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Field Measurement Study on the Law of Surface Movement and Deformation of Fully Mechanized Mining Face with Large Mining Height in Deep Thick Loose Strata

Zhang Meng
School of Civil Engineering, Henan Polytechnic University, Jiaozuo 454003, China

Abstract: In order to grasp the evolution characteristics of surface subsidence under the conditions of large mining depth and large mining height, taking the 1303 working face of a mine in the Lu'an mining area, Shanxi Province, China, as the engineering background, linear observation stations on the strike and dip main sections were laid out, and continuous field measurements lasting more than two years were carried out by GPS RTK technology. The distribution laws of subsidence, inclination, curvature, horizontal movement and horizontal deformation were systematically analyzed, the surface movement angular parameters, dynamic parameters and prediction parameters of the probability integral method were obtained, and the damage grade of surface buildings was evaluated. The results show that: the working face reaches full mining in the strike direction, and the maximum subsidence value reaches 5203 mm; affected by local geological structures and the superimposed mining of adjacent working faces, the deformation law in some areas is abnormal; the damage grade of the masonry buildings above the working face reaches Grade IV. The research results can provide measured basis and technical parameters for coal mining under buildings, water bodies and railways and for the protection of surface structures in this mining area.

Keywords: Deep thick loose strata; Large mining height fully mechanized mining; Surface movement and deformation; Probability integral method; Angular parameters

1. Mine Overview and Mining Conditions of the Working Face

1.1 Research Background

Constrained by the energy endowment, coal has long occupied the dominant position in China's primary energy consumption. With the depletion of shallow resources, the mining depth and mining intensity continue to increase, and the surface movement laws summarized from shallow mining are no longer applicable to deep high-intensity mining scenarios. In the industry, a mining depth of 400 m is taken as the boundary of deep mining: first, the parameters in the existing regulations are mostly derived from observation data within 400 m; second, when the mining depth exceeds 400 m, the proportion of Quaternary loose strata decreases, and its influence on surface movement parameters weakens significantly.

Previous studies have shown that with the increase of mining depth, the surface deformation decreases, the deformation rate slows down and the range of the subsidence basin expands; with the increase of mining thickness, the amplitudes of subsidence and horizontal deformation increase. Rock hardness, loose strata thickness, coal seam dip angle, roof management method and working face advance speed all affect the surface movement characteristics. According to the ratio of mining depth to mining thickness: when it is less than 30, the deformation is violent and discontinuous failure is likely to occur; when it is between 30 and 100, the deformation is continuous and highly regular; when it is greater than 100, the subsidence deformation is weak.

1.2 Overview of the Mine and the Working Face

The mine is located in Zhangzi County, Shanxi Province, and belongs to the Lu'an mining area with convenient transportation. The mine field is located in the low mountain and hilly area in the west of the Shangdang Basin, with terrain elevations of +927.6 m to +1061.7 m, a continental climate and a seismic fortification intensity of degree VI; the overall structure is a monocline dominated by broad and gentle folds, with only a few reverse faults developed, so the geological structure is simple. Working face 1303 mainly mines coal seam No. 3, with a strike length of 1046.7 m, a dip width of 280 m, an average coal thickness of 4.76 m and an average dip angle of 5 degrees; the fully mechanized mining with full-seam cutting at one time is adopted, and the roof is managed by the full caving method. The average mining depth of the working face is 515 m, and the thickness of the topsoil is about 90 m.

The roof and floor of the working face are generally of medium-hard rock: the immediate roof is sandy mudstone and siltstone, soft in lithology and relatively low in strength; the main roof and the main floor are both fine-grained sandstone. Two normal faults were exposed during roadway excavation; at the southwest corner, affected by a scouring zone, the coal seam may become locally thinner.

2. Layout and Observation of the Surface Movement Observation Station

2.1 Layout Scheme of the Observation Station

Profile-line ordinary observation stations were adopted in this survey. Two mutually perpendicular observation lines along the strike and dip directions were laid out along the main section of the movement basin, following the principles of laying out on the main section, making the length exceed the basin range, not being affected by adjacent mining, and adapting the measuring point density to the mining depth.

The dip observation line is 784 m away from the open-off cut and is laid out along the Tunlong highway; the strike observation line is located on the strike main section, with an offset of 12 m towards the downhill direction. The strike survey line has a total length of 2075 m, with 84 working measuring points and 3 control points; the dip survey line has a total length of 1100 m, with 45 working measuring points and 3 control points; the spacing between measuring points is 25 m. The measuring points are precast concrete foundation piles of 200 mm x 200 mm x 1500 mm, buried below the frost line and compacted; a 3 mm steel nail is embedded at the top of the pile as the measuring mark, exposed 150 mm above the ground surface and numbered. The control points are arranged outside the movement basin to ensure the stability of the datum.

2.2 Observation Method and Implementation

Network RTK technology based on the CORS system (Hi-Target H32 equipment) was adopted; the measurement accuracy reaches the centimeter level, which solves the problems of limited line of sight and low efficiency of the traditional total station.The observation station was built in May 2018. The layout of the survey lines and the observation stations is shown in Figs. 1 and 2.Before mining, two initial observations were completed and their average value was taken as the datum; in September 2018, when the working face had advanced 184 m, obvious surface subsidence appeared, and by October 2020 the surface was stable (the cumulative subsidence within six months was less than 30 mm); a total of 21 effective observations were completed. During the observation, information such as the advancing position of the working face, roof caving, surface cracks and geological structures was recorded simultaneously.

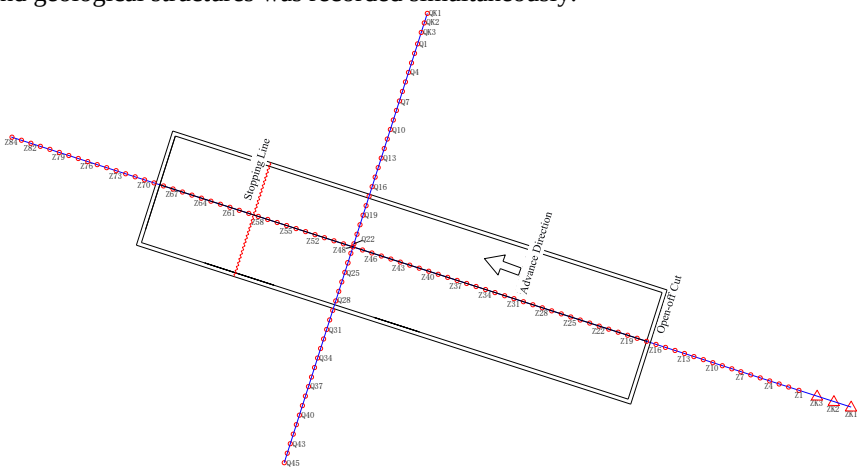


Fig. 1: Layout of the observation lines at working face 1303



(a) Precast concrete foundation pile (b) Buried concrete foundation pile

Fig. 2: Examples of surface movement observation stations

3. Laws and Parameters of Surface Movement and Deformation

3.1 Static Movement and Deformation Characteristics

Surface movement and deformation include five core indexes, namely subsidence, inclination, curvature, horizontal movement and horizontal deformation, which can comprehensively reflect the surface subsidence and deformation characteristics caused by mining. When the working face had advanced 184 m, the surface began to subside, and the strike direction finally reached full mining: the maximum subsidence of the whole working face is 5203 mm (385 m from the open-off cut, exceeding the mining thickness under the influence of local geological structures); the maximum subsidence in the full-mining area is about 3400 mm, and the subsidence curve presents flat-bottom characteristics. The maximum subsidence in the dip direction is 3286 mm (120 m from the boundary of the intake airway); on the uphill side, affected by the superimposed mining of adjacent working face 1302, an abnormal trough appears in the subsidence curve.

In terms of inclination and curvature, the maximum positive and negative inclination values in the strike direction are 21.92 mm/m and −22.72 mm/m, and the maximum positive and negative curvature values are 0.46 mm/m² and −0.519 mm/m², with obvious value fluctuations in the structurally abnormal area. On the downhill side in the dip direction the law is normal, with a maximum positive inclination of 24.6 mm/m; on the uphill side, affected by adjacent mining, the inclination alternates between positive and negative, with a maximum negative inclination of −18.52 mm/m; the maximum negative curvature along the whole dip direction is −0.499 mm/m².

In terms of horizontal movement and deformation, the maximum positive and negative horizontal movements in the strike direction are 0.907 m and −0.221 m, and the maximum positive and negative horizontal deformations are 15 mm/m and −8.5 mm/m; in the dip direction, the maximum positive and negative horizontal movements are 1.167 m and −0.875 m, and the maximum negative horizontal deformation is −16.46 mm/m; the deformation fluctuates significantly in the area affected by adjacent mining.

3.2 Angular and Dynamic Parameters

The complete set of surface movement angular parameters was obtained by measurement: the boundary angles are 64.32 degrees in the strike direction, 62.67 degrees downhill and 50.02 degrees uphill; the movement angles are 70.73 degrees, 66.77 degrees and 54.65 degrees respectively; the fissure angles are 80.1 degrees, 81.3 degrees and 68.37 degrees respectively; the maximum subsidence angle is 88.03 degrees, and the full mining angle in the strike direction is 72.74 degrees. The parameters on the uphill side are generally smaller, which is caused by the superimposed influence of the mining of working face 1302.

In terms of dynamic parameters, the starting distance of the working face is 184 m (about 0.35 times the average mining depth), the advance influence distance is 115 m and the advance influence angle is 77.41 degrees; the subsidence velocity in the full-mining area shows a single-peak distribution, with a maximum subsidence velocity of 58 mm/d, a lag distance of 305 m and a lag angle of 59.3 degrees. The total duration of surface movement is 789 days, including an active period of 474 days and a recession period of 315 days; the measured value is shorter than the result calculated by the empirical formula, and the empirical formula for the movement duration of this mining area was revised accordingly.

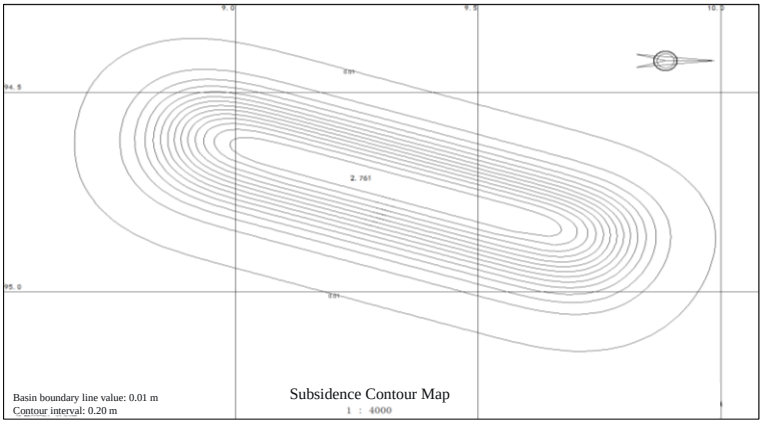
4. Study on Prediction Parameters of Surface Movement and Deformation

The probability integral method was adopted as the surface subsidence prediction method. Based on the random medium theory, this method is the mainstream technical means for mining subsidence prediction in China. In this study the curve fitting method was used to obtain the prediction parameters; based on the least squares principle, the lsqcurvefit nonlinear fitting function of MATLAB software was used to carry out a joint inversion combined with the measured data of subsidence and horizontal movement.

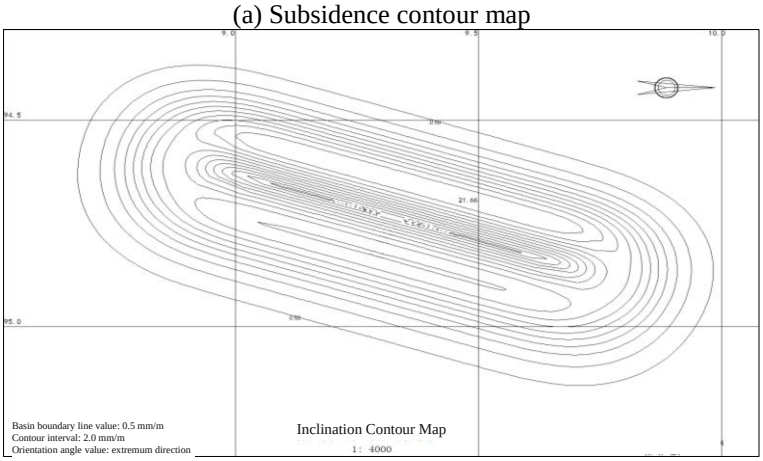
The prediction parameters of the probability integral method for working face 1303 obtained by fitting are as follows: the subsidence coefficient q = 0.72 and the horizontal movement coefficient b = 0.27; the tangent of the main influence angle is 3.5 downhill, 2.75 uphill and 2.75 in the strike direction; the inflection point offset is 45 m downhill, 60 m uphill, 85 m on the left side and 25 m on the right side; the mining influence propagation angle is 88.6 degrees. The parameter values generally conform to the empirical range under medium-hard overburden conditions and show good consistency with the measured parameters of adjacent mining areas.

The parameters were substituted into a professional surface subsidence prediction system to generate contours of various deformations of the stabilized movement basin. The results show that the subsidence contours are approximately elliptical, with the maximum subsidence at the centre decreasing towards the edge; the inclination and horizontal movement contours each form two groups of ellipses whose long axes are perpendicular to the corresponding direction; the curvature and horizontal deformation contours each form four groups of ellipses; the overall distribution law conforms to the general characteristics of subsidence in large

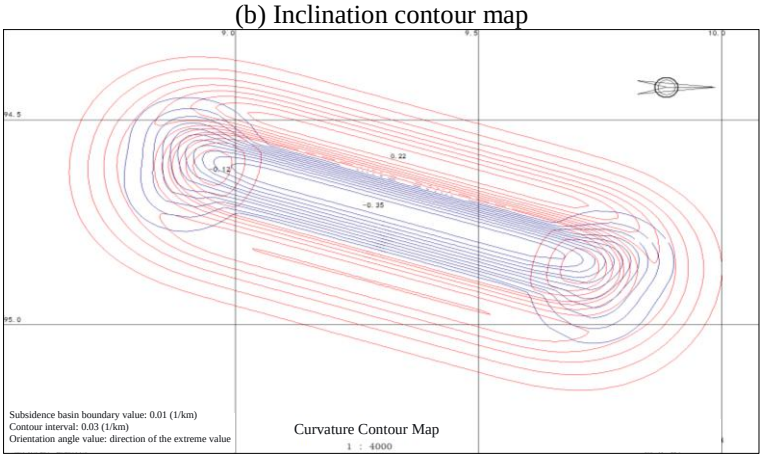
mining height working faces. The distribution law of the contours after the surface deformation is stabilized is shown in Fig. 3.



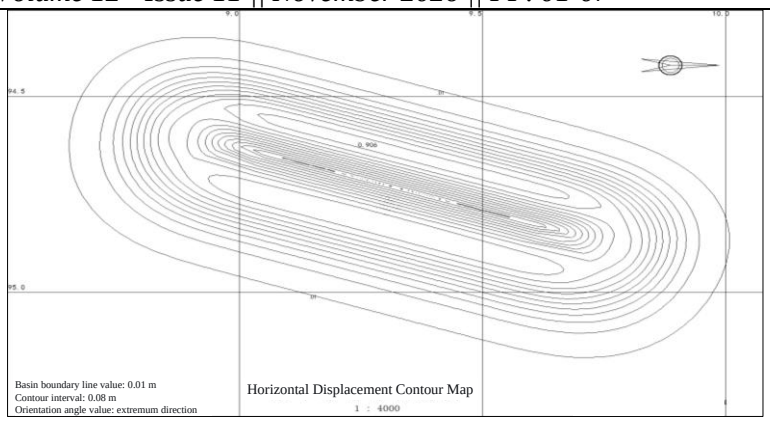
(a) Subsidence contour map



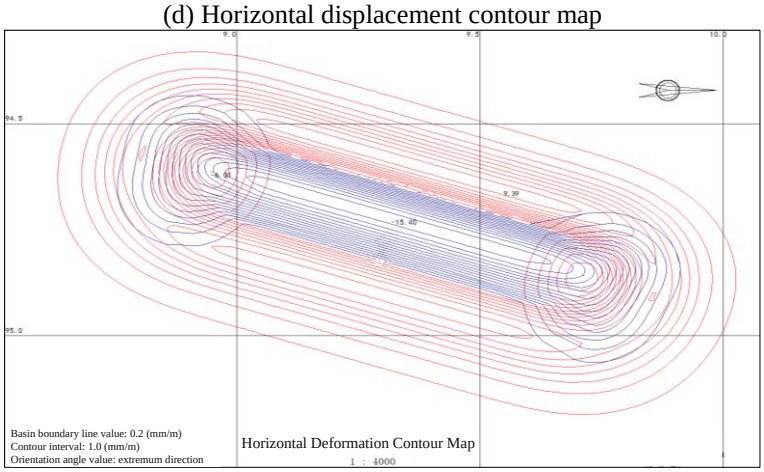
(b) Inclination contour map



(c) Curvature contour map



(d) Horizontal displacement contour map



(e) Horizontal deformation contour map

Fig. 3: Distribution law of the contours after surface deformation stabilization

5. Evaluation of Mining Influence on Surface Buildings

The surface movement and deformation caused by underground mining destroy the initial equilibrium state of buildings and foundations. Through the redistribution of the foundation reaction, additional stress is generated in the building structure, which in turn causes wall cracking, structural inclination, deformation of doors and windows and other damage. Among them, horizontal tensile deformation and curvature deformation cause the most significant damage to masonry structures; the deformation intensity at the edge of the goaf is greater than that in the middle, and the damage is aggravated when the long axis of the building is parallel to or obliquely intersects the advancing direction of the working face.

According to the damage grade standard for masonry structures in the Regulation on Coal Pillar Design and Mining under Buildings, Water Bodies, Railways and Main Roadways, the maximum inclination value of 24.6 mm/m and the maximum horizontal deformation value of −16.46 mm/m within the working face range far exceed the threshold of Grade IV damage. The on-site investigation shows that through cracks, horizontal dislocation, outward bulging of walls and house inclination appear in the walls of surface buildings, and some houses are at risk of collapse; the damage grade is judged as Grade IV (extremely serious damage), requiring demolition and reconstruction.

It is suggested to organize the relocation of residents and buildings within the surface range in advance before the mining of subsequent working faces; if important buildings need to be retained, protective mining technologies such as backfill mining, strip mining and slicing with reduced height can be adopted to control the surface deformation intensity. Fig. 4 shows the damage to the buildings above the working face.



(a) Dislocation cracks in the wall

(b) Through cracks in the wall

(c) Open cracks in the wall

(d) Inclined building

Fig. 4: Damage to the surface buildings

6. Conclusions

(1) Working face 1303 reaches full mining in the strike direction. The measured extreme values of surface movement and deformation are: a maximum subsidence of 5203 mm, a maximum inclination of 24.6 mm/m, a maximum negative curvature of −0.519 mm/m², a maximum horizontal movement of 1.167 m and a maximum negative horizontal deformation of −16.46 mm/m. In local areas, affected by geological structures and the superimposed mining of adjacent working faces, the deformation law is abnormal.

(2) A complete set of angular parameters, including the boundary angle, movement angle, fissure angle, maximum subsidence angle and full mining angle, was obtained; the parameters on the uphill side are smaller under the influence of the mining of working face 1302. Dynamic parameters such as the starting distance, advance influence angle, subsidence velocity and movement duration were also obtained, and the total duration of surface movement is 789 days.

(3) The prediction parameters of the probability integral method were obtained based on MATLAB curve fitting and conform to the characteristics of medium-hard overburden; the distribution law of various deformation contours of the stabilized movement basin was predicted, which can provide a basis for subsidence prediction and coal pillar design of subsequent working faces.

(4) The damage grade of the masonry structures above the working face reaches Grade IV. It is suggested to carry out relocation in advance before the mining of subsequent working faces, or to adopt protective mining technologies to control surface deformation, so as to guarantee the safety of personnel and buildings.

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