SUBSIDENCE CAUSED BY TUNNELING IN JOINTED ROCK

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Abstract

During the excavation of a shallow tunnel overlying buildings, streets or utilities should be prevented from damage. In order to reach to this goal, the designer must predict the ground conditions and decide for the tunnel size and the construction methods. Several real tunnels and model studies in homogenous, isotropic material in the laboratory showed that, the settlements above a tunnel at shallow depths unless caused by a local disturbance are more or less symmetrical about the vertical axis of the tunnel. During this study, by means of physical and numerical models, the validity of this statement is examined.

PHYSICAL MODELING

Isotropic, Homogenous rock and discontinuous rock

Generally speaking, the subsidence curve forms a through- like depression with a shape roughly resembling the error function or the normal probability curve. The maximum settlement at any cross section perpendicular to the tunnel axis is denoted by δ_x. The properties of the normal probability function helps to estimate the settlements to be expected at varying distances (x), laterally from the center line of a tunnel by the following formula (after Cording):

$$\delta = \delta_{max} e^{\left(\frac{-x^2}{2i^2}\right)}$$

where **i** is the point of inflexion, also as shown in Figure 1.

If the value of **i** can be established, any table of the ordinates to the error curve can be used to establish the ordinates at any distance. This formula and subsidence curves are well validated for the models in isotropic and homogenous rock masses in the laboratory. The rock mass used in the model tests was corresponding to a very weak rock mass such as weak clays with 0.6 kgf/cm^2 uniaxial compressive strength (after Karaca). This rock type is chosen due to the fact that the settlements above and adjacent to the tunnels in weak, plastic clays may be drastically larger than those in stiffer, more brittle cohesive granular soils.

The same model material is used in order to prepare the blocks to represent the discontinuous media where the tunnels are excavated. The mechanical characteristics of the rock mass and the geometrical parameters related to the model were kept same as in the previous case. Under various joint orientations the tunnels are excavated and the development of subsidence was observed and measured (Fig.2).

NUMERICAL MODELING

Finite element and distinct element analysis

The code used in this study (EFEMER) solves two dimensional static equilibrium equations by the method of finite elements, by considering the nodal points displacements of the examined domain as the unknowns of the problem and holds the hypothesis of small deformations (Fig.3). Distinct element method provide powerful models to simulate the behaviour of jointed media in different conditions (static-dynamic). Code UDEC was used during this research program. Due to the weak mechanical properties of the rock mass simulated, fully deformable blocks were used (Fig.4).

CONCLUSIONS

- In isotropic, homogenous models and in the real tunnels, the form of the settlement curve is similar to the normal probability curve. The non-symmetric settlement curves with respect to the vertical center line of the tunnel happens when the discontinuities are involved in the media.
- The distance of inflection point on the settlement curve is a parameter which is useful in determining the width of the subsidence zone. With the help of **i**, the damage to the buildings around the tunnel can be predicted during the construction of tunnels. The shape of the settlement curves change with respect to the structural geology.
- The empirical values found for the inflexion point in different models is as the following:

Physical models		
From the vertical axis	Left side	right side
Horizontal model	i= 0.15 (z+r)	i= 0.15 (z+r)
model 30°(*)	i= 0.16 (z+r)	i= 0.15 (z+r)
model 45°(*)	i= 0.18 (z+r)	i= 0.19 (z+r)
model 60°(*)	i= 0.20 (z+r)	i= 0.22 (z+r)

Numerical models		
From the vertical axis	Left side	right side
Horizontal model	i= 0.15 (z+r)	i= 0.17 (z+r)
model 30°	i= 0.23 (z+r)	i= 0.22 (z+r)
model 45°	i= 0.32 (z+r)	i= 0.21 (z+r)
model 60°	i= 0.32 (z+r)	i= 0.22 (z+r)

(*) Inclination of the major discontinuity set from the horizontal, r=tunnel radius

- The numerical calculations and physical models in jointed media showed that, as long as the rupture process was governed by the discontinuities, the form of the settlement curve over a tunnel was non-symmetric with respect to the vertical axis of the tunnel. When the failure phenomena is dominated by the failure of the intially intact rock, the settlement curves take the shape of the normal distribution curve.
- The values of the inflexion point was found to be larger in the numerical models. The possible reason for this is that the dilatation of the rock mass was not considered during the calculations with the finite element code and insufficiently (only at the joints) with the discrete element code.

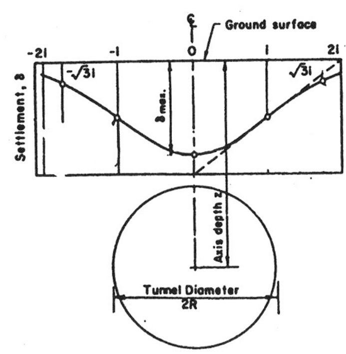

Fig.1) Observed settlement (in the shape of the the normal probability curve) in isotropic, homogenous media, along the cross-section of the tunnel.

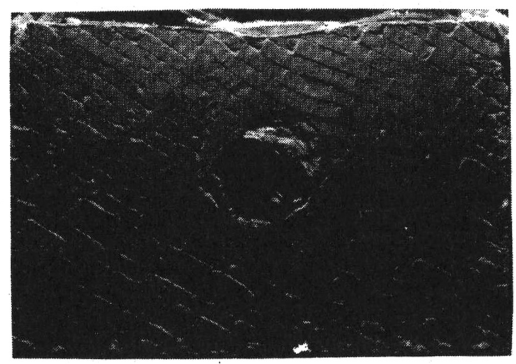

Fig.2) Irregular subsidence at the surface of a physical model for the case where the stratification is 30° from the horizontal.

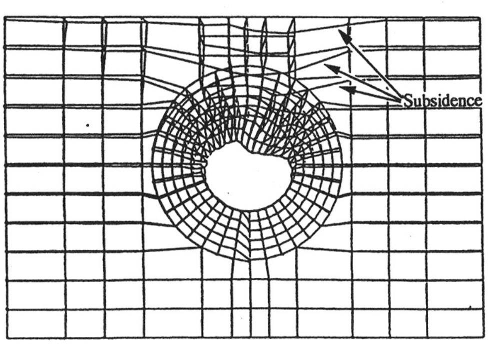

Fig.3) Non-symmetric settlement over a tunnel, where the layers are dipping 30° from the horizontal, Finite Element Code.

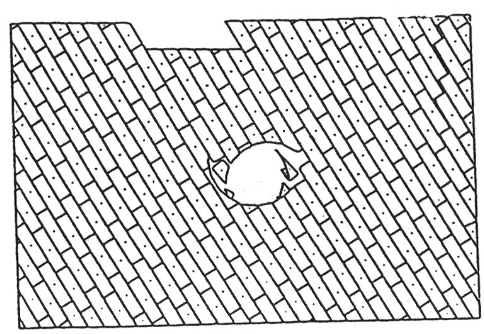

Fig.4) Form of the settlement at the surface due to the presence of steeply inclined layers, Distinct Element Code.

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- Karaca, M. (1991). Stabilité des tunnels à faible profondeur en milieu discontinu. Ph. D. dissertation, Swiss Federal Institute of Technology, Lausanne.
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