Study on stress distribution under pillar floor of room in Potash mine with room and pillar mining technology

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Abstract: Room and pillar mining is a traditional mining method in the world. Carnallite/potash salt is easy to absorb water and has a strong cohesive force, its physical and mechanical properties are completely different from those of coal. The span of the room and pillar in the potash mine is small, generally ranging from 8 to 15m. Taking a solid potash mine in Laos as engineering background, basing on the elastic semi-infinite space theory, this paper sets up the mechanical model of room and pillar mining, adopts Flamant and Boussinesq solution under linear load to make research on the additional stress caused by mining in the transmission, distribution and impact depth of floor. The results indicate that depth 6 m under pillar bottom, the σz at various points is around 0.1 p. If 0.1p is used as the judgment basis for the critical impact depth of additional stress, it can be considered that the impact depth of stress concentration on bottom plate caused by mining is about 6b.

1. Introduction
The world's potassium resources are mainly in solid form, mainly distributed in Canada, Russia, belarus, etc., whose proven reserves account for about 80% of the world's total reserves, while China's potassium resources are deficient, accounting for only 5.53%[1]. The solid potassium salt mine mainly adopts room and pillar mining, that is a series of mining rooms with a width of 8-15m, and a pillar with a width of 8-20m is left to support the roof to ensure the safety of the working face. As a common green mining method, room-piller mining has a small surface deformation, which can effectively reduce the damage to the surface caused by mining and protect the surface vegetation, villages and buildings.

In recent years, relevant scholars have made in-depth research on the dimension of coal pillars and surface subsidence in longwall mining method. GuoZengzhang and XieHeping have studied the relationship between room width, pillar width and surface deformation under room and pillar mining through probability density function[2]. Jiang Yan and other have studied the calculation method of surface subsidence by using elastic mechanics[3]. XieHeping, Zhou Hongwei and others have studied the application of Flac3D numerical simulation software in the prediction of surface subsidence, and believed that Flac3D was an objective model based on the occurrence, buried depth, geological structure and characteristics of mining technology, which effectively avoided the determination of key parameters in the probability integral method and could be regarded as a more reasonable option[4][5].

The above research results has laid a good theoretical basis in aspect of room width, pillar width and the surface subsidence, but has few studies on the spread of the distribution of the stress in the pillar bottom few studies, and the vast majority of surface subsidence in the present stage of research focused on the coal mining areas, potassium with coal is a sedimentary rock, but the physical and chemical properties of ore and metallogenic environment is completely different.

This paper takes a solid potash mine in Laos as the engineering background, elastic mechanics
theory, establishes the mechanical model of strip mining under semi-infinite space and adopts plane strain problem to solve theoretical formula of abutment pressure distribution function and to make research on pressure distribution. Finally, this paper preliminarily determines to make 10% $p$ of additional stress as influence depth. All of researches would provide some references for Chinese potash mine in Laos.

2. Engineering Background
Laos has a huge potential potash reserves, and the potassium deposits are relatively shallow, easy to extract and low cost. Laos is located in the center of Asia. If it can successfully expand its production capacity, it will surely create a potash production base radiating Asia, southeast Asia and South Asia. Therefore, seizing the potassium resource market in Laos will have a huge impact on the supply pattern of potash, and it is of great strategic significance to ensure the continuous, stable and effective supply of potash for China.

Some solid potassium salt mine in Laos, carnallite ($\text{KCl-MgCl}_2\cdot6\text{H}_2\text{O}$) and sylvine salt ($\text{KCl}$) mixed beds. The average ore grade is 26.1%, the mining width of the mining room is 8m and the width of the pillar is ranging from 8 to 10m. The top and bottom seam are mainly rock salt with great thickness. At present, the average mining thickness is 4m, leaving about 2m carnallite or sylvine layers to maintain the stability of the roof in the mining space, and to ensure that the roof does not collapse or fall during mining operations without supporting on the roof. The average mining depth is 300m. The comprehensive bar chart of the mining area and the mechanical parameters of ore are shown below.

| Table 1 physical and mechanical parameters parameters of carnallite and sylvine |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| NO.             | natural density ($\text{g/cm}^3$) | Tensile Strength (MPa) | compressive strength (MPa) | Modulus of Elasticity (GPa) | poisson ratio $\mu$ | cohesion (MPa) |
| Carnallite      | 1.728           | 0.98            | 9.304           | 3.522            | 0.171            | 1.843           |
| Sylvine         | 2.081           | 2.01            | 31.489          | 5.625            | 0.193            | 7.69            |

3. Theoretical study on distribution of abutment pressure in floor

3.1. mechanical analysis of ore pillar
Room and pillar mining span in Potash mine is not very big, only 8m. The width of the pillar is larger, generally more than 8m. Carnallite ore with big cohesion and pillar is not easy to lose stability. In order to ensure that the roof does not collapse or fall under the condition that the roof is basically not supported, and to maintain the safety of the working space, carnallite/potash ore layer about 2m is left at the top of the roadway during mining. Therefore, the room has basically no roof caving, that is, there is no possibility of bearing the roof load with caving gangue piles.

It can be considered that all the weight of overlying strata within the width of the ore chamber is
transferred to the width of the ore pillar. Therefore, the bearing characteristics of the ore pillar are calculated according to the effective zone theory\cite{6}. The mean is the total mean stress of the pillar and the additional supporting pressure of the pillar caused by mining.

![Fig 2 Layout plan of mine room and pillar](image)

Total Force \[ F = (b + c) a \gamma H \] (1)

Average stress \[ \sigma_1 = F / (a \times b) = (a + c) b \gamma H / (a \times b) \] (2)

Additional stress \[ \sigma_2 = F / (a \times b) - \gamma H = (a + c) b \gamma H / (a \times b) - \gamma H \] (3)

\( a \)—pillar length, 100m; \( b \)—pillar width; \( c \)—room width;
\( \gamma \)—average bulk density of overlying strata;
\( H \)—mining depth, 300m.

| Table 2 Pillar load under different mining width, pillar width and mining height |
|---------------------------------|-----------------|-----------------|-----------------|
| \( b=8m, c=8m \)               | \( 1.2 \times 10^7 \) N | 15 MPa          | 7.5 MPa         |
| \( b=10m, c=8m \)              | \( 1.35 \times 10^7 \) N | 13.5 MPa        | 6 MPa           |

3.2. The distribution of abutment pressure under pillar floor

The study shows that when the cross-section width of the load is \( b \) and the longitudinal extension length \( L \) is greater than or equal to \( 10b \), the stress distribution of the load is basically the same as the stress distribution in the bottom plate when \( L/b=\infty \), that is, it can be equivalent to the plane strain problem of strip load. The length of strip is \( 70 \sim 120m \) and the width is \( 8 \sim 10m \) in the potash mine, so its length/width = \( L/b \geq 10 \). Therefore, the stress form of potash pillar can be equivalent to the plane strain problem of strip load. Linear load \( p \) is shown in figure 3 below. Flamant solution is used to obtain:

\[ \sigma_z = \int_{-\infty}^{\infty} \frac{3pz^3 dy}{2\pi(x^2+y^2+z^2)^{3/2}} = \frac{2pz^3}{\pi(x^2+z^2)^2} \] (4)

![Fig 3 Mathematical model of stress distribution of bottom plate under linear load](image)

Potash pillar width is \( b \), the vertical uniformly load distributed on the pillar is \( p \), adopting integral method within the scope of the pillar width \( b \), taking \( d\zeta \) as integral width:
Fig 4 Mathematical model of stress distribution under pillar

\[ d\sigma_z = \frac{2z^3}{\pi \left( (x-\xi)^2 + z^2 \right)^{3/2}} p d\xi \] (5)

Along the width b of the pillar, \( d\sigma_z \) is integrated as follows:

\[ \sigma_z = \int_{-b/2}^{+b/2} \frac{2z^3}{\pi \left( (x-\xi)^2 + z^2 \right)^{3/2}} p d\xi \]

\[ = \frac{p}{\pi} \left[ \arctan \frac{1-2n}{2m} + \arctan \frac{1+2n}{2m} - \frac{4m \bullet (4n^2 - 4m^2 - 1)n}{(4n^2 + 4m^2 - 1) + 16m^2} \right] \]

\[ = \alpha_z P \]

\[ m = x/b, n = z/b \]

Select 7 representative points in the bottom plate: A, B, C, D, E, F and G. As shown in Figure 5 for details. Where point A is located in the center of the pillar, B and C are respectively located at the point that is (1/4) b away from center, D and E are located at the pillar edge, F and G are located respectively near the center of the room on the left and right sides of the pillar. Calculate vertical stress \( \sigma_z \) at 7 points under different buried deep in the bottom of pillar, draw Horizontal stress distribution curve and Vertical stress distribution curve under different buried deep, as shown in Figure 5. According to the stress curve, make comprehensive, accurate, detailed analysis and research on spread distribution of abutment pressure in floor.

![Fig 5 position distribution diagram of theoretical calculation points](image)

Table 3 additional stresses under different buried depths at theoretical calculation points

| Z/b | X/b=0   | X/b=0.25 | X/b=0.5  | X/b=1.0  |
|-----|---------|----------|----------|----------|
|     | \( \alpha_x \) | \( \sigma_x \) | \( \alpha_x \) | \( \sigma_x \) | \( \alpha_x \) | \( \sigma_x \) | \( \alpha_x \) | \( \sigma_x \) | \( \alpha_x \) | \( \sigma_x \) |
| 0   | 1.000   | p        | 1.000    | p        | 0.500    | 0.5p      | 0         | 0         | 0         | 0         |
| 0.5 | 0.818   | 0.818p   | 0.735    | 0.735p   | 0.480    | 0.48p     | 0.084     | 0.084p    |
| 1.0 | 0.550   | 0.550p   | 0.510    | 0.510p   | 0.409    | 0.409p    | 0.185     | 0.185p    |
| 1.5 | 0.396   | 0.396p   | 0.379    | 0.379p   | 0.334    | 0.334p    | 0.211     | 0.211p    |
| 3.0 | 0.208   | 0.208p   | 0.206    | 0.206p   | 0.198    | 0.198p    | 0.171     | 0.171p    |
| 6.0 | 0.106   | 0.106p   | 0.105    | 0.105p   | 0.104    | 0.104p    | 0.1       | 0.1p      |
According to Horizontal distribution curve, vertical distribution curve and $\sigma_z$ contour at different buried depths, the results shows that:

1) $\sigma_z$ is not only distributed directly under the area of the pillar, but also distributed outside the area of the pillar. For example, point F and point G also have vertical stress in different buried depths, which is caused by the diffusion distribution of stress in the bottom plate.

2) The horizontal plane at different depth Z under the pillar bottom, $\sigma_z$ is the largest in the axis under the pillar bottom center point, the more further the distance is away from the axis, the more smaller $\sigma_z$ is;

3) Within the width range of the pillar, such as points A, B, C, D and E, the vertical stress $\sigma_z$ gradually decreases with the increase of depth, and decreases rapidly within a certain depth. Beyond this depth, decrease gradually eases and tends to be stable;

4) Outside the load distribution range of the pillar, such as points F and G, the vertical stress $\sigma_z$ at any point increases from zero to a certain value and then decrease with the increase of depth, and finally gradually becomes stable.

5) When the buried depth under the pillar bottom plate reaches 6b, the stress at points A, B, C, D, E, F and G basically tends to be the same, that is, the additional stress coefficient $\alpha_z$ on the horizontal section at the depth Z=6b is about 0.1, that is, the additional stress is about 0.1p.

4. Conclusion

If 0.1p is taken as the critical impact depth of additional stress, it can be considered that the impact depth of stress concentration on bottom plate caused by mining is about 6b.

Reference

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