SIMSG ISSMGE

ISSMGE Bulletin

Volume 13, Issue 5
October 2019

International Society for Soil Mechanics and Geotechnical Engineering

If the quality of the distributed file is not satisfactory for you, please access the ISSMGE website and download an electronic version.

www.issmge.org

TABLE OF CONTENTS

EDITORIAL BOARD

Research highlights

Institute for Geotechnical Engineering, ETH Zurich

ETH Zurich

Founded by the Swiss Federal Government in 1854, the Swiss Federal Institute of Technology, ETH Zurich, is consistently ranked among the top universities in the world. It currently ranks 6th in the world according to the QS World University Rankings. A total of 21 Nobel Prizes have been awarded to students or professors of ETH Zurich, the most famous being Albert Einstein (1921 Nobel Prize in Physics) and Niels Bohr (1922 Nobel Prize in Physics). With its 16 Departments, ETH Zurich covers a broad academic spectrum. The departments are composed of institutes or laboratories, professorships and department-specific bodies.

Institute for Geotechnical Engineering

The Institute for Geotechnical Engineering is one of the 10 Institutes of the Department of Civil, Environmental and Geomatic Engineering. The Institute is responsible for teaching, research and provision of services across the entire spectrum of soil and rock mechanics through to clay mineralogy, as well as in geotechnical engineering and environmental geotechnics. The Institute for Geotechnical Engineering strives for excellence in geotechnical modelling of the ground, including soil-structure interaction, underground structures, geotechnical natural hazards, transportation-geotechnics, as well as clay mineralogy and geotechnical monitoring. This knowledge flows directly into teaching and services, including specialist laboratory and field testing, expertise and continuing professional education.

Research highlights (Con't)

Institute for Geotechnical Engineering, ETH Zurich

Research Groups
The research activities of the institute are carried out by four research groups, which cover a wide range of areas in geotechnical engineering:

- Chair of Underground Construction (Prof. Anagnostou)
- Chair of Geotechnical Engineering - Geomechanics (Prof. Puzrin)
- Chair of Geotechnical Engineering (Prof. Anastasopoulos)
- Geo-environmental Engineering and Clay Mineralogy Research Group (Dr. Plötze)

Research Areas
Research areas include important topics of foundation engineering, tunnelling, soil and rock mechanics, and environmental engineering. Current projects focus primarily on:

- Geotechnical design (typically including soil-structure interaction, tunnelling, foundation engineering, geosynthetics-geosystem engineering, transportation geotechnics, flood-protection works, earthquake engineering);
- Stability analysis (natural and engineered soil slopes and rock walls);
- Sustainability of geo-structures (for example, in environmental geotechnics);
- Development and application of novel sensor technologies in geotechnical monitoring;
- Complex coupled processes often underlying natural and potential anthropogenic hazards (such as radioactive-waste disposal, including important aspects of clay mineralogy and problems relating to unsaturated soil mechanics).

Prof. Georgios Anagnostou
Chair of Underground Construction
MSc in Civil Engineering, University of Karlsruhe
PhD in Rock Mechanics, ETH Zurich

Prof. Anagnostou's research deals mainly with tunnelling through squeezing or swelling rock, stability and deformation issues of mechanized tunnelling in rock or soft ground and geotechnical auxiliary measures such as advance drainage, artificial ground freezing, face reinforcement and forepoling. A recent research topic concerns rock mechanical aspects of underground compressed air energy storage. Prof. Anagnostou has been involved as a tunnelling expert or consultant in major infrastructure projects such as the Gotthard and the Ceneri base tunnels (Switzerland), the Bosporus subsea motorway tunnel (Turkey), the Gibraltar strait tunnel (Morocco – Spain), the Athens Metro (Greece) and the Lake Mead Intake Tunnel No 3 (USA).

Current research topics

1 Tunnelling in squeezing ground

Squeezing is the phenomenon of large, often time-dependent, deformations that develop when tunnelling through weak rocks, particularly under a great depth of cover. The large Swiss alpine tunnelling projects have triggered considerable research over the last decade, about the mechanical behaviour of squeezing rocks; the effect of geometric nonlinearities associated with very large deformations; the conceptual design and the dimensioning of segmental linings in shield tunnelling through squeezing ground; the pressure developing upon tunnel boring machines and the problem of shield jamming (Fig. 1b); the interplay between squeezing ground and yielding supports; and the reasons of the observed variability of squeezing intensity during tunnelling. The experimental techniques and computational methods that have been developed at ETH Zurich have been applied in a series of projects such as the Ceneri Base Tunnel, the Semmering Base Tunnel in Austria, the Strait of Gibraltar Tunnel, the Uluabat Tunnel in Turkey and the Lake Mead project in the United States.

Research highlights (Con't)

Institute for Geotechnical Engineering, ETH Zurich

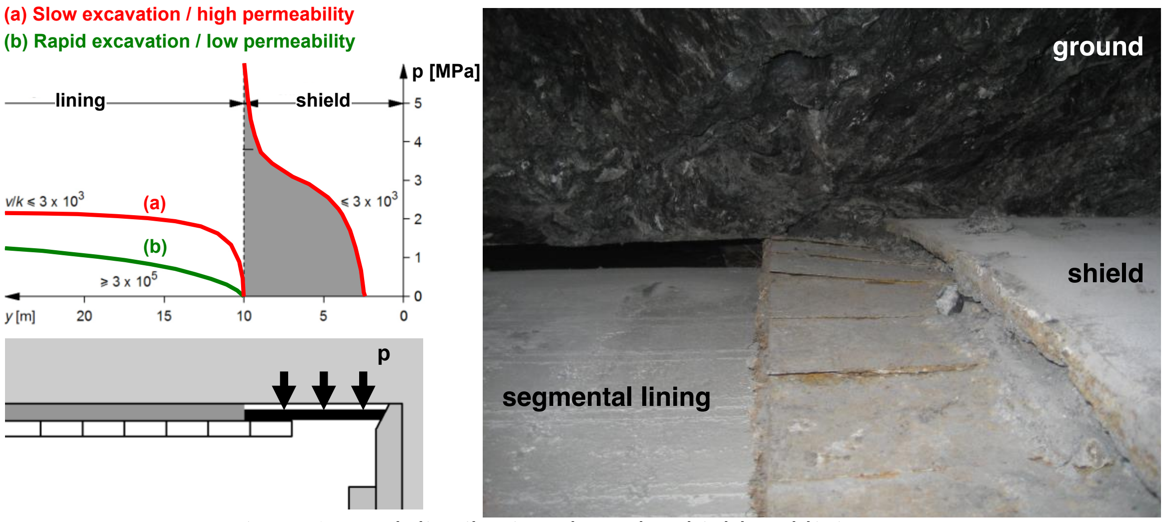


Figure 1. Load distribution along the shield and lining

Current research aims to analyse the face stability of deep tunnels through heavily squeezing ground, considering the softening and the geometric nonlinearity associated with the large, excavation-induced extrusion of the ground at the face. Another question under investigation concerns the shield and lining loading developing during TBM advance in a ground that experiences creep and consolidation (Fig. 1).

2 Tunnelling in swelling rock containing anhydrite

Swelling rocks increase in volume when interacting with water. In tunnelling, the swelling causes a heave of the tunnel floor, which may impair the serviceability of the structure or even damage the tunnel lining. Particularly problematic (in terms of swelling deformations and pressures) are claystones containing anhydrite. They are widely distributed in Switzerland and Southwest Germany and have caused serious damage, lengthy operational disruptions and very costly repairs in a number of tunnels (Fig. 2a).

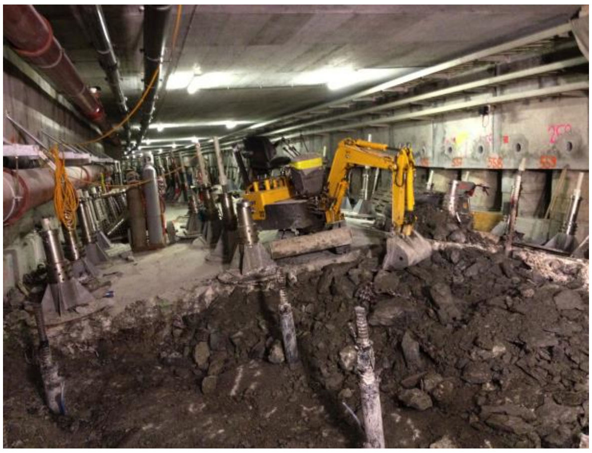
The swelling of anhydritic claystones is mainly caused by the chemical transformation of anhydrite into gypsum. Past theoretical and experimental research in Prof. Anagnostou's group focused mainly on the fundamental mechanisms underlying the macroscopically observed swelling behaviour of anhydritic claystones and improved understanding about: the thermodynamics and kinetics of the involved chemical reactions (anhydrite dissolution and gypsum precipitation); the effect of diffusion; the reasons for the occurrence of anhydrite rather than gypsum at shallow depths; the relationship between the crystallisation pressure of gypsum and the macroscopically developing swelling pressure; the effect of sealing of the anhydrite by the formed gypsum on the time development of swelling; and the effect of confining pressure on the swelling strains.

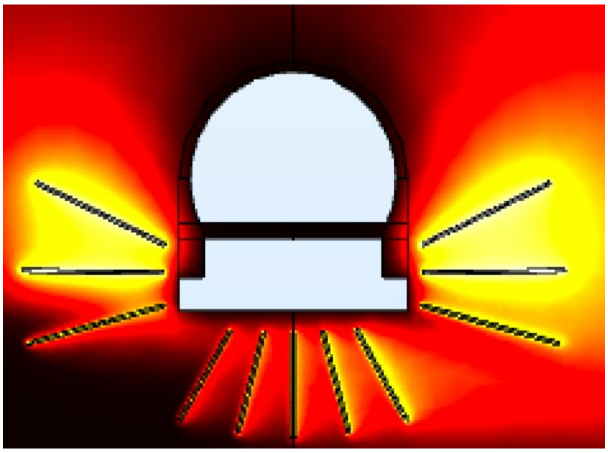
On-going research deals with the swelling in the scale of underground openings. Specifically, a multi-coupled computational model is developed (taking account of chemically induced strains and stresses, seepage flow and ionic transport) with the aim to analyse the processes around tunnels in anhydritic claystones and to predict the swelling-induced deformations and rock pressures.

A further research subject is the technological and economic feasibility of a novel tunnel rehabilitation method, which makes use of a known thermodynamic property of the anhydrite-gypsum-water system. Specifically, considering that anhydrite is stable at temperatures above 40 - 50 °C, it is investigated for a particularly problematic Swiss tunnel how and with which energy consumption one could control the swelling deformations via heating of the rock (Fig. 2).

Research highlights (Con't)

Institute for Geotechnical Engineering, ETH Zurich





(a) (b)

Figure 2 (a) Extreme floor heave in a Swiss tunnel; and (b) temperature field around a tunnel with thermal control of swelling

3 Geotechnical auxiliary measures

Auxiliary geotechnical measures such as grouting, artificial ground freezing, advance drainage, face reinforcement and forepoling are mostly undertaken from the tunnel face, alternating with the actual excavation and support works, thus rendering tunnelling very slow and expensive. Therefore, they need a careful design (considering geotechnical, constructional and technological aspects) and this triggered considerable research activities at the ETH, particularly about the effectiveness and feasibility of advance drainages, the stability of reinforced tunnel faces and the design of artificial ground freezing under seepage flow conditions. Current research deals with the structural design of forepoling and with artificial ground freezing of alternating aquifers and aquitards with locally high seepage flow velocities.

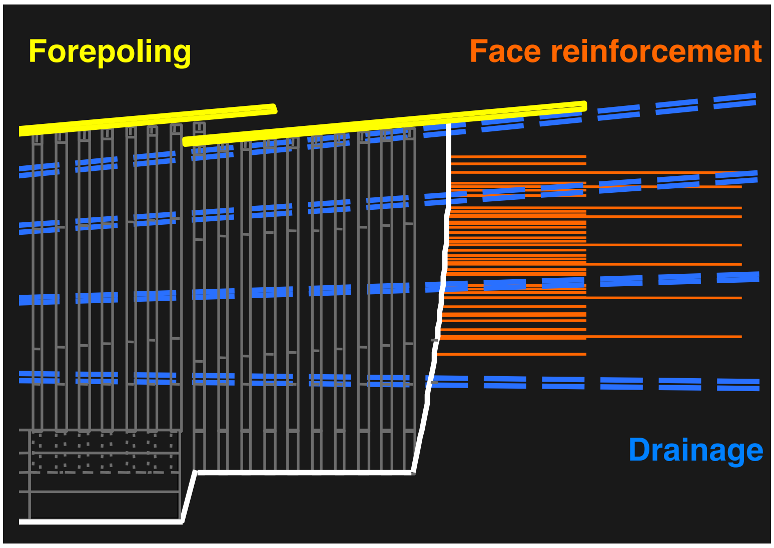


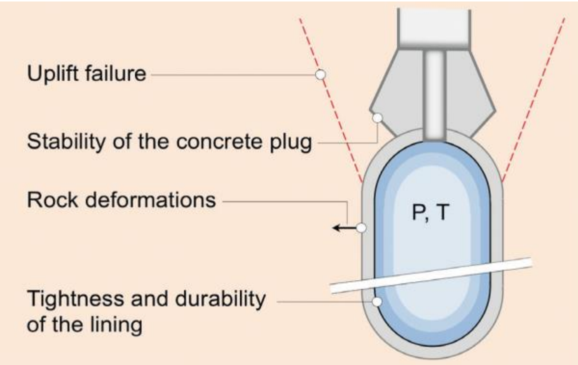
Figure 3. Common auxiliary measures in tunnelling through weak ground

Research highlights (Con't)

Institute for Geotechnical Engineering, ETH Zurich

4 Compressed air energy storage (CAES)

Underground CAES makes use of the high resistance of the surrounding rock mass to the internal gas pressure. Key design issues are: uplift failure of the overlying rock up to the surface; deterioration and loss of tightness of the lining due to the cyclic pressure and temperature loading during operation; shearing of the plug closing the cavern (Fig. 4). Current research deals with the sealing system and with the optimization of the cavern layout.



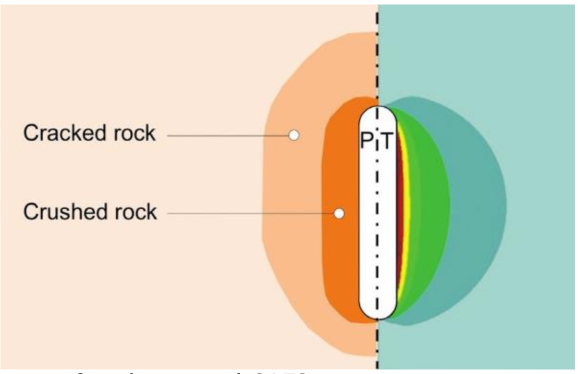


Figure 4. Key rock mechanical aspects of underground CAES

Prof. Alexander M. Puzrin
Chair of Geotechnical Engineering Geomechanics
BSc and MSc in Civil Engineering, Moscow Institute of Civil Engineering
PhD in Geotechnical Engineering, Technion – Israel Institute of Technology

Prof. Puzrin's main research interests are geohazards, constitutive modeling of geomaterials, progressive and catastrophic failure in soils with applications to slope stability and retaining structures. Other interests include novel sensor technologies for geotechnical monitoring, forensic geotechnical engineering and mitigation of geotechnical eco-hazards. He has been involved as an expert and consultant in large-scale onshore and offshore geotechnical projects in the UK, the US, Switzerland, Mexico, Azerbaijan, Russia, and Israel. He is a co-founder of the ETH Zurich spin-off company Marmota Engineering AG providing high-tech fiber-optics monitoring services to industry.

Current research topics

1. Submarine landslide evolution

The goal of this research effort is to quantify submarine landslide hazards by creating a powerful computational platform for mechanically consistent explanation of dynamic landslide evolution and predicting likelihood of future landslide events and their consequences. The seafloor of continental slopes, lakes and river deltas bears hidden scars of enormous submarine landslides. Their consequences include tsunami waves, underwater debris flows and offshore failures retrogressing onshore, causing loss of life and property. What caused them and can they happen again, and where?

Research highlights (Con't)

Institute for Geotechnical Engineering, ETH Zurich

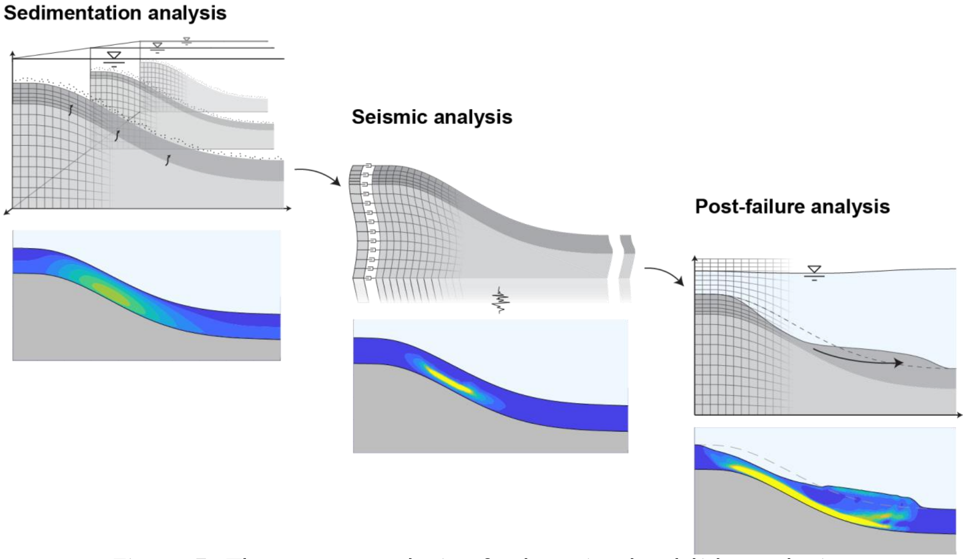


Figure 5. Three-step analysis of submarine landslide evolution

Currently, the following research topics are supported by the Swiss National Science Foundation:

- Constitutive modelling and laboratory testing of clays under cyclic loading
- Pre-conditioning and seismic triggering of submarine landslides
- Investigation of post-failure behavior of submarine Landslides
- Application of the shear band propagation to the GIS based 3D slope stability analysis

2. Risk assessment and construction on permanent landslides

Permanent landslides are quite common in mountainous regions and are characterised by their slow, continuous creeping movement. Communities are expanding into such regions, overbuilding large areas of permanent landslides, with many buildings getting damaged over their life span. A special class of problems concerns artificial water reservoirs, where acceleration of continuous creeping movement of the reservoir flanks endangers both the reservoir operation and the downstream communities. The goal of this research effort is to develop methodology for the short and long-term risk assessment and management associated with creeping landslides, with particular emphasis on their interaction with infrastructure and on their response to earthquakes and extreme weather events affected by global climate changes.

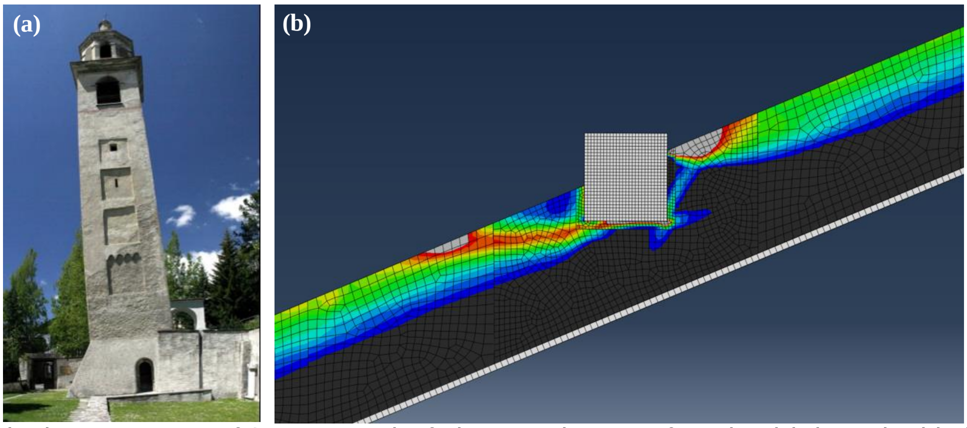


Figure 6. (a) The leaning tower of St. Moritz; (b) failure mechanisms for a landslide-embedded structure

Research highlights (Con't)

Institute for Geotechnical Engineering, ETH Zurich

Currently, the following research topics have been supported by the Swiss National Science Foundation, Swiss Federal Office of Energy and Swiss Federal Office of Environment:

- Creeping-constrained landslides under extreme conditions
- Principles of construction on permanent landslides
- Seismic behaviour of creeping landslides at the flanks of water reservoirs

3. Novel sensor technologies for geotechnical monitoring and research

The use of fibre optics (FO) as sensing system for geotechnical and structural health monitoring is rapidly growing, thanks to their many qualities: optical fibre sensors are immune to electromagnetic fields, chemically and biologically inert, small and lightweight; they can withstand high temperatures; the signal can be transported for kilometres. FO sensors used for strain monitoring in civil engineering face two important challenges: on one hand, they need a good mechanical contact between the fibre sensor and the structure (or soil) to follow the movements, while on the other hand they must be protected from mechanical damage. The goal of this research effort is to explore novel applications of the FO sensing for geotechnical and structural research and monitoring.

Currently, the following research topics have been supported by the Swiss Federal Office of Transportation, National Cooperative for the Disposal of Radioactive Waste (NAGRA) and Innosuisse – Swiss Innovation Agency (in collaboration with HSR, Gehlma AG and Marmota AG):

- Non-destructive analysis of pavements by means of distributed FO technology
- Distributed FO sensing for nuclear waste disposal
- Assessment and optimization of self-drilling pile foundations using distributed FO sensors
- Surface-object identification using ground-buried FO sensors
- Failure behaviour of cantilever retaining walls – soil-structure interaction and monitoring

(a) **(b)**

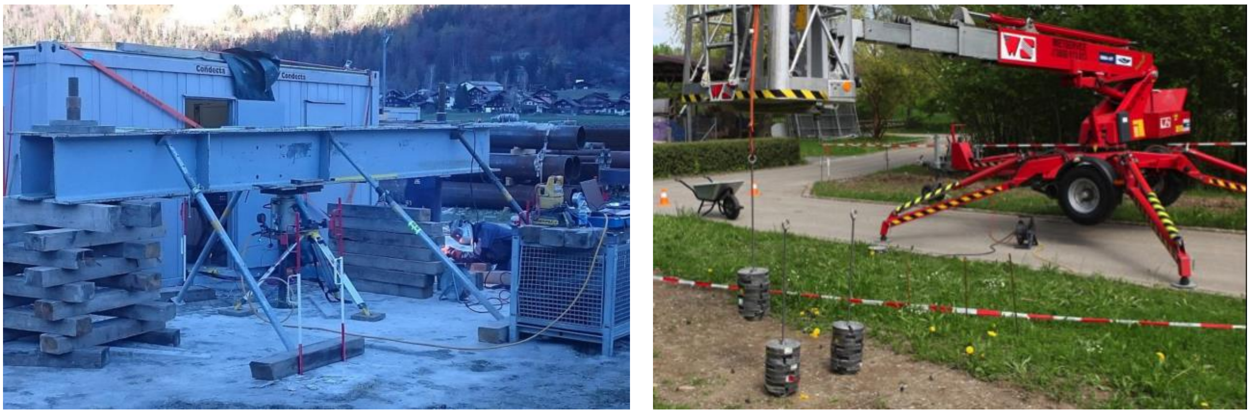


Figure 7. Application of novel sensor technologies: (a) pile test; (b) object identification test

4. Risk assessment and mitigation of geotechnical eco-hazards

Geotechnical failures and environmental pollution are often interrelated, creating a special type of hazards: Geo-Eco-Hazards. In the past 10 years, the unique combination of expertise shared by Dr. Michael Ploetze's Clay Lab and Prof. Puzrin's Chair allowed for successful investigation of challenging geo-eco-hazard problems in the USA, Mexico, Italy and Israel, and for prevention of potential geotechnical failures leading to ecological catastrophes in Azerbaijan and Switzerland. This work has demonstrated that there is a clear need in a pro-active multidisciplinary approach for geo-eco-hazard assessment and mitigation.

Research highlights (Con't)

Institute for Geotechnical Engineering, ETH Zurich

(a) (b)

Figure 8. (a) landslide breaks an oil pipeline in Mexico; (b) Phosphogypsum stack collapse in Israel.

Currently, the following problems are investigated in collaboration with Dr Michael Ploetze's Clay Lab:

- Geotechnical aspects of the phosphogypsum stack stability
- Stability of tailing dams (collaboration with the University of Sao Paulo, Brazil)
- Mitigation of offshore pollution (collaboration with the Politecnico di Bari, Italy)

Prof. Ioannis Anastasopoulos
Chair of Geotechnical Engineering
Diploma in Civil Engineering, National Technical University of Athens
MSc in Civil Engineering, Purdue University, West Lafayette, IN
PhD in Civil Engineering, National Technical University of Athens

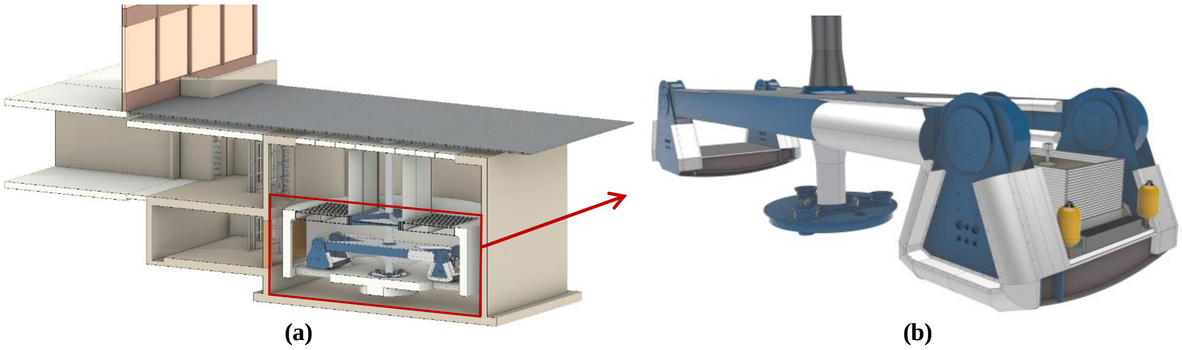
Prof. Anastasopoulos specializes in geotechnical earthquake engineering and soil-structure interaction, combining numerical with experimental methods. His research interests include the development of innovative seismic hazard mitigation techniques, faulting and its effects on infrastructure, site effects and slope stabilization, railway systems and vehicle-track interaction, offshore geotechnics, and earthquake crisis management systems. He has been involved as a consultant in a variety of projects of significance in Europe, but also in the US and the Middle East. His consulting work ranges from special seismic design of bridges, buildings, retaining walls, metro stations and tunnels, to harbor quay walls, and special design against faulting-induced deformation applying the methods he has developed. He is the inaugural recipient of the Young Researcher Award of the ISSMGE in Geotechnical Earthquake Engineering, and winner of the 2012 Shamsher Prakash Research Award.

Centre of Excellence in Centrifuge Modelling

Experiments are indispensable to gain insights, validate numerical models, and evaluate mitigation techniques. Expected to be operational in 2020, the Centre of Excellence in Centrifuge Modelling (Fig. 9a), the new facility includes a 9 m diameter beam centrifuge of 500gton capacity (Fig. 9b): 2ton payload at 250g. Centrifuge modelling can overcome the problem of scale-effects by scaling up gravity to recreate the same stress levels as in reality. The new centre offers a unique combination of capabilities, including: (a) *seismic shaking*, using an (Actidyn) centrifuge-mounted earthquake simulator, capable of shaking models of up to 700 kg at 100 g; (b) *faulting* and its effects on structures, using a custom-built (in-house) split-box; (c) *tsunami loading*, using an innovative (in-house) Centrifuge-mounted Miniaturized Tidal Generator (C-MTG); as well as (d) *monotonic & cyclic loading*.

Research highlights (Con't)

Institute for Geotechnical Engineering, ETH Zurich



(a) (b)

Figure 9. Centre of Excellence in Centrifuge Modelling: (a) new lab facilities; and (b) 500 g-ton beam centrifuge

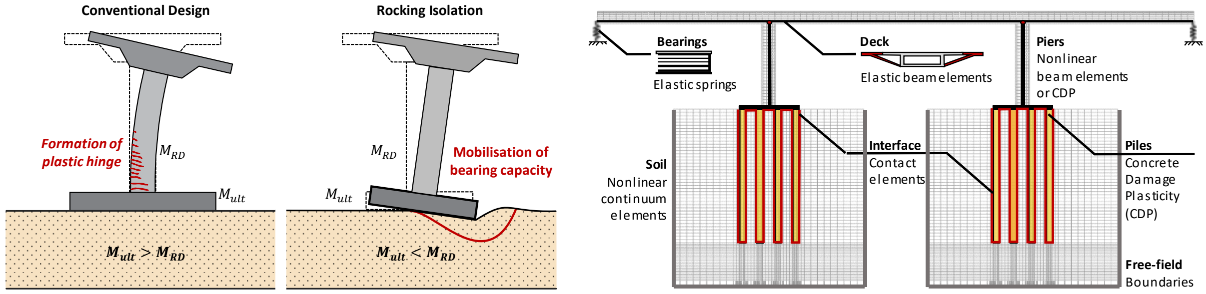
Current research topics

1. Design of New and Retrofit of Existing Structures mobilizing Nonlinear Soil Response

It has been several decades since the realization of the earthquake engineering community that the increase of strength of a structural system does not necessarily enhance safety. This led to the development of new design principles and performance-based design. Less attention has been given to the soil-structure system as a whole. In fact, current design practice attempts to avoid full mobilization of foundation bearing capacity. However, neglecting such phenomena prohibits exploitation of strongly nonlinear energy dissipation mechanisms in defense of the superstructure.

Prof. Anastasopoulos and co-workers have been investigating the mechanisms governing seismic soil-structure interaction (SSI), with emphasis on the rocking response of shallow foundations. A new design philosophy termed "rocking isolation" has emerged, exploiting soil "failure" to protect the superstructure (Fig. 10a). By intentionally under-designing the foundation, this acts as a "fuse" and the plastic hinge is "invited" into the foundation soil. In this way, the soil yields progressively while the structure remains undamaged; the ductility capacity of the entire system is significantly increased. The price to pay is reflected in residual settlements (and rotations) that need to be accounted for in design.

Supported by the Swiss Federal Road Office, current research focuses on the retrofit of existing bridges on pilegroups (Fig. 10b). In Switzerland (and worldwide), the vast majority (over 90%) of existing bridges were built before the 90's, without any or just "basic" seismic design. This renders seismic loading a critical element of retrofit design. Incomplete understanding of dynamic soil-structure interaction (SSI) often leads to over-conservative pilegroup design, prohibiting full mobilization of their capacity. Allowing strongly nonlinear pilegroup response may substantially reduce the required interventions, also offering the potential of *improved seismic performance*. This may allow optimization of retrofit design, taking advantage of the benefits of controlled nonlinear response.



(a) (b)

Figure 10. (a) conventional design vs. rocking isolation; and (b) model of bridge on pilegroups

Research highlights (Con't)

Institute for Geotechnical Engineering, ETH Zurich

2. Faulting and its effects on structures

Recent earthquakes, such as Kocaeli (Turkey 1999), Chi-Chi (Taiwan 1999), Wenchuan (China 2008), Kaikoura (NZ 2016) and Kumamoto (Japan 2016) have shown that faulting-induced deformation can cause substantial damage to infrastructure. Until recently, little field evidence was available on the interaction of foundations and structures with a surface fault rupture. Prof. Anastasopoulos and co-workers have been studying Fault Rupture–Soil-Foundation-Structure Interaction (FR–SFSI) employing an integrated approach, combining field studies, centrifuge model testing and numerical analyses, culminating to the development of a validated methodology for analysis and design of structures against faulting–induced ground deformation. These methods have been applied to a number of projects of significance (25 bridges, 8 tunnels, and several important buildings).

While substantial research has been devoted to new structures subjected to dip-slip faulting, almost no work has been done on *existing structures* subjected to *strike-slip* faulting, which is the focus of current research efforts. The aim is to understand the interaction mechanisms of strike-slip faults with shallow and deep foundations, as well as representative bridges and buildings, and develop simplified design methods. In addition to numerical analysis, centrifuge tests will be conducted as soon as the new centrifuge facility is operational, using a custom-built centrifuge-mounted split-container.

Innovative mitigation techniques are being developed, including sacrificial members and "smart" barriers. Their efficiency has been demonstrated for an idealized shallow foundation (Figs. 11a,b). A "smart" barrier is employed to divert the fault rupture, by introducing a minimum energy path. The "smart" barrier is composed of two sheet-pile walls, connected with rows of sacrificial members. The latter are steel rings, the performance of which is a function of geometry. The proposed system can be produced in the form of prefabricated panels (Fig. 11c). The barrier is compressed, absorbing tectonic deformation with minimum disturbance to the protected structure.

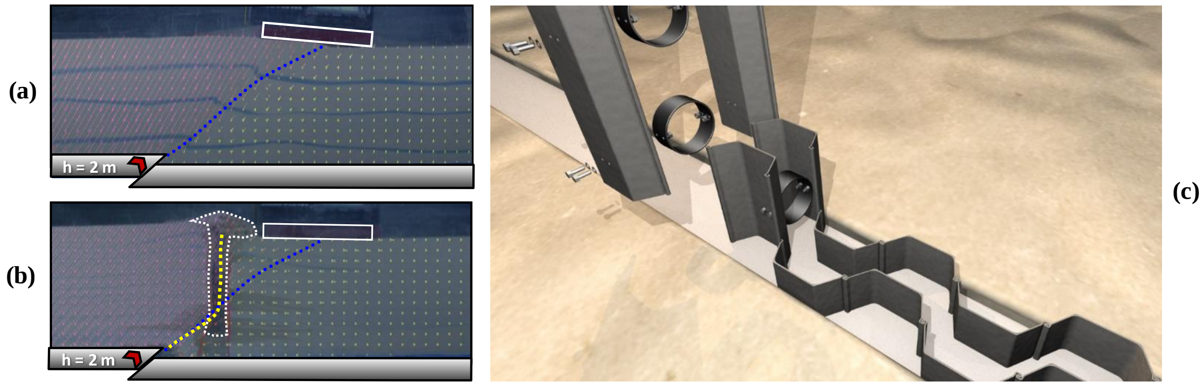


Figure 11. Experimental proof of concept: (a) no mitigation, compared to (b) mitigation with "smart" barrier; and (c) conceived prefabricated panel, assembled from sheet-pile walls and cylindrical sacrificial members.

3. Tsunami-loading of coastal infrastructure

Despite being rare in relative terms, Tsunamis are increasingly impactful to the built environment, due to the rapidly increasing population in coastal areas. Coastal infrastructure needs to remain at least partially operable after impact, allowing access to relief vessels, and decreasing the risk of "cascading effects". The latter can magnify the impact of tsunamis, such as in the 2011 Tohoku earthquake and Tsunami, where failure of flood protection led to one of the most serious nuclear incidents in history. It is therefore crucial to improve understanding of the failure mechanisms of coastal infrastructure.

Research highlights (Con't)

Institute for Geotechnical Engineering, ETH Zurich

After the 2011 Tohoku Earthquake and Tsunami, breakwaters were reported to be badly damaged. Worryingly, many of those were designed to be "Tsunami Resistant". A standout such example is the Kamaichi breakwater (Fig. 12a), which was the biggest in the world (50 m height). Such failures reveal that the critical failure mechanisms are fundamentally different to those considered in design. Their failure is complex, being a combination of hydraulic and geotechnical failures, where one initial small failure can trigger the other: hydraulic scour at the base may trigger bearing or slope failure. The response of such systems is a function of effective stress changes (pore pressure build-up), and more crucially, geometry changes due to scour and erosion processes.

A Centrifuge-mounted Miniaturized Tidal Generator (C–MTG) is being developed, by adapting a recently completed 1g MTG concept (Fig. 12b). The system uses re-circulation pumps, allowing constant flow over the model space, vastly reducing the required volume of water stored in the main tank. Recirculation is facilitated by "pump" tanks, which can pump large volumes of water at low velocity, with minimal mechanical complexity. The pump-tanks function using air pressure and a system of check valves. Operating like a pair of bellows, in conjunction with the main tank they can produce Tsunami waves of any duration. As soon as the new beam centrifuge is operational, the C–MTG will be used to study critical failure mechanisms of coastal geotechnical structures, derive insights on the interplay between hydraulic and geotechnical failure mechanisms, and develop robust design procedures. After understanding the fundamental mechanisms, mitigation techniques will be tested.

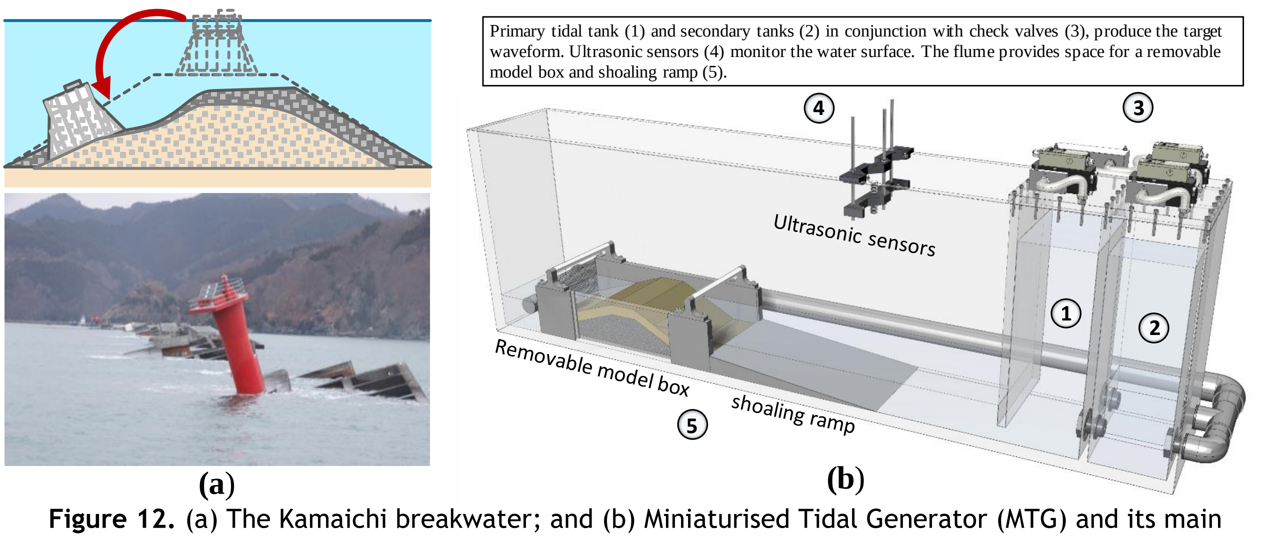
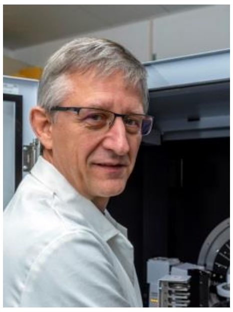


Figure 12. (a) The Kamaichi breakwater; and (b) Miniaturised Tidal Generator (MTG) and its main components.

Research highlights (Con't)

Institute for Geotechnical Engineering, ETH Zurich



Dr. L. Michael Plötze
Group Leader of Geo-environmental Engineering and Clay Mineralogy
MSc and PhD in Mineralogy, TU Bergakademie Freiberg, Germany

Dr. Plötze's primary areas of research are in the characterization of fundamental properties of different kind of materials and minerals, especially clay minerals with respect to various applications in environmental geotechnics and materials science as well as the specific modification of the properties to the related application parameters.

Special topics of interest include:
- Interactions between geotechnical failures and environmental pollution and mitigation (geotechnical eco-hazards)
- Mineral-fluid reactions and transport processes in porous adsorbing media
- Effects of pore water chemistry and of chemical and physical alteration of clay minerals on macroscopic clay/soil properties
- (Clay) mineral – organic matter interaction
- Mineral alteration processes during weathering processes in the "Critical Zone" part. in cold environments
- Developments in quantitative analysis of clay minerals and mineral assemblages

Current research topics

1. (Clay) mineral – organic matter interaction

The research of the group faces such important questions: How, and to what extent, does mineralogy control the amount and composition of organic matter stabilized in soils and preserved in sediments? What are the adsorption mechanisms of organic matter on different (clay) mineral surfaces and what are the mechanisms through which (clay) minerals stabilize organic carbon in soils and sediments? How does organic matter affect contaminant uptake and dissolution from mineral surfaces (stabilization/degradation/fractionation)? How does organic matter and pollution affect the soil mechanical properties of (clay) soils?

In a joint project with Prof. Eglinton's Biogeoscience Group at the Geoscience Department the control of different minerals, in particular phyllosilicates, on the stabilization and preservation of natural organic matter in soils and sediments is assessed. The link between mineralogy and associated organic matter reveals that continentally-derived organic matter of pedogenic origin is stripped from smectite mineral surfaces upon discharge and dispersal to distal ocean settings.

2. Mineral-fluid reactions and effects of chemical and physical alteration of clay minerals

The influence of the pore water chemistry and other chemical and physical alteration on macroscopic clay/soil properties such as swelling, stress-strain behavior, and hydraulic conductivity is a well-known phenomenon. The question is, can we control mineral-fluid reactions e.g. in processes concerned with waste disposal? The research of the group focuses on investigations of coupled thermo-hydro-mechanical and chemical phenomena in clayey barrier systems part. in conditions in radioactive waste repository. In cooperation with Nagra (the Swiss National Cooperative for the Disposal of Radioactive Waste), the influence of physical factors like temperature gradients, pressure, and ionizing radiation on the crystal structure and properties of (clay) minerals but also of chemical factors (interaction with metal, cement, and rock) are investigated with regard to their impact on transport processes in porous adsorbing media to assess the functionality and stability of the engineered and geological barriers. Another field of research related to effects of pore water chemistry on clay/soil properties is the investigation of the influence but also the

Research highlights (Con't)

Institute for Geotechnical Engineering, ETH Zurich

targeted modification of properties like hydraulic conductivity, shear strength and swelling behavior, e.g. by salts, organic matter, and polymers.

3. Weathering processes in the "Critical Zone"

This research is aimed at the investigation of weathering processes especially in cold regions. In connection with retreating glaciers and thawing permafrost, numerous environmental geotechnical questions are of interest, such as rock and slope instabilities and erosion processes, but also the release of substances due to changes in the extreme environmental conditions. The group is focusing in its research on the investigation of hydromechanical and weathering processes in unstable zones in part. on structural properties of rocks and soils (e.g. porosity), on natural hazards risk assessment and mitigation (e.g. clogging of streams, release of free aluminum ions at low pH), and on field analysis of mineral transformation processes and mineral-microbe interactions.

4. Developments in quantitative analysis of clay minerals and mineral assemblages

The group maintains a research laboratory (ClayLab) with state-of-the-art instruments and techniques for determining fundamental parameters (mineralogy, chemistry, physical properties) of a wide range of materials. The main equipment in the laboratory are:

Powder X-ray diffractometer (mineralogy)
Thermogravimetry coupled with mass spectrometer
Elemental analyzer for carbon and sulfur
Particle sizer (laser scattering)
Pycnometer (true and bulk density)
Vane shear test device and rheometer
FT-IR spectrometer (mineralogy)
ICP-OES spectrometer (chemistry)
Photometer (chemistry)
Mercury intrusion porosimetry
Gas and water adsorption measurements
Thermal conductivity meter

The quantitative mineralogical analysis of (clayey) rocks and soils is of crucial importance for geoscience and geotechnical engineering as well as for industry but still a challenge. In order to ensure and improve the quality of the analyses, the participation in international round robin tests is for laboratory routine. The Reynold's Cup Competition from the Clay Minerals Society (CMS) is such a round robin open to anyone interested in quantitative mineral analysis, with particular emphasis on clay mineralogy. The IGT ClayLab has achieved top positions in the Reynolds Cup for 14 years. In 2012 the laboratory excelled with a 1st place. In 2018, as in 2004, it was able to secure 3rd place by winning against 57 laboratories from 25 countries (http://clays.org/Reynolds.html).

5. Risk assessment and mitigation of geotechnical eco-hazards

Geotechnical failures and environmental pollution are often interrelated, creating a special type of hazards: Geo-Eco-Hazards. In the past 10 years, the unique combination of expertise shared by Dr. Plötze's ClayLab and Prof. Puzrin's Chair allowed for successful investigation of challenging geo-eco-hazard problems in the USA, Mexico, Brazil, Italy and Israel, and for prevention of potential geotechnical failures leading to ecological catastrophes in Azerbaijan and Switzerland. This work has demonstrated that there is a clear need in a pro-active multidisciplinary approach for geo-eco-hazard assessment and mitigation by conducting fundamental research towards:

- Understanding effects of pollutants and organic matter on stability of soils and geotechnical structures;
- Development of novel approaches to risk assessment of geo-eco-hazards;
- Development of novel mitigation and (green) remediation techniques.

Included in this research topic is the development of new in situ microsensor technologies to explore applications for geo-environmental research and monitoring, e.g using ground-buried FO sensors to analyze chemical parameters in the pore water and air of contaminated areas. Currently, the following Geo-Eco-Hazard case studies are investigated in collaboration with Prof. Puzrin's Chair

- Geotechnical aspects of the phosphogypsum stack stability
- Stability of tailing dams (collaboration with the University of Sao Paulo, Brazil)
- Mitigation of offshore pollution (collaboration with the Politecnico di Bari, Italy)