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FIRE ANALYSIS OF REINFORCED CONCRETE TUNNEL LINING

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ABSTRACT

Fire analysis of precast segmental tunnels involves several problems, mainly related to the soil-structure interaction during fire exposure, coupled with material degradation. This problem has been analyzed using an ideal case of a precast segmental tunnel excavated in a stratified soil. The analysis has been conducted with a commercial nonlinear FE element code. Initially, excavation of the tunnel was modeled in order to predict stresses in the lining due to the soil pressure and eventually fire exposure was considered. The reinforced concrete lining was modeled with a crack model in order to simulate the actual behavior. Results show the importance of considering the interaction with the soil and the degradation of the concrete lining.

Keywords: non-linear phased analysis, fire design, tunnels.

INTRODUCTION

Tunnel construction with the Tunnel Boring Machine (TBM) is, today, the most extensively adopted method both in soft soil and rock. During the excavation process, the TBM places the tunnel lining, usually made of precast reinforced concrete segments, and uses these elements as contrast in the advancing process. Behavior of a tunnel under fire conditions has become a relevant topic, during the last years, due to several accidents that have occurred. Fire behavior of a tunnel excavated with the TBM can be of interest since the lining thickness can be relatively small (from 250 to 500 mm).

The effect of fire exposure is not solely related to material degradation, but also to the coactions that can arise due to differential thermal expansion, which can jeopardies safety. Another aspect, which should be considered in the stress analysis, is related to material degradation under high temperatures.

In this paper, a lining with typical characteristics of a tunnel built in soft soil is considered. Analyses are performed with the FE program DIANA[11]. In the analysis, excavation of the tunnel is modeled first in order to predict stresses in the lining due to the soil pressure, and after this fire exposure is considered. The nonlinear behavior of the reinforced concrete lining is taken into account in order to simulate the actual response of the tunnel.

TUNNEL MODELING

The tunnel is modeled in 2D, under the assumption of plane strain. This assumption is based on the hypothesis of worst possible fire scenario for the tunnel section, and neglects thermal expansion along the tunnel. A construction phase analysis is performed with the aim of simulating the different stages of construction and the exceptional event due to fire exposure.

This aspect is important because the actual behavior of the tunnel under fire depends on the initial stress field in the lining, due to the soil pressure. In the first phase, only the soil is considered and stresses are initialized. Three layers of soil, having different characteristics, have been considered. In the second phase, excavation and installation of the tunnel segments are considered, with the tunnel segment being connected to the surrounding soil with interface elements following a friction Coulomb material model with tension cut-off. Finally, fire is applied assuming that the air temperature varies in time according to the RWS law.

The constitutive material law for concrete in compression is that suggested in the Eurocode 2. In tension, it is assumed that concrete behavior is elastic-brittle, with tensile strength and Young's Modulus decaying with temperature as it does in compression. Concrete has been modeled with a rotating total strain crack model: the stress is defined as function of the total strain and the concept of coaxial stress-strain is used. The steel reinforcement follows an elasto-plastic law with yielding strength decaying with temperature as described in the Eurocode 2.

RESULTS AND CONCLUSIONS

Figure 1a shows the vertical stress field in the soil and the principal stresses in the tunnel lining prior to fire loading. The tunnel lining is subject to eccentric compression, which is typical for a superficial circular tunnel excavated in soft soils. Figure 1b shows the crack pattern after 120 min of fire exposure. When the fire load is applied, the differential thermal expansion causes tension at the extrados and compression at the intrados. When cracking occurs, this reduces the overall structural stiffness and, in this way, mitigates the effect of the differential thermal expansion. At the intrados, thermal damage is limited to a very thin layer and causes yielding of the reinforcement. Despite cracking and yielding of reinforcements, structural stability of the tunnel is ensured up to 120 minutes of fire duration.

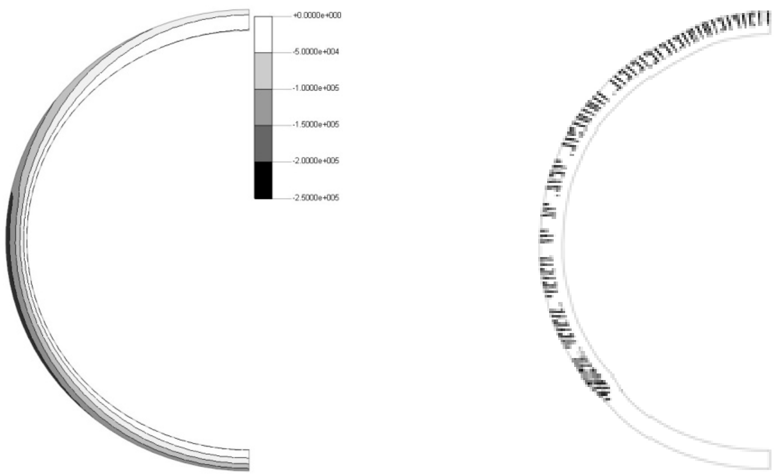

Fig. 1 - Tensile test results

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