STRESS DISTRIBUTION AROUND THE TUNNEL: INFLUENCE OF INSITU STRESS AND SHAPE OF TUNNEL

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ABSTRACT: Sustainable development of urban areas requires an increasingly large use of underground facilities, especially to ensure a greater transportation demand and for preserving the environmental quality. The factors that influence the stability of any underground excavations are the shape and size of opening, in-situ state of stress, induced stress field and related deformations when the openings are made. To ensure safe and economical construction of underground sections one should know the distribution of stresses around the tunnel. In this paper numerical analyses of underground structures were done using FLAC3D software by varying the coefficient of earth pressure ‘k’ and the shape of the tunnel. It was found that the shape and lateral earth pressure ratio has little influence on the plastic zone created.

INTRODUCTION

Underground structures such as subways and railways, highways, material storage, and sewage and water transport are an integral part of the infrastructure of modern society. Most of which are so essential to human life that they are called “lifeline” facilities. The stability of underground excavations are affected by its shape, size of opening, in situ stress, soil conditions etc. Eventhough the shape of the opening mainly depends on the purpose for which it is to be used, the safe design and construction of an underground opening requires the knowledge of the stress distribution and the displacements that occurs in and around the openings. When an opening is excavated in a medium, the in situ stress field is disturbed and new set of stresses are induced around the surrounding of the opening(Fig 1). Knowledge of the magnitudes and directions of these in situ and induced stresses is an essential component of underground excavation[1].

In this paper the stresses in and around an underground opening is analysed using the FLAC3D software. FLAC3D utilizes an explicit finite difference formulation that can model complex behaviours. Materials are represented by polyhedral elements within a three-dimensional grid. Each element behaves according to a prescribed linear or nonlinear stress/strain law in response to applied forces or boundary restraints[2].

The present analysis was done to know the distribution of stresses around the opening after excavation and to decide how it varies with the shape and insitu stress state. An analytical solution for the stress distribution in a stressed elastic plate containing a circular hole was published by Kirsch (1898)[1] and this formed the basis for many early studies of rock behaviour around tunnels and shafts. The following sketches shows the comparison of analytical and numerical (using FLAC 3D) solutions for a circular tunnel (Figs 2 & 3).

Fig. 1 Illustration of principal stresses induced in an element of rock close to a horizontal tunnel subjected to a vertical in situ stress $\sigma_v$, and horizontal in situ stress $\sigma_h$ in a plane normal to the tunnel axis and a horizontal in situ stress $\sigma_h$ parallel to the tunnel axis[3].

Fig. 2 Variataion of horizontal(radial) and vertical stress (circumferential) along the horizontal direction for a circular tunnel (elastic solution).
The horizontal stress applied was varied based on the insitu stress ratio. The stress distribution was varied at the springing line (A), crown (D), at an angle 30 (B) and 60 degree (C) with the horizontal (Fig 5).

The far field boundaries are fixed at ten times the radius of the tunnel to approximate infinite boundaries. The model is analysed using the elasto plastic Mohr Coulomb model. The initial insitu stress condition is applied to the model first and then the elements inside the circular tunnel are removed in single step to simulate the tunnel excavation using the null model. The various shapes used for the study were the circular, rectangular and horse shoe shape. The lateral earth pressure ratio was kept as one for the study of stress variation around the tunnel for various shapes. The variation of stresses around the tunnel with different shape is studied by varying the lateral earth pressure ratio to 2, 1.5, 1, 0.75 and 0.5.

**SHAPE OF THE TUNNEL**

Tunnel with following cross sections are analysed for its stresses:

- Circular
- Horseshoe
- Rectangular

The shape most preferred by the construction engineers are the horse shoe shape. The horse shoe provides a wide flat floor for equipment and also provides a pleasant working platform. This shape is suitable for shallow tunnels in good quality soil. Horse shape tunnels are commonly used for highway tunnels and there are many hundreds of kilometers of horseshoe shaped tunnels all over the world[5].

Figure 6 shows the distribution of circumferential stress around the opening of the tunnel for different shapes. The redistribution of stresses will be more in the diagonal direction for horse shoe shape tunnel compared to other shapes. The stresses at crown and springing line are almost zero for rectangular section but along the diagonal direction the stress concentration will be more. But in the case of
Stress distribution around the tunnel: influence of in situ stress and shape of tunnel

Circular and horse shoe tunnel at the springing line and along the radial direction stress development occurs but at crown it is zero.

Fig. 6 Distribution of Circumferential stress around the tunnel (At points A, B, C and D)

So it is clear that the stress distribution is more for a horse shoe shape tunnel as compared to the other shapes. In poor quality soil 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.

Fig 7 shows the variation of vertical stress along the horizontal direction from the face of the tunnels. The redistribution of stresses is concentrated close to the tunnel and that, at a distance of say three times the radius from the centre of the hole, the disturbance to the in situ stress field is negligible. The peak stress shows the plastic stress ($I_p$) and after that the stress is of elastic nature. The shape has no effect on the peak plastic stress formed.

INSITU STRESSES

Since the 1960s extensive efforts have been extended to develop stress measuring techniques. Today a number of tools exist to measure the two- and three-dimensional in situ stress state. The use of these tools and indirect observations have led to the development of the World Stress Map[2]. The vertical stress can be estimated by the weight of the overburden and is very difficult to estimate the horizontal stresses. In general the horizontal stresses are estimated by assuming a suitable lateral earth pressure ratio.

In this paper the analyses were done by varying the insitu stress ratio (Lateral Earth Pressure ratio) as 0.5, 0.75, 1, 1.5 and 2 to see how the value affects the redistribution of stresses. The analysis were done for circular, rectangular and horse shoe shape. The redistribution of stresses was observed at the springing line (A) along the horizontal direction.

The results obtained for circular tunnels (Figs 8 & 9) show that the redistribution of stresses will be less in the case of higher lateral earth pressure ratios. When the lateral earth pressure ratio is more than one means the tunnel is confined by a horizontal stress greater than the vertical stress.

Fig. 8 Variation of horizontal stress along the horizontal direction for a circular tunnel.

Fig. 9 Variation of vertical stress along the horizontal direction for a circular tunnel.
The same trend was obtained for both horse shoe (Figs 10 & 11) and rectangular shape (Figs 12 & 13). There is increase in peak stress ($I_p$) with increase in insitu ratio. In case of high insitu ratio the vertical stress at the far end has tendency to increase rather than to approach the far field stress. This is mainly due to the more confinement in Horizontal direction compared to the vertical direction.

Fig.10 Variation of horizontal stress along the horizontal direction for a horse shoe tunnel.

Fig.11 Variation of vertical stress along the horizontal direction for a horse shoe tunnel.

Fig.12 Variation of horizontal stress along the horizontal direction for a rectangular tunnel.

Fig.13 Variation of vertical stress along the horizontal direction for a rectangular tunnel.

CONCLUSIONS
Stress concentration is more in the radial direction for horse shoe shaped tunnel than the other shapes. The shape has not much influence on plastic zone created and the peak plastic stress developed around the tunnel. As the insitu stress ratio increases redistribution of stresses decreases, mainly due to the high confining effect in the horizontal direction. Lateral earth pressure ratio has not much influence on the plastic zone created but it affects the peak stress developed. The peak stress developed increases with decrease in lateral earth pressure ratio.

REFERENCES