OptumG3

Verification of solid elements for punch-through failure of a circular foundation

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1 Introduction

1.1 Problem

This document verifies the solid elements available in OptumG3 with respect to the bearing capacity of a circular foundation on Mohr-Coulomb sand overlying a soft Tresca clay. For these types of problems one may experience so-called punch through failure with the mechanism extending down through the soft clay layer.

1.2 Solid elements

Three elements are available: Lower, Upper, and Mixed.

The Lower element computes limit loads that are generally below the exact solution. The element aims to satisfy the differential equations of equilibrium everywhere (as opposed to standard finite elements which impose equilibrium on average). In OptumG3, a slight relaxation is used for free surfaces. This increases the accuracy substantially but may result in limit loads that are slightly above the exact solution.

The Upper element computes limit loads that are generally above the exact solution. As with standard finite elements, the element satisfies the strain-displacement relations everywhere. In addition, the flow rule is satisfied everywhere. To avoid the well-known locking problem a slight relaxation of the strict upper bound requirements is used. This may in principle result in limit loads that are slightly below the exact solution although it is a very rare occurrence.

The Mixed element combines the different requirements of the Upper and Lower bound elements to deliver an element with a superior performance. The limit loads may, depending on the problem, converge from above or below, though almost always with a relatively limited error, even for coarse meshes. The Mixed element is the default and recommended element in OptumG3.

1.3 Benchmark solution

The benchmark solution for this problem has been obtained using Upper and Lower bound Limit Analysis with OptumG2. In this way, the exact bearing has been found as

$$q_u = 130.73 \pm 0.3\% \tag{1.1}$$

2 Punch through problem

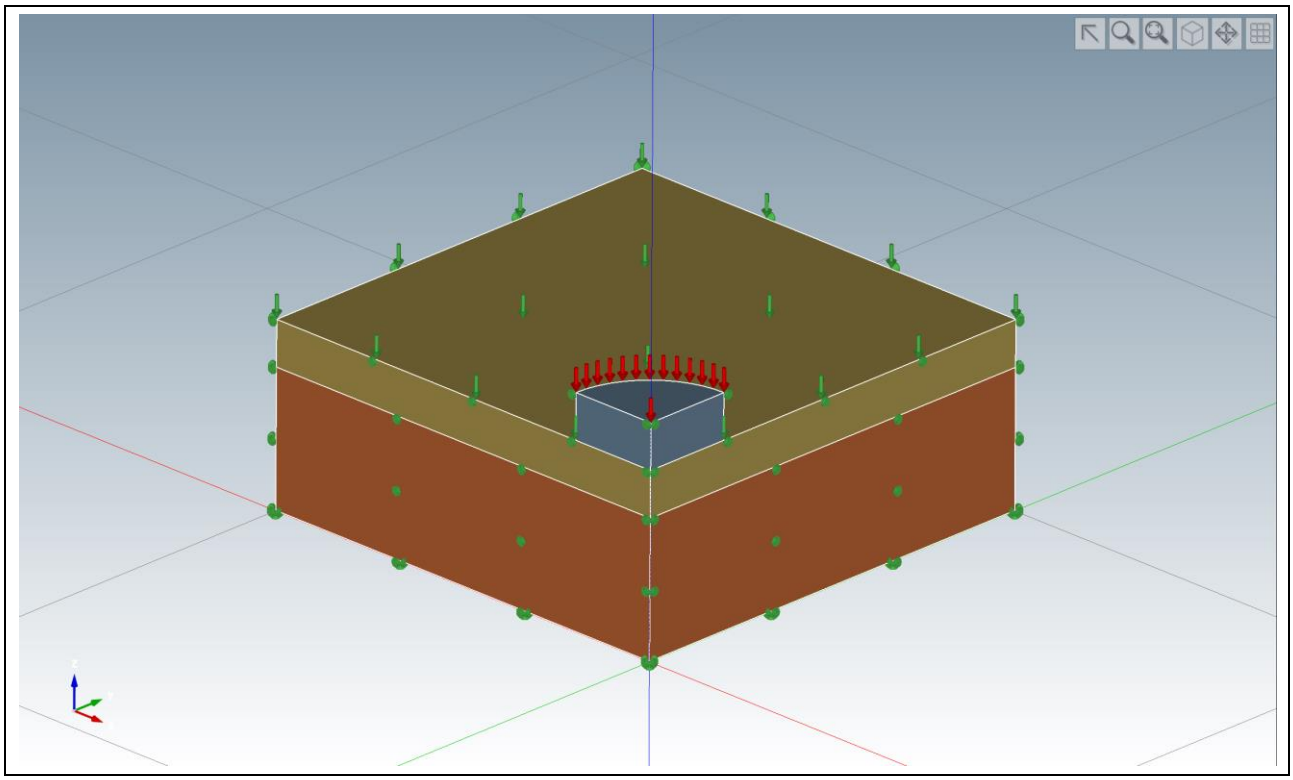

Figure 1: Punch-through problem

General description:
Solid domain: 5x5x2m with a 0.5 m Mohr-Coulomb sand overlying 1.5 m Tresca clay. Foundation: Rigid weightless solid modelled as an N-Prism with N = 48 (N = 12 for the quarter model). Sides are supported normally, bottom is fully fixed. A fixed distributed surcharge load of -10 kPa acts on the top surface. A distributed multiplier load of -1kPa is applied to the top of the foundation. The upper sand layer is modelled as a Mohr-Coulomb material with c = 0, ϕ = 35°, and γ = 18 kN/m^3. The bottom clay layer is modelled as a Tresca material with s_u = 10 kPa. Limit Analysis is used to determine the limit loads (collapse multipliers).

Results
The limit loads obtained are shown in the table below.

Element	Limit load	Benchmark	Discrepancy (%)
Lower	122.067	130.73	-6.6
Upper	137.380	130.73	+5.1
Mixed	131.474	130.73	+0.56

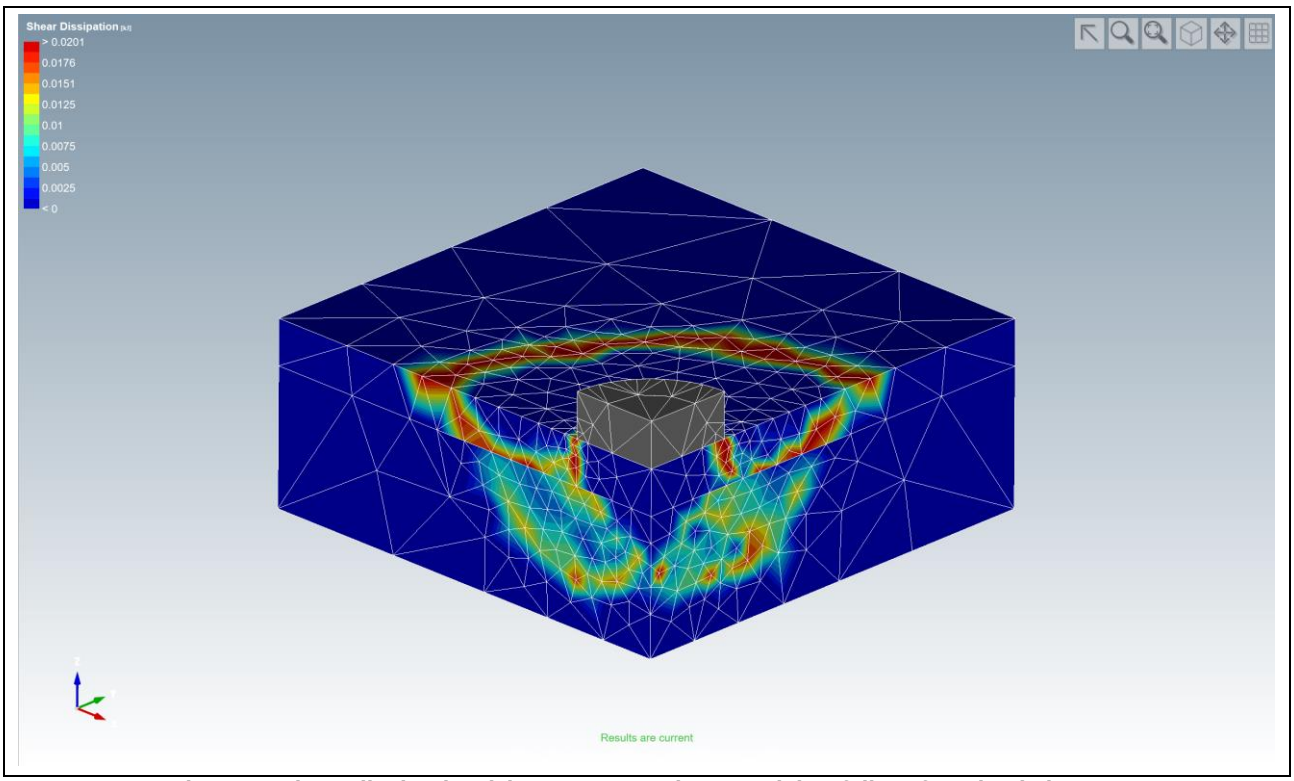

Figure 2: Shear dissipation (shear stress x shear strain) at failure for Mixed element

Mohr-Coulomb (upper layer)

Strength	
c (kPa)	0
ϕ (°)	35

Unit Weight	
γ (kN/m^3)	18

Tension Cut-Off

Flow Rule	
Flow Rule	Associated

Tresca (lower layer)

Strength	
Option	Standard
s_u (kPa)	10

Unit Weight	
γ (kN/m^3)	18

Stage settings:

Settings	
Element Type	Mixed
No of Elements	5000

Mesh	
Mesh Adaptivity	Yes
Adaptive Iterations	3
Start Elements	1000

Note: Element Type = Lower and Element Type = Upper are used for the first two analyses.

Reference:

OptumG2 (2019), www.optumce.com.