values of four coal bunkers in the X-direction

/	**Calculate point coordinates and x-direction**			**Sinking (mm)**	**Inclination (mm/m)**	**Lateral deformation (mm/m)**
Rows	X	Y	h	W	it	Et
Coal bunkers	37345	30458	180°	215	-1	-0.68
	37333	30480	180°	275	1	-1.23
	37322	30502	180°	286	2	-0.46
	37310	30524	180°	280	2	-0.28

4 Stability evaluation

4.1 Calculation of overlapping failure height

After coal seam mining, the overlying strata generally formed collapse zones, fault zones, and bending zones [5]. The development height of collapsed fault zones was mainly related to the thickness, inclination angle, mining size, overlying rock lithology, roof management methods, etc. of the coal layer [6-7]. Referring to the "Buildings, Water Bodies, Railways, and Main Roadway Coal Pillar Setting and Coal Mining Specification", the calculation formula was selected as follows:

$$H_{crack} = \frac{100\sum M}{1.6\sum M+3.6} + 5.6 \tag{1}$$

In the formula: $\sum$ M - accumulative mining thickness of coal seam in layered mining, m.

Coal seams mined near the site area mainly consist of three groups of coal, namely Group Wu, Group Ji, and Group Gen. Cumulative mining thickness of Group E coal was 5.6 m. Due to the large spacing between each group of the coal seams, only the maximum development height of the collapse fault zone of Group E coal was calculated, and the H_{crack} was 50 m.

4.2 Calculation of the influence depth of building loads

The depth of influence of building loads increased with the increase of building loads [8]. Generally, when the additional stress generated by the building load in the local foundation was equal to 20% of the self-weight stress of the foundation at the corresponding depth, it could be considered that the impact of the additional stress on the foundation at the depth was negligible, but when there was high-compressed soil or other instability factors below it, such as the goaf collapse and fracture zone, the additional stress should be calculated until the position where the self-weight stress of the foundation was 10%, and it could be considered that the additional stress did not have the significant impact on the foundation at the depth. This depth was the depth affected by the building load ($H_{influence}$).

The diameter of the coal bunker was 23 m, the height was 50 m, the buried depth was 6.0 m, and the load approximately was 2780 KN/m^2. The designed coal bunker load acted on the circular foundation of the building plane size, and the additional stress of the foundation was calculated based on the uniformly distributed rectangular load. After calculation, the depth of load influence ($H_{influence}$) of the coal bunker was 72 m.

4.3 Stability of goaf foundation

After coal seam mining, when the minimum mining depth ($H_{critical}$) was greater than the sum of the height of the collapse fault zone (H_{crack}) and the depth affected by building loads ($H_{influence}$), the caving fracture zone in goaf would no longer move again due to the disturbance of new building load, that is:

$$H_{critical} > H_{crack} + H_{influence}$$

The load influence depth ($H_{influence}$) of the coal bunkers was 72 m, the H_{crack} was 50 m, and the sum of the two was 122 m. The minimum mining depth of the coal seam in the proposed area was 80 m. Therefore, the building loads of the newly built coal bunkers would cause further activation of the goaf of the coal seam in Group Wu, and the surface deformation was intensified, so the large uneven settlement occurred again in the goaf.

It should be considered when calculating the residual subsidence deformation of the surface, the surface subsidence coefficient q of Group E coal was adjusted to 0.06, and necessary safety protection technical measures were taken for the coal bunkers.

5 Protective technical measures

5.1 Observation of surface movement and deformation

To ensure the safe use of the newly built coal bunkers, it was necessary to establish the coal bunkers observation station [9], the movement and deformation of the coal bunkers should be monitored in time, at the same time, according to the monitoring damage of the coal bunkers, maintenance and reinforcement measures were taken in time.

(1) Layout of measuring points

Coal bunker observation points included essential measurement points (buried at the junction of the foundation ring beam and the structural column) and the corresponding surface measurement points.

To monitor the settlement of the coal bunkers, the basic measurement points and corresponding surface measurement points were established in four coal bunkers. The method of cast-in-place concrete was used for wall points, and the exposed part was approximately 50-80 mm. Surface observation points should be buried in the ground soil corresponding to the observation points of the building, and the horizontal distance was 1.5 m from the building. To grasp the inclined deformation of the coal bunkers in time, it was necessary to set up the inclined deformation observation points. Measuring points were set at the tops of the coal bunkers and corresponded to the basic measuring points.

According to the needs, 16 pairs of structural measuring points were arranged in four coal bunkers, and each coal bunker was arranged in 4 pairs. The layout scheme of coal bunker measuring points is shown in Fig. 1.

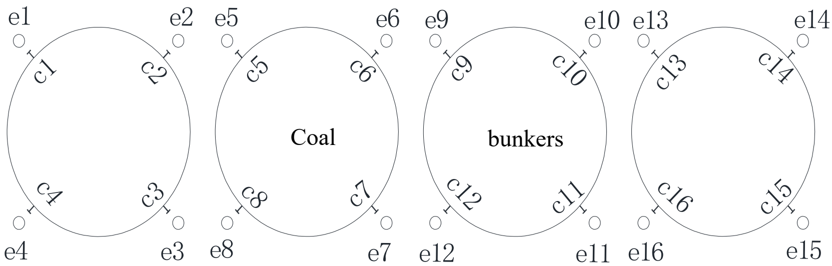

Fig. 1. Coal bunker measuring points layout diagram

(2) Observation of movement and deformation of coal bunkers

Movement and deformation observations of coal bunkers were mainly divided into inclination observation and foundation settlement deformation observation. Settlement observation of the coal bunker foundation was mainly achieved through the observation of the foundation measurement points and corresponding surface points, and the observation accuracy could refer to the accuracy requirements of third-class leveling [10].

5.2 Anti-deformation technical measures for coal bunkers

Cross-sections of the coal bunkers were circular, and under the condition of meeting the bearing capacity of the foundation, the foundation should be buried as shallowly as possible. All slab foundation types with good integrity or low-box foundation could be selected. Thick wall reinforced concrete now-poured shaft wall design was used for the silo wall. To increase the deformation resistance of the silo wall and improve the integrity and stiffness of the silo wall, the reinforcement amount of the silo wall could be appropriately increased [11-12]. In addition, after the completion of the coal bunkers, it was found during observation that the slurry skin cracks occurred on the silo wall, the cracking area could be treated with anchor mesh spray locking. The inclination of the coal bunker exceeded the allowable deformation value, and the jack lifting method could be used for the foundation correction.

6 Conclusion

(1) Under the influence of mining, the newly built coal bunkers were not only affected by surface subsidence but also mainly by inclined deformation caused by the ground subsidence. After calculation, the maximum tilt deformation of the coal bunkers was 2.0 mm/m, which did not exceed the allowable tilt deformation value of the coal bunkers.

(2) The sum of the depth affected by the load of the new coal bunkers and the height of overburden failure was 122 m, exceeding the minimum mining depth of the coal seams, which would inevitably cause the activation of the old goaf. Residual deformation of the goaf posed a certain safety hazard to the operation of the coal bunkers. To ensure the long-term stability of the new coal bunkers, it was necessary to take certain safety protection technical measures for the coal bunkers.

(3)16 pairs of observation points were set up for the newly built coal bunkers, and the settlement and tilt deformation of the coal bunker foundations were observed mainly.

(4) Anti-deformation technology of thick wall reinforced concrete now-poured shaft wall and integral box foundation had been adopted, and the measures for repairing the shaft wall and anchor mesh spray locking and rectification measures for foundation deviation by jack lifting method had been proposed.

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