Simulation of Stress Induced Deformation and Translation of Mining Fields using Similar Material Model

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Abstract — **Awaiting revised text**.

Keywords* — *Overlying strata; Failure morphology; Migration law; Model test; Spatiotemporal coupling

I. INTRODUCTION

Stope (step-like working in a mine) wall rock activity was the root of mining pressure formation, and the mine pressure appearance was embodiment of stope wall rock activity [1]. Due to the differences of the overlying rock strata structure, structural properties, strength thickness, joint production and horizon relationship, roof activity showed a wide variety of movement forms, roof structure properties determined the characteristics of overlying strata movement and make a key factor in the concept of roof control and decision-making[2]. Mining scholars has made large many researches on broken mechanism of stope covered rock and surrounding rock deformation features. Liu Shu-xian and Wei Xiao-gang[3-4] studied on the mechanism of rock movements evolved to disaster and stope covered rock mechanical evolution effect affected by deep mining disturbance, established the rock beam system mechanical model of hard thick coal roof, and concluded stress evolution features and the deformation damage law of covered rock spatial structure; Zhang Jun and Wang Jian-peng [5] based on stope covered rock broken forms and developing features of mining moving fractures, made test research and measured certification on face roof "Three Zones" distribution features and the development trends; Xiao Peng and Li Shu-gang[6] focused on evolution form and distribution law of covered rock mining moving fractures with solid gas coupled of experiment system; Wang Xin-feng and Gao Ming-zhong [7] analyzed the fracture features, rock movement law and pressure features of the mid-thick seam stope roof systematically with numerical simulation.

In order to fully understand the spatial fragmentation formation, overlying strata movement law and mining pressure characteristics of stope roof, real-time observation and qualitative analysis of roof broken, fracture development, rock movement distortion and the whole time of stress evolution must be taken which based on the analysis of roof structure and characteristics of surrounding rock. Using similar material simulation test, setting the geological prototype of 16128 face in Zhang Ji coal mine for the background, making further probe into the temporal and spatial evolution of the mining overburden rock fracture field, roof fractured field, strata displacement field and surrounding rocks stress field which disturbed by excavation, established the firm theoretical basis for surrounding rock controlling mechanism research.

II. TEST OBJECT AND GEOLOGY OVERVIEW

This test with 16128 face in ZhangJi mine studies, research work carried out in the face of specific geological conditions. 16128 face is located in the western third district, east from the F27 fault, west to fault Fs715, unmined coal 8 entities on the South side, and 16118 face of local mining in the North. 600m in buried depth of coal face, from 691m to 755m in strike length, 240m in dip length, industrial reserves 700,800t, recoverable reserves 665,800 t. Face mined with 8 coal seams, coal thickness from 0.6m to 5.4m, 2.9m in aver-age thickness, small seam dip angle, was flat seam. Roof in working face was thin-bedded fine-grained siltstone, average thickness 3.6m, immediate roof with the sandy mudstone and carbonaceous mudstone block structure, average thickness 7.0m, immediate floor with gray thick-massive Sandy mudstone, average thickness 1.1m. Face with complex hydrogeological conditions, the major water sources for 8 coal seam were roof sandstone fissure water, faults water, 16118 goaf ponding of water and drilling water during mining.

III. SIMILAR MODEL TEST

A. *Model Design*

Similar model tested on a two-dimensional plane model frame, following the geometric proportion 1:100. Model designed sizes is to 3m×0.3m×1.3m (length × width × height), equivalent to simulate 130m rock structure. In accordance with the principle of similarity and requirements of the dimensional analysis, converted the similar constants and site conditions (roof and floor rock lithology, thickness and strength) to the basis of specific parameters in the model, determined the density ratio for 1:1.8, stress similarity ratio for 1:180, time scale for 1:10. Chosen sand as aggregate, with lime and gypsum as cement, in order to obtain similar material ratio parameters, selected large blocks of rock mechanical testing specifically, and after repeated adjustments, eventually obtained the optimum ratio table of similar materials in each layer (see table 1). According to the best ingredient ratio table, determined the proportion, dimensions, layer thickness and quantity, made model test, spreading mica powder among the various layers to facilitate observation during the testing making process.

TABLE 1. THE CONTRAST TABLE OF SITE CONDITIONS AND SIMULATION PARAMETERS

Prototype parameters				Model parameters		
Granite	Thickness (m)	Compressive strength(Mpa)	Bulk density (kg/m^3)	Thickness (cm)	Materials proportioning	Water utiliza-tion ratio
siltstone-2	10.5	160.26	3180	10.5	5:0.6:0.4	1/10
mudstone-4	14.8	62.80	2610	14.8	7:0.7:0.3	1/10
coal Streak-2	0.7	8.35	1350	0.7	10:0.5:0.5	1/10
carbonaceous mudstone-2	2.5	26.33	2550	2.5	7:0.7:0.3	1/10
siltstone-1	4.3	152.62	3220	4.3	5:0.6:0.4	1/10
mudstone-3	13.2	70.38	2710	13.2	7:0.7:0.3	1/10
medium Sand	8.7	180.25	3420	8.7	5:0.6:0.4	1/10
sandy mudstone-8	3.8	33.55	2570	3.8	8:0.7:0.3	1/10
middle-fine sandstone -2	12.1	140.38	2980	12.1	6:0.6:0.4	1/10
9-2 coal	0.3	8.32	1335	0.3	10:0.5:0.5	1/10
sandy mudstone-7	3.5	35.72	2580	3.5	8:0.7:0.3	1/10
9-1 coal	0.8	8.25	1340	0.8	10:0.5:0.5	1/10
sandy mudstone-6	10.8	38.90	2610	10.8	8:0.7:0.3	1/10
middle-fine sandstone -1	3.6	135.46	3070	3.6	6:0.6:0.4	1/10
carbonaceous mudstone-1	0.2	23.25	2530	0.2	7:0.7:0.3	1/10
sandy mudstone-5	6.7	35.60	2830	6.7	8:0.7:0.3	1/10
8 coal	2.9	8.43	1330	2.9	10:0.5:0.5	1/10
sandy mudstone-4	1.1	29.83	2580	1.1	8:0.7:0.3	1/10
coal streak -1	0.2	8.22	1335	0.2	10:0.5:0.5	1/10
mudstone 2	3.4	62.78	2660	3.4	7:0.7:0.3	1/10
7-2 coal	0.9	8.22	1330	0.9	10:0.5:0.5	1/10
sandy mudstone-3	1.0	33.70	2560	1.0	8:0.7:0.3	1/10
siltstone	0.6	138.52	2780	0.6	6:0.6:0.4	1/10
Sandy mudstone-2	4.5	32.30	2550	4.5	8:0.7:0.3	1/10
7-1 coal	1.2	8.35	1340	1.2	10:0.5:0.5	1/10
sandy mudstone-1	6.0	33.85	2580	6.0	8:0.7:0.3	1/10
mudstone -1	12	65.72	2650	12	7:0.7:0.3	1/10

According to the optimum ratio of face rock making ingredients, floor laying. Considered the climatic characteristics and climate factors, model piled up in a week or so, sun dried then added the sides restraint. Loading the surrounding rock with iron counterweight, vertical loading three times separately with an interval of 8 hours or so.

During counterweight loading process, observed the structural changes in the model of rock to avoid overloaded that model instability, loading slowly, loading uniformly. Recording strata displacement as critical variables to facilitate comparative analysis before mining. Face plane model is shown in Figure 1.

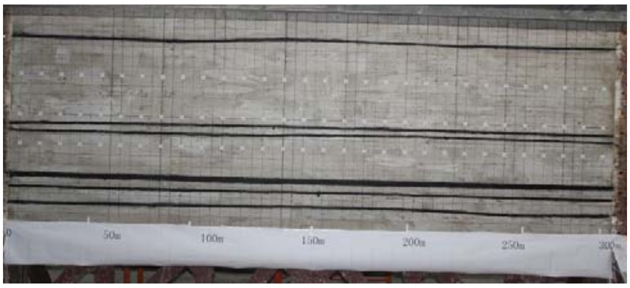


Fig. (1). Two-Dimensional Plane Model Of Working face

B. Test Equipment and Methods

1) Stress Monitoring And Measuring Point

The test adopted CM-2B-64 instrument of static strain testing system for stress monitoring, supporting the use of strain sensor BX120-50AA strain gauge, used for observation the stress variation of coal and rock, using 7v14 data acquisition system for data acquisition system, the system consisted of data acquisition equipment, data communication equipment, computers and data analysis software package, and could directly convert sensor data into a computer, and dynamic data acquisition and analysis. Stress data collection and analysis system, as shown in Figure 2.

The test face took 8 coal seam as mainly mining layer, so the model focused on the process of mining coal 8 breaking a comprehensive observation of over-lying strata. Laid pressure sensors in lower 8 coal roof of sandy mudstone-6 and middle part of sandy mud-stone-8 respectively while laying model, totally laid 2 layers, excavated the model from right to left that simulated face retreating mining mode. Layout the first pressure sensor began from model right 30cm away of each layer (that is open-off cut location), buried into pressure sensor successively by interval 40cm, laid pressure sensors from open-off cut 0cm, 40cm, 80cm, 120cm, 160cm, 200cm, 240cm away positions respectively, laid seven pressure sensors each layer, totally laid 14 pressure sensors, and numbered pressure sensors, ordered numbers from 1# to 14#. Took the observation as the benchmark before and after model load once and took the observation before and after excavation once, noted strain by resistance strain gauge, then calculated the stresses by a calibration curve, compared stresses change during the mining, then concluded the relevant law of the field.

(a) BX120－50AA Resistance Strain Gage

(b) CM-2B-64 Static Strain Meter

Fig. (2). The Stress Collection And Analysis System

2) Displacement Measuring Line Arrangement

Laid out displacement measured points by cross point method on the model surface, using electronic theodolite for measuring points observation. Laid out 1th, and 2nd, and 3rd observation line respectively above from 8 coal seam 15cm, middle part of sandy mudstone-6, and from seam 30cm, bottom of the fine sandstone-2 and from seam 50cm, upper of the sand-stone, each measuring line laid out 30 measuring points, measuring points by 10cm interval, three observation line amounted to 90 measuring points. Excavated the model from right to left in sequence, reserved 30cm mining line on the right side of the model and reserved 30cm stop line on the left, excavated 240cm actually, laid out measuring points from right to left. For facilitate statistical analysis, set observed once every 20cm face advanced. Layout model of face stress measuring points and measuring lines was shown in Figure 3.

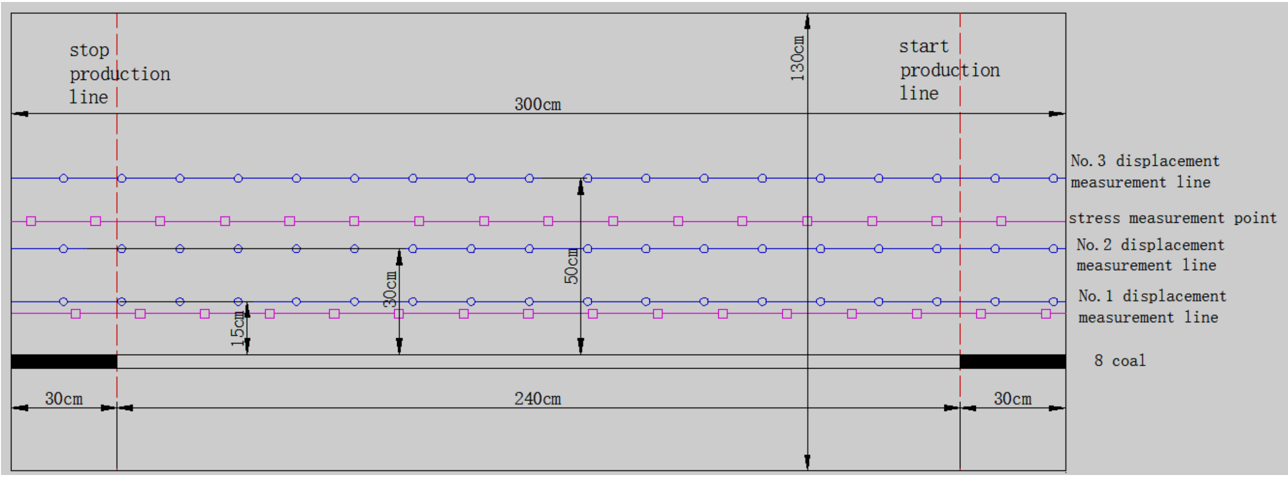


Fig. (3). The layout model of stress measurement points and displacement measurement line

C. Test Mining Plan

Reserved 30cm of protective coal pillar on each side of the model to eliminate border effects. Simulated mining 240cm of model face, equivalent to actual mining 240m. Open the front and back baffles before mining so that the entire model in a state of no lateral force and avoiding the effect of support plates on overburden activities. Excavated the model from right to left, retreating mining, all caving roof management. Mining once every two hours, advancing 5cm once, divided into 48 times, took 96 hours completing the test totally.

IV. Analysis Of Experiment Result

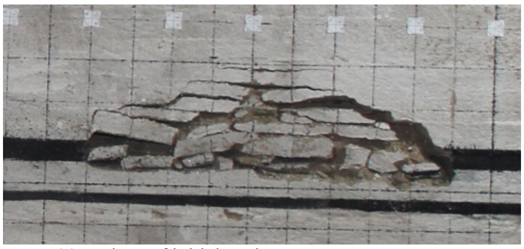
Successive observation and tracking the roof dam-age morphology, fracture development status, characteristics of overlying strata movement and evolution law of the displacement field and stress field of the face during the advancing, obtained the overlying strata break regularity and the essential features of rock movement and strain.

A. Roof Damage Morphology

Immediate roof collapsed firstly after coal mining. The immediate roof began collapse when face advanced to the location 30m front of the wall, collapsing height 1.2m. Main roof overhang area increased with the face progressing until up to the limited span, broken to three-hinged arch balance and broken rock blocks slide and failure, bench convergences appeared in roof [7-8].

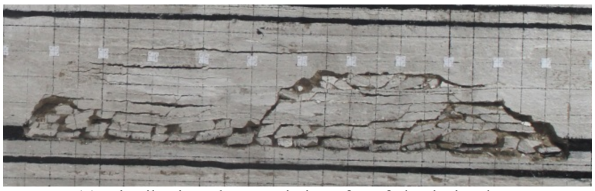
The main roof fractured and collapsed first time when advancing 45m, working face roof cantilevered after collapsing and sidestep-shaped collapse appeared behind the working face (as shown in Fig.4(a)). After the initial fracture of main roof, as the face continued to move forward, advancing to 58m away from the open-off cut, main roof fractured secondly, with caving step length of roof 13m. Rock block formed hinged rock beam away from the seam roof 8~10m after the fracture, and sidestep-shaped collapse appeared behind the working face away from the face 8~10m, as shown in Fig. 4(b) below. Deformation and failure of surrounding rock kept upward and forward dynamic developing during face advancing, and periodic ruptured and collapsed.

When face advanced to the position 110m away from the open-off cut, mining-induced fractures derived above the roof, cracks increased significantly, when face advance to 120m away from the open-off cut, the roof abscission layer appeared above the coal seam roof, a trend of separation presented between the rock layers, as shown in Fig.4(c) as shown. Abscission height increased as the face advancing, then sink volume decreased and stabilized due to the key stratum's impact on the roof above the abscission, as shown in Fig.4 (d).

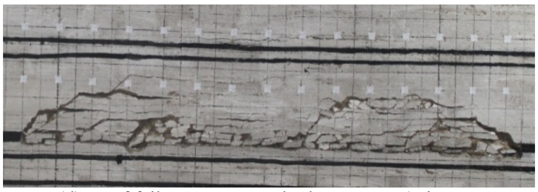


(a) Main roof initial caving pattern

(b) Main roof secondary caving pattern



(c) Distribution characteristics of roof abscission layer



(d) Roof failure pattern under key stratum's impact

Fig. (4). Morphological Evolution Of Roof Damage Space

Determining the average interval of periodical weighting was 10.5m by observation and record breaking status of the overburden rock during periodical weighting in working face, specific pressure value as shown in Table 2. As shown in the table, weighting value had a certain range of fluctuation, reflecting the instability of the roof. Roof pressured more intense in the early time, bigger of weighting distance. Then weighting value tended to moderate, entering a period of stability, overburden moved steady, obtained better effect of surrounding rock control. Observation of overburden failure reflected that rocks in falling zone rock crushed, laminated fracture characteristics of the strata appeared in fractured zone.

TABLE 2. THE STATISTICAL TABLE OF PRESSURE STEP

Main roof initial fractured (m)	**İnitial weighting interval(m)**	**Second weighting interval(m)**	**Third weighting interval(m)**	**Forth weighting interval(m)**	**Fifth weighting interval(m)**
45	13	11.5	8.5	9.5	10
Average interval of weighting(m)			10.5		

B. *Fracture Development Status*

Abutment pressures of stope overlying strata decreased slowly under the influence of unloading of coal seam mining in the process of coal mining, diverted the stress of the surrounding rock deep into the coal seam, roof moved and deformed, then produced a number of fissures, including interlayer broken cracks and abscission layer crack.

The test reflected that generation and development of fissures certainly related to the movement of overburden. The procedure of overburden that moved, deformed, failure till collapsed was a gradient and continuous process, and overburden fractures went with the whole dynamic process, moved forward in a progressive manner. Fig.5 depicted the development of overburden fractures, directly reflecting the range and trend of the fissures extending. Early in the face advancing, immediately roof collapsed, generated the fractures of covered rock, then main roof occurred initial fracture, with abscission and fractures derivative development, and upward and forward dynamic developed constantly. The main roof occurred periodical broken subsequently, fractured rock block compacted the abscission layer lower of goaf, limited the fractures' further development into the middle of the goaf, left some inter-formational fracture structure in the upper of fractured zone. Comprehensively, roof fractured zone experienced the dynamic evolution process of unloading pressure and lost stability, crack expanding, shrinkage, fractures anastomosis and crack closed [9], and the spatial configuration of face mining fracture during advancing presented two big features: the wave shaped fractures of the overburden rock evolved forward fast in level direction and ladder shape extended upward in vertical direction.

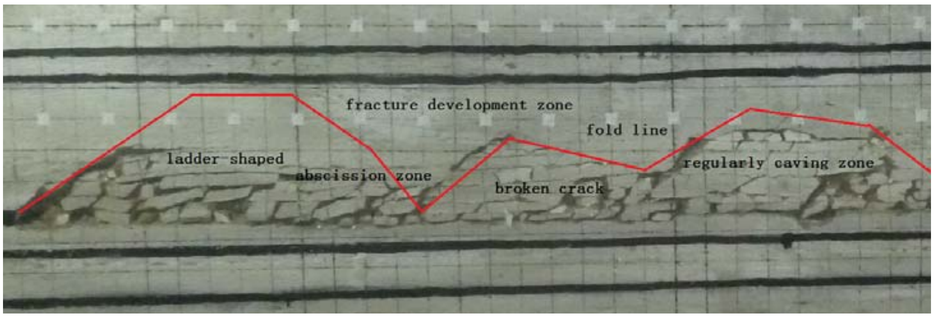
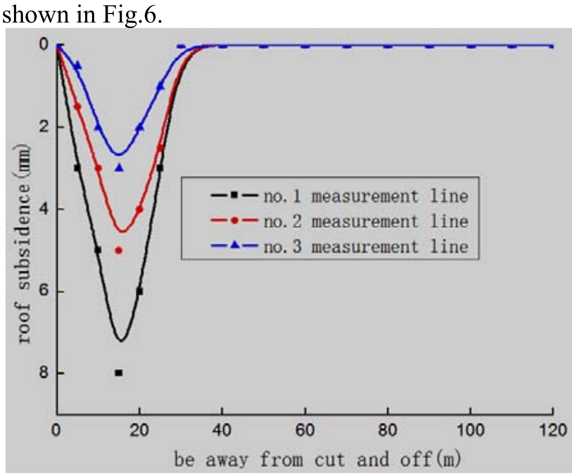


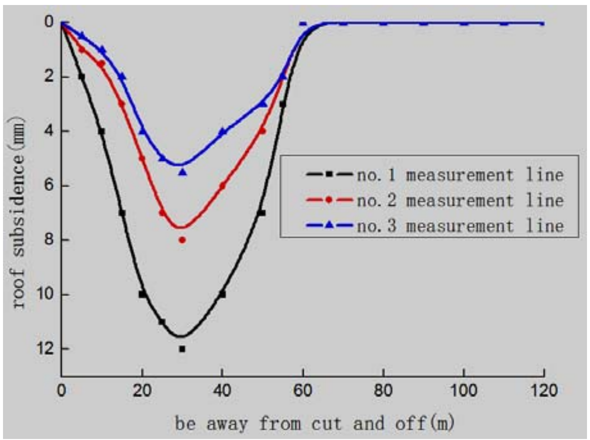
Fig. (5). Development Status Of Overburden Rock Fracture

C. *Overburden Movement Law*

Coal mining activity caused deformation, failure and movement of overburden. According the continue features and law of overburden movement, the strata collapse has caused vertical displacement and lateral displacement of the strata during coal mining, then caused the roof subside, the displacement curve reflected the specific displacement situations face of roof displacement directly during mining, as shown in Fig.6.

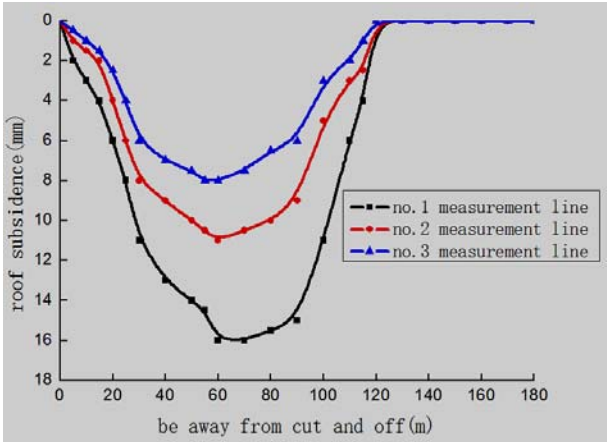


a. Face advancing 30m

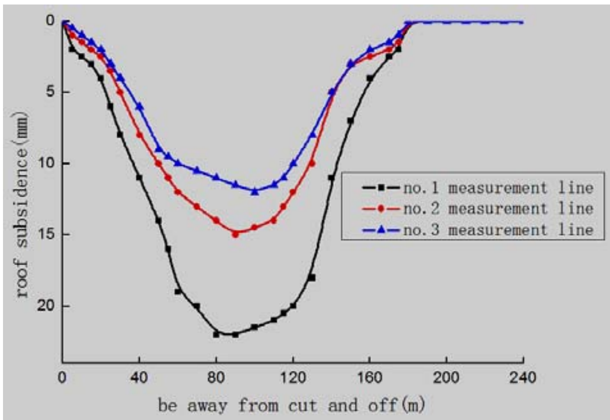


b. Face advancing 60m

Fig. (6), a and b: The Displacement Line Under Different Speed Curve

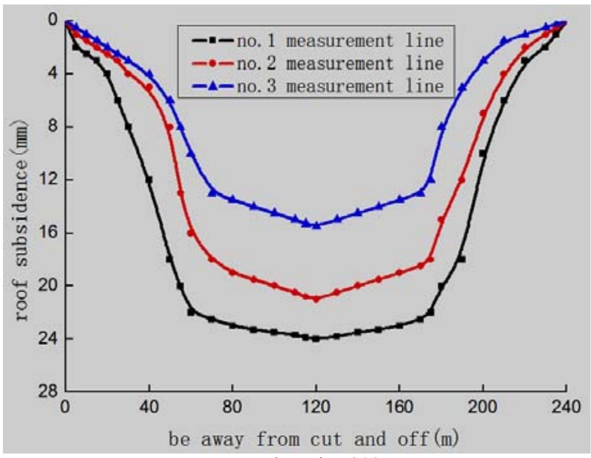


c. Face advancing 120m



d. Face advancing 160m

Fig. (6), c and d: The Displacement Line Under Different Speed Curve



e. Face advancing 200m

Fig. (6), e: The Displacement Line Under Different Speed Curve

As shown in Fig.6, rock sank presented a non-linear status bottom up, and strata movement trajectory was asymmetric. Early in the advancing, roof sank smaller, exploitation affected strata movement gently, displacement variated smoothly, displacement curve showed the sharp bottom trough trend, as shown in Fig.6(a) and (b). With face advancing, rock moved actively, damage features of covered fractured zone and fissured zone gradually appeared, roof sinking volume increased gradually, space configuration of the roof sinking curve presented bowl-like (as Fig.6(c)), then deep chassis-like (as Fig.6(d)). Development status of "Two-Zone" affected by weakening effect of vertical stress transmission mechanism with face advancing, rock activities tended to stable, then roof displacement sinking curve turned to flat chassis-like (as Fig.6(e)).

Subsidence of overlying strata was a continuous and progressive dynamic process during the whole mining phase, the further overburden distanced from the overlying coal seams, the weaker displacement measuring affected, the less roof sunk, the more continued of strata movement, the closer between overburden movement curves and features and distribution characteristics of the surface points. But the closer stope roof from seam, the stronger the effects of displacement measuring lines, the larger roof sink volume, the worse the continuity of the movement, displacement jumped strongly, the more irregular of roof subsidence curves.

D. Evolution Characteristics Of Stress

The weight of overlying strata mainly hold up by front and back pillars and fell rock after coal seam mining, the half-arch structure of surrounding rock formed abutment pressure, and divided into stress increased district, stress reduction district and pressure regulator zone within a certain range. As research shown, stope surrounding rock stress of distribution features closely related to rock movement, covered rock strain caused by abutment pressure affected the cutting movement and wall stability of the roadway significantly, and was potential factors of rock burst inducing, gas emission, roof fall and wall collapse, bracket sliding and water outburst accidents, so discussion of stope abutment pressure distribution law was important research con-tent of mine pressure control [10]. Experimental studies discovered the characteristics of surrounding rock stress intuitively and revealed the failure mechanism of over-lying strata.

Seam excavation activities brought about roof vertical stress redistribution and development evolution, model test recorded the variation of stope roof abutment pressure through layout the pressure sensor in rock layer during seam mining, recorded the stress value of advancing 30m, advancing 60m, advancing 90m, advancing 120m, advancing 160m and advancing 200m respectively, organized and analyzed the collected data then drawn the stress curve as shown in Fig.7.

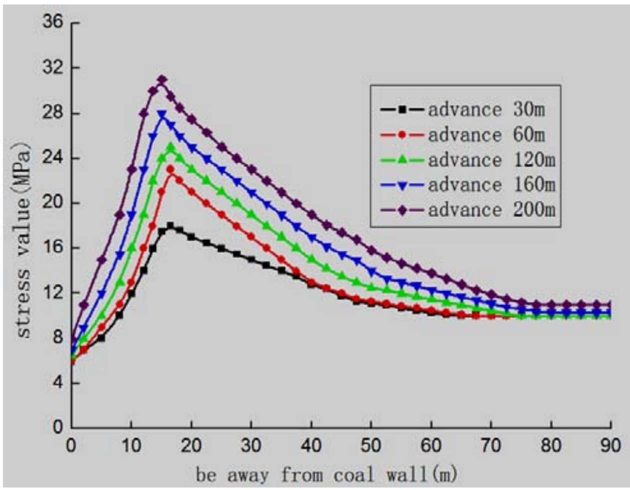


Fig. (7). Abutment Pressure Distribution VS Working Face Positions

Analyzed from the perspective of evolution of mechanical behavior, the essence of seam mining activities was also the process of surrounding rock stress produced randomly, changed incrementally, adjusted timely, evolved dynamically and developed continually, the front abutment pressure distribution configuration greatly influenced by mining progress. Face advanced from open-off cut to the 200m away, the coal-body front abutment pressure experienced the evolution process of initial formation, medium-term development, subsequent stability, stress distributions with significant timeliness and spatiality, spatial-temporal coupling characterized apparently. For stress change curves under the same advance, from the near to the distant of coal wall, the front abutment pressure peak evolution tendency tended to rapidly increased nearby then slow decreased remote evolution. In range front of coal wall 0~20m, stress increased rapidly, larger increase, achieved the peak soon, the position of peak 16~18m away from coal wall; then in the distance of 20~70m stress decreased gradually, gently declined, stress distribution characterized continually; stress variated stably when distance between roof and wall more than 70m, the stress becomes stable, overlying strata movement and rock failure presented periodical characteristics.

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V. CONCLUSIONS

1) Test received the roof damage spatial evolution patterns, determined the main roof weighting interval for 10.5m, periodic pressure value has a certain fluctuated range which reflecting the instability of the roof loading. During the mining, deformation and failure of the roof developed upward and forward continually and dynamically, and fractured and collapsed cyclical, with the spatiotemporal characteristics of instantaneous destruction, segmental extend and partition mobility.

2) Study showed that overburden fissures experienced the dynamic evolution process of unloading pressure and lost stability, crack expanding, shrinkage, fractures anastomosis and crack closed, and the wave shaped fractures of the overburden rock evolved for-ward fast in level direction and ladder shape extended upward in vertical direction.

3) Studies showed that subsidence of overlying strata was a continuous and progressive dynamic process during the whole mining phase, rock sank presented a nonlinear status bottom up, and strata movement trajectory was asymmetric. The further overburden distanced from the overlying coal seams, the weaker displacement measuring affected, the less roof sunk, the more continued of strata movement, the closer between overburden movement curves and features and distribution characteristics of the surface points. But the closer stope roof from seam, the stronger the effects of displacement measuring lines, the larger roof sink volume, the worse the continuity of the movement, displacement jumped strongly, the more irregular of roof subsidence curves.

4) Test recovered the spatiotemporal evolution characteristics of stress field, revealing the failure mechanism of overlying strata. The coal-body front abutment pressure experienced the evolution process of initial formation, medium-term development, subsequent stability, stress distributions with significant timeliness and spatiality, spatial-temporal coupling characterized apparently during face advancing.

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