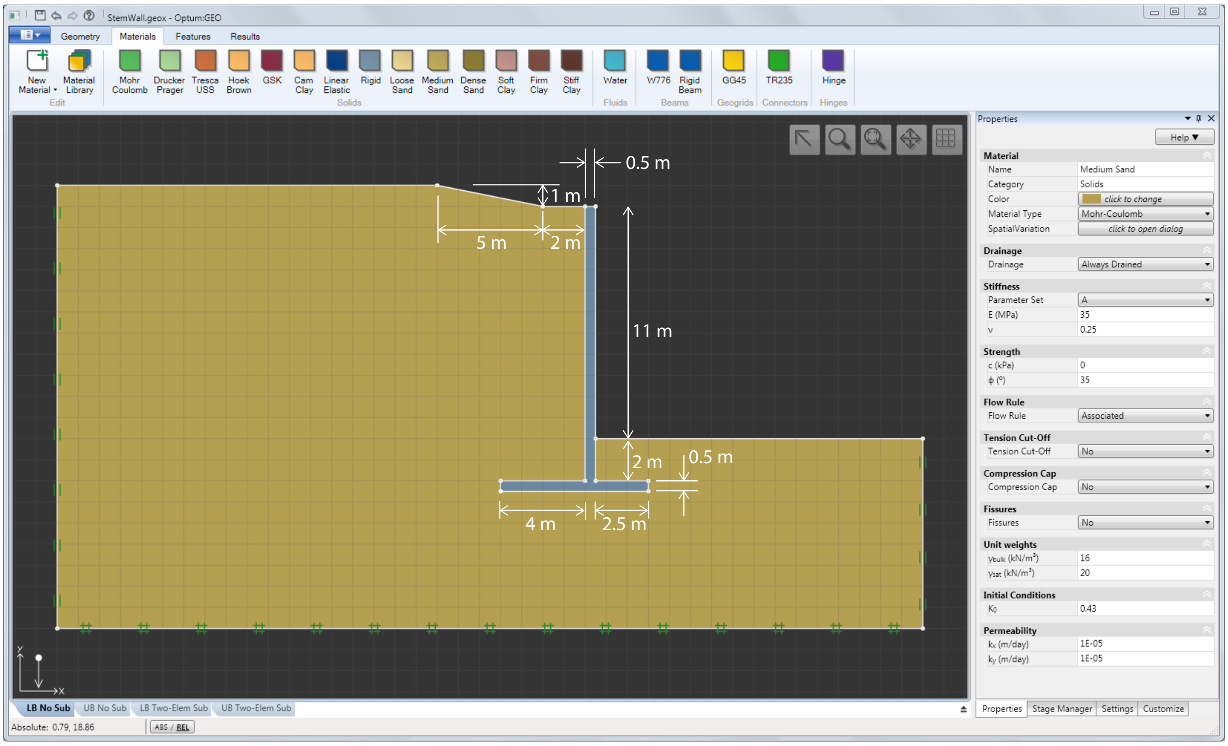
13 STABILITY OF STEM WALL

The next example is, on the surface, relatively uncomplicated and can be handled in much the same way as the previous example. It concerns the stability of a stem wall as shown in Figure 13.1. The soil consists of the default Medium Sand-MC material (a purely frictional Mohr-Coulomb material with $\phi = 35°$) and the wall is modeled as Rigid material with a unit weight of 20 kN/m^3.



Material
Name: Medium Sand
Category: Solids
Color: click to change
Material Type: Mohr-Coulomb
SpatialVariation: click to open dialog

Drainage
Drainage: Always Drained

Stiffness
Parameter Set: A
E (MPa): 35
ν: 0.25

Strength
c (kPa): 0
ϕ (º): 35

Flow Rule
Flow Rule: Associated

Tension Cut-Off
Tension Cut-Off: No

Compression Cap
Compression Cap: No

Fissures
Fissures: No

Unit weights
γ_{bulk} (kN/m^3): 16
γ_{sat} (kN/m^3): 20

Initial Conditions
K_0: 0.43

Permeability
k_x (m/day): 1E-05
k_y (m/day): 1E-05

Figure 13.1: Stem wall.

As in the previous example, Strength Reduction analysis is used to determine the strength based factor of safety, FS$_s$. We begin by calculating upper and lower bounds for a fixed number of elements without using mesh adaptivity.

	No subdivision			Two-element subdivision		
No Elem	Lower	Upper	Mean±Err	Lower	Upper	Mean±Err
1,000	0.071	1.63	0.85 ± 0.78	1.45	1.63	1.54 ± 0.09
2,000	0.073	1.61	0.84 ± 0.77	1.45	1.59	1.52 ± 0.07
4,000	0.095	1.59	0.84 ± 0.75	1.45	1.57	1.51 ± 0.06
8,000	0.097	1.55	0.83 ± 0.73	1.46	1.55	1.51 ± 0.04
16,000	1.46	1.53	1.49 ± 0.04	1.46	1.53	1.49 ± 0.04

Table 13.1: Strength reduction factors for stem wall with and without subdivision.

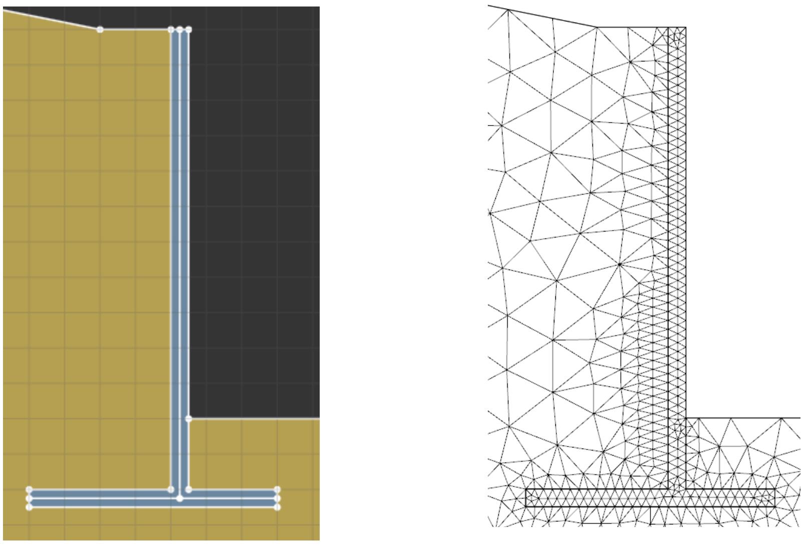


Figure 13.2: Manual subdivision of wall (left) and mesh resulting from specifying a minimum element size of 0.25 m for the wall (right).

The results, shown in left half of Table 13.1, reveal a very significant gap between the upper and lower bound solutions up to 16,000 elements where the gap suddenly reduces to an acceptable magnitude. More precisely, the lower bounds up to the largest number of elements considered are very poor and in all cases predict that the structure is far from being stable. The upper bounds, on the other hand, display a less erratic convergence behaviour.

On closer examination of the meshes produced in the various runs, it is observed that only a single layer of elements across the width of the wall is produced for the 1,000 to 8,000 element runs. When the number of elements reaches 16,000, two layers of elements are present in most of the wall. This phenomenon, that rigid domains may affect lower bound solutions adversely if they are not resolved properly, is well-known. Indeed, since the lower bound method requires that the stress fields satisfy the strong form of the equilibrium equations, all parts of the domain – rigid and well as deformable – must necessarily be represented with enough elements to accommodate the exact stress distribution to within a reasonable degree of accuracy. The upper bound method, on the other hand, balances the internal and external work rates and since no work is dissipated in rigid parts, their resolution is of less importance as clearly seen from the results.

In this case – and in general – the only remedy to improving the lower bound solutions is to use more elements to discretize the wall. With OptumG2, this is most easily done by subdividing the wall as shown in Figure 13.2. This subdivision guarantees at least two elements across the width of the wall and improves the results dramatically as summarized in Table 13.1. It should also be noted that mesh adaptivity will be of little utility unless the wall is subdivided so that a reasonable initial solution, on the basis of which the subsequent mesh is adapted, is available.

As an alternative to manual subdivision, the Mesh Size tool available under Features can be used to specify a minimum element length. As a general rule, the minimum element length should be one third to one half of the wall thickness. For the present example, a minimum element size of 0.25 m (half the wall thickness) leads to the desired layer of two elements across the wall thickness (see Figure 13.2) and thereby to satisfactory results.