

### 1. loose/dense specimen

- Prepare a specimen for an axisymmetric drained triaxial test at a given confining pressure ( $\sigma_{11} = \sigma_{33}$ ) and fix the compaction friction angle to a value higher than  $30^\circ$ , plot the volumetric strain ( $\varepsilon_{11} + \varepsilon_{22} + \varepsilon_{33}$ ) in terms of the axial strain  $\varepsilon_{22}$ .  
*Notice the contractant volumetric behaviour (loose specimen)*
- Now prepare a new specimen by setting the compaction friction angle to a value smaller than  $10^\circ$ , perform the triaxial test and plot the same curve as above.  
*Notice the dilatant volumetric behaviour (dense specimen)*
- Plot for both specimens the deviatoric stress  $q = \sigma_{22} - \sigma_{33}$  in terms of the axial strain  $\varepsilon_{22}$ .  
*Notice that for the loose specimen the deviatoric stress continuously increases (positive hardening regime) toward a limit plateau and that for the dense specimen the deviatoric stress increases to reach a peak and then decreases (softening regime)*
- For the next simulations choose one of the two specimens. For the specimen you have chosen, pick out the values of  $q^p$  corresponding to the peak or to the plateau of deviatoric stress curve.

### 2. Stress state/ anisotropy (distribution of contacts orientations)

In the following, interest will be focused on the positive hardening regime (before the peak or the limit plateau).

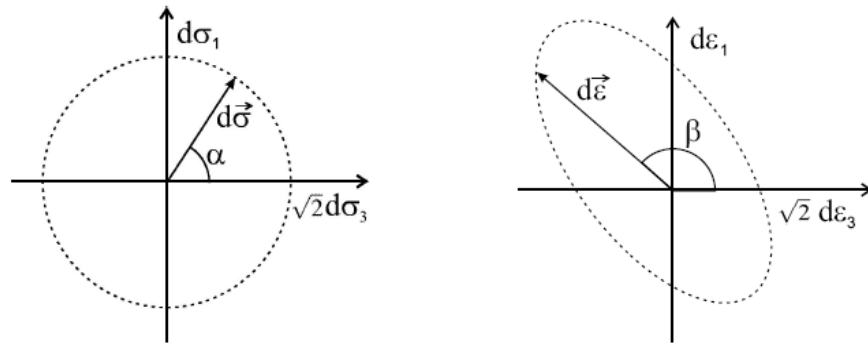
- let's consider two different stress states, an isotropic one defined by  $q^i = 0$  and a deviatoric stress state defined by  $q^d \sim 0.6 q^p$ . Compute the axial stress  $\sigma_{22}^d$  corresponding to  $q^d$
- Now perform stress controlled drained triaxial compression to reach the deviatoric stress state by setting 'triax.sigma2' to the value of  $\sigma_{22}^d$  and save the resulting anisotropic states. It will be used as initial state from where stress probes will be applied (see further)
- Plot (rose plot) the distributions of contact orientations (projected on the planes  $(x_1, x_2)$  and  $(x_3, x_1)$ )  
For this, all contact normals should be considered and projected on the planes defined above and then sorted according to their angle of orientation.  
Notice that the anisotropy becomes more marked as the stress state gets nearer the peak or plateau

### 3. Directional Analysis/Stress probes

The stress states defined by  $q^i$  and  $q^d$  are considered as initial states for directional analysis.

An identical loading increment  $d\sigma$  is applied in each direction corresponding to the angle  $\alpha$  defined in the Rendulic plane of the stress increment (*see figure below*).

Varying  $\alpha$  from  $0^\circ$  to  $360^\circ$ , each stress direction is inspected and for each loading increment  $d\sigma$ , a response vector  $d\varepsilon$  is associated.  $d\varepsilon$  is defined in the Rendulic plane of strain increments by its norm and its angle  $\beta$  (*see figure below*).



**Definition of the Rendulic plane:**  
stress directional analysis (left), strain response envelope (right)

A stress probe is performed in three steps: first stabilizing the specimen at a given stress state (already done for states at  $q^i$  and  $q^d$ ), then performing the stress probes in different directions. For this one needs to set

- The norm of the stress increment ' $dSnorm$ '
  - The number of stress directions to be tested ' $nbProbes$ ' (choose for example to perform a stress probe each  $30^\circ$ )
  - The number of iterations ' $rampIte$ ' to increase the stress state until the final desired stress value
  - Finally the number of iterations ' $stabIte$ ' to stabilize the specimen after each stress probe direction.
- Perform stress probes for each stress state already prepared.
  - Plot the response envelopes (increment of axial strain  $d\varepsilon_{22}$  in terms of increment of lateral strain  $\sqrt{2} d\varepsilon_{33}$ ) corresponding to each directional analysis.

*Notice that for the isotropic state, the response envelop corresponds to an ellipse centered to the origin of the frame (linear elasticity) and for the deviatoric state, the ellipse stretches out (not an ellipse any more)*

#### 4. Existence of a flow rule

Starting from the deviatoric state corresponding to  $q^d$ , perform the same stress probes by setting the contact friction angle close to  $90^\circ$ , let's say ( $89.999^\circ$ ).

By doing this, the strain response to the stress probes is purely elastic, and this can be checked by plotting the response envelop which should be in this case an ellipse centered to the origin of the frame (as for the isotropic state).

- Compare the orientations of the two ellipses corresponding to the elastic responses of both isotropic and deviatoric states.  
*Notice the change of the orientations of the ellipses, due to the change of the fabric of the specimen from isotropic to anisotropic one.*
- Compared to the previous strain responses (total response) at the same stress state, plastic response can be determined by computing the difference between the total and elastic strain response increments in all directions.

- Plot the plastic response corresponding to the deviatoric stress state.

*Notice that the plastic response envelop is a line which indicates the existence of a flow rule*