Strutted Excavation

1 Introduction

This is a simple example that illustrates the procedure and steps involved in simulating the staged construction of a strutted excavation.

Figure 1 illustrates the problem setup. The soil is assigned a total unit weight of 20 kN/m^3 and a Poisson's ratio of 0.334, which represents a K_o of 0.5.

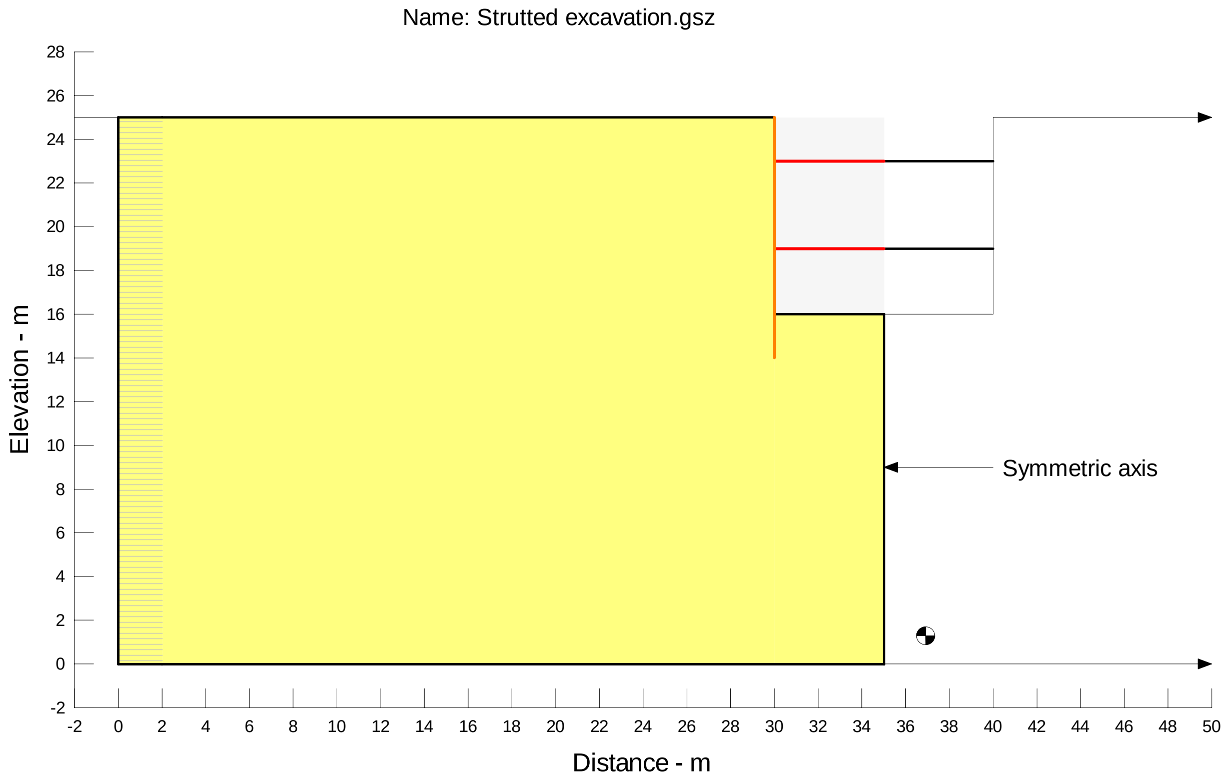
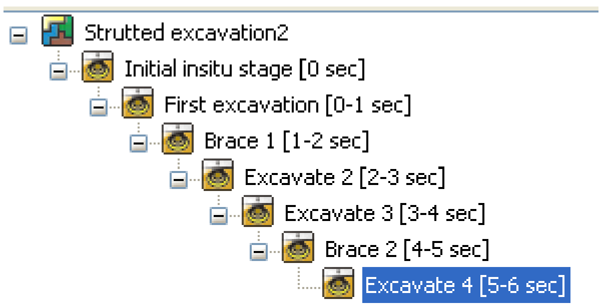


Figure 1 Problem configuration

2 Analysis tree

The following diagram shows the analysis tree.



The first step is to establish the starting insitu stresses. The sheet pile wall is then 'wished' into place and the first 2 m are excavated. The top brace is then installed and a further 2 m is excavated. In the third step another 2 m are excavated. Then finally, the lower strut is installed and last 3 m are excavated.

The braces have a small pre-stress. This is just to activate the analysis. Without some applied load the analysis will not run.

3 Lateral wall stresses

The insitu horizontal stress along a profile that will become the wall is shown in Figure 2. This pressure diagram represents the force that will act on the wall once the soil has been excavated. The area under the pressure diagram represents the total force that will act on the wall once the excavation is complete, or the total energy that will be transmitted to the wall and the struts.

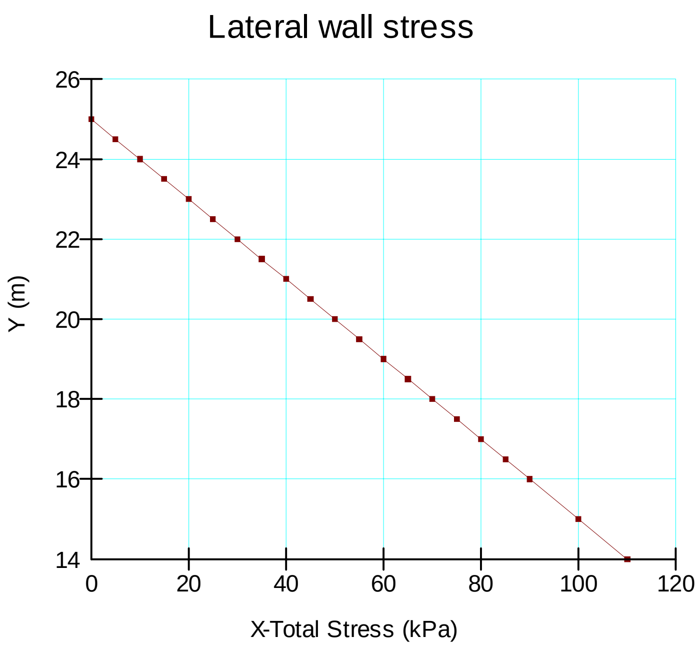


Figure 2 Lateral insitu stress along wall profile

In a finite element analysis, the excavation process is simulated by pulling on the excavation side of the wall by an amount equal to the stress that was there before the soil was removed. This can be done with a Hydrostatic Pressure type of boundary condition. The action is specified as 25 m, which is the ground surface. The rate of increase in the lateral pressure is 10 kN/m of depth. The maximum is 110 kPa at the bottom of the excavation.

The removal of the soil is represented by an upward pressure. Removing 2 m of soil represents an upward pressure of 40 kPa. Removing 3 m of soil represents an upward pressure of 60 kPa.

Figure 3 shows the boundary conditions for the first and last steps. The same boundary condition is applied on the vertical wall, but for different segments as the excavation proceeds. The first step involves removing 2 m and therefore the upward pressure is 40 kPa. The last step involves removing 3 m and therefore the upward boundary pressure is 60 kPa (note the different color).

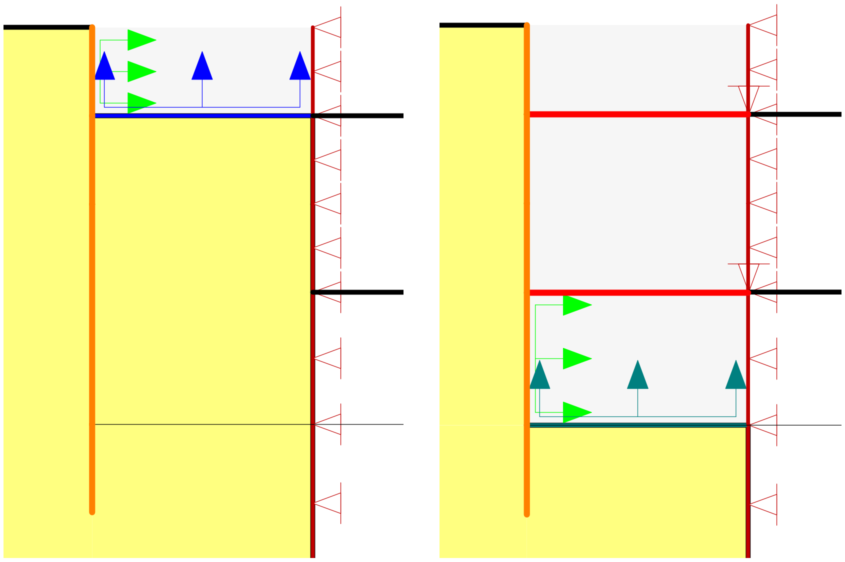


Figure 3 Boundary conditions for the first and last steps

4 Infinite elements

Infinite elements are used on the left side, so that the far field boundary is well removed from the excavation.

5 Lateral displacement of the wall

Figure 4 shows the lateral displacement of the wall at each of the construction stages. According to this diagram, the wall moves back away from the excavation over the top 2 m, and the wall pivots about the upper strut. The primary reason for this is the applied uplift pressure along the base of the excavation. This action has the effect of wanting to rotate the structure.

When the uplift pressures are ignored, the wall deflections are as shown in Figure 5. Intuitively, this seems more correct. The wall at the top moves into the excavation, and there is less movement at the lower tip of the wall. Also, the total lateral displacement is less – about 24 mm versus 37 mm with the uplift.

This issue is discussed further below.

To simulate the effect of no uplift, it is necessary to apply a vertical uplift boundary condition, but with a very small magnitude, such as 0.1 kPa. If the uplift boundary condition is missing, SIGMA/W will attempt to compute uplift pressure from the insitu stresses.

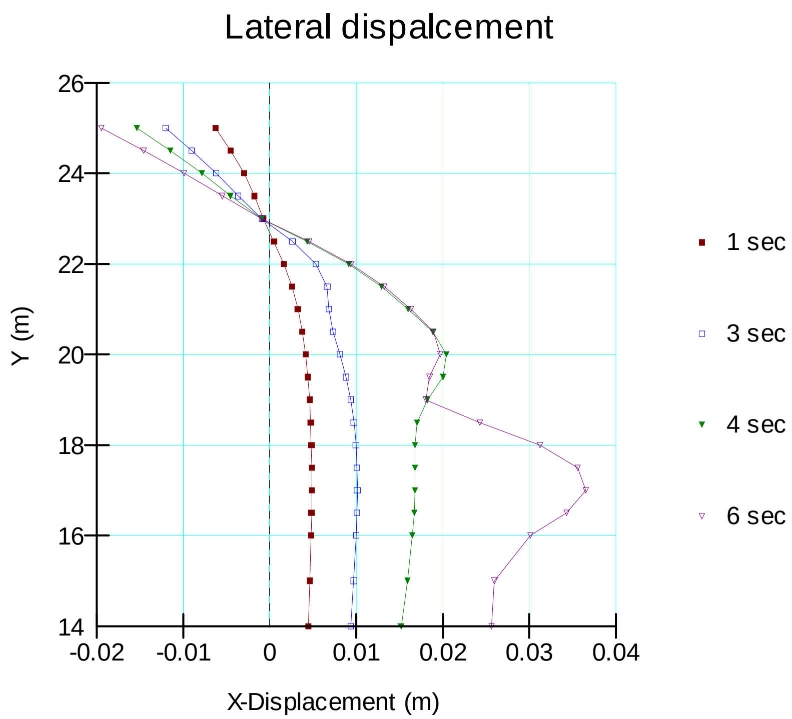


Figure 4 Lateral displacements of the wall with base uplift pressures

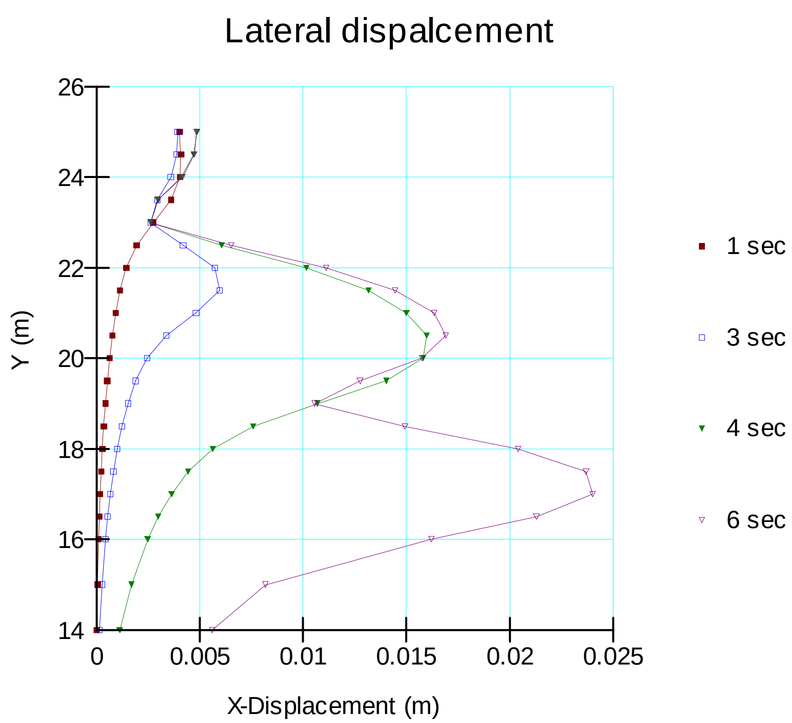


Figure 5 Lateral displacements of the wall when the uplift is ignored

6 Wall bending moments

Figure 6 and Figure 7 compare the bending moments in the wall with and without the excavation base uplift. Comparison of these two figures shows that the bending moments are essentially the same. Certainly the maximum moment is about 20 kN-m for each case.

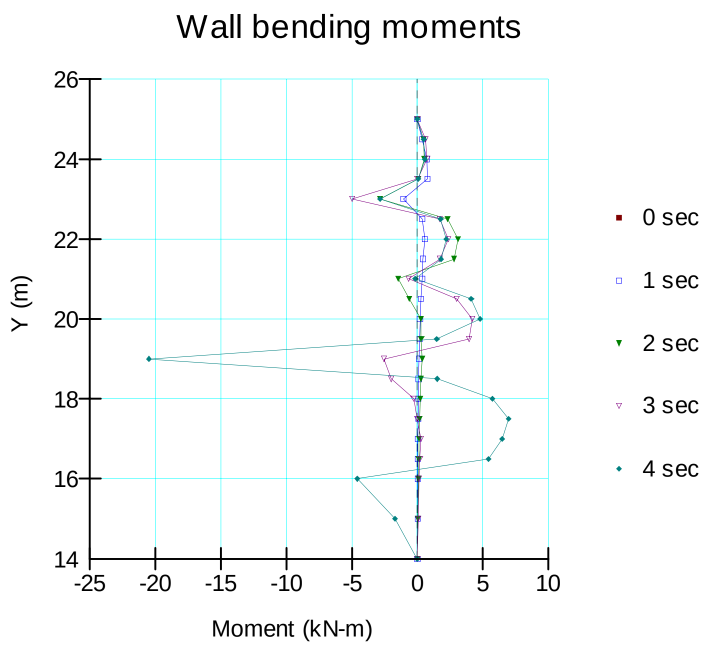


Figure 6 Wall bending moments with excavation base uplift

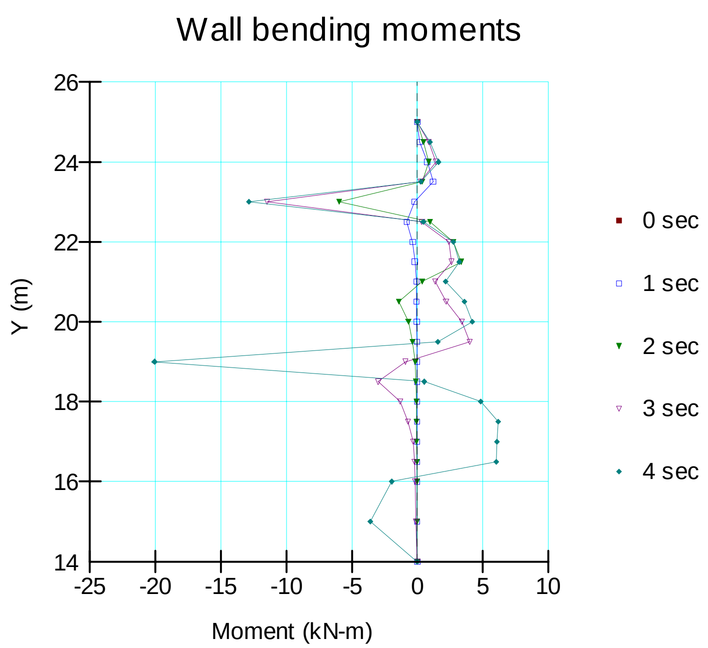


Figure 7 Wall bending moments with no excavation base uplift

7 Strut forces

The upper strut forces are shown in Figure 8. The force increases when the third step excavation is applied, but then decreases as the last excavation step is applied. Again, this is due to the tendency for the wall to rotate as the lower soil is removed.

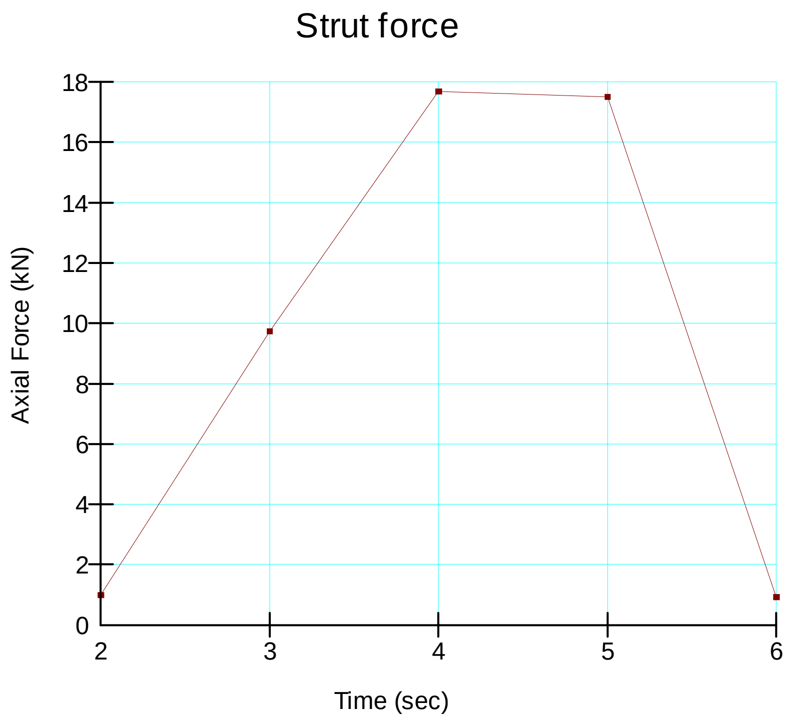


Figure 8 Axial forces in the upper strut

Most of the force is taken up by the lower strut. The analysis shows a force of 108 kN in the lower strut, which is about 10 times greater than the upper strut. This is logical when the lateral pressure diagram is considered – the stresses at the bottom are much greater than at the top.

8 Vertical displacements

When the displacements are plotted as a deformed mesh as in Figure 9, the analysis indicates that the ground behind the wall has heaved. Once again this is counter-intuitive to what one would expect.

It must be recognized that the displacements are very small. When the displacements are plotted at a true scale, they are not recognizable relative to the scale of the excavation, as illustrated in Figure 10.

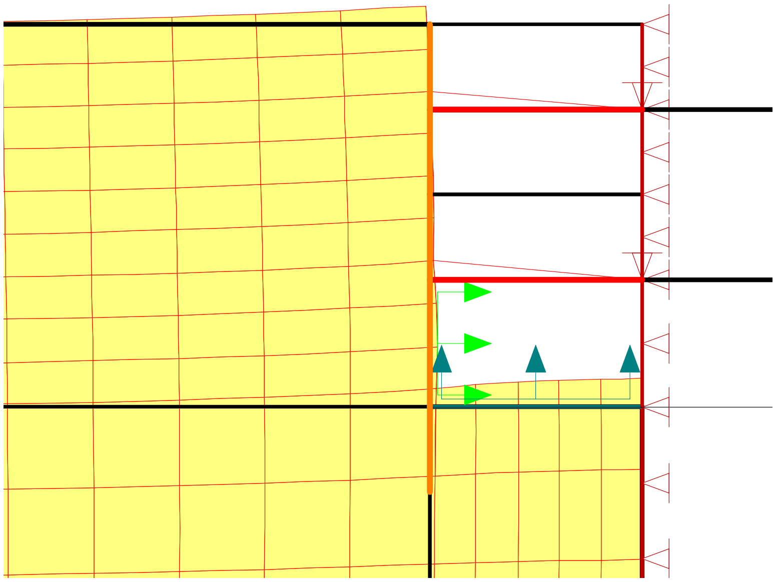


Figure 9 Displacements with uplift pressures applied (5x exaggeration)

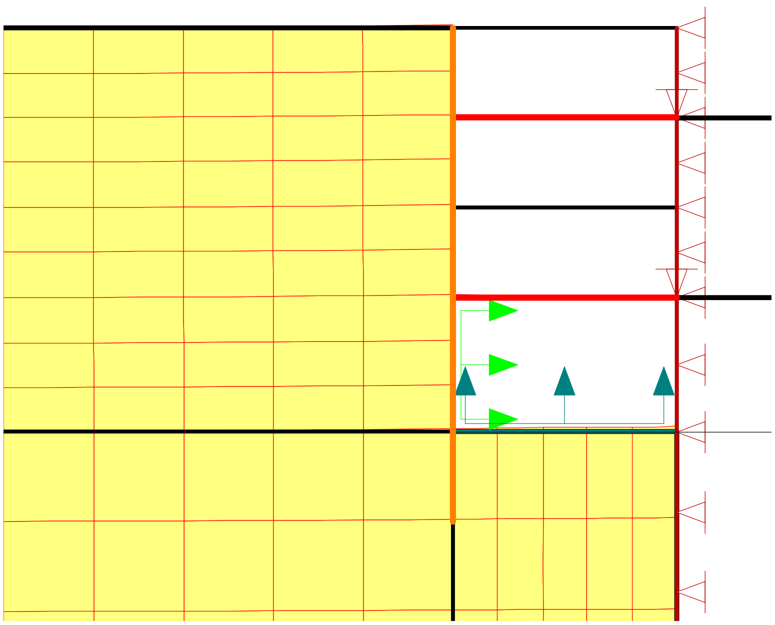


Figure 10 Displacements with uplift pressures at a true scale

9 Discussion

The best procedure to use regarding the base excavation uplift pressures is not entirely clear. Ignoring the uplift seems to give displacements that are more intuitively realistic; however, not including the uplift is ignoring a real energy component. There will always be some elastic rebound if a soil is unloaded.

Perhaps there is some heave outside the wall in real field cases, but it is so small that it is never evident amongst all the surface construction activity.

Also, in real field cases, there may be some loss of soil behind the wall, which leads to surface settlement. The finite element analysis cannot capture this effect. Furthermore, there maybe some wall movements before the wall picks up the load. Again, the finite element analysis does not capture this, and may be another reason why there may be a difference between the numerical simulation and field observations. There is no question that construction techniques have an effect on the wall performance, and this needs to be considered when interpreting the finite element results.

A companion illustrative SIGMA/W example is the Berlin Wall case history. This case history study shows that a better match is obtained between the computed and measured wall deflections when the uplift is included in the analysis.

No definitive recommendations can be offered on this subject. Both approaches should be considered and then be judged in the context of each specific project. To help with making this judgment, the wall deflections should be plotted at a true scale.

10 Concluding remarks

This is a simple example that illustrates how SIGMA/W can be used to simulate the construction of a strutted excavation, and discusses important issues that must be considered when interpreting the results.