## 6. Preliminary numerical simulations and computational model verification

This section is aimed at applying the computational modeling to simulate deformation and stress in two academic twin tunnels configurations. The numerical results provided in these illustrative applications may be viewed as preliminary verifications of the F.E formulation. The first application refers to unlined twin tunnels excavated in an elastic rock mass, whereas the second application addresses the situation of unlined twin tunnels excavated in an elastoplastic medium.

**6.1 Unlined twin tunnels in elastic medium**

## In the context of plane strain conditions, Guo et al. [6] addressed the configuration of deep twin tunnels excavated in a homogeneous elastic medium in which prevails a hydrostatic initial stress distribution. The authors formulated approximate analytical solutions for the stress distribution establishing far behind the face, which are induced in the rock mass by the excavation of two parallel circular tunnels. The model geometry of the twin circular tunnels as well as the loading associated with initial hydrostatic stress are displayed in Fig. 12.

Simulation of the problem has been addressed by means of the 3D finite element model and the numerical results obtained for the stress distribution far behind the faces of the twin tunnel shall be compared to the analytical stress solution derived by Guo et al**.** [6] in the framework of plane strain conditions. The simulations have been performed taking advantage of symmetry with respect to the midplane between twin tunnels and considering the following model data: tunnel radius 𝑅𝑡 = 4 m, rock Young modulus 𝐸 = 500 MPa and Poisson ratio 𝜈 = 0.23, isotropic initial stresses of 𝜎𝑣 = 𝜎ℎ = 2.2 MPa.

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Figure 12: Geometry model and loading mode of the twin circular tunnels studied in Guo et al. [6].

Denoting by the displacement component following the -axis, Fig. 13 displays the convergence curves 𝑈𝐵 = −𝑢𝑦 (B)∕𝑅𝑡 that characterize the inward movement at the tunnel roof as a function of normalized longitudinal distance to the facing. Several values of normalized distances between the twin tunnels axes 𝑑1∕2𝑅𝑡 have been investigated, and the configuration of single tunnel may be viewed as the limiting case . It is recalled that in the latter configuration, the convergence far from the tunnel face that is obtained from an elastic analysis reads 𝑈 = 𝜎𝑣 (1+𝜈)∕𝐸. As expected, this figure indicates that the closer the longitudinal tunnels, the greater the convergence at the roof.

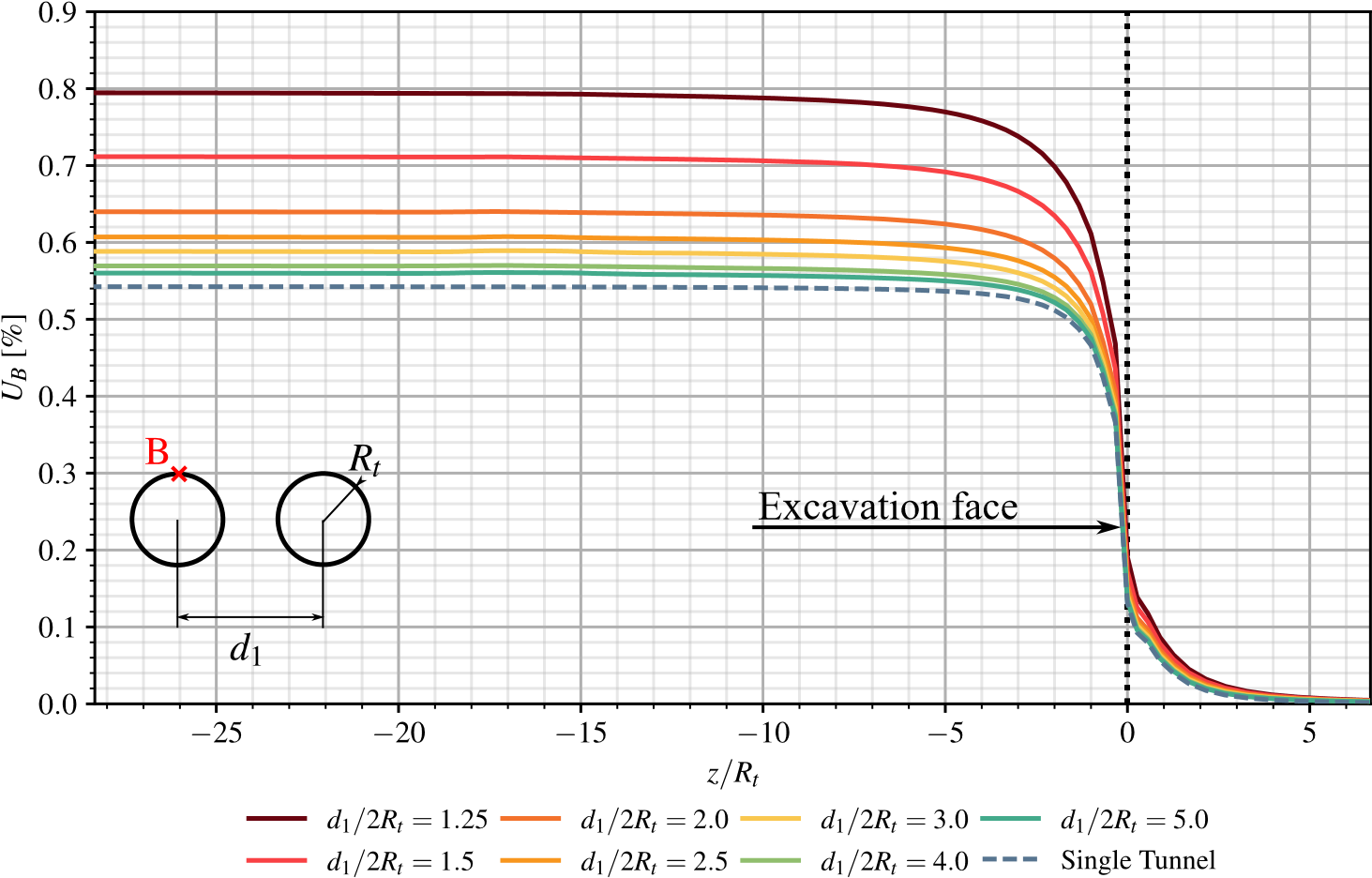
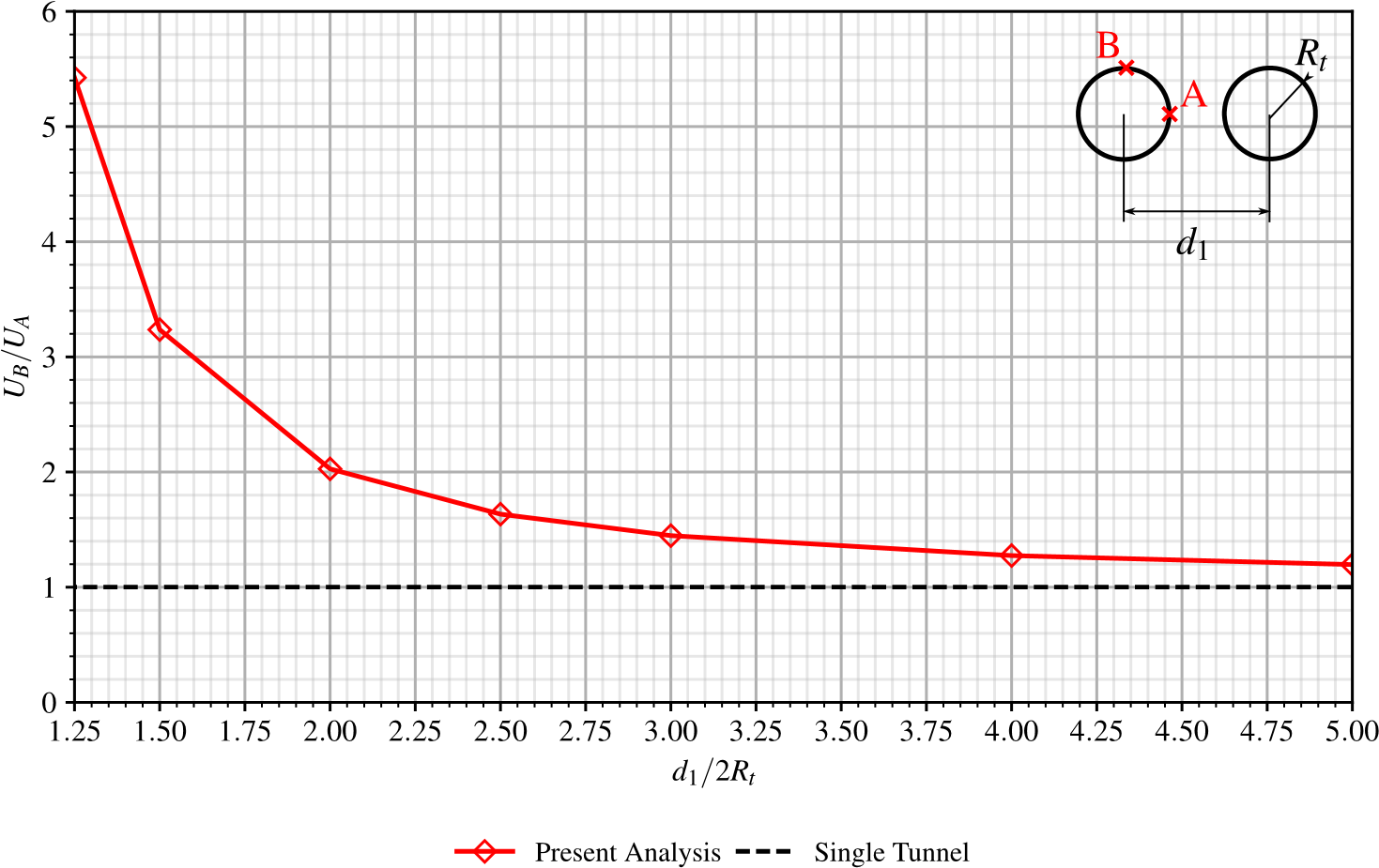


Figure 13: Convergence profiles at the tunnel roof B.

The tunnel deformation anisotropy induced by the twin tunnels proximity is illustrated in Fig. 14, which plots the ratio  between the vertical displacement at the roof B and the horizontal displacement at the side wall . The results refer to a tunnel section located far behind the facing at normalized distance 𝑧∕𝑅𝑡 = −25. They emphasize the significative tunnel ovalization induced by the proximity of twin tunnel as the distance  decreases.

Figure 14: Illustration of the tunnel wall deformation anisotropy induced by twin tunnels proximity.

The stress distribution prevailing far from the facing that were obtained from the 3D numerical simulations are compared in Fig. 15 to the stress solutions derived analytically and numerically in Guo et al. [6]. In this figure, the tangential stress concentration factor  computed at the sidewall  is plotted for several values of the normalized twin tunnels distance Finally, Fig. 16 displays the distribution of tangential stress 𝜎𝜃𝜃 around the tunnel boundary {r=Rt, 0 ≤ 𝜃 ≤ Pi} considering 𝑑1∕2𝑅𝑡 = 1.5. The predictions of stress component 𝜎𝜃𝜃 obtained from the 3D finite element. The results of the theoretical solution to a plate containing two circular holes of equal size presented in Ling et al. [37] are also reported in Fig. 15. It is observed that the results of the 3D finite element simulations correspond to a tunnel section located at normalized distance 𝑧∕𝑅𝑡 = −25 from the facing, which is considered sufficient for the plane strain conditions to establish. Interestingly, the tangential stress concentration obtained for a deep single tunnel under plane strain condition simply reads . Although the overall agreement observed between the different predictions, it appears from the comparison that the approximate analytical stress solution provided in [6] slightly overestimates the tangential stress computed at point A as the value of distance  increases.

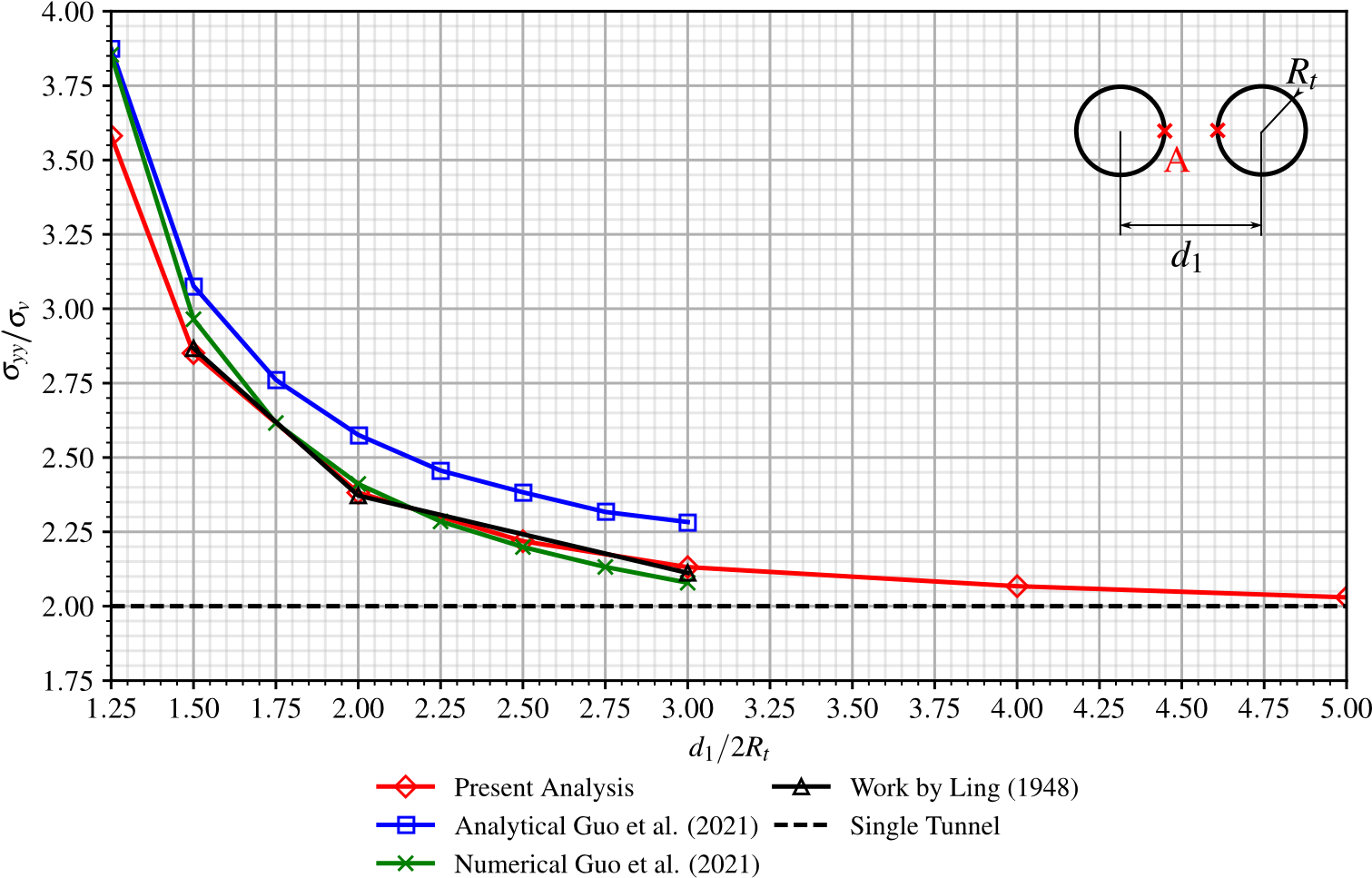
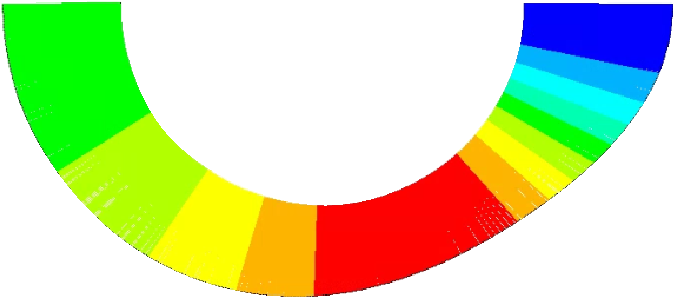
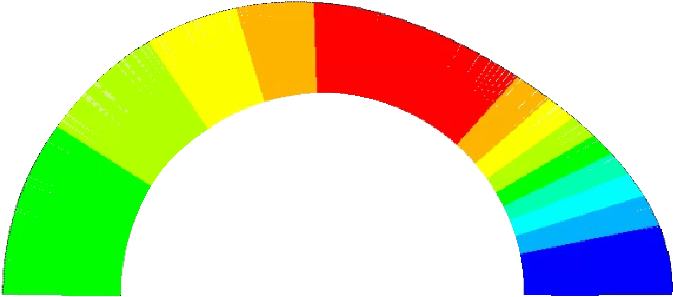


Figure 15: Tangential stress concentration factor at the side wall A versus twin tunnels distance .

Finally, Fig. 16 displays the distribution of tangential (orthoradial) stress 𝜎𝜃𝜃 around the tunnel boundary considering 𝑑1∕2𝑅𝑡 = 1.5. The predictions of stress component 𝜎𝜃𝜃 obtained from the 3D



-3.80

Current

D model

3

solution

Analytical Solution

Guo, et al. (2021)

-6.30

-5.99

-5.69

-5.38

-5.07

-4.76

-4.45

-4.15

-3.84

-3.53

-5.00

-4.97

-4.13

-3.80

-3.74

-6.72

Figure 16: : Distribution of tangential stress 𝜎𝜃𝜃 around the tunnel wall prevailing far behind the facing ( twin tunnels distance 𝑑1∕2𝑅𝑡 = 1.5).

finite element simulations far behind the facing are shown together with the strain plane solutions derived analytically in [6], emphasizing the ability of the computational model to accurately capture the effect of tunnels proximity on stress distribution.

## Keeping in mind it addresses only an academic configuration, the results provided in this section may be viewed as a first preliminary verification of the accuracy of the computational model formulated for the mechanical interaction in deep twin tunnels.

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