LECTURE 21

6.6 EXCAVATION SHAPE AND BOUNDARY STRESS

Most of the time, a simple horseshoe shape for tunnels is preferred as it gives a wide flat floor for the equipment used during construction. For relatively shallow tunnels in good quality rock, this is an appropriate tunnel shape and there are many hundreds of kilometres of horseshoe shaped tunnels all over the world. In poor quality rock masses or in tunnels at great depth, the simple horseshoe shape is not a good choice because of the high stress concentrations at the corners where the sidewalls meet the floor or invert. In some cases failures initiating at these corners can lead to severe floor heave and even to failure of the entire tunnel perimeter.

The stress distribution in the rock mass surrounding the tunnel can be improved by modifying the horseshoe shape. The sharp corners at the junction between the floor and the tunnel sidewalls create high stress concentrations and also generate large bending moments in any lining installed in the tunnel. Floor heave is reduced significantly by the concave curvature of the floor of the modified horseshoe shape, in many cases, these modifications to the horseshoe shape may be sufficient to prevent or at least minimise the type of damage. However, in most cases, a circular tunnel profile is invariably the best choice. Here, stresses around some specific shapes is being discussed.
6.6.1 Oval Shape

\[ \sigma_A = p(1 - K + 2q) = p \left( 1 - K + \sqrt{\frac{2W}{p_A}} \right) \]

\[ \sigma_B = p \left( K - 1 + \frac{2K}{q} \right) = p \left( K - 1 + K \sqrt{\frac{2H}{p_B}} \right) \]

\( p_A \) and \( p_A \) are the radii of curvature at point A and B. Higher the boundary curvature (lower the radius of curvature), it is found that higher the stress concentration. This means, corners with sharp edges will have very high stress concentration.
6.6.2 Ovaloidal Shape Openings

W/H ratio is 3 and the radius of curvature of side wall is H/2

\[ \sigma_A = p \left( 1 - 0.5 \sqrt{\frac{2 \times 3H}{H/2}} \right) \]

\[ = 3.96p \]

\[ \sigma_B = -0.17p \]

This shows that the radius of boundary curvature and the excavation aspect ratio \((W/H)\) are very important to develop a reasonable accurate picture of the state of stress around opening.
### 6.6.3 Square Opening with Rounded Corner

It is also observed that, changing the shape of a opening presents a most effective method of controlling boundary stresses. Maximum boundary stresses can be reduced if the opening dimension is increased in the direction of major principal stress. For an excavation subject to an extremely high vertical principal stress and extensive side wall failure, an elliptical excavation with the long axis horizontal may be preferred excavation shape. Figure 6.19 shows how the increase in the height of the tunnel is actually helping to reduce the side wall stresses.

![Figure 6.18: Boundary stresses around square opening with rounded corners](image)

\[
\sigma_A = p \left\{ 1 - 1 + \left[ \frac{2B(2^{1/2} - 0.4(2^{1/2} - 1))}{0.2B} \right]^{1/2} \right\} \\
= 3.53p
\]

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6.6.4 Excavations with special shapes

Many applications, some shapes of openings are also required, e.g., opening shape shown in Figure 6.20. Such excavation geometry can be useful in case of a need of crusher station, battery charging station or machine workshop where a bench is retained for equipment installation. (W/H ration = 2/3). A, B, C are likely to be highly stressed as the boundary curvature is high. Local cracking is to be expected in these zones – No problem of Integrity. D is likely to be at low state of stress due to be negative curvature.
6.7 STRESS DISTRIBUTION DUE TO DEVELOPMENT OF FRACTURED ZONE

The problem geometry is shown in Figure 6.22a, with a circular opening excavated in a medium subject to hydrostatic stress. The field stresses and rock mass strength are such that an annulus of failed rock is generated in the excavation periphery. The main questions are the relation between the radius, \( r_e \), of the failed zone, the applied support pressure, \( p_i \), and the stress distribution in the fractured rock and elastic domains. It is assumed that the strength of the rock mass is described by a Mohr–Coulomb criterion, i.e.

\[
\sigma_i = \sigma_1 \frac{(1 + \sin \phi)}{(1 - \sin \phi)} + \frac{2c \cos \phi}{1 - \sin \phi}
\]

The strength of fractured rock is taken to be purely frictional with the limiting state of stress within the rockmass

\[
\sigma_i = \sigma_1 \frac{(1 + \sin \phi')}{(1 - \sin \phi')}
\]
Figure 6.21: Stress distribution around a circular opening in a hydrostatic stress filed due to development of fractured zone

6.8 TUNNELING IN STRATIFIED ROCK AND BLOCKY ROCK

Rock with horizontal layering, tend to open up in the roof/ sides of an underground opening. When the strata are dipping, zone of interbed separation and potential buckling or sliding may occur. The extent depend on the interlayer friction, thickness and inclination of layers.
Figure 6.22: Interbed separation and buckling or sliding of strata in tunnels in stratified rocks

Tunneling in blocky rocks

If tunneling has to be done in a blocky rock mass, the different block types may be identified first. As per Goodman (Figure 6.23) six different types of block commonly identified.

Non-removable

1. Block with no free faces (Block VI).
2. Infinite blocks (Block V).
3. Non-movable Tapered block (Block IV).

Removable

1. Safe block under the action of gravity (Block III).
2. Safe block by virtue of friction (Block II).
3. Movable block, unless supported (Block I).
Fig. 6.23: Different type of Blocks in tunnels in blocky rocks
6.9 ROCK FRACTURES AND SCALE/SIZE EFFECT

It is found that, the larger the size of the excavation there is increased potential for blocky fall-out. Figure 6.25 a) describes the effect of reduction in the size of opening in a fractured rock mass in relative scale, here the blocks are more unstable due to increased relative size of the openings. Figure 6.25 b) explains, how increase in the fracture intensity would affect the tunnel o the same size.

Figure 6.24: a) Effect of reduction in the size of opening in a fractured rock mass in relative scale  b) Increase in the fracture intensity for the same size of the opening