III-338 An FEM analysis of tunnel excavation based on the constitutive model with strain softening

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1 Introduction

In order to properly design and construct a tunnel, it is very important to understand the actual mechanical behavior of the adjacent ground during tunnel excavation phase and to establish an analytical procedure with suitable constitutive model to describe as accurately as possible. In this paper, the characteristic curve known as Fenner-Pacher curve in NATM (New Austrian Tunneling Method) is discussed in connection with the strain hardening and softening characteristics of ground material. A finite element analysis by making use of an elasto-plastic constitutive model with strain softening is proposed to simulate the tunnel behavior predicted by the Fenner-Pacher curve.

2 Simulation of Fenner-Pacher curve based on constitutive model with strain softening

By introducing the stress history tensor, Oka and Adachi (1985) developed an elasto-plastic constitutive model for geological materials in order to express both strain hardening and softening behavior. The stress history tensor is a functional of the stress history with respect to strain measure and is given by,

$$\sigma^*_{ij}=\frac{1}{\tau}\int_0^z \exp\left(-\frac{z-z'}{\tau}\right)\sigma_{ij}(z')dz' \qquad (1) \qquad\qquad dz=\sqrt{de_{ij}de_{ij}} \qquad (2)$$

where τ is the material parameter which controls the strain hardening and strain softening phenomena, z is the strain measure, and e_{ij} is the deviatoric strain. The detail of the constitutive model can be referred to [1)]

In order to simulate the Fenner-Pacher curve in NATM by using Adachi-Oka model mentioned above, a finite element analysis is carried out for Maiko testing tunnel . The FEM analysis is considered in plane strain condition. The ground material of tunnel is sand with fine grained soil which belong to Osaka diluvial layers. The geometry of tunnel and finite element mesh used in the analysis are given in Fig.1. 8-node isoparametric finite element is used in calculation. Beam element is introduced to simulate the lining. Table 1 gives the material parameters of the ground.

Needless to say, within plain strain condition, it is difficult to simulate precisely the excavating stages in real tunnel excavation by releasing the initial stress around the tunnel wall. Here , we assume that each excavating stage is equivalent to releasing some percentages of the initial stress around whole tunnel wall.

At first, we investigate the ground behavior during tunnel excavation without lining. Fig.2 shows the relation among octahedral stress, stress history and strain at some point of tunneling wall. It is clear that the initial octahedral stress history is not equal to zero and monotonously increases during the whole deformation process and finally lead to residual state. In order to find appropriate initial stress releasing steps for the stable convergence of solution, calculations with various steps have been done and it is found that when the steps is taken more than 40, stable solution can be obtained.

Fig.3 shows the displacement contours in which the settlements of crown and upright ground are 4.50cm and 1.95cm respectively. By comparing this result with observed data, it is found that the analytical results are much larger than observed data, 0.39cm at crown and 0.0 at upright ground. It is also clear from the figure that even in those points far from the tunnel, the settlement is still very large. The reason why this discrepancy occur is that the lining is not installed in tunneling.

Fig.4 gives the softening area and displacement pattern around tunneling wall when 90% of the initial stress is released for the case without linings. The softening area range from 66.5° to 109.4°. we can see that if lining is not installed in tunnel excavation, large deformation will occur and tunnel wall will lose stability.

Now let's consider the case then tunnel lining is placed in the analysis. In the analysis, the installation of primary lining is simulated as follow; beam elements (as the primary lining) are introduced at the prescribed initial stress released step and subsequently the remaining initial stress is removed.

Fig 5 shows the relation between the loads acting upon the lining and the displacements of tunneling wall. It can be seen that, at invert and crown, the loads acting upon lining decrease almost linearly with the increase of deformation in both cites and no prominent plastic strain occurs.

Fig.6 is the comparison between observed data and calculated results of displacement when the lining is placed after 20% of the initial stress is released. Fig.7 is the comparison between observed data and calculated results of stress in lining when the lining is placed after 20% of the initial stress is released.

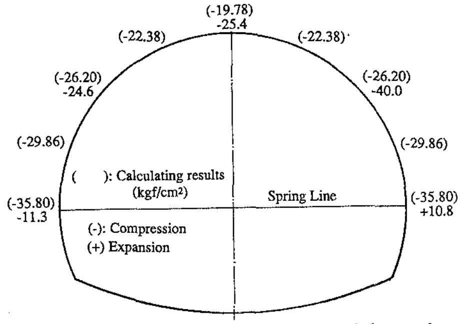

Fig.7 comparison between observed data and calculated results of stress in lining when the lining is placed after 20% of the initial stress is released.

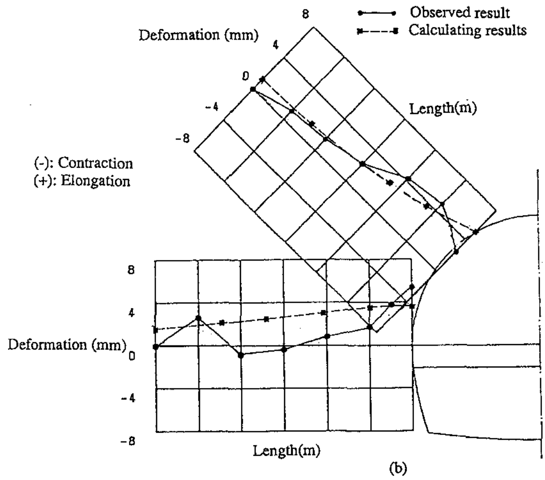

Fig 6 Comparison between observed data and calculated results of displacement when the lining is placed after 20% of the initial stress is released.

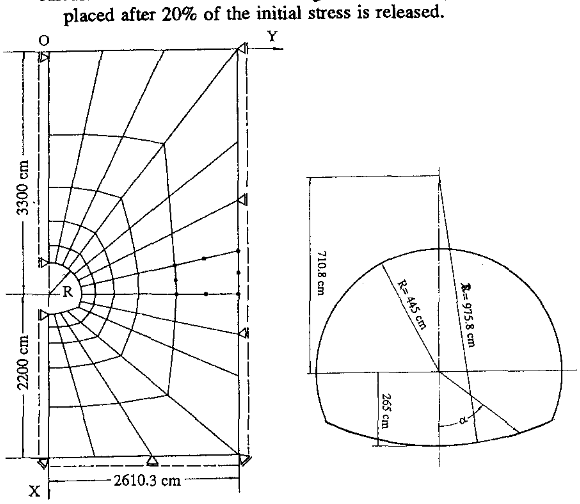

Fig.1 Geometry of tunnel cross section and finite element

Table 1

α_f	1.35	μ	0.35
β_f	- 0.10	G'	130.0
a	0.009	σ_{mb}(kgf/cm^2)	100.0
β_τ	-0.10	b(kgf/cm^2)	10.0
E_0(kgf/cm^2)	1059.00	M_m	1.08
E_1	+0.10	μ_{beam}	0.30
E_{beam}(kgf/cm^2)	100000	EI_{beam}(kgf.cm^2)	6.67x10^8
EA_{beam}(kgf)	2.0x10^7		

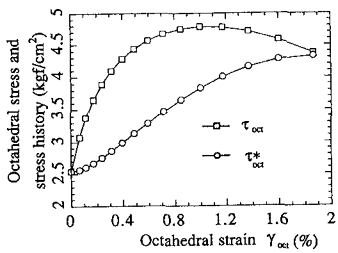

Fig 2.Relationship among octahedral stress, stress history and strain for the element at spring line

3 Conclusion

In this paper, a finite element analysis for Maiko Testing Tunnel by making use of an elasto plastic constitutive model with strain softening is carried out to simulate the tunnel behavior predicted by the Fenner-Pacher curve. The result shows that the Fenner-Pacher can be obtained by using a fitting constitutive model with strain softening in the analysis.

4 Reference

1) Oka, F. and Adachi, T.:'A constitutive equation of geologic materials with memory' Proc. 5th Geomachanics,1,pp.293-300, 1985

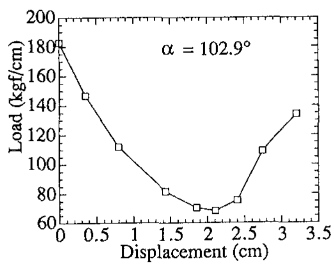

Fig 5 Relation between load acting upon lining and deformation of tunnel lining

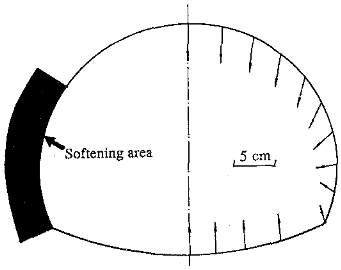

Fig.4 Softening area and deformation pattern around tunnel periphery when 90% of initial stress released without lining

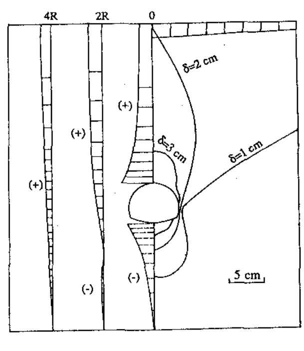

Fig.3 Displacement contour, surface subsidence and vertical displacements along some vertical axes when 90% of initial stress released without lining