Anura3D
MPM Research Community

Soil model interface in Anura3D

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Deltares Enabling Delta Life

Governing equations (coupled 2-phase problem)

Dynamic equilibrium liquid $$\rho_l \dot{\mathbf{v}}_l = \nabla p - \frac{n\gamma_l}{k}\left(\mathbf{v}_l - \mathbf{v}_s\right) + \rho_l \mathbf{g}$$

Dynamic equilibrium mixture $$\left(1-n\right)\rho_s \dot{\mathbf{v}}_s + n\rho_l \dot{\mathbf{v}}_l = \nabla \cdot \boldsymbol{\sigma} + \rho \mathbf{g}$$

Mass balance liquid $$\dot{p} = \frac{K_l}{n}\left[(1-n)\dot{\varepsilon}_s^{vol} + n\dot{\varepsilon}_l^{vol}\right]$$

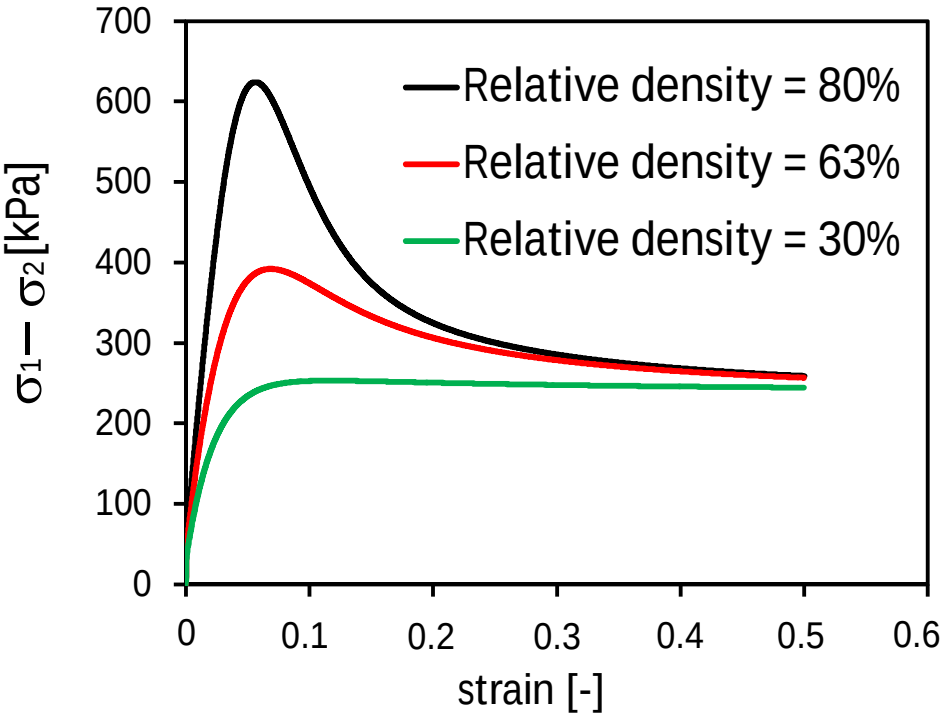
Constitutive equation $$\dot{\boldsymbol{\sigma}} = \mathbf{D} : \dot{\boldsymbol{\varepsilon}}$$

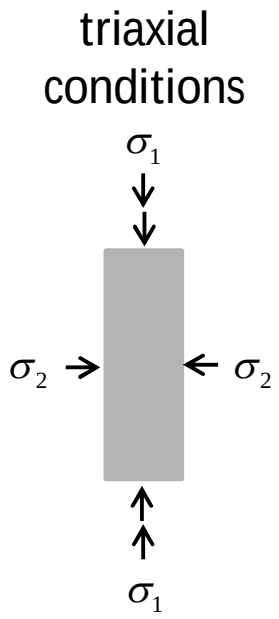
MPM is a continuum-based method

$\mathbf{v}_s$	soil skeleton velocity	p	liquid pressure
$\mathbf{v}_l$	liquid velocity	$\boldsymbol{\sigma}$	total stress tensor
n	porosity	$\boldsymbol{\varepsilon}$	strain tensor
ρ_s	solid density	$\mathbf{D}$	tangent stiffness tensor
ρ_l	liquid density	K_l	liquid bulk modulus
ρ	density of the mixture	$\mathbf{g}$	gravity vector

Constitutive model

advanced material models can depend on:
plastic strain, stress and strain rates, density, ...





handling the history of state parameters is essential

Current constitutive models in Anura3D

- Linear Elasticity
- Mohr-Coulomb Elasto-Plasticity
- Mohr-Coulomb Elasto-Plasticity (Teunissen)
- Mohr-Coulomb Strain-Softening
- Mohr-Coulomb Suction Dependent
- Isotropic Cone Hardening
- Hypoplasticity Sand (Von Wolffersdorff)
- Original Cam-Clay (Schofield and Wroth)
- Modified Cam-Clay (Burland)
- Nor-Sand (Jefferies)
- Unsaturated Nor-Sand (Fern)
- SANISAND (Dafalias and Manzari)
- User-defined soil model (UMAT/VUMAT)

at different levels of:
availability,
validation,
testing,
documentation,
robustness,
reliability,
applicability,
...

General constitutive model

Approach for user-defined soil model:

- external library (DLL) containing constitutive model
- standardised user-defined soil model interface (UMAT format)
- standardised material parameter input
- can be used in several environments (e.g. Abaqus, Plaxis, Tochnog, ...)

Benefits

- standardised software interface (UMAT format)
  - modular set-up, well-documented
  - transferable to other (commercial) software products
  - development is software independent
- validation and testing possibilities
  - by e.g. using in other software, also single-element test
- straightforward implementation (using Fortran)
  - no specific Anura3D code knowledge necessary
- straightforward input of material parameters
  - standard interface in GiD available
- includable in material models database
  - automated testing and documentation

UMAT/VUMAT interface

www.soilmodels.info

UMAT+VUMAT routines,
open source database of models, documentation

UMAT → used in Abaqus/Standard

VUMAT → used in Abaqus/Explicit

→ for differences and interface: Bienen et al., 2014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Interface enabling constitutive models coded as user materials to be employed in explicit analysis

Research report

by

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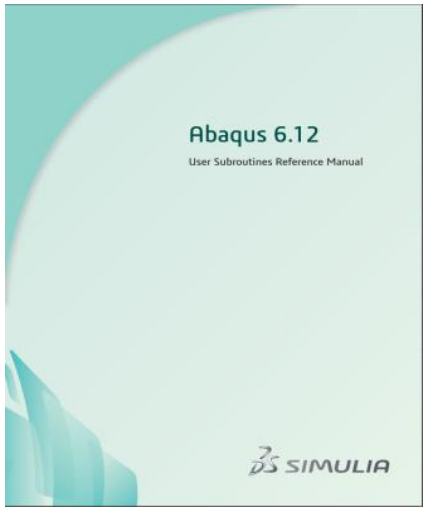


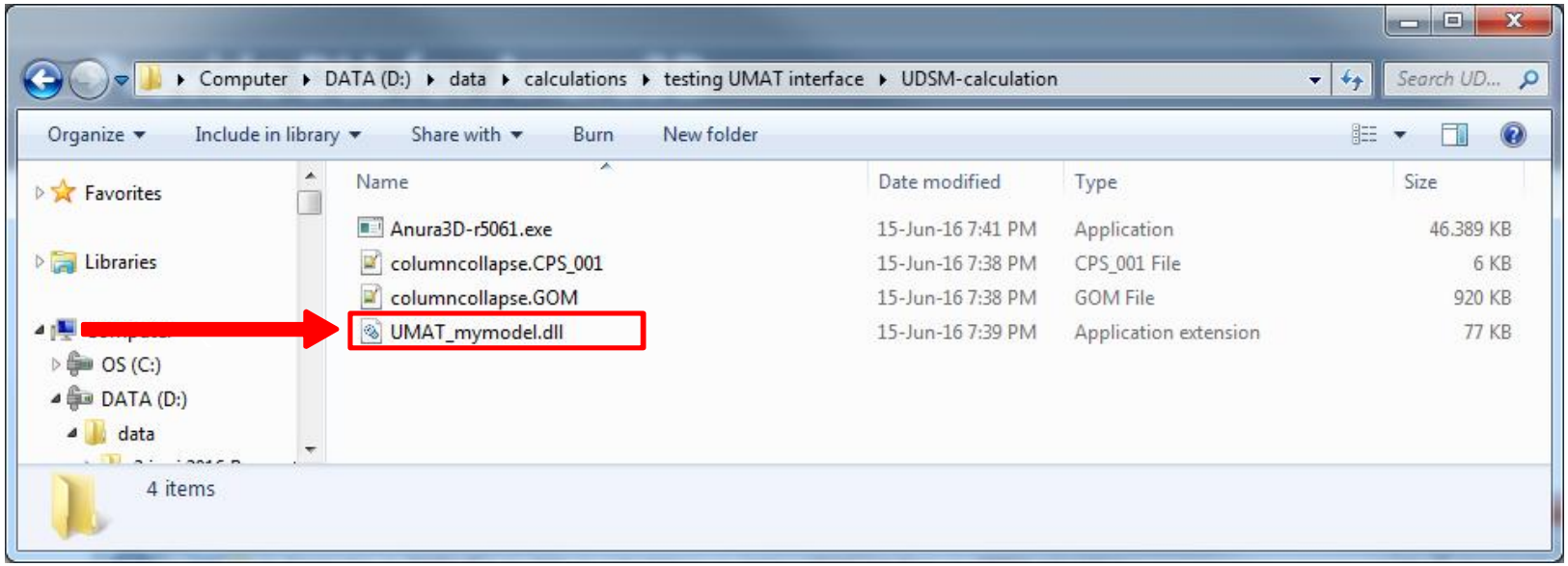
Full definitions of the UMAT and VUMAT requirements and conventions are detailed in the Abaqus User Subroutines Reference Manual v6.12 (Dassault Systèmes, 2012)

Example UMAT

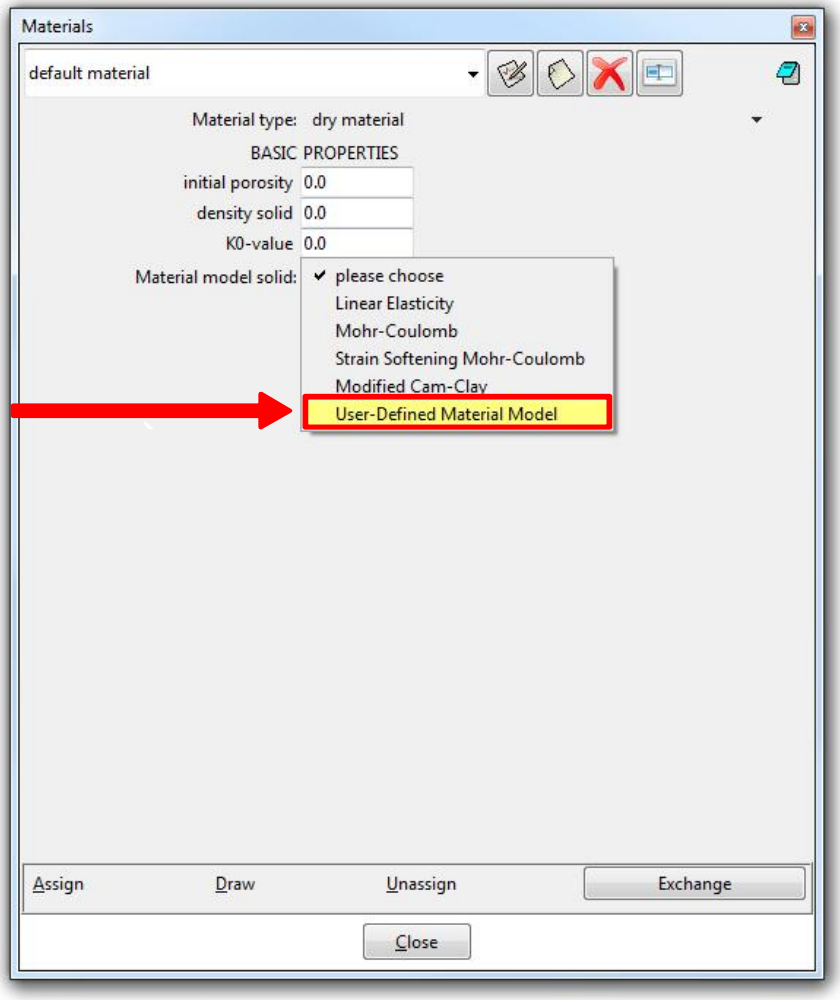
```
*USER SUBROUTINES
      SUBROUTINE UMAT(STRESS,STATEV,DDSDDE,SSE,SPD,SCD,
     1 RPL,DDSDDT,DRPLDE,DRPLDT,
     2 STRAN,DSTRAN,TIME,DTIME,TEMP,DTEMP,PREDEF,DPRED,CMNAME,
     3 NDI,NSHR,NTENS,NSTATEV,PROPS,NPROPS,COORDS,DROT,PNEWDT,
     4 CELENT,DFGRD0,DFGRD1,NOEL,NPT,LAYER,KSPT,KSTEP,KINC)

      !DEC$ ATTRIBUTES DLLEXPORT, ALIAS:"UMAT" :: UMAT
      INCLUDE 'ABA_PARAM.INC'

      CHARACTER*80 CMNAME
      DIMENSION STRESS(NTENS),STATEV(NSTATEV),
     1 DDSDDE(NTENS,NTENS),DDSDDT(NTENS),DRPLDE(NTENS),
     2 STRAN(NTENS),DSTRAN(NTENS),TIME(2),PREDEF(1),DPRED(1),
     3 PROPS(NPROPS),COORDS(3),DROT(3,3),DFGRD0(3,3),DFGRD1(3,3)


        ! Arguments:
        !          I/O  Type
        !  PROPS    I   R()  : List with model parameters
        !  DSTRAN   I   R()  : Strain increment
        !  DDSDDE   O   R(,) : Material stiffness matrix
        !  STRESS  I/O  R()  : stresses
        !  STATEV  I/O  R()  : state variables

        !---  Local variables
        dimension dSig(6), Sig(6)

        ! Contents of PROPS(2)
        !  1 : G       shear modulus
        !  2 : ENU     Poisson's ratio

        G = PROPS(1)
        ENU = PROPS(2)
        one = 1.0d0
        two = 2.0d0

        ! calculate elastic stress increment (DSigE = elastic stiffness D * strain increment DEps)
        FAC = two * G / ( one - two * ENU )
        D1 = FAC * ( one - ENU )
        D2 = FAC * ENU
        DSTRANVOL = DSTRAN(1) + DSTRAN(2) + DSTRAN(3)
        dSig(1) = (D1 - D2) * DSTRAN(1) + D2 * DSTRANVOL
        dSig(2) = (D1 - D2) * DSTRAN(2) + D2 * DSTRANVOL
        dSig(3) = (D1 - D2) * DSTRAN(3) + D2 * DSTRANVOL
        dSig(4) = G * DSTRAN(4)
        dSig(5) = G * DSTRAN(5)
        dSig(6) = G * DSTRAN(6)

        ! elastic stress
        Sig = STRESS + dSig

        ! stress state parameters update
        do i = 1, ntens
          STRESS(i) = Sig(i)
        end do

        return

      end subroutine umat
```

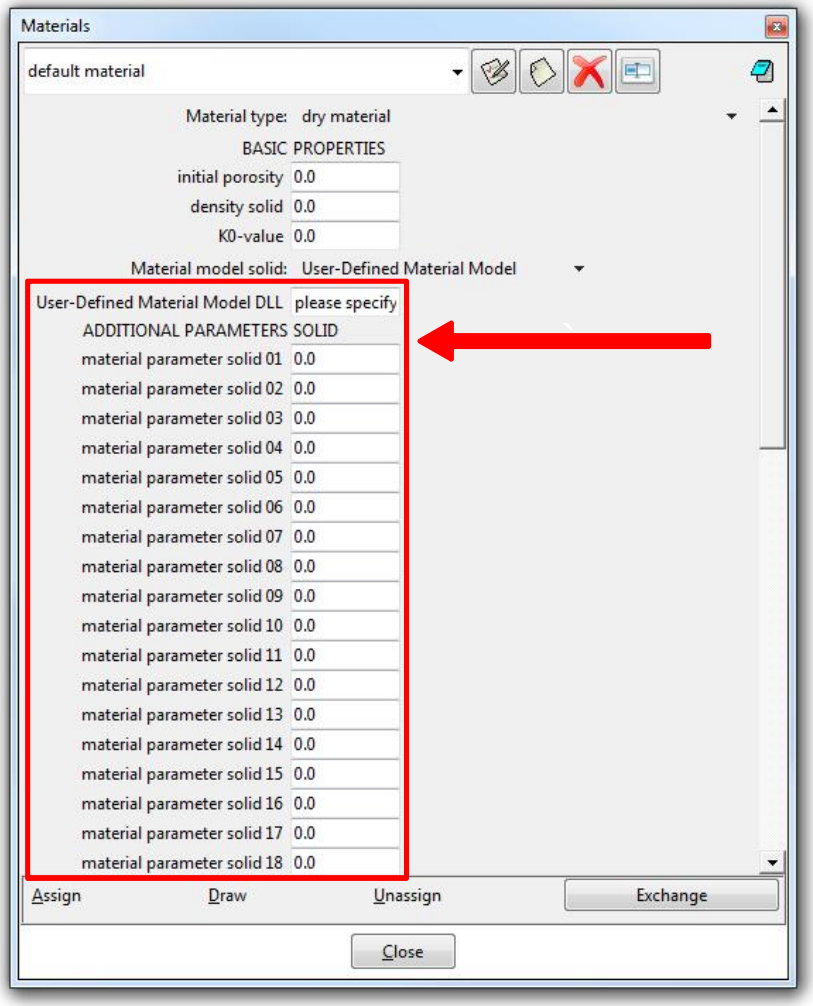
Provide DLL for Anura3D

To use the external user-defined soil model, copy the DLL **`UMAT_mymodel.dll`** into the calculation directory together with the executable of Anura3D and the input files (CPS_001 and GOM)



Interface for user-defined soil model





Input file in ASCII format

columncollapse.GOM

```
2296  $$NUMBER_OF_MATERIALS
2297  1
2298  $$MATERIAL_INDEX
2299  1
2300  $$MATERIAL_NAME
2301  sand
2302  $$MATERIAL_TYPE
2303  1-phase-solid
2304  $$POROSITY_SOLID
2305  0.35
2306  $$DENSITY_SOLID
2307  2650
2308  $$K0_VALUE_SOLID
2309  0.5
2310  $$INTRINSIC_PERMEABILITY_LIQUID
2311  0.0
2312  $$MATERIAL_MODEL_SOLID
2313  user_defined_soil_model
2314  $$SOIL_MODEL_DLL
2315  UMAT mymodel.dll
2316  $$MATERIAL_PARAMETER_SOLID_01
2317  1000
2318  $$MATERIAL_PARAMETER_SOLID_02
2319  0.3
2320  $$MATERIAL_PARAMETER_SOLID_03
2321  0.0
2322  $$MATERIAL_PARAMETER_SOLID_04
2323  0.0
2324  $$MATERIAL_PARAMETER_SOLID_05
2325  0.0
2326  $$MATERIAL_PARAMETER_SOLID_06
2327  0.0
2328  $$MATERIAL_PARAMETER_SOLID_07
2329  0.0
```

automatically generated

when selecting “User-defined Soil Model”

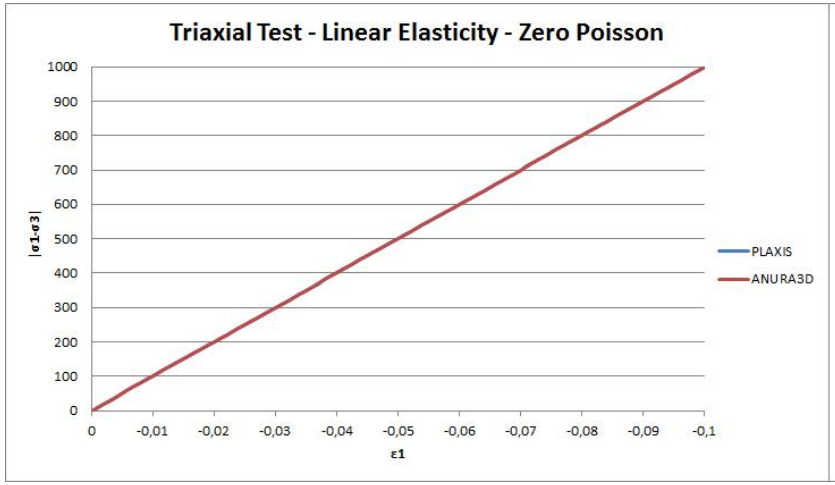
as “Material model solid” in pre-processor GiD

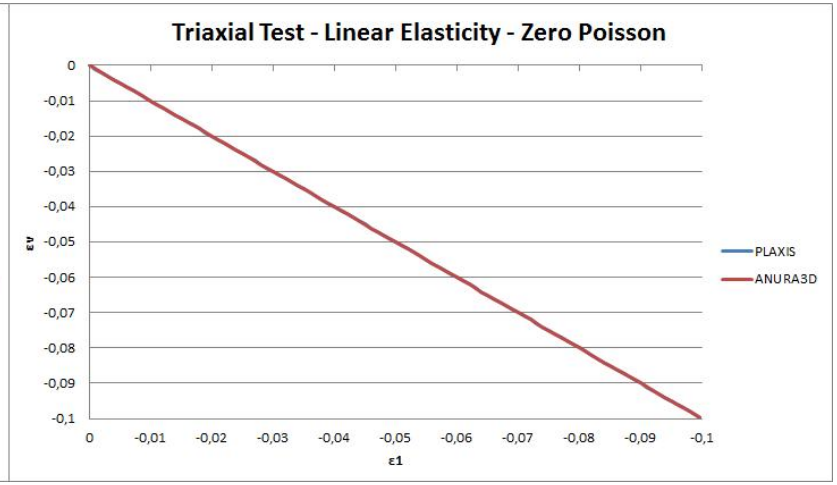
name of the external DLL containing the user-defined soil model

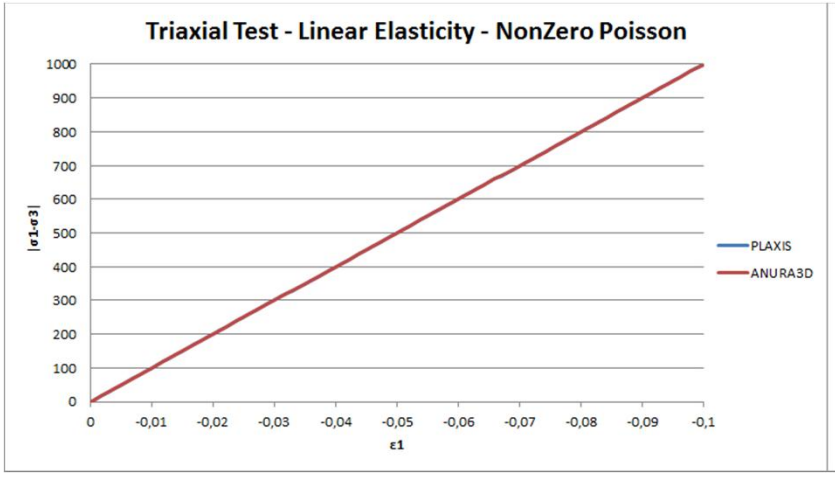
array of 50 values specifying the material properties

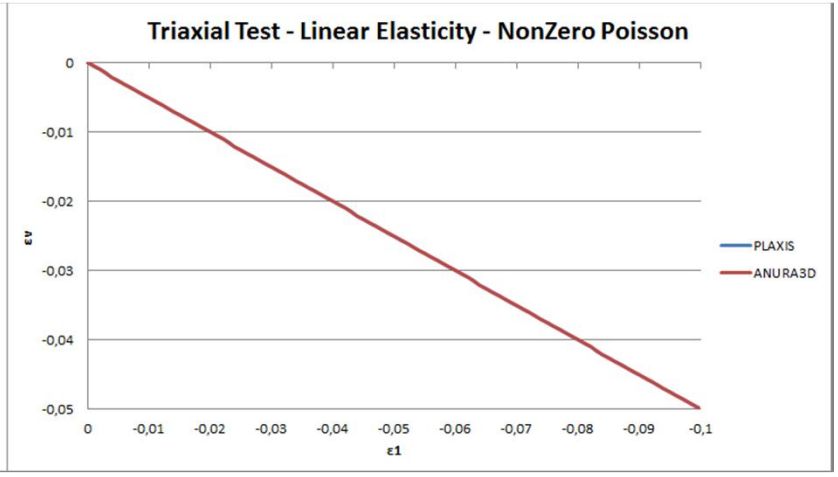
Triaxial Test Simulation

Linear Elasticity



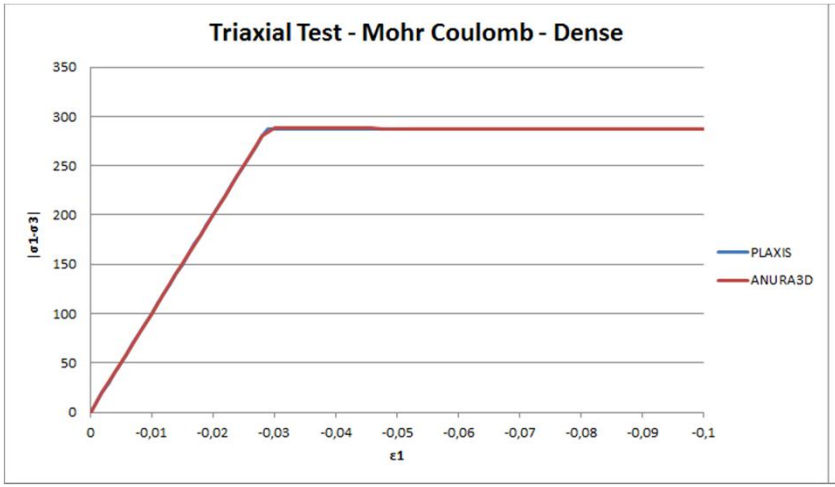


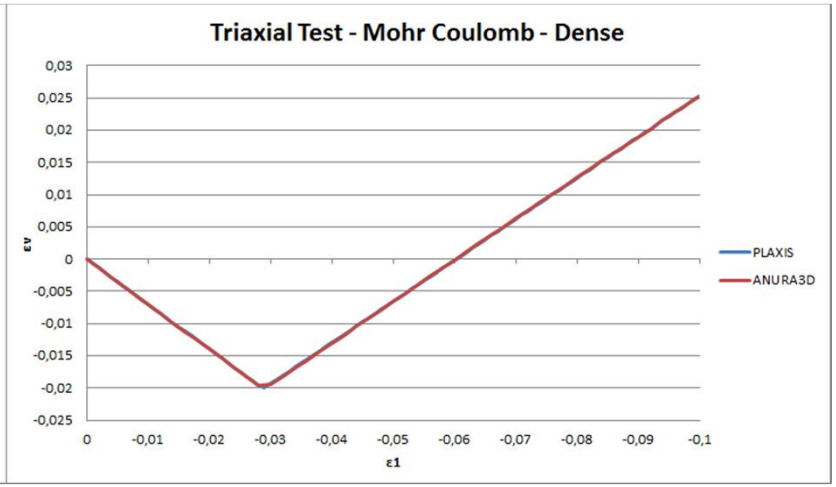


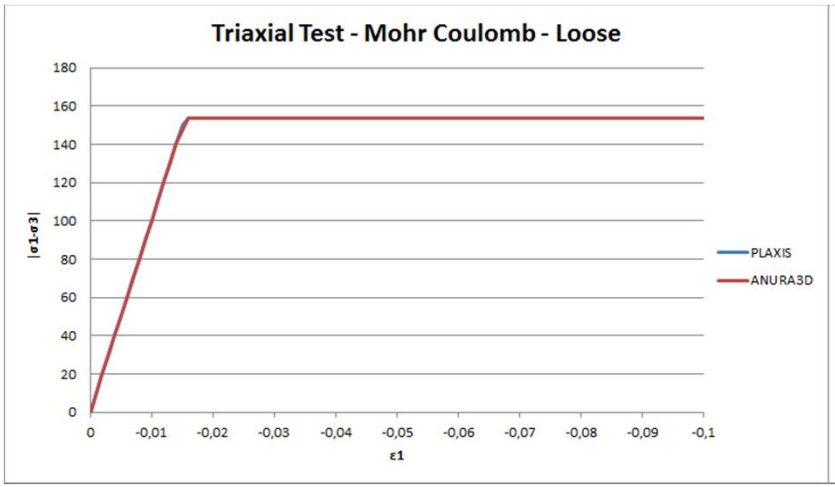


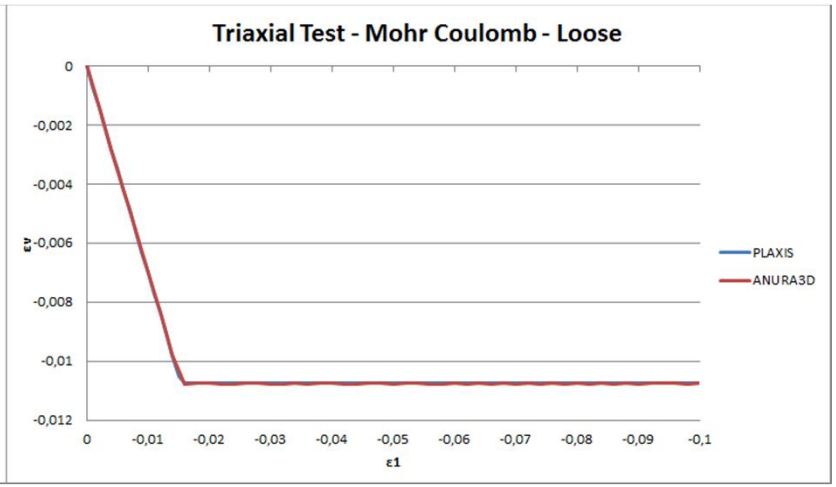
Triaxial Test Simulation

Mohr-Coulomb









Summary

- user-defined soil model interface available in Anura3D
- develop models in UMAT/VUMAT format
- test and compare UMAT with other (FE) software