Created in COMSOL Multiphysics 6.1

Triaxial and Oedometer Test with Modified Cam-Clay Material Model

Introduction

The Modified Cam-Clay (MCC) model is a popular constitutive model for soft soils and clays. The MCC model has a nonlinear relation between stress and strain with a smooth yield surface. In this example, simulations of triaxial tests are carried out to examine the constitutive relation of the MCC model, as it is originally developed for triaxial loading conditions. The oedometer test is also an important test in the field of geomechanics, which is used frequently to determine the material parameters of soils. In this example, the drained triaxial compression test and the oedometer test presented in Ref. 1 are simulated.

The Cam-Clay family of models do not have any stiffness at zero stress; hence, it always starts with an initial mean stress. In COMSOL Multiphysics, the initial mean stress of the MCC model is equal to the reference pressure. The MCC model comes in two flavors: it either requires the specification of a constant shear modulus or a constant Poisson's ratio. In this example, the constant Poisson's ratio formulation is used in order to match the results in Ref. 1. Although the analysis presented in Ref. 1 is transient, a stationary analysis is sufficient to predict the behavior.

Model Definition

In both the triaxial and oedometer tests, a cylindrical soil specimen of 3.91 cm in diameter and 8 cm in height is used. For the triaxial test (see Figure 1), a confinement pressure is applied to create a state of isotropic compression, and later the soil sample is compressed axially. For the oedometer test, the bottom and side boundaries of the cylindrical specimen are constrained in the normal direction and an axial load is applied on the top boundary.

SOIL PROPERTIES

The soil properties for the MCC material model as given in Ref. 1 are

- Density $\rho = 2400\ \mathrm{kg/m^3}$, Poisson's ratio $\nu = 0.35$, slope of critical state line $M = 1.2$, swelling index $\kappa = 0.02$, compression index $\lambda = 0.1$, void ratio $e_{ref} = 1$ at a reference pressure $p_{ref} = 98$ kPa, and initial consolidation pressure $p_{c0} = 100$ kPa or 500 kPa.

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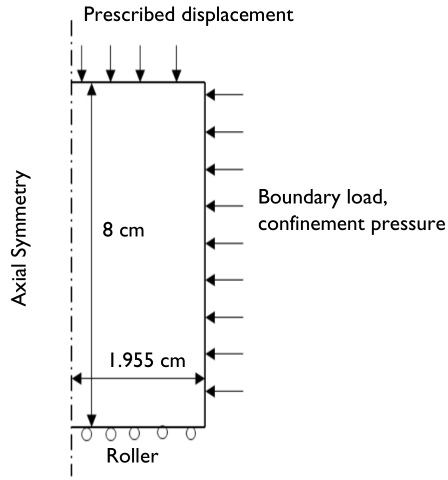

Figure 1: Dimensions, boundary conditions, and boundary loads for the triaxial test.

CONSTRAINTS AND LOADS

- For the isotropic compression stage in the triaxial test, a mean stress of 100 kPa is maintained throughout the test. As the MCC model has an initial mean stress equal to the reference pressure, an additional pressure of 2 kPa is applied using an **External Stress** node with the *in-situ stress* option.
- For the axial compression stage in the triaxial test, the soil sample is compressed by applying a prescribed displacement on the top boundary. Allow the right boundary to expand freely in the radial direction, and apply a roller boundary condition at the bottom boundary.
- For the axial compression stage in the oedometer test, the soil sample is compressed using a boundary load on the top boundary. A roller boundary condition is applied on the bottom and right vertical boundaries in order simulate confinement (zero radial strain).

Results and Discussion

Note that for the sake of consistency with geomechanics conventions, the compressive axial stress and strain are plotted along the positive axis, whereas the tensile stress and strain are plotted along the negative axis in all the figures. The response of the MCC model with different overconsolidation ratios (OCRs) are plotted in the same figures for comparison purposes.

The OCR is a ratio between the initial consolidation pressure to the initial mean effective stress. For the oedometer test in Ref. 1, the OCR is the ratio of the initial consolidation pressure to the initial vertical load. A soil with an OCR equal to 1 is referred to as normally consolidated. When the OCR is equal to 5 or 50, the soil is instead referred to as highly overconsolidated.

The variation in von Mises stress versus axial strain with different OCRs is shown in Figure 2. The stress-strain curve is nonlinear, which is a characteristic of the MCC model. As the axial displacement increases, the von Mises stress increases hyperbolically and approaches a critical state asymptotically. When the soil attains the critical state, additional loading does not produce any volume changes or hardening. The response of the soil in Figure 2 matches very closely with the numerical results given in Ref. 1 (see Figure 7 in Ref. 1).

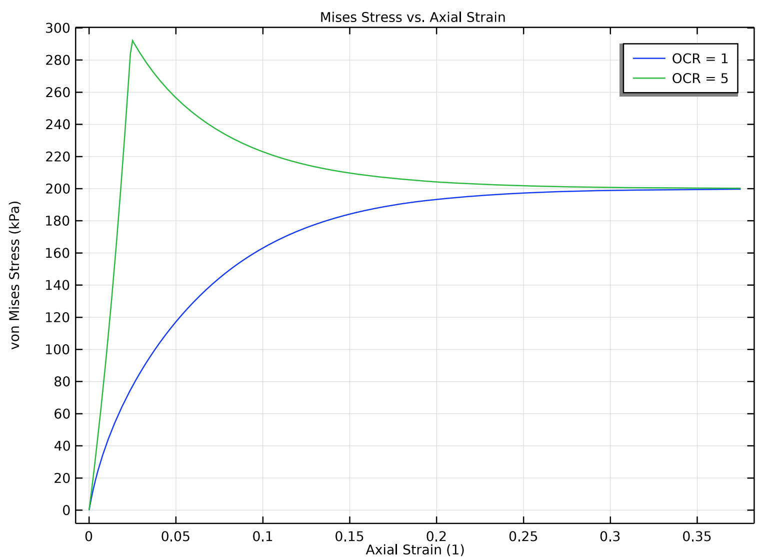

Figure 2: von Mises stress versus axial strain.

The variation in the total volumetric strain versus the axial strain with different OCRs can be seen in Figure 3, which matches very closely with the numerical results given in Ref. 1 (see Figure 8 in Ref. 1). For normally consolidated soils (OCR = 1), the total volumetric strain remains compressive. In contrast, the volumetric response for highly overconsolidated soils turns tensile after an initial compressive phase. This counterintuitive behavior can be further explained by Figure 4 and Figure 5.

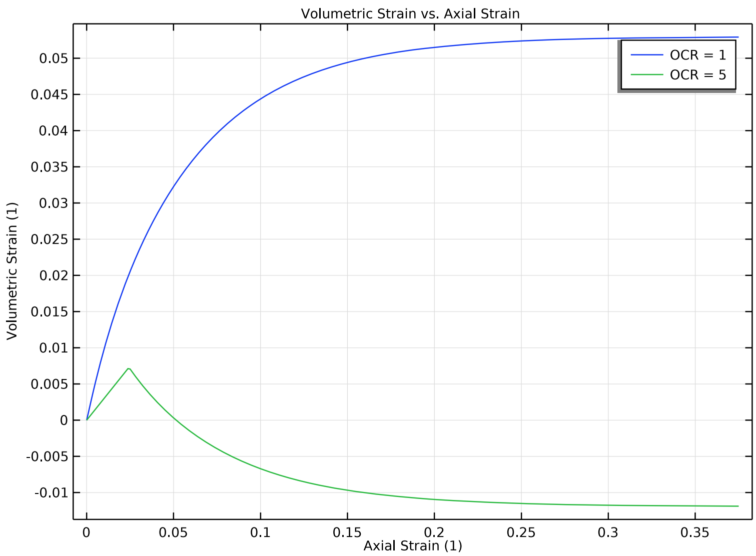

Figure 3: Volumetric strain versus axial strain.

The evolution of the consolidation pressure and the volumetric plastic strains is shown in Figure 4 and Figure 5, respectively. For normally consolidated soils, the consolidation pressure increases, indicating that the final yield envelope is expanding. This, in turn, gives compressive volumetric plastic strains, see Figure 5. This behavior is called isotropic hardening. For highly overconsolidated soils, the consolidation pressure is decreasing, indicating the shrinking of the final yield envelope, which in turn develops tensile volumetric plastic strains, see Figure 5. This behavior called isotropic softening

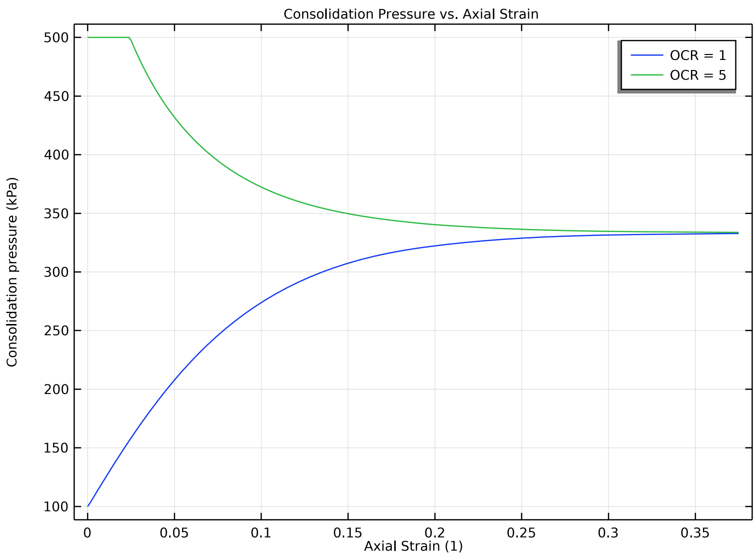

Figure 4: Consolidation pressure versus axial strain.

In COMSOL Multiphysics, the reference pressure acts as an initial stress and needs to be nonzero. For the oedometer test in Ref. 1, there seems to be no initial stress. Hence, for the corresponding test in COMSOL Multiphysics, set the reference pressure to 1 kPa. The void ratio at the reference pressure is calculated based on its value at 98 kPa as

$$e = e_{\mathrm{ref}} - \lambda \ln \frac{p}{p_{\mathrm{ref}}}$$

$$e_{\mathrm{ref}} = 1 + 0.1\ln(98) = 1.4584$$

The variation in the void ratio versus the logarithm of the vertical load for the highly overconsolidated soil in the oedometer test is plotted in Figure 6, which matches qualitatively with numerical results given in Ref. 1 (see Figure 6 in Ref. 1). The slight difference in the results can be due to the different initial conditions.

The variation in the total volumetric strain versus the axial load for the highly overconsolidated soil in the oedometer test can be seen in Figure 7. When the yield limit is reached, the response is nonsmooth.

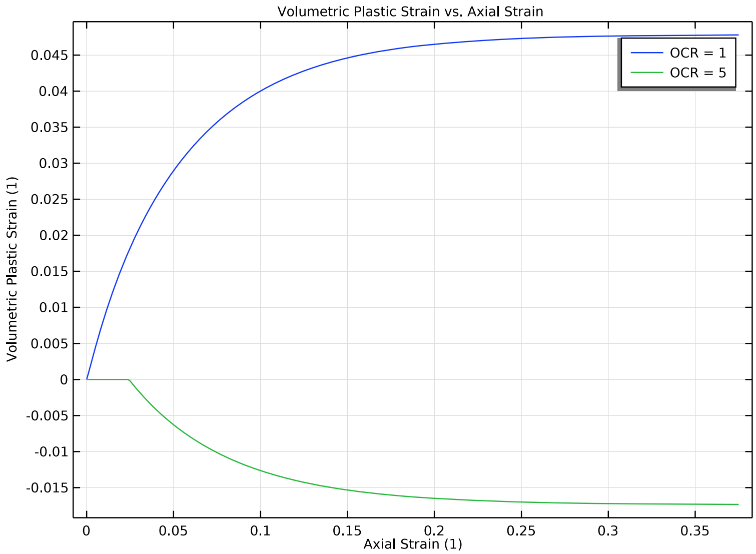

Figure 5: Volumetric plastic strain versus axial strain.

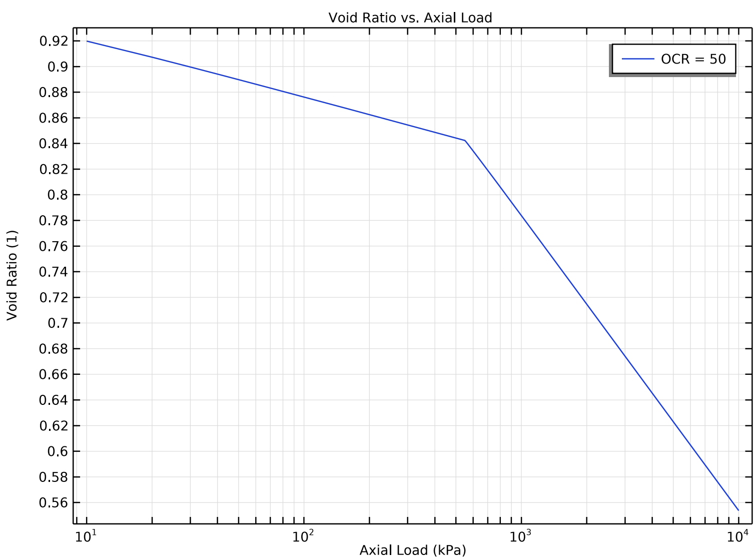

Figure 6: Void ratio versus the axial load (log-scale).

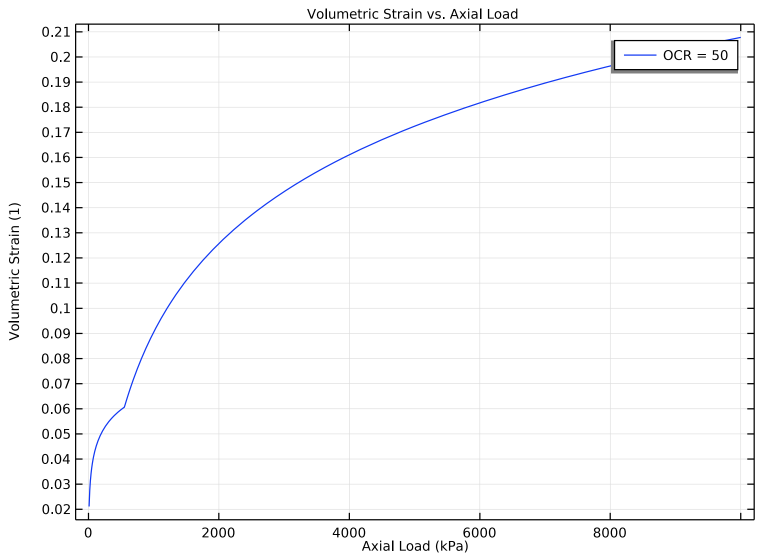

Figure 7: Volumetric strain versus axial load.

Notes About the COMSOL Implementation

In COMSOL Multiphysics, the MCC model comes in two flavors: it either requires specification of constant shear modulus or a constant Poisson's ratio. For the constant shear modulus option, the Poisson's ratio is computed based on the bulk modulus and the given shear modulus. This Poisson's ratio depends on deformation, but does not enter into the constitutive relation and remains only as a postprocessing variable. For the constant Poisson's ratio option, the shear modulus is calculated from the bulk modulus and the Poisson's ratio. This variable shear modulus does enter into the constitutive relation.

The in-situ stresses are the stresses in the soil sample in the strain-free configuration. There are two methods to account for in-situ stresses in COMSOL Multiphysics. One method is to create two stationary study steps or studies, with a combination of **Initial Stress and Strain** and **External Stress** nodes. The second method is to use the *in-situ stress* option in an **External Stress** node with single study, which gives initial stresses in the soil sample without any strain. In this example, the second method is used to model the initial/in-situ stresses in the triaxial test.

Reference

1. G. Ye and B. Ye, "Investigation of the Overconsolidation and Structural Behavior of Shanghai Clays by Element Testing and Constitutive Modeling," *Underground Space*, vol. 1, pp. 62-77, 2016.

Application Library path: `Geomechanics_Module/Verification_Examples/triaxial_and_oedometer_test_mcc`

Modeling Instructions

From the **File** menu, choose **New**.

NEW

In the **New** window, click **Model Wizard**.

MODEL WIZARD

1 In the **Model Wizard** window, click **2D Axisymmetric**.

2 In the **Select Physics** tree, select **Structural Mechanics>Solid Mechanics (solid)**.

3 Click **Add**.

4 Click **Study**.

5 In the **Select Study** tree, select **General Studies>Stationary**.

6 Click **Done**.

GLOBAL DEFINITIONS

Parameters 1

1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.

2 In the **Settings** window for **Parameters**, locate the **Parameters** section.

3 In the table, enter the following settings:

Name	Expression	Value	Description
disp	0[cm]	0 m	Axial displacement
p0	2[kPa]	2000 Pa	Pressure
OCR	5	5	Overconsolidation ratio

Name	Expression	Value	Description
F	10[kPa]	10000 Pa	Axial load
isOedometerTest	0	0	Boolean for oedometer test

Add variables for the reference void ratio and the reference pressure, which are different for the two tests.

DEFINITIONS

Variables 1

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Definitions** and choose **Variables**.

2 In the **Settings** window for **Variables**, locate the **Variables** section.

3 In the table, enter the following settings:

Name	Expression	Unit	Description
e_ref	1*(1-isOedometerTest)+1.4584*isOedometerTest		Void ratio at reference pressure
p_ref	98[kPa]*(1-isOedometerTest)+1[kPa]*isOedometerTest	Pa	Reference pressure

GEOMETRY 1

Rectangle 1 (r1)

1 In the **Geometry** toolbar, click **Rectangle**.

2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.

3 In the **Width** text field, type 1.955[cm].

4 In the **Height** text field, type 8[cm].

5 Click **Build Selected**.

SOLID MECHANICS (SOLID)

Modified Cam-Clay Material Model

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Solid Mechanics (solid)** and choose **Material Models>Elastoplastic Soil Material**.

2 In the **Settings** window for **Elastoplastic Soil Material**, type Modified Cam-Clay Material Model in the **Label** text field.

3 Select Domain 1 only.

4 Locate the **Elastoplastic Soil Material** section. From the e_{ref} list, choose **User defined**. In the associated text field, type `e_ref`.

5 In the p_{ref} text field, type `p_ref`.

6 In the p_{c0} text field, type `100[kPa]*OCR`.

The triaxial test is carried out in two steps. The first step is needed to get the initial stress state of the sample, and the second step is an axial compressive loading. The initial stress state can be modeled using the **In situ stress** option of the **External Stress** node.

External Stress [Triaxial Test]

1 In the **Physics** toolbar, click **Attributes** and choose **External Stress**.

2 In the **Settings** window for **External Stress**, type `External Stress [Triaxial Test]` in the **Label** text field.

3 Locate the **External Stress** section. From the **Stress input** list, choose **In situ stress**.

4 In the σ_{ins} text field, type `-p0`.

Roller [Triaxial Test]

1 In the **Physics** toolbar, click **Boundaries** and choose **Roller**.

2 In the **Settings** window for **Roller**, type `Roller [Triaxial Test]` in the **Label** text field.

3 Select Boundary 2 only.

Prescribed Displacement [Triaxial Test]

1 In the **Physics** toolbar, click **Boundaries** and choose **Prescribed Displacement**.

2 In the **Settings** window for **Prescribed Displacement**, type `Prescribed Displacement [Triaxial Test]` in the **Label** text field.

3 Select Boundary 3 only.

4 Locate the **Prescribed Displacement** section. Select the **Prescribed in z direction** check box.

5 In the u_{0z} text field, type `disp`.

Roller [Oedometer Test]

1 In the **Physics** toolbar, click **Boundaries** and choose **Roller**.

2 Select Boundaries 2 and 4 only.

3 In the **Settings** window for **Roller**, type `Roller [Oedometer Test]` in the **Label** text field.

Boundary Load [Oedometer Test]

1 In the **Physics** toolbar, click **Boundaries** and choose **Boundary Load**.

2 Select Boundary 3 only.

3 In the **Settings** window for **Boundary Load**, locate the **Force** section.

4 From the **Load type** list, choose **Pressure**.

5 In the p text field, type `F`.

6 In the **Label** text field, type `Boundary Load [Oedometer Test]`.

MATERIALS

Soil Material

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Materials** and choose **Blank Material**.

2 In the **Settings** window for **Material**, type `Soil Material` in the **Label** text field.

3 Locate the **Material Contents** section. In the table, enter the following settings:

Property	**Variable**	**Value**	**Unit**	**Property group**
Poisson's ratio	nu	0.35	1	Young's modulus and Poisson's ratio
Swelling index	kappaSwelling	0.02	1	Cam-Clay
Compression index	lambdaComp	0.1	1	Cam-Clay
Slope of critical state line	M	1.2	1	Cam-Clay
Density	rho	2400[kg/m^3]	kg/m³	Basic

One element is sufficient for this analysis.

MESH 1

Mapped 1

In the **Mesh** toolbar, click **Mapped**.

Distribution 1

1 Right-click **Mapped 1** and choose **Distribution**.

2 In the **Settings** window for **Distribution**, locate the **Boundary Selection** section.

3 From the **Selection** list, choose **All boundaries**.

4 Locate the **Distribution** section. In the **Number of elements** text field, type `1`.

5 Click **Build Selected**.

Disable the features that are not needed in this study.

STUDY: TRIAXIAL TEST

Disable the default plots for this study.

1 In the **Model Builder** window, click **Study 1**.

2 In the **Settings** window for **Study**, type `Study: Triaxial Test` in the **Label** text field.

3 Locate the **Study Settings** section. Clear the **Generate default plots** check box.

Disable the features that are not needed in this study.

Step 1: Stationary

1 In the **Model Builder** window, under **Study: Triaxial Test** click **Step 1: Stationary**.

2 In the **Settings** window for **Stationary**, locate the **Physics and Variables Selection** section.

3 Select the **Modify model configuration for study step** check box.

4 In the tree, select **Component 1 (comp1)>Solid Mechanics (solid)>Roller [Oedometer Test]** and **Component 1 (comp1)>Solid Mechanics (solid)>Boundary Load [Oedometer Test]**.

5 Right-click and choose **Disable**.

6 Click to expand the **Study Extensions** section. Select the **Auxiliary sweep** check box.

7 Click **Add**.

8 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
disp (Axial displacement)	`range(0,-0.0001,-0.03)`	`m`

Add a **Parametric Sweep** node to study the soil specimen for different OCRs.

Parametric Sweep

1 In the **Study** toolbar, click **Parametric Sweep**.

2 In the **Settings** window for **Parametric Sweep**, locate the **Study Settings** section.

3 Click **Add**.

4 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
OCR (Overconsolidation ratio)	1 5	1

5 In the **Study** toolbar, click **Compute**.

Add a second study for the axial compression step in the oedometer test.

ADD STUDY

1 In the **Study** toolbar, click **Add Study** to open the **Add Study** window.

2 Go to the **Add Study** window.

3 Find the **Studies** subsection. In the **Select Study** tree, select **General Studies>Stationary**.

4 Click **Add Study** in the window toolbar.

5 In the **Study** toolbar, click **Add Study** to close the **Add Study** window.

Disable the features that are not needed in this study.

STUDY: OEDOMETER TEST

Disable the default plots for this study.

1 In the **Model Builder** window, click **Study 2**.

2 In the **Settings** window for **Study**, locate the **Study Settings** section.

3 Clear the **Generate default plots** check box.

4 In the **Label** text field, type `Study: Oedometer Test`.

5 In the **Study** toolbar, click **Parametric Sweep**.

Parametric Sweep

1 In the **Settings** window for **Parametric Sweep**, locate the **Study Settings** section.

2 Click **Add**.

3 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
isOedometerTest (Boolean for oedometer test)	1	1

Step 1: Stationary

1 In the **Model Builder** window, click **Step 1: Stationary**.

2 In the **Settings** window for **Stationary**, locate the **Physics and Variables Selection** section.

3 Select the **Modify model configuration for study step** check box.

4 In the tree, select **Component 1 (comp1)>Solid Mechanics (solid)>Modified Cam-Clay Material Model>External Stress [Triaxial Test]**, **Component 1 (comp1)>Solid Mechanics (solid)>Roller [Triaxial Test]**, and **Component 1 (comp1)>Solid Mechanics (solid)>Prescribed Displacement [Triaxial Test]**.

5 Right-click and choose **Disable**.

6 Locate the **Study Extensions** section. Select the **Auxiliary sweep** check box.

7 Click **Add**.

8 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
F (Axial load)	`range(10,10,10000)`	`kPa`

9 In the **Study** toolbar, click **Compute**.

RESULTS

Mises Stress vs. Axial Strain [Triaxial Test]

1 In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Mises Stress vs. Axial Strain [Triaxial Test]` in the **Label** text field.

3 Click to expand the **Title** section. From the **Title type** list, choose **Manual**.

4 In the **Title** text area, type `Mises Stress vs. Axial Strain`.

5 Locate the **Plot Settings** section.

6 Select the **x-axis label** check box. In the associated text field, type `Axial Strain (1)`.

7 Select the **y-axis label** check box. In the associated text field, type `von Mises Stress (kPa)`.

Point Graph 1

1 Right-click **Mises Stress vs. Axial Strain [Triaxial Test]** and choose **Point Graph**.

2 In the **Settings** window for **Point Graph**, locate the **Data** section.

3 From the **Dataset** list, choose **Study: Triaxial Test/Parametric Solutions 1 (sol2)**.

4 From the **Parameter selection (OCR)** list, choose **First**.

5 Select Point 2 only.

6 Locate the **y-Axis Data** section. In the **Expression** text field, type `solid.mises`.

7 From the **Unit** list, choose **kPa**.

8. Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.
9. In the **Expression** text field, type `-solid.eZZ`.
10. Click to expand the **Legends** section. Select the **Show legends** check box.
11. From the **Legends** list, choose **Manual**.
12. In the table, enter the following settings:

Legends
`OCR = 1`

Point Graph 2

1. Right-click **Point Graph 1** and choose **Duplicate**.
2. In the **Settings** window for **Point Graph**, locate the **Data** section.
3. From the **Parameter selection (OCR)** list, choose **Last**.
4. Locate the **Legends** section. In the table, enter the following settings:

Legends
`OCR = 5`

5. In the **Mises Stress vs. Axial Strain [Triaxial Test]** toolbar, click **Plot**.

Volumetric Strain vs. Axial Strain [Triaxial Test]

1. In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.
2. In the **Settings** window for **1D Plot Group**, type `Volumetric Strain vs. Axial Strain [Triaxial Test]` in the **Label** text field.
3. Locate the **Title** section. From the **Title type** list, choose **Manual**.
4. In the **Title** text area, type `Volumetric Strain vs. Axial Strain`.
5. Locate the **Plot Settings** section.
6. Select the **x-axis label** check box. In the associated text field, type `Axial Strain (1)`.
7. Select the **y-axis label** check box. In the associated text field, type `Volumetric Strain (1)`.

Point Graph 1

1. Right-click **Volumetric Strain vs. Axial Strain [Triaxial Test]** and choose **Point Graph**.
2. In the **Settings** window for **Point Graph**, locate the **Data** section.
3. From the **Dataset** list, choose **Study: Triaxial Test/Parametric Solutions 1 (sol2)**.
4. From the **Parameter selection (OCR)** list, choose **First**.

5 Select Point 2 only.

6 Locate the **y-Axis Data** section. In the **Expression** text field, type `-solid.evol`.

7 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.

8 In the **Expression** text field, type `-solid.eZZ`.

9 Locate the **Legends** section. Select the **Show legends** check box.

10 From the **Legends** list, choose **Manual**.

11 In the table, enter the following settings:

Legends
`OCR = 1`

Point Graph 2

1 Right-click **Point Graph 1** and choose **Duplicate**.

2 In the **Settings** window for **Point Graph**, locate the **Data** section.

3 From the **Parameter selection (OCR)** list, choose **Last**.

4 Select Point 4 only.

5 Locate the **Legends** section. In the table, enter the following settings:

Legends
`OCR = 5`

6 In the **Volumetric Strain vs. Axial Strain [Triaxial Test]** toolbar, click **Plot**.

Consolidation Pressure vs. Axial Strain [Triaxial Test]

1 In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Consolidation Pressure vs. Axial Strain [Triaxial Test]` in the **Label** text field.

3 Locate the **Title** section. From the **Title type** list, choose **Manual**.

4 In the **Title** text area, type `Consolidation Pressure vs. Axial Strain`.

5 Locate the **Plot Settings** section.

6 Select the **x-axis label** check box. In the associated text field, type `Axial Strain (1)`.

7 Select the **y-axis label** check box. In the associated text field, type `Consolidation pressure (kPa)`.

Point Graph 1

1 Right-click **Consolidation Pressure vs. Axial Strain [Triaxial Test]** and choose **Point Graph**.

2 In the **Settings** window for **Point Graph**, locate the **Data** section.

3 From the **Dataset** list, choose **Study: Triaxial Test/Parametric Solutions 1 (sol2)**.

4 From the **Parameter selection (OCR)** list, choose **First**.

5 Select Point 2 only.

6 Click **Replace Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)>Solid Mechanics>Soil material properties> Modified Cam-Clay>solid.epsm1.pc - Consolidation pressure - Pa**.

7 Locate the **y-Axis Data** section. From the **Unit** list, choose **kPa**.

8 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.

9 In the **Expression** text field, type `-solid.eZZ`.

10 Locate the **Legends** section. Select the **Show legends** check box.

11 From the **Legends** list, choose **Manual**.

12 In the table, enter the following settings:

Legends
`OCR = 1`

Point Graph 2

1 Right-click **Point Graph 1** and choose **Duplicate**.

2 In the **Settings** window for **Point Graph**, locate the **Data** section.

3 From the **Parameter selection (OCR)** list, choose **Last**.

4 Select Point 4 only.

5 Locate the **Legends** section. In the table, enter the following settings:

Legends
`OCR = 5`

6 In the **Consolidation Pressure vs. Axial Strain [Triaxial Test]** toolbar, click **Plot**.

Volumetric Plastic Strain vs. Axial Strain [Triaxial Test]

1 In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Volumetric Plastic Strain vs. Axial Strain [Triaxial Test]` in the **Label** text field.

3 Locate the **Title** section. From the **Title type** list, choose **Manual**.

4 In the **Title** text area, type `Volumetric Plastic Strain vs. Axial Strain`.

5 Locate the **Plot Settings** section.

6 Select the **x-axis label** check box. In the associated text field, type `Axial Strain (1)`.

7 Select the **y-axis label** check box. In the associated text field, type `Volumetric Plastic Strain (1)`.

Point Graph 1

1 Right-click **Volumetric Plastic Strain vs. Axial Strain [Triaxial Test]** and choose **Point Graph**.

2 In the **Settings** window for **Point Graph**, locate the **Data** section.

3 From the **Dataset** list, choose **Study: Triaxial Test/Parametric Solutions 1 (sol2)**.

4 From the **Parameter selection (OCR)** list, choose **First**.

5 Select Point 2 only.

6 Locate the **y-Axis Data** section. In the **Expression** text field, type `-solid.epvol`.

7 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.

8 In the **Expression** text field, type `-solid.eZZ`.

9 Locate the **Legends** section. Select the **Show legends** check box.

10 From the **Legends** list, choose **Manual**.

11 In the table, enter the following settings:

Legends
`OCR = 1`

Point Graph 2

1 Right-click **Point Graph 1** and choose **Duplicate**.

2 In the **Settings** window for **Point Graph**, locate the **Data** section.

3 From the **Parameter selection (OCR)** list, choose **Last**.

4 Select Point 4 only.

5 Locate the **Legends** section. In the table, enter the following settings:

Legends
`OCR = 5`

6 In the **Volumetric Plastic Strain vs. Axial Strain [Triaxial Test]** toolbar, click  **Plot**.

Void Ratio vs. Axial Load [Oedometer Test]

1 In the **Home** toolbar, click  **Add Plot Group** and choose **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Void Ratio vs. Axial Load [Oedometer Test]` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Study: Oedometer Test/ Parametric Solutions 2 (sol6)**.

4 Locate the **Title** section. From the **Title type** list, choose **Manual**.

5 In the **Title** text area, type `Void Ratio vs. Axial Load`.

6 Locate the **Plot Settings** section.

7 Select the **x-axis label** check box. In the associated text field, type `Axial Load (kPa)`.

8 Select the **y-axis label** check box. In the associated text field, type `Void Ratio (1)`.

9 Locate the **Axis** section. Select the **x-axis log scale** check box.

Point Graph 1

1 Right-click **Void Ratio vs. Axial Load [Oedometer Test]** and choose **Point Graph**.

2 Select Point 2 only.

3 In the **Settings** window for **Point Graph**, click **Replace Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)> Solid Mechanics>Soil material properties>Modified Cam-Clay>solid.epsm1.evoid - Void ratio**.

4 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.

5 In the **Expression** text field, type `F`.

6 From the **Unit** list, choose **kPa**.

7 Locate the **Legends** section. Select the **Show legends** check box.

8 From the **Legends** list, choose **Manual**.

9 In the table, enter the following settings:

Legends
`OCR = 50`

10 In the **Void Ratio vs. Axial Load [Oedometer Test]** toolbar, click **Plot**.

Volumetric Strain vs. Axial Load [Oedometer Test]

1 In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Volumetric Strain vs. Axial Load [Oedometer Test]` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Study: Oedometer Test/ Parametric Solutions 2 (sol6)**.

4 Locate the **Title** section. From the **Title type** list, choose **Manual**.

5 In the **Title** text area, type `Volumetric Strain vs. Axial Load`.

6 Locate the **Plot Settings** section.

7 Select the **x-axis label** check box. In the associated text field, type `Axial Load (kPa)`.

8 Select the **y-axis label** check box. In the associated text field, type `Volumetric Strain (1)`.

Point Graph 1

1 Right-click **Volumetric Strain vs. Axial Load [Oedometer Test]** and choose **Point Graph**.

2 Select Point 2 only.

3 In the **Settings** window for **Point Graph**, locate the **y-Axis Data** section.

4 In the **Expression** text field, type `-solid.evol`.

5 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.

6 In the **Expression** text field, type `F`.

7 From the **Unit** list, choose **kPa**.

8 Locate the **Legends** section. Select the **Show legends** check box.

9 From the **Legends** list, choose **Manual**.

10 In the table, enter the following settings:

Legends
OCR = 50

11 In the **Volumetric Strain vs. Axial Load [Oedometer Test]** toolbar, click **Plot**.