

### Exercise 4: Thermo-mechanical analysis on an Energy Wall

A shallow tunnel has to be constructed in an urban environment. The possibility of thermal activation is being considered by the owner of the site, hence a preliminary estimation of the thermally-induced mechanical effects has to be evaluated. The tunnel structure has a rectangular cross section and the heat exchanger pipes should be installed on the walls but not on the slab.

The student is required to analyse the tunnel structure (in terms of bending moment and shear forces) and to calculate the following requirements:

1. To evaluate the lateral earth pressure distribution on the side of the wall.
2. To analyse and solve the structure before the thermal activation.
3. To analyse and solve the structure with thermal loads (cooling:  $\Delta T = -5^\circ\text{C}$ ).
4. To analyse and solve the structure with thermal loads (heating:  $\Delta T = +5^\circ\text{C}$ ).
5. To sum the effects of points “2. and 3”. and points “2. and 4.” and evaluate the envelope of bending moments and shear forces.
6. To compare and comment the results of point 5.

#### Materials

Consider a shallow tunnel constructed in a uniform soil deposit with groundwater table (GWT) located 1 m below the surface. The soil is considered to be fully saturated below the GWT and dry above the GWT. The tunnel is made of reinforced concrete. The soil and wall properties are listed in Tables 1 and 2.

Table 1. Soil properties.

	$\gamma'_s$	$\gamma'_{dry}$	$\gamma'_w$	$\varphi'$
	[kN/m <sup>3</sup> ]	[kN/m <sup>3</sup> ]	[kN/m <sup>3</sup> ]	deg
<b>Soil</b>	10	15	10	30

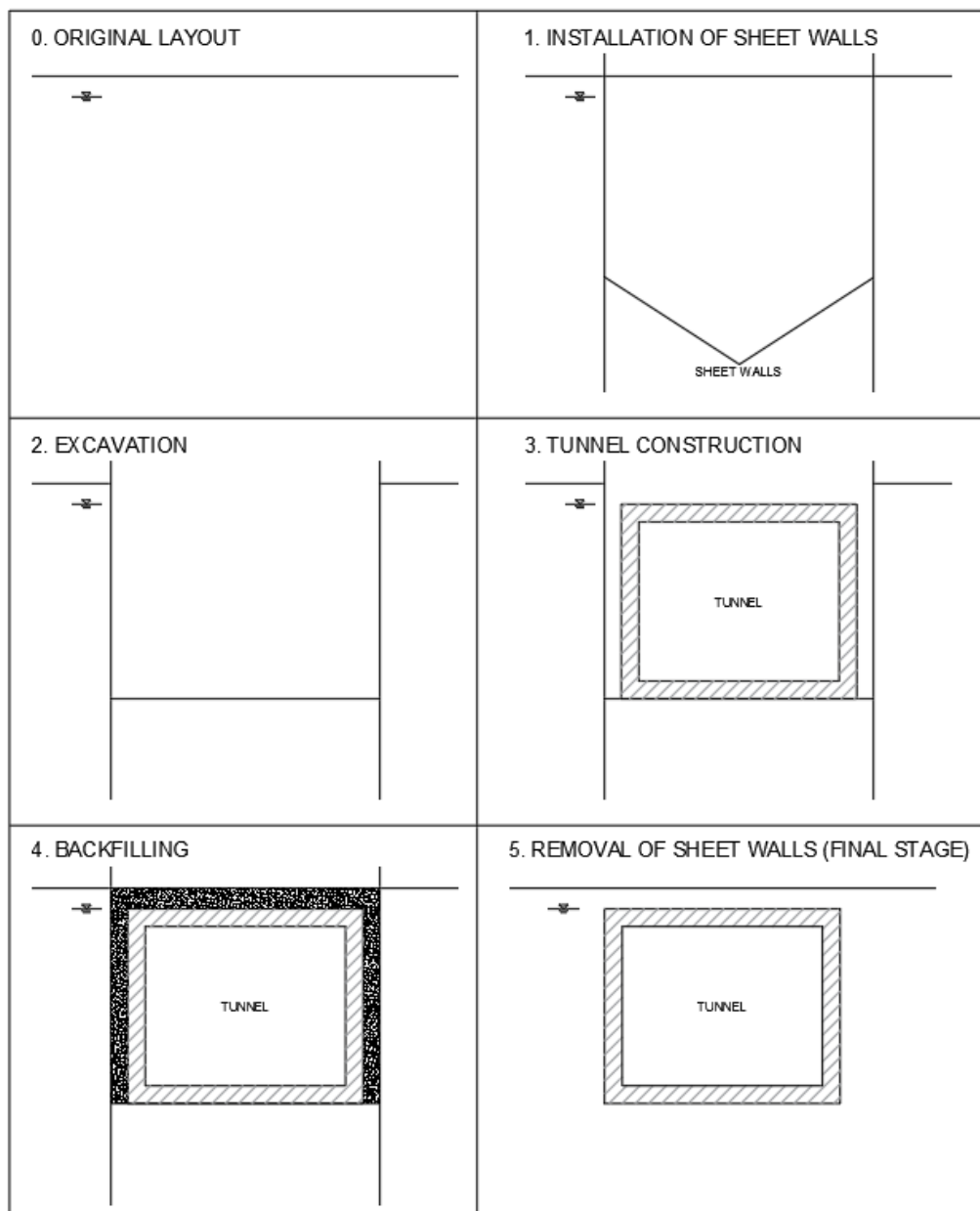
Table 2. Wall properties.

	$E_{concrete}$	$\alpha_{concrete}$
	[MPa]	[ $\mu\epsilon/^\circ\text{C}$ ]
<b>Concrete</b>	25000	10

### Construction stages

In order to get the final step of construction, a number of stages have to be taken into account and are reported in Figure 1.

Figure 1 Construction stages

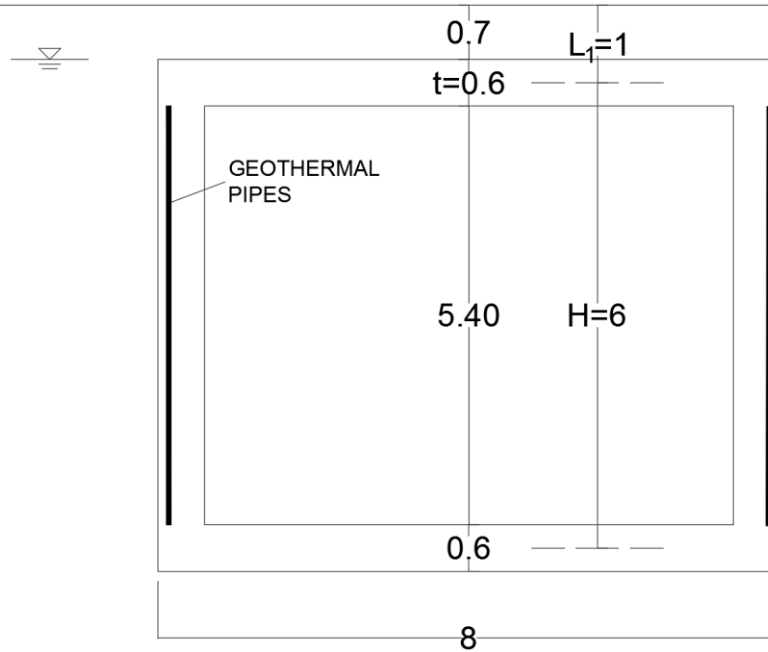


The thermal activation takes place after the end of stage 5. Because of the construction technique, the soil surrounding the tunnel can be considered *at rest* conditions.

## Geometry

The final geometry of the tunnel is described in Figure 2.

Figure 2 Geometry of the tunnel. Quotes in meters.



The calculations should be performed with reference to a slice of  $b=1$  m of tunnel.

Table 3. Geometry.

<b>H</b>	<b>t</b>	<b>L<sub>1</sub></b>	<b>b</b>
<b>m</b>	m	m	m
<b>6</b>	0.6	1	1

Due to the construction technique, the walls can be considered as *perfectly clamped* with the slabs at the top and at the bottom, hence the following thermo-mechanical schemes should be used for the resolution of the structure (Figure 3).

Figure 3 Thermo-mechanical schemes

