OPTUM GX

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 OPTUM GX 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 OPTUM GX, 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 OPTUM GX.

1.3 Benchmark solution

The benchmark solution for this problem has been obtained using Upper and Lower bound Limit Analysis with GX using 2D axisymmetric analysis. In this way, the exact bearing has been found as

$$q_u = 130.7 \quad \pm 0.3\% \tag{1.1}$$

2 Punch through problem

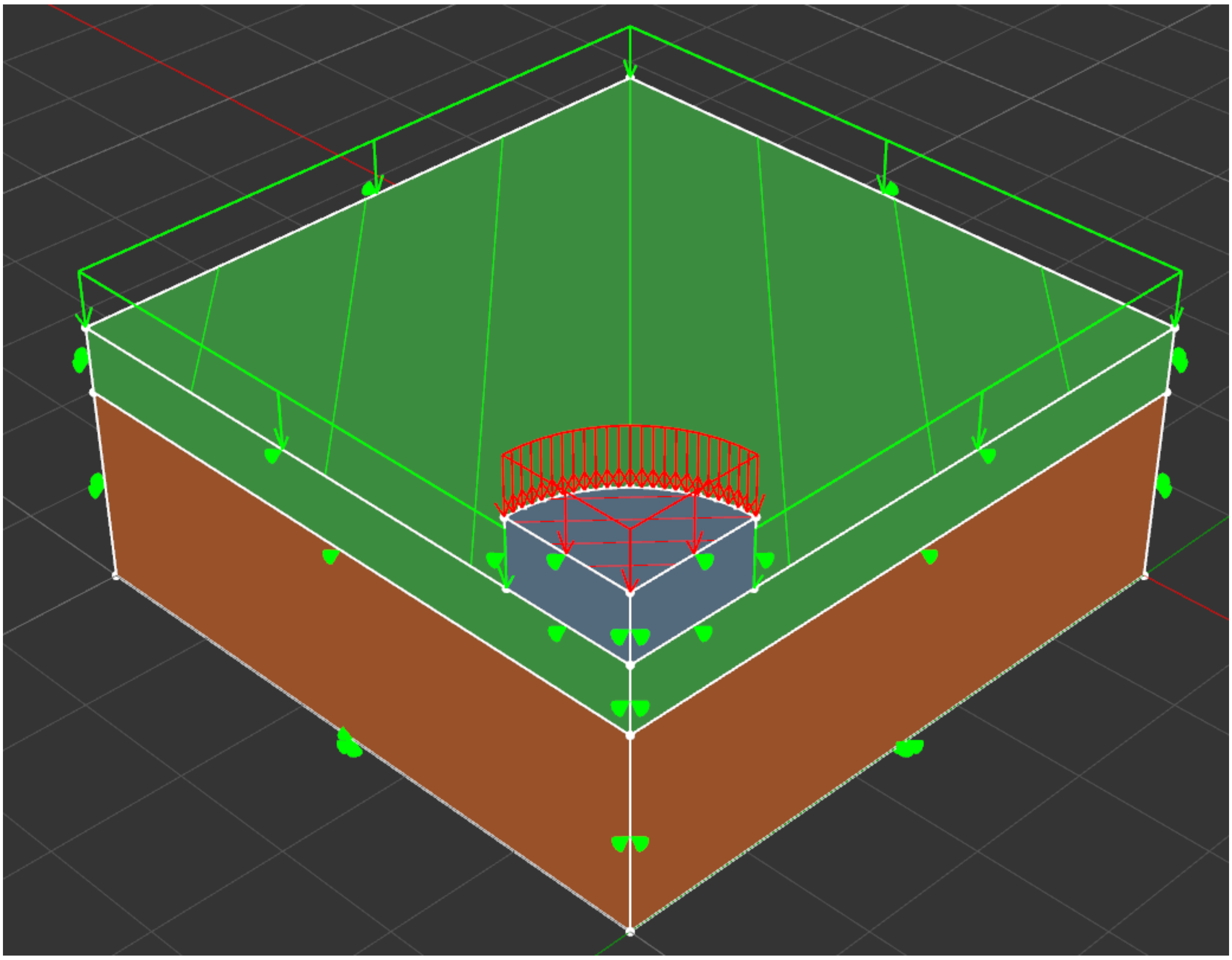

Figure 1: Punch-through problem

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	122.1	130.73	-6.6
Upper	135.9	130.73	+4.0
Mixed	131.3	130.73	+0.46

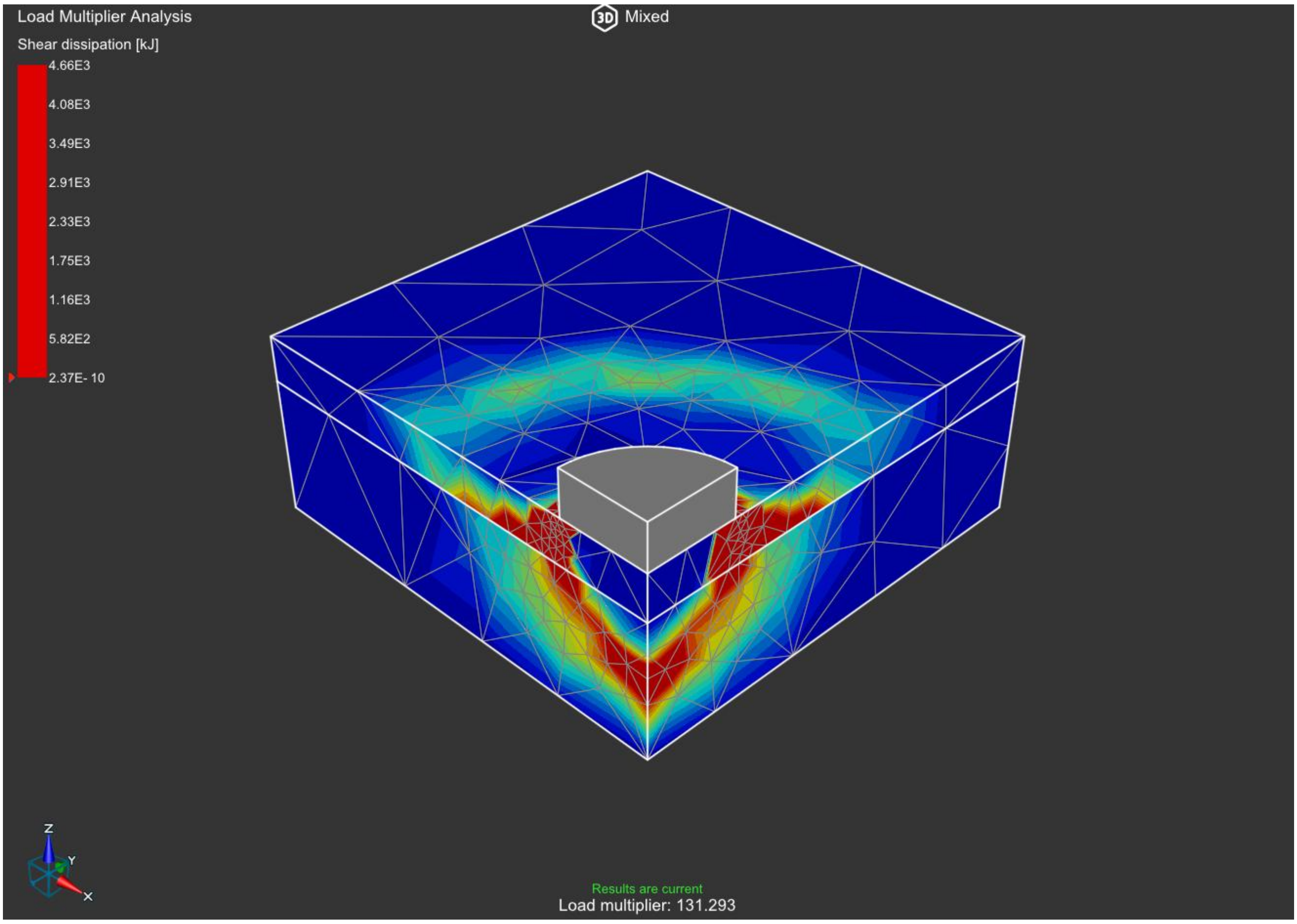

Figure 1: Punch-through problem

Mohr-Coulomb (upper layer)	
Stiffness	
E (MPa)	30
ν	0.25
Strength	
c (kPa)	0
ϕ (°)	35
Flow Rule	
Flow Rule	Associated
Unit Weights	
γ_{dry} (kN/m^3)	18
γ_{sat} (kN/m^3)	20

Tresca (lower layer)	
Stiffness	
E_u (MPa)	30
Strength	
c_u (kPa)	10

Stage settings:

PROPERTIES	
Settings	
Element Type	Mixed
Mesh	
Mesh	Medium
Mesh Adaptivity	Yes
Initial Conditions	
From	None
Safety	
Design Approach	Unity
Time	
Time Scope	Long Term

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