Hans Cloos lecture 2024
Five decades of education and research for engineering geology in the Netherlands

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ORIGINAL PAPER

Hans Cloos lecture 2024: *Five decades of education and research for engineering geology in the Netherlands*

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Abstract
The Hans Cloos Lecture (HCL) 2024 was delivered by the first author Niek Rengers, in an abridged version, during the opening session of the 4th EurEngeo conference of the International Association for Engineering Geology and the Environment (IAEG), in Dubrovnik, Croatia, October 10th, 2024. Niek Rengers looks back on his personal involvement in more than 60 years of study, teaching, and research in engineering geology, and, with the team of authors, they focus on the main activities of the Dutch engineering geological community during the five decades since 1973. A brief description is given of the challenges of civil engineering over the past 2,000 years in once marshy land, below high tide sea level, with soft soils, and subject to flooding by the sea and the main rivers Rhine and Meuse. Dutch engineers tackled these challenges by dike construction, land reclamation in polders, and the use of pile foundations for building on soft soils. They so gathered over the ages a wealth of practical experience with soft soils. Based on this practical expertise, Dutch engineers developed a sound basis for theoretical and experimental Soil Mechanics. However, in the early seventies, it became clear that a thorough knowledge of the geological structure of the underground was indispensable for adequate geotechnical analysis and modelling. This led to the founding of the Dutch National Group of the IAEG in 1974. Since 1972 the International Institute for Aerospace Surveys and Earth Sciences (ITC) offered full year university level courses in engineering geology. The Mining Engineering faculty of the Technical University Delft followed in 1975. In close cooperation and with extensive staff exchange, both institutions have further developed engineering geological education and research programs leading to MSc and PhD degrees. A summary description is given of these developments during the last 5 decades.

Keywords Hans Cloos · Eng geol mapping · Rock mass classification · Hazard and risk modelling · Geomaterials testing · Dredging

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Introduction

As the title of my Hans Cloos Lecture 2024 shows, I do not only look back on my personal involvement in Engineering Geology (and speak in those sections of the manuscript in the I form) but together with the team of co-authors we also focus on the main activities and achievements of the wider engineering geological community in the Netherlands during the five decades since 1973.

My geology university education in Leiden, focussed on petrology culminating in an MSc thesis on field mapping and petrology of an area in Galicia, NW Spain. For my Minor, I analysed on aerial photographs the surface fault patterns along a hydropower tunnel alignment with a 3-week field check near Eidfjord in Norway. After graduation in 1964, I developed a method to analyse joint and fault patterns in vertical rock outcrops using stereo-terrestrial photography, leading to my first scientific paper in 1966 in the Springer Journal Rock Mechanics and Engineering Geology (Rengers 1967).

My interest in engineering geology had been triggered, and with financial support of the Dutch organisation for Scientific Research (ZWO) I could arrange in 1966 a one-year internship at the newly established division of Rock Mechanics of the faculty of Civil Engineering at Karlsruhe University, Germany, under the leadership of Prof. Leopold Müller (Fig. 1). Prof. Müller was an Austrian civil engineering consultant, renowned for his expertise, and involved in many geotechnical problem projects worldwide. After the Malpasset dam failure, in France in December 1960, Müller brought together an international group of geotechnical experts and founded in May 1962 in Salzburg, Austria, the International Society for Rock Mechanics. He always stressed the importance of close collaboration between civil engineers and geologists.

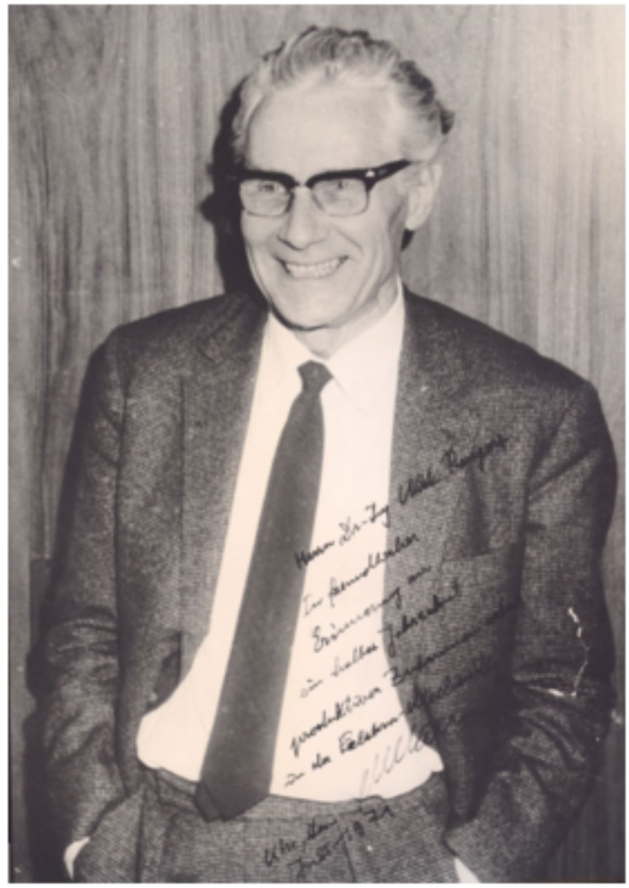


Fig. 1 Prof. Leopold Müller (1908–1988) at Karlsruhe University, Germany, in 1970

My first task in Karlsruhe was the design and execution of dynamic geomechanical model tests (Fig. 2) to analyse the internal deformation process of the Monte Toc landslide during the 1962 catastrophic Vajont landslide event, which destroyed the city of Longarone in the Italian Alps. Prof. Müller was one of the courts appointed experts deeply involved in the analysis of the event. About these model tests I published with Leopold Müller my second scientific paper (Rengers and Müller 1969).

At the end of my one-year internship I was invited to lead a PhD research project of 4 years on the measurement and characterisation of surface roughness of rock joints in granite with wave longitudes from mm to m scales. The equipment that I developed for this purpose ranged from a stereomicroscope connected to a xy-plotter for mm roughness to a profilograph (Fig. 3) and geological compass (Fig. 4) for wavelengths up to two meters measured in field outcrops (Fecker and Rengers 1971).

We built a special shear box with maximum normal and shear stresses up to 50 MPa, for friction testing on rock samples with a length of 40 cm and width of 15 cm to determine the influence of their surface roughness on the friction characteristics of granite rock joints (Rengers 1970). The influence of normal stress on the sliding-up and shearing-through characteristics of the asperities was determined on numerous granite joint planes with varying degrees of interlocking asperities (Fig. 5).

The results of this research were published in my PhD thesis at the faculty of civil engineering and geodesy in Karlsruhe. (Rengers 1971).

After graduation I returned to the Netherlands and joined the International Institute for Aerial Surveys and Earth Sciences (ITC) in 1971. The ITC was founded in 1951 in Delft, as contribution to the Dutch development cooperation efforts. ITC offered English language training programs in aerial survey techniques for mid-career professionals from developing countries to support decolonized countries in the inventory of their natural resources.

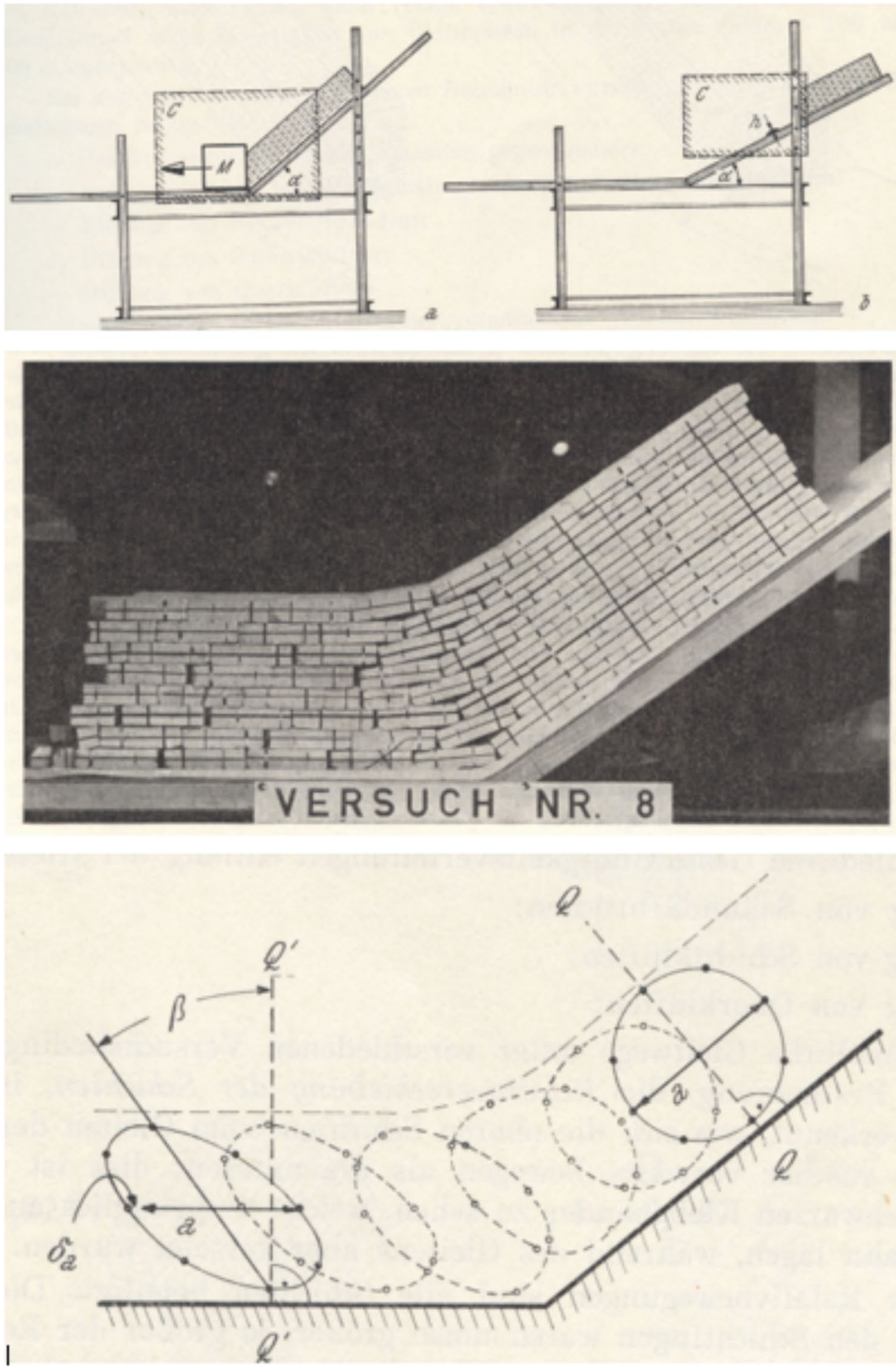


Fig. 2 Model test to simulate the kinematics of the Monte Toc landslide that caused the Vajont disaster in 1962 (Rengers and Müller 1969)

In 1971 most of the ITC courses were moved from Delft to a new building in Enschede, while the courses for Mineral Exploration and Geophysics remained in Delft, as they were closely cooperating with the faculty of Mining Engineering of Delft University. My task at ITC Enschede was to set up a new division of engineering geology, and to develop a BSc-level course on aerial photo interpretation for engineering geological mapping.

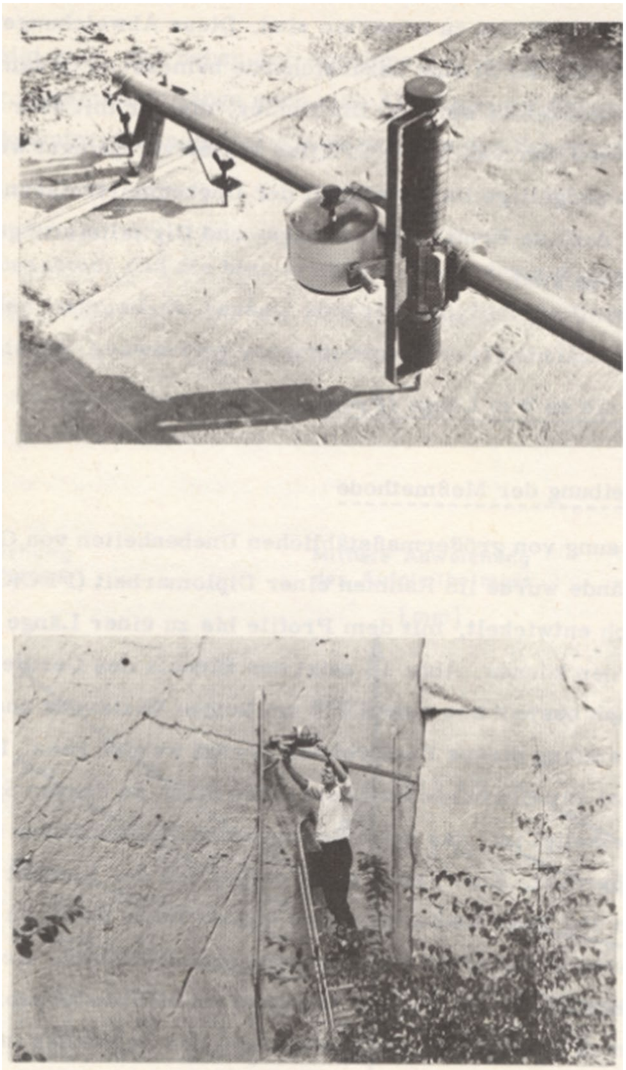


Fig. 3 Profilograph to measure surface roughness profiles of 2 m length along outcrops of rock joints in the field (Fecker and Rengers 1971)

Civil engineering in a soft soil country

The Netherlands, with its soft soil and low-lying terrain, has been transformed over the past 2,000 years through significant civil engineering efforts. Much of the country was once marshy land, below high tide sea level, and subject to flooding. Dutch engineers tackled this challenge by developing three key engineering methods: dike construction, land reclamation in polders, and the use of pile foundations for building on soft soils. These activities have shaped the country as we know it now. "God created the world, but the Dutch created their own country" has often been said about this process of many ages (Fig. 6).

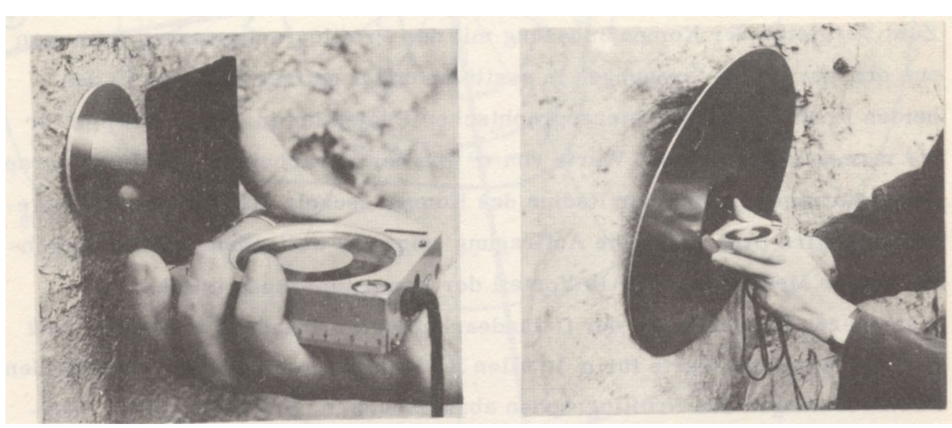
Dike building, which began around the year 800, was essential to protect the settlements that were formed in the low-lying coastal areas. On a small scale, streams were dammed (from there originated such city names as Rotterdam and Amsterdam). Over time, techniques improved, and the traditional dikes, consisting of soft soils, were fortified on their surface with stone material imported from countries as Belgium and Norway. These dikes now protect the country against flooding by the sea and by the rivers Rhine and Meuse.

Engineering geologists at TU Delft are presently carrying out research with remote sensing techniques to study the internal build-up and stability of old dikes in the Western part of the country. (Cundill et al. 2014).

The *polder system* for land reclamation was well established in the seventeenth century. For one of the first big polder projects: the Beemster lake polder (Fig. 7), first a dike was built around the Beemster lake. The soil material for this dike was excavated from a ring canal around the dike at such an elevated level that the water from the ring canal could be drained into the sea.

The water was then pumped out of the lake into the ringvaart (ring canal) with 43 windmills, located in rows to pump the water up in steps (Fig. 8). After five years of continuous pumping, the Beemster lake was dry, and the new land, the "polder", was subdivided in parcels for agriculture

Fig. 4 Measurement on a joint plane with different sizes of compass contact area. After plotting in a stereographic projection diagram, the waviness characteristics can be determined for different directions (Fecker and Rengers 1971)



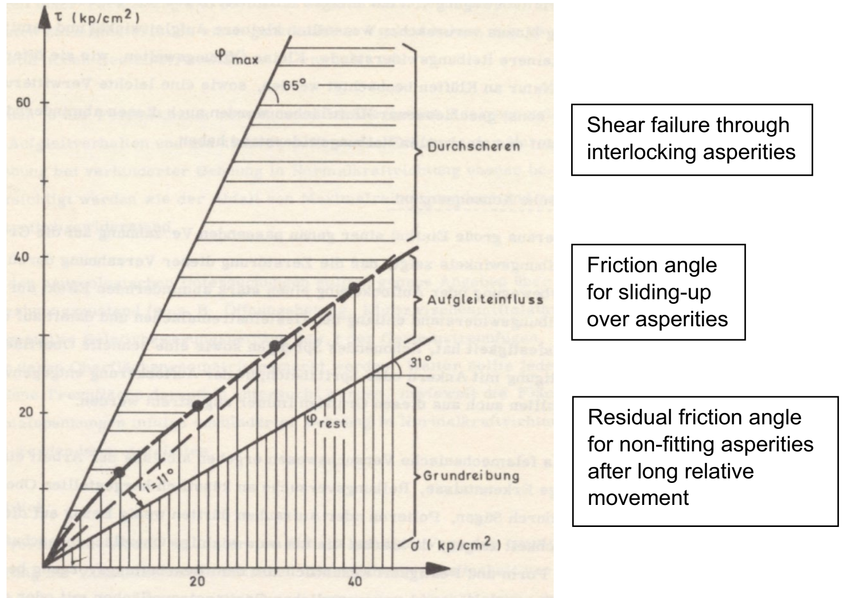


Fig. 5 Compilation in a normal stress (σ) vs shear stress (τ) diagram of experimental shear test data for rock separation planes with interlocking asperities of both sample parts (Rengers 1971)

(Fig. 7). As 26% of the Dutch territory is presently located below sea level, continuous pumping is still nowadays necessary to keep our feet dry.

End Bearing Pile foundations in soft soils were crucial to construct cities like Amsterdam, on a thick top layer of soft subsoil. The worldwide use of wooden piles, driven into soft soils near rivers and wetlands to create stable platforms for their homes, dates to prehistoric times. The industrial revolution in the nineteenth century led to a growth of large engineering works and housing projects. In Amsterdam early wooden piles of 6 to 7 m length, gave way to longer piles, of steel and concrete, penetrating down to 15 m to find support on deep Quaternary sand layers, improving the durability of the foundations. For decades now, to prevent settlement damage, Amsterdam is replacing old short wooden piles by longer steel and concrete piles, an extremely expensive operation (Figs. 9, 10).

Based on the massive practical experience from ages of dike building, land reclamation and pile driving, the applied science of soil mechanics was well developed in the Netherlands during the twentieth century. Dutch engineers developed the Cone Penetration Test (CPT), which is globally known as “the Dutch cone test” for the determination of the engineering properties of the soft soils down to tens of meters below the terrain surface.

In the early seventies, geologists and civil engineers in the Netherlands became aware that close collaboration is necessary to tackle the often-difficult circumstances when building ever larger buildings and infrastructure on top of and into a complicated deltaic geological environment. Engineering geologists became important participants in the decision-making processes in consultancy companies and in contractors’ organisations and at the construction site. It became clear that there was a need for engineering geological education and research at university level.

Education and training

Starting in 1972 in Enschede, the 12 months ITC postgraduate course in engineering geological mapping for mid-career professionals from developing countries was the first full time engineering geology course in the Netherlands. Sporadically also Dutch university students followed modules of this course at the ITC in Enschede.

The appointment of David Price (Fig. 11) as Professor of Engineering Geology at the Faculty of Mining Engineering at Delft Technical University (TUD) in 1975, introduced education and research in Engineering Geology in the Dutch university system. Regular courses leading to an MSc degree started at TUD in 1975.

Students from earth science departments of all Dutch universities had access to lectures, laboratories, and fieldwork programs through flexible arrangements between their universities, ITC and TUD.

In 1985, David Price and Niek Rengers launched a successful joint MSc program in Engineering Geology for TUD and ITC students. This two-year program included lectures, extensive soil and rock testing in the lab and in the field, and a month of fieldwork in the Spanish Pyrenees. The program emphasized on acquiring practical experience through geotechnical problem-solving and imaginary engineering projects in lecture hall games and during fieldwork.

During the one-month fieldwork in Spain, students prepared engineering geological maps of an area of 15 to 20 km^2, analysed slope instability phenomena (Fig. 12), and

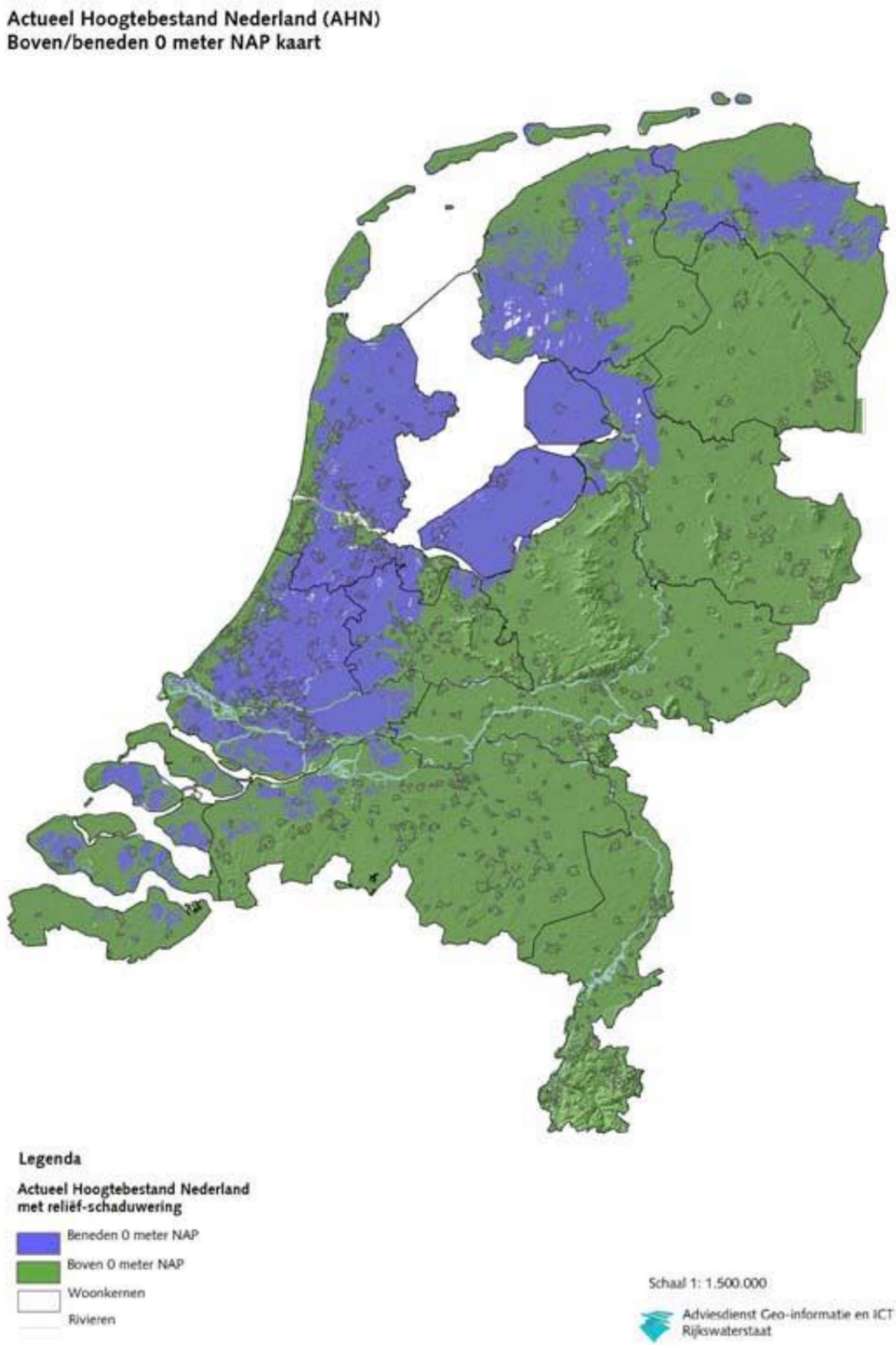


Fig. 6 26% of the Dutch territory is presently located below sea level (Actueel Hoogtebestand Nederland n.d., https://viewer.ahn.nl)

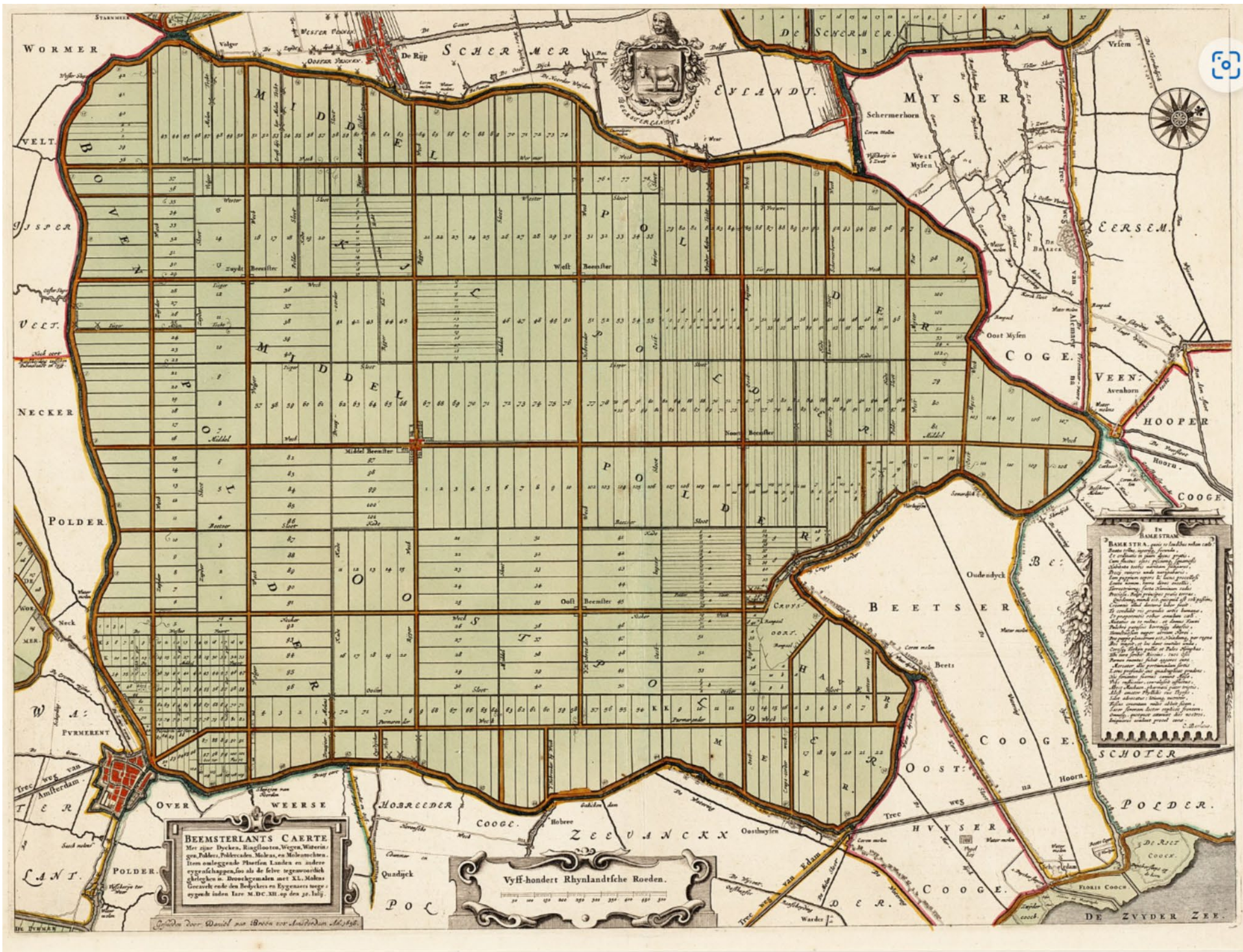


Fig. 7 Historical map of the Beemster polder, 1658, engraved by Daniël van Breen. (Map collection of the Provinciale Atlas Noord Holland n.d., https://noord-hollandsarchief.nl)

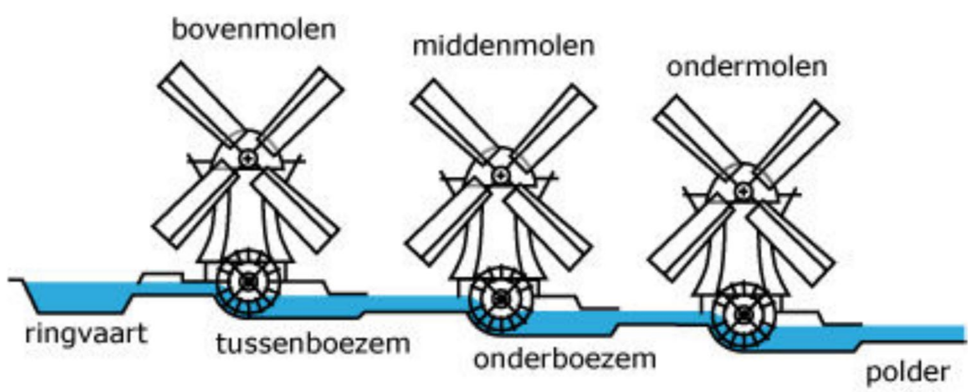


Fig. 8 Water pumped up from the polder in steps by a series of windmills into the ringvaart (https://logbankje.nl/molengang)

visited large construction sites (Figs. 13, 14). The engineering properties of the engineering geological rock and soil map units were determined in a comprehensive field lab. Students were taught on site to perform classification tests on soils and index strength tests on rock samples. Rock core sampling was done on site. Equipment for dynamic cone penetration and in-situ density, permeability and plate bearing testing was available. Data collected by

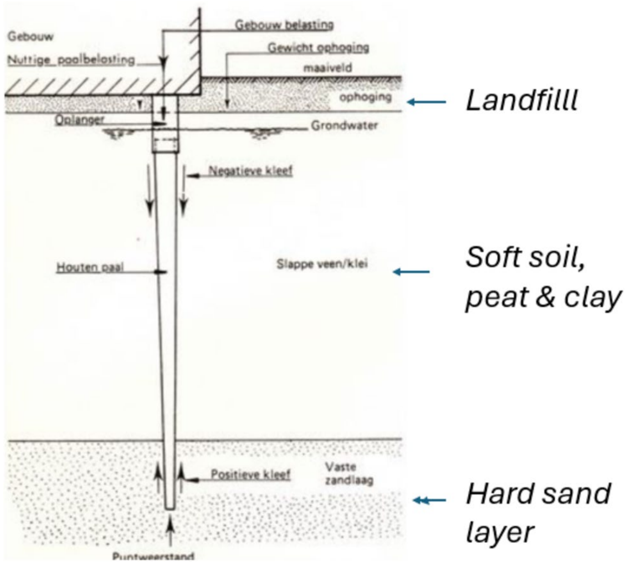


Fig. 9 End Bearing Pile foundation on soft soil (Funderingen op palen, https://berkela.home.xs4all.nl)

Fig. 10 The so-called "dancing houses" in Amsterdam, showing settlement damage (https://www.dreamstime.com/royalty-free-stock-image-historic-amsterdam)

students during their fieldwork were also used for research programs of staff and PhD students.

During the second year of the joint MSc program, specialization modules were offered, leading to an individual research project supervised by TUD or ITC staff, culminating in a thesis defence. Between 1975 and 2024, 350 to 400 Dutch and foreign students obtained the MSc in Engineering Geology at TUD and ITC.

Modules of the MSc program as well as individual lecture series were also offered abroad,

Worth mentioning are the following extra-curricular programmes:

- 1971–1990: CIAF Centro Interamericano de Fotointerpretacion in Bogota Colombia: short courses in *Engineering Geology with emphasis on slope stability analysis*
- 1975 Training course on *Engineering geological photointerpretation* at the Laboratorio Nacional de Engenharia Civil (LNEC) in Lisbon, Portugal
- 1987: Course on *Quaternary Engineering Geology* at the Asian Institute of Technology (AIT) in Bangkok, Thailand
- 1990–2002: *ITC-Unesco Regional Action Program for Central America* (RAPCA) in Central America, on natural hazards and risks (Fig. 15)
- 2003–2005: In-service training program for the Department of Geology and Mines in Thimphu, Bhutan (Fig. 16)
- 2006–2024: *PAO* TM Techniek en Management (n.d.) (Post academic course Engineering Geology) given 7 times since 2006 to groups of on average 10–15 geotechnical engineers, hydraulic engineers and structural engineers in the Netherlands, to better assess risks related to geology in civil engineering projects.

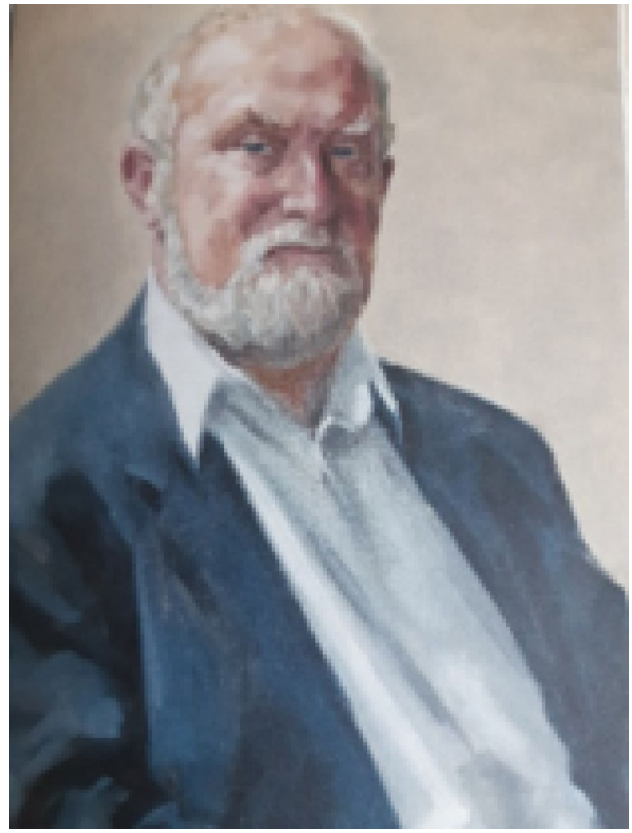


Fig. 11 Portrait painting of David Price (1932–1999) by Marike Bok

Fig. 12 Field instruction for slope stability analysis (Photograph W.Verwaal)

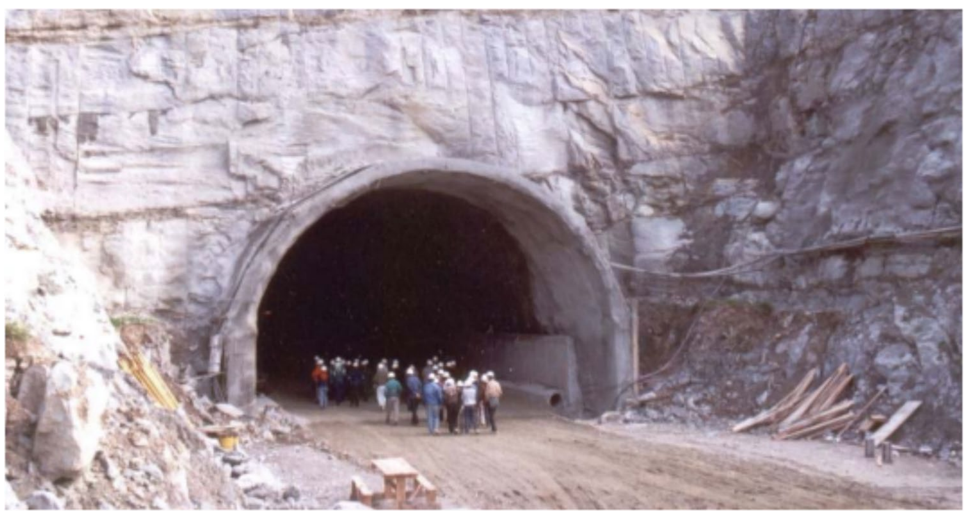


Fig. 13 Visit with students during fieldwork in Spain to a tunnel construction site (Photograph W. Verwaal)

Estimated total number of foreign and Dutch participants trained in these extra-curricular programs: 300 −350 over 50 years.

Research and development

Education programs and Research and Development projects were closely connected and interacting in the ITC-TUD cooperation. Data collected during fieldwork with students were often used for PhD research by staff and students.

Engineering geological mapping

In 1971, the main topic of engineering geological research at ITC was to develop the methodology to train mid-career professionals from developing countries to improve their mapping skills for engineering geology by using aerial photography.

The zonation of terrain into "geotechnically homogeneous rock and soil zones" (Fig. 17) was carried out by the interpretation of stereo aerial photography and was based on the characteristic relief and vegetation of each zone and

Fig. 14 Excursion in 1988 to a construction site for a German high speed railway line, with at the upper left staff members Michiel Maurenbrecher, Keith Turner and Wolter Zigterman (Photograph N. Rengers)

Fig. 15 ITC-UNESCO Regional Action Program for Central America (RAPCA) meeting at the ITC in 2000 (Photograph ITC)

their position in the 3D landscape as visible on stereo-aerial photography.

Homogeneous soil zones were genetical units (e.g. alluvial, colluvial, residual). After preparation of a draft map from photointerpretation, samples of the various homogeneous soil zones were collected during a subsequent field check. Their geotechnical characteristics were determined in a comprehensive field laboratory, and they were classified geotechnically in the Unified Soil Classification System and on basis of their Sand Equivalent value (Fig. 18).

Homogeneous rock zones were delineated visually on aerial photography on basis of their relief and their outcrop expression (high, medium, and low rock mass strength) and were characterized in the field in a diagram of material strength (determined by point load tester and/or Schmidt Hammer) versus discontinuity spacing (Fig. 19).

Delineation and classification of *Mass movement* types was based on their level of activity (active in red and non-active in black) (Fig. 18).

Fig. 16 In-service training at the Bhutanese dept of Geology and Mines

Since the nineties, satellite remote sensing images became widely available. This has improved the mapping speed, accuracy, and engineering geological feature analysis. The introduction of multispectral data analysis and GIS has further enhanced the methodology. (Rengers et al. 1992).

3D subsurface geotechnical modelling started in the Netherlands in the nineties, with improved interpolation routines and property modelling techniques developed by Orlic (1997) and Özmutlu and Hack (2003). These innovative approaches allow for a more detailed and comprehensive understanding of geological formations and their behaviour, leading to better planning and risk management (Bremmer et al. 2000; Hack et al. 2006) (Fig. 20).

3D terrestrial laser scanning has automated the characterization of discontinuities in steep rock slopes, providing more accurate and efficient results. Slob's research (Slob et al. 2005; Slob 2010) demonstrated that laser scanning

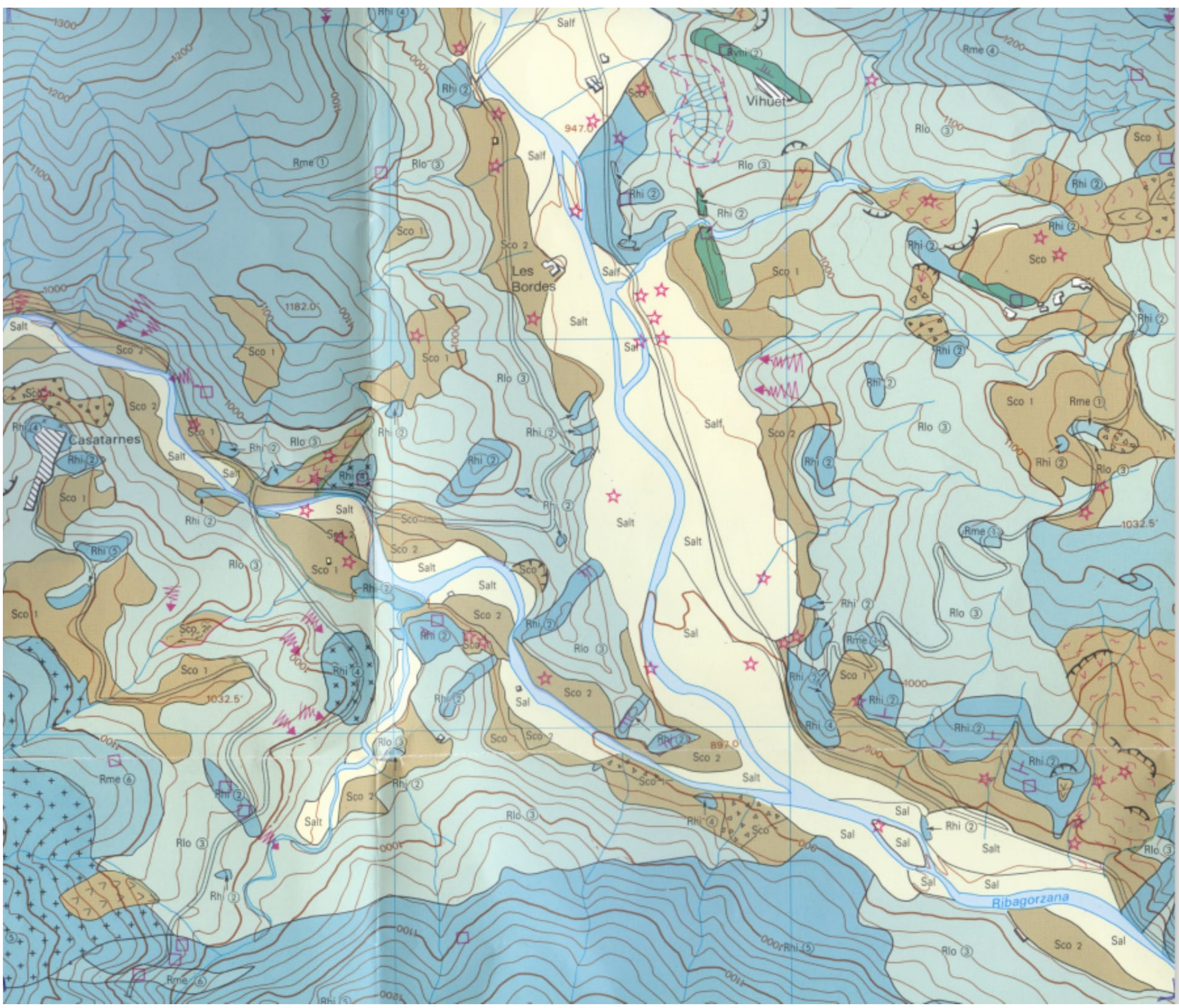


Fig. 17 Detail of an Eng. Geol. map based on interpretation of aerial photographs. North is up. The area covers 2.94 km in EW direction and 2.56 km in NS direction. See legends for the map units in figs. 18 and 19 (Rengers et al. 1990, 1991)

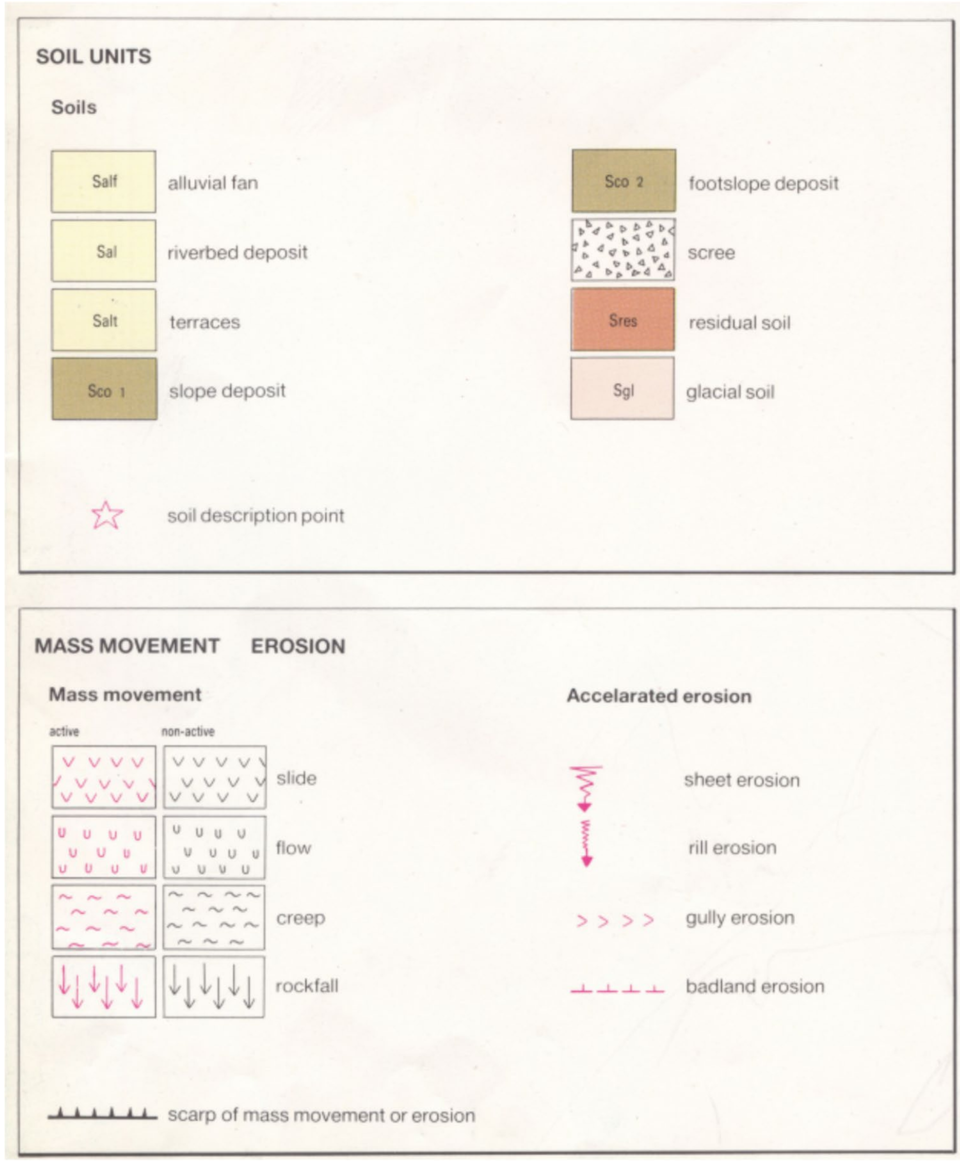


Fig. 18 Legend for homogeneous soil zones in Fig. 17 (Rengers et al. 1991)

offers superior resolution and operational advantages over terrestrial photogrammetry (Fig. 21).

Rock mass classification and weathering

A strong connection between education and research has been, right from the beginning, one of the strong points of the TUD-ITC collaboration. The collection of data by students during the MSc fieldwork in Spain in the region of Falset (Tarragona) in the nineties provided databases for the development of rock mass classification systems for rock slope stability analysis, and for investigations into soil and rock weathering processes. The variation of the geology and the abundance of deep cuts in the geology for new road construction projects made this region to an ideal fieldwork location.

The *Problem Recognition Index (PRI)* is developed to identify general engineering problems caused by critical characteristics of the rock or soil ground masses (Price et al. 1996, 2009). Figure 22 shows a photograph of a series of road cut exposures with a strong variation of geotechnical properties. Figure 23 shows a map with PRI values for the same area. The PRI is a planning tool that identifies possible problems with engineering due to low values of intact rock strength, brokenness of rock masses, weathering horizons, susceptibility to weathering, and presence of soluble or aggressive minerals or high groundwater pressures.

Another classification system developed with data from the Falset area is the *Slope Stability Probability Classification (SSPC)* (Hack et al. 2003). This classification system for estimating stability of slopes is based on weighting

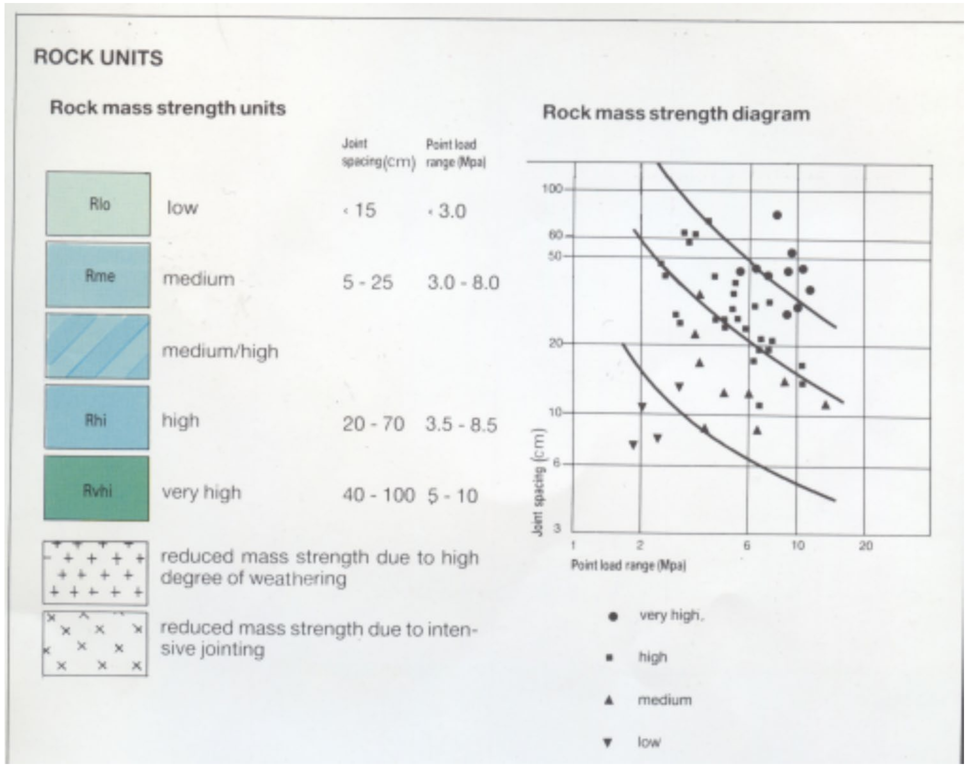


Fig. 19 Legend for homogeneous Rock Mass Strength units in Fig. 17 (Rengers et al. 1991)

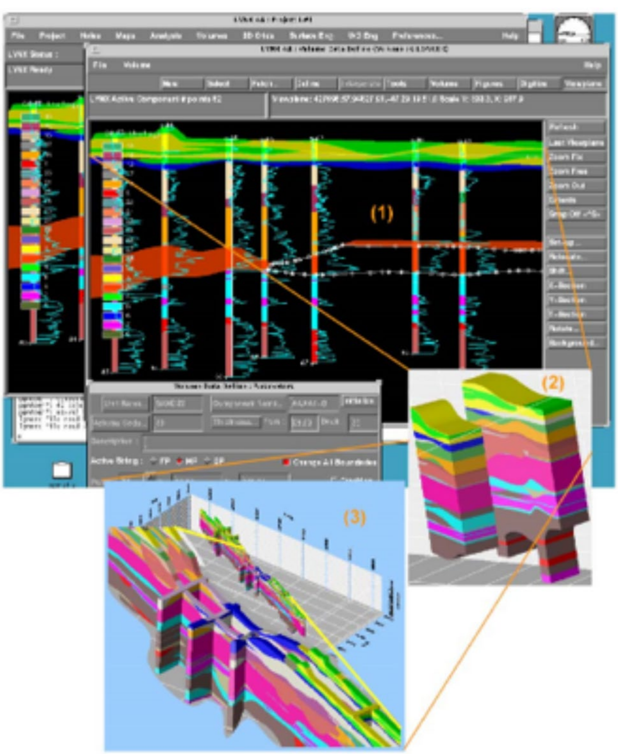


Fig. 20 Interactive modelling of the subsurface geotechnical properties from borehole and sounding data (Bremmer et al. 2000)

factors for weathering and excavation damage, intact rock strength, discontinuity spacing and shear strength.

The system is nowadays used worldwide (e.g. Asmare and Hailemariam 2021; Dhakal et al. 2005; Ersöz and Topal 2018; Lindsay et al. 2000; Tao et al. 2021).

Figure 24 shows an example of a bicycle path rock cut in Germany, which is steeper than the original natural slope, with a safety factor just over 70% for orientation-independent stability (Hack and Schmitz 2023). However, weathering and loss of structure cause the slope to disintegrate and according to the SSPC the stability is reduced (Fig. 25).

Weathering of rock and soil masses. Any rock mass classification based on field data describes a specific moment in time, while artificially excavated slopes are subject to (sometimes very rapid) degradation. The properties of rock masses change over engineering timescales, and become generally weaker, due to three main processes:

- *Relaxation* or redistribution of stress and strain, leading to loss of structural integrity.
- *Weathering* and thereby weakening of both the rock material and the rock mass.
- *Erosion* of the fresh or weathered slope material.

Weathering rates of exposed rock masses in outcrops, created by civil engineering and mining, must be considered. Even small quantities of weathered material or slight

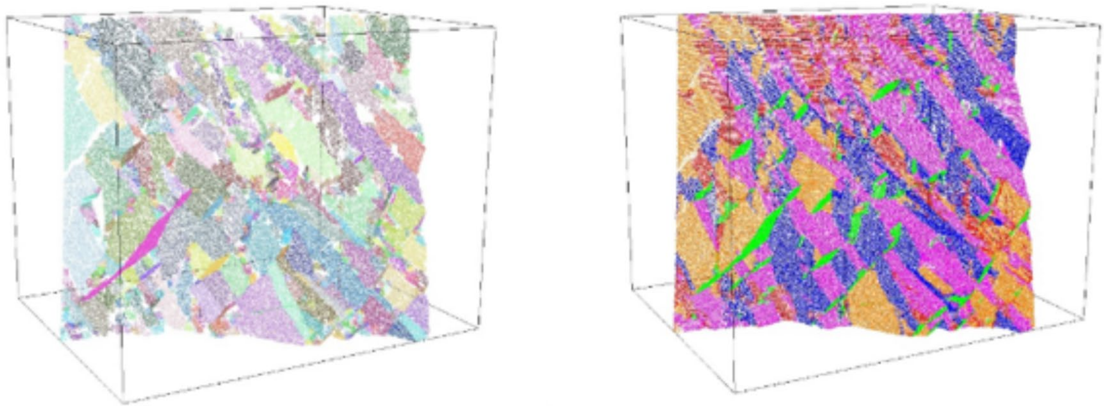


Fig. 21 Colored laser scan point cloud classified into individual planes (left) and classified by discontinuity set (right) (Slob 2010)

Fig. 22 In the background three road cut exposures in different rock masses with highly different geotechnical properties (Price et al. 1996)

changes in geotechnical properties can cause a complete change of behaviour of a groundmass. For example, slight weathering of a discontinuity surface may be enough to cause the sliding of a large block. Therefore, slope stability will undergo changes with time, when rock masses are uncovered and exposed to the environment.

Research by Huisman (2006) investigated this time-dependency due to weathering for slopes in the Falset area and quantified the influence of factors such as the slope aspect and local climatic conditions on the weathering rate (Fig. 26) (Huisman et al. 2006, 2011). Tating (2015) later extended this to tropical climates.

Extension to oil/gas and geothermal reservoir stability. Weathering as observed at the terrain surface also plays a role in processes of erosion and degradation of oil & gas and geothermal reservoirs. The expertise gained in the weathering at the terrain surface has been used to evaluate the stability of clay cap rocks in reservoirs and reservoir erosion, among others in relation to microbial corrosion (Madirisha et al. 2022).

Natural hazard and risk modelling

Extreme disaster events can lead to *complex interaction of hazards*. For example, the 1991 Mount Pinatubo volcanic eruption in the Philippines, caused ash-related hazards and volcanic debris flows (Daag 2003). Another example, the 2008 Wenchuan earthquake in Szechuan Province, China, triggered landslides, leading to floods from breached landslide dams (Fan 2013; Tang and Van Westen 2018). Spatial

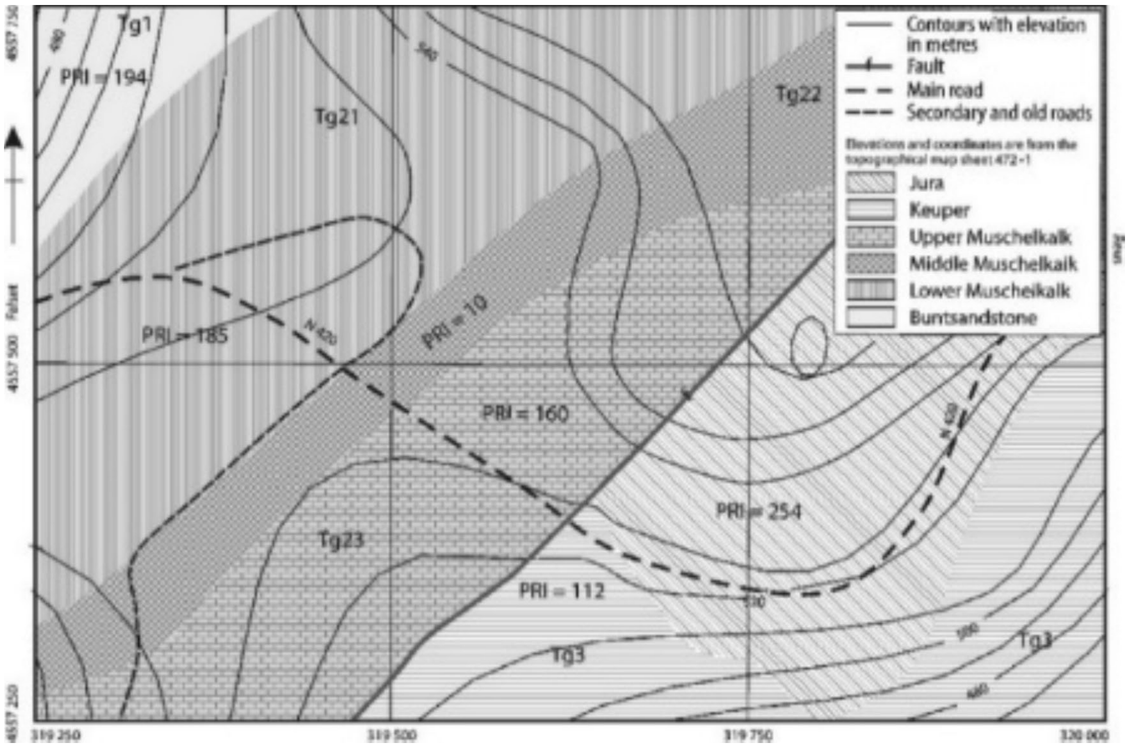


Fig. 23 Map showing PRI values in the area with the exposures in Fig. 22 (Price et al. 1996)

Fig. 24 Cut in Heimbach Schichten (insert shows the foot and bicycle path cut into the natural slope along a lake) (Hack and Schmitz 2023)

modelling plays an essential role in assessing and mitigating geological hazards like landslides and earthquakes, to minimize the impact of natural disasters on communities by safer infrastructure planning. It has been one of the spearpoints of research at the ITC since 1990.

Hazard assessments alone are insufficient as a basis for decision-making. Risk assessments combine hazard data with information on assets (population, infrastructure, agriculture, etc.) and their vulnerabilities. A schematic presentation of multi-hazard modelling is given in Fig. 27. The figure indicates the main components of a multi-hazard risk assessment. As Gill and Malamud (2014) stated "A multi-hazard risk assessment should identify all possible and relevant hazards and the valid comparison of their contributions to hazard potential, including the contribution to hazard potential from hazard interactions and spatial/temporal coincidence of hazards, while also taking into account the dynamic nature of vulnerability to multiple stresses". Hazard modelling requires the spatial analysis of the potentially hazardous events, with their intensity and frequency.

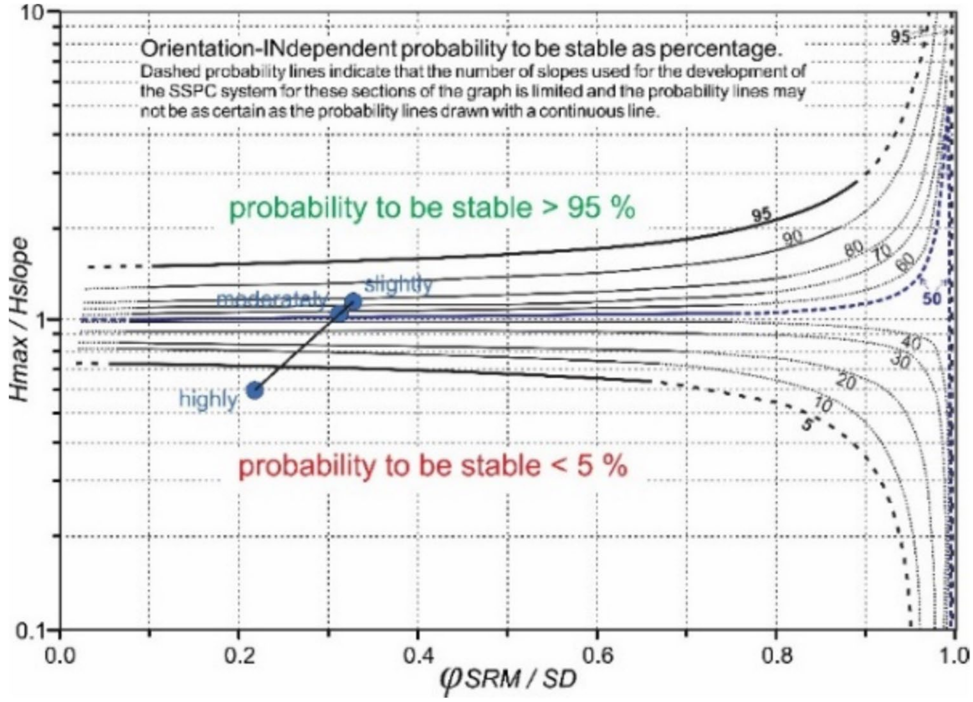


Fig. 25 SSPC orientation-independent stability of Heimbach Schichten with different degrees of weathering (Hack and Schmitz 2023)

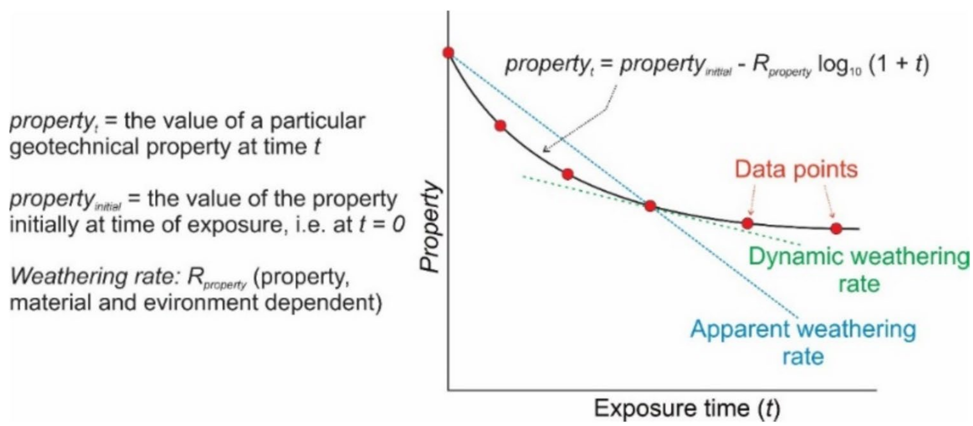


Fig. 26 Weathering of a geotechnical property as function of the time of exposure (Huisman 2006)

The analysis of geomorphological hazards (e.g., landslides, soil erosion) has evolved significantly using satellite remote sensing. Optical satellite data with enhanced spatial and temporal resolution allow land cover monitoring, while Digital Elevation Models (DEM), derived from data acquisition by satellites and drones, can map earth surface morphology changes with precision. Expert interpretation of aerial images, once crucial, can now be improved and sometimes replaced by automated techniques like machine learning and artificial intelligence for identification of landslides and other hazards. Geographic Information Systems (GIS) and statistical methods further improved hazard analysis, enabling large-scale spatial–temporal modelling. Physically based modelling approaches are now possible for large areas, especially for processes such as flooding, although the application of such models for landslides at a regional level is still limited by the lack of detailed sub-soil information. Nevertheless, large steps have been made, also in the speed of modelling, with models such as FastFlood and FastSlide that are based on global datasets and are over 1000 times faster than conventional models (Bout 2020). The availability of global datasets for assets (e.g. buildings, population, infrastructure) has greatly improved, due to the application of high-resolution satellite imagery, collaborative mapping (e.g. OpenStreetMap), AI (e.g. OpenBuildingMap) and spatial modelling (e.g. Worldpop). Availability of vulnerability data is often still a challenge, both as socio-economic indicators and as physical vulnerability curves. A range of software tools is now available to combine the hazard, exposure and vulnerability data in risk maps, although many require specific programming skills or expert knowledge. The RiskChanges tool is an example of an open-source

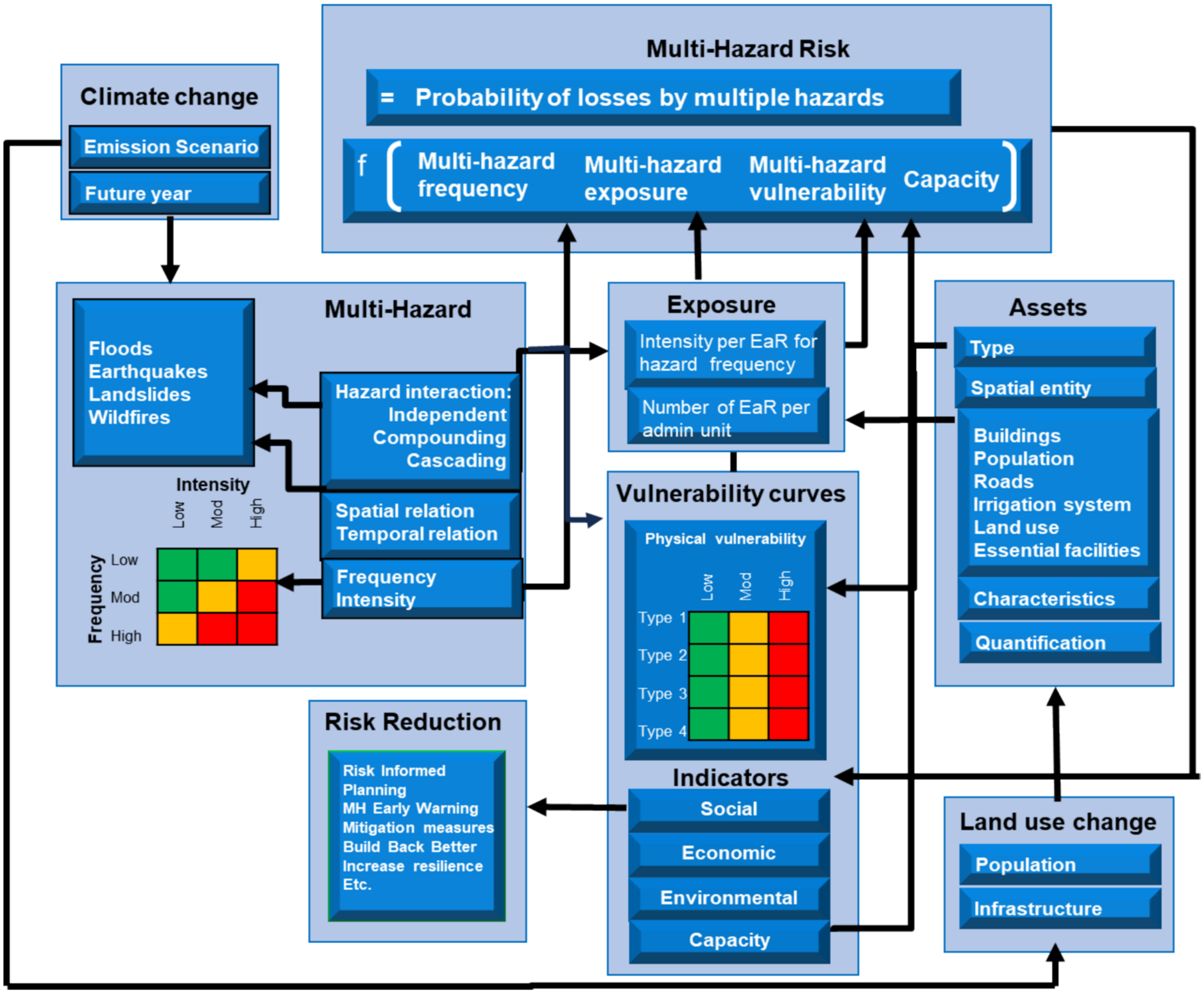


Fig. 27 Schematic presentation of multi-hazard risk modelling, (van Westen and Greiving 2017)

web-based tool with a graphical user interface (RiskChanges 2024).

Figure 28 shows how risk assessment is carried out for spatio-temporal risk modelling (van Westen and Greiving 2017). Current risk is analysed first, after which several future scenarios related to climate, population and land use changes are defined, for given future years (e.g. 2050). Changes in drivers (e.g. rainfall intensity and frequency) are included in the hazard models, and changes in assets and vulnerability are based on scenarios. The risk components are combined to provide information how the expected losses in the future might differ from the current ones. Several alternatives for risk reduction, such as engineering measures, nature-based solutions, or strengthening of the built environment, are then defined, based on the hazard types considered. The changes in expected losses are assessed for each of these alternatives, and compared with the current ones, using tools such as Cost–Benefit analysis or Spatial Multi-Criteria Evaluation.

Early initiatives like the UNESCO-ITC Regional Action Program for Central America (UNESCO RAPCA 2003) were the start of many capacity building projects with training on multi-hazard risk assessment for disaster management professionals, many of whom are now influential decision makers in their own countries. Collaborative research has produced significant publications, such as the *Atlas of Wenchuan Earthquake Geohazards*, a co-production of ITC and the State Key Laboratory for Geohazard Prevention (SKLGP) Chengdu, China (Tang and van Westen 2018).

New current challenges for ITC focus on understanding climate change's impact on multi-hazards and risks, in collaboration with humanitarian sectors like the Red Cross.

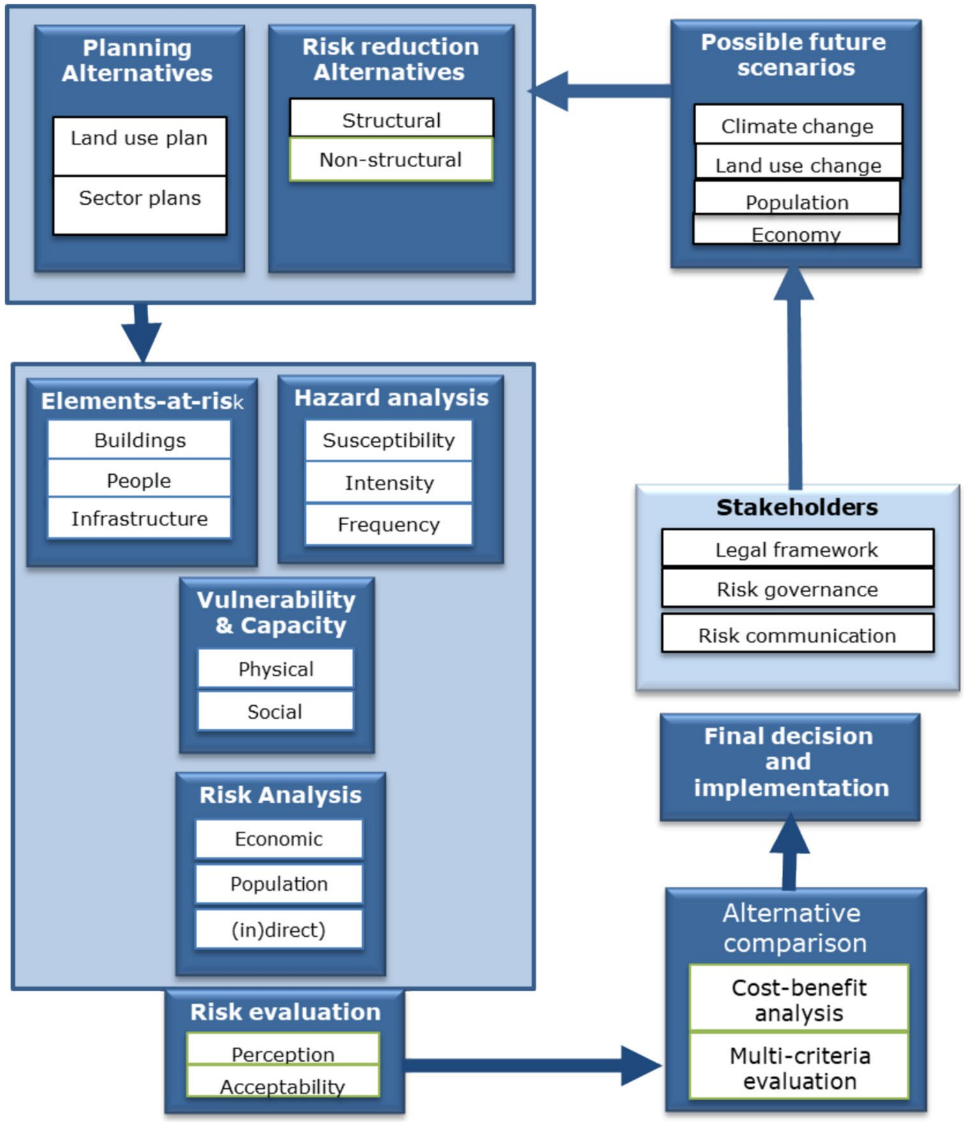


Fig. 28 Schematic presentation how risk information is used dynamically for future scenarios and risk reduction alternatives (van Westen and Greiving 2017)

Geotechnical materials testing

The basic philosophy of the TUD-ITC MSc program in Engineering Geology, that started in 1985, was that students should be offered not only theoretical subjects but also hands-on experience with mechanical testing of soil and rock samples in the laboratory and in the field for geotechnical classification purposes. Collaboration between ITC and TUD led to the creation, in 1976, of the TU Delft Laboratory of Engineering Geology (DLEG), located at the TUD Faculty of Mining Engineering. It served both institutions. The TUD Faculty had a wide range of equipment for soil testing but equipment to test stronger materials like rock was not available. With limited funds, the first available equipment for rock strength testing was the Point Load Tester and for elasticity determination the Schmidt Hammer.

The thesis work of some of the first students of the program was dedicated to the development of simple tools to obtain reliable index values for geotechnical rock properties. An example of this is the development of a ball rebound tester by Marinus Pool in 1978: a rock core clamping device with a vertical tube in which a steel ball was freely falling on the core from a fixed height (Price et al. 1978). The rebound height of the ball was measured and used as an index value. This principle of a rebounding body had already been commercially developed by the company Proceq, for the measurement of hardness on steel surfaces. Our research resulted in the use of the so-called Equotip type D for testing on rock surfaces in the laboratory as well as in the field (Verwaal and Mulder 1993 and Hack et al. 1993).

A significant early research project for the DLEG was the collection of rock mass properties for the assessment of the stability of abandoned room and pillar mines in Cretaceous

Fig. 29 Block shear test in a large quarry of Cretaceous calcarenite near Maastricht (NL) (Photograph W. Verwaal)

Fig. 30 Cutting of a sample block out of a pillar in an abandoned calcarenite mine by lab technician Arno Mulder (photograph W. Verwaal)

calcarenite in the Southeastern Netherlands. Over a period of several years, also during students fieldwork, a large variety of in situ tests were performed in a large quarry and in the abandoned room and pillar mines: vertical and horizontal plate bearing tests, large and small size shear tests and strength tests on small cutout pillars (Figs. 29 and 30). All tests were supplemented with monitoring of P and S wave velocities.

Numerical modelling with the collected geotechnical data was used to predict and address the instability of the abandoned mines. Based on laboratory and field studies in several mines, Bekendam (1998) developed a methodology to define the stability of individual pillars focusing on risk assessment of a large-scale collapse and management of subsurface excavations. Key factors included rock mass quality, in-situ stress, water presence, and pillar shape.

The need for accurate rock strength measurement on weak rock as the Cretaceous calcarenite was the trigger to design and build two stiff servocontrolled compression machines in 1985. One up to 500kN for unconfined and confined general rock testing and one up to 50 kN for unconfined and confined testing of weak rock, but also for Brazilian and fracture toughness tests. Close-loop deformation-controlled testing made it possible to study the complete stress–strain behaviour of rock including post failure behaviour.

The DLEG was often consulted by Dutch dredging contractors to test rock and aggregates to predict the long-time stability of armour stone for piers and breakwaters. Contacts with the dredging industry also resulted in research on wear of rock cutting_tools by downscaling the cutting process to laboratory wear simulation tests with a lathe (Verhoef 1997; Deketh 1995; Alvarez Grima 2000).

The Directorate-General for Public Works and Water Management encountered problems with lifetime durability and skin friction of their Very Open Asphalt Concrete (ZOAB Zeer open asfaltbeton n.d.) road top layer. DLEG research resulted in a series of publications on this topic.

The DLEG staff has also supported foreign research institutes abroad in the development of basic engineering geological testing facilities. Figure 31 shows the lab facilities at the Department of Geology and Mines in Thimphu, Bhutan.

Fig. 31 Geotechnical field Lab for the Department of Geology and Mines in Thimphu, Bhutan (Photograph W. Verwaal)

Presently the DLEG is fully integrated in the Laboratory of Geoscience & Engineering of the Faculty Civil Engineering and Geosciences of Delft University of Technology.

Dredging and wear of rock cutting tools

Dredging is essentially the excavation of ground material below the free water table to deepen streams, canals, create new waterways, and/or produce material to reclaim land.

From the beginning of civilisations, people, equipment, commodities and materials have been transported over water. The ability to ship people and goods via inland waterways and seas was – and still is – largely dependent on water depth. The natural phenomena of siltation and sedimentation decrease the navigational depth of rivers and their deltas.

Historically, dredging was done manually with simple tools (Fig. 32).

In the 17 th ("Dutch golden") age, when the Netherlands were a world power with trade and shipping, dredging became important to dig canals and create new harbours.

It wasn't until 1857 that a *suction dredger* was built in the United States, it was equipped with a single 47 cm-diameter suction pipe and a deck-mounted centrifugal pump. In 1867, suction dredgers designed by the French engineer Henri-Émile Bazin were used for the construction of the Suez Canal. The *cutter suction dredger* made its appearance towards the end of the 19 th Century. It was developed to overcome the limitations of traditional suction dredgers, that were unable to deal with harder soils or even rock (IHC 2014).

From the sixties, Dutch and Belgian companies expanded their dredging fleets, becoming leading global players in *capital dredging*: construction of new large docks, sluices, and canals, or preparation of the sea-bottom for offshore-installations like windmills, cables and pipelines, in l*and reclamation*: creation of artificial islands

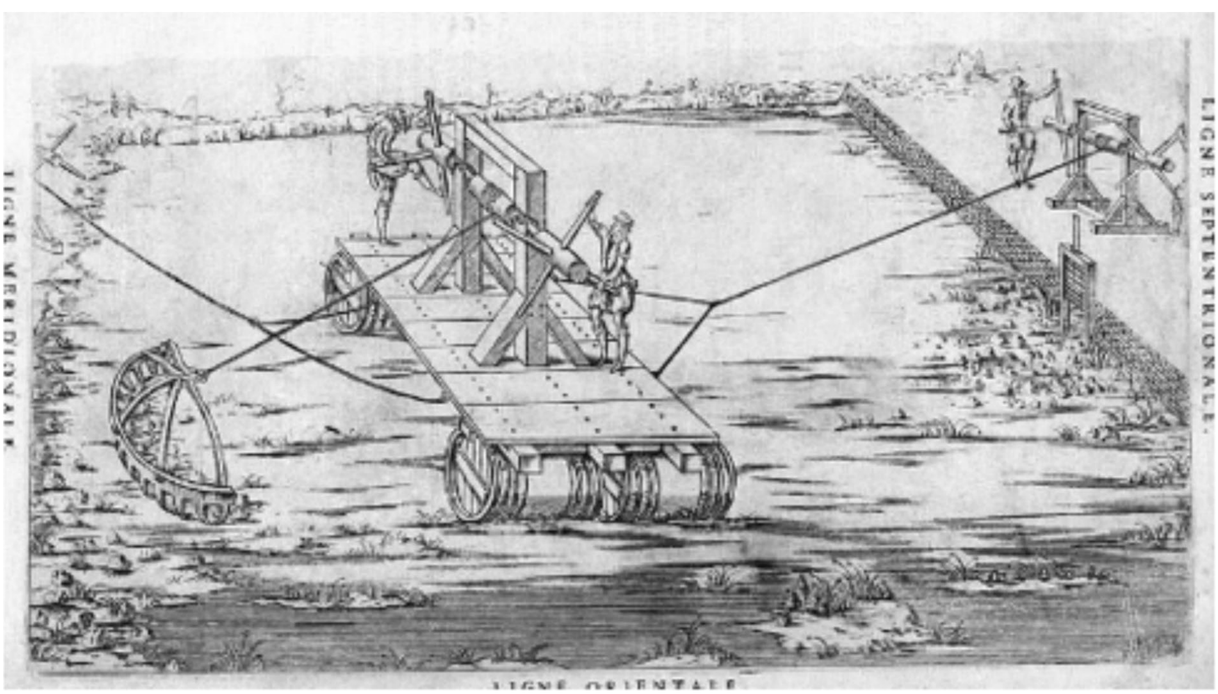


Fig. 32 Mud scraper, a dredging machine powered by man, in the sixteenth century to excavate and deepen canals and rivers. (16.th century artwork, photography by Science Photo Library)

Fig. 33 Construction of Palm Island Dubai, using dredged material for land reclamation (www.aboutcivil.org/palm-island-dubai-megastructure.html)

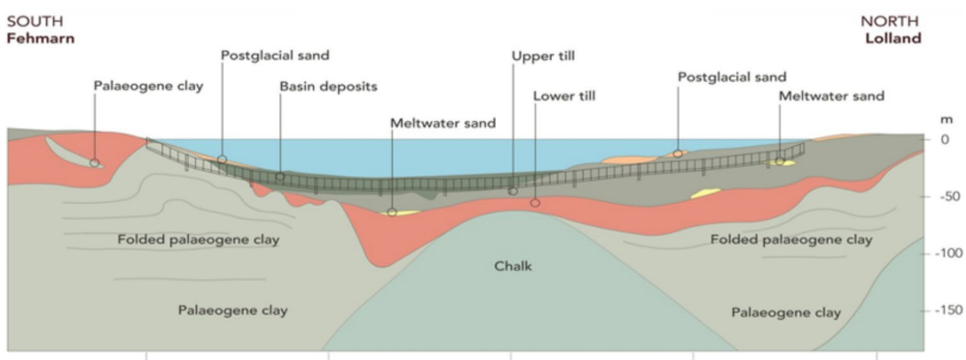


Fig. 34 Cross section through the geological ground model for the Fehmarn Belt tunneling project (Femern Sund Baelt 2013)

(Fig. 33), and in *maintenance dredging*: for waterways and harbours to correct for siltation.

The dredging process includes excavation, material raising, and the transport, and use of the dredged material for land reclamation. A challenging aspect of worldwide dredging activity is the variety of geological project conditions that are encountered. Current projects require often very strict demands concerning disturbance of environmental conditions by the dredging. Re-use of the dredged materials, preferably within the same project, is a target commonly aimed for.

The purpose of ground investigations for dredging works is to determine the volumes of the different rock and soil types to be excavated by determining the 3D distribution of the soil and rock units, for which a so-called 3D GIS based *geotechnical ground model* is prepared.

First a good geological model is needed (Fig. 34). In a second step, the subdivision of the site in geotechnically homogeneous engineering geological units is made. The geotechnical properties, that influence the dredging process (*the dredgeability*), within each of these units must be uniform. Engineering geologists are the specialists to apply the methods and techniques to collect and process the required data. An important development is the availability of 3D site investigation information systems in digital format. A good example for dredging projects is the current Fehmarn belt 18 k m long immersed tunnelling project between Germany and Denmark (Femern Sund Baelt 2013).

All data for the Fehmarn Belt tunneling project were available for the contractors in digital form during the tendering phase, including the geotechnical ground model developed by the client. The contractor can examine the information in its own GIS system (Fig. 35).

Many projects have caused difficulties for dredging companies, deploying their soft soil dredging equipment (typical in the Netherlands) in hard soil or rocky material (typical overseas in for example the Middle East). Experience in the sixties and seventies showed that *excessive wear of rock*

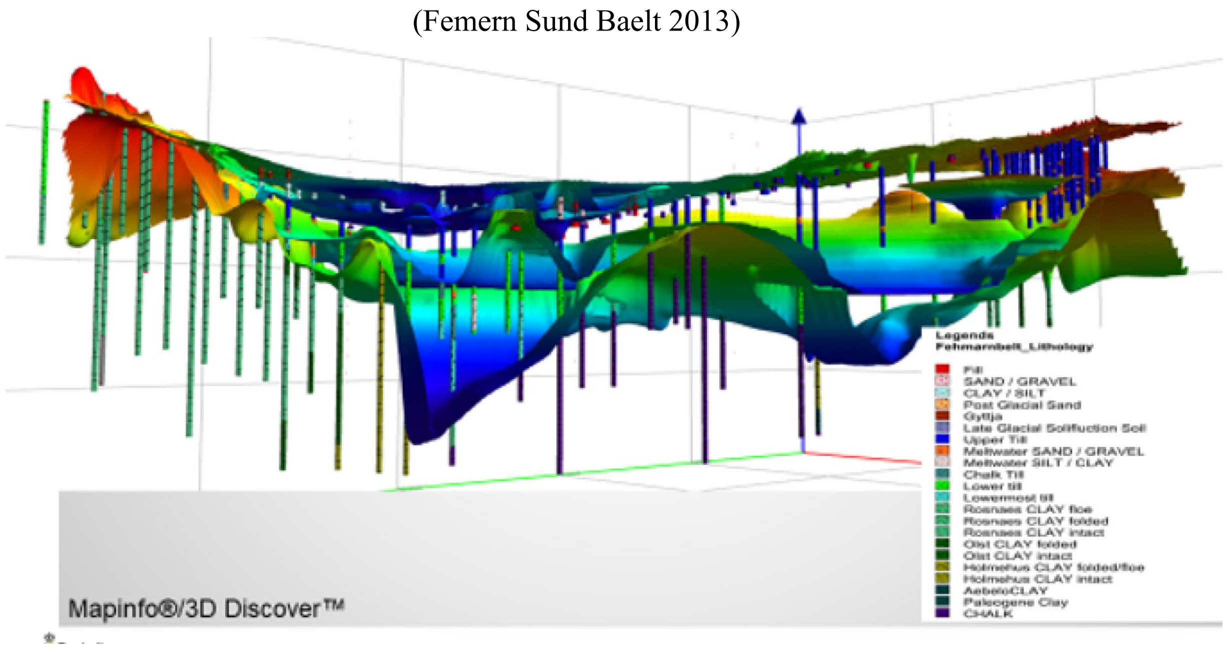


Fig. 35 3D Geotechnical Ground Model for the Fehmarn tunnel project (courtesy Boskalis)

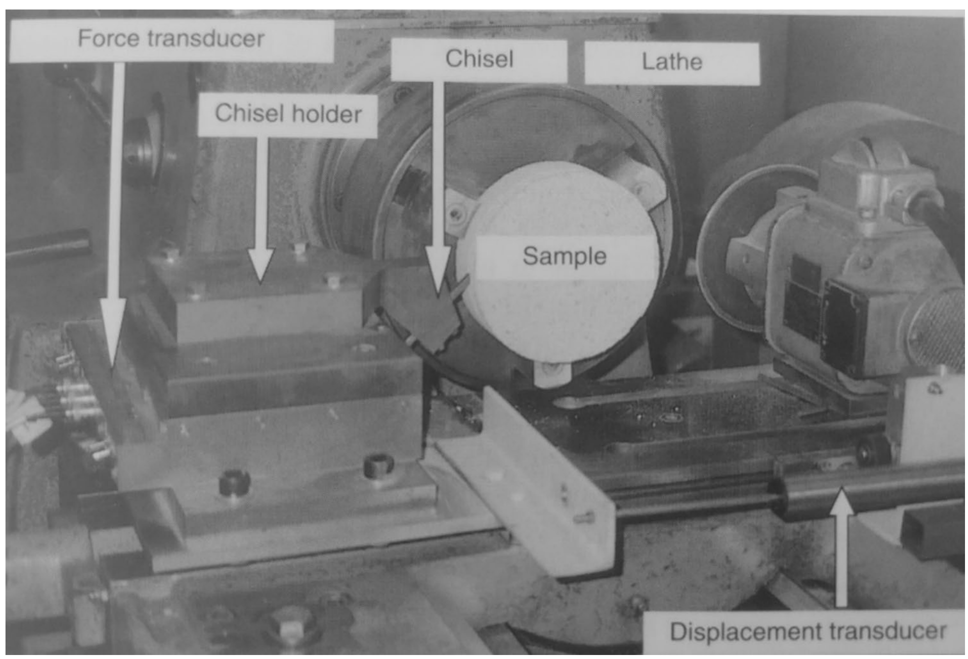


Fig. 36 laboratory scraping test machine (photograph by Deketh)

cutting tools, pipelines and pumps is a recurring problem. In particular, the amount of wear and tear of pick points on the cutter heads of the dredging equipment caused unpredictable loss of production and high costs to replace the worn and damaged parts. This led to a research project from 1989 to 2000, carried out by the Engineering Geology Department of TUD.

Research began with the hypothesis that a better understanding of the geological and geotechnical properties of rock during cutting and excavation could be part of the solution to reach a better predictability of the wear and tear of dredging equipment and other types of heavy-duty rock excavation machinery, such as rock cutting trenchers and tunnel boring machines.

For laboratory tests under controlled conditions on artificial and natural rock materials, Deketh (1995) developed a scraping test using a lathe with a special motor drive,

Fig. 37 Rock trencher Vermeer T655 Commander III

enabling the cutting velocity to be constant under the test chisel as it was driven into the rock sample disc (Fig. 36).

From the laboratory test results carried out, and from (on the job) field measurements on the wear and tear performance of rock-cutting trenchers (Fig. 37) and dredgers (Alvarez Grima and Verhoef 1999; Deketh et al. 1996), the following general *conclusions on tool wear* could be drawn (Verhoef 1997): tool wear is sensitive to the following rock index parameters:

- during shallow rock cutting (scraping), or during initial penetration of the cutting tools, wear depends on the unconfined compressive strength (UCS), the volume percentage of abrasive minerals in the rock and the grain size of these (hard) minerals.
- during rock cutting at higher cutting depths, the amount of wear depends on the Brazilian Tensile Strength (BTS), the volume percentage of abrasive minerals and the grain size of these minerals.
- bit consumption of rock trenchers is determined by wear when rock cutting takes place in massive rock and mainly by breakage of the tool when ripping occurs in discontinuous (fractured) rock.

For the *rock cutting* process the following conclusions could be drawn concerning the influence of the brittleness or ductility of the rock (Verhoef 1997):

- the density and the geometrical pattern of fractures (discontinuities) in the rock mass will determine the degree in which ripping, cutting, or a combination of both will occur.
- the compressive and tensile strength of the intact rock material should both be known to estimate the degree of brittleness or ductility
- the mineralogical composition and grain size of the minerals in the rock (by petrographic examination) must be known before conclusions can be drawn on the abrasiveness of the rock. Laboratory wear tests are less suitable for this purpose

Alvarez Grima (2000), and Alvarez Grima et al. (1999) demonstrated the usefulness of neuro-fuzzy (AI) modelling using data from their research project, and concluded that this modelling tool is useful for other applications in Engineering Geology.

Perspectives for education and research

The Netherlands has collected centuries of experience in living in low-lying areas, constantly battling encroaching waters from the sea, rivers, the ground, and in the form of rain. Unfortunately, costly mistakes have been made along the way. Presently, environmentally friendly solutions that

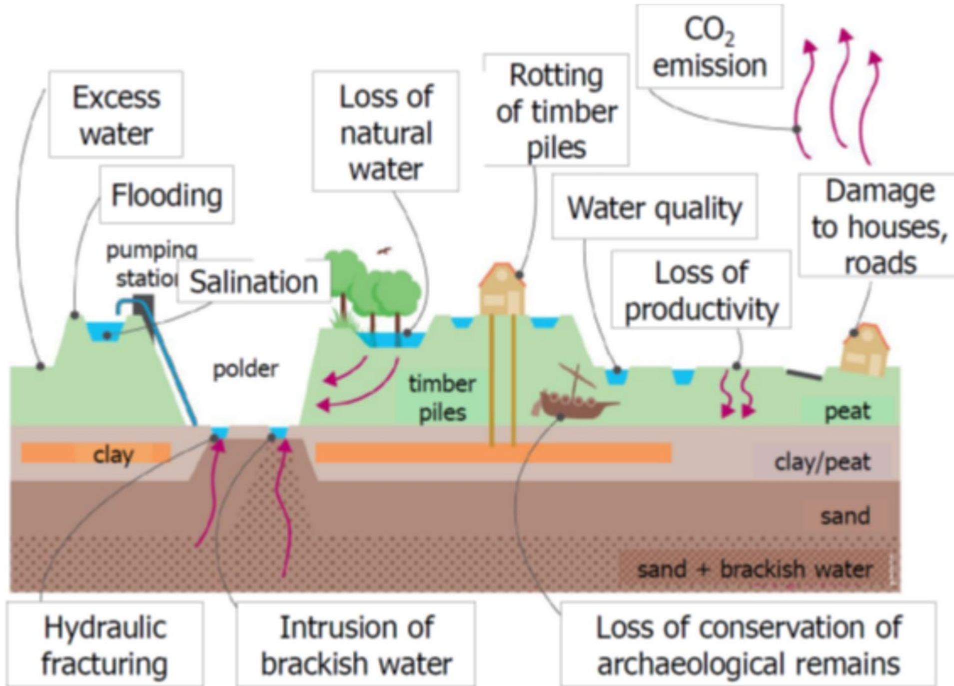


Fig. 38 Consequences of surface subsidence in polders (Planbureau voor de Leefomgeving 2016)

can mitigate, or at least not exacerbate, the impact of climate change are actively being researched.

The Dutch have reclaimed and reshaped their land over the past 2000 years, but this process is far from future proof. The renowned Dutch *polder dewatering* system, which allows low-lying terrain to be used for various purposes, including intensive agriculture, is not sustainable. It requires continuous maintenance, which imposes significant costs on society and has a considerable environmental impact. As the polders sink relative to sea level, *the risk of flooding* rises, requiring higher, broader, and stronger defences against flooding by the sea and the main rivers Rhine and Meuse. *Subsidence* also has numerous other negative effects on both the environment and society: it exacerbates *seawater intrusion*, particularly during droughts, and disrupts local ecosystems. Additionally, it exposes the top of timber foundations to air, accelerating their deterioration, which leads to damage of historical buildings (Fig. 38).

Organic soils as peat have oxidized due to the lowering of groundwater levels, causing the land surface to sink and necessitating further groundwater extraction. This cycle will continue as long as the groundwater table remains below the top of the peat layer. The oxidation of peat releases carbon dioxide, contributing to global warming. Moreover, the intensive livestock farming that thrives on the dewatered polders is a major source of ammonia, that promotes eutrophication and degrades the quality of soil, water, and air.

Sand loading, a ground consolidation technique commonly used in the Netherlands to develop residential and industrial areas or infrastructure on soft soils (Fig. 39), is another source of long-term problems.

After consolidation, creep settlement can be substantial, often causing the rupture of sewers and service lines at their connection points to structures founded on piles. These effects have led to serious financial distress for several municipalities in the western Netherlands.

Figure 38 summarizes the problems of the Dutch polders. With their understanding of the Quaternary geology of the Netherlands and the impacts of human intervention on the Dutch landscape, engineering geologists can pinpoint areas requiring priority intervention. Drawing on their broad knowledge, including expertise in chemistry, they can develop innovative strategies to positively influence the carbon and nitrogen cycles, creating a safer and more sustainable environment, less sensitive to land subsidence and its cascading effects.

Recent policies, focused on *water and soil quality*, have sparked innovative ideas, many of which are being tested in pilot field studies. Examples include:

- the installation of submerged drains to prevent land loss,
- the cultivation of peat for turf production to replace the extraction of natural peat (which releases stored greenhouse gases), and
- the alternative use of materials once considered unsuitable, such as contaminated mud dredged from waterway bottoms.

Fig. 39 Sand pre-loading for soft ground consolidation before highway construction (Courtesy Erik van der Putte)

Research in *"building with nature"* and *bio-ground engineering* is also flourishing, with, for instance, projects focused on accelerating consolidation, combating piping that weakens dikes, and addressing scouring in riverbeds and around hard offshore foundations. Moreover, if the western Netherlands were to be abandoned due to a dramatic rise in sea levels, to be relocated to the elevated areas in the eastern part of the country, engineering geologists would play a pivotal role in planning the responsible redevelopment of the nation.

The Dutch have not only engineered the surface and shallow subsurface of their country but have also *extracted coal, limestone, salt, gas, and oil* from deeper layers on an industrial scale for many decades. This has left a lasting impact, ranging from sinkholes and regional subsidence to ground(water) pollution, and to induced seismicity, in addition to greenhouse gas emissions. Proper aftercare of both past and ongoing subsurface activities is essential to building trust in new ventures, particularly within the context of the energy transition.

Today, the Netherlands is planning its *energy transition* through several initiatives, including.

- increased wind energy production in the North Sea,
- extraction of heat from deeper ground layers,
- carbon dioxide sequestration in depleted North Sea gas and oil reservoirs,
- hydrogen storage in salt caverns, and
- nuclear energy generation with the disposal of radioactive waste in the most impermeable clay layers.

Ground modelling and close monitoring are vital at all stages of these projects—from initial feasibility studies to construction, ongoing operation, and eventual decommissioning. Addressing climate change via the energy transition creates a substantial demand for highly skilled geo-engineers in the densely populated Netherlands.

Engineering geological education and research programs are designed to deliver professionals who can address the challenges mentioned, to develop application-specific subsurface models and predict the effects of human activities on the Earth's system, and vice versa. They should be capable to reduce, or at least quantify, uncertainty in their designs and predictions by incorporating geological constraints. Furthermore, the geo-engineers must be proficient in analysing large datasets using state-of-the-art tools, including artificial intelligence, while leveraging their geological expertise to fill gaps in data and critically assess AI-generated conclusions. Lastly, they should be educated as independent thinkers, ready to act as whistleblowers when necessary. In conclusion it is clear that engineering geology will play a great role in the processes necessary to prepare the Netherlands for a sustainable future, by turning challenges into opportunities.

Contributions of the Netherlands National Group to the work of IAEG

In 1974, April 24, at 20.28 h, a group of Dutch geologists and civil engineers, founded the "Ingeokring" at the ITC in Enschede, in the presence of Richard Wolters, Secretary General of IAEG at that time. The group was established within the structure of the Dutch Royal Geological and Mining Society (KNGMG), and counted in 1974 already more than 100 geologists and civil engineers working in various sectors of universities, research organisations, large construction firms, and consultancy firms. The Ingeokring was installed in August 1974 in Sao Paulo by the IAEG as its Netherlands National Group.

The Ingeokring has actively participated in international congresses, conferences and symposia, and in IAEG Commissions. These events have facilitated knowledge sharing, research advancements, and definition of best practices, promoting international collaboration and progress in our professional field:

- **1974**: IAEG Symposium "North Sea and Surroundings" at ITC in Enschede, sponsored by the IAEG commission on Sand, Gravel, and Crushed Stone, chaired by Henk Wiegers
- **1981**: the IAEG Commission on Site Investigation Techniques, chaired by David Price, with Niek Rengers as secretary, published its report in the Bulletin of Engineering Geology, No. 24, pp. 185 –226
- **1990**: The 6 th International IAEG Congress convened in Amsterdam with more than 650 participants
- **1994**: 20-year Jubilee symposium of the Ingeokring in Delft: "Engineering Geology of Quaternary Sediments"
- **2004**: First European Regional IAEG Conference in Liège, Belgium, organised together by the Dutch, Belgian and German National groups of the IAEG.
- **2026**: the 15 th International IAEG Congress in Delft.

The IAEG has acknowledged the high level of scientific achievements of the Dutch academic community by awarding the Richard Wolters Prize to two persons who carried out their PhD research work in engineering geology in the Netherlands: Dr Cees van Westen (PhD at TUD) in 1996 and Dr. Fan Xuanmei (PhD at ITC) in 2016.

Fig. 40 The Board of the Federation of International Geoengineering Societies (FedIGS) after the founding meeting at London University in January 2008. From left to right: Niek Rengers (IAEG), John Hudson (ISRM), Neil Taylor (ISSMGE), Pedro Seco e Pinto (ISSMGE) (back), Nielen van der Merwe (ISRM)(front), William van Impe (ISSMGE), Sebastien Dupray (IAEG), Fred Baynes (IAEG), and Luis Lamas (ISRM)

Conclusions

The past five decades have seen remarkable advancements in engineering geology in the Netherlands, driven by the efforts of a relatively small group of dedicated professionals. Through joint efforts in education, research, and technological innovation, the field has significantly enhanced the understanding and application of engineering geological principles. This paper celebrates these achievements.

For me personally, the early choice in my life for engineering geology as the topic of my academic studies and professional life has been a choice that I have never regretted. It has brought me a challenging combination of nature observation and translation of these observations into consequences for civil engineering. As an extra, it has brought me a working environment at ITC and TUD with creative colleagues in a stimulating academic environment, focussing on a student-oriented style of working. Unfortunately, we have lost during the last few years our colleagues Michiel Maurenbrecher, Keith Turner, Wolter Zigterman, and Roland Bekendam, who played a very important role in the ITC-TUD team.

The choice to become an active member of IAEG has brought me numerous opportunities for warm and stimulating personal contacts with many colleagues worldwide, and a platform on which it was possible to bring people together and collaborate to stimulate international cooperation. In particular I mention the collaboration with the boards of our sister societies ISRM and ISSMGE at the European and International level (Fig. 40), and, after my retirement at ITC and TUD, with my Chinese colleagues at the State Key Laboratory of Geohazard Prevention and Geoenvironmental Protection (SKLGP) in Chengdu, China.

I am proud about the role that our National Group has played in Engineering Geology nationally and internationally. As a relatively small group of dedicated professionals who put collaboration over competition. I see the award of the Hans Cloos Medal 2024 also as an honour to these colleagues.

My wife and daughters have not always been positive about my dedication to my professional life but fortunately have been able to join me often in my activities, bringing them to various interesting and challenging locations in the world and in contact with many very special personalities who formed my professional environment.

Thank you all for reading these reflective words of an old colleague who still feels young, and is deeply interested in opportunities for the sustainable and peaceful development of our future world, which I trust that you will pursue in good international cooperation.

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