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Stability assessment of shallow tunnels subjected to fire load

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Abstract

During recent fire accidents in European tunnels, significant spalling with spalling depths up to 50% of the thickness of the concrete lining was observed. In addition to spalling, the remaining part of the lining was subjected to thermal degradation, resulting in an increase of the compliance of the lining support. In tunnels with high overburden, this increase of the support compliance activates the load-carrying capacity of the surrounding soil. In shallow tunnels, on the other hand, the soil as such may not be able to maintain the stability of the tunnel. In order to assess the stability of shallow tunnels with continuously increasing support compliance in consequence to fire load, the extension of the "beam-spring" model towards consideration of effects associated with tunnel fires is proposed. At first, layered finite beam elements are used for the discretization of the lining, allowing consideration of spalling by deactivation of layers following a prespecified spalling scenario. Secondly, the change of material properties in consequence of high temperatures is accounted for within elastoplastic material models employed for the description of the mechanical behavior of concrete and steel. Based on different fire-load scenarios and spalling histories, an answer to the central question "*whether or not spalling can cause collapse of shallow tunnels*" is attempted by the application

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Nomenclature

A	surface area of lining related to one soil spring-element
c	heat capacity
d	thickness of tunnel lining
d_k	thickness of kth soil layer
d_s	spalling depth
d_s^∞	final spalling depth
d_RF	equivalent thickness of reinforcement layer within the layer concept
E	Young's modulus
E_k	Young's modulus of kth soil layer
F	force in soil spring-element
f_D	Drucker–Prager yield function
f_R1,f_R2	Rankine yield functions
f_RF	yield function for reinforcement steel
f_c	compressive strength of concrete
f_t	tensile strength of concrete
f_y	yield stress of reinforcement steel
I_1	first invariant of stress tensor
J_2	second invariant of stress deviator
J_act	set of active yield surfaces
K	stiffness of soil spring-element
$\bar{K}$	stiffness of soil spring-element related to average radius of tunnel cross-section
K_0	coefficient of lateral pressure
k	thermal conductivity
L	level of loading
n	number of reinforcement bars per meter
p	soil pressure acting on tunnel lining
q_D	hardening variable of Drucker–Prager criterion
$\bar{q}_\mathrm{D}$	material resistance of Drucker–Prager criterion
q_RF	hardening variable of reinforcement-steel yield criterion
$\bar{q}_\mathrm{RF}$	material resistance of reinforcement-steel yield criterion
R	radius of tunnel cross-section
$\bar{R}$	average radius of tunnel cross-section
t	time
T	temperature
$\bar{T}$	prescribed temperature at the inner surface of the lining
$\bar{T}_\mathrm{max}$	maximum value of prescribed temperature
u	radial displacement of tunnel lining
v	vertical displacement at top of tunnel cross-section
x	horizontal coordinate
y	vertical coordinate
α_D	internal variable of Drucker–Prager criterion