AN APPROACH TO ANALYTICAL METHOD FOR THE MINIMUM SAFE MINING DEPTH WITH SOLUTION MINING IN SALT MINE

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Abstract: This paper mainly discusses the importance of the safety evaluation in solution mining, and attempts to collect various specifications and formulas for calculating the minimum safe mining depth. It also points out its pros and cons and conditions for application. Examples are given to show the rationality of the formu1as, which provides practical reference for the safety evaluation of mining, to which more and more attention is paid nowadays.

Key words: Minimum safe mining depth; Applicable condition; Application example

1 INTRODUCTION

According to "Regulation on prevent and control of earthquake" promulgated on 2003 by the State Council, in the ground rock salt mining design and mine construction, it cannot avoid evaluating safe mining. Since safe mining is not only the requirement for declaration procedure of construction project, but also the highest principle for the mining design in rock salt mining, it determines directly the basis of design and has an influence on a series of important indexes including resource utilization, mining engineering arrangement, effective utilization of construction investment and mine service life etc. Hence the evaluation of safety mining is very important.

However, the safety evaluation, which is the important basis of solution mining design, has no definite industry standard now. Though, some province applied individual standard, there was no substantial, easy operation formulas for safety evaluation. In other words, for the well mine salt industry in the country, this aspect was in the chaos. Generally speaking, people always find formulas beneficial to the project to explain what happen was in the project, however the formulas are often not comprehensive and objective, which may bring some mine irreversible problem. The reason of no unified standard is that, not only the mining industry is small, but unifying safety evaluation standard is difficult and it covers a wild range. Hence, the paper is focus on discussing the importance problem-minimum safe mining depth problem and hoping more people pay attention on the aspect.

2 THEORETICAL BASIS AND THE COMMON FORMULAS FOR MINIMUM SAFE MINING DEPTH ANALYSIS

2.1 Basic understanding of the development of solution mining cavity

Since solution mining method is adopt to halite bed, it makes the mined-out area with some shape and size-cavity formed under ground and stress state of the surrounding rock changed. If the stress is over the strength of rock, the cavity is unstable and then damage, collapse or caving occurs, which has effect on solution mining and ground safety. Since the distribution of tensile stress in the cavity roof is maximum in the medium and is reduced from the medium to both sides, the rock in the middle of roof is easier to collapse than that in the side of roof and the shape of roof is arch, which is called natural balance arch.

According to plastic mechanics, natural balance arch can be divided into three zones: fracture zone, plastic deformation zone and elastic deformation zone or divided into two zones: caving zone and water flowing fractured zone for the practical and common purpose. In general, it is considered to be safe if water flowing fractured zone cannot develop quaternary unconsolidated layers or water bearing zone of bedrock. However, it is necessary to take account into protection layer for ground water safety. The minimum safe mining depth should be satisfied as follows:

$$H_S = H_F + H_P + H_U$$

where H_F :fractured zone,m

H_P :protection layer thickness,5~30m

H_U :unconsolidated layer thickness,m

2.2 The factors related with the stability of cavity roof

objective factors: seam buried depth, surround rock structure and strength and seam structure (the relation between seam and non-mine interlayer)

subjective factors: cavity span, safety pillar width, cavity shape, mining layer thickness and number and brine water density

2.3 Common formulas of minimum safe mining depth analysis

Centering on the common understanding and the factors related with stability of cavity, some representative formulas are listed as follows:

1)According to "Regulation on Coal Industry Design"

$$H_C = (3 \sim 4)\text{M}$$

$$H_F = (100\text{M})/(3.3\text{N} + 3.8) + 5.1$$

$$H_p = (6 \sim 7)M / N$$

where, H_C : caving zone height,m

H_F : fracture zone thickness,m

M : salt layer thickness,m

N : the number of slice mining,m

2)According to Tianquan Liu's "The Principle Method of Safety Coal Pillars for underwater Coal Mining" (1981, World Coal Technology")

$$H_C = (100\text{M})/(4.7\text{M} + 19) \pm 2.2$$

$$H_F = (100\text{M})/(1.6\text{M} + 3.6) \pm 5.6$$

3)According to Pu's compressive arch theory:

$$H_1 = [b + 2M \cdot \tan(45^o - \varphi/2)] \times 100/2 \times 10.2\sigma_1$$

$$H_2 = 2.5H_1$$

where, H_1: collapse height in mined-out zone,m

H_2 : salt layer thickness,m

φ : friction angle in rock layer,

σ_1: compressive strength,kg/cm2

4)Considering the pressure of internal water according to "Engineering Geological Handbook", when the roof in the natural balance state cannot collapse, the critical depth formulas is

$$H_o = \frac{B(1-\rho_e/\rho)}{\tan\varphi \cdot \tan^2(45-\varphi/2)}$$

where, H_o: critical depth,m

B: maximum cavity width,m

ρ_e: brine water density, which is taken to 1.2g/cm3

ρ: intact rock density in overlying strata,which is taken to 2.4g/cm3

φ: friction angle of the roof of salt layer, which is taken to 40°

The criterion is : actual buried depth $H < H_O$, roof is unstable

When $H_O < H < 1.5H_O$, roof is little stable ;

when $H > 1.5H_O$, roof is stable.

5)According to rock dilatancy theory, after rock roof collapsed, the whole mined-out zone was filled with rock due to volume expansion, which can support the roof conversely and restore the balance of the parts of rock.

In general, the shape of collapsed cavity is arch, hence the volume of the cavity can be calculated by the intact parabolic rotator, whose volume can be expressed as:

$$V_1 = 0.5\pi R^2 h_1.$$

When the cavity is blocked, the roof will not collapse. The collapsed height h_1 can be estimated as follows:

$$V_1 k = V_o + V_1; \qquad V_1 = F h_1 / 2$$

where, V_o: cavity volume

V_1: collapsed rock volume

k: rock volume expansion coefficient, the most common value is 1.5 in the data.

h_o: cavity height

F: cavity roof area, $F = \pi R^2$

6) According to "Well Mine Salt Geological Foundation & Mining Techology"

$$H_C = (1\sim2)\sum M$$

$$H_F = 20(\sum M)^{1/2}$$

$\sum M$: average accumulated thickness of ore bed

3 REVIEW ON THE APPLICATION OF FORMULAS ABOVE

3.1 The formula is provided by "Regulation on Coal Industry Design", with the characteristics of easiness, practicality and authority. Though solution mining seems to be similar to coal mining, there are lots of differences in fact, which includes single layer mining thickness, mining support method, the shape of mined-out zone and empty cavity filling. Most formulas related with coal mining only take account into mining thickness, hence the calculated results from the formulas was quite contrary to the actual data.

3.2 The formula based on compressive arch theory takes account into more aspects, however, the object is mainly short span mined-out zone and it also neglect the support effect of brine water pressure. For roof rock layer, the tensile strength is more important. Despite the problems above, this formula can be used as reference.

3.3. The critical formula in "Engineering Geological Handbook", worths recommending. Since "Engineering Geological Handbook" is a handbook leased by the country, the formula has a higher authority and more aspects especially including inner water pressure are taken account into the formula, which is the most difference from other formulas. The critical formula has a disadvantage of neglecting the mining thickness, which applies the case of relatively stability;

hence, it has little guiding significance for thin layer mine.

3.4 The formula based on dilatancy theory, is reliable and conservative, which applies the case of small ratio of mining height to cavity width and thin layer salt mine comparing to the critical formula in the "Engineering Geological Handbook". For thick layer salt mine, the formula cannot apply this case.

4 APPLICATION EXAMPLE OF THE FORMULAS

According to actual case of a mining section in Pindingshan salt field, application example is as follows:

4.1 Mining section engineering geological characteristics

According to rock characteristics, unconsolidated sediments cover rock is divided

rock is formed by middle-fine sparry, whose structure is thin layer. The average thickness of single layer is 4.5m, maximum thickness of single layer is 17.65m. The accumulated thickness when single layer thickness > 4m, is 64.46% of total thickness. Mudstone rock, whose structure is dense, is formed by non-formed rock. Bedding Texture is developed from horizonation and the connection ability among layers is bad; the vertical tension fracture development cannot cross the layers with different salt characteristics and the tension fracture is mainly filled with halite or gypsum.

4.2 Physical mechanics index of mining section

The physical mechanics index of salt rock strata, which is the important basis for evaluating the stability of cavity and mining ground, is as follows:

Compressive strength of halite rock is 13.60-31.20MPa, the average is 21.66MPa; Tensile strength is 0.82-1.10MPa, the average is 0.96Mpa; cohesion is 1.90-8.80MPa, the

into silty clay, sandy gravel, fine sand interbed; quaternary strata is not formed into rock and the diagenesis degree of neogene strata is bad; quaternary strata thickness is about 135-139 m.

The engineering geological characteristics of salt layer roof is that the roof rock is composed of half-diagenesis rock and the structure of roof rock is dense in whole; the structure is mainly thin-middle thick layer and the local structure is thick layer or massive; the roof rock is developed by horizontal bedding and vertical tension fracture, however tension fracture is mainly filled with mud or gypsum.

The engineering geological characteristics of salt layer. Salt layer is buried in 935-1381.05m, whose rock characteristic is that the salt layer is composed of halite rock, mudstone, gypsum mudstone and gypsum rock interlayer and local shale. Salt layer ore bearing rate, which is about 49-57.3%, increases from south to north and halite rock accumulated thickness increases from north to south. Halite average is 5,50MPa; internal friction angle is 31°23′-36 °52′, the average is 34 °17′.

The halite rock roof and floor is mainly mudstone rock and gypsum mudstone rock. Compressive strength of halite rock is 5.90-74.80MPa, the average is 17.59MPa; tensile strength is 0.47-3.87MPa, the average is 1.39MPa; internal friction angle is 32°31′-37 °02′, the average is 34 °39′.

4.3 Empirical formula of roof caving zone

Combining with rock characteristics and rock mechanical property, empirical formula of roof caving and fractured zone to calculate the maximum height in "Regulation on Coal Industry Design" is as follows:

When quaternary strata thickness is about 135-169m, which is buried in 935m underground and the pure salt thickness is 120m, the results are listed as follows:

Table 1 Roof caving calculation factor

Mining layer number	Accumulated thickness	Maximum height of caving zone	Maximum height of water flowing fracture zone	Minimum distance between fracture zone and ground
N	M (m)	H_C (m)	H_F (m)	(m)
4	200×60%	480	593	/

The calculated results are that the maximum height of caving zone is 480m, the maximum influence height of fracture zone is 593m, water flowing fracture zone will be extended to the top of quaternary unconsolidated sediments. The results, which show that it is not safe, are contrary to actual situation.

4.4 Estimation method for roof collapse blockage, the collapse height h_1 is estimated as

$$h_1 = 2h_o / k - 1$$

where rock volume expansion coefficient,

k is taken to 1.2, $h_1 = 2h_o / k - 1 = 10h_o = 1000m$

k is taken to 1.5, $h_1 = 2h_o / k - 1 = 4h_o = 400m$

It is shown from the formula that when k is taken to 1.2 for mudstone, the collapse height is 10 times cavity height and the height is over ground. This is contrary to the fact. The key factor of the method is selection of k and the method cannot apply to thick salt mine. Since it neglects the shape of cavity, it also cannot apply to stripy or zonal mining.

Considering the pressure of internal water according to "Engineering Geological Handbook", when the roof in the natural balance state cannot collapse, the critical depth formula is as follows:

$$H_o = \frac{B(1-\rho_e/\rho)}{\tan\varphi \cdot \tan^2(45-\varphi/2)}$$

where, H_o:critical depth,m

B: maximum cavity width, which is taken to 120m

ρ_e: brine water density ,which is taken to 1.2g/cm3

ρ: intact rock density in overlying strata,which is taken to 2.4g/cm3

φ: friction angle of the roof of salt layer, which is taken to 34°

When cavity width is 120m, H0=314m, H>H0 and the roof thickness is 3 times critical thickness. The result is shown that the mine roof is stable when cavity is 120m.

5 Conclusions

5.1 From the example, for the thick salt mine in the Pindingshan salt field, the critical formula in "Engineering Geological Handbook" is in accordance with the facts when we discusses the problem of the minimum safe mining depth. It didn't deny other formulas, which only explains that different formulas have different application. Meanwhile, it needs to take into account authorization when we choose these formulas and the most authoritative method is better at the same time. Besides, we can demonstrate the case by different method at same time.

5.2 It is not practical and possible in the future to be dependent on a simple formula to determine safe mining depth. We should have a dynamic understanding of the problem, which safe mining depth is not absolute and varied, since the problem is one aspect of the ground safety problem and varies with other factors. Hence, the further scientific method is to take into account many variables and built a software model, which can calculate different index allowable value of ground deformation. In the end, it needs to build the standard closed to the mining industry.