On the use of the Hardening Soil model

Rafal OBRZUD

GeoMod Ing. SA, Lausanne
Content

- Introduction
- Example 1 – Berlin Sand - excavation problem
- Example 2 – Montreux – 3D excavation problem
- Example 3 – London Clay - tunnel excavation
- Example 4 – Almere - trial embankment problem
Why do we need advanced constitutive models?

GEOENGINEERING COMPUTINGS

LIMIT STATE ANALYSIS
- Bearing capacity
- Slope, wall stability

DEFORMATION ANALYSIS
- Pile, retaining wall deflection
- Supported deep excavations
- Tunnel excavations
- Consolidation

Basic models e.g. Mohr-Coulomb

Advanced soil models

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Basic differences between implemented soil models

Mohr-Coulomb

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Mohr-Coulomb

Mohr-Coulomb
Basic differences between implemented soil models

Mohr-Coulomb

Volumetric cap models

- Yield surface
- $K_0$-line
- Linear elastic domain
- Isotropic hardening mechanism
- $\sigma_1'$ constant
- Stiffness degradation
- Retaining walls (active)

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Basic differences between implemented soil models

Mohr-Coulomb

Volumetric cap models

Hardening Soil models

$q$ vs $p'$

yield surface

$K_0$-line

Linear elastic domain

isotropic hardening mechanism

Linear elastic domain

+ shear hardening mechanism

NON-LINEAR elastic domain

$q$ vs $\varepsilon_1$

Linear elastic domain

Stiffness degradation

Stiffness degradation

$E = E_{ur}$

$E < E_{ur}$

$E_0$
Basic differences between implemented soil models

Small strain stiffness in geotechnical practice

- Mohr-Coulomb
- Modified Cam Clay
- Cap model
- HS-Standard
- HS-Small

Normalized soil stiffness $G/G_0$ [-]

Non-linear elasticity at very small strains

Linear elasticity at small strains

Shear strain $\gamma_s$ [-]

Linear elasticity at very small strains

Axial Strain $\varepsilon$ [-]

1E-06 1E-05 \( \cdots \) 0.0001 0.001 0.01 0.1

SCPT

Unloading-Reloading PMT

DMT

Larger strains

Initial loading PMT

Smaller strains

Very small strains

Geophysical methods

Local gauges

Conventional soil testing

Shear modulus $G/G_0$ [-]

1E-06 1E-05 \( \cdots \) 0.0001 0.001 0.01 0.1

e.g. Atkinson, Jardine and many others

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Example 1: Berlin Sand - excavation problem (Schweiger, 2002)

Engineering draft

FE mesh

Anchors

Diaphragm wall

Impermeable barrier

Sand

Sand

Sand

Truty (2008)
Example 1: Berlin Sand - excavation problem

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Example 2: – Montreux – 3D excavation problem

No continuum elems: 41’108

Existing building

Av. des Alpes

River

Fill

Gravel

15-20m diaphragm wall excavation

No shell elems: 3’412
No truss elems: 930

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Example 2: – Montreux – 3D excavation problem

On the use of the Hardening Soil model
Example 2: – Montreux – 3D excavation problem

Mohr-Coulomb

Lifting of retaining wall

UY = +1.5cm

E = 60MPa

E = 360MPa

Section A-A

HS-SmallStrain

Settlements behind the retaining wall

UY = -0.5cm

UY = +5.3cm

E_u0 = 132MPa
E_0 = 264MPa
E_50 = 44MPa
at 15m

Section A-A

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Example 3: – London Clay - tunnel excavation (Addenbrooke et al., 1997)

Problem statement

FE mesh

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Example 3: – London Clay - tunnel excavation (Addenbrooke et al., 1997)
Example 3: London Clay - tunnel excavation

Mohr-Coulomb
Tunnel level:
\( E = 183 \text{ MPa} \)

\( \text{max } u_{\text{abs}} = 16.8 \text{ mm} \)

HS-SmallStrain
Tunnel level:
\( E_0 = 500 \text{ MPa} \)
\( E_{ur} = 90 \text{ Mpa} \)
\( E_{50} = 40 \text{ MPa} \)

\( \text{max } u_{\text{abs}} = 61.3 \text{ mm} \)

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Example 3: – London Clay - tunnel excavation

Excavation of Westbound Tunnel

- Surface settlements [mm]
- Offset from the westbound tunnel [m]

- Field data
- M-C (Ko=1.0, E=6000z kPa)
- HS-Std (Ko=1.0)
- HS-Small (Ko=1.0)
- Model - J4 (Ko=1.5)

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Example 4: – Almere - trial embankment problem (Bringreve & Vermeer (1992)
Rowe, Soderma (1985))

Sand fill
Retaining bank

2m

Stages:
1. Excavation
2. Embankment + Fill
3. Consolidation

Sand layer
Organic Clay OCR = 2

Clay layer modeled with: Mohr-Coulomb and Hardening Soil-SmallStrain

\[ E^{MC} = 13\,750\, \text{kPa} \]

\[ E_{ur} = 2\cdot E^{MC} \]

\[ E_{50} = E^{MC} / 2 \]

\[ E_{0} = 2\cdot E_{ur} \]

\[ \sigma_{ref} = 30\, \text{kPa} \]

\[ E_{oed} = E_{50} \]
Example 4: – Almere - trial embankment problem

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Example 4: – Almere - trial embankment problem

Pt A – Embankment top

Pt B – Embankment base

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Summary

Hardening Soil-SmallStrain model:

- correctly reproduces strong reduction of soil stiffness with increasing shear strain amplitudes
- is recommended for Serviceability Limit State analyses as it generally closer predicts soil behavior and field measurements than basic linear-elasticity models
- is applicable to most soils as it accounts for pre-failure nonlinearities for both sand and clay type materials regardless of overconsolidation state