

# 5

## Stability of a diaphragm wall excavation

This lesson is concerned with a diaphragm wall that is constructed in a stiff sandy clay layer with a groundwater level at 1.0 m below the surface. The excavation process of a diaphragm wall is executed in a specific sequence to obtain the maximum support from the surrounding soil and to prevent soil collapse. A diaphragm wall consists of a number of individually constructed sections. The construction of one such section is modelled in this exercise.

### Objectives

- Defining user-defined water conditions
- Modelling of diaphragm walls installation

### Geometry

A single diaphragm section is excavated in three parts, and the construction can be modelled in five phases. In the first three phases, the wall is excavated part by part in the sequence as shown in the figure below. During the excavation, fluid bentonite with a unit weight of  $11 \text{ kN/m}^3$  is simultaneously pumped in the trench so that the bentonite pressure and the arching in the soil prevents the surrounding soil from collapse. After digging of the trench has been completed, in the fourth phase, fluid concrete is poured in the trench replacing the bentonite. In the fifth phase the concrete hardens, and the diaphragm wall section is complete. The stability of the excavation is lowest in the third phase, when the section is entirely excavated and filled with bentonite. A safety factor is calculated through a phi-c reduction procedure after each phase to observe the stability of the excavation.

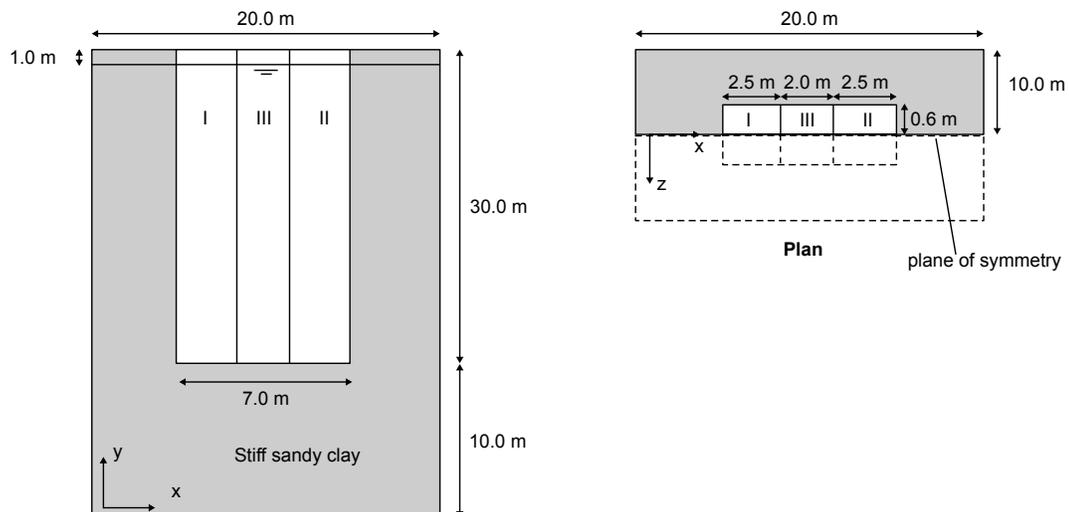


Figure 60: Geometry of the diaphragm wall

# Stability of a diaphragm wall excavation

Create a new project

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## 5.1 Create a new project

The diaphragm wall considered in this exercise is 30 m deep and 1.2 m thick. One section is 7.0 m wide and consists of three excavation parts; part I and II are 2.5 m wide and part III is 2.0 m wide. The wall is symmetric about its central plane, so only one half of the thickness needs to be modelled. The interaction between the wall and the soil is considered to be fully rough, therefore interfaces are not required.

To define the geometry for this exercise, follow these steps:

1. Start the **Input** program and select **New project** from the **Create/Open project** dialog box.
2. Enter an appropriate title for the project.
3. Keep the standard units and set the model dimensions to
  - a.  $x_{\min} = 0$  and  $x_{\max} = 20$ ,
  - b.  $y_{\min} = 0$  and  $y_{\max} = 10$ .
4. Click **OK**.

## 5.2 Define the soil stratigraphy

In the current example only one horizontal soil layer is present. A single borehole is sufficient to define it.

1. Click the **Create borehole** button  and create a borehole at (0 0 0). The **Modify soil layers** window pops up.
2. In the **Modify soil layers** window add a soil layer with top boundary at  $z = 40$  m and bottom boundary at  $z = 0$  m.
3. Set the **Head** to 39 m.

## 5.3 Create and assign the material data sets

The material properties for the data sets are shown in the table below.

**Table 13: Material properties for the soil and concrete**

| Parameter      | Name  | Stiff sandy clay | Concrete       | Unit |
|----------------|-------|------------------|----------------|------|
| <b>General</b> |       |                  |                |      |
| Material model | Model | Mohr-Coulomb     | Linear Elastic | -    |
| Drainage type  | Type  | Drained          | Non-porous     | -    |

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Definition of the diaphragm wall

| Parameter                             | Name             | Stiff sandy clay   | Concrete            | Unit              |
|---------------------------------------|------------------|--------------------|---------------------|-------------------|
| Soil unit weight above phreatic level | $\gamma_{unsat}$ | 15                 | 24                  | kN/m <sup>3</sup> |
| Soil unit weight below phreatic level | $\gamma_{sat}$   | 20                 | -                   | kN/m <sup>3</sup> |
| <b>Parameters</b>                     |                  |                    |                     |                   |
| Young's modulus                       | $E'$             | 50·10 <sup>3</sup> | 2.6·10 <sup>7</sup> | kN/m <sup>2</sup> |
| Poisson's ratio                       | $\nu'$           | 0.3                | 0.2                 | kN/m <sup>2</sup> |
| Cohesion                              | $c'_{ref}$       | 15                 | -                   | kN/m <sup>2</sup> |
| Friction angle                        | $\varphi'$       | 30                 | -                   | °                 |
| Dilatancy angle                       | $\psi$           | 0.0                | -                   | °                 |
| <b>Interfaces</b>                     |                  |                    |                     |                   |
| Interface strength                    | -                | Rigid              | Rigid               | -                 |
| <b>Initial</b>                        |                  |                    |                     |                   |
| K <sub>0</sub> determination          | -                | Automatic          | Automatic           | -                 |

1. Click the **Materials** button .
2. Create the data sets for the soil layer and the concrete as specified in [Table 13](#) (on page 84).
3. Assign the 'Stiff sandy clay' material data set to the soil layer and close the **Material sets** window.

## 5.4 Definition of the diaphragm wall

The diaphragm wall is modelled in the **Structures** mode. The volume elements composing the diaphragm wall are generated by extruding rectangular surfaces.

The coordinates for the surfaces are given in the following table:

**Table 14: Surfaces composing the diaphragm wall**

| Segment | Point coordinates                               |
|---------|---|
| I       | (6.5 0 40) (9 0 40) (9 0.6 40) (6.5 0.6 40)     |
| II      | (11 0 40) (13.5 0 40) (13.5 0.6 40) (11 0.6 40) |

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Generate the mesh

| Segment | Point coordinates                         |
|---------|---|
| III     | (9 0 40) (11 0 40) (11 0.6 40) (9 0.6 40) |

1.  Click the **Create surface** button in the side toolbar and create three surfaces accordingly to [Table 14](#) (on page 85).
2.  Select the created surfaces by keeping the **<Ctrl>** key pressed while clicking them in the model.
3.  Click the **Extrude object** button in the side toolbar. Set the extrusion vector to (0 0 -30) and the extrusion vector length to 30.

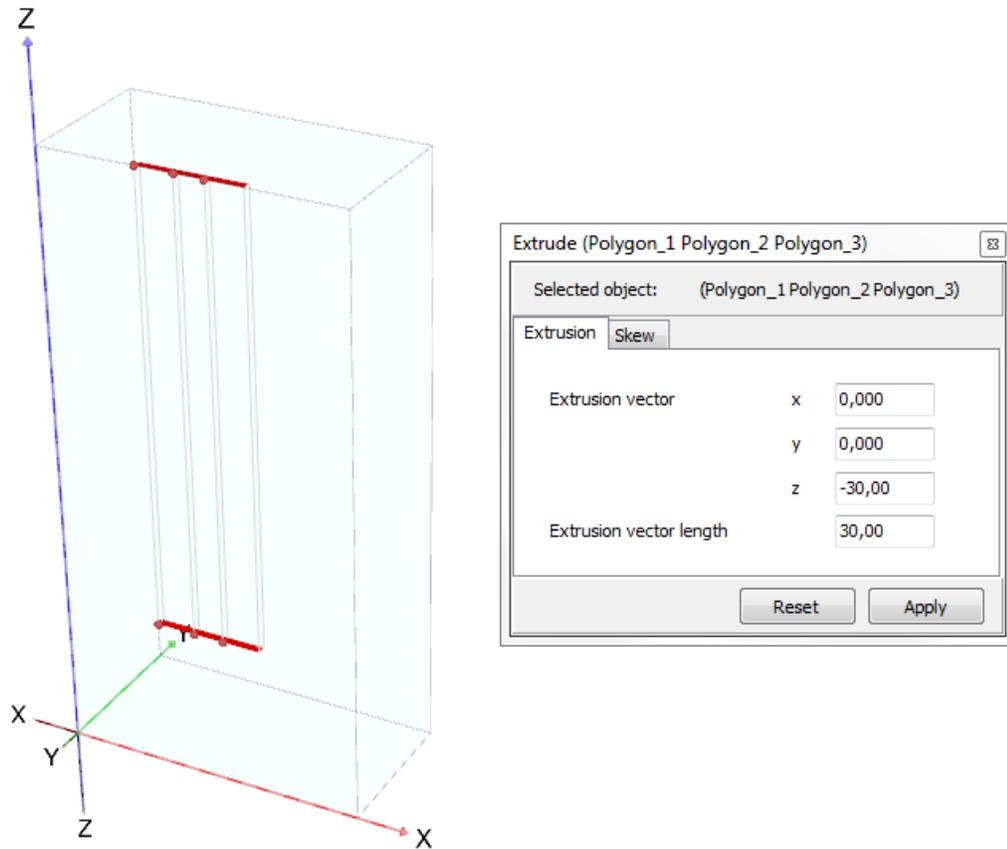


Figure 61: Extrude surfaces

4. Delete the surfaces.

## 5.5 Generate the mesh

In order to generate the mesh:

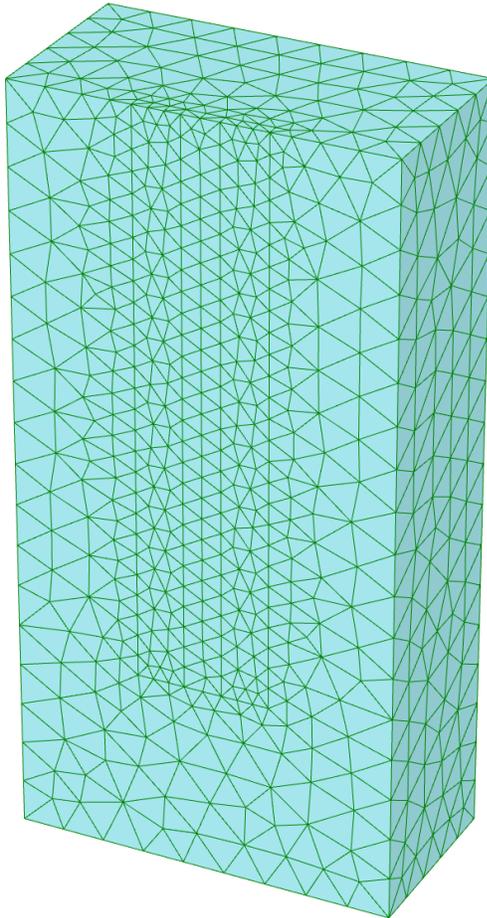
1. Click on the **Mesh** tab to proceed to the **Mesh** mode.

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2. Multi-select all the volume elements of the diaphragm wall.
3. In the *Selection explorer* set the value of *Coarseness factor* to 0.50.
4.  Click the *Generate mesh* button. The default option (*Medium*) is used to generate the mesh.
5.  Click the *View mesh* button to inspect the generated mesh.



*Figure 62: The generated mesh*

6. Proceed to the **Staged construction** mode.

### 5.6 Define the calculation

The calculation consists of five phases. In the first phase, part I of the excavation is removed and simultaneously filled with bentonite. The bentonite, with a unit weight of  $11 \text{ kN/m}^3$ , is simulated employing an artificial 'water' pressure that increases linearly with depth. This pressure replaces the original water pressure inside the excavation. In the second and third phases of the excavation parts, II and III are removed and filled with bentonite. In the fourth phase, the entire excavated trench is filled with fluid concrete. The fluid concrete with a unit weight of  $24 \text{ kN/m}^3$  is simulated by a change in the artificial 'water' pressure. In phase 5, the hardening of

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Define the calculation

the concrete is simulated by removing the artificial pressures, reactivating the excavated clusters and assigning the concrete material set to these clusters.

### 5.6.1 Initial phase

The initial phase consists of the generation of the initial stresses using the ***K0 procedure***. The default settings for the initial phase are valid.

### 5.6.2 Phase 1 - Excavation of part I

1.  Add the first calculation phase.
2. Select the first excavation volume (part I).
3. In the selection explorer, deactivate the soil volume. Set the water condition to ***User-defined*** and enter  $z_{\text{ref}} = 40$  m,  $p_{\text{ref}} = 0.0$  kN/m<sup>2</sup> and  $p_{\text{inc}} = -11$  kN/m<sup>2</sup>/m.

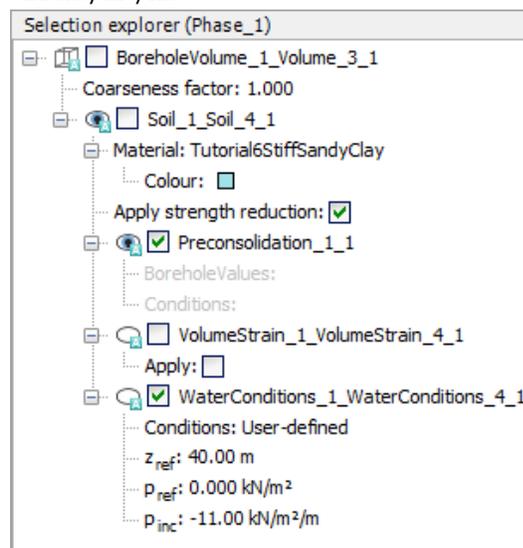


Figure 63: User-defined water condition in part I

A bentonite pressure is now defined in part I of the excavation, starting at 0 kN/m<sup>2</sup> at the reference level of 40 m and increasing at 11 kN/m<sup>2</sup> per m depth, resulting in 330 kN/m<sup>2</sup> at the bottom of the excavation.

4.  Click the ***Preview phase*** button to check the settings for the current phase.

### 5.6.3 Phase 2 - Excavation of part II

1.  Add a new phase.
2. Select the second excavation volume (part II).
3. In the selection explorer, deactivate the soil volume. Set the water condition to ***User-defined*** and enter  $z_{\text{ref}} = 40$  m,  $p_{\text{ref}} = 0.0$  kN/m<sup>2</sup> and  $p_{\text{inc}} = -11$  kN/m<sup>2</sup>/m.

## Stability of a diaphragm wall excavation

Define the calculation

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### 5.6.4 Phase 3 - Excavation of part III

1.  Add a new phase.
2. Select the third excavation volume (part III).
3. In the selection explorer, deactivate the soil volume. Set the water condition to **User-defined** and enter  $z_{\text{ref}} = 40$  m,  $p_{\text{ref}} = 0.0$  kN/m<sup>2</sup> and  $p_{\text{inc}} = -11$  kN/m<sup>2</sup>/m.

### 5.6.5 Phase 4 - Fluid concrete

The bentonite in the excavation is now replaced by fluid concrete with a weight of 24.0 kN/m<sup>3</sup>.

1.  Add a new phase.
2. Select the three excavation volumes.
3. In the selection explorer, change the **User-defined** water conditions and enter  $p_{\text{inc}} = -24$  kN/m<sup>2</sup>/m. The other parameters must be kept at their original values ( $z_{\text{ref}} = 40$  m,  $p_{\text{ref}} = 0.0$  kN/m<sup>2</sup>).

### 5.6.6 Phase 5 - Cured concrete

1.  Add a new phase.
2. Select the three excavation volumes.
3. In the selection explorer, reactivate the soil volumes and set the material to concrete.
4. Set the water condition to **Dry**.

#### Note:

Although the concrete is non-porous and the calculation program will automatically assume zero pore pressures in these elements, it is a good practise to regenerate the water pressures such that the generated pore pressures correspond to those used in the calculation program.

### 5.6.7 Phase 6 to 9 - Safety analysis

In Phases 6 to 9, stability calculations are defined for the previous phases respectively except for the fluid concrete phase (less critical than the bentonite phase thanks to the higher unit weight). Phase 3 should be the most critical because the support pressure from the bentonite is low. Also, the excavation is at its full width, which reduces the possibility for lateral arching. A check on whether Phase 3 is the most critical stage can be carried out by calculating the safety factors for the first three phases through a **Safety** analysis.

1. Select Phase\_1 in the **Phases explorer**.
2.  Add a new calculation phase and proceed to the **Phases** window.
3.  Set **Calculation type** to **Safety**. The **Incremental multipliers** option is valid as **Loading type**.
4. Select the **Reset displacements to zero** option in the **Deformation control** subtree.
5. In the **Numerical control parameters** subtree set the **Max steps** parameter to 40.

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### Results

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6. Follow the same procedure to add **Safety** analysis phases following phases 2, 3 and 5.

### 5.6.8 Execute the calculation

1.  In the **Staged construction** mode select some nodes near (10 1 40) and (10 4.5 40) for curves.
2.  Start the calculation process.
3.  Save the project when the calculation is finished.

## 5.7 Results

The stability of the excavation can be evaluated from the calculated safety factor after each excavation stage. Use the Curves program to plot  $\Sigma$  Msf (the safety factor) as a function of the displacements  $|u|$  (see [Figure 64](#) (on page 91)). In Phase 3, the stability is the lowest. However,  $\Sigma$  Msf remains greater than 1 and so collapse would not be expected.

In order to evaluate the safety factors for the three situations in this way, follow these steps:

1. Click the **Curves manager** button in the toolbar.
2. Click **New** in the **Charts** tabsheet.
3. In the **Curve generation** window, select one of the two nodes for the x-axis. Select **Deformations > Total displacements >  $|u|$** .
4. For the y-axis, select **Project** and then select **Multiplier >  $\Sigma$  Msf**. The Safety phases are considered in the chart. As a result, the curve of [Figure 64](#) (on page 91) appears.
5. Set x-axis interval maximum to 0.1 in **Chart** tab.

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## Results

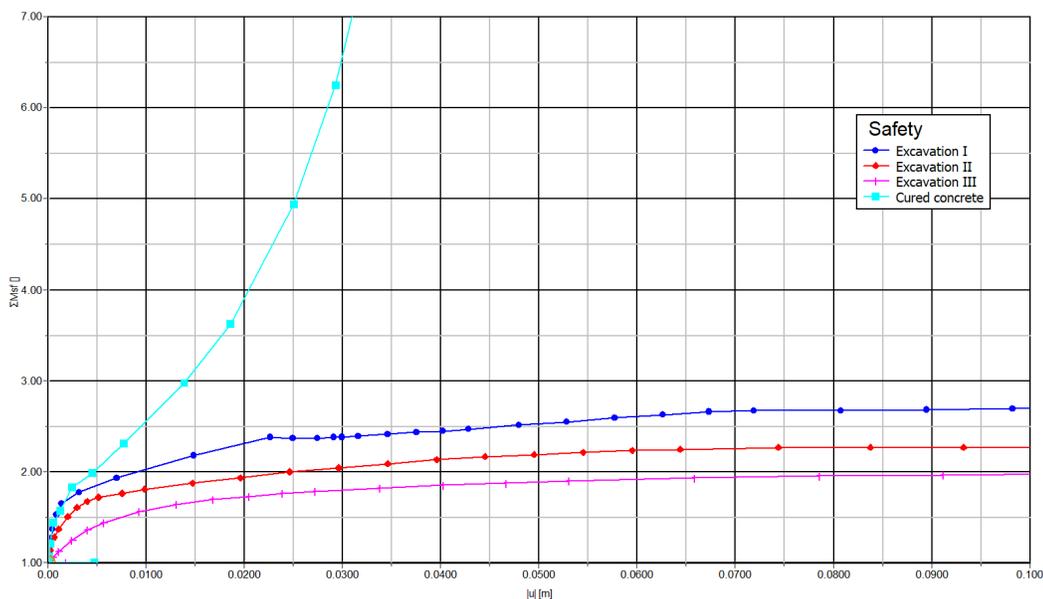


Figure 64:  $\Sigma M_{sf}$  (safety factor) as a function of the total displacement

An important phenomenon that keeps the excavation stable is arching in the soil. This phenomenon is shown in the three figures below. To see the principal stresses directions at a chosen depth, make a horizontal cross section by clicking the **Horizontal cross section** button.

1.  To create such plots, make a horizontal cross-section by clicking the **Horizontal cross section** button in the side bar.
2. In the window that appears fill in a cross section height of 25 m (at the mid-height of the diaphragm wall).
3. Select the menu item **Stresses > Principal total stresses > Total principal stresses**.
4.  Select the top view in **View > Viewpoint** to reorientate the model in order to obtain a clearer view of the arch effect.

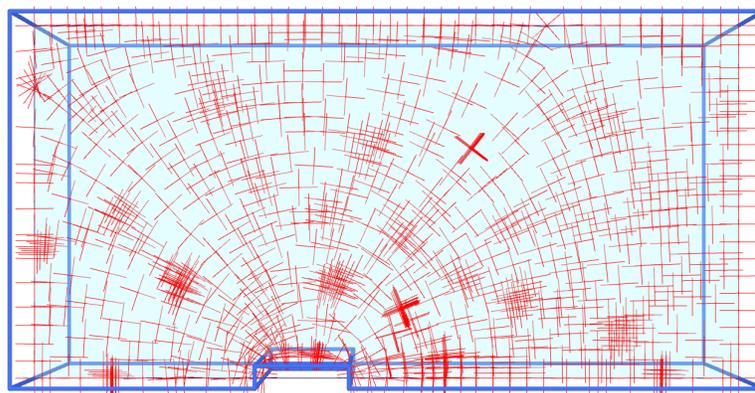


Figure 65: Principal stresses directions at  $z = 25$  m at the end of Phase\_1

# Stability of a diaphragm wall excavation

Results

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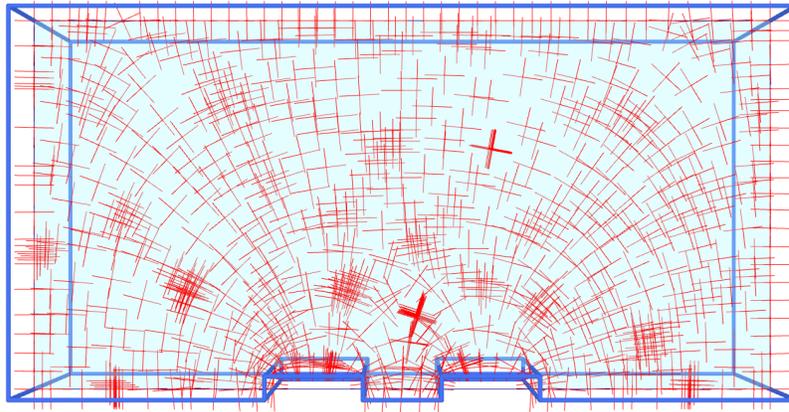


Figure 66: Principal stresses directions at  $z = 25$  m at the end of Phase\_2

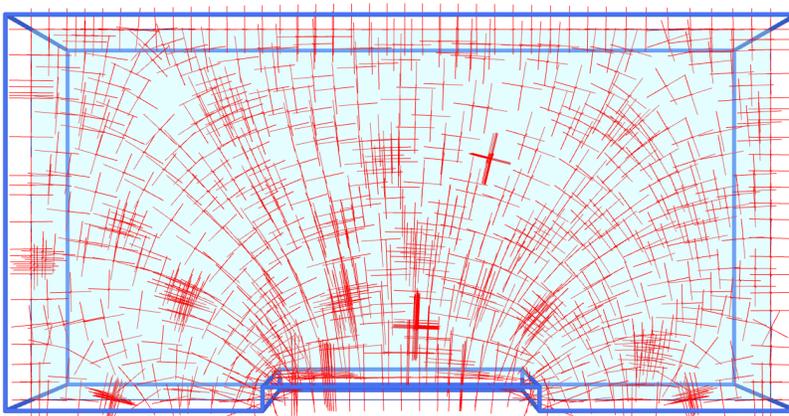


Figure 67: Principal stresses directions at  $z = 25$  m at the end of Phase\_4