THE UNIVERSITY OF WARWICK

International Symposium on Geohazards and Geomechanics
ISGG2015

Symposium Detailed Programme

10-11 September 2015
University of Warwick, School of Engineering

SIMSG ISSMGE	International Society for Soil Mechanics and Geotechnical Engineering TC105 Geo-mechanics from Micro to Macro TC208 Slope Stability in Engineering Practice TC302 Forensic Geotechnical Engineering
BGA	British Geotechnical Association
MARIE CURIE ACTIONS	EU FP7 Marie Curie Action IRSES project "Geohazards & Geomechanics"

Contents

All the events in the programme take place in the Mathematics and Statistics (MS) building (see the map at the end of the booklet) apart from the Gala dinner that takes place at Warwick castle. So Hall, MS.01 and MS.03 are inside the Mathematics and Statistics building.
Presentations in parallel sessions last **10 minutes** followed by **5 minutes** of questions and answers.

Thursday 10th September

08.30 - 09.30 **Registration** Hall		
09.30 - 09.45 **Welcome** Room: MS.01		
Welcome	*Dr Stefano Utili* – University of Warwick (UK), Symposium Chairperson *Dr Marcos Arroyo* – Universitat Politècnica de Catalunya (Spain) *Prof. Mingjing Jiang* – Tongji University (China)	
09.45 - 11.05 **Keynote Lectures** Room: MS.01		
Keynote 1 09.45 - 10.15	Physical modelling of rainfall induced flow failures in loose granular soils *Dr. Andy Take* - Queen's University (Canada)	
Keynote 2 10.15 - 10.45	Geotechnical hazards associated with closed municipal solid waste landfill sites *Prof. William Powrie* - University of Southampton (UK)	
10.45 - 11.05	Questions & Answers	
11.05 - 11.30 Tea, coffee and refreshments		
11.30 - 12.45 **Parallel Session 1a** Room: MS.01		Chair: H Wang Rapporteur: E Bowman
11.30 - 11.45	Centrifuge tests of dyke collapse on soft subsoil *J Fern, D de Lange, C Zwanenburg and J A M Teunissen*	
11.45 - 12.00	Effect of Ground Water Table Rising and Slurry Reduction during Diaphragm Wall Trenching on Stability of Adjacent Piles *A Mohamed*	
12.00 - 12.15	Methods for the physical measurement of collisional particle flows	

		D Gollin, E Bowman and P Shepley
	12.15 - 12.30	Centrifuge model study of thresholds for rainfall-induced landslides in sandy slopes *V Matziaris, A M Marshall, C M Heron and H-S Yu*
	12.30 - 12.45	An experimental model for slopes subject to weathering *C Voulgari*
11.30 - 12.45 **Parallel Session 1b** Room: MS.03		Chair: M Arroyo Rapporteur: D Muir Wood
	11.30 - 11.45	Evaluating the capability of a critical state constitutive model to predict the collapse potential of loose sand *A Azizi, G Bella and I Farshchi*
	11.45 - 12.00	An experimental study of the initial volumetric strain rate effect on the creep behaviour of reconstituted clays *M Bagheri, M Rezania and M M Nezhad*
	12.00 - 12.15	Response of shallow geothermal energy pile from laboratory model tests *A Marto and A Amaludin*
	12.15 - 12.30	Engineering properties of cement/lime-stabilized Egyptian soft clay *M A Mansour, A M Samieh and H E Matter*
	12.30 - 12.45	Correlation between index properties and electrical resistivity of hydrocarbon contaminated periodic marine clays *P Tiwari and MV Shah*
12.45 - 12.55 Group photos Hall		
12.55 - 14.00 Lunch Hall		
14.00 - 15.20 **Keynote Lectures** Room: MS.01		
	Keynote 3 14.00 - 14.30	Recent developments of the Material Point Method for the simulation of landslides *Prof. Eduardo Alonso* - Universitat Politècnica de Catalunya (Spain)
	Keynote 4	Landslides falling onto a shallow erodible substrate or water layer: an experimental and numerical approach

	14.30 - 15.00	*Prof. Giovanni Crosta* - Universita Milano Bicocca (Italy)
	15.00 - 15.20	Questions & Answers
15.20 - 15.45 Tea, coffee and refreshments		
15.45 - 17.30 **Parallel Session 2a** Room: MS.01		Chair: GB Crosta Rapporteur: I Towhata
	15.45 - 16.00	Comparing kinematically detachable rock masses and rockfall scar volumes *O Mavrouli and J Corominas*
	16.00 - 16.15	Application of geotechnical and geophysical field measurements in an active alpine environment *DR Lucas, K Fankhauser and SM Springman*
	16.15 - 16.30	Strategies for rock slope failure early warning using acoustic emission monitoring *D Codeglia, N Dixon, G J Fowmes and G Marcato*
	16.30 - 16.45	Shear wave velocity analysis of a deep seated gravel landslide structure using the microtremor survey method *L Su, X Xu, H Liao and X-Y Geng*
	16.45 - 17.00	Using several monitoring techniques to measure the rock mass deformation in the Montserrat Massif *M Janeras, J A Jara, F López, J Marturià, M J Royán, J M Vilaplana, A Aguasca, X Fàbregas, F Cabranes and J A Gili*
	17.00 - 17.15	Monitoring of unstable slopes by MEMS tilting sensors and its application to early warning systems *I Towhata, T Uchimura, I Seko and L Wang*
	17.15 - 17.30	Flood control and loss estimation for paddy field at midstream of Chao Phraya river basin, Thailand *TC Cham, Y Mitani*
15.45 - 17.30 **Parallel Session 2b** Room: MS.03		Chair: R Castellanza Rapporteur: E Alonso
	15.45 - 16.00	Investigation of the slope stability problem using the Material Point Method *F Fatemizadeh and C Moormann*
	16.00 - 16.15	MPM dynamic simulation of a seismically induced sliding mass *C Moormann and F Hamad*

	16.15 - 16.30	Runout analysis of landslides using material point method *Y Sun, J Yang and E Song*
	16.30 - 16.45	Earthquake-induced displacements of cohesive-frictional soil slopes subject to cracks. *A H Abd*
	16.45 - 17.00	3D numerical analyses for the quantitative risk assessment of subsidence and water flood due to the partial collapse of an abandoned gypsum mine. *R Castellanza, GM Orlandi, C Di Prisco, G Frigerio, L Flessati, JA Fernandez Merodo, F Aglardi, S Grisi and GB Crosta*
	17.00 - 17.15	Forensic analysis of Malin landslide in India *P Ering, R Kulkarni, Y Kolekar, S M Dasaka and GL S Babu*
	17.15 - 17.30	Evolution of rock falls in the Northern part of the Peloponnese, Greece *V Zygouri and I K Koukouvelas*

17.30 - 18.00 **Findings from parallel sessions** Room: MS.01	Discussion leader: GB Crosta
Session 1a Rapporteur E Bowman Session 1b Rapporteur D Muir Wood Session 2a Rapporteur I Towhata Session 3b Rapporteur E Alonso	
18.05 - 19.00 **Poster Session** Hall	
18.05 - 19.00 **Workshop run by Elsevier for early stage researchers** Room: MS.01	
How to write a scientific paper and get it published. Insight into how the publishing process works. Tips on how to produce a good paper. With an emphasis on Engineering Geology, an international journal. *Hsein Juang*, Co-Editor in Chief, *Engineering Geology* *Kate Hibbert* – Elsevier Journal Publisher *Regional Geology and Planetary Sciences*	
19.15 Coach Departure to Warwick Castle Meeting Point: bus stop in Academic loop Road adjacent to the Mathematics and Statistics building	
19.35 – 19.45 Tour of Warwick Castle	

19.45 – 20.15 Reception drinks
20.15 - 22.30 Gala Dinner
22.30 Coach Departure to return to Warwick Campus

Friday 11th September

08.30 - 09.30 **Registration** Hall		
09.30 - 10.50 **Keynote Lectures** Room: MS.01		
	Keynote 5 09.30 - 10.00	Research-informed design, management and maintenance of infrastructure slopes: development of a multi-scalar approach *Prof. Stephanie Glendinning* - University of Newcastle upon Tyne (UK)
	Keynote 6 10.00 - 10.30	Reliability-based assessment of stability of slopes *Prof. Hsein Juang* - Clemson University (USA)
	10.30 - 10.50	Questions & Answers
10.50 - 11.15 Tea, coffee and refreshments		
11.15 - 13.00 **Parallel Session 3a** Room: MS.01		Chair: S GL Babu Rapporteur: H Juang
	11.15 - 11.30	Macro-level assessment of seismically induced landslide hazard for the state of Sikkim, India based on GIS technique *J Naveen and T G Sitharam*
	11.30 - 11.45	Susceptibility analysis of rapid flowslides in southern Italy *MC Mandaglio, N Moraci, D Gioffrè and A Pitasi*
	11.45 - 12.00	GIS-aided statistical landslide susceptibility modelling and mapping of Antipolo Rizal (Philippines) *AJ Dumlao and JA Victor*
	12.00 - 12.15	Risk assessment and management of unstable slopes on the national forest estate in Scotland *M Humphreys, I Nettleton and K Leech*
	12.15 - 12.30	System reliability analysis of granular filters for protection against piping in dams *A Srivastava and S GL Babu*
	12.30 - 12.45	Geohazard assessment lifecycle for a natural gas pipeline project. *D Lekkakis, M D Boone, E Strassburger, Z Li and W P Duffy*

	12.45 - 13.00	Advancement of liquefaction assessment in Chinese building codes *H Sun, F Liu and MJ Jiang*
11.15 - 13.00 **Parallel Session 3b** Room: MS.03		Chair: X Geng Rapporteur: MA Hicks
	11.15 - 11.30	Effect of hysteresis on the stability of an embankment under transient seepage *K Liu, PJ Vardon, P Arnold and MA Hicks*
	11.30 - 11.45	A surface and subsurface model for the simulation of rainfall infiltration in slopes *H Zhang, F Zhang, K Shen and M Yuan*
	11.45 - 12.00	Stabilization columns for embankment support – investigation, verification and further development of analytical analyses *H Pankrath, H Kaya and R Thiele*
	12.00 - 12.15	Soil moisture and strength index for earthwork construction quality control *A Sawangsuriya, S Wachiraporn and W Sramoon*
	12.15 - 12.30	Experiences from the small historical dams failures during heavy floods *I Vaníček, M Vaníček, D Jirásko and T Pecival*
	12.30 - 12.45	Analytical solutions to assess the stability of rock slopes subject to cracks via limit analysis *W Wu*
	12.45 - 13.00	The costs of housing developments on sites with elevated landslide risk in the UK *K Barclay and A Heath*
13.00 - 14.00 Lunch		
14.00 - 15.20 **Keynote Lectures** Room: MS.01		
	Keynote 7 14.00 - 14.30	Preliminary experimental study on three-dimensional contact behavior of bonded granules *Prof. Mingjing Jiang* - Tongji University (China)
	Keynote 8	Understanding the effects of inter-particle contact friction on the elastic moduli of granular materials

	14.30 - 15.00	*Prof. Stefan Luding* - University of Twente (Netherlands)
	15.00 - 15.20	Questions & Answers
15.20 - 15.45 Tea, coffee and refreshments		
15.45 - 17.00 **Parallel Session 4a** Room: MS.01		Chair: MJ Jiang Rapporteur: C Thornton
	15.45 - 16.00	Can we reduce debris flow to an equivalent one-phase flow? *B Chareyre, D Marzougui and J Chauchat*
	16.00 - 16.15	Impact of dry granular masses on rigid barriers *F Calvetti, C di Prisco and E Vairaktaris*
	16.15 - 16.30	A deep seated movement in a marly-arenaceous formation: analysis of slope deformation and pore pressure influence *S Assefa, A Graziani and A Lembo-Fazio*
	16.30 - 16.45	DEM analyses of shear behaviour of rock joints by a novel bond contact model *M J Jiang, J Liu, C Sun and H Chen*
	16.45 - 17.00	Micromechanical study of the elastic stiffness in frictional granular soils *K Taghizadeh, V Magnanimo and S Luding*
15.45 - 17.00 **Parallel Session 4b** Room: MS.03		Chair: M Arroyo Rapporteur: B Chareyre
	15.45 - 16.00	The effects of the coordination on the fragmentation of a single grain *Y Salami, C Dano, P-Y Hicher, G Colombo and P Denain*
	16.00 - 16.15	DEM analyses of the whole failure process of shallow foundation in plate load test on dense sand *L Li, M J Jiang, T Li and S L Chen*
	16.15 - 16.30	Inter-relationship between joint dilatancy and frictional resistance: impact on fracture behaviour *K I-I Eshiet and Y Sheng*
	16.30 - 16.45	A simplified DEM numerical simulation of vibroflotation without backfill *MJ Jiang, WW Liu, J He and Y Sun*

	16.45 - 17.00	Modelling of a rapidly evolving rockslide: the Mt. de la Saxe case study *R Castellanza, GB Crosta, P Frattini, C di Prisco, G Dattola, D Bertolo*
17.00 – 17.30 **Findings from Parallel sessions** Room: MS.01		Discussion leader: S. Luding
Session 3a Rapporteur H Juang Session 3b Rapporteur MA Hicks Session 4a Rapporteur C Thornton Session 4b Rapporteur B Chareyre		
17.30 – 17.45 **Closure** Room: MS.01		
Closing remarks	*Dr Elisabeth Bowman* – secretary of TC208 *Prof. G L Sivakumar Babu* – chair of TC302 *Prof. Mingjing Jiang* – vice chair of TC105 *Dr Stefano Utili* – University of Warwick (UK), Symposium Chairperson	
17.45 Wine and soft drinks, cheese and snacks 19.00		

Abstracts

Physical modelling of rainfall induced flow failures in loose granular soils

Dr. Andy Take - Queen's University (Canada)

The tragic consequences of the March 2014 Oso landslide in Washington, USA were particularly high due to the mobility of the landslide debris. Confusingly, a landslide occurred at that exact same location a number of years earlier, but simply slumped into the river at the toe of the slope. Why did these two events differ so drastically in their mobility? Considerable questions remain regarding the conditions required to generate flow failures in loose soils.

Geotechnical centrifuge testing, in combination with high-speed cameras and advanced image analysis has now provided the landslides research community with a powerful new tool to experimentally investigate the complex mechanics leading to high mobility landslides. This paper highlights recent advances in our understanding of the process of static liquefaction in loose granular soil slopes achieved through observations of highly-instrumented physical models. In particular, the paper summarises experimental results aimed to identify the point of initiation of the chain-reaction required to trigger liquefaction flow failures, to assess the effect of slope inclination on the likelihood of a flowslide being triggered, and to quantify the effect of antecedent groundwater levels on the distal reach of landslide debris with the objective of beginning to explain why neighbouring slopes can exhibit such a wide variation in landslide travel distance upon rainfall-triggering.

Geotechnical hazards associated with closed municipal solid waste landfill sites

Prof. William Powrie - University of Southampton (UK)

As pressure for new infrastructure and development grows, it is inevitable that building projects will encounter some of the 20,000 closed former solid waste landfills in the UK, many of which will have accepted municipal solid wastes (MSW). Construction on or across these sites brings a special set of geohazards associated with the potential for large and difficult to predict settlements, gas (and odour) release or generation, contaminated leachate and the breach of containment systems and other environmental controls. The presentation will discuss these issues with reference to recent research into understanding and predicting settlements in municipal solid waste landfills; assessing the total, current and residual gas potential of biodegradable wastes; the role of the hydraulic regime in the flushing of contaminants from the waste and the quality of leachate; and the need or otherwise for the long term integrity of engineered barriers and controls.

Centrifuge tests of dyke collapse on soft subsoil

J Fern, D de Lange, C Zwanenburg and J A M Teunissen

This paper presents the results of an experimental investigation on the failure or collapse of dykes with a strong contrast of stiffness between the dyke itself and its foundation layers. In deltaic regions, dykes are commonly built out of stiff sandy or clayey materials and rest on soft foundations layers (e.g. soft clay or peat). Their interaction is largely unexplored and the failure mechanism unknown. The tests presented in this paper aim to highlight the difference in failure mechanisms. The tests consisted mainly of stiff dykes on soft subsoils but a few soft dykes on stiff subsoil were also investigated. The dykes were made out of Speswhite clay or Baskarp sand whereas the subsoil was made out of silicon or clay. The silicon was used to replicate a soft elastic subsoil for which it was possible to control the stiffness. The model was then subjected to increasing gravity up to 100 G-level. The results show that slope failures take place in the dyke when the foundations layers are stiff. It is believed to be the consequence of a build up of pore pressure due to the volumetric contraction of the dyke. On the other hand, soft foundation layers underwent large settlements which in turn deformed the stiff dyke without any slope failure taking place. However, diffused sheared zones were observed in the core of the dyke.

Effect of Ground Water Table Rising and Slurry Reduction during Diaphragm Wall Trenching on Stability of Adjacent Piles

A Mohamed

The process of diaphragm wall trenching normally effects the surrounding environment. The existing of piles near diaphragm wall trench could be affected by trenching process as well. During trenching the slurry level and natural ground water level is assumed to be constant. However the flood of River Rhône at Pierre-Bénite, France causes a failure in some panels of trench excavation due to the increase of ground water level (Morgenstern and Amir-Tahmasseb, 1965). A reduction in slurry level is also possible and could cause failure in the trench. Piles located near a trench could be affected greatly if the trench is subjected to reduction of slurry or increase of soil ground water table. This research focuses on studying numerically the stability of piles adjacent to diaphragm wall during trenching process, especially in cause of slurry reduction or increase of ground water level. The cause of slurry reduction was simulated numerically using finite different analysis and compared with previous laboratory work (Choy, 2004). A parametric study was made to study the slurry reduction effect on pile group using finite different analysis. The effect of the increase in ground water table was assumed and simulated using finite element analysis for a previous case study in Giza, Egypt (Abdel-Rahman, El-Sayed, 2002).

Piles are generally affected by the trenching process. The behavior of the pile is related to its position from the slurry trench. The stability of the pile may not be affected greatly by a normal and success trenching process. However slurry reduction or increase of the water level could cause a great effect on the stability of the nearby piles. Trenching in general causes an increase in pile settlement, horizontal displacement and bending moment. The pile skin friction and end bearing are affected as well. The amount of the change in slurry level or ground water table governs the pile horizontal movement and bending moment. The amount of change that could cause failure was discussed.

Methods for the physical measurement of collisional particle flows

Gollin D., Bowman E. and Shepley P.

Particle image velocimetry (PIV) and particle tracking velocimetry (PTV) are used in this paper to test their ability in measuring kinematic properties of granular flows, such velocity fluctuations and granular temperature. A small inclined chute geometry was used here to reproduce Flows encompassing different flow regimes. An experimental investigation of a dry free-surface flow composed of almost spherical monodisperse ceramic beads is presented. The two image velocimetry techniques are directly applied to images captured in a region of the flow where an apparent uniform steady regime was observed. Our results shows that PTV is capable of measuring the movement of individual particles resulting in estimations of granular temperature that can be compared with other studies. In contrast, PIV tends to damp the magnitude of the random component of the velocities, which in turn produces lower values of granular temperature.

Centrifuge model study of thresholds for rainfall-induced landslides in sandy slopes

V. Matziaris, A.M. Marshall, C.M. Heron and H.-S.Yu

Rainfall-induced landslides are very common natural disasters which cause damage to properties and infrastructure and may result in the loss of human life. These phenomena often take place in unsaturated soil slopes and are triggered by the saturation of the soil profile due to rain infiltration which leads to the decrease of effective stresses and loss of shear strength. The aim of this study is to determine rainfall thresholds for the initiation of landslides under different initial conditions. Model tests of rainfall-induced landslides were conducted on the Nottingham Centre for Geomechanics geotechnical centrifuge. Initially unsaturated plane-strain slope models made with _ne silica sand were prepared at varying densities at 1g and accommodated within a centrifuge

container with rainfall simulator. During the centrifuge flight at 60g, rainfall events of varying intensity and duration, as well as variation of groundwater conditions, were applied to the slope models with the aim of initiating slope failure. This paper presents a discussion on the impact of soil state properties, rainfall characteristics, and groundwater conditions on slope behaviour and the initiation of slope instability.

An experimental model for slopes subject to weathering
C Voulgari

Landslides and debris flows can constitute a very dangerous natural hazard. Better understanding of the failure mechanisms of the slopes will lead to more reliable predictions and mitigation strategies. In this paper, an experimental prototype model to study the influence of cracks on the morphologic evolution of natural cliffs subject to progressive retreat induced by weathering is presented. A set of small scale laboratory tests is designed to investigate weathering induced successive landslides. Weathering is applied to the slope model by wetting the slope crest through a rainfall simulator device. The moisture content and the suction of the soil during the tests are monitored by soil moisture sensors and tensiometers that are buried inside the slope model. High resolution cameras are recording the behaviour of the slope model and GeoPIV is used to analyse the frames and obtain the deformations of the slope model during the tests. After a short time of rainfall, vertical cracks appear in the slope model and significant vertical deformations start to occur around the crack, until the first failure is reached, the procedure carries on until a second failure is observed. Experimental results indicate that there is a strong connection between moisture content - thus degree of weathering - and the occurrence of a landslide. A prediction model of slope failures can be introduced based on the observed moisture content response of the slope models.

Evaluating the capability of a critical state constitutive model to predict the collapse potential of loose sand
A Azizi, G Bella and I Farshchi

Many catastrophic flow failures in granular soil slopes are believed to be caused by a rise in pore water pressure associated with substantial loss of soil shear strength. This failure mechanism is known as prefailure instability or static liquefaction. Constant shear (CS) and consolidated undrained (CU) triaxial tests can reproduce stress paths, in which such instability may occur before reaching the failure. In the present study, a previously proposed critical state constitutive model was first used to simulate the behavior of loose saturated sand in CU tests. It was then employed to predict the instability of loose sand subjected to the CS loading. Under such loading, loose dry sand initially experience small volume increase, and then start to contract substantially. In saturated sand, such contractions can lead to the generation of pore water pressure and sudden decrease of shear strength. The capability of the model to predict the onset of the volume contraction and collapse potential of loose dry sand was examined by comparing the model predictions with experimental results of CS tests. The comparison showed that the effect of initial void ratio, consolidation and deviatoric stresses on behavior of loose dry sand can be well predicted by the model.

An Experimental study of the initial volumetric strain rate effect on the creep behaviour of reconstituted clays
M Bagheri, M Rezania and M M Nezhad

Clayey soils tend to undergo continuous compression with time, even after excess pore pressures have substantially dissipated. The effect of time on deformation and mechanical response of these soft soils has been the subject of numerous studies. Based on these studies, the observed time-dependent behaviour of clays is mainly related to the evolution of soil volume and strength characteristics with time, which are classified as creep and/or relaxation properties of the soil. Apart

from many empirical relationships that have been proposed in the literature to capture the rheological behaviour of clays, a number of viscid constitutive relationships have also been developed which have more attractive theoretical attributes. A particular feature of these viscid models is that their creep parameters often have clear physical meaning (e.g. coefficient of secondary compression, C_α). Sometimes with these models, a parameter referred to as initial/reference volumetric strain rate, $\dot{v}_0$ has also been alluded as a model parameter. However, unlike C_α, the determination of $\dot{v}_0$ and its variations with stress level is not properly documented in the literature. In an attempt to better understand $\dot{v}_0$, this paper presents an experimental investigation of the reference volumetric strain rate in reconstituted clay specimens. A long-term triaxial creep test, at different shear stress levels and different strain rates, was performed on clay specimen whereby the volumetric strain rate was measured. The obtained results indicated the stress-level dependency and non-linear variation of $\dot{v}_0$ with time.

Response of shallow geothermal energy pile from laboratory model tests

A Marto and A Amaludin

In shallow geothermal energy pile systems, the thermal loads from the pile, transferred and stored in the soil will cause thermally induced settlement. This factor must be considered in the geotechnical design process to avoid unexpected hazards. Series of laboratory model tests were carried out to study the behaviour of energy piles installed in kaolin soil, subjected to thermal loads and a combination of axial and thermal loads (henceforth known as thermo-axial loads). Six tests which included two thermal load tests (35˚C and 40˚C) and four thermo-axial load tests (100 N and 200 N, combined with 35˚C and 40˚C thermal loads) were conducted. To simulate the behaviour of geothermal energy piles during its operation, the thermo-axial tests were carried out by applying an axial load to the model pile head, and a subsequent application of thermal load. The model soil was compacted at 90% maximum dry density and had an undrained shear strength of 37 kPa, thus classified as having a firm soil consistency. The behaviour of model pile, having the ultimate load capacity of 460 N, was monitored using a linear variable displacement transducer, load cell and wire thermocouple, to measure the pile head settlement, applied axial load and model pile temperature. The acquired data from this study was used to define the thermo-axial response characteristics of the energy pile model. In this study, the limiting settlement was defined as 10% of the model pile diameter. For thermal load tests, higher thermal loads induced higher values of thermal settlement. At 40˚C thermal load an irreversible settlement was observed after the heating and cooling cycle was applied to the model pile. Meanwhile, the pile response to thermo-axial loads were attributed to soil consistency and the magnitude of both the axial and thermal loads applied to the pile. The higher the thermos-axial loads, the higher the settlements occurred. A slight hazard on the model pile was detected, since the settlement occurred was greater than the limiting value when the pile was loaded with thermo-axial loads of 40˚C and 200 N. It is therefore recommended that the global factor of safety to be applied for energy pile installed in firm soil should be more than 2.3 to prevent any hazard to occur in the future, should the pile also be subjected to thermal load of 40˚C or greater.

Engineering properties of cement/lime-stabilized Egyptian soft clay

M A Mansour, A M Samieh and H E Matter

Soft clay formations are extensively located in many coastal areas around the world. The significant high compressibility and low shear strength of these formations impose challenging engineering problems. The deep cement/lime-mix-in-place method is one of the ground improvement techniques exhibiting successful use in stabilizing soft clay. Analysis and design of the deep mixing systems necessitate the identification of the additive content, the proportions of the lime to cement and the characteristics of the stabilized clay. This paper investigates experimentally the influence of adding lime and cement or cement alone, as stabilizing additives, on the engineering behaviour of an Egyptian soft clay extracted from the north delta region. A series of laboratory tests were carried

out considering, different additive contents of 8, 10, 12, and 14% of the dry weight, with different proportions of lime to cement of 50:50, 25:75 and 0:100. A series of unconfined compression strength tests were performed after different periods; one week, four weeks and 8 weeks, to assess the effect of curing period on the stabilized clay response. In addition, one dimensional consolidation tests were carried out to evaluate the compressibility properties of the stabilized clay. This study declared that the use of an additive content in the range of 12% and more is recommended to improve the characteristics of the considered Egyptian clay. It was pointed out that addition of lime and cement to soft clay significantly increases the strength characteristics and significantly reduces the compressibility characteristics of such clay.

Correlation between index properties and electrical resistivity of hydrocarbon contaminated periodic marine clays

P Tiwari and M Shah

Hydrocarbon contamination is a measure issue of concern as it adversely affects the soil inherent properties viz. index properties and strength properties. The main objective of this research work is to determine Electrical resistivity to study and correlate with soil index properties and engineering properties contaminated with hydrocarbon at the rate of 3%, 6% and 9% for the period of 15, 30 45 and 60 days and compare it with the results obtained for non-contaminated marine clay. Electrical resistivity of virgin marine clay (bentonite which is expansive in nature) and hydrocarbon contaminated clay for each percent of contamination is obtained in the laboratory for each period and its co-relation with index properties and engineering properties is proposed. CEC, EDAX tests were performed to evaluate the effect of ions of montmorillonite clays and their penetrability into hydrocarbon- clay matrix. The correlations at the end of each period for each percentage of contamination thus enabled to integrate index properties of non-contaminated and hydrocarbon contaminated marine clays with Electrical resistivity. The above study reveals that there is a major influence of hydrocarbon contamination on engineering behavior of clays. This leads us advance assessment of influence of both percentage contamination and periodic contamination on strength characteristics of such marine clays.

Recent developments of the Material Point Method for the simulation of landslides

Prof. Eduardo Alonso - Universitat Politècnica de Catalunya (Spain)

The paper describes first the theoretical framework of a “single layer” three phase material. The formulation is general and particular cases are dry and fully saturated soils. The formulation and discretization of the motion and balance equations is presented. Two constitutive equations are used in the applications described: A brittle model for saturated soils and a Mohr-Coulomb elastoplastic soil formulated in terms of net stress and suction. Three aspects of the behaviour of landslides are discussed: first time failures in over-consolidated clays; internal shearing in deep seated landslides and rain induced failures in unsaturated slopes. The discussion is supported by three real cases which are described and analyzed in detail.

Landslides falling onto a shallow erodible substrate or water layer: an experimental and numerical approach

Prof. Giovanni Crosta - Universita Milano Bicocca (Italy)

Landslides often collapse in areas covered by alluvial deposits forming an erodible layer. This erodible substrate may deform plastically under the intense shear stress of the landslide mass. In other cases, the collapse occurs onto a water basin or tidal flat, creating impulse water waves whilst the landslide may be lubricated by a water layer underneath. In either case the presence of a medium underneath the landslide will change its dynamics introducing complex processes. While frictional, dry masses and taluses generally hamper the landslide motion. In this work, we present some experiments mimicking the collapse of a landslide onto shallow erodible or water layers. The landslide is simulated with a granular material (sand or gravel) flowing on an incline (35-66°)

followed by a horizontal sector covered with a granular bed 1 to 2 cm thick or with a 0.5-1 cm of water. Monitoring evolution in time allows us to describe in detail the process of fluidization of the material at impact, the generation of impact waves, and the erosion process. Concerning impact on a sand layer, the apparent friction coefficient (H/L) is found to increase with the chute slope angle and with the thickness of the erodible layer, and to decrease with the volume. At low slope angles, the material accumulates backwards in a shock wave mode, while at larger slope angles (>45°) it accumulates by progressing forward. A granular avalanche falling from the slope is partially reflected at the sharp slope break where erosion occurs and then propagates initially as a wave partially eroding the superficial material. Folding and thrusting occur within the dense shear flow and the erodible layer. Experiments with a water layer show that the dynamics depends much on the permeability of the granular avalanche. FEM numerical simulations replicate and allow describing and understanding both the spreading and the erosion, and internal deformation recorded in the erodible layer. Experimental findings are compared with real rock avalanches, flowslides and snow avalanches characteristics and morphological features. A medium with low permeability may be lubricated by the presence of water, resulting in a front acceleration and a final double-ringed deposit.

Comparing kinematically detachable rock masses and rockfall scar volumes

O Mavrouli and J Corominas

In rockfall prone areas the evaluation of the risk due to worst case scenarios requires the establishment of maximum thresholds for the expected rockfall volumes in an area. The magnitude of such instabilities is often related to the properties of the jointed rock mass, with the characteristics of the existing unfavourably dipping joint sets playing a major role. The study-site here is the chute of Forat Negre in Andorra. The size distribution of the missing volumes from the scars was calculated using terrestrial laser scanner point cloud data and reaches up to few thousands of m3. On the other hand, the application of Markland criteria on a Digital Elevation Model of the zone indicated the kinematically detachable rock masses to be up to tens of thousands of m3. As the size of the scar areas does not indicate the occurrence of such events in the past, the effect of the persistence as assumed for the two analyses is discussed here. The areas of the exposed surfaces belonging to each discontinuity set are obtained and their use as a measure of the relative persistence of each set is proposed. The average and median length of the sets F3 and F5 (sliding planes) are found to be similar to the average and median spacing of the intersecting set F7 (tension crack), suggesting that the F7 set exerts a control over the persistence of the former ones.

Application of geotechnical and geophysical field measurements in an active alpine environment

D R Lucas, K Fankhauser and S M Springman

Rainfall can trigger landslides, rockfalls and debris flow events. When rainfall infiltrates into the soil, the suction (if there is any) is reduced, until positive water pressure can be developed, decreasing the effective stresses and leading to a potential failure. A challenging site for the study of mass movement is the Meretschibach catchment, a location in the Swiss Alps in the vicinity of Agarn, Canton of Valais. To study the effect of rainfall on slope stabilities, the soil characterization provides valuable insight on soil properties, necessary to establish a realistic ground model. This model, together with an effective long term-field monitoring, de-liver the essential information and boundary conditions for predicting and validating rainfall-induced slope instabilities using numerical and physical modelling. Geotechnical monitoring, including soil temperature and volumetric water content measurements, has been performed on the study site together with geophysical measurements (ERT) to study the effect of rainfall on the (potential) triggering of landslides on a scree slope composed of a surficial layer of gravelly soil. These techniques were combined to provide information on the soil characteristics and depth to the bedrock. Seasonal changes of precipitation and temperature were reflected in corresponding trends in all

measurements. A comparison of volumetric water content records was obtained from decagons, time domain reflectometry (TDR) and electrical resistivity tomography (ERT) conducted throughout the spring and summer months of 2014, yielding a reasonable agreement.

Strategies for rock slope failure early warning using acoustic emission monitoring

D Codeglia, N Dixon, G J Fowmes and G Marcato

Research over the last two decades has led to development of a system for soil slopes monitoring based on the concept of measuring Acoustic Emission (AE). A feature of the system is the use of waveguides installed within unstable soil slopes. It has been demonstrated that the AE measured through this technique are proportional to soil displacement rate. Attention has now been focused on the prospect of using the system within rock materials. The different nature of the slope material to be monitored and its setting means that different acoustic trends are measured, and development of new approaches for their interpretation are required. A total of six sensors have been installed in two pilot sites, firstly in Italy, for monitoring of a stratified limestone slope which can threaten a nationally important road, and secondly in Austria, for monitoring of a conglomerate slope that can endanger a section of the local railway. In this paper an outline of the two trial sites is given and AE data collected are compared with other physical measurements (i.e. rainfall and temperature) and traditional geotechnical instrumentation, to give an overview of recurring AE trends. These include clear AE signatures generated by stress changes linked to increased ground water levels and high energy events generated by freeze-thaw of the rock mass.

Shear wave velocity analysis of a deep seated gravel landslide structure using the microtremor survey method

L Su, X Xu, H Liao and X-Y Geng

The depth and geometry of potential failure surface is the fundamental for evaluating the mechanisms of a landslide. Traditional techniques to acquire information on potential sliding surface are mainly drilling, pitting, and trenching, but these techniques are time consuming and expensive. In this study, microtremor signals and the dispersion curves of surface wave are extracted from the vertical component of microtremor records using the spatial autocorrelation (SPAC) method to estimate shear wave velocity structure. The results suggest that the buried depth of phyllite bedrock is approximately 47.4m, and the thickness of weathered bedrock layer is about 9.9m at about 57.3m deep, which could be interpreted as the potential sliding surface of this landslide, in accordance with borehole data. The microtremor survey method (MSM) is flexible, non-invasive, relatively quick and deployable on the landslide. It clearly demonstrat that it is an effective tool to improve the drilling success rate, and hence allow a large scale and high density investigation of structure characteristics of a deep seated landslide.

Using several monitoring techniques to measure the rock mass deformation in the Montserrat Massif

M Janeras, J A Jara, F López, J Marturià, M J Royán, J M Vilaplana, A Aguasca, X Fàbregas, F Cabranes and J A Gili

Montserrat Mountain is located near Barcelona in Catalonia, at the north-east corner of Spain, and its massif is formed by conglomerate interleaved by siltstone/sandstone with steep slopes very prone to rock falls. The increasing visitor's number in the monastery area, reaching 2.4 million per year, has pointed out the risk derived from rock falls for this building area and also for the terrestrial accesses, both roads and rack railway. A risk mitigation plan is currently been applied for 2014-2016 that contains monitoring testing and implementation as a key point. The preliminary results of the pilot tests carried out during 2014 are presented, also profiting from previous sparse experiences and data, and combining 4 monitoring techniques under different conditions of continuity in space and time domains, which are: displacement monitoring with Ground-based Synthetic Aperture

Radar and characterization at slope scale, with an extremely non uniform atmospheric phase screen because of the stepped topography and atmosphere stratification; Terrestrial Laser Scanner surveys quantifying frequency for unnoticed activity of small rock falls, and monitoring rock block displacements over 1cm; monitoring of rock joints with a wireless net of sensors; and tentative surveying for singular rocky needles with Total Station.

Monitoring of unstable slopes by MEMS tilting sensors and its application to early warning systems

I Towhata, T Uchimura, I Seko and L Wang

The present paper addresses a newly developed early warning technology that can help mitigate the slope failure disasters during heavy rain. Many studies have been carried out in the recent times on early warning that is based on rainfall records. Although those rainfall criteria of slope failure tells the likelihood of disaster on a regional scale, it is difficult for them to judge the risk of individual slopes. This is because the rainfall intensity is spatially too variable to forecast and the early warning based on rainfall alone cannot take into account the effects of local geology, hydrology and topography that vary spatially as well. In this regard, the authors developed an alternative technology in which the slope displacement/deformation is monitored and early warning is issued when a new criterion is satisfied. The new MEMS-based sensor monitors the tilting angle of an instrument that is embedded at a very shallow depth and the record of the tilting angle corresponds to the lateral displacement at the slope surface. Thus, the rate of tilting angle that exceeds a new criterion value implies an imminent slope failure. This technology has been validated against several events of slope failures as well as against a field rainfall test. Those validations have made it possible to determine the criterion value of the rate of tilting angle to be 0.1 degree/hour. The advantage of the MEMS tilting sensor lies in its low cost. Hence, it is possible to install many low-cost sensors over a suspected slope in which the precise range of what is going to fall down during the next rainfall is unknown. In addition to the past validations, this paper also introduces a recent application to a failed slope in the Izu Oshima Island where a heavy rainfall-induced slope failure occurred in October, 2013.

Flood Control and Loss Estimation for Paddy Field at Midstream of Chao Phraya River Basin, Thailand

TC Cham, Y Mitani

2011 Thailand flood has brought serious impact to downstream of Chao Phraya River Basin. The flood peak period started from August, 2011 to the end of October, 2011. This research focuses on midstream of Chao Phraya River Basin, which is Nakhon Sawan area includes confluence of Nan River and Yom River, also confluence of Ping River and Nan River. The main purpose of this research is to understand the flood generation, estimate the flood volume and loss of paddy field, also recommends applicable flood counter measurement to ease the flood condition at downstream of Chao Phraya River Basin. In order to understand the flood condition, post-analysis is conducted at Nakhon Sawan. The post-analysis consists of field survey to measure the flood marks remained and interview with residents to understand living condition during flood. The 2011 Thailand flood generation at midstream is simulated using coupling of 1D and 2D hydrodynamic model to understand the flood generation during flood peak period. It is calibrated and validated using flood marks measured and streamflow data received from Royal Irrigation Department (RID). Validation of results shows good agreement between simulated result and actual condition. Subsequently, 3 scenarios of flood control are simulated and Geographic Information System (GIS) is used to assess the spatial distribution of flood extent and reduction of loss estimation at paddy field. In addition, loss estimation for paddy field at midstream is evaluated using GIS with the calculated inundation depth. Results show the proposed flood control at midstream able to minimize 5% of the loss of paddy field in 26 provinces.

Investigation of the slope stability problem using the Material Point Method

F Fatemizadeh and C Moormann

The Finite Element Method (FEM) has become a standard tool in engineering, although its shortcoming in large deformation analysis is apparent. Mesh distortions are common in this area. In order to be able to investigate applications including large deformations or displacements of the material, advanced numerical methods are needed. In this study we introduce the Material Point Method (MPM) as a powerful tool to simulate applications including large deformations. This capability of MPM plays an important role in the study of land and rockslides, avalanches, mudflow, etc. Here we will present a brief introduction on the governing equations and the solution procedure of MPM. Based on the presented formulation and using a two dimensional program developed, a slope stability problem is solved to show the capability of this method to be used in studying geohazard related phenomena. At the end some concluding remarks and recommendations are presented.

MPM dynamic simulation of a seismically induced sliding mass

C Moormann and F Hamad

In some geotechnical applications, material can undergo large displacement combined with excessive deformation; e.g. the sliding mass problem. Owing to the limitations of classical Lagrangian and Eulerian finite element methods to model these problems, the Material Point Method (MPM) has been developed about two decades ago to cope with the large deformation. In MPM, the continuum field is represented by Lagrangian material points (particles), which can move through a fixed background of a computational mesh. Therefore, it can be seen as a mesh-based method formulated in arbitrary Lagrangian–Eulerian description. Although MPM represents the continuum by material points, solution is performed on the computational mesh. Thus, imposing boundary conditions is not aligned with the material representation. In this paper, a non–zero kinematic condition is introduced where an additional set of particles is incorporated, which tracks the moving boundary by carrying the time– dependent boundary evolution. Furthermore, the material point method has been adopted to simulate the progressive failure of a sliding granular slope triggered by a seismic excitation. In order to represent the topographical bottom of the sliding mass, on which the seismic motion is applied, a rigid boundary is implemented by introducing an additional set of particles. A frictional contact algorithm is defined between the boundary and the descending mass, which allows sliding and rolling with friction. The traction due to contact is incorporated into the discretised momentum equation as an external force where the solution of this equation is performed separately for each body in contact. Defining the local coordinate system accurately in this algorithm is essential to avoid interpenetration. Thus, a two-dimensional triangular discretisation is utilised within the three-dimensional tetrahedral elements to track the surface progression of each body in contact. Complying with other continuum models findings performed on granular materials, the present model overpredicts the lateral deformations. Therefore, a local damping proportional to the out-of-balance nodal forces is included. In spite of the simple Mohr- Coulomb failure criteria being used, the results of the present numerical model are comparative to another continuum based model.

Runout analysis of landslides using material point method

Y Sun, J Yang and E Song

Dynamic simulation of runout landslides is essential for assessment, prevention and mitigation of landslide-induced disasters, but difficult for traditional numerical methods. This paper use the material point method (MPM) to simulate the long runout landslides. The basic theories and the solution procedure of MPM are presented first. Then a landside experiment with the soil modelled by aluminium bars is simulated to validate this method for landslide analysis. The numerical results of the final configuration and the failure surface of the landslide agree well with the experiment

results. Finally, the landslide of Erman Mountain in China Sichuan province is simulated. The velocities, affected areas, flow intensity and impact forces on structures are investigated.

Earthquake-induced displacements of cohesive-frictional soil slopes subject to cracks.

AH Abd

The upper bound theorem of limit analysis together with Newmark's method is employed to evaluate the displacement of soil slopes subject to cracks. The pseudo static approach has been routinely used in the literature to estimate the seismic displacement of soil slopes. However, the effect of cracks on the slope displacement has yet to be tackled. In this paper, a new technique is proposed to estimate the horizontal displacement at the slope toe, due to a given earthquake postulating a rough estimation of real time crack formation. Rotational failure mechanisms for intact slopes exhibiting the formation of cracks as part of the failure process and the case of cracks pre-existing in the slope were considered. On the basis of Newmark's method, the seismic induced displacement is calculated by incorporating a stepwise yield acceleration corresponding to the cracks occurring in the slope. Results of the proposed technique may reasonably bridge the gap between the conservatism of assuming the slopes subject to the most detrimental cracks, and the overestimation of slope stability due to ignoring crack formation. An example illustrating the procedure for a given earthquake is presented. Also, charts providing the values needed to calculate the stepwise yield accelerations are presented.

3D numerical analyses for the quantitative risk assessment of subsidence and water flood due to the partial collapse of an abandoned gypsum mine.

R Castellanza, GM Orlandi, C Di Prisco, G Frigerio, L Flessati, JA Fernandez Merodo, F Agliardi, S Grisi and GB Crosta

After the abandonment occurred in the '70s, the mining system (rooms and pillars) located in S. Lazzaro di Savena (BO, Italy) , grown on three levels with the method rooms and pillars, has been progressively more and more affected by degradation processes due to water infiltration. The mine is located underneath a residential area causing significant concern to the local municipality. On the basis of in situ surveys, laboratory and in situ geomechanical tests, some critical scenarios were adopted in the analyses to simulate the progressive collapse of pillars and of roofs in the most critical sectors of the mine. A first set of numerical analyses using 3D geotechnical FEM codes were performed to predict the extension of the subsidence area and its interaction with buildings. Secondly 3D CFD analyses were used to evaluated the amount of water that could be eventually ejected outside the mine and eventually flooding the downstream village. The predicted extension of the subsidence area together with the predicted amount of the ejected water have been used to design possible remedial measurements.

Forensic Analysis of Malin Landslide in India

P Ering, R Kulkarni, Y Kolekar, SM Dasaka and S GL Babu

A devastating landslide occurred on 30th July 2014, resulting in the burial of a village of about 40 houses called Malin, in western India and also led to about 160 deaths. The landslide was triggered by heavy rainfall in the area and mass movement of debris. The paper investigates slope failure in the Malin area using back analysis and numerical methods. Site investigation was conducted to obtain representative information of the area. Finite difference analyses using FLAC 2D is performed for the failed slope to determine the possible cause of failure. Analysis results show that slope failure occurred due to the loss of suction strength at the interface between rock and local soil.

Evolution of rock falls in the Northern part of the Peloponnese, Greece

V Zygouri and IK Koukouvelas

Rock falls are a common fast – moving type of slope failures. Earthquake triggered rock falls attracted widespread attention since they represent serious hazard during strong earthquakes, causing severe damages and even fatalities. Strong earthquakes and their associated rock falls give rise to a sudden change in landscape evolution in tectonically active areas. The associated risk can be high both to communities and to critical infrastructures even far away from the active source slopes. Distinguishing between climatic induced and tectonically induced rock falls triggered by past earthquakes is a challenging task based on the development and the fault related discontinuities of a rock slope. We chose two case studies located in the Northern part of the Peloponnese (in Ilia and Corinthia prefecture), the Skolis Mountain and the Acrocorinthos area, in order to establish the rock fall susceptibility for each case study through the implementation of shadow angle β. The proposed methodology is based on the integrated analysis of the recurrence of rock falls, their spatial distribution and their mapping through field survey and aerial photography. Our mapping is integrated through Geographic Information System taking into account also the catalogue of historical and recent recorded seismicity in an attempt to examine triggering mechanisms and causes including the effects of climatic conditions for each case study. After the analysis of the spatial relationships between rock falls and the distribution of seismic epicentres and active faults as seismogenic sources, we conclude that both studied areas have suffered extensive rock fall phenomena induced by shallow seismicity and that the relationship between geomorphologic parameters and rock fall occurrence is strong. The research steps are described, namely, the recognition, identification, mapping and evolution of rock fall phenomena through time. Our results propose a critical threshold value of 24º for shadow angle β as the worst case scenario, suggesting that isolated boulders pose the greater risk on the associated communities.

Research-informed design, management and maintenance of infrastructure slopes: development of a multi-scalar approach

Prof. Stephanie Glendinning - University of Newcastle upon Tyne (UK)

The UK's transport infrastructure is one of the most heavily used in the world. The performance of these networks is critically dependent on the performance of cutting and embankment slopes which make up £20B of the £60B asset value of major highway infrastructure alone. The rail network in particular is also one of the oldest in the world: many of these slopes are suffering high incidents of instability (increasing with time). This paper describes the development of a fundamental understanding of earthwork material and system behaviour, through the systematic integration of research across a range of spatial and temporal scales. Spatially these range from microscopic studies of soil fabric, through elemental materials behaviour to whole slope modelling and monitoring and scaling up to transport networks. Temporally, historical and current weather event sequences are being used to understand and model soil deterioration processes, and climate change scenarios to examine their potential effects on slope performance in futures up to and including the 2080s. The outputs of this research are being mapped onto the different spatial and temporal scales of infrastructure slope asset management to inform the design of new slopes through to changing the way in which investment is made into aging assets. The aim ultimately is to help create a more reliable, cost effective, safer and more resilient transport system.

Reliability-based assessment of stability of slopes

Prof. Hsein Juang - Clemson University (USA)

Multiple sources of uncertainties often exist in the evaluation of slope stability. When assessing stability of slopes in the face of uncertainties, it is desirable, and sometimes necessary, to adopt

reliability-based approaches that consider these uncertainties explicitly. This paper focuses on the practical procedures developed recently for the reliability-based assessment of slope stability. The statistical characterization of model uncertainty and parameter uncertainty are first described, followed by an evaluation of the failure probability of a slope corresponding to a single slip surface, and the system failure probability. The availability of site-specific information then makes it possible to update the reliability of the slope through the Bayes' theorem. Furthermore, how to perform reliability-based design when the statistics of random variables cannot be determined accurately is also discussed. Finally, case studies are presented to illustrate the benefit of performing reliability-based design and the procedure for conducting reliability-based robust design when the statistics of the random variables are incomplete.

Macro level assessment of seismically induced landslide hazard for the state of Sikkim, India based on GIS technique

J Naveen and TG Sitharam

This paper presents a macro-level seismic landslide hazard assessment for the entire state of Sikkim, India, based on the Newmark's methodology. The slope map of Sikkim was derived from ASTER Global Digital Elevation Model (GDEM). Seismic shaking in terms of peak horizontal acceleration (PHA) at bedrock level was estimated from deterministic seismic hazard analysis (DSHA), considering point source model. Peak horizontal acceleration at the surface level for the study area was estimated based on nonlinear site amplification technique, considering B-type NEHRP site class. The PHA at surface was considered to induce driving forces on slopes, thus causing landslides. Knowing the surface level PHA and slope angle, the seismic landslide hazard assessment for each grid point was carried out using Newmark's analysis. The critical static factor of safety required to resist landslide for the PHA (obtained from deterministic analysis) was evaluated and its spatial variation throughout the study area is presented. For any slope in the study area, if the in-situ (available) static factor of safety is greater than the static factor of safety required to resist landslide as predicted in the present study, that slope is considered to be safe.

Susceptibility analysis of rapid flowslides in southern Italy

MC Mandaglio, N Moraci, D Gioffrè and A Pitasi

Qualitative and quantitative estimation of distribution of the existing landslides or that could occur inside a determined area is named landslide susceptibility. The zoning of landslide susceptibility consists of inventory of landslides occurred in the past and identification of the areas where the landsliding could occur in the future. The paper shows the results of a study of fast flowslides susceptibility performed on an area placed between Scilla and Favazzina (RC) regularly and historically interested by rainfall and in some cases by earthquake induced landslides. The trend of inclination and lithological features of the potential detachment zones has been analyzed at 1:5.000 scale. Classes of inclinations, where the most part of detachment zones are clustered, have been identified and the distribution of these classes for each lithological type has been graphed. Among all surveyed events, the inclinations and lithological features of the detachment zones similar to those of the events occurred in the 2001 and 2005 have been found. Finally, in order to evaluate the susceptibility of the area, the paths of flowslides have been evaluated by numerical simulations using the SPH model.

GIS-aided Statistical Landslide Susceptibility Modeling And Mapping Of Antipolo Rizal (Philippines)

AJ Dumlao and JA Victor

Slope instability associated with heavy rainfall or earthquake is a familiar geotechnical problem in the Philippines. The main objective of this study is to perform a detailed landslide susceptibility assessment of Antipolo City. The statistical method of assessment used was logistic regression.

Landslide inventory was done through interpretation of aerial photographs and satellite images with corresponding field verification. In this study, morphologic and non-morphologic factors contributing to landslide occurrence and their corresponding spatial relationships were considered. The analysis of landslide susceptibility was implemented in a Geographic Information System (GIS). The 17320 randomly selected datasets were divided into training and test data sets. K- cross fold validation is done with k= 5. The subsamples are then fitted five times with k-1 training data set and the remaining fold as the validation data set. The AUROC of each model is validated using each corresponding data set. The AUROC of the five models are; 0.978, 0.977, 0.977, 0.974, and 0.979 respectively, implying that the models are effective in correctly predicting the occurrence and nonoccurrence of landslide activity. Field verification was also done. The landslide susceptibility map was then generated from the model. It is classified into four categories; low, moderate, high and very high susceptibility. The study also shows that almost 40% of Antipolo City has been assessed to be potentially dangerous areas in terms of landslide occurrence.

Risk assessment and management of unstable slopes on the national forest estate in Scotland
M Humphreys, I Nettleton and K Leech

The National Forest Estate in Scotland has a wide range of geotechnical hazards present, primarily landslides, which may cause a significant risk to people and key infrastructure. UK land owners are increasingly required to understand the risks associated with their land and how their activities may affect landsliding and, in particular, where landslides originating from their land may impact third party assets. A Geographic Information System (GIS) based landslide susceptibility assessment by the British Geological Survey (BGS) identified a number of sites in the National Forest Estate as being susceptible to landslide hazards. Coffey Geotechnics Ltd and the BGS are currently undertaking "groundtruthing" of selected sites to identify and characterise the hazards, pathways and elements at risk. A "Slope Stability Appraisal of Risk" system was used to assign a risk category to areas identified during the "ground-truthing" phase which need to be managed. This system is based on the combination of hazards, receptor type, vulnerability and pathway in a similar manner to that of the Australian Geomechanics Society. A long term strategy for risk management of unstable slopes is under development by Forestry Commission Scotland to provide strategic guidance on future land management and guidance for existing felled sites. Options for risk management include: maintenance of existing systems i.e. drainage; silviculture where establishment of woodland can assist in slope stabilisation; and engineering works such as barrier systems, retaining structures and rock remedial works.

System reliability analysis of granular filters for protection against piping in dams
A Srivastava and SGL Babu

Granular filters are provided for the safety of water retaining structure for protection against piping failure. The phenomenon of piping triggers when the base soil to be protected starts migrating in the direction of seepage flow under the influence of seepage force. To protect base soil from migration, the voids in the filter media should be small enough but it should not also be too small to block smooth passage of seeping water. Fulfilling these two contradictory design requirements at the same time is a major concern for the successful performance of granular filter media. Since Terzaghi era, conventionally, particle size distribution (PSD) of granular filters is designed based on particle size distribution characteristics of the base soil to be protected. The design approach provides a range of D15f value in which the PSD of granular filter media should fall and there exist infinite possibilities. Further, safety against the two critical design requirements cannot be ensured. Although used successfully for many decades, the existing filter design guidelines are purely empirical in nature accompanied with experience and good engineering judgment. In the present study, analytical solutions for obtaining the factor of safety with respect to base soil particle

migration and soil permeability consideration as proposed by the authors are first discussed. The solution takes into consideration the basic geotechnical properties of base soil and filter media as well as existing hydraulic conditions and provides a comprehensive solution to the granular filter design with ability to assess the stability in terms of factor of safety. Considering the fact that geotechnical properties are variable in nature, probabilistic analysis is further suggested to evaluate the system reliability of the filter media that may help in risk assessment and risk management for decision making.

Geohazard Assessment Lifecycle for a Natural Gas Pipeline Project.

D Lekkakis, MD Boone, E Strassburger, Z Li and WP Duffy

This paper is a walkthrough of the geohazard risk assessment performed for the Front End Engineering Design (FEED) of a planned large-diameter natural gas pipeline, extending from Eastern Europe to Western Asia for a total length of approximately 1,850 km. The geohazards discussed herein include liquefaction-induced pipe buoyancy, cyclic softening, lateral spreading, slope instability, groundwater rise-induced pipe buoyancy, and karst. The geohazard risk assessment lifecycle was comprised of 4 stages: initially a desktop study was carried out to describe the geologic setting along the alignment and to conduct a preliminary assessment of the geohazards. The development of a comprehensive Digital Terrain Model topography and aerial photography data were fundamental in this process. Subsequently, field geohazard mapping was conducted with the deployment of 8 teams of geoprofessionals, to investigate the proposed major reroutes and delve into areas of poor or questionable data. During the third stage, a geotechnical subsurface site investigation was then executed based on the results of the above study and mapping efforts in order to obtain sufficient data tailored for risk quantification. Lastly, all gathered and processed information was overlain into a Geographical Information database towards a final determination of the critical reaches of the pipeline alignment. Input from Subject Matter Experts in the fields of landslides, karst and fluvial geomorphology was incorporated during the second and fourth stages of the assessment. Their experience in that particular geographical region was key to making appropriate decisions based on engineering judgment. As the design evolved through the above stages, the pipeline corridor was narrowed from a 2-km wide corridor, to a 500-m corridor and finally to a fixed alignment. Where the geohazard risk was high, rerouting of the pipeline was generally selected as a mitigation measure. In some cases of high uncertainty in the assessment, further exploration was proposed. In cases where rerouting was constrained, mitigation via structural measures was proposed. This paper further discusses the cost, schedule and resource challenges of planning and executing such a large-scale geotechnical investigation, the interfaces between the various disciplines involved during the assessment, the innovative tools employed for the field mapping, the classifications developed for mapping landslides, karst geology, and trench excavatability, determining liquefaction stretches and the process for the site localization of the Above Ground Installations (AGI). It finally discusses the objectives of the FEED study in terms of providing a route, a ± 20% project cost estimate and a schedule, and the additional engineering work foreseen to take place in the detailed engineering phase of the project.

Advancement of liquefaction assessment in Chinese building codes

H Sun, F Liu and MJ Jiang

China has suffered extensive liquefaction hazards in destructive earthquakes. The post-earthquake reconnaissance effort in the country largely advances the methodology of liquefaction assessment distinct from other countries. This paper reviews the evolution of the specifications regarding liquefaction assessment in the seismic design building code of mainland China, which first appeared in 1974, came into shape in 1989, and received major amendments in 2001 and 2010 as a result of accumulated knowledge on liquefaction phenomenon. The current version of the code requires a detailed assessment of liquefaction based on in situ test results if liquefaction concern cannot be eliminated by a preliminary assessment based on descriptive information with respect to site

characterization. In addition, a liquefaction index is evaluated to recognize liquefaction severity, and to choose the most appropriate engineering measures for liquefaction mitigation at a site being considered.

Effect of hysteresis on the stability of an embankment under transient seepage

K Liu, PJ Vardon, P Arnold and MA Hicks

Hysteresis is a well-known phenomenon that exists in the soil water retention behaviour of unsaturated soils. However, there is little research on the effects of hysteresis on slope stability. If included in slope stability analyses, commonly the suction in the unsaturated zone is taken as non-hysteretic. In this paper, the authors investigate the effect of hysteresis on the stability of an embankment under transient seepage. A scenario of water level fluctuation has been assessed, in which a cyclic external water level fluctuates between a low and high level. It was found that the factor of safety (FOS), the volumetric water content and the suction in the unsaturated zone are significantly affected by hysteresis. It was also found that, when the period of water level fluctuation in one cycle is relatively small, there is little difference in the FOS between the hysteretic case and non-hysteretic case. However, when the period exceeds a certain threshold value, significant differences between these two cases can be observed. Compared to the case in which hysteresis is considered, the FOS is higher in the case which does not consider hysteresis. This suggests that the non-hysteretic case may overestimate slope stability, leading to a potentially dangerous situation. Moreover, the period under which there emerge large differences between the hysteretic and non-hysteretic case is strongly related to the magnitude of hydraulic conductivity and the period of the cyclic water level fluctuation.

A surface and subsurface model for the simulation of rainfall infiltration in slopes

H Zhang, F Zhang, K Shen and M Yuan

Rainfall infiltration is one of the major triggering factors leading to slope failures in geotechnical engineering. Numerical investigation on rainfall infiltration is often based on Richards' equation, which ignores the surface water effects and simplifies the boundary conditions. In reality, rainfall, infiltration, and surface runoff are interacted simultaneously. In this paper a new conjunctive one-dimensional surface flow and two-dimensional subsurface flow model for geotechnical slope is developed. The interaction between surface and subsurface flow is the interface infiltration rate, which is obtained by iterations. The results of comparisons between coupled and uncoupled models show that the surface water depth rises up as runoff increases and it tends to a dynamic balance state with a steady surface water depth. Interaction between surface and subsurface flow has remarkable effects on infiltration process. According to the results of coupled model, more rainwaters infiltrate into the slope. Therefore, pore water pressure changes faster and the wetting front moves deeper into the soil. Under initial drier condition, the capacity of infiltration is higher and more rainfall can be absorbed into slope, thus the differences of infiltration rate and pore water pressure between the coupled and uncoupled model are more significant.

Stabilization Columns for Embankment Support – Investigation, Verification and Further Development of Analytical Analyses

H Pankrath, H Kaya and R Thiele

As a technical and economical alternative to foundations on piles, but also to shallow foundations on improved soil, in recent decades a high number of soil improvement methods have been developed and established. Many of these methods use non-reinforced, cylindrical load bearing elements. A very common application of stabilizing columns is the improvement of a few meters thick soft soils below dams and embankments. But especially for this application, many failure cases are documented worldwide. In the contribution the substantial content and results are presented for investigation, testing and further development of methods for evaluating the slope

stability. After a description of the problem and consequential tasks the contribution contains main results of the investigations of international sources with the stepwise development of analytical solutions. Next to the in practice wellknown approaches for gravel columns, less common approaches from Scandinavia are explained. The contribution is completed with a presentation and discussion of an illustrative example, taking into account a number of different failure modes of the columns and the surrounding soil. The example was compared and validated with a 3D Model using the Finite Element Method.

Soil Moisture and Strength Index for Earthwork Construction Quality Control
A Sawangsuriya, S Wachiraporn and W Sramoon

This paper presents the implementation of soil moisture and strength index measurements for earthwork construction quality control as well as a link between the in situ testing and structural property of earthen materials. Use of the convenient Dynamic Cone Penetrometer (DCP) in conjunction with conventional moisture-density measurements enhances quality control by achieving acceptable level of compaction, more uniform structural properties, and aids developing a controlled design parameter during the earthwork construction. Soil strength in term of DCP index normalized by the deviation of compaction moisture content from the optimum moisture content is proposed as performance criteria for a variety of engineered earth fills and special engineering assessment, prevention, and mitigation of geohazards e.g. earthen flood defense embankments.

Experiences from the small historical dams failures during heavy floods
I Vaníček, M Vaníček, D Jirásko and T Pecival

Roughly between 400 and 600 years ago many small earth dams were constructed mainly in the south part of the Czech Republic. They were used for fish production and flood protection. To our days roughly one third survived, which means about 25 000 of them. During catastrophic floods in 2002 many of them had some problems but less than 0.3% failed. Experiences gained from the failure evaluation are presented. Firstly from the view of limit states of failures, when limit states of internal erosion and surface erosion played most important role and were the main reason of failures. Secondly, from the view of so called domino effect of failure, when the most important dam on the catchment basin failed and after that the other ones, situated below, had limited chance to survive. The failures are described for catchment basin of the small river Lomnice in south part of the Czech Republic close to the town Blatna. The experiences obtained there led to the evaluation of other catchment basins where domino effect of failure can play also very important role. For the evaluation of potential risk, the numerical modelling was used to study the flood wave propagation below the critical dam, especially at the moment when this wave is reaching the dam situated below the critical one. Finally, the recommendations are specified, not only for individual dams but also for catchment basin, where the risk of domino effect failure is very high.

Analytical solutions to assess the stability of rock slopes subject to cracks via limit analysis
W Wu

Based on the kinematic approach of limit analysis, a full set of upper bound solutions for the stability of homogeneous rock slopes subjected to tension cracks are obtained. The generalized Hoek-Brown failure criterion is employed to describe the non-linear strength envelope of rocks. In this paper, critical failure mechanisms are determined for cracks of known depth but unspecified location, cracks of known location but unknown depth, and cracks of unspecified location and depth. It is shown that there is a nearly up to 50% drop in terms of the stability factors for the rock

slopes intersected by a tension crack compared with intact ones. Tables and charts of solutions in dimensionless forms are presented for ease of use by practitioners.

The costs of housing developments on sites with elevated landslide risk in the UK
K Barclay and A Heath

New housing targets are being set for local planning authorities resulting in more areas being zoned for development. There is currently no requirement for a landslide assessment prior to this zoning, and sites at elevated risk of landslides are being put forward for development without consideration of the additional costs and other impacts of building on these higher risk sites. This study aimed to reveal the increased financial, economic, social and environmental costs associated with these decisions. Case studies were focused on the city of Bath, an area of increasing population and "one of the most intensely landslipped areas in Britain". The case studies found the financial costs associated with building in a landslide risk area to be significantly higher than the equivalent construction in areas of greater geological stability. Furthermore, it was found that uncertainty in cost when developing in unstable areas exacerbates this problem as the final cost cannot be accurately predicted before construction.

Preliminary experimental study on three-dimensional mechanical behaviors of bonded granules
Prof. Mingjing Jiang - Tongji University (China)

In order to explore the microscopic contact behaviour of structured sands, devices were developed for specimen preparation and for carrying out tests on mechanical contact behaviour of three-dimensional (3D) bonded spheres. The specimen preparation device can cement two separate aluminium hemispheres by epoxy adhesive with accurate size control. The auxiliary loading devices can carry out compression, tension, shear, bending and torsion tests and any of their combinations. The experimental results show that the peak shear force, bending moment and torque of the bonded hemispheres are normal force dependent; that is, they first increase with the normal force and then decrease after the normal force exceeds a critical value.

Understanding the effects of inter-particle contact friction on the elastic moduli of granular materials
Prof. Stefan Luding - University of Twente (Netherlands)

Understanding the pre-failure, elastic behavior of dense granular systems is of interest in many fields, such as soil mechanics, material science and physics. The main difficulty is the discreteness and disorder in granular materials at the microscopic scale, which requires a multi-scale approach. The Discrete Element Method (DEM) allows to inspect the influence of microscopic contact properties of its individual constituents on the bulk behavior of granular assemblies. In this study, isotropic deformations are applied to polydisperse packings of both frictionless and frictional spheres; after preparation by isotropic compression of samples with different contact friction, at various volume fractions, the effective bulk modulus is determined from the incremental stress response to the application of strain-probes. As we are interested first in the reversible, elastic response, the amplitude of the applied perturbations has to be small enough to avoid much opening and closing of contacts, which would lead to irreversible rearrangements in the sample. Counterintuitively, with increasing inter-particle contact friction, the bulk modulus decreases for samples with the same volume fraction. We explain this by differences in the microstructure (isotropic fabric) that characterize the samples state after preparation.

Can we reduce debris flow to an equivalent one-phase flow?
B Chareyre, D Marzougui and J Chauchat
A recent extension of the discrete element method is reported for the simulation of dense mixtures of non-colloidal particles and viscous fluids in the non-inertial regime. As an application, we examine the interplay between rate dependent dilatancy and hydro-mechanical coupling which can be expected in debris flow. The numerical model includes sphere-sphere contacts using a soft contact approach [2], short range hydrodynamic interactions defined by frame-invariant expressions of forces and torques in the lubrication approximation, and drag forces resulting from the poromechanical coupling computed with the DEM-PFV technique [3]. The bulk shear stress is decomposed into contact stress and hydrodynamic stress. Both contributions are shown to be increasing functions of a dimensionless shear rate Iv, in agreement with experimental results [4]. Statistics of microstructural variables highlight a complex interplay between solid contacts and hydrodynamic interactions. In contrast with a popular idea, the results suggest that lubrication may not necessarily reduce the contribution of contact forces to the bulk shear stress. The proposed model is general and applies directly to sheared satured granular media in which pore pressure feedback plays a key role. We argue that it can be the case for debris fow, especially during the triggering phase, when run-out include transitional phases, and when the flow is stopped. It is then concluded that debris cannot be computed by assuming solely the rheological properties of an equivalent mixture.

Assessment of maximum impact forces of dry granular masses on rigid barriers
F Calvetti, C di Prisco and E Vairaktaris
This work concerns the impact of dry granular masses on rigid artificial obstacles. The problem has been approached by the authors by performing an extensive campaign of numerical analyses. A commercial code based on the discrete element theory has been used. As is well known, at present, the standard approaches employed to design sheltering structures are exclusively based on the assessment of the Maximum Impact Force (MIF) exerted by the soil mass on the obstacle, since the sheltering structure is usually designed according to simple pseudo-static approaches. In a previous paper the authors considered the dependence of MIF on the Froude number and on a large series of both geometrical and mechanical parameters. In contrast, since they are aware that to optimize the design of this type of structures, even the impulsive nature of the force exerted by the soil onto the structure has to be known, in this paper the evolution with time of the force and, in particular, the nature of the mechanical phenomenon are investigated. During the impact, the granular mass seems to experience an interesting mechanical process of phase transition: with time, part of the soil seems to be fluidized and another one to behave like a solid.

A deep seated movement in a marly-arenaceous formation: analysis of slope deformation and pore pressure influence
SM Assefa, A Graziani and A Lembo-Fazio
The case history of a deep-seated slope movement in a complex rock formation (Marly-Arenaceous Formation) is analyzed. The movement, monitored for more than 20 years, was recognized after the discovery of intense cracking in the concrete lining of a hydraulic tunnel running across the slope. The time history of displacements shows that the ongoing deformation process is essentially a stationary creep phenomenon, also influenced by transient variations in pore pressure distribution.

The slip surface is formed by a tectonized clay gouge layer and the mobilized shear strength is close to residual. The slope has been modelled (UDEC code) as a complex blocky structure defined by several joint sets: bedding joints, inclined and sub-vertical discontinuities. Different geometries of the slip surface, reasonably varied within the range of hypotheses compatible with field evidences, have limited influence on the limit friction angle of the slip surface. Joint patterns have influence on the deformation mode and minor impact on the mobilized friction angle. The model response is less sensitive to the water level at the slope toe as compared to the rise of groundwater table.

DEM analyses of shear behaviour of rock joints by a novel bond contact model
MJ Jiang, J Liu, C Sun and H Chen

The failure of rock joints is one of the potential causes for the local and general rock instability, which may trigger devastating geohazards such as landslide. In this paper, the Distinct Element Method (DEM) featured by a novel bond contact model was utilized to simulate shear behaviour of centre/non-coplanar rock joints. The DEM results show that the complete shear behaviour of jointed rock includes four stages: elastic shearing phase, crack propagation, the failure of rock bridges and the through-going discontinuity. The peak shear strength of centre joint increases as the joint connectivity rate decreases. For intermittent non coplanar rock joints, as the inclination of the rock joints increases, its shear capacity decreases when the inclination angle is negative while increase when positive. Comparison with the experimental results proves the capability of this DEM model in capturing the mechanical properties of the jointed rocks.

The effects of the coordination on the fragmentation of a single grain
Y Salami, C Dano, P-Y Hicher, G Colombo and P Denain

The main objective of this study is to understand the effects of the coordination number on the behaviour of a single grain, before and during fracture. A new apparatus is designed, with the purpose of conducting multipoint crushing tests, and to investigate the effects of the contacts number, type and position on the failure of a particle. Some of the tests were monitored using digital image correlation (DIC), in order to get an in-depth view into the mechanics of fracture. The fragmentation of the grains was studied, and the cracks were shown to follow specific paths. The failure forces of multiple contact configurations were compared to show the effect of the number and position of contact forces on the primary and secondary cracks. It was shown that the position and magnitude of the contact forces plays a significant role in the fragmentation of the grain.

DEM analyses of the whole failure process of shallow foundation in plate load test on dense sand
L Li, M J Jiang, T Li and SL Chen

Shallow foundations are widely used in civil engineering practice, but the instability mechanism is still unclear yet. Previously, the Finite Element Method (FEM) was commonly used to analyze the failure process of shallow foundations, but it meets difficulty in properly simulating the whole failure process of shallow foundation on the strain-softening material. Hence, the Discrete Element Method (DEM) is employed in this paper to study the instability mechanism of the shallow foundation via numerical plate load test with focus on the microscopic features evolution during vertical loading. In the simulation, an amplified gravity was applied to a dense granular ground to reproduce a gravity stress state at a large scale. Then, a plate was put on the granular ground to simulate the plate load test. Deformation pattern, particle velocity and distribution of void ratio in

the ground were examined to illustrate the microscopic features in the whole failure process of the granular ground. The results show that: 1) There are a marked peak value and a settlement softening branch in the stress-settlement relationship. 2) The grids close to the edge of the plate are peculiarly extended and twisted. 3) Four particle motion patterns were observed in the velocity fields and the percentage of each motion pattern changes during loading. 4) The void ratio field varies during loading, and the distinguishing interface tends to be similar to Terzaghi's shear failure surface.

Inter-relationship between joint dilatancy and frictional resistance: impact on fracture behaviour

KII Eshiet and Y Sheng

The subsistence of the various forms of discontinuities (joints) such as instigated and naturally occurring faults, fractures, as well as heterogeneities due to the co-existence of different types and forms of rocks impacts considerably on the response of subsurface systems. The behaviour of the subsurface is therefore a function of the structural and compositional makeup of the underground environment. Amongst these components include rock joints which possess features that alter both the characteristics of rock formations and the fracturing process. Two important properties that govern the shear behaviour and dilatancy behaviour of discontinuities have been considered by applying a numerical procedure by the execution of the discrete element method (DEM) through which these properties were considered individually and in combination. The ability of a frictional joint to suppress fracture growth decreases as the frictional resistance increases; however, the rate and extent of fracturing increases with joint dilatancy. The influence of joint frictional resistance is more dominant at high values and in this range effects of small magnitudes of dilatancy are correspondingly insignificant. Even so, at low joint friction the occurrence of even a small amount of dilation increases the severity of the fracturing process. This study highlights the interactions between two main joint properties with the anticipation that the concepts derived hereof will be beneficial during predictions of fracture behaviour at the subsurface.

A simplified DEM numerical simulation of vibroflotation without backfill

MJ Jiang, WW Liu, J He and Y Sun

Vibroflotation is one of the deep vibratory compaction techniques for ground reinforcement. This method densifies the soil and improves its mechanical properties, thus helps to protect people's lives and property from geological disasters. The macro reinforcement mechanisms of vibroflotation method have been investigated by numerical simulations, laboratory and in-situ experiments. However, little attention has been paid on its micro - mechanism, which is essential to fully understand the principle of the ground reinforcement. Discrete element method (DEM), based on discrete mechanics, is more powerful to solve large deformation and failure problems. This paper investigated the macro-micro mechanism of vibroflotation without backfill under two conditions, i.e., whether or not the ground water was considered, by incorporating inter-particle rolling resistance model in the DEM simulations. Conclusions obtained are as follows: The DEM simulations incorporating rolling resistance well replicate the mechanical response of the soil assemblages and are in line with practical observations. The void ratio of the granular soil fluctuates up and down in the process of vibroflotation, and finally reduces to a lower value. It is more efficient to densify the ground without water compared to the ground with water.

Modelling of a rapidly evolving rockslide: the Mt. de la Saxe case study
R Castellanza, GB Crosta, P Frattini, C di Prisco, G Dattola, D Bertolo

To model the temporal evolution of complex landslides, a 1D pseudo-dynamic visco-plastic approach, based on Perzyna's theory, has been conceived. In the original version of the model the viscous nucleus has been assumed to be bi-linear: irreversible deformations develop uniquely for positive yield function values whereas, in a more general case, even for negative values. In this work the model has been enriched by considering: i) an exponential viscous nucleus, ii) a strain-rate softening to reduce friction angle as sliding velocity increases and iii) block interaction forces to cope with complex 3D geometries for the sliding mass. The application of the proposed model to the La Saxe rockslide (Italy) clearly shows how a relatively simple model can be applied to a complex landslide by considering a spatial discretization of the sliding mass.

Maps

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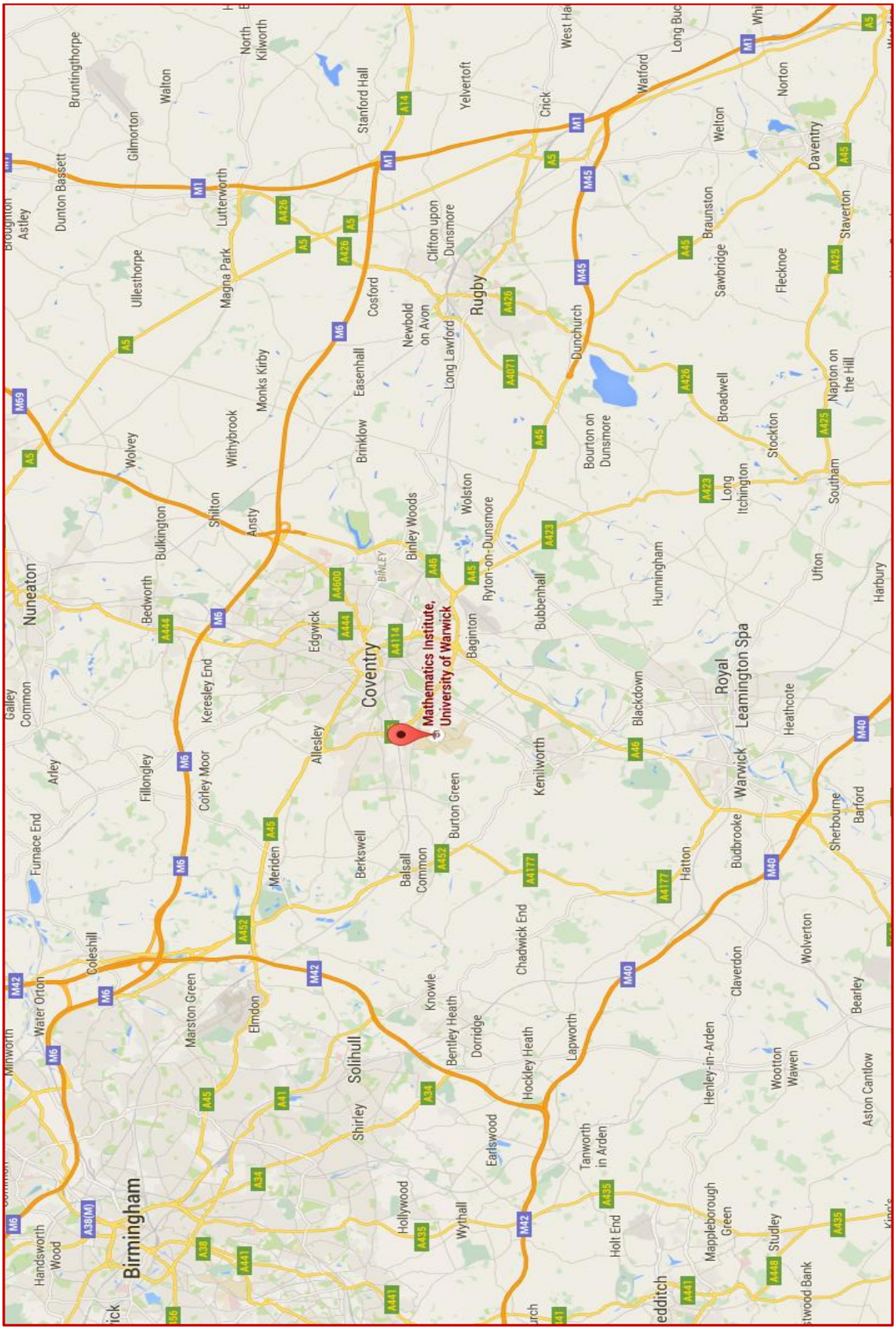

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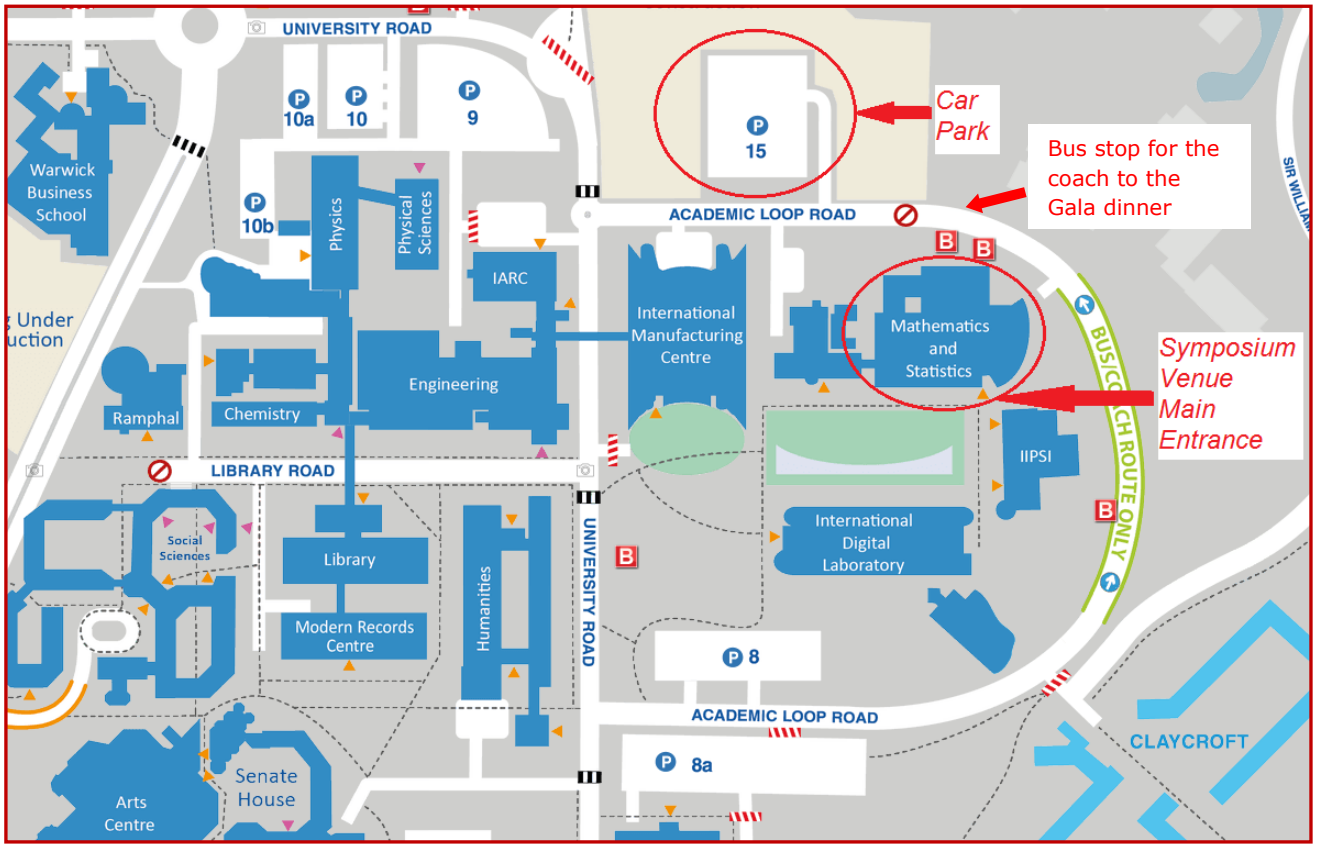

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