Publishable summary

The project brought together the complementary expertise of world leading groups currently engaged in research on the engineering assessment, prevention and mitigation of geohazards, the main ones being landslides and earthquakes.

In the project the key aspects of major geohazards (landslides and earthquake induced) have been investigated. Knowledge exchange among experts in complementary research fields has taken place via the several exchanges undertaken and several Early Stage Researches have received training during their stay at the host institutions.

To enable research collaborations and knowledge exchange, the following activities took place: 1) mobility of nationals from Europe to India and China and vice versa; 2) joint bi-annual events and 3) a major International Symposium at University of Warwick (for details see http://www2.warwick.ac.uk/fac/sci/eng/research/civil/geo/conference/).

The main scientific results of the research carried out are described in the project website (http://www2.warwick.ac.uk/fac/sci/eng/research/civil/geohazards/). A summary of results is given below in bullet point format:

- **Rock slope instability**

A unified bond contact model considering the bond size effect was established based on micro-mechanical test data. This model was implemented into a DEM code to analyse the time-dependent behaviour of weathered rocks and then jointed rock slope failure due to weathering (**Figure 1**).

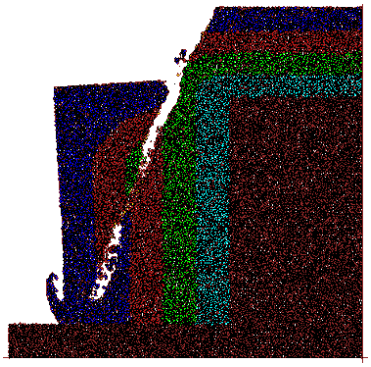

Figure 1. DEM simulation of a rock slide as a result of weathering.

Based on a series of laboratory tests on the bonded granules idealized by two glued aluminum rods, a normal force dependent bond contact model was proposed and implemented into a two-dimensional (2D) DEM code. This 2D DEM code was used to carry out a series of numerical simulations, including uniaxial and biaxial compression tests, direct tension and Brazilian tension tests. In addition, the validated model was then used to simulate crack propagation and rock fracture in single-flawed and double-flawed samples with different flaw inclinations, and the simulations were then compared with experimental observations. The numerical results demonstrate that the proposed bond model incorporated into the distinct element method is able to capture the main mechanical behaviors of crystalline rocks (Lac du Bonnet granite and Hwangdeung granite).The limitations associated to a low strength envelope angle and high ratio between tensile strength and compressive strength frequently formed in DEM simulations of rock behaviors are solved.

- **Material Point Method for the simulation of landslides**

Material Point Methods (MPM) are rapidly evolving in the geotechnical field especially in slope stability problems. This is because of their capability to analyse the whole instability problem in a unified calculation including the transition from the pre-failure stage, characterized by the development of small strains, to the accelerated post-rupture phase in which large deformations of the sliding mass are involved. The role of internal shearing in compound landslides was investigated. Vajont landslide was analysed from this perspective (**Figure 2**). This is a case of progressive failure and a final accelerated motion. The damage of the rock could be followed during the sliding motion. It was found that the very high estimated velocity of the slide could only be reproduced

by a zero friction at the basal surface, a result that supports the thermal pressurization hypothesis to explain the full drop of shear strength at the sliding surface.

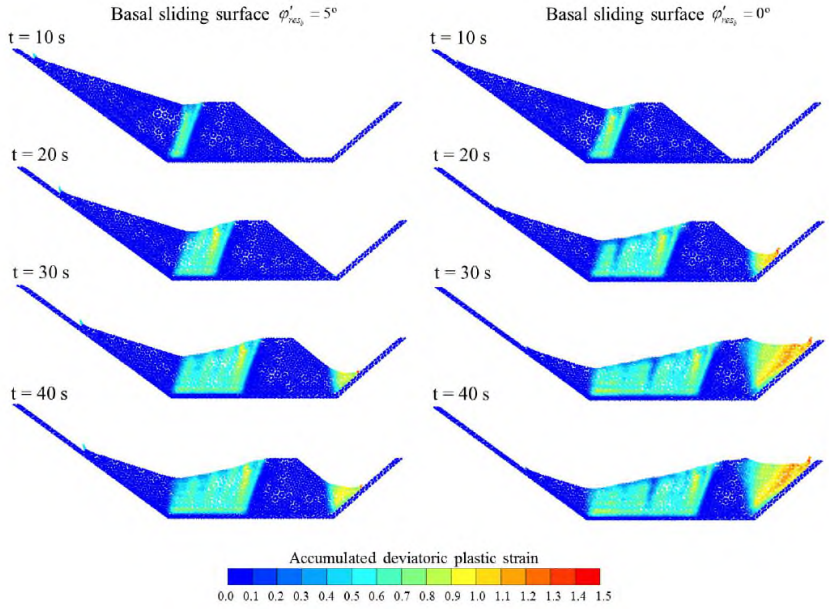

Figure 2. MPM simulation scenarios for the Vajont slide.

- **Earthquake induced liquefaction hazard mapping**

This collaborative research is intended to develop a quantitative mapping method for lateral spread hazard associated with earthquake-induced liquefaction (**Figure 3**), considering all possible earthquakes occurring at a site. This is a fundamental problem for a seismic risk assessment over large spatial area. The proposed approach includes a probabilistic model of liquefaction-induced lateral spread considering seismic randomness and uncertainty of soil properties. This model enables quantitative maps of lateral spread displacement at any exceedance probability in a specified time period, or exceedance probability of any pre-defined displacement threshold. Two mapping procedures have been proposed based on available cone penetration test data. These maps highlight the hotspots susceptible to serious lateral spread displacements, providing useful information on need of project-specific in-depth geotechnical investigation. The mapping procedure is based on either geostatistical interpolation or stochastic simulation. The geostatistical interpolation method has the merit to be less computationally expensive, while the stochastic simulation method seems more rational as it explicitly model the uncertainty of soil parameters and their spatial structure. The effectiveness of the model and procedure was demonstrated via case studies.

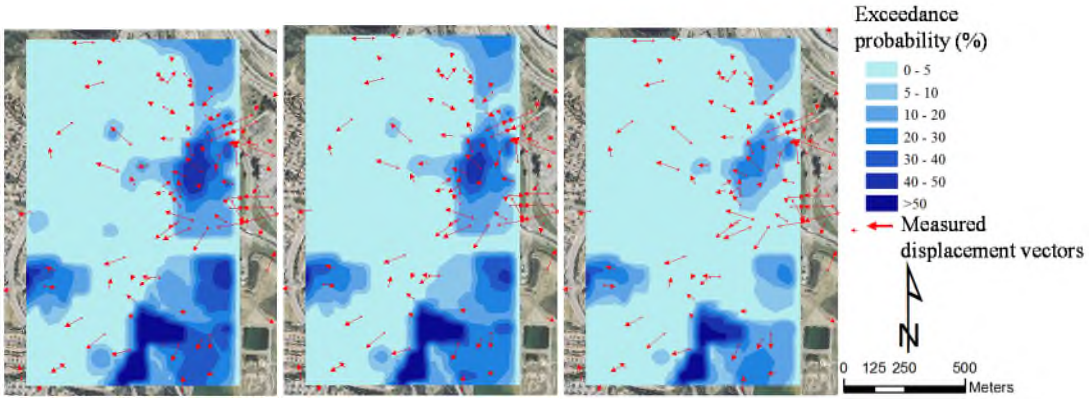

Figure 3. Lateral spread hazard maps.

- **Geo-hazards associated with the exploitation of methane hydrate bearing sediments**

New numerical tools for analysing the hazard of potential failures and submarine landslides triggered by the exploitation of methane hydrate bearing sediments (MHBS) in deep seabeds have been developed. A new thermal-hydro-mechanical coupled bond contact model of MHBS was formulated based on micro-mechanical tests. This model was then implemented into the distinct element method (DEM) to investigate the effect of backpressure and formation of shear bands in MHBS. Boundary value problems such as bearing capacity of pile foundations embedded in MHBS and submarine landslide triggered by dissociation of MHBS were analysed by DEM or CFD-DEM code equipped with the new bond contact model (**Figure 4**).

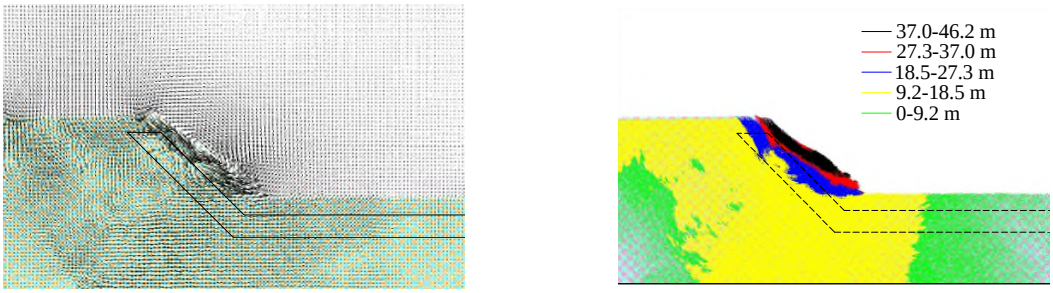

Figure 4. CFD-DEM analysis of a submarine landslide triggered by thermal dissociation of methane hydrate.

List of Keywords
Geohazards, Earthquakes, Landslides, Floods, Discrete Element method, Finite Element Method

Websites where additional information may be found
http://www2.warwick.ac.uk/fac/sci/eng/research/civil/geo/conference/

Management report
Each local scientist in charge was responsible for the management of the programme at his/her institution. Updates on the programme of visits were reported to the coordinator (Prof. Stefano Utili) on a regular basis.
The allocation of financial resources between beneficiaries has changed over the duration of the 4 year project due to new beneficiaries stepping in to replace either beneficiaries that have abandoned the programme or underperforming beneficiaries.