Modelling plasticity

FLAC3D

Constitutive Models for *FLAC and FLAC3D*

Built-in Models

Elasticity models:
Isotropic
Transversely isotropic
Orthotropic

Plasticity models:
Drucker-Prager
Mohr-Coulomb
Ubiquitous-joint
Caniso
Strain-hardening/softening
Bilinear strain-hardening/softening/ubiquitous-joint
Double-yield
Modified Cam-clay
Hoek-Brown
Cysoil – friction hardening, with elliptical cap
Chsoil – simplified Cysoil (alternative to Duncan-Chang)
PH - plastic hardening
Swell

Dynamic Liquefaction models:
Finn (Martin et al., 1975) model
Bryne, 1991 model

Creep models:
Viscoelastic
Burger's substance viscoelastic
Two-component power law
Reference creep formulation (WIPP)
Burger-creep/Mohr-Coulomb viscoplastic
Two-component power law/Mohr-Coulomb viscoplastic
Two-component power law/Mohr-Coulomb viscoplastic with ubiquitous joints
WIPP-creep/Drucker-Prager viscoplastic
Crushed-salt

User-defined Models*

Elasticity models:
Hyperbolic elastic
Duncan-Chang, 1980

Plasticity models:
NorSand
Jardine et al., 1986
Manzari-Dafalias, 1997
Kleine et al., 2006
Concrete hydration
vonWolffersdorff hypo-plastic
UBCHyst
JointedRock

Dynamic Liquefaction models:
UBCSAND
UBCTOT
PM4Sand
Wang, 1990
Roth et al.,2001
NTUA-SAND
SANISAND

Creep models:
Minkley viscoplastic
Hein-crushed salt
Salzer creep
Lubby2 creep

*partial list of models created by (or developed for) code users

Elastic VS plastic

Elasticity

- Describes the behavior of material in which after discontinuing the applied stress the entire deformation remains reversible; the relationship between stress and strain is usually linear.

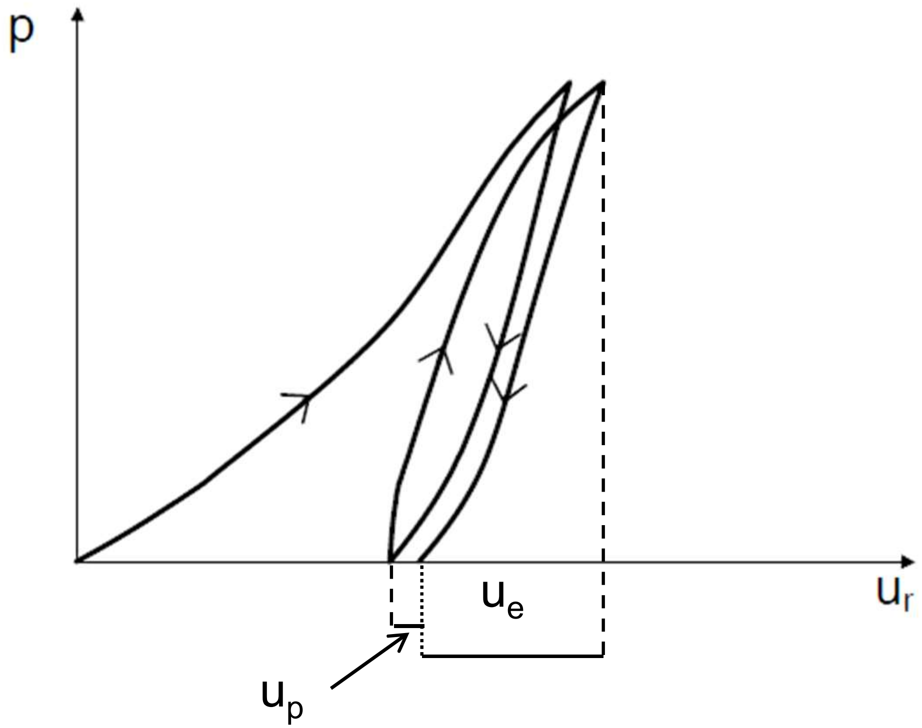
Plasticity

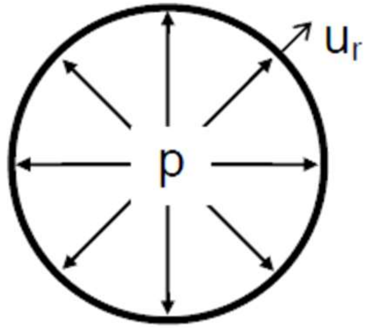
- Describes a behavior of material which can deform continuously without collapsing under stresses surpassing the one necessary to cause yielding.

Deformation

Elastic and plastic deformations

- Reversible and permanent



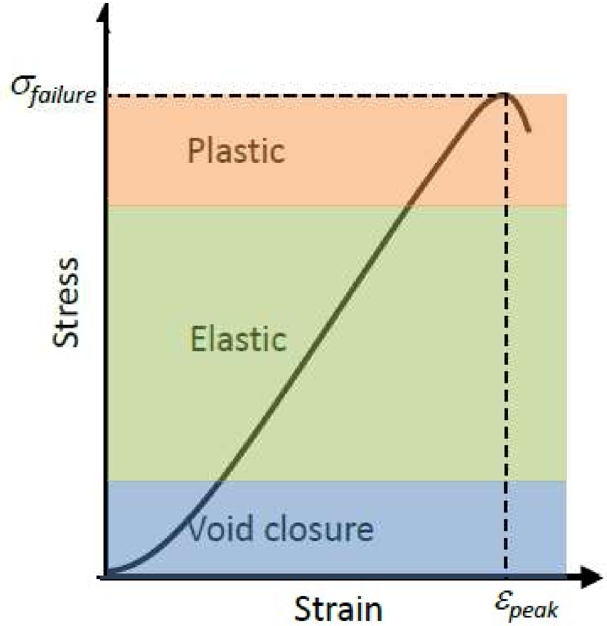


Deformation behaviour

- The stress-strain curve has 3 components before failure:

1. Void closure – where the voids in the specimen close
2. Elastic component – elastic deformation
3. Plastic deformation – permanent deformation

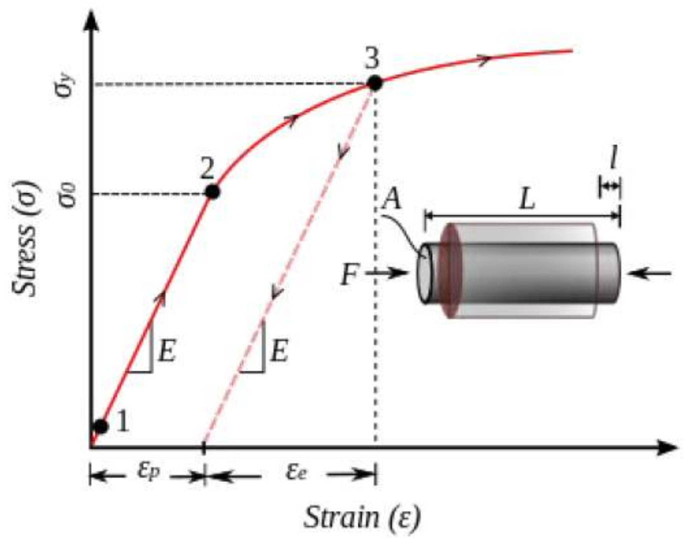
- Each of the above 3 component play an important role in failure process of rock specimen



Calculating plasticity

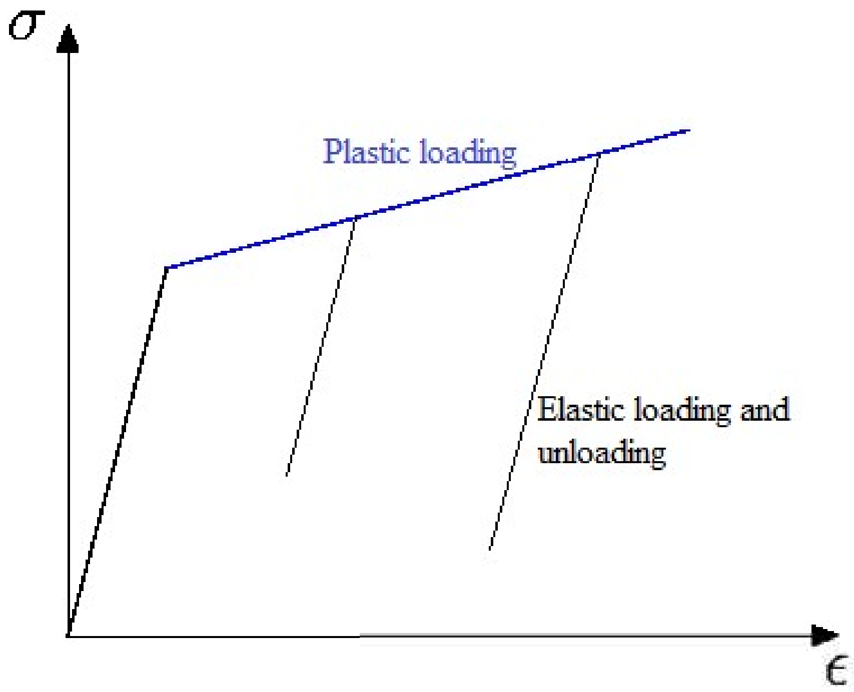
$\Delta\varepsilon = \Delta\varepsilon^p + \Delta\varepsilon^e$

where $\Delta\varepsilon^e$ is the incremental elastic strain and $\Delta\varepsilon^p$ is the incremental plastic strain



Calculating plasticity

- Active only during plastic loading



Flow rule
– what happens after we reach the yield criteria?

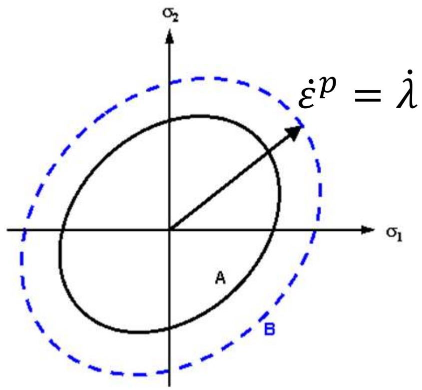
- A constitutive relation for the plastic strain increment
  - Associated

$$g(\sigma) = f(\sigma)$$

  - Non associated

$$g(\sigma) \neq f(\sigma)$$

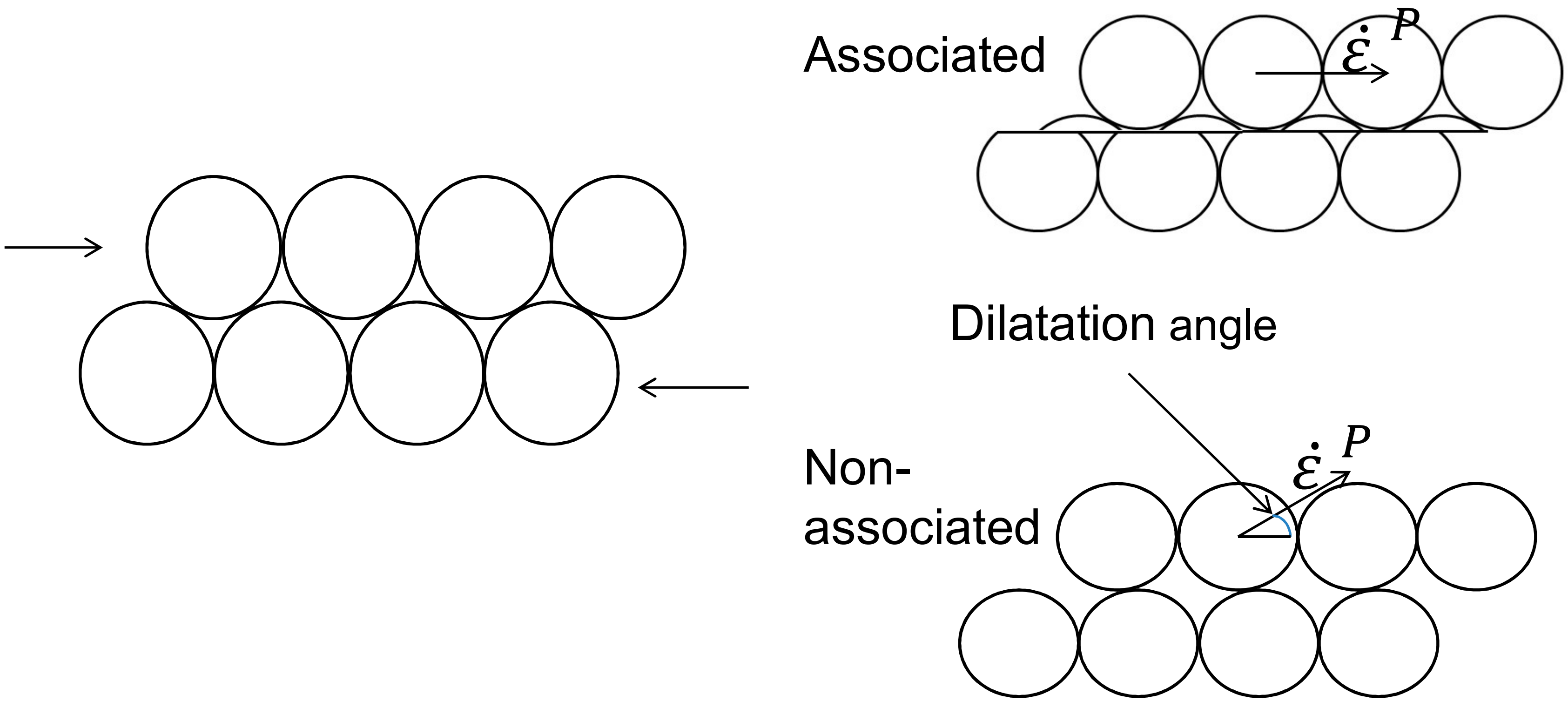
Where g is the plastic potential function



$$\dot{\varepsilon}^p = \dot{\lambda}\frac{\partial g}{\partial \sigma}$$

Flow rule
– what happens after we reach the yield criteria?

If the material has a friction angle =0



FLAC3D – Mohr-Coulomb model

Initial yield surface is given by

$f^i = -\sigma_1 + \sigma_3 N_\emptyset - 2c\sqrt{N_\emptyset}$ where

$N_\emptyset = \frac{1+\sin\emptyset}{1-\sin\emptyset}$ and $\emptyset$ is the internal friction angle

The plastic potential is given by

$g^s = -\sigma_1 + \sigma_3 N_\psi$ where

$N_\psi = \frac{1+\sin\psi}{1-\sin\psi}$ and ψ is the dilatation angle

FLAC3D – Mohr-Coulomb model

The Mohr-Coulomb model thus always relates to non-associated flow and the post-peak behavior is controlled by the dilatation angle (as well as any softening criteria applied)