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## THEORY AND APPLICATION OF LIMIT EQUILIBRIUM ON ROADWAY FLOOR HEAVE

### 1. Introduction

The roadway floor heave is one of the most common distortions and breakage modes of the roadway of soft rock mass[1]. In fact, the roadway floor heave differs from the distortions of any other parts in the roadway. In a common roadway floor heave, the displacement of the lateral sides and the roof will be steady after a distortion about a few centimeters. Even if this displacement can not be steady after the initial distortion, it could be controlled by reinforcements or any other support means. Under this circumstance, the distortion will not influence the normal use of the tunnel. But, once the roadway floor heave take place in a roadway of soft rock mass, the distortion will not only be continuous but also be difficult to stabilize by itself. On the other hand, the commonly used reinforcements and support means are not easy to succeed because the bottom rock mass locates in a special place. As a result, a roadway can not be put into normal use because of it's floor heave problem. Some tunnels have to repair frequently because of it's continuous uncontrollable floor heave. The result is that the floor

displacement can not be stable and the distortion have a serious influence on the stability of the lateral sides and the roof. Therefore, how to control the roadway floor heave effectively has been one of the difficult tasks in the support modes of soft rock mass roadway.

### 2. Analysis of the stress fields of the roadway floor heave

When the stress state of the roadway floor rock mass reach or exceed the yielding condition of the rock mass, the rock mass will get into plastic-flow state. The slippage line field of the roadway floor which gets into the yielding state is shown in Figure 1[2][3]. From Figure 2 (a), we can get the following equation:

$$\sigma = \frac{c \cdot \operatorname{ctg} \varphi + q_s}{1 - \sin \varphi} \quad (1)$$

$$\theta = 0$$

In the above-mentioned equation,  $\theta$  is the angle between main stress and  $x$  axis. So we can see that the corresponding angles between line  $\alpha$ , line  $\beta$  and  $x$  axis are respectively

$$\frac{\pi}{4} - \frac{\phi}{2} \text{ and } -\left(\frac{\pi}{4} - \frac{\phi}{2}\right).$$

As the same way considering of area  $\triangle ABC$  or area  $\triangle FGE$ ,

providing that there are no shear stress on area AB and line AB, line BC are beelines, we can conclude that area  $\triangle ABC$  is an even stress region also. In the area BCD, according to the first theorem of Hencky, the group of slippage line  $\alpha$  are beelines and the angle between line  $\alpha$  and line  $\beta$  is

$$2\left(\frac{\pi}{4} - \frac{\varphi}{2}\right).$$

We can prove that line  $\beta$  is a group of logarithm screwy curves shown as following :

$$r = r_0 \exp(\theta \tan \varphi) \quad (2)$$

where  $r_0$  is radius as  $\theta$  equates to 0. From point C to point D along line  $\beta$ , we can get the following equations :

$$\begin{aligned} \ln \sigma_c + 2\theta_c \operatorname{ctg} 2\mu &= \\ &= \ln \sigma_D + 2\theta_D \operatorname{ctg} 2\mu, \end{aligned} \quad (3)$$

$$\begin{aligned} \sigma_c &= \sigma_D \times \\ &\times \exp[2\sigma_D - 2\sigma_c \operatorname{ctg} 2\mu] \end{aligned} \quad (4)$$

In the above equations,

$$\mu = \frac{\pi}{4} - \frac{\phi}{2}.$$

Since the area  $\triangle ABC$  is an even stress region whose stress state shown in Figure 2(b), we can calculate that terminal load  $q$  transferred from lateral sides to the roadway floor

$$\begin{aligned} q &= (c \cdot \operatorname{ctg} \varphi + q_s) \frac{1 + \sin \varphi}{1 - \sin \varphi} \times \\ &\times \exp(\pi \cdot \operatorname{ctg} 2\mu) - c \cdot \operatorname{ctg} \varphi \end{aligned} \quad (5)$$

As indicated in formula (5), the roadway floor rock mass will get into plastic-flow state when

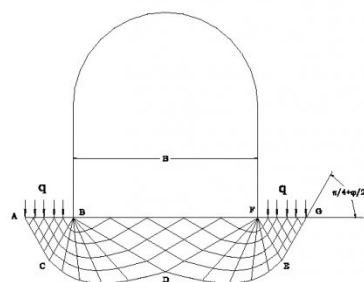


Figure.1. The slippage line field of the roadway floor

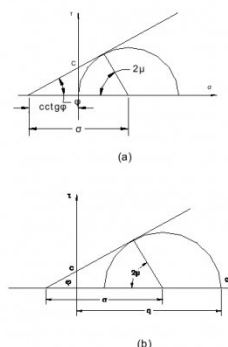


Figure.2. The stress state of  $\triangle RDF$  and  $\triangle ARC$

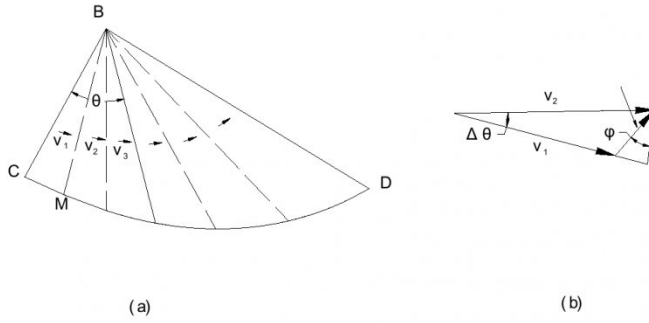


Figure 3. The analysis of velocity field in region  $\triangle BCD$

the load transferred from lateral sides to the floor reaches  $q$ . That means bottom swelling will take place continuously. When the roadway floor take place, the lateral sides will also get into plastic state. So the magnitude of the load transferred to the roadway floor can be determined by the rock property and the status of lateral sides and support mode.

### 3. Analysis of the velocity fields of the roadway floor heave

In Figure 1, both groups of slippage line in the area  $\triangle ABC$  and the area  $\triangle EFG$  are beeline, therefore, the velocity weight  $v_\alpha$  and  $v_\beta$  of any point in these regions are all constant. That is to say the displacement in these two areas are rigid displacements. For example, in area  $\triangle ABC$ , if the vertical velocity is  $v_q$  caused by load  $q$  and the outside of line AC is rigid region, so the velocity of any point in this region can be described as :

$$v_0 = v_q \cdot \sec\left(\frac{\pi}{4} + \frac{\varphi}{2}\right). \quad (6)$$

The velocity distributing of the region  $\triangle BCD$  shown in Figure 1 can be described by Figure 3(a). Since the area  $\triangle BCD$  does instantaneous rigid movement with velocity  $v_0$  which plumbs to line BC, therefore, the normal velocity of all points belong to line BC in area  $\triangle ABC$  are all  $v_0$  also. In order to educe the velocity distributing of the area BCD, we can divide the top angle of this region into

many small bended sides triangles, as shown in Figure 4(a), then we can calculate the velocity of any point in this region:

$$v = v_q \sec\left(\frac{\pi}{4} + \frac{\varphi}{2}\right) \times \exp(\theta \cdot \tan \varphi) \quad (7)$$

From the formula listed above, in area BCD, the velocity only concern with polar angle  $\theta$ , but it has nothing to do with polar radius  $r$ , that means the velocity of all the points lie in the same line are constant. The velocity of line BD are shown as below:

$$v_{BD} = v_q \sec\left(\frac{\pi}{4} + \frac{\varphi}{2}\right) \times \exp\left(\frac{\pi}{2 \cdot \tan \varphi}\right) \quad (8)$$

All the slippage lines in area  $\triangle BDF$  shown in Figure 1 are all beelines, so the velocity field is an uniformity field. The combined velocity of the velocities  $v_{DF}$  and  $v_{BD}$  is shown as below.

$$v_d = 2v_q \cdot \tan\left(\frac{\pi}{4} + \frac{\varphi}{2}\right) \times \exp\left(\frac{\pi}{2} \cdot \tan \varphi\right) \quad (9)$$

### 4. The application of the theory of limit equilibrium on the roadway floor heave

A water storehouse lies in the powdery sandstone, the section of the roadway is half-round arch roof with vertical side walls. This roadway adopt combine support mode of anchoring、spraying

cement and reinforcing steel bar net. But the roadway has an obvious distortion only within two months, especially the roadway floor moved upwards and swelled wholly. In order to keep on tunneling normally in the foreside, people had to take up the floor and pave rails. But the floor could not maintain stability for so a long time before it reentered into continuous swelling distortion. That did affect the mine's normal work seriously.

The anti-slide piles is one of the most common means to reinforce rock mass in slope project [4]. The piles are buried in the rock mass so that to resist instability of the slide rock mass by integrating with the stable rock mass into one. The applications of ant-slide piles in slope projects have proved that such piles have good capacity to resist slide、high flexibility in disposing piles and convenience in constructing. This technique is suit to be used in the slope with smooth slide surface, moreover, it has a rather good effect when the slide surface situates at a shallow position. The forementioned theory of limit equilibrium on the roadway floor heave has shown the main reason of floor rock mass. It is load transferred from the lateral sides to the the roadway floor rock mass has exceeded the carrying capacity of floor rock that the rock mass gets into the plastic-flow state leads to continuous distortion. One property of such kind of distortion is that the scope of the plastic-flow state is not too much, only the shallow part of floor rock gets into plastic state, the other parts are still in elastic state or in rigid region. Shearing slippage is the other one property of such kind of distortion, with its slide surface parallel to rigid region. The distortion and instable state under this circumstance are similar to slope's. So it is an effective way for anti-slide piles to be used to control the roadway floor heave.

It is a reinforcement project applying anti-slide piles combined with bottom slurry-injection and reinforced concrete slate as shown in Figure 4.

The length of anti-slide piles can be worked out according to Figure 4 and formula (2), while the pile's anchoring depth is decided by the pile's top constraints. Generally speaking, the anchoring depth is about 0.6 to 0.8 times of load's length. Therefore, we used two rail piles in this project, 2.4 meters long each, they were placed symmetrically with the space between them is 1 meter.

### 5. Conclusion.

5.1 The main reason of the roadway floor heave is that the

floor gets into plasticflow state. Therefore, the theory of slippageline can describe the stress state and the distortion property of the rock mass effectively.

5.2 The analysis of the roadway floor heave in theory is significant in choosing the appropriate method to control the roadway floor heave, at the same time, it can provide theory reference in choosing reinforcement parameters correctly.

5.3 By referring to the theory of anti-slide piles in slope reinforcement, the anti-slide piles is used to control the roadway floor heave here. It is a reinforcement method of the roadway floor by utilizing the

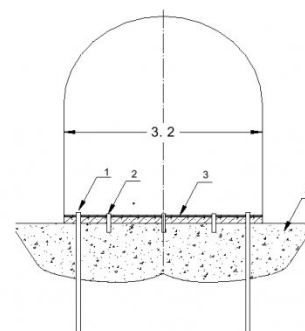


Figure 4. An example of rail stake to control tunnel bottom swelling.

1- rail stake, 2—slurry-injection pipe, 3—reinforced concrete slate, 4—slurry-injected mass

theory of plastic slippage line. This method has its many strongpoints, such as: great anti-slide force, credible effect, convenient construction process, good adaptability and low cost, etc.

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## NON-LINEAR DYNAMICAL FEATURES FOR STRATA MOTION

### 1. Introduction

China is the country that is abundant in coal resource. However, because of the limitation of embedding depth and geological conditions, underground excavation is the main method of coal mining in China. One of the drawbacks this method brings about is the failure of strata and catastrophe movement, such as roof fall abruptly, rock burst, bump of coal and mash gas etc., which can result in casualties. Further more, with the development of excavation towards the depth, the disaster will be more severe, and even can affect the safety of excavation. So in the view of the predicting

mechanism for strata motion, it is needed to break through the definite theory of Newton, and to find out a new predicting method for strata motion.

### 2. Self-organization for strata motion

Order variable is used to describe the degree of ordering of system. If the self-organization process for strata motion is studied by synergetic theory, then first of all we must determine the order variables describing the evolving process of the system and parameters of the related subsystem. According to the references [1, 2], AE can be selected as the variable describing the failure process of rock.