Research Highlights

Geotechnical Research group at Pontificia Universidad Católica de Chile (PUC) and the Universidad de Chile

The frequent occurrence of large magnitude earthquakes and the existence of an important mining industry have been driving, to a high degree, much of the progress in the field of soil mechanics and geotechnical engineering in the last decades in Chile. Most of this progress can be associated with two Geotechnical centers that form a part of the civil engineering schools at the Pontificia Universidad Católica de Chile and the Universidad de Chile. A brief description of the capabilities, faculty members, and research topics of these two centers is presented below.

UNIVERSIDAD DE CHILE

Pontificia Universidad Católica de Chile (PUC)

The Pontificia Universidad Católica de Chile was founded on June 21, 1888 by Monsignor Mariano Casanova, Archbishop of Santiago. His goal was to create an institution capable of blending academic excellence and training based on the Christian doctrine. In 1889, the Faculty of Legal Sciences was created, along with the San Juan Evangelista Academy and two professional schools: the San Rafael Commercial and Literary Academy, and the Nuestra Señora del Carmen Industrial School. In 1892 the University offered the first civil engineering courses, which served as a starting point for the discipline in Chile. The first graduates of the Pontificia Universidad Católica completed majors in civil engineering, architecture, and law.

Faculty members

Prof. Carlos Ovalle
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Motivated by the environmental challenges of large-scale rockfill dams and mine waste deposits composed by mixtures of fines, sands and rock aggregates, professor Ovalle has been interested in the mechanical behavior of granular materials and the degradation of their hydro-mechanical properties.

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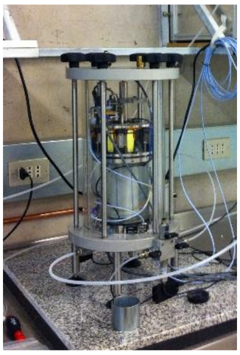
The source of the material behavior can be found at meso- and micro-scales, and is strongly affected by environmental conditions. In other words, it depends on mineralogical, structural, geometrical and mechanical characteristics of individual grains, and on their loading conditions through particle contacts. Therefore, a multi-scale approach is needed in order to develop physical-based predictive methods.



Observations through the scales have allowed professor Ovalle to contribute for a better understanding of the hydro-mechanical degradation of different granular materials, such as natural soft soils, tailings and rockfills experiencing large compressibility, softening and creep deformation, which could be responsible for several pathologies in civil works.

Prof. Esteban Sáez
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Soil characteristics can completely define the perception and effects of seismic movement in different areas of a city. In seismic-active countries such as Chile, these site effects are particularly relevant as they influence the design of every building project nationwide. However, estimating these effects is not a simple problem.

On one hand, it is essentially a blind problem as it is not possible to obtain a full description of the soils characterizing a particular site because their properties naturally vary from one point to another. On the other hand, during seismic events the behavior of soils is inelastic, making the task of mathematical modeling more difficult. Moreover, there may be complex phenomena of interaction between solid particles of the soil and the water that often inundates its pores. Finally, there is no certainty regarding the precise characteristics of the next seismic event, which adds even more uncertainty to the problem.

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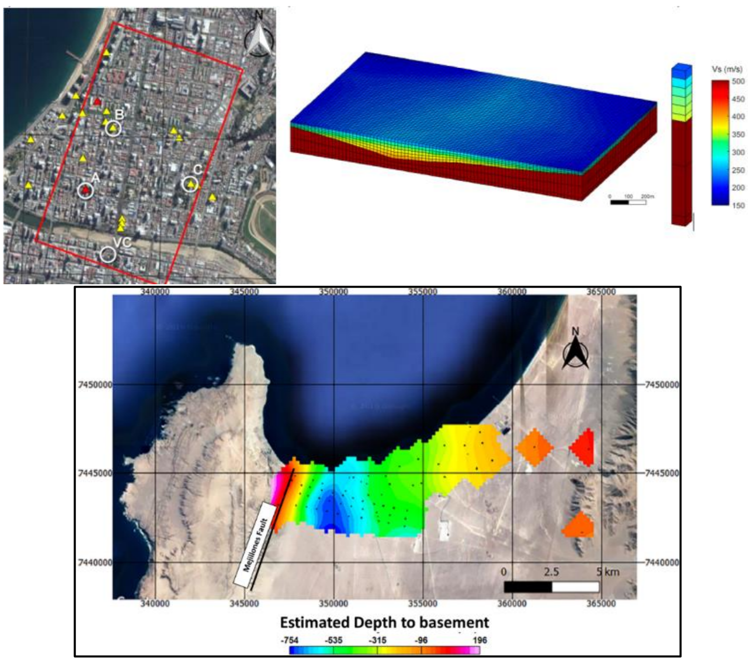
Geotechnical laboratory equipment

- Standard triaxial and direct shear tests
- WF/Controls Cyclic triaxial
- WF/Controls Resonant column
- WF/Controls Torsional shear
- Unsaturated GDS triaxial and oedometric cells
- Axis translation technique
- Relative humidity loop control technique
- Tensiometer
- High pressure GDS triaxial cell (4 MPa) including bender elements
- On triaxial sample small-strain measurement
- 1D transparent laminar shear box

Professor Sáez's research addresses the various aspects of this problem using different experimental and computational strategies. With respect to the in-situ characterization of soils, he uses geophysical techniques based on micro vibrations and surface wave dispersion to make in-depth characterization and identification of the natural properties of soils. This has allowed him to develop several maps for soil amplification and seismic micro-zoning in different parts of the country, particularly in the north of Chile.

Once the natural distribution and basic properties of soils have been characterized, the generation of computer models needs to be calibrated using the stress-strain curves of the materials. To do this, professor Sáez is supported by a complete experimental laboratory for soil dynamics which uses samples collected in the field to reproduce the load they will be subjected to during a seismic event.



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Current research

Once their behavior has been characterized, micro and macro mechanical models are calibrated, allowing for the understanding and reproduction of the fundamental aspects that characterize the seismic response of each soil type and define the effects of seismic wave amplification.

Finally, based on the description of the field and laboratory results, high-performance, large-scale computer models are generated for entire cities or neighborhoods that take into account all of the data and allow quantitative estimates to be made of the effects of seismic amplification for different parts of a city, identifying singularities or defining areas that are potentially more exposed than others to complex seismic site effects.

According to prof. Sáez, although this research will not necessarily conclude with modifications to regulatory plans, it will provide recommendations that may encourage the authorities to review the standards.

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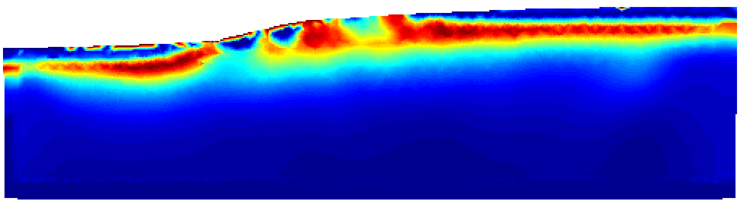
Most people do not feel comfortable acknowledging risk. Professor Ledezma believes that the perception of society on engineering should include this awareness. This is exacerbated in soil mechanics, where risk is not as easily quantifiable as in other areas, such as structural engineering.

Facilities, i.e. structures, are supported by soils, which may have a certain probability of experiencing adverse effects as a result of, for instance, an earthquake. The soil is a given foundation and is not always fully understood or controllable.



Research Highlights

Geotechnical Research group at Pontificia Universidad Católica de Chile (PUC) and the Universidad de Chile (Con't)

Current research

Liquefaction-induced lateral spreading

Prof. Ledezma researches the relationship between soil lateral spreading and deformations in pile-supported structures such as bridges or ports. During an earthquake "large portions of a pile-supported structure, and its corresponding backfill, which are supported on liquefiable soils, may begin to shift, applying very high loads and eventually affecting the structure." The supporting piles and the structure will try to resist, "but it is a phenomenon that we still know little about, which is difficult to quantify."

Ultimately, he wants to identify quantifiable recommendations and provide better design tools. "My interest is to help minimize the impacts; it is not just an issue of human lives, which are certainly very important, nor just an economic cost, but also the country's operating costs, insofar as hospitals, bridges and communication lines are concerned," he explains.

He combines design with uncertainty. The design of bridges, for instance, should consider performance requirements. A bridge that needs to be operational the day after an earthquake requires higher standards than one that can wait for a month.

"Given the characterization of an earthquake, with all of its uncertainty, and given the model, which also has uncertainties, as well as a particular level of prediction of damages and costs, the ideal scenario would integrate all relevant aspects in a given location and provide a certain degree of foresight."

Universidad de Chile

The Geotechnical Engineering Group (GEG) is part of the Department of Civil Engineering of the University of Chile, the largest public university in the country. The group is among the most active research groups in Chile and focuses on solving geotechnical problems related to the development of infrastructure in the country in an environment influenced by natural and anthropic hazards.

The group participates at a postgraduate level in the Master Program on Structural, Seismic, and Geotechnical Engineering, and very soon in the PhD Program on Civil Engineering (starting 2019). Our graduates develop their professional careers in several areas of geotechnical engineering, such as public repartitions, consulting companies, and academia. The group also offers a Diploma on Applied Soil Mechanics, which is oriented to professional engineers who want to improve in the geotechnical field.

The geotechnical engineering group actively collaborates with other units of the Faculty of Physical and Mathematical Sciences at the University of Chile, such as the Advanced Mining Technology Center, the National Seismological Center, the Geophysics, the Geology and the Mining Engineering Departments, as well as governmental and private institutions.

Faculty members

Prof. Felipe Ochoa-Cornejo
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Prof. Felipe Ochoa-Cornejo is a geotechnical engineer and assistant professor at the Department of Civil Engineering. He obtained his M.Sc. from University of Chile, and Ph.D. from Purdue University. His research focuses on liquefaction phenomena, seismic site response, and soil behavior.

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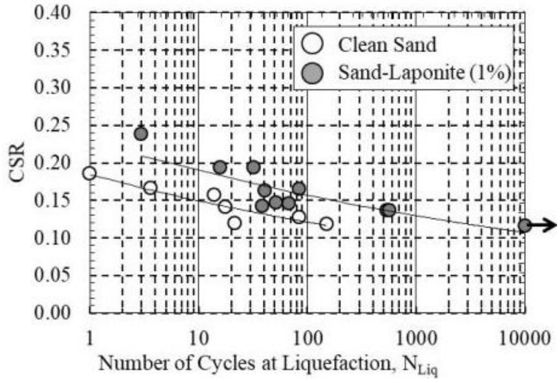
Research topics

1. Liquefaction of sands with nanoparticles

In this research topic we examine the effect of the presence of small percentages of Laponite (1-5% by dry mass of the sand), a synthetic nanoclay with plasticity index exceeding 1000%, on the cyclic response of sand with D_r~ 20%. Experimental testing considers cyclic triaxial tests performed on specimens prepared by pluviating sand and laponite under dry conditions and then permeated with water. It has been observed that 1% of Laponite impacts all stages of the cyclic tests, from the response during the first loading cycle to liquefaction, increasing the cyclic resistance.

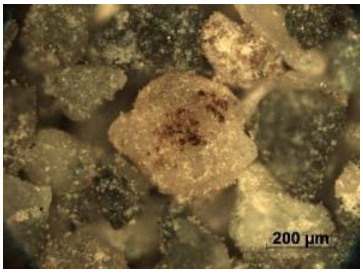


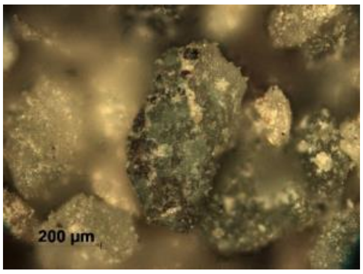
Cyclic stress ratio (CSR) of sand-laponite mixture compared with clean sand (Ochoa-Cornejo et al. 2016)

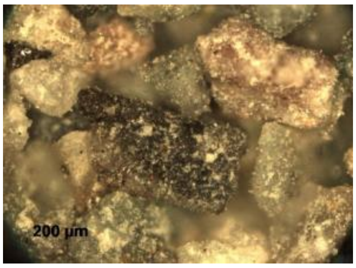
Further benefits are observed with a longer pre-shear aging period for higher dosages (3-5%) of laponite. The observed behavior is associated with reduced mobility of the sand particles during cyclic loading, which can be ascribed to two mechanisms: (1) bonding/bridging at the particle contacts due to the charged laponite fines which are attracted to the sand grains; and (2) formation of a pore fluid with solid-like properties. The first mechanism appears to control the behavior with 1% laponite, while it is proposed that the second mechanism is responsible for the response with higher dosages of laponite.

2. Particle crushing under isotropic and anisotropic conditions of loading under large stresses

Our research in this field focuses on experimental investigations on the effects of the confinement and fine content in the drained and undrained monotonic behavior of the sands of tailings dams. We work with a wide range of pressures that vary between 0.1 MPa to 5 MPa. The content of non-plastic fines varies between 1%, 5%, 10% and 20%. The context that motivates this research is the large production and low grade of mining deposits in Chile, which impacts the construction of tailings dam over 150 m, inducing loads that exceed 1 MPa, inducing potential particle breakage, increasing compressibility, and loss of strength. Our results show that the compressibility increases with increasing the fine content at low confining pressures, since they contribute to the sliding of coarse grains of sand. As the effective confinement increases, the differences in volumetric deformation disappear, tending to the formation of a meta structure. On the other hand, the peak angle of internal friction decreases with the presence of fines at low confining pressures. The increase in confinement causes the loss of peak friction angles, and a polishing of angular particle edges, resulting in a decrease in the internal friction angle. Finally, observations suggest that the sands of tailings in the steady state of deformation do not suffer an explosive breaking of particles up to confinements of 5 MPa, but rather a polishing of the angular edges. It is observed that this polishing is greater, and is accentuated, during shearing stages, rather than in isotropic consolidation.







Reference: Ochoa-Cornejo, F., Bobet, A., Johnston, C. T., Santagata, M., & Sinfield, J. V. (2016). Cyclic behavior and pore pressure generation in sands with laponite, a super-plastic nanoparticles. Soil Dynamic and Earthquake Engineering, 88, 265 – 279.

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Geotechnical Research group at Pontificia Universidad Católica de Chile (PUC) and the Universidad de Chile (Con't)

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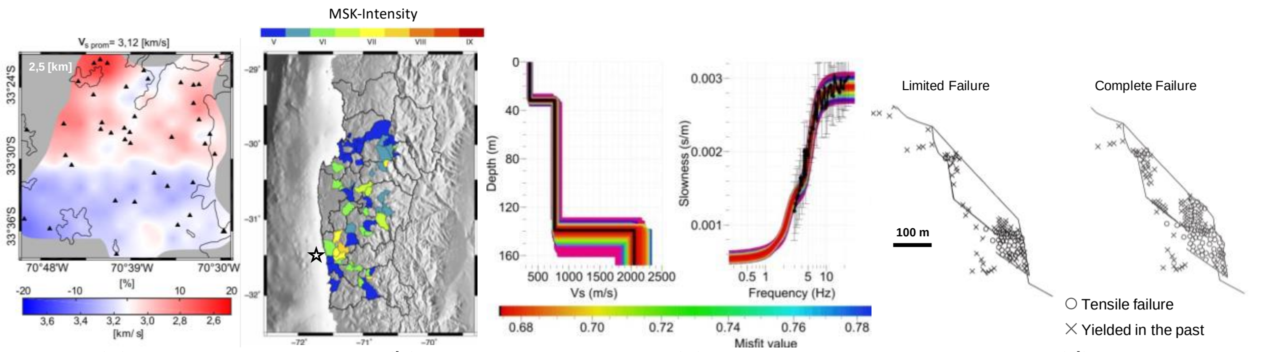
Prof. César Pastén is a geotechnical engineer and assistant professor at the Department of Civil Engineering. He was awarded his Ph.D. from the Georgia Institute of Technology. His research focuses on earthquake engineering, particularly on the seismic site characterization of soil deposits with non-invasive methods and the analysis of basin seismic site response. His research interests also include the long-term effects of mechanical and thermal loading on geotechnical systems, and the physical stability of tailings deposits.

Research Topic:
1. Earthquake Engineering
Chile is one of the most seismically active countries in the World. The GEG develops research on several aspects of the earthquake engineering relevant to the resilience of civil infrastructure in the country.

- Definition of the Santiago sedimentary basin structure using ambient seismic noise tomography and modelling of the basin seismic response (Fig. 1a)
- Estimates of intensity and site effects caused by large mega-earthquakes, such as the 2015 Mw 8.3 Illapel and the 1960 Mw 9.5 Valdivia earthquakes (Fig. 1b)
- Seismic characterization of seismic stations of the Chilean National Seismic Network using surface waves methods (Fig. 1c)
- Impact of earthquake input motions on rockslides in the Andes Range (Fig. 1d)



(a) (b) (c) (d)

Figure 1. Research on earthquake engineering. (a) Shear wave velocity map of the Santiago basin at 2.5 km depth obtained with ambient seismic noise tomography, (b) MSK intensities of the 2015 Mw 8.3 mega-thrust Illapel earthquake, (c) shear wave velocity and dispersion curves of one of the seismic stations of the Chilean National Seismic Network, (d) seismic behavior of a stepped planar rock-slope in central Andes range subjected to different earthquake input motions.

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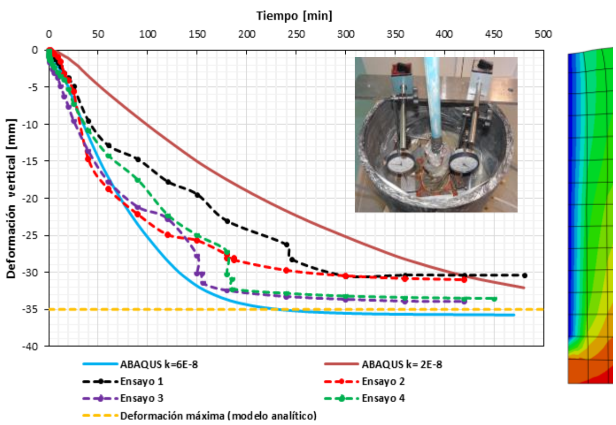
2. Stability of tailings deposits

The operation of tailings deposits is crucial for ensuring operational continuity and strengthening the industry's relationship with the environment and the communities. In recent years, international incidents have highlighted the relevance of preventive controls of physical stability. Chile has more than 700 tailings deposits in different stages of operation and closure. Examples of the research that the GEG develops are:

- Methods to improve the slimes properties and water recovery from tailings ponds, such as the vacuum preloading method (Fig. 2a)
- Definition of a physical stability indices that assess the stability of tailings deposits against the main mechanisms of failure
- Development of technology to monitor tailings deposit online and in real time (Fig. 2b)
- Dynamic numerical modeling of tailings deposits subjected to subductive earthquakes (Fig. 2c)
- Laboratory characterization of tailings hydro-mechanical properties



(a)

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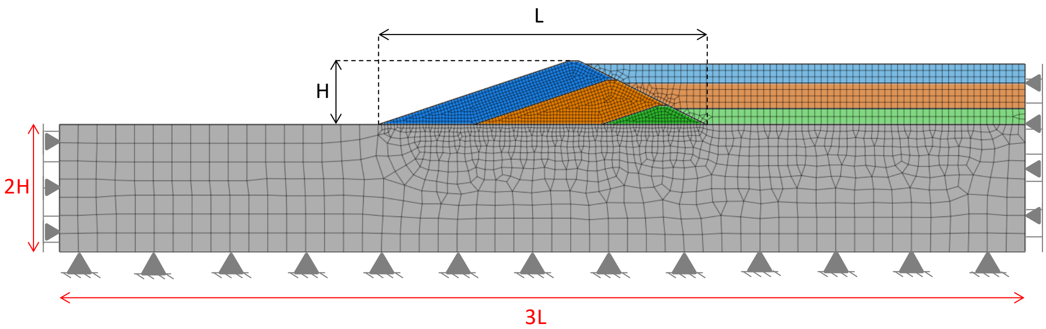

(c)

Figure 2. Research on stability of tailings deposits. (a) Proof of concept of the vacuum preloading method to improve the properties of slimes, (b) seismographs network deployed to monitor the dynamic behavior of a tailing deposit, and (c) numerical modelling of the tailing deposit subjected to earthquake loading.

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Geotechnical Research group at Pontificia Universidad Católica de Chile (PUC) and the Universidad de Chile (Con't)

3. Long-term effects of thermo-mechanical loading on geosystems

Extended service life of infrastructure requires evaluation of the long-term performance of geomaterials and the interaction with other construction materials when several cycles are applied. In many cases, both mechanical and temperature cycles are applied simultaneously. Research that the GEG performs includes:

- Development of constitutive models to assess the long-term behavior of foundations (Fig. 3a)
- Thermo-mechanical ratcheting mechanism in interfaces subjected to temperature changes (Figs. 3b and c)
- Changes in properties of volcanic soils subjected temperature changes
- Monitoring of crack formation in fine-grained soils and displacements in coarse grained soils (Fig. 3d)

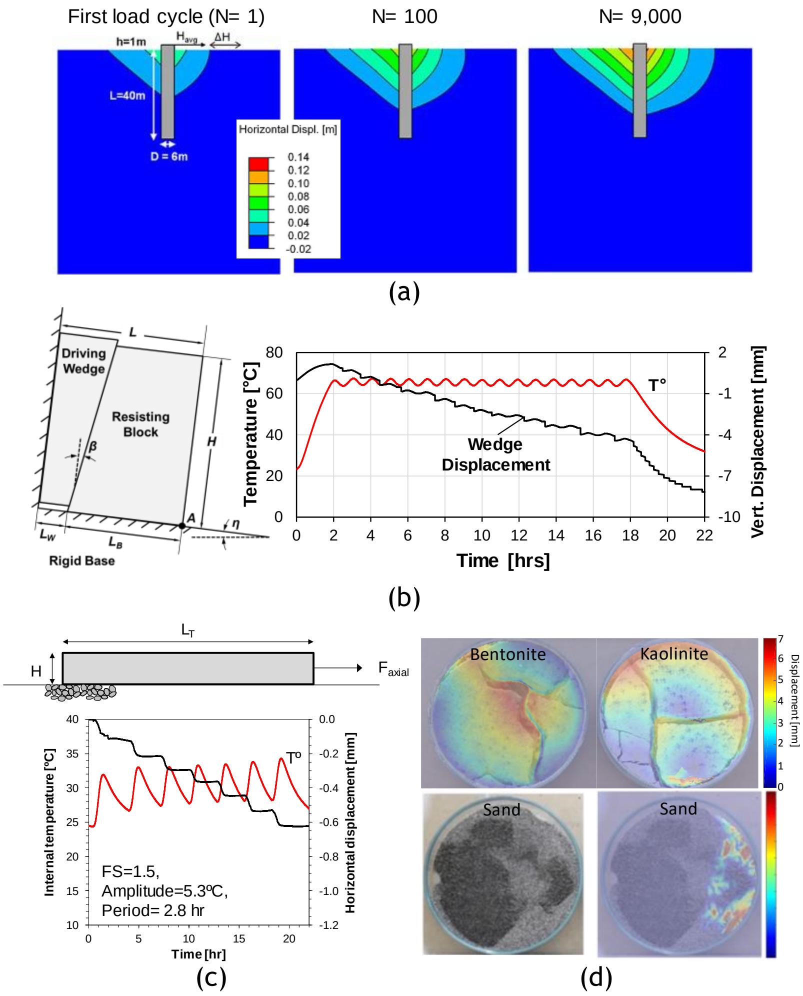

Figure 3. Research on long-term effects of thermo-mechanical loading on geosystems. (a) Long-term monopile foundation response subjected to cyclic horizontal load analyzed with an explicit constitutive model for cyclic loading. (b) Thermally-induced wedging mechanism in jointed rock masses. (c) Thermo-mechanical ratcheting of soil-continuum interfaces. (d) the use of photogrammetry for detection of desiccation cracks in fine grained soils and sand movement.

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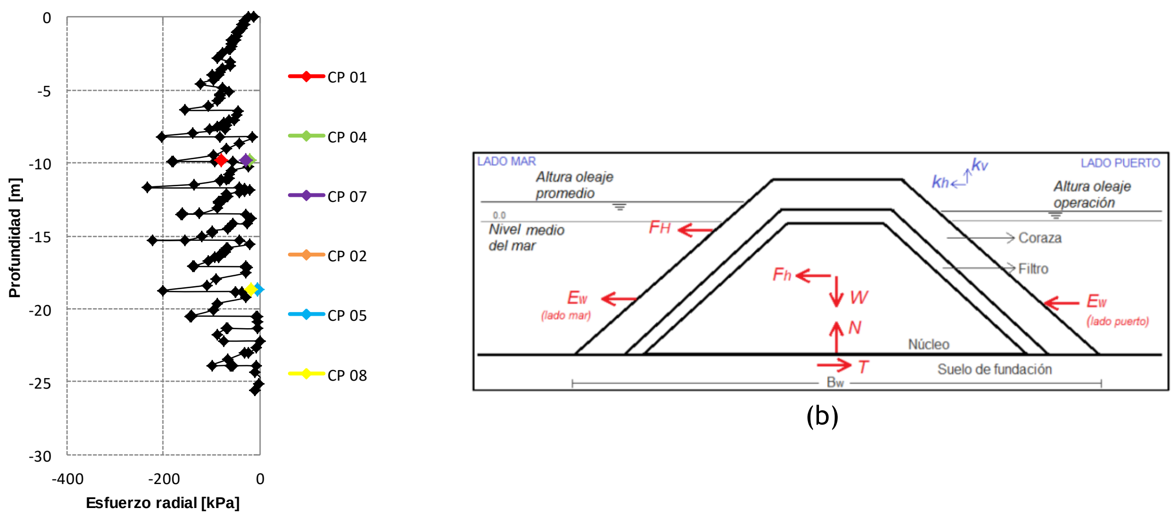
Prof. Roberto Gesche is a geotechnical engineer and adjunct professor who works part-time at the Department of Civil Engineering. He obtained his a M.Sc. degree in Geotechnics and Infrastructure from the Leibniz Universität Hannover. His research focuses on geotechnical and structural instrumentation and monitoring of port infrastructure, underground structures and tailings deposits. Roberto has worked in the industry as a geotechnical consultant for the last 16 years, both in Europe and in South America.

Research Topic:

1. Instrumentation and monitoring

The instrumentation and monitoring of infrastructure enables the engineers to assess the behavior of structures and confirm that the design was satisfactory or that remedial actions should be implemented. Effective instrumentation and monitoring could also modify the design philosophy from worst-case scenario to most probable case scenario provided that a contingency plan exists, as per the observational method. Adequate instrumentation and monitoring should be used to provide an indication on the safety condition of a structure.

- Monitoring of underground circular shafts to determine the actual earth pressure distribution with depth (Fig. 4a)
- Monitoring methods for shallow urban tunnels
- Development of monitoring of abandoned tailings deposits



(a)

(b)

Figure 4(a) Comparison of readings from load cell pressures (CP) with results of numerical model of lateral earth pressure distribution for a circular shaft with top-down construction method (24,4 m total depth). (b) Conceptual diagram for the stability assessment against horizontal displacement of a breakwater. (W: self-weight, F_h: Seismic horizontal force, E_w: water seismic pressure, N: normal force, T: shear resistance at foundation level, F_H: negative wave load, $K_{v/h}$: seismic coefficient horiz./vert.).

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2. Port infrastructure

Chile has an extensive coast that extends from latitude 18°28´S in Arica to latitude 53°9´S in Punta Arenas. Our main exports, mining and agriculture products, in addition to our increasing demand on imports, generate an ongoing need for port infrastructure. This infrastructure faces two main challenges. These are: (a) deep waters, (b) earthquakes and tsunamis. From a geotechnical viewpoint, the soil investigation in deep waters and open sea areas requires large equipment which is expensive. Earthquakes and tsunamis could generate loading conditions that could exceed the typical worst storm scenarios. Therefore, site specific ground investigation methods and techniques should be developed to better characterize the seabed. On the other hand, breakwaters and other protective infrastructure should include seismic verifications (Fig. 4b).

Research Facilities of the center

The GEG maintains a research laboratory for graduate and undergraduate programs. The main equipment in the laboratory are:

- High-pressure triaxial device with confining pressures up to 6 MPa.
- Unsaturated triaxial device.
- Monotonic and cyclic triaxial devices.
- Direct shear device for 30 cm x 30 cm specimens.
- Simple shear device.
- Strain-controlled consolidation cell.
- Microscopes.

High-pressure triaxial device