Evolution of soil fabric and its interpretation using different methods

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Abstract.
Different methods to study the evolution of fabric anisotropy are presented. DEM simulations on assemblies of spheres subjected to different stress paths using a three-dimensional periodic cell are used for the analysis of these methods. The links between soil fabric and macro-scale behaviour are also discussed.

Summary.
Macro-scale soil response is anisotropic, considering stiffness, strength, permeability, etc. The underlying source of this anisotropy must be an anisotropy in the material itself. This anisotropy can be quantified by coupling statistical metrics of fabric with data from DEM simulations, thin sections or CT tomography. Oda et al (1985) proposed that at least three factors must be taken into account when discussing fabric anisotropy: 1) the distribution of contact normals, 2) the shape of the particles and 3) the shape of the voids. In this study, the particles are modelled as spheres and the shape of voids is not taken into consideration. Hence, fabric anisotropy of assemblies of spheres will be described in terms of contact normals only. For each contact in an assembly of spheres, a branch vector ($\boldsymbol{l}$) can be constructed joining the centroids of two contacting particles. For each branch vector, the unit contact normals ($\boldsymbol{n}=\boldsymbol{l}\ /|\boldsymbol{l}|$) can be calculated. These unit contact normals are the basis for most of the methods to quantify fabric and hence describe anisotropy. For assemblies whose fabric can be considered statistically symmetric about a given axis, some researchers have used Fourier series approximations of the distribution of contact normals $E(\boldsymbol{n})$ (i.e. Rothenburg and Bathurst,1989; Oda et al, 1985). In these approaches the coefficients of the Fourier series approximation have a meaning related with the major principal orientation of fabric. Many coefficients can be used, but in general terms, no more than two are used; one coefficient of the Fourier series may indicate the concentration of contact normals in a particular direction. If two coefficients are used, then the second one can indicate the major or minor principal direction of anisotropy. More general approaches consider the orientation tensor (Φ) computed from the unit contact normals and its eigenvector and eigenvalues are used to obtain a quantitative characterisation of fabric (i.e. Cui and O'Sullivan,2006; Ng, 2004; Thornton, 2000). The orientation tensor is defined as:

$$\Phi = \frac{1}{N_c}\sum n_i n_j \quad \text{for } i=1,2,3$$

where N_c is the total number of contacts in the assembly and n_i is the corresponding component of the contact normal $\boldsymbol{n}$. Cui and O'Sullivan (2006) and Thornton (2000) use the eigenvectors of the this orientation tensor for fabric analyses. These eigenvectors indicate the direction of the major principal fabric. They have found that the direction of the major principal stress coincides with the orientation of the major principal fabric. Furthermore, they have found that the evolution of deviatoric stress ($q=\sigma_1-\sigma_3$) with straining is qualitatively similar to the evolution of the deviatoric fabric ($\Phi_1-\Phi_3$). Ng (2004) uses the same approach and additionally calculates "shape" and "strength" factors. These factors are dependant on the eigenvalues of the orientation tensor defined above and are statistical descriptors of orientation data. Ng (2004) has also found a relationship between these factors and the macro-scale behaviour of DEM specimens. For example, he has found relationships between the "shape" factor and the stress ratio (σ_1/σ_3). Contour plots of orientation data under a vertical equal area projection have been widely used for the visualization of bedding and rupture planes in Geology (i.e. Newton, 1968). These types of contour lines provide easy visualisation and qualitative analysis of any kind of orientation data, including distributions of contact normals. This approach has been used by Ng (1997) to study the effects of particle geometry in soil behaviour. A schematic representation of just some of these methods is shown in Figure 1. In the current study, all the previously described methods are used to analyse a series of DEM simulations of spherical assemblies subjected to different stress paths. The evolution of anisotropy is assessed by monitoring the contact normals at several stages along the different stress paths. The results are linked to different features of the macro-scale behaviour of the assemblies.

Conclusions

This work considers the advantages and disadvantages of the different methods of analysis of fabric evolution. Itis shown that all the methods are very consistent and the parameters derived from all these methods can be linked to different aspects of the observed macro-scale behaviour of soils. Possible points of discussion include the following:

- Can the combined use of the methods provide a better understanding of the micro-scale processes affecting the behaviour of granular materials? Or should we decide upon a standard approach to fabric quantification in the geomechanics communitiy?
- Are these quantitative approaches really needed? Qualitative methods could be also used for a better understanding of the evolution of fabric.

References

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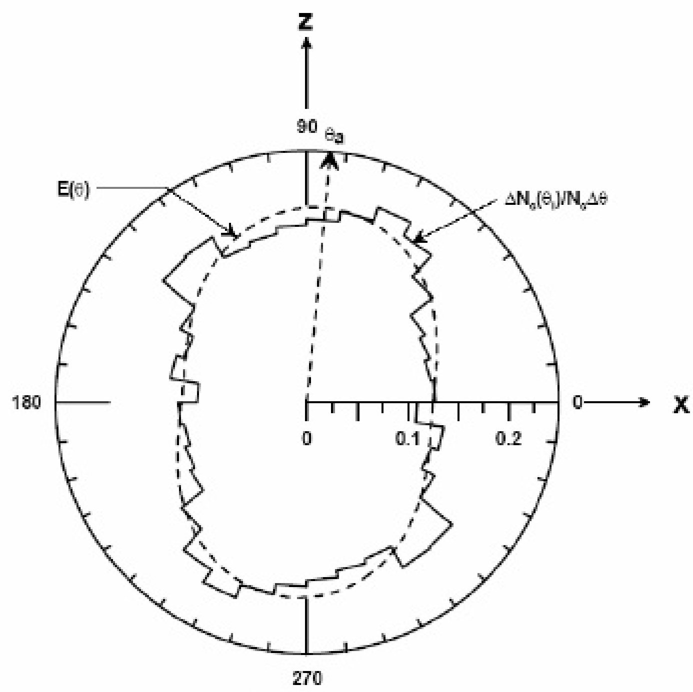
Figure 1

. Examples of methods of analysis. Left: Qualitative approach used by Ng (1997). Right: Distribution of contact normals and its Fourier series approximation as used by Rothenburg and Bathurst (1989)



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$\Delta N_o(\theta_i)/N_o\Delta\theta$
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x
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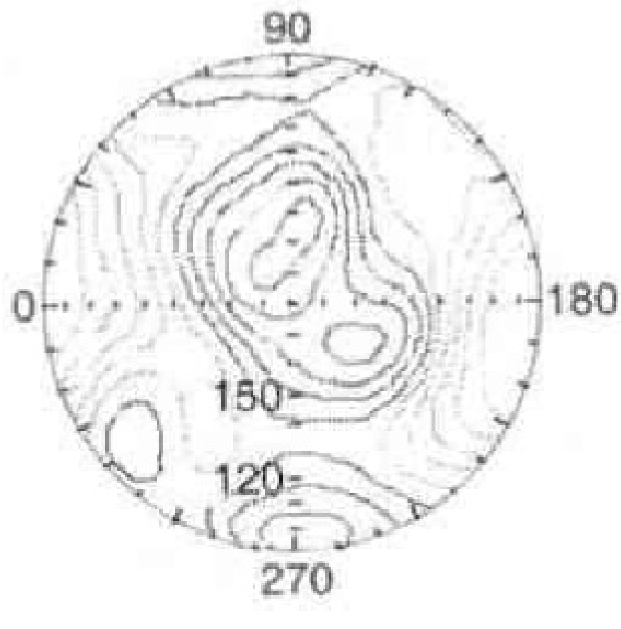

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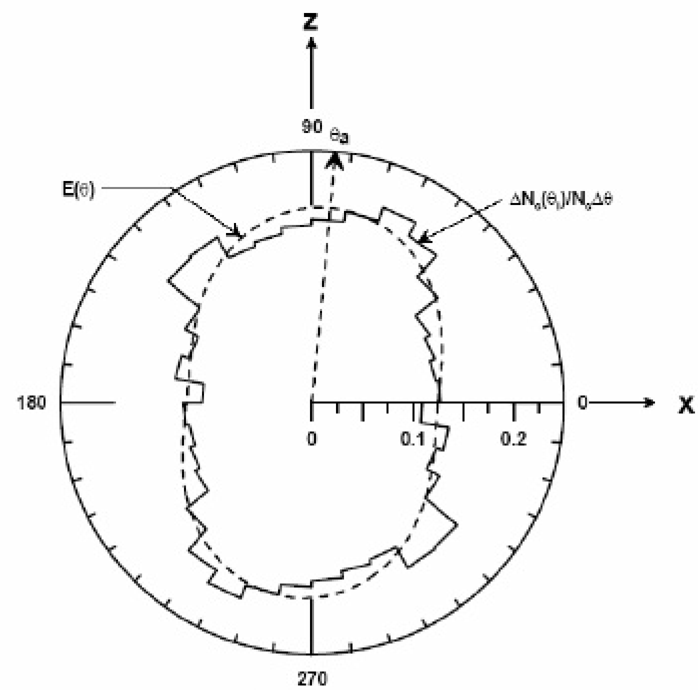
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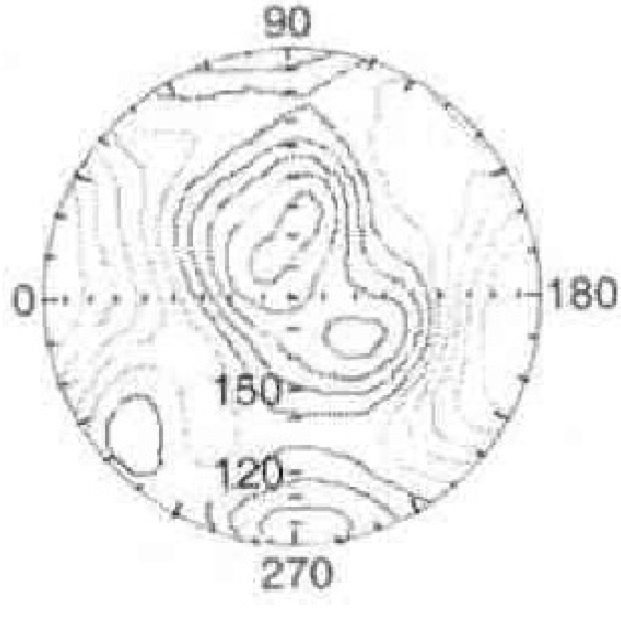
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