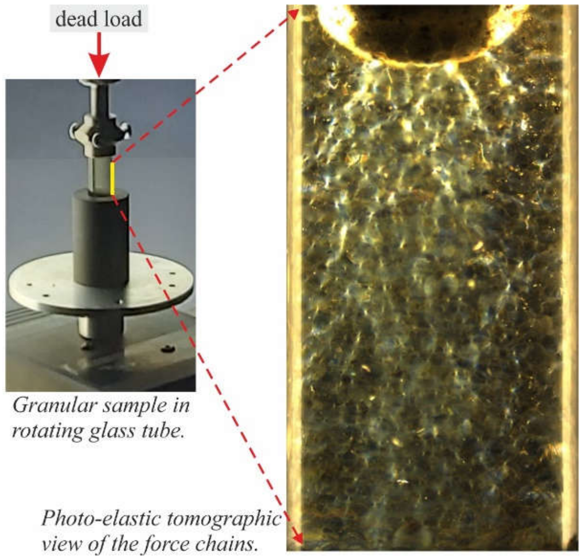
Multi-scale study of the contact force network in cohesionless granular materials

Abstract for general public

Cohesionless granular material is an assembly of macroscopic particles of different shapes, origin and surface properties. The best-known example of granular material is sand (non-cohesive soil), but there exist many other, present in our everyday life: natural soils, industrial materials (cement, coal, ores, ash), food and other natural grains (corn, flour, nuts, coffee, peas, other seeds), pharmaceutical powders, snow. Even iceberg collections, asteroid belts and entire galaxies, when looked at from the proper distance, can be treated as specific granular matter.

Exploring granular materials is a challenging task because of a great number of interacting grains to be considered. It is not surprising then that the physics of granular materials as a discipline is still in its infancy. The collective behaviour of a mass of individual grains needs specific tools to be observed and explained. The general scientific goal of the project is to fill in some gaps existing in basic knowledge on granular materials. The most exciting phenomena discovered some decades ago are so-called 'force chains' – filaments of brightly shining grains, visible in circularly polarised light and indicating load concentration. Digital photography and modern image analysis have shown that force chains form regular force networks – a clear symptom of self-organization. The traditional photo-elastic method is limited to two-dimensional plane boundary value problems. The hypothesis is accepted in the project, supported by preliminary research, that force chains and the whole contact force networks in realistic granular materials are always three-dimensional (3D), regardless of the external macro-scale conditions and they can be observed, described and modelled using the idea of photo-elastic optical tomography supplemented by discrete element method (DEM).



Granular sample in rotating glass tube.

Photo-elastic tomographic view of the force chains.

The basic scientific problems addressed in the project are: the impact of the topology of contact force networks on macro-scale behaviour of granular materials, localization phenomenon in contact force network and its relation to strain localization, the phenomenon of discrete force chains in three-dimensional arrangements of grains, force chains statistics, mechanisms of formation, disappearance and re-formation of force chains, 3D photo-elastic effect in individual grain, individual grains behaviour inside a shear band, calibration of photo-elastic images of large granular assemblies by photo-elastic effect in individual grains and the influence of individual grain features on geometrical characteristics of force chains at different boundary conditions.

The addressed problems are largely universal because they concern any assembly of macroscopic particles. Recognizing multi-scale mechanisms of load transmission through contact force networks is especially important in civil engineering and transport, mostly dealing with the most common granular materials – soils building the upper layer of the earth's crust.

The pioneering element of the project is the idea of photo-elastic optical tomography. Recognition of the real micro-mechanism of localization in granular materials using currently available experimental and numerical tools is also one of the innovative aspects of the project. Another one is a direct application of Fourier transforms to extract governing structural characteristics of contact force networks.

The proposed research is based on two approaches: experimental and numerical. The experimental part of the project consists of laboratory and model testing of substitute granular materials (glass granules, crushed glass and PDMS grains). Except for the integrated photo-elasticity also digital image correlation (DIC), digital volume correlation (DVC) and discrete element method (DEM) are employed in the experimental part of the project. The numerical part is based on discrete element method DEM and supplemented by finite element method FEM. For the numerical simulations, TRYTON supercomputer and PCs will be used. The project idea is based on the direct comparison of experimental and numerical results, using the latter in the areas that are inaccessible to experimental testing.