KRATOS GEOMECHANICS

Finite element model

Verification Report

Version: 0.1
SVN Revision: 00

October 13, 2021

KRATOS GEOMECHANICS, Verification Report

Published and printed by:
Deltares
Boussinesqweg 1
2629 HV Delft
P.O. 177
2600 MH Delft
The Netherlands

telephone: +31 88 335 82 73
fax: +31 88 335 85 82
e-mail: info@deltares.nl
www: https://www.deltares.nl

For sales contact:
telephone: +31 88 335 81 88
fax: +31 88 335 81 11
e-mail: software@deltares.nl
www: https://www.deltares.nl/software

For support contact:
telephone: +31 88 335 81 00
fax: +31 88 335 81 11
e-mail: software.support@deltares.nl
www: https://www.deltares.nl/software

Contents

List of Figures

List of Tables

1 Introduction

This document contains verification examples for the Kratos-Geomechanics application. To achieve this different benchmarks are created to test different parts of the Kratos-Geomechanics application.

2 Benchmark 1: Bi-axial shearing test with linear elastic model

In this benchmark Bia-axial shearing test conditions are tested in the Kratos-Geomechanics application. In that way, this example can be used to verify elastic deformation with a linear elastic model.

2.1 Geometry and boundary conditions

The geometry created in Kratos is a 2-D square specimen ($1 \times 1m^2$). To create the geometry click on the *Create line* button and enter the points as they are described in Table 2.1. After creating the square specimen a surface needs to be created so that the soil elements can be assigned to it. This can be done by clicking the *create NURBS surface* and then the surface of the square specimen created.

Table 2.1: *Coordinates of square specimen*

x-coordinate	y-coordinate
0	0
0	1
1	1
1	0
0	0

For the boundary conditions the following constrains are applied to the model:

- ◇ a *Solid Displacement* is used to fix the bottom boundary in the y direction. By setting the *SOLID DISPLACEMENT Y* to <0.0>.
- ◇ a *Solid Displacement* is used to fix the bottom left corner in the x and the y direction. By setting the *SOLID DISPLACEMENT Y* and the *SOLID DISPLACEMENT X* to <0.0>.

The loads applied to the geometry are line load in this case and they are applied to the edges of the geometry. This is done by selecting the *Loads* menu and inputting the loads that are shown in Table 2.2.

Table 2.2: *Line Load inputs for benchmark 1*

Direction Setting	Assigned Line Coordinate x	Assigned Line Coordinate y	Value	Unit
LINE LOAD X	[0,1]	[1,1]	-1	N/m
LINE LOAD X	[0,0]	[1,0]	+1	N/m
LINE LOAD Y	[0,0]	[0,1]	-1	N/m
LINE LOAD Y	[1,1]	[0,1]	+1	N/m

2.2 Material

The material selected for this benchmark is a linear elastic drained soil material. The inputs of this can be seen in Figure **??** and can be set on the *Elements* menu item.

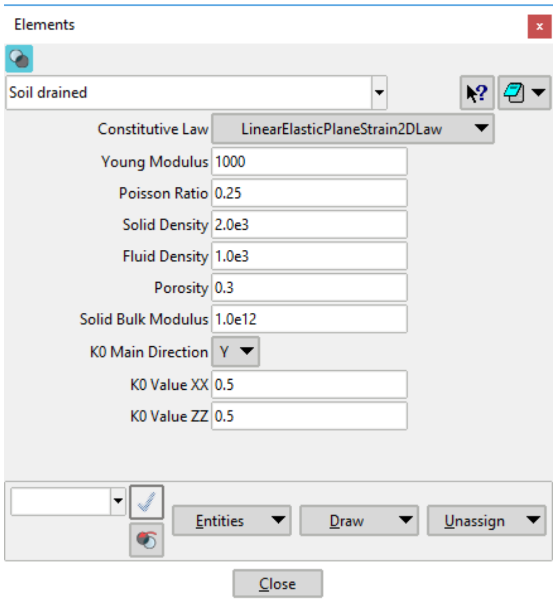

Figure 2.1: *Material input of benchmark 1*

2.3 Mesh Generation

The mesh in this case should be generated coarsely. In this case only two elements will be produced. To produce the mesh click on *Mesh* menu and then from the drop down list select *Generate mesh* and enter for *Enter size of elements to be generated* <1>.

2.4 Results

The Kratos-Geomechanics application uses as output strain tensor the *Green-Langrange-Strain-Tensor*. The output of the calculation in this case is $\epsilon_{xy} = 1.25 \times 10^{-3}$ which is half of shear strain τ. Therefore, the shear strain is $\tau = 2.5 \times 10^{-3}$.

The analytical solution can be calculated as follows from Equation (2.1) and Equation (2.2).

$$G = \frac{E}{1(1+\nu')} = 400kN/m^2 \tag{2.1}$$

$$\tau = \frac{\gamma}{G} = 2.5 \times 10^-3 for \tau = 1kN/m \tag{2.2}$$

The comparison of the displacements calculated by Kratos can be compared with the results of the analytical solution in Table 2.3.

Table 2.3: *Results of displacements for benchmark1*

Kratos	Benchmark	Error[%]
2.50×10^{-3}	2.50×10^{-3}	0.00

To run this benchmark run file smoothrigidfootingonelasticsoil.gid.

3 Benchmark 2: Bending of plates

In this benchmark the bending of plate elements with Kratos-Geomechanics will be tested. Two different plate elements of unit length are tested. In the first case a point load is applied on the first plate and the second case a line load is applied in the second plate. The plates are modeled in 2D geometry thus the material used to model the plates are beam elements.

3.1 Bending of plate when point load is applied

3.1.1 Geometry

In this case a line of 1m needs to be created. To create the line click on the *Create line* button and enter the points that are part of Table 3.1.

Table 3.1: *Coordinates plate element*

x-coordinate	y-coordinate
0	0
0.5	0
1	0

The beam is simply-supported so solid displacements are used to model the fixities at the points. For points <0,0> and <1,0> a *Solid Displacement* of <0.0> is applied for x and y direction.

The point load is applied on point <0.5,0> from the menu item *Loads*. By selecting *Point Load* and setting *POINT LOAD Y* to <100N> the load can be defined.

3.1.2 Material

The material of the plate element can be defined by selecting the menu item *Elements* and then filling out the values of Figure 3.1.

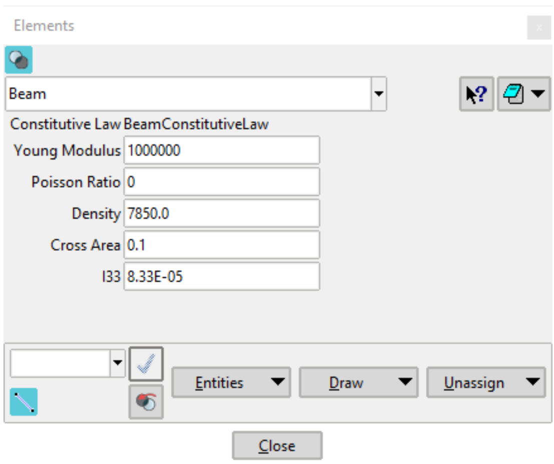

Figure 3.1: *Beam element of benchmark 2*

3.1.3 Results

In this benchmark the result of the maximum deflection is compared with the analytical result. The analytical calculation of simply supported beam with point load at the center is described in Equation (3.1). In this case $F = 100kN$, $l = 1m$ and $EI = 83.33kNm^2/m$.

$$u_{max} = \frac{1}{48}\frac{Fl^3}{EI} = 25.00mm \tag{3.1}$$

After performing the calculation in Kratos-Geomechanics the results are compared with the benchmark in Table 3.2

Table 3.2: *Results of deflection for benchmark 2 with the application of point load*

Kratos	Benchmark	Error
[mm]	[mm]	[%]
25.01	25.00	0.04

3.2 Bending of plate when line load is applied

3.2.1 Geometry

In this case a line of 1m needs to be created. To create the line click on the *Create line* button and enter the points that are part of Table 3.3.

Table 3.3: *Coordinates plate element*

x-coordinate	y-coordinate
0	0
1	0

The beam is simply-supported so solid displacements are used to model the fixities at the points. For points <0,0> and <1,0> a *Solid Displacement* of <0.0> is applied for x and y direction.

The line load is applied on the full length of the beam from the menu item *Loads*. By selecting *Line Load* and setting *POINT LOAD Y* to <200N/m> the load can be defined.

3.2.2 Material

The material of the plate element can be defined by selecting the menu item *Elements* and then filling out the values of Figure 3.2.

3.2.3 Results

In this benchmark the result of the maximum deflection is compared with the analytical result. The analytical calculation of simply supported beam with line load at the center is described in Equation (3.2). In this case $q = 100kN/m$, $l = 1m$ and $EI = 83.33kNm^2/m$.

$$u_{max} = \frac{5}{384}\frac{ql^4}{EI} = 31.25mm \tag{3.2}$$

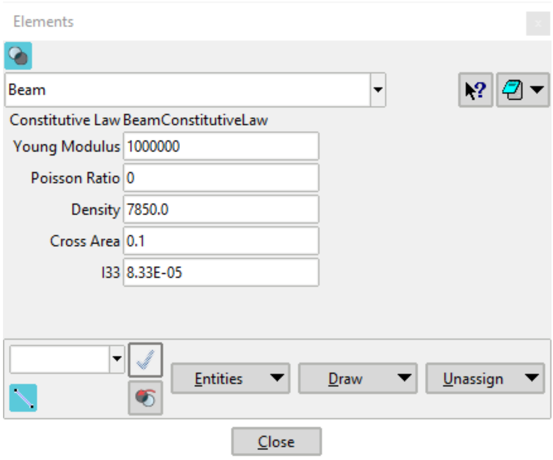

Figure 3.2: *Beam element of benchmark 2*

After performing the calculation in Kratos-Geomechanics the results are compared with the benchmark in Table 3.4

Table 3.4: *Results of deflection for benchmark 2 with the application of line load*

Kratos	Benchmark	Error
[mm]	[mm]	[%]
31.25	31.25	0.00

To run this benchmark run file Kratos_line_load.gid and bendingofplatepointload.gid.

4 Benchmark 3: Smooth rigid footing on elastic soil

In this benchmark a smooth rigid footing is tested on elastic soil with Kratos-Geomechanics.

4.1 Geometry

A uniform displacement of 0.01 m is applied

The geometry and mesh is shown in Figure 4.1

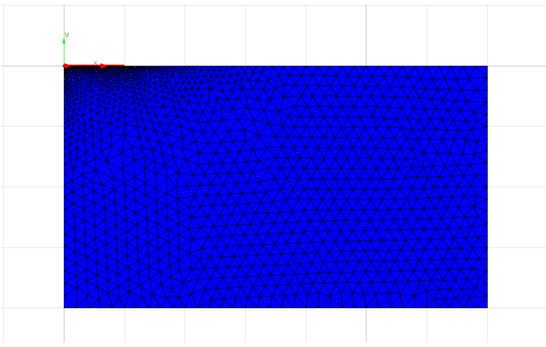

Figure 4.1: *Geometry and mesh of model*

4.2 Material

In this benchmark, the soil is modelled with linear elastic drained elements. The applied Youngs Modulus, $E = 1333kN/m^2$; the applied Poisson ratio, $nu' = 0.333$.

4.3 Meshing

The mesh is generated using 6-node triangular elements. Along the footing, a mesh size is chosen of 0.015 m, within the rest of the geometry, a mesh size of 0.2 m is chosen.

4.4 Results

$$F = \frac{2u(1+\nu')G}{\delta} = 15.15 \tag{4.1}$$

Since the problem is symmetric, the reaction force to compare is half the analytically calculated reaction force, i.e. $F = 7.57$.

Table 4.1: *Results of reaction force for benchmark 3 with the application of a settlement*

Kratos	Plaxis 2D	Benchmark	Error
[mm]	[mm]	[mm]	[%]
7.39	7.36	7.57	2.43

In Figure 4.2 it is shown how the vertical stress develops underneath the rigid footing, results are shown following a Plaxis calculation, a Kratos-Geomechanics calculation and an analytical calculation. The results following the Plaxis calculation and the Kratos-Geomechanics calculation are effectively equal, both these results are in good accordance with the analytical results.

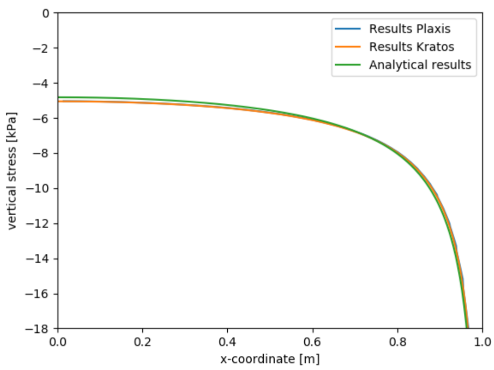

Figure 4.2: *Vertical stress underneath rigid footing benchmark 3*

5 Benchmark 4: 1D consolidation on elastic soil

In this benchmark 1D consolidation is tested on linear elastic soil, using Kratos-Geomechanics. This benchmark includes multiple stages and a time dependent calculation.

5.1 Geometry

This benchmark is tested on a soil profile with a height of 1.0 m and a width of 0.1 m. See figure @@. The side and bottom boundaries are impermeable. At the top boundary, a 0 pore pressure condition and a line-load of 1kN/m are applied.

@@ add figure @@

5.2 Materials

The soil is modelled with linear elastic undrained elements. The applied Youngs modulus, $E = 1000kN/m^2$; the applied Poisson's ratio, $\nu' = 0.0$ and the applied permeability in x- and y-direction, $k = 0.001m/day$.

5.3 Meshing

The mesh is generated using 6-node triangular elements with a size of 0.05 m.

5.4 Calculation

The first phase is calculated as *Soil undrained*, the following phases are calculated as *Soil two phase*. All phases are calculated using the Quasi-Static solution type. The 0 pore pressure boundary condition is activated from phase 2 and onwards. In total, 11 phases are calculated at: [0.0 0.1, 0.2, 0.5, 1.0, 2.0, 5.0, 10.0, 20.0, 50.0, 100.0] days.

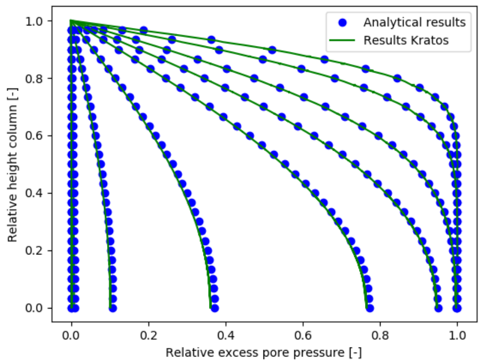

Figure 5.1: *Relative excess pore pressure versus relative height on different time steps*

5.5 Results

Relative excess pore pressure can be determined analytically as a function of time and depth, as shown in the following formula [@@ref@@].

$$\frac{p}{p_0} = \frac{3}{\pi} \sum_{j=1}^{\text{inf}} \frac{(-1)^{j-1}}{2j-1} \cos[(2j-1)\frac{\pi}{2}\frac{y}{h}] \exp[-(2j-1)^2 \frac{\pi^2}{4}\frac{c_v t}{h^2}] \tag{5.1}$$

Bibliography