A Pile Pull Out Test

1 Introduction

This example simulates pulling a pile out of the ground. It is not a realistic field case, but numerically the simulation makes it possible to verify the behavior of a structural element with slip elements on both sides. The primary purpose of this example is to check the behavior of the slip (interface) elements in SIGMA/W when there is a beam along the center of the slip elements.

2 Configuration and setup

Figure 1 shows the problem configuration and setup. Basically, there are interface elements down the center of a box with a beam along the center of the interface elements.

Of significance is that the beam does not go to the bottom of the interface elements, and that the beam extends up into the air above the ground. To have the beam above the ground surface, we need a geometric Line in space and then the beam can be attached to the Line.

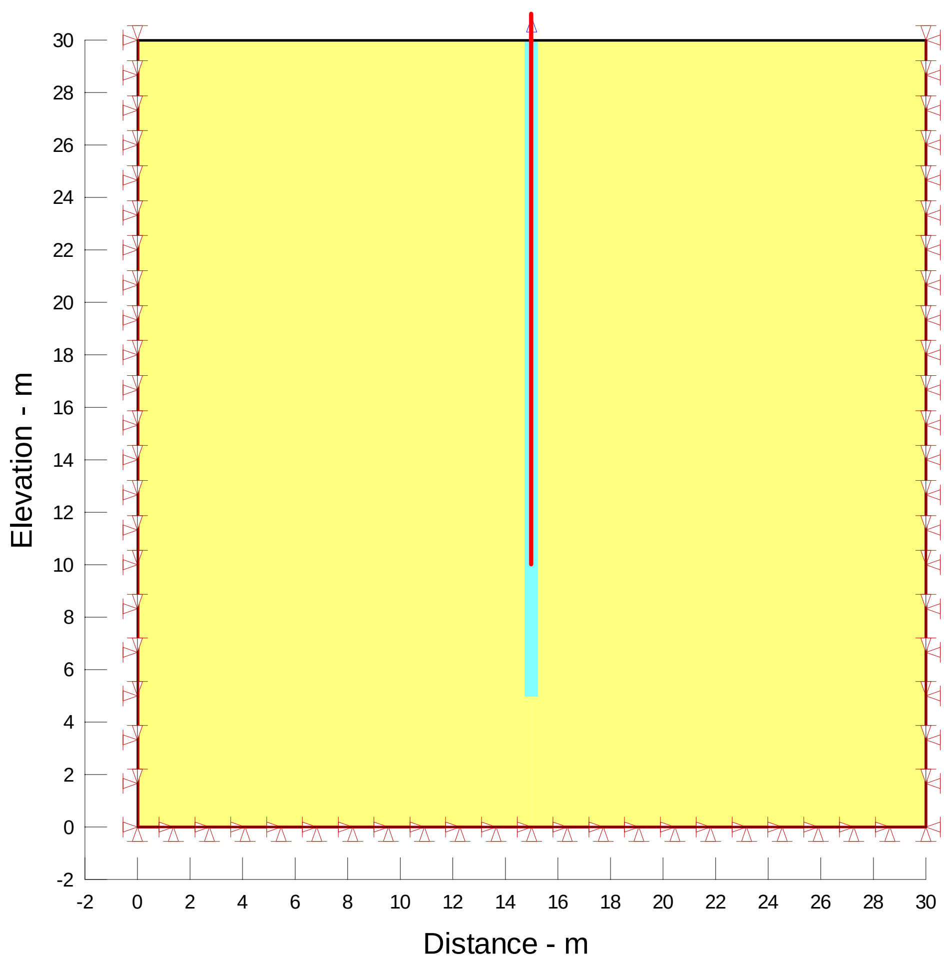

Figure 1 Configuration and setup for pile pullout test

The interface (slip) zone extends below the bottom end of the beam, as shown in the magnified view in Figure 2. The reason for this is that we do not want to directly connect the beam to a mesh node that is common with the soil; that is to say, we do not want the beam directly attached to the soil. We want the beam to be able to slip within the soil.

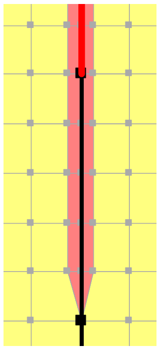

Figure 2 Conditions at the end of lower end of the pile (beam)

The pulling effect is simulated with a displacement boundary condition at the top of the pile of +0.01 m per load step (the + sign indicates upward or in the direction of the positive y-direction).

The pile is modeled as a beam. The properties of the beam are not all that important, except that the stiffness (E) should be considerably great than that for the soil.

3 Analysis: Insitu

We need the lateral stress on the pile to activate the friction between the soil and the pile. Therefore, we need to start with an insitu analysis to set up the stress state in the ground. The soil is assigned a Poisson's Ratio of 0.495. This is analogous to a K_o condition of 0.98. (It is not possible to make $\nu = 0.5$ to get K_o exactly equal to 1.0). The total unit weight of the soil is 20 kN/m^3. Figure 3 shows the lateral stress on the pile. The pile is 20 m long and with $\gamma = 20$ and $K_o = 0.98$, the lateral stress at the bottom of the pile should be close to 400 kPa which is the case as shown in Figure 3.

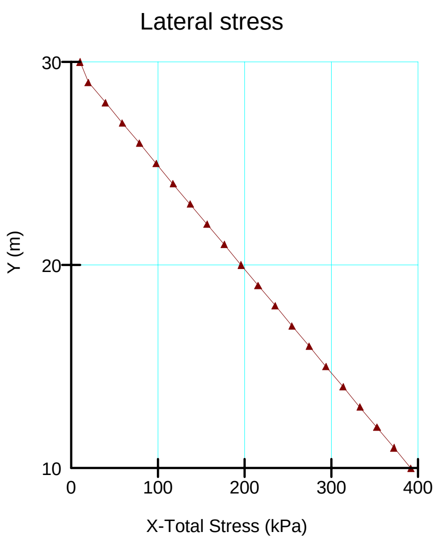

Figure 3 The lateral stress on the pile

4 Analysis: Pull out cohesion

This test uses only undrained strength for the frictional behavior between the pile and the soil. Since the cohesive strength is not a function of the lateral stress, it is numerically a more stable test and easier to compare with hand calculations.

Figure 4 shows the slip force between the soil and pile on the left and on the right. The pile is 20 m long, C is 100 kPa and the total frictional slip force therefore should be 2000 kN. The maximum value in Figure 4 is just above 2000. The slight additional resistance is due to end-effects at the bottom of the pile, even though the pile is not directly connected to the soil, as discussed earlier.

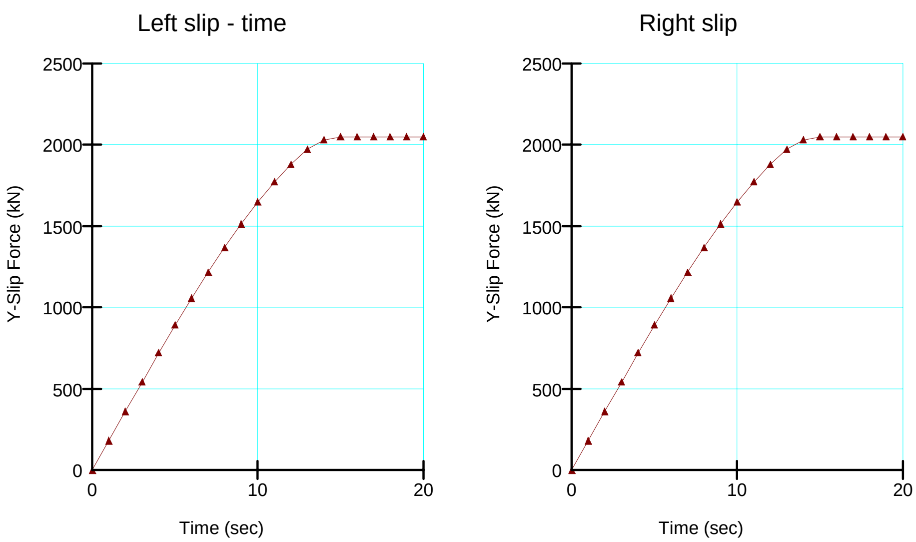

Figure 4 Slip forces between soil and pile on the left and on the right

The total frictional resisting force will be the sum of the left and right sides. This can be illustrated by looking at the slip forces along the center of the interface elements. Physically, there are no slip surfaces down the middle, but numerically, the comparable forces are available due to the double-layer formulation of the interface elements. In this case, because the outside two slip forces are in the same direction, the middle forces will be the sum of the outer two, but of the opposite sign (the algebraic sum must be zero). This is confirmed in Figure 5.

The middle slip forces are physically in the pile (beam), not in the center of the interface.

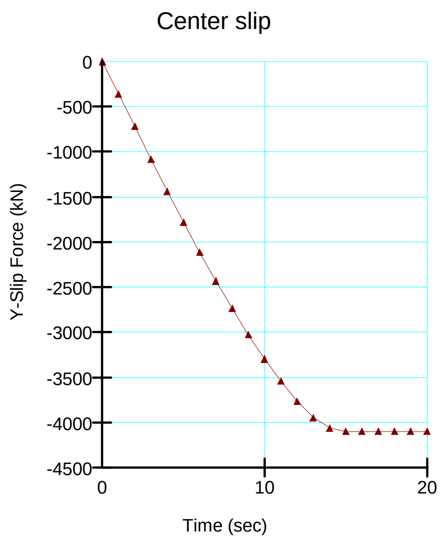

Figure 5 Slip forces along the center of the interface elements

Figure 6 shows the axial force in the pile. The maximum is -4082 kN at the top, which matches the total frictional resistance as indicated in Figure 5 (the minus sign indicates tension). At the bottom, the axial force approaches zero as it correctly should.

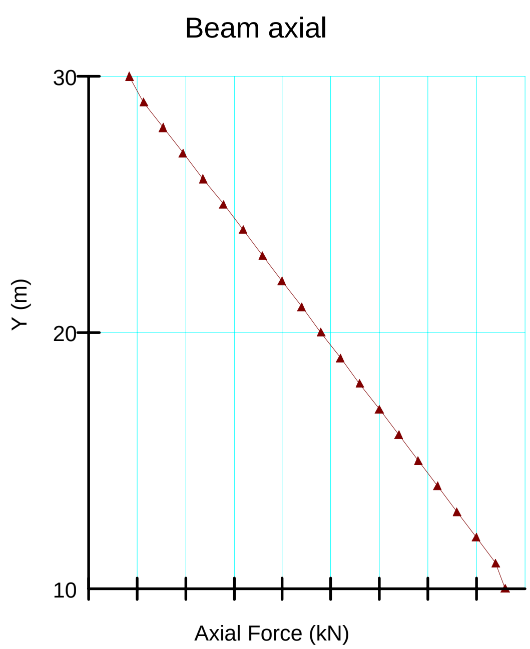

Figure 6 need to re-capture this figure

5 Analysis: Pull out friction

Now we will switch the properties of the interface material from C = 100 kPa and Ø = zero to C = zero and Ø = 30 degrees. In this case, it is not as simple to compare the SIGMA/W results with hand calculations, due to the variable lateral stress with depth and since the frictional resistance is a function of the lateral stress.

If the pile and soil would remain in perfect contact, and if the lateral stress distribution with depth would remain unaltered by pulling on the pile, then the total frictional force should be around:

$F = \gamma * h^2 /2 * \tan Ø = 20 * 20 * 20 /2 * \tan 30 = 2310$ kN times 2 sides = 4620 kN.

The soil and pile, however, do not remain in perfect contact and the lateral stress gets altered by the pulling. As a result, the SIGMA/W frictional forces do not match the hand-calculated values, as is evident in Figure 7. The resulting total is only about 3360 kN.

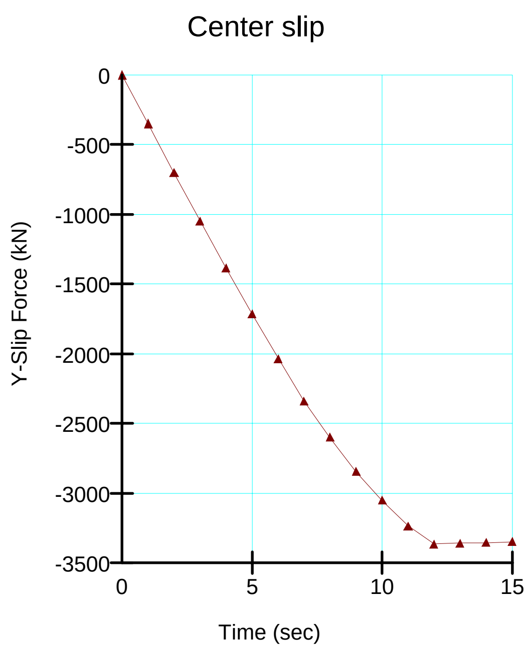

Figure 7 Total frictional slip forces

One of the reasons for the difference is that the soil and pile separate at the top and consequently the slip forces go to zero. This is evident in Figure 8, where at the top the slip surface has gone to zero.

This is further evident in Figure 9, which shows the axial force distribution in the pile. The distribution is nearly linear in the bottom half of the pile, but then varies significantly in the top half. The forces actually become nearly constant near the top, which is a reflection of almost no frictional resistance toward the end of the pulling.

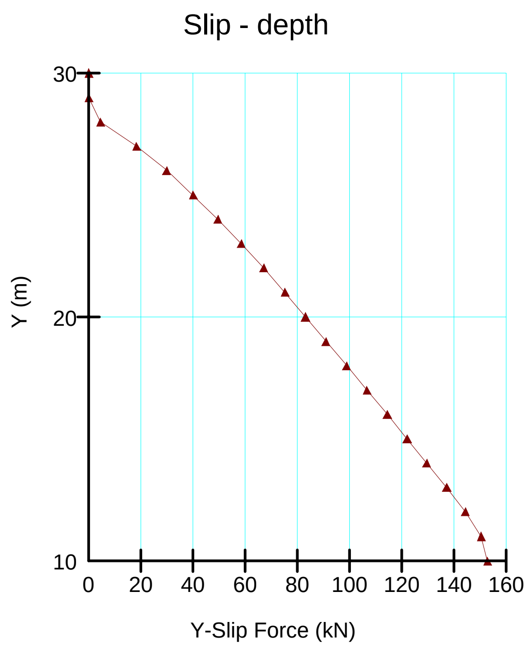

Figure 8 Slip forces with depth on the left side

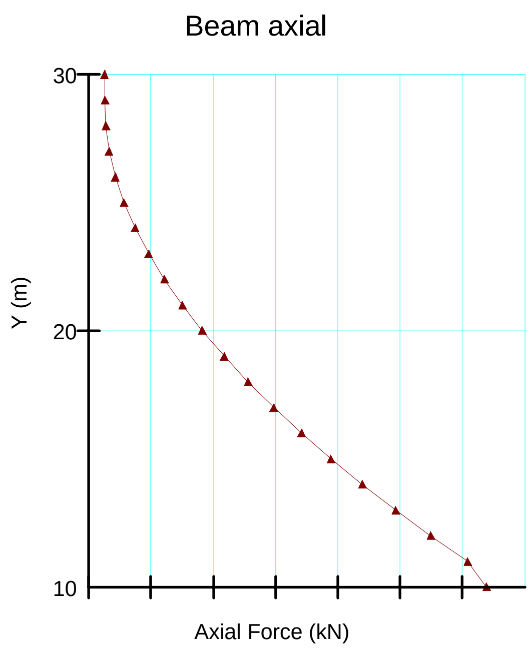

Figure 9 Axial force distribution in the pile

6 Conclusion

The example confirms the correct behavior of a beam along the middle of interface elements and the correct behavior of the slip elements when they are vertical.