The Dynamic Simulation Research of Overburden Strata Failure Characteristics and Stress Dependence of Metal Mine

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***Abstract*—In order to seek for the relationship of dynamic failure characteristics and dynamic stress, the mining model according to the extremely complex characteristics of metal mine geology is built in this paper; the relationship between dynamic failure characteristics and dynamic stress under the condition of mining disturbance of metal mine overlying rock mass is also discussed in the view of micro-macroscopic points. Firstly ,according to the relationship between different processes of overlying rock damage evolution and stress (tensile stress, shearing stress and compressive stress), overburden rock dynamic damage and different stress were linked with each other to analyze the mechanics mechanism of different damage characteristics of overburden rock that caused by different stress. Secondly, from the different damage characteristics that shearing stress, tensile stress and compressive stress made on overburden strata, the internal stress distribution of overburden rock was separated into four areas: tensile-tensile stress area, tensile-compressive stress area, the compressive-compressive stress area and the shearing-compressive stress area. Finally, the horizontal stress and vertical stress of goaf strata were discussed in one section and it turned out that horizontal stress and vertical stress changed with mining work process, and the reasons were also analyzed. Meanwhile, stress concentration curve attachment is a vaulted curve on different goaf horizontal level under different working size. Centrostigma of vertical stress and shearing stress is also an arch curve, they format a compressive balance arch.**

Keywords-Metal mine; overburden strata; mining failure feature;stress;dynamic research

I. INTRODUCTION

Material damage is closely related to it's external stress environment, i.e., when the external load exceeds the critical load that the material can bear, material itself would be destroyed. Rock material is a kind of brittle materials. A large number of goaves that were left after mining and mine dynamic mining process bring dynamic change to the surrounding rock stress environment. Dynamic stress can lead to strata movement, which brings various disasters like mine rock burst, pressure bump, rock caving and surface subsidence[1-4]. Therefore, taking good command of the internal law of overburden rock strata activities is of practical significance to the stability evaluation and effective control measures of goaf. Domestic and foreign scholars have done mature theoretical researches on the failure mechanism and movement rules of coal rock strata[5-6], and have successfully applied those theories in many mines, but the research on dynamic damage of metal mine overburden strata has remained elusive[7-8]. Since metal mine contains large amount of fractured blocky rock mass, it has no continuity and irregularity, meanwhile, there are obvious differences of stratal configuration, orebody shape, occurrence conditions and mining methods between coal mine and metal mine, and most of the collapse turn out to be tubular, tubular or funnel, as a result, it is hard to predict metal mine overburden strata objectively and difficult to handle it. Things above posed great challenge on managing the movement of metal mine overburden strata[9-10]. Therefore, doing research on stress varying pattern in process of the mining strata and the mining strata failure characteristics can provide important information for the prevention of local power disaster and the reasonable arrangement of roadways and shorings. The damage characteristics of metal mining overburden strata material in depth under different dynamic stresses are discussed and analyzed from the view that stress environment of rock material varies with dynamic mining process.

II. MECHANICS MODEL AND PARAMENTER SETTING

Using RFPA calculation software[11-12], taking some gold mine in China as research background, this paper discussed the relationship between stresses and overburden strata dynamic failure features, as well as processes under the condition of dynamic changes and extension of goaf in the dynamic mining of overburden strata. The 90 meters long ore body, with an average thickness of 5 meters and a nearly horizontal dip angle, was buried 500 meters underground. The silty clay on the layer surface contains gravels, the roof rock of the ore contains sandstone and shale, siltstone and mudstone are also included, and a little fracture zone appears in overburden strata; the floor strata was composed of sandstone and shale. Plane strain model is adopted in this paper, which is 150 meters along both horizontal and vertical directions. The ore body is 5 meters thick, 35 meters above from the lower boundary, and 30 meters from both the left and right borders. Through studying and analyzing tectonic stress of adjacent mines, combined with the geological features of the ore, it was calculated that tectonic stress should be 2 MPa. While in the vertical direction, on the one hand, the gravity stress should be taken into consideration, on the other hand, the model cannot reach the surface due to its size limits, so it was calculated that 7MPa stress should be applied in the vertical direction (Table 1). In order to reflect the complexity and irregularity of metal mine geological storage conditions authentically, random values were given to overburden strata unit, where elastic modulus took the average value, other physical parameters were set according to the mechanical property of rock. The method of excavating 10 meters each step was used to study the actual mining process. But since the mine used open mining method, the strut effect is insufficient due to the design strength, construction technology and other factors, which will result in the shifting or even collapsing of overburden strata. In order to sufficiently discuss the dynamic failure characteristics of goaf strata in metal mining, the goaf would not take any support or filling measures.

TABLE I. BOUNDARY CONDITION AND SIMULATION MINING PARAMETERS CONTROLS

Loading conditions	**Horizontal direction pressures**	**Tectonic stress (*MPa*)**	2	**Loading mode**	Plane strain
	Vertical direction pressures	**Overburden gravity(*MPa*)**	7	**Strength criterion.**	Mohr-Coulomb criterion
Mining simulation	**upper boundary(*m*)**	110	**Orebody thickness(*m*)**	5	
	Each mining step length(*m*)	10	**Total mining step(step)**	9	

III. DISCUSSION AND ANALYSIS

Overburden strata destruction is mainly related to the stress it subjected to, and different stresses (shear stress, tensile stress and compressive stress) exert in different failure regions with different failure modes. In this part, the failure and damage mechanisms and regular patterns of overburden strata under various stresses were studied. Due to the close relationship between destruction of rock material and tensile stress or shear stress, the conditions of strata damage were discussed and analyzed as a focus.

A. *Discussion of overburden strata failure process and stress*

According to the different strata failure processes, the relationship between stress and the strata can be divided into the following stages:

- Microscopic crack embryonic stage of overburden strata

To analyze this question concisely, some representative stresses and the failure and damage conditions of overburden strata under the stress were studied. Before the working face is 40m away, overburden strata almost had no damage. Fig.1-a showed that shearing strength gathered as a circle around the goaf and very few rock material got microscopic crack in this high stress region. In tensile stress area of Fig.1-b (negative meant tensile stress and positive meant compressive stress), tensile stress mainly gathered above and below goaf roof strata, presenting like a “butterfly”, what’s more, the area of upper tensile stress and it’s stress value were both higher than underpart due to the influence of upper goaf’s gravity stress. As everyone knows, tensile stress is the most important factor which leads to the damage of overburden strata, as a result, tensile failure first happened in the middle of strata roof above the goaf. It can be also seen from the stress value that at this time, maximum shear stress is 6.73MPa, which was almost equal to the maximum tensile stress, 6.78MPa, but tensile stress caused more serious damage. At this time, overburden strata area began to transform from the elastic area to the plastic one.

- Partial crack-bud stage of overburden strata

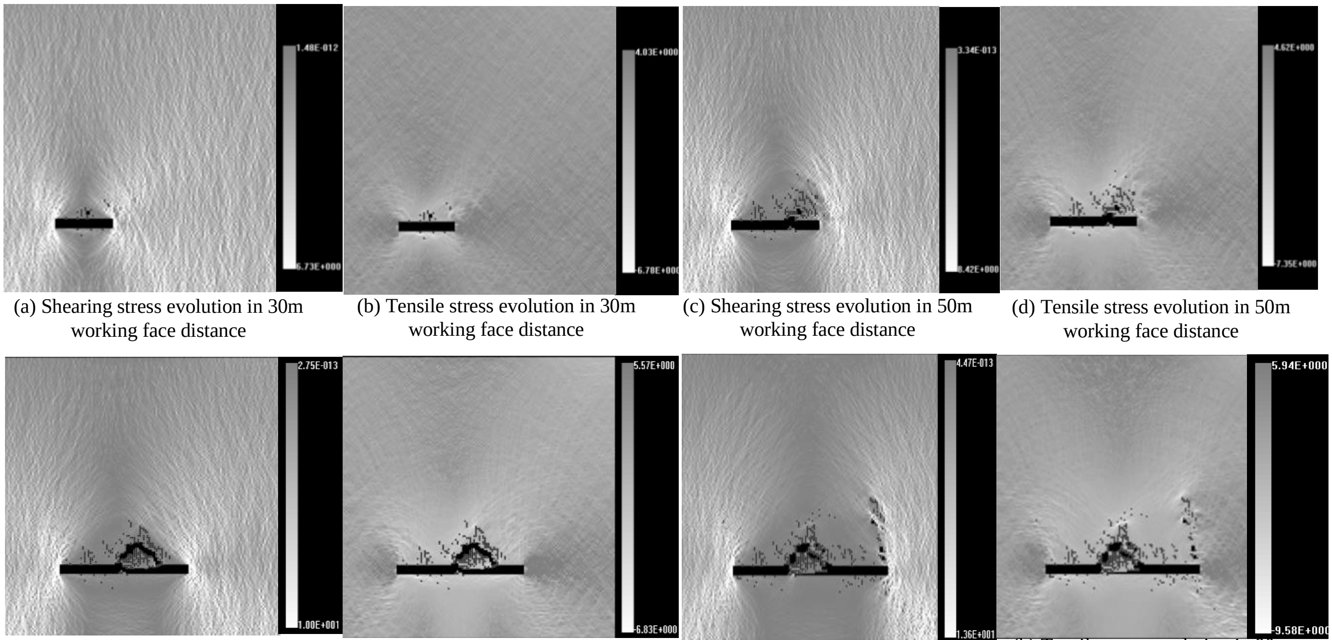
As the working face advanced to 50m, shearing stress was centered on the corners of goaf strata as an oval, with increased value and enlarged area (Fig.1-c). Larger stress value appeared mainly at the two ends of the short shafts of the oval. At this time some fracture also happened in rock material molecular under shearing stress, with an increased plastic range. Fig.1-d showed that the “butterfly” shape became bigger in tensile stress area. Under the tensile stress, part caving appeared on the goaf roof appeared. Obvious tendency of rock material rupture and cutthrough happened above the caving zone, although the maximum shearing stress 8.42MPa is bigger than the maximum tensile stress 7.35 MPa, the tensile stress has caused partial sporadic caving of the overburden strata. Then, the caving zone was going to be formed.

- Caving starting stage of overburden strata

When the working face advanced to 70m, overburden strata caving zone came into being. At this time, the maximum shearing stress reached 10.2 MPa, and shearing stress area kept on expanding, with larger stress areas distributed at the two ends of long shafts of the oval (Fig.1-e). Tensile stress area kept on increasing, but the maximum tensile stress was 6.66 MPa (Fig.1-f), smaller than that in 50m, the main reasons are: widespread caving damage happened to overburden strata, the tensile strength was reduced and the energy was released. After the caving zone generated, the gravitational stress and tectonic stress of overburden strata kept applying external forces on surrounding rock of undamaged zone, which lead to the expansion of surrounding rock rupture and broadened its plastic region.

- Caving expansion stage of overburden strata

After the ore body ended at 90m, shearing stress has been increasing, even reaching 13MPa. High stress region apparently gathered at both ends of the roadway. With the increasing of goaf volume, tensile stress kept rising, micro fracture developed ceaselessly under the combined effect of gravitational stress and tectonic stress, which would lead to the further increase of plastic region. At this time, the maximum tensile stress reached 10.3 MPa (figure1-h). The happening of big caving would absorb and transfer a large proportion of strata energy, thus reducing the tensile stress, while with the continuous increasing of goaf region, tensile stress would reach a new height until a new big caving region appeared, and then would decrease after a large proportion of energy was absorbed and released, and so forth.



(a) Shearing stress evolution in 30m working face distance
(b) Tensile stress evolution in 30m working face distance
(c) Shearing stress evolution in 50m working face distance
(d) Tensile stress evolution in 50m working face distance
(e) Shearing stress evolution in 70m working face distance
(f) Tensile stress evolution in 70m working face distance
(g) Shearing stress evolution in 90m working face distance
(h) Tensile stress evolution in 90m working face distance

Figure 1. strata fracture damage evolution process under different stresses

B. *Relationship between overburden strata damage and stress area division*

From fracture damage evolution processes of goaf strata under different stresses, it can be seen that shearing stress is mainly concentrated around the four corners of the goaf, tensile stress is mainly concentrated in the roof areas of goaf, and shearing stress and tensile stress mutually superimposed around the goaf surrounding rock. In the aspect of the damage of the surrounding rock in the goaf, both shearing stress and tensile stress will cause damage on surrounding rock, microscopic fracture was caused by shearing stress and tensile stress produced macroscopic tensile failure on goaf roof, as a whole, tensile stresses made the most significant damage on overburden strata rock. Shearing stress is the main factor that brings strata plastic damage while tensile stress is the leading factor causing the caving of overburden strata .

Through the above research and analysis, it can be summed that strata stress is distributed in four areas: tensile stress-tensile stress area, tensile stress-compressive stress area, compressive stress- compressive stress area and shearing stress-compressive stress area. In tensile stress-tensile stress area, the maximum and minimum primary stress acted as tensile stress in strata with an angle of about 45°. Molecule structure would frustrate and stress would be released when tensile stress reached rock material with less tensile strength. The region generally appeared in the above goaf strata near the impending surface as shown in Fig.2 area A, with small patches in the bottom of goaf. Compressive stress was maximum principal stress in tensile stress-compressive stress area, in overburden strata, compressive stress kept perpendicular on goaf working face and open-off cut, then deflected gradually to goaf direction and gradually turned horizontal in the goaf center at last. The maximum principal stress value changed from small to big and went through a process of ascending from the data. Tensile stress is the minimum principal stress. It kept horizontal on goaf working face and open-off cut and produced vertical direction pull crack.

Tensile stress has an angle with horizontal direction in the process of gradually skewing to the center above goaf, turning into vertical direction above goaf center. It can put tensile stress effect on strata pull crack, leaving an abscission layer. This area was mainly distributed in outer edge of goaf strata and local floor. In compressive stress and compressive stress area, compressive stress played as the maximum and minimum principal stress. This area contains compressive zone and the original rock stress area, mainly distributed in peripheral upper part of area B (Fig.2,C area) and the area free of mining disturbance. In shearing stress-compressive stress area, shearing stress and the maximum compressive stress play roles in front of working face and the surrounding rock around the open-off cut (Fig.2,D area).

Shearing stress and compressive stress worked together to bring plastic deformation and shearing damage to this region.

With the influence of stratum, lithology, rock position and other complex factors, the stress distributions of overburden strata were different, but generally abode by distribution pattern as shown in Fig.2.

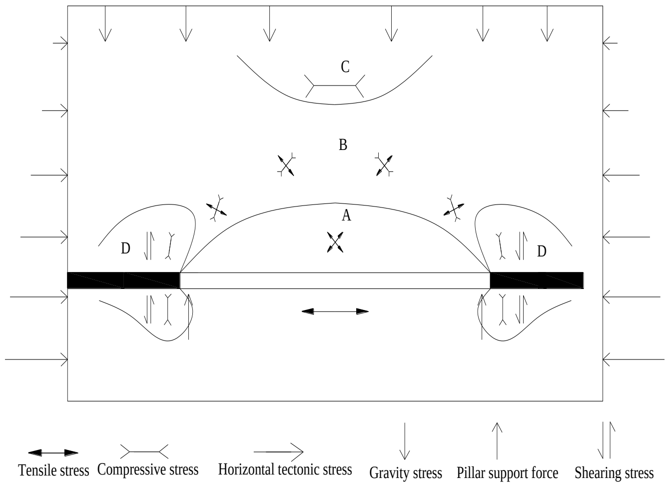


Figure 2. Metal strata stress distribution and region division under mining influence

C. Discussion of horizontal stress and vertical stress distribution in overburden strata

Due to the length limitation of the paper, horizontal stress and vertical stress inside strata section that was 10m away from goaf roof will be analyzed to take further study on goaf strata fracture characteristics.

Horizontal stress change process: with the advancing of working face, pressure balance arch shaped above the goaf, horizontal stress concentrated on top of the arch, the height of the arch increased with the goaf enlargement, horizontal concentrated stress were separated to both sides of the section (Fig. 3, where the working face was advanced to 30m), tensile stress also gradually appeared and increased, which formed symmetrical "凸"-shaped concentrated stress on the arch axis, suggesting that compressive stress and tensile stress concentration emerged in some strata interior area. Fig. 3 revealed that compressive stress and tensile stress had a corresponding relationship of upwards and downwards. The concentration phenomenon of horizontal stress was directly related to pressure balance arch formation, when the "凸"-shaped horizontal stress concentrated on the top of arch, symmetrical horizontal stress concentration appeared on the arch axis, at this time, compressive stress concentration and tensile stress concentration coexisted on the section. Horizontal compressive stress decrease and tensile stress increase with the advancing of the working face, suggesting that it has great impact on strata material damage .

Vertical stress change process: vertical stress increased rapidly while working face was 10m away, compressive stress and tensile stress also increased in the meantime. Vertical stress kept increased from 12.9MPa at the beginning of the working face excavation up to 32.8 MPa at the end. While tensile stress emerged until the working face advanced to 40m, when the caving was about to happen and gradually increased with its advancing. Vertical stress reducing area formed above the goaf at the beginning of excavation. The "凹" -shaped vertical stress concentrated on both sides of the goaf, and the span of this “凹” shape enlarged with the development of working face accelerated, which is the same as tensile stress. Compressive stress and tensile stress distributed symmetrically in the vertical direction of pressure balance arch.

Fig. 4 is diagrams of horizontal stress concentration curves when goaf advanced at 90m, and 5m,10m, 20m, 30m, 50m, 80m away from goaf roof, respectively. Stress concentration points were linked with curved lines, shaping into arch curves. It can be concluded from the diagrams that the arch curve span increased in proportion to the advancing distance, namely the goaf length. The arch springing was in front of open-off cut and working face, and the height of the arch increased with the advancing of working face. It can be also concluded that the concentration points of vertical stress and shearing stress would formarch curves too. The arch keeps in the pressure balance state in front of goaf and arch springing, forming a pressure balance arch. This balance arch is affected by the horizontal stress, the vertical stress and shearing stress (omitted), it’s stress state can be detected on Fig. 5, which is consistent with [13].

IV. CONCLUSION

- Strata damage can be divided into four stages according to different strata damage evolution processes under different stress conditions: micro crack embryonic stage, partial fracture initiation stage, caving starting stage and caving expansion stage.
- As a whole, tensile stress caused the most significant damage on overburden strata rock. Shearing stress was the main factor that brought strata plastic damage while tensile stress was the leading factor which caused the caving of the overburden strata. According to the different strata failure characteristics and regions, strata stress can

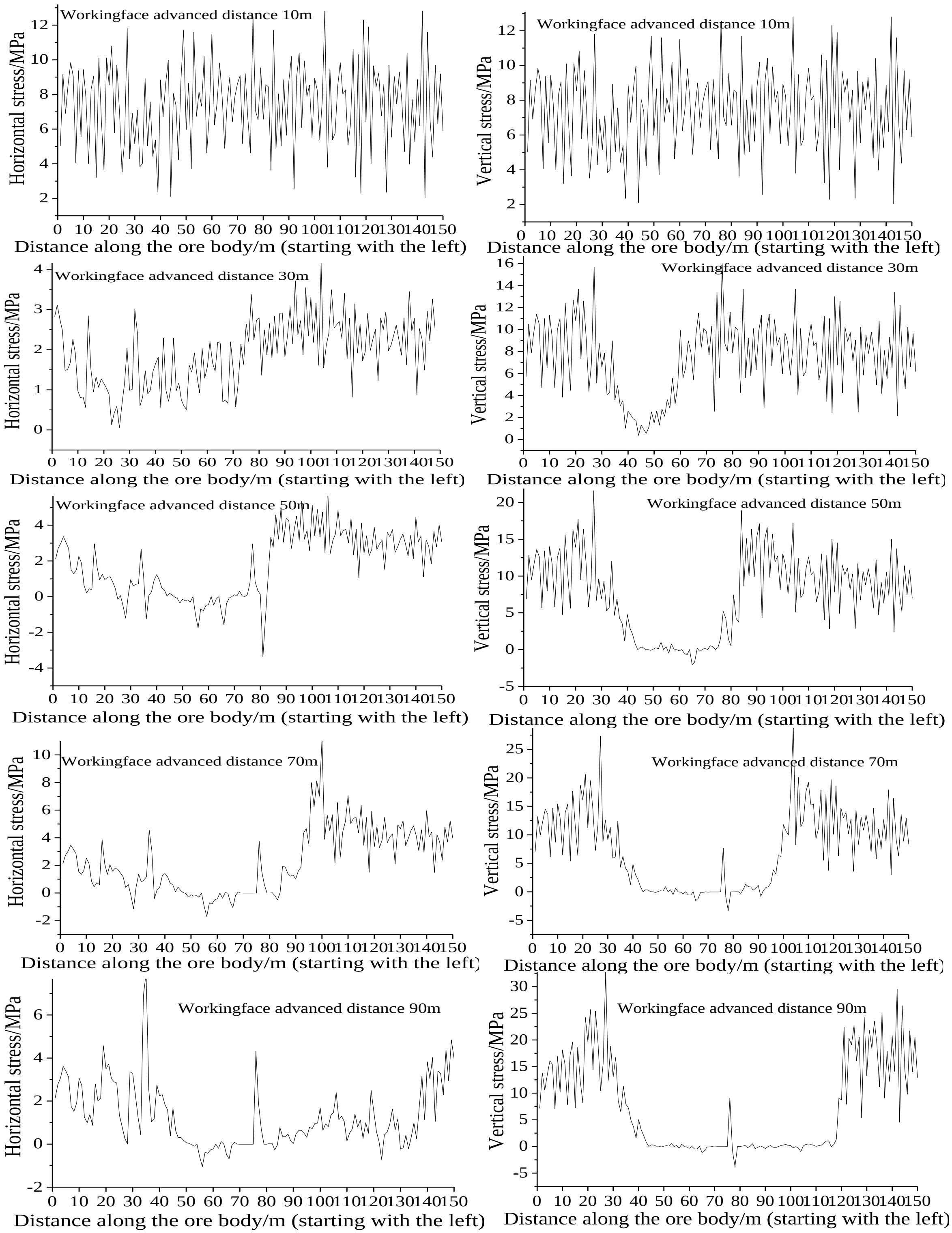


Figure 3. Horizontal stress and vertical stress curve changes of horizontal section

be distributed in four areas: tensile stress-tensile stress area, tensile stress-compressive stress area, compressive stress-compressive stress area and shearing stress-compressive stress area.

- With the advancing of working face, a pressure balance arch shaped above the goaf. At the top of the arch, horizontal stress concentration was formed. The height of the arch increased with the

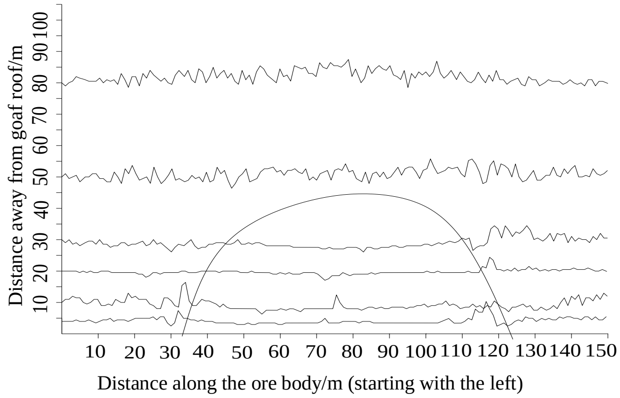


Figure 4. Horizontal stress concentration arch trace

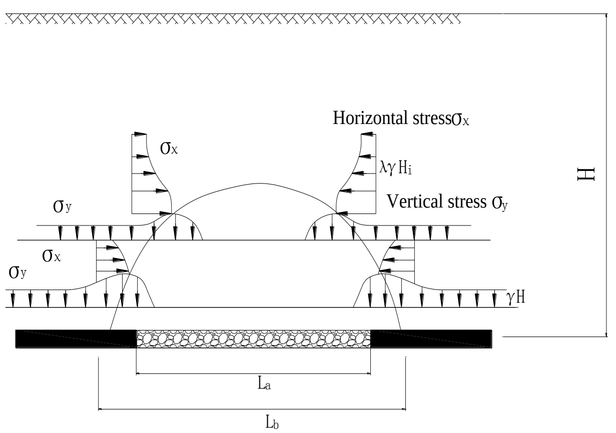


Figure 5. Stress state map of pressure balance arch

enlargement of goaf, horizontal concentrated stress separated to both sides of the section, tensile stress also gradually appeared and increased, which formed symmetrical a "凸"-shaped concentrated stress on the arch axis, suggesting that compressive stress and tensile stress concentration appeared in some strata interior area. Vertical stress increased rapidly while working face were advancing, following with the increasing of compressive stress and tensile stress. At the beginning of excavation, vertical stress reducing area formed above the goaf, the "凹"-shaped vertical stress concentrated on both sides of the goaf, and the span of the "凹" shape increased with the development of working face, so did the tensile stress. Compressive stress and tensile stress distributed symmetrically in the vertical direction of the pressure balance arch.

- When the goaf advanced different distances, horizontal stress concentration curves would formed in places of different distances far from goaf roof. Stress concentration points of these curves would be linked with curved lines to be an arch curve, the span of which was in proportion to the goaf length. In the same way, it can be also concluded that the concentration points of vertical stress and shearing stress would form arch curves as well, shaping into pressure balance arches. The balance arches were affected by horizontal stress, vertical stress and the shearing stress. This result agrees with[13].

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