Solution for Problem Set 2

For Shallow tunnel:

1. Based on the Excel Worksheet from the Problem 1, the convergence-confinement curve (λ – u) at the tunnel wall (r = R) for elastic – plastic ground, is presented on the following *Figure 1.*

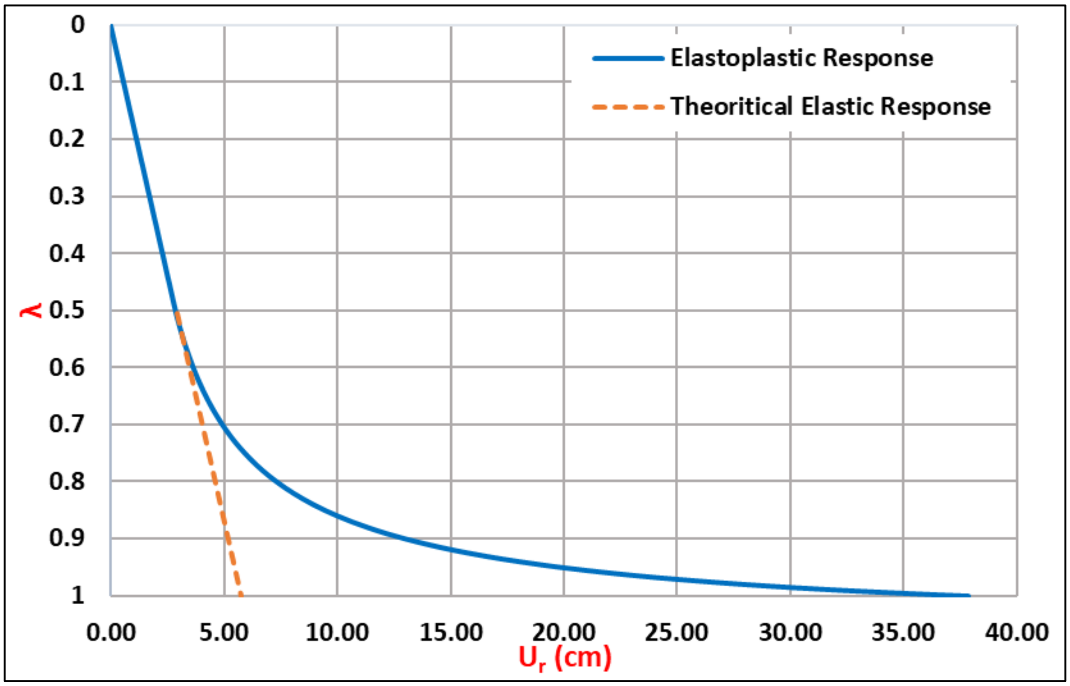

Figure 1. Convergence-confinement curve

2. Based on the Excel Worksheet from the Problem 1, the radial stress (σ_r) along the tunnel wall (r=R) for elastic – plastic ground is presented on the following *Figure 2* and the circumferential (σ_θ) stress is presented on the following *Figure 3.*

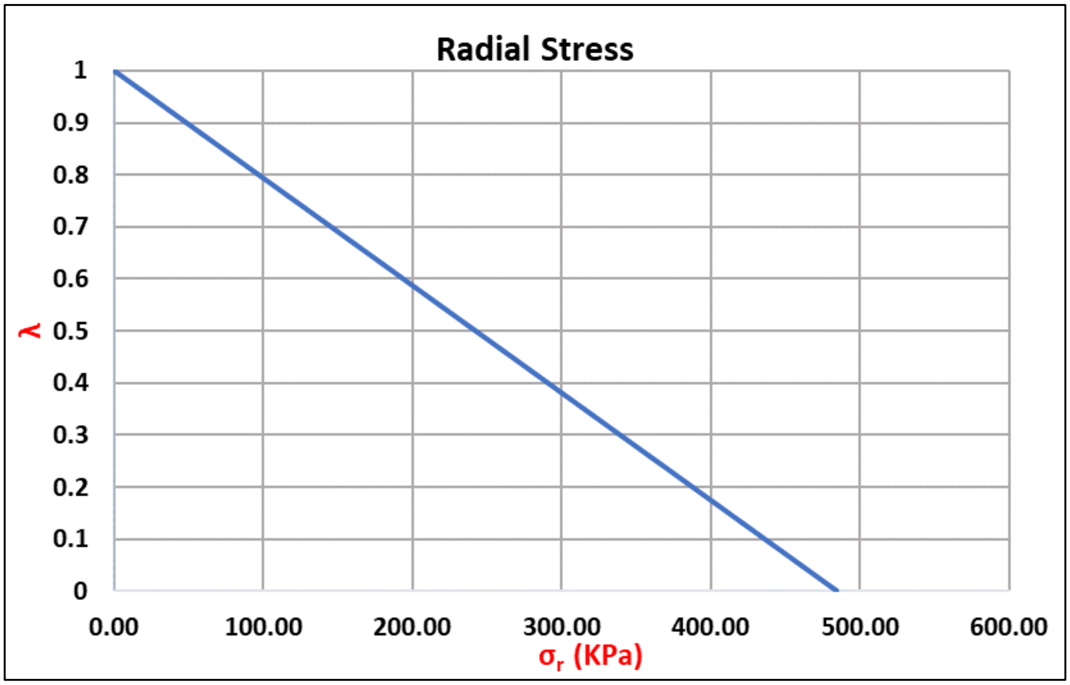

Figure 2. Radial stress (σ_r) along the tunnel wall (r=R)

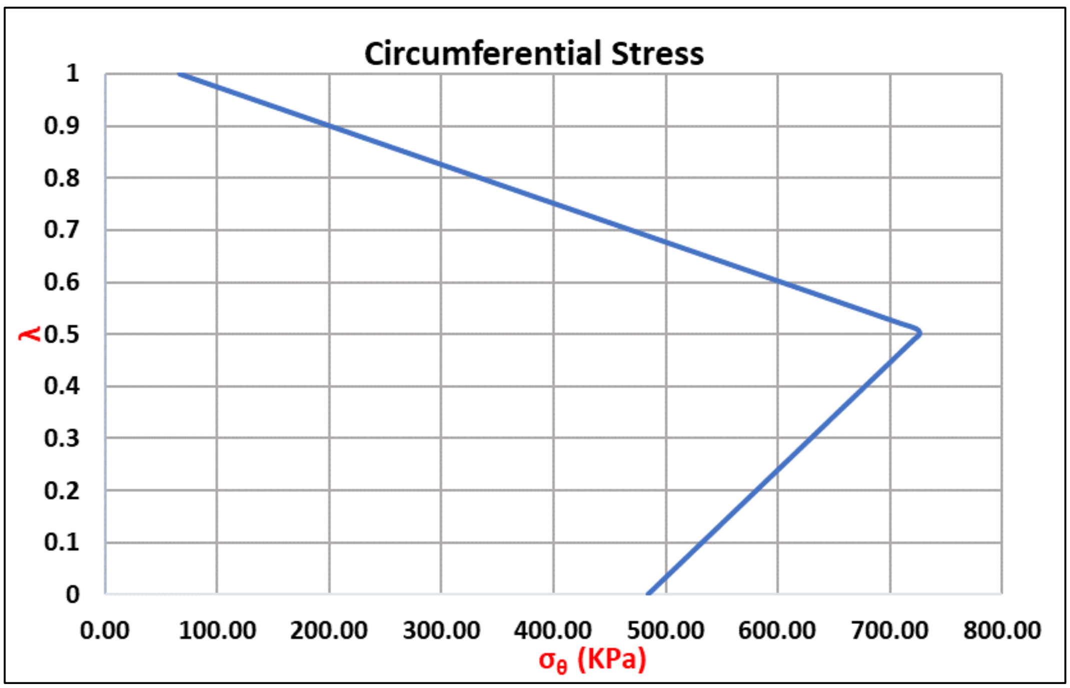

Figure 3. Circumferential stress (σ_ϑ) along the tunnel wall (r=R)

3. Using the *Chern et al (1998)* method for the longitudinal tunnel wall displacement along the tunnel axis, for characteristic locations along the tunnel axis: x/R = -0.3, 0, 0.3, on the following *Table 1* calculated values are presented.

Table 1. Characteristic calculated values along the tunnel axis, based on Chern et al (1998) LDP method.

Location	Radial displacement (u_r)	Radius of plastic zone (R_{pl})	Radial stress (σ_r)	Equivalent internal pressure (p)
x/R = -0.3	14,1cm	8,1m	42KPa	42KPa
x/R = 0	11,5cm	7,3m	58KPa	58KPa
x/R = +0.3	9cm	6,6m	77KPa	77KPa

4. Using the *Chern et al (1998)* method for the longitudinal tunnel wall displacement along the tunnel axis, at distance x/R = -0.1, the equivalent support pressure (p), is calculated p= 50KPa.

For case of tunnel support with shotcrete with total thickness t= 20cm, the compressive stress (σ) in the shotcrete ring, is calculated as follow:

$$\boldsymbol{\sigma} = p \times \left(\frac{R}{t}\right) = 50KPa \times \left(\frac{400cm}{20cm}\right) = \mathbf{1000}\boldsymbol{KPa} = \mathbf{1}\boldsymbol{MPa}$$

Based on the previous *Table 1*, at distance x/R = -0.3 the equivalent support pressure (p), is p= 42KPa.

For case of tunnel support with shotcrete with total thickness t= 20cm, the compressive stress (σ) in the shotcrete ring, is calculated as follow:

$$\boldsymbol{\sigma} = p \times \left(\frac{R}{t}\right) = 42KPa \times \left(\frac{400cm}{20cm}\right) = \mathbf{840}\boldsymbol{KPa} = \mathbf{0.84}\boldsymbol{MPa}$$

The difference on the compressive stress (σ), between case x/R= -0.3 and x/R= -0.1 is due to the fact that in case x/R= -0.3 the support location distance from the tunnel face is higher than in case x/R= -0.1 and the deconfinement factor (λ) is higher, which mean that the equivalent support pressure (p) is lower.

It is preferred to install the support measures at distance x/R= -0.1, in order to reduce the surficial settlements, as the tunnel characterizes as shallow, which means that the effect of the tunnel excavation on the ground surface must restricted. At distance x/R= -0.1, the expected tunnel radial displacement (u_r) and the equivalent surficial displacements will be lower than in case of tunnel support installation at distance x/R= -0.3.
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For Deep tunnel:

1. Based on the Excel Worksheet from the Problem 1, the convergence-confinement curve (λ – u) at the tunnel wall (r = R) for elastic – plastic ground, is presented on the following *Figure 4.*

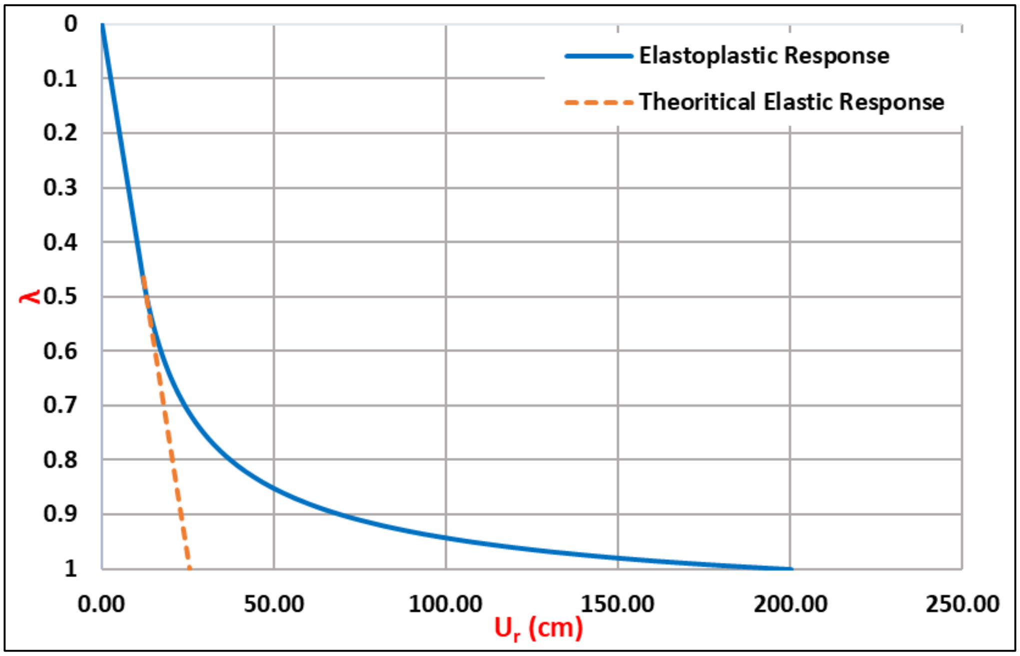

Figure 4. Convergence-confinement curve

2. Based on the Excel Worksheet from the Problem 1, the radial stress (σ_r) along the tunnel wall (r=R) for elastic – plastic ground is presented on the following *Figure 5* and the circumferential (σ_θ) stress is presented on the following *Figure 6.*

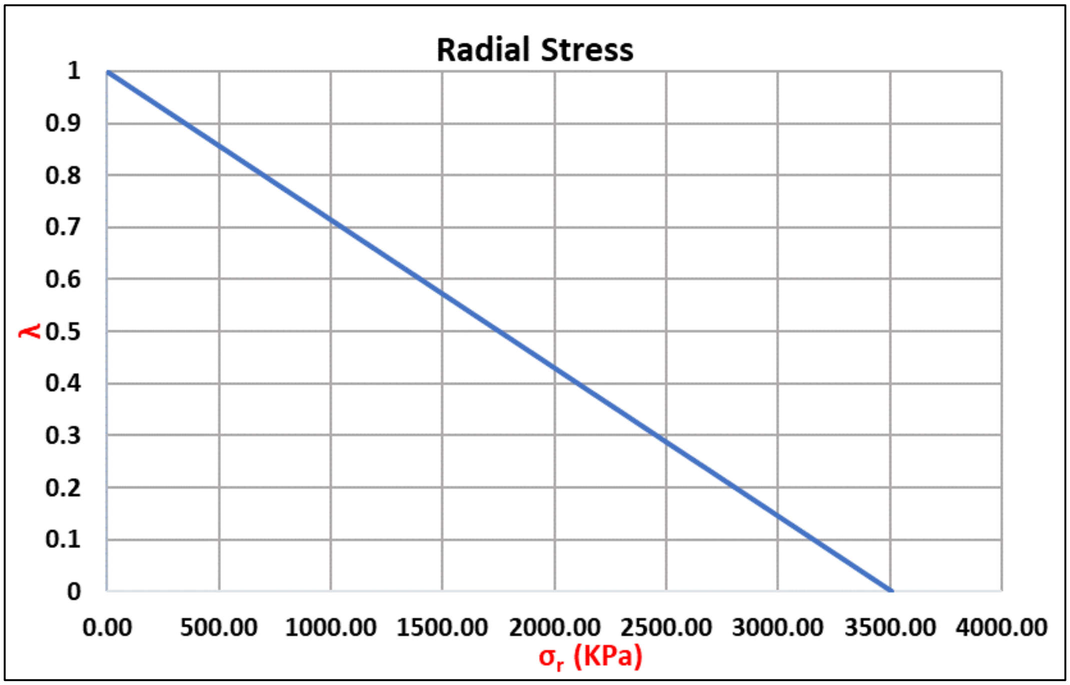

Figure 5. Radial stress (σ_r) along the tunnel wall (r=R)

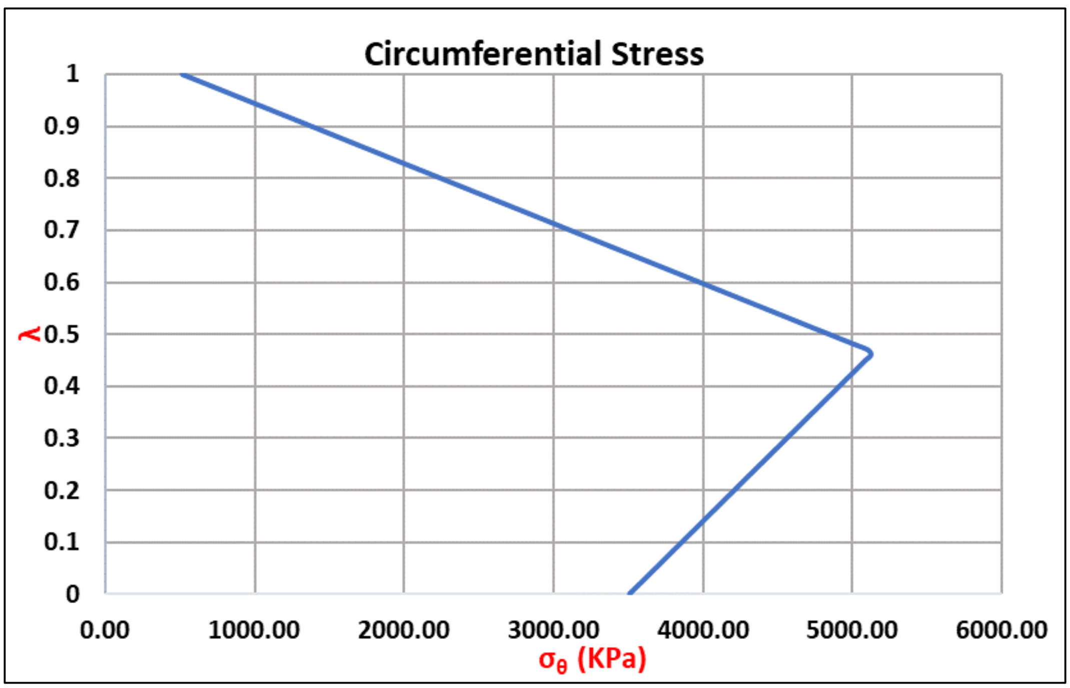

Figure 6. Circumferential stress (σ_ϑ) along the tunnel wall (r=R)

3. Using the *Chern et al (1998)* method for the longitudinal tunnel wall displacement along the tunnel axis, for characteristic locations along the tunnel axis: x/R = -0.3, 0, 0.3, on the following *Table 1* calculated values are presented.

Table 2. Characteristic calculated values along the tunnel axis, based on Chern et al (1998) LDP method.

Location	Radial displacement (u_r)	Radius of plastic zone (R_{pl})	Radial stress (σ_r)	Equivalent internal pressure (p)
x/R = -0.3	75,4cm	15,9m	316KPa	316KPa
x/R = 0	60,2cm	14,4m	421KPa	421KPa
x/R = +0.3	46,7cm	12,9m	562KPa	562KPa

4. Using the *Chern et al (1998)* method for the longitudinal tunnel wall displacement along the tunnel axis, at distance x/R = -0.1, the equivalent support pressure (p), is calculated p= 380KPa.

   For case of tunnel support with shotcrete with total thickness t= 20cm, the compressive stress (σ) in the shotcrete ring, is calculated as follow:

$$\boldsymbol{\sigma} = p \times \left(\frac{R}{t}\right) = 380KPa \times \left(\frac{400cm}{20cm}\right) = \boldsymbol{7600KPa = 7.6MPa}$$

   Based on the previous *Table 2*, at distance x/R = -0.3 the equivalent support pressure (p), is p= 316KPa.

   For case of tunnel support with shotcrete with total thickness t= 20cm, the compressive stress (σ) in the shotcrete ring, is calculated as follow:

$$\boldsymbol{\sigma} = p \times \left(\frac{R}{t}\right) = 42KPa \times \left(\frac{400cm}{20cm}\right) = \boldsymbol{6320KPa = 6.32MPa}$$

   The difference on the compressive stress (σ), between case x/R= -0.3 and x/R= -0.1 is due to the fact that in case x/R= -0.3 the support location distance from the tunnel face is higher than in case x/R= -0.1 and the deconfinement factor (λ) is higher, which mean that the equivalent support pressure (p) is lower.

   It is preferred to install the support measures at distance x/R= -0.3, where the appropriate support pressure (p) is lower than in case at distance x/R= -0.1, in order to reduce the tunnel support cost. Despite the fact that in case of x/R= -0.3, the expected tunnel radial displacement (u_r) will be higher than in case of tunnel support installation at distance x/R= -0.1, there is no limitation on the expected tunnel wall deformation and the expected surficial displacements, as the tunnel is characterized as deep.

***Note that in all cases, the dilation angle (δ) is set to: δ=φ/4, where φ is the ground friction angle.**