# PLAXIS

## Initial Stress Definition in a Rock Mass: K0-Procedure vs Field Stress

PLAXIS 2D 2024.1

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# 1.

# Introduction

The aim of this exercise is to illustrate two fundamental techniques in defining in-situ stresses for a rock mass respectively the K0-procedure and the field stress to represent an initial stress situation defined as:

$$\begin{cases} \sigma_V = \gamma h \\ \sigma_H = K_{0,H}.\sigma_V \\ \sigma_h = K_{0,h}.\sigma_V \end{cases}$$

where,

- $K_{0,H}$ is the coefficient of earth pressure at rest (in major horizontal direction)
- $K_{0,h}$ is the coefficient of earth pressure at rest (in minor horizontal direction)

for the analysis of a circular tunnel excavation at a depth of 500 m in a uniform rock mass characterized by $\gamma$ = 25 kN.m-3, $K_H$ = 1.2 and $K_h$ = 0.8. In this example, two PLAXIS models will be built up for the analysis of the tunnel excavation process followed by the activation of a 20 cm thickness shotcrete lining each model using a different initial stress definition technique.

**Keywords**: PLAXIS 2D, PLAXIS 3D, Rock, Field Stress, K0-procedure, Circular Tunnel, Shotcrete

# 2.

# Model Construction: K0-Procedure

Project properties are set as shown in Figure 1 The model is 200 m wide and uses 15-noded plane strain elements.

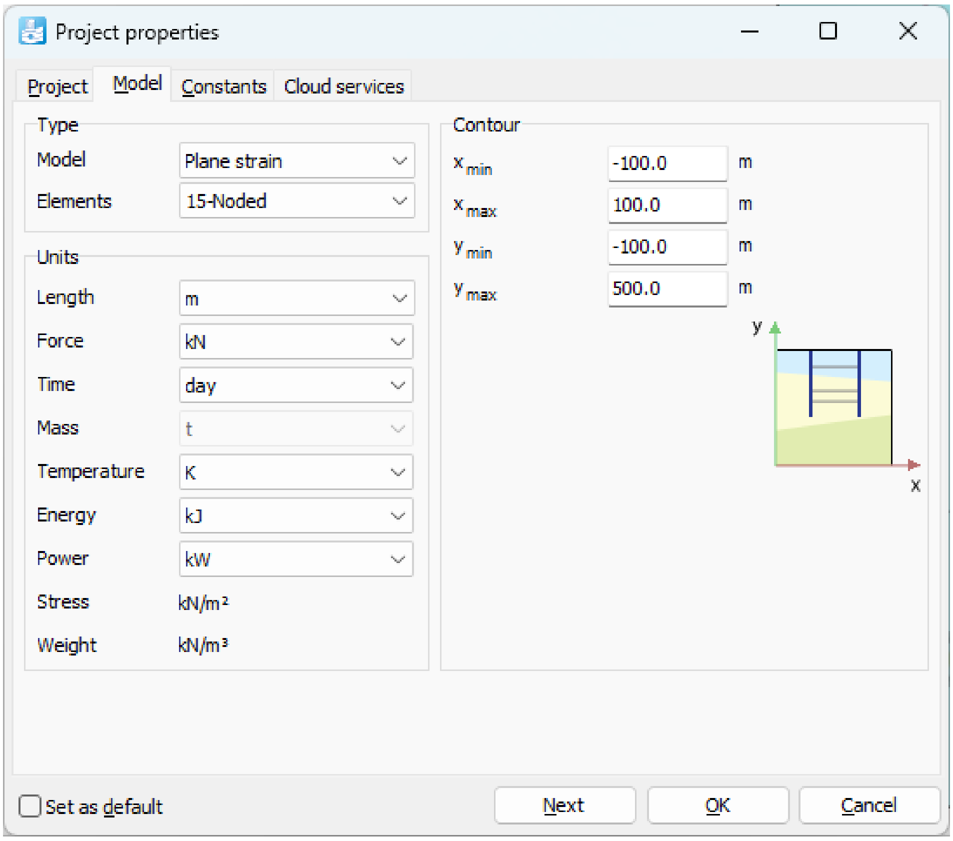



Figure 1: Project properties definition.

*Soil geometry and material properties*

A borehole is defined at x = 0 with a unique soil layer ranging from 500 m down to -100 m. Corresponding material properties are summarized in Table 1. The water level is set at *Head* = -100 m (see Figure 2) such that the entire rock formation is initially dry.

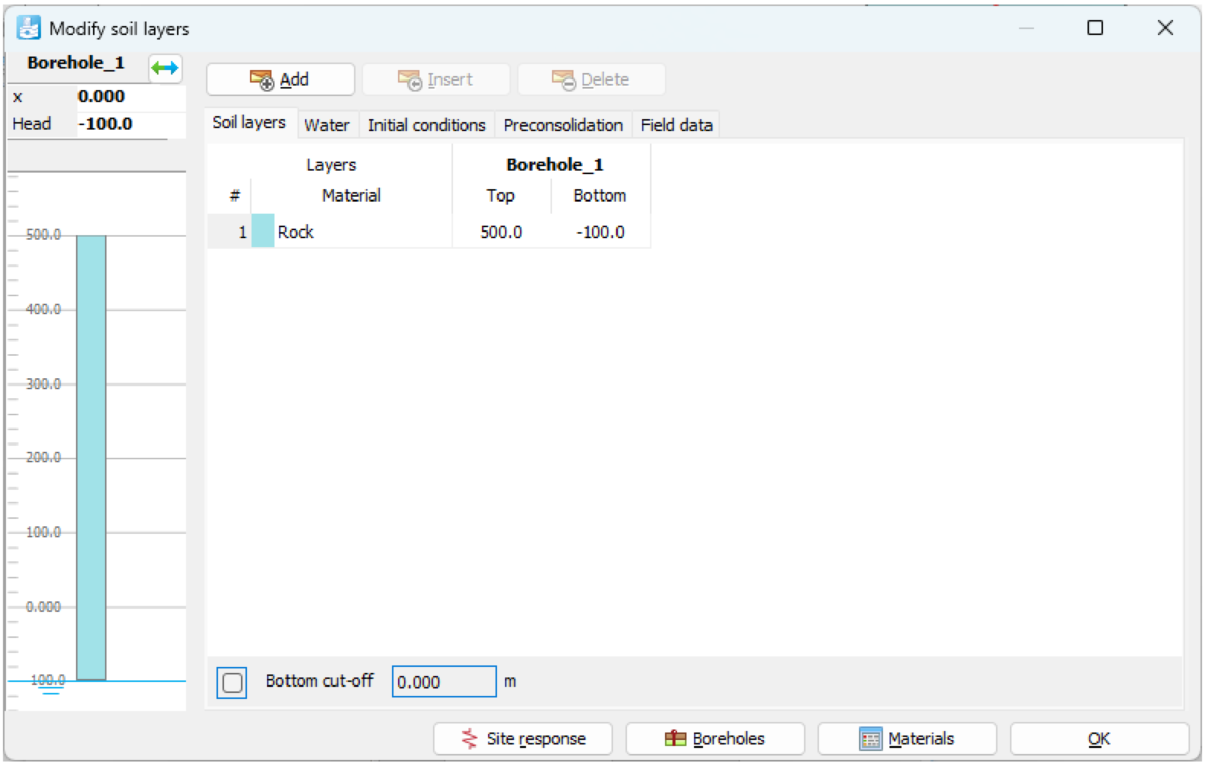



Figure 2: Borehole definition.

Table 1: Soil material model parameter summary

| Material Name | Shale I |
|---|---|
| Soil Model | Mohr-Coulomb |
| Drainage Type | Drained |
| Unit weight unsaturated $\gamma_{unsat}$ | 25 kN.m$^{-3}$ |
| Unit weight saturated $\gamma_{sat}$ | 25 kN.m$^{-3}$ |
| Young's modulus $E'_{ref}$ | 2.0E6 kPa |
| Poisson ratio $v$ | 0.25 |
| Cohesion $c'_{ref}$ | 250 kPa |
| Friction angle φ | 40º |
| Dilatancy angle ψ | 0º |
| Tensile strength | 0 kPa |
| $K_{0,x}$ | 1.2 |
| $K_{0,zx}$ | 0.8 |

*Tunnel definition*

Go to the *Structures* mode and create a tunnel at (0, 0).

In the *Cross section* mode:

- In the General tabsheet:

- Set the *Shape type* to *Circular* and make sure you have chosen to define the whole tunnel.
    - Set the *Offset to begin point* with
        - Axis 1: 0 m
        - Axis 2: -3 m
- In the Segments tabsheet:
    - Select both circular segments and set the *Radius* to 3 m

In the *Properties* mode:

- In the *General* tabsheet:
    - Select the two *SliceSegments* of the tunnel and create plates and negative interfaces along each of them.

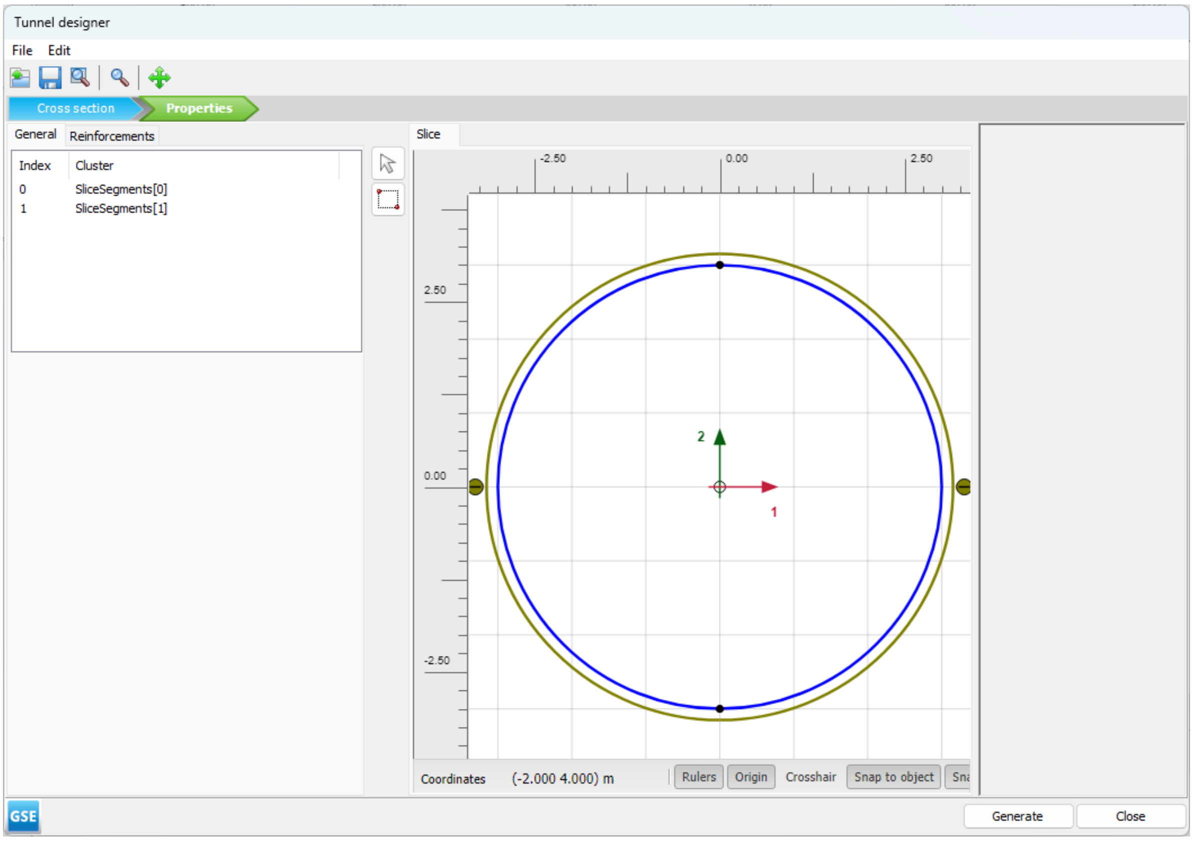



Figure 3: Tunnel configuration

Assign to the plate elements the *Shotcrete* property provided in Table 2. The resulting tunnel configuration is presented in Figure 3. Finalize the tunnel creation by clicking on *Generate* and close the Tunnel designer dialog box.

Mesh refinement will be provided around the tunnel lining and for that purpose the contour of the mesh refinement area should be defined. With that respect define four lines:

- from (-15, -15) to (15, -15),
- from (15, -15) to (15, 15),
- from (15, 15) to (-15, 15),
- from (-15, 15) to (-15, -15).

Table 2: Summary of plate material parameters.

| Material Name | Shotcrete |
|---|---|
| Material type | Elastic |
| Unit weight w | 4.8 kN/m/m |
| Isotropic | Yes |
| Normal stiffness $EA_1 = EA_2$ | 6E6 kN/m$^2$ |
| Bending stiffness $EI$ | 20E3 kN/m$^2$ |
| Poisson's ratio $v$ | 0.2 |

Finally, draw a line from (-100, 100) to (100, 100). The final model geometry is presented in Figure 4.

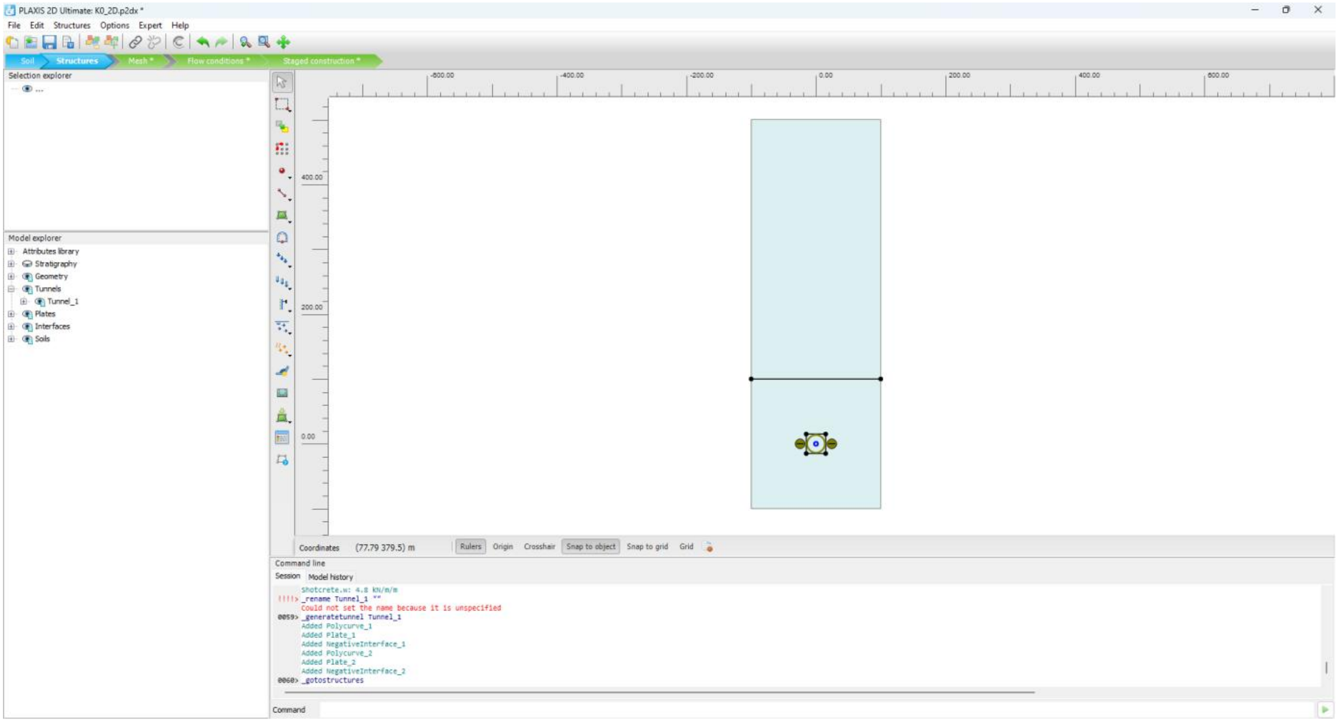


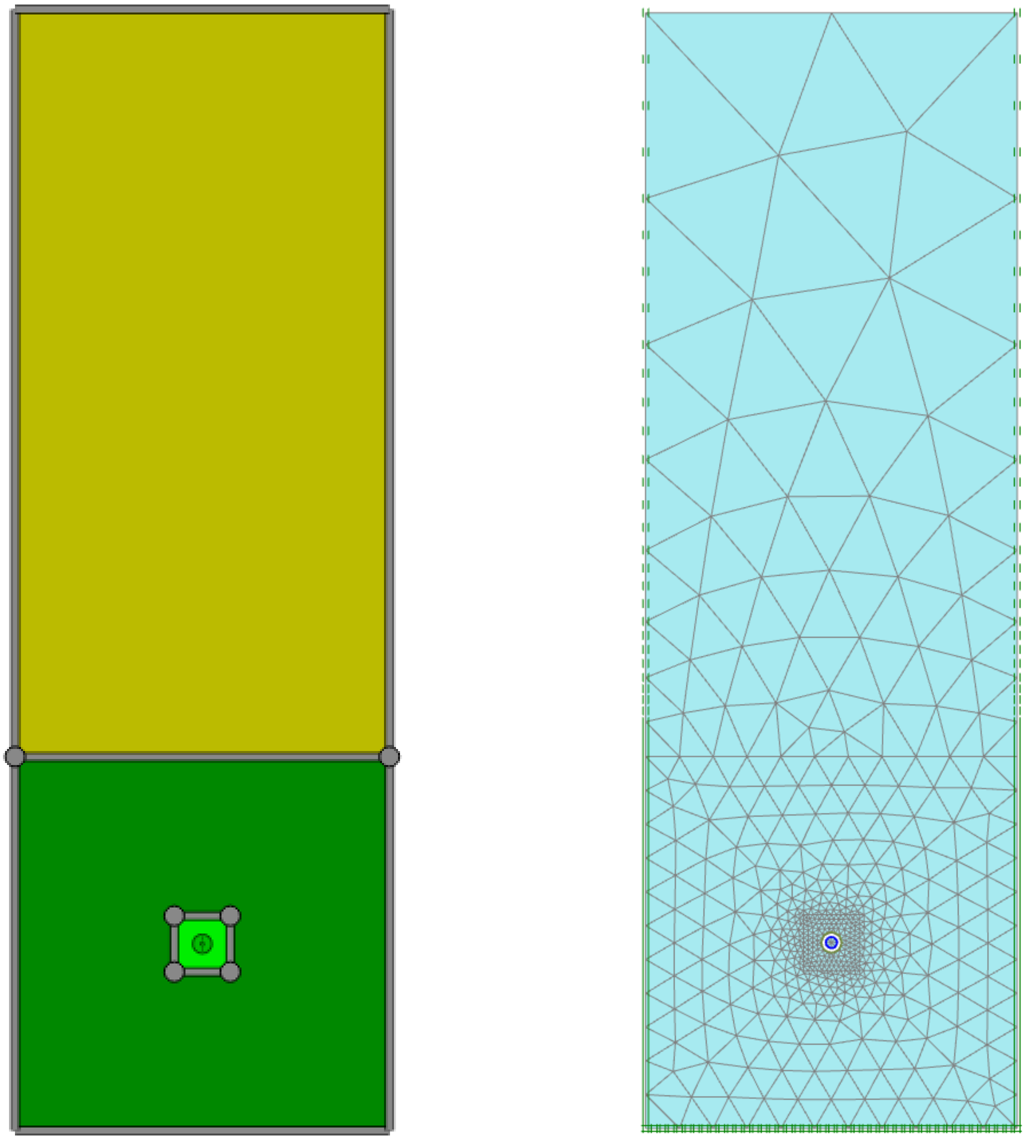

Figure 4: Final model geometry presentation

*Mesh generation*

Go to *Mesh* mode and set the coarseness factor such that:

- the two inner polygons connected to the excavation circular shape has a factor to 0.1,
- the lowest outer polygon has a factor to 0.75,
- the largest upper polygon has a factor to 4.

Generate a mesh using a ***Fine*** element distribution (corresponding to an average element dimension of 25 m). The generated mesh in PLAXIS is presented in Figure 5.



(a) Coarseness definition

(b) Mesh presentation

Figure 5: Mesh generation

<u>*Construction stage definition*</u>

### *Initial conditions*

For the initial phase check the analysis type is set to *K0-procedure.*

### *Phase 1*

Create a new phase entitled “*Excavation 90 %*”. Select the inner polygon and:

- Deactivate it.
- Set the deconfinement (1- $\beta\beta$) to 90 %

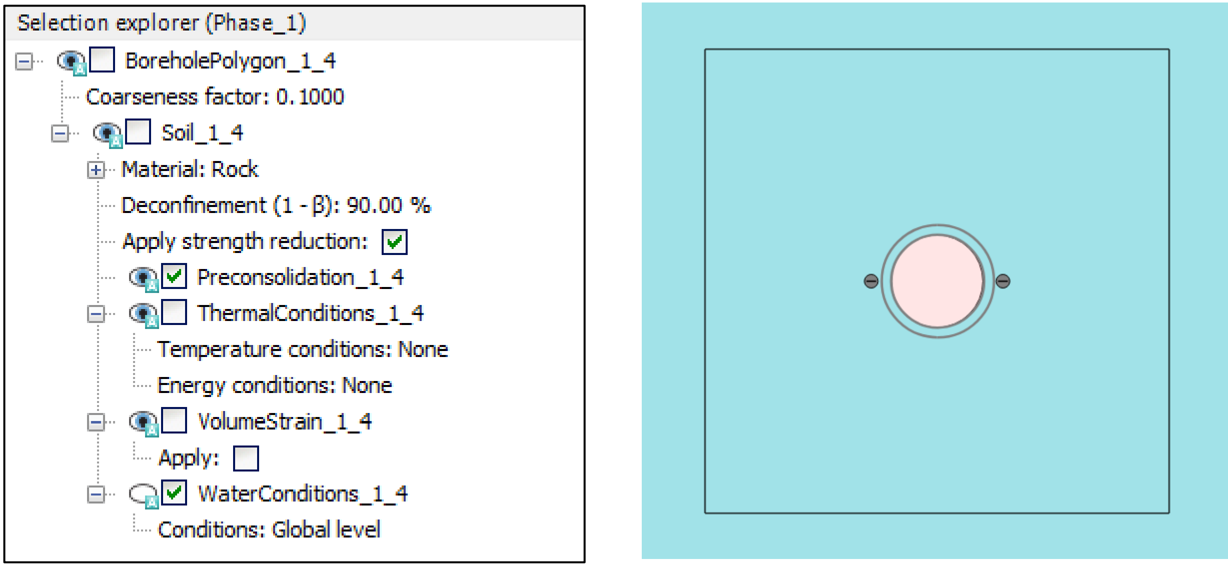



Figure 6: Phase 1 definition

***Phase 2***

Create a new phase entitled “*Shotcrete installation*” and then:

- Activate both shotcrete plate and corresponding negative interface elements,
- Set the deconfinement (1- $\beta$) of the previously deactivated (rock) polygon to 100 %.

Select a few points for curve generation for instance at (3,0) and (0, 3) for instance. Once all phases have been created and points for curves selected, one can start the calculation by clicking on *Calculate*. Once completed, save the PLAXIS 2D analysis run as *K0_2D.p2dx.*

# 3.

# Model Construction: Field Stress

Create a new project and set the project properties as shown in Figure 7. The model is 200 m wide and uses 15-noded plane strain elements.

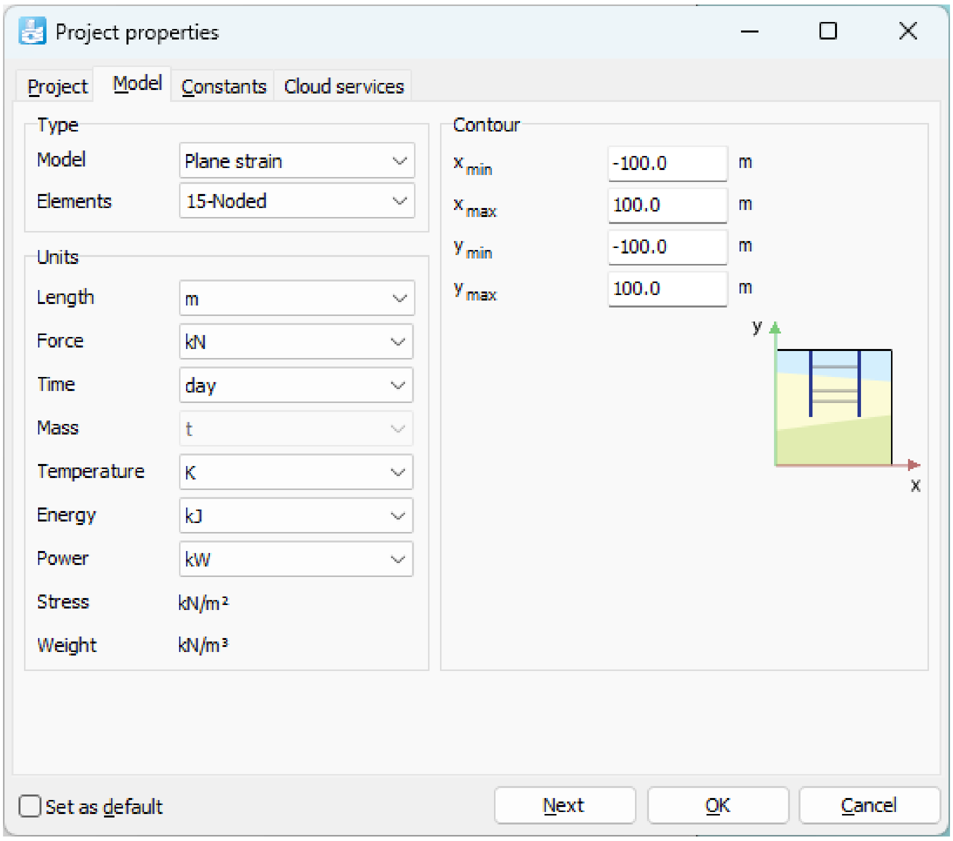



Figure 7: Project properties definition.

*Soil geometry and material properties*

A borehole is defined at x = 0 with a unique soil layer ranging from 100 m down to -100 m. Corresponding material properties are summarized in Table 3. The water level is set at *Head* = -100 m (see Figure 8) such that the entire rock formation is initially dry.

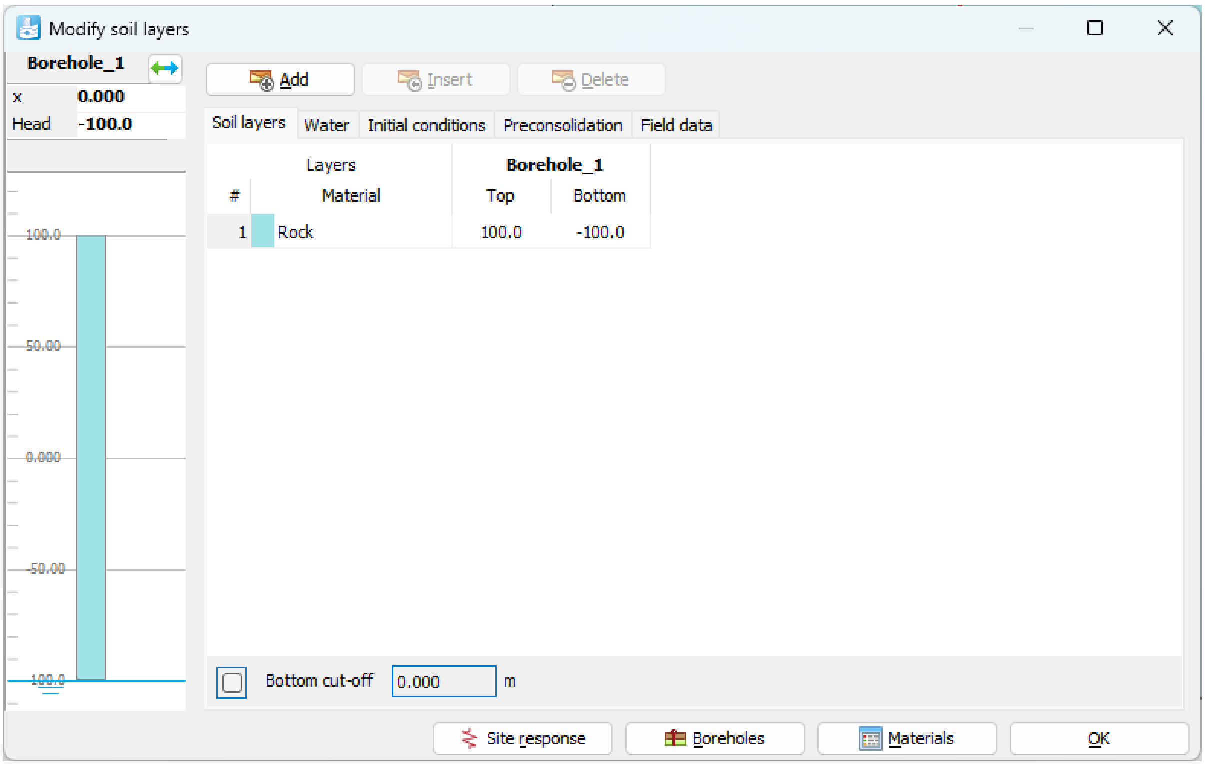



Figure 8: Borehole definition.

*Tunnel definition*

Go to the *Structures* mode and create a tunnel at (0, 0).

In the *Cross section* mode:

- In the General tabsheet:
  - Set the *Shape type* to *Circular* and make sure you have chosen to define the whole tunnel.
  - Set the *Offset to begin point* with
    - Axis 1: 0 m
    - Axis 2: -3 m
- In the Segments tabsheet:
  - Select both circular segments and set the *Radius* to 3 m

In the *Properties* mode:

- In the *General* tabsheet:
  - Select the two *SliceSegments* of the tunnel and create plates and negative interfaces along each of them.

Attach to the plate elements, the *Shotcrete* property provided in Table 4.

The resulting tunnel configuration is presented in Figure 9. Finalize the tunnel creation by clicking on *Generate* and close the Tunnel designer dialog box.

Table 3: Soil material model parameter summary

| Material Name | Shale I |
|---|---|
| Soil Model | Mohr-Coulomb |
| Drainage Type | Drained |
| Unit weight unsaturated $\gamma_{unsat}$ | 25 kN.m$^{-3}$ |
| Unit weight saturated $\gamma_{sat}$ | 25 kN.m$^{-3}$ |
| Young's modulus $E'_{ref}$ | 2.0E6 kPa |
| Poisson ratio $v$ | 0.25 |
| Cohesion $c'_{ref}$ | 250 kPa |
| Friction angle $\varphi$ | 40º |
| Dilatancy angle ψ | 0º |
| Tensile strength | 0 kPa |
| $K_{0,x}$ | 1.2 |
| $K_{0,z}$ | 0.8 |

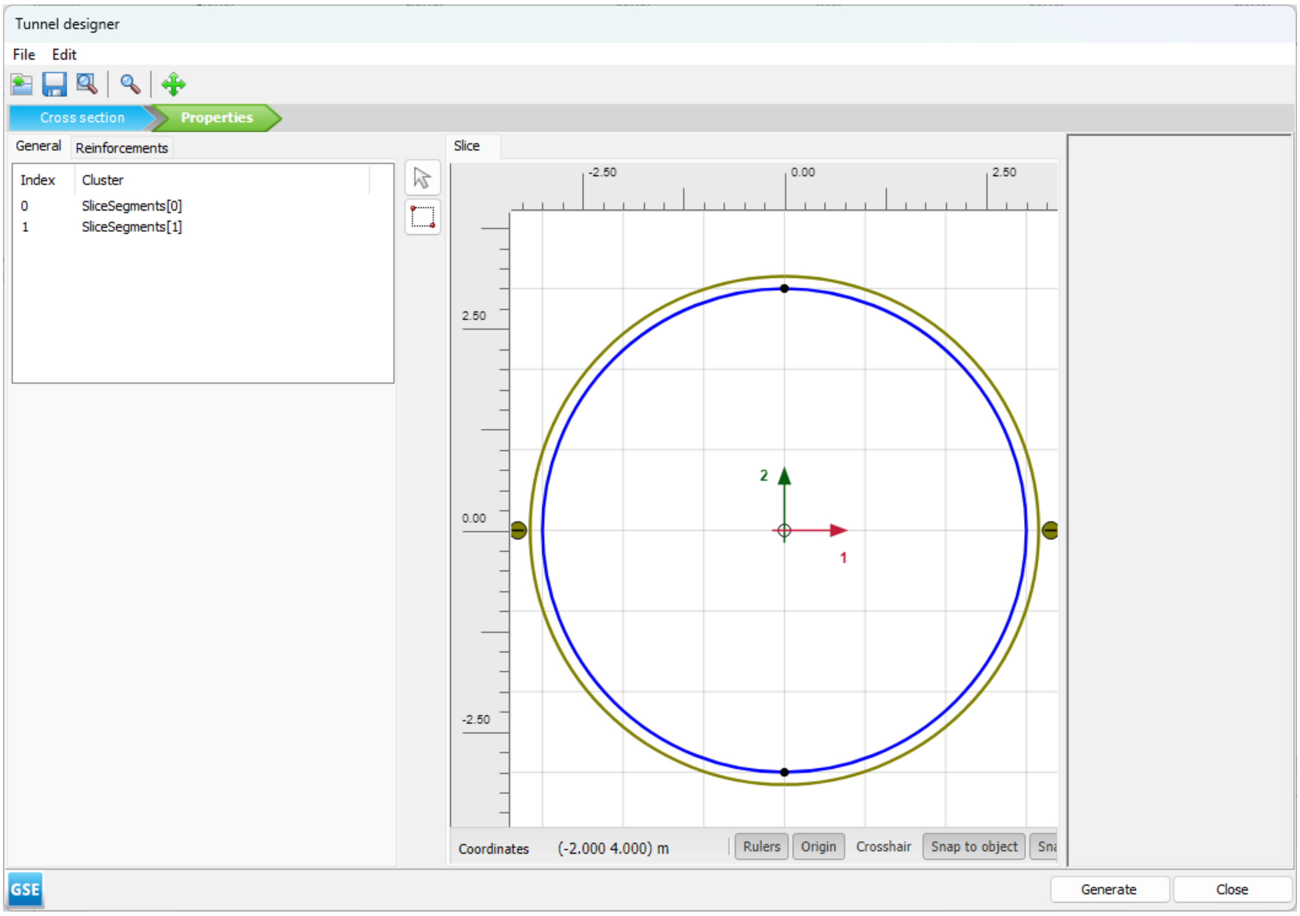



Figure 9: Tunnel configuration

Table 4: Summary of plate material parameters.

| Material Name | Shotcrete |
|---|---|
| Material type | Elastic |
| Unit weight w | 4.8 kN/m/m |
| Isotropic | Yes |
| Normal stiffness $EA_1$ = $EA_2$ | 6E6 kN/m$^2$ |
| Bending stiffness *EI* | 20E3 kN/m$^2$ |
| Poisson's ratio *v* | 0.2 |

Mesh refinement will be provided around the tunnel lining and for that purpose the contour of the mesh refinement area should be defined. With that respect define four lines

- from (-15, -15) to (15, -15),
- from (15, -15) to (15, 15),
- from (15, 15) to (-15, 15),
- from (-15, 15) to (-15, -15),

The final model geometry is presented in Figure 10.

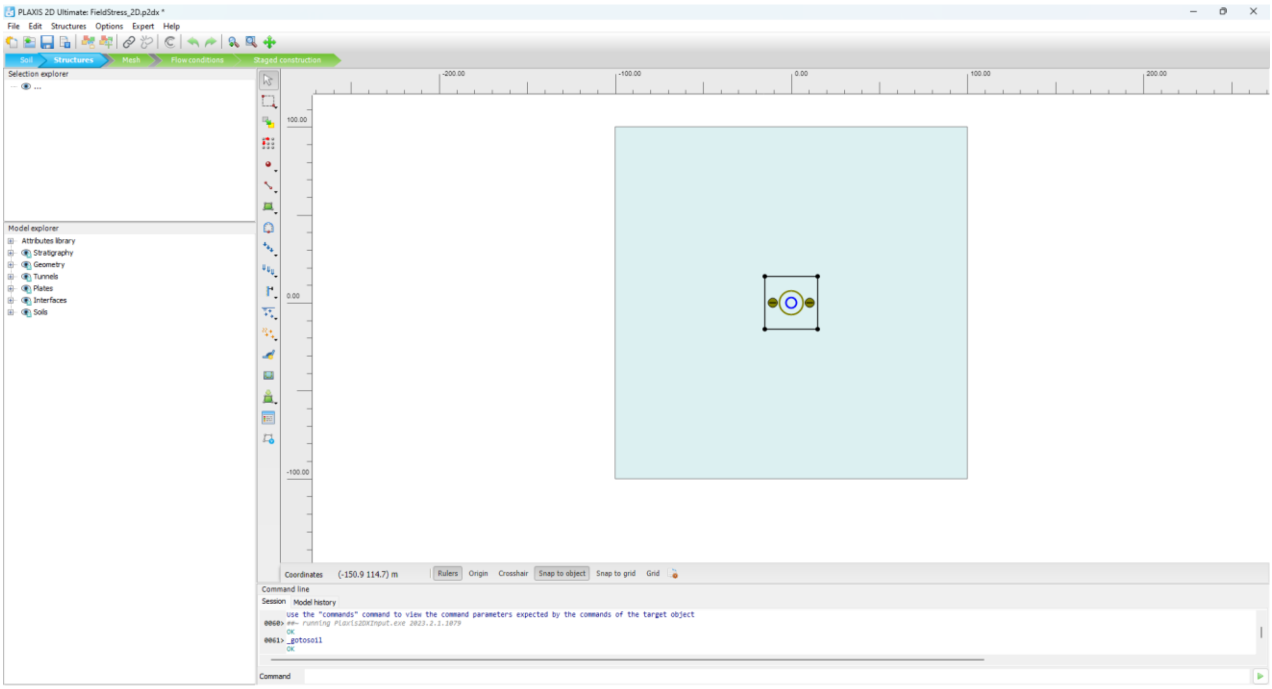



Figure 10: Final model geometry presentation

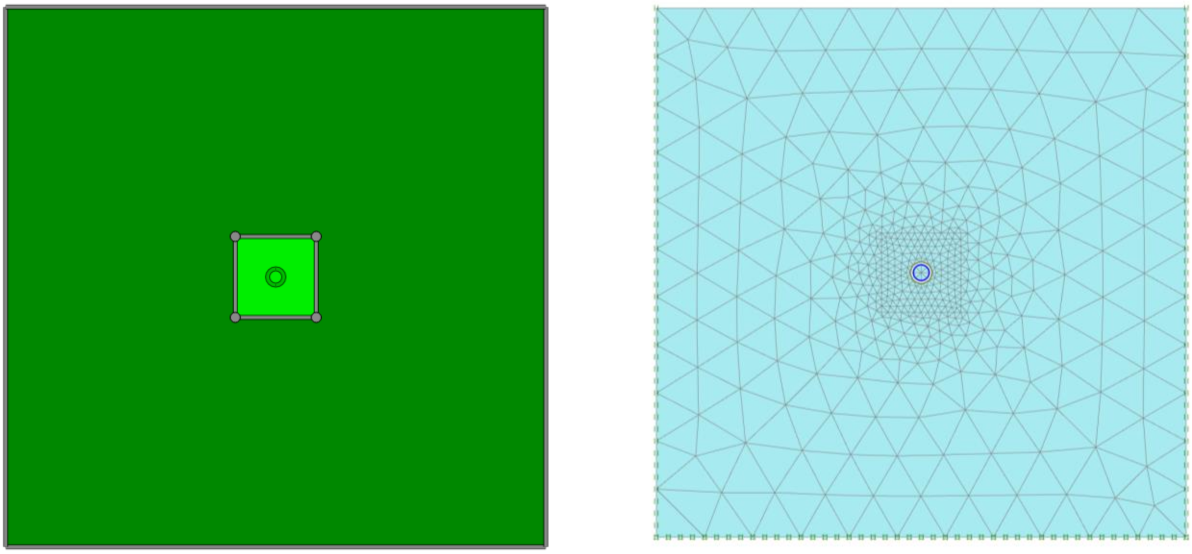
*Mesh generation*

Go to *Mesh* mode and set the coarseness factor such that:

- the two inner polygons connected to the excavation circular shape has a factor to 0.1,

- the lowest outer polygon has a factor to 0.75,

Generate a mesh using an element distribution corresponding to an average element dimension of 25 m (and therefore exactly matching the element dimension used in the previous example). The generated mesh is presented in Figure 11.



(a) Coarseness definition

(b) Mesh presentation

Figure 11: Mesh generation

<u>*Construction stage definition*</u>

***Initial conditions***

For the initial phase set the analysis type to *Field stress.* Then modify the default boundary conditions in the *Deformations* item of the *Model conditions* in the *Model explorer* such that:

- BoundaryXMin: Normally fixed
- BoundaryXMax: Normally fixed
- BoundaryYMin: Normally fixed
- BoundaryYMax: Normally fixed

Finally set the values of the uniform initial stress field in the *FieldStress* item as:

- $\sigma_1$: -12500 kPa
- $\sigma_2$: -15000 kPa
- $\sigma_3$: -10000 kPa

with Axis 1 = (0, 1).

***Phase 1***

Create a new phase entitled "*Excavation 90 %*". Select the inner polygon and:

- Deactivate it.

- Set the deconfinement (1- $\beta\beta$) to 90 %

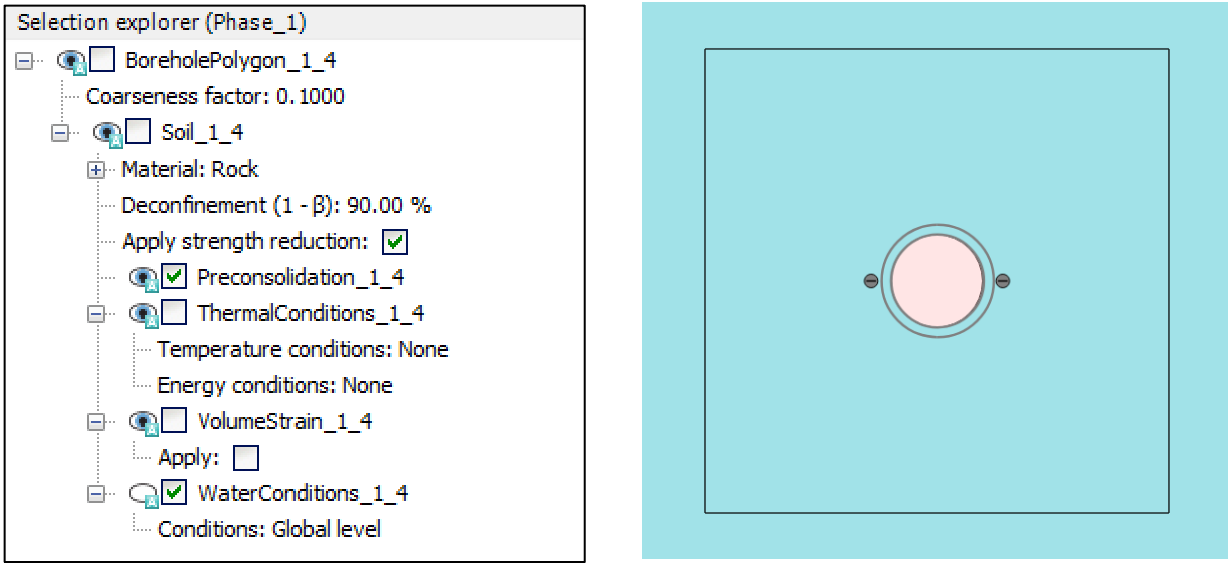



Figure 12: Phase 1 definition

***Phase 2***

Create a new phase entitled "*Shotcrete installation*" and then:

- Activate both shotcrete plate and corresponding negative interface elements,
- Set the deconfinement (1- $\beta$) of the previously deactivated polygon to 100 %

Select a few points for curve generation for instance at (3,0) and (0, 3).
Once all phases have been created and points for curves selected, one can start the calculation by clicking on *Calculate*.
Once completed, save the PLAXIS 2D analysis run as *FieldStress_2D.p2dx*

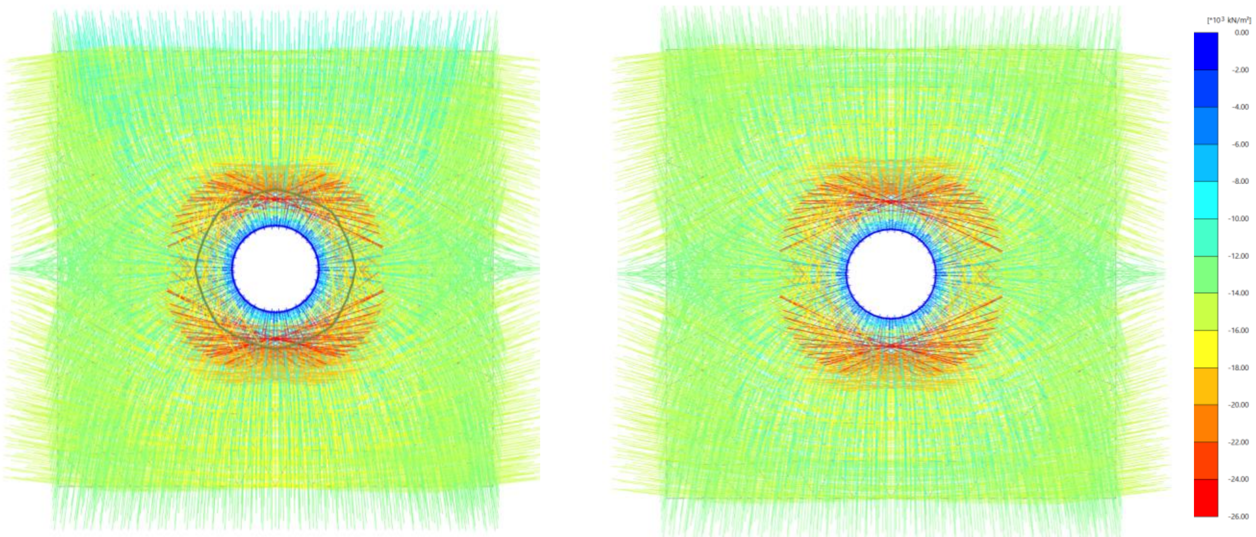
# 4.

# Main Results

The comparison between the two approaches can be made by comparing the results obtained for each model *K0_2D.p2dx* and *FieldStress_2D.p2dx* for the last calculation phase and for wich similar results are expected to be obtained.

*Total principal stresses*

Select the *Total principal stress* result and display stress directions symbols as shown in Figure 13.



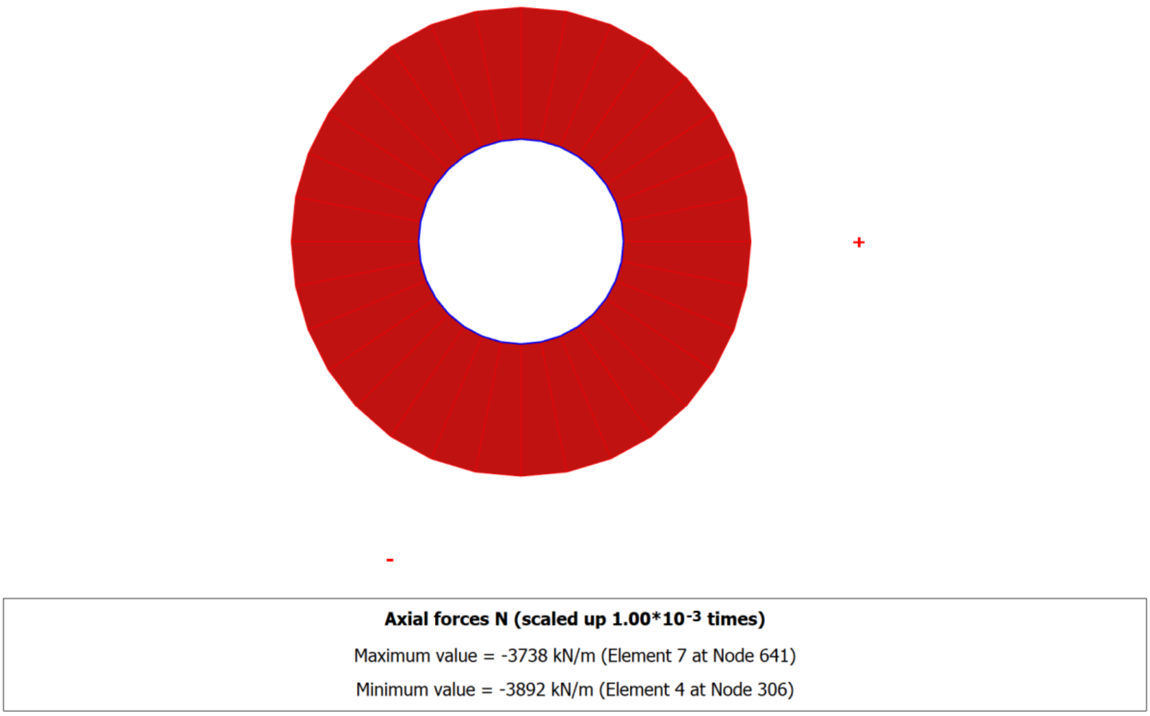

(a) *K0_2D* model

(b) *FieldStress_2D* model

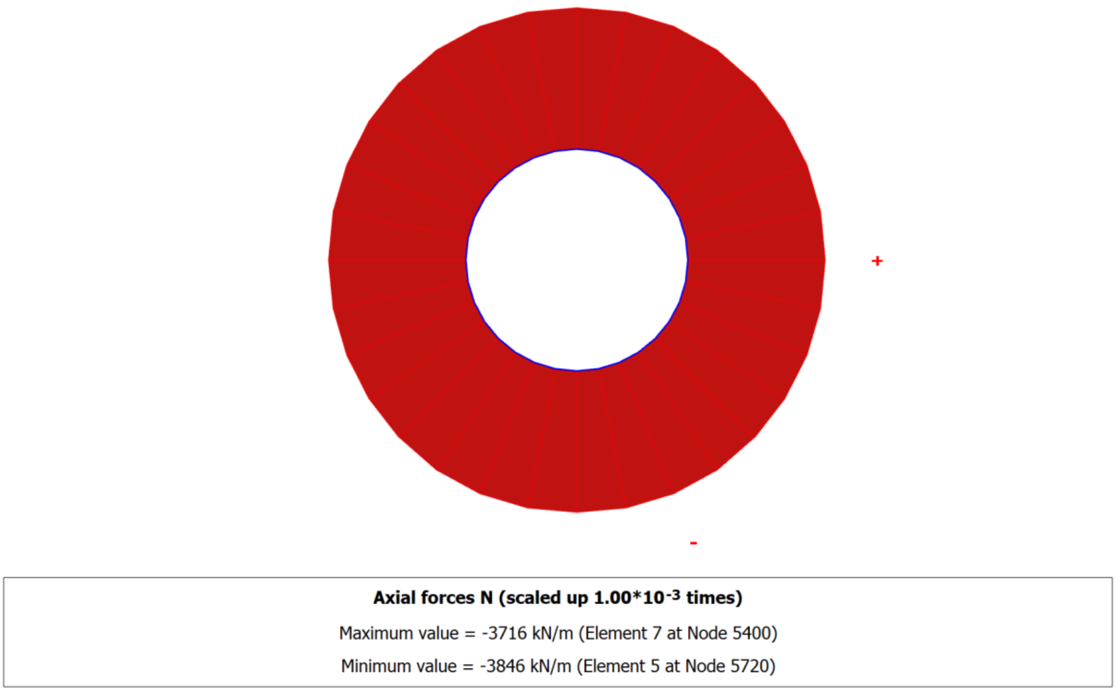
Figure 13: Initial stresses distribution

*Axial forces in shotcrete lining*

Select *the Axial Forces N* result and display their distribution as shown in Figure 14.




(a) *K0_2D* model

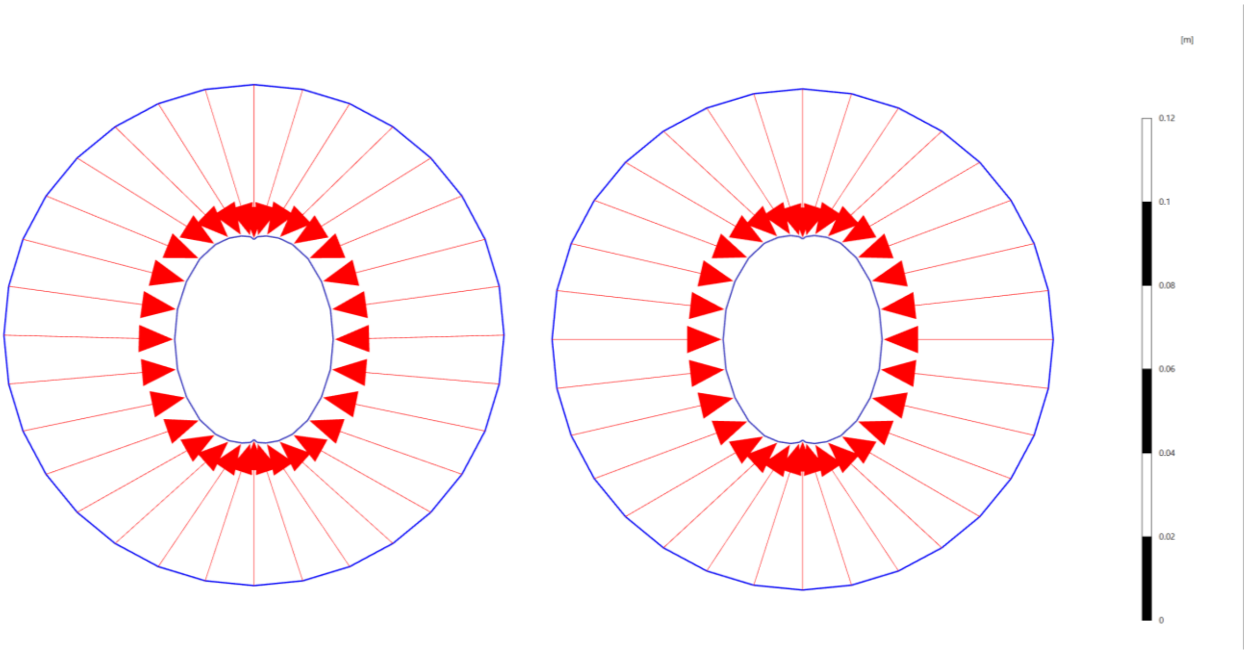



(b) *FieldStress_2D* model

Figure 14: Normal force distribution (Scale factor = 0.001)

*Total displacement around shotcrete lining*

Select the plate elements and view them in the *Structures* mode. Select the *Total displacement* result and display their distribution as shown in Figure 15.




(a) *K0_2D* model

(b) *FieldStress_2D* model

Figure 15: Total displacement distribution (Scale factor = 50)