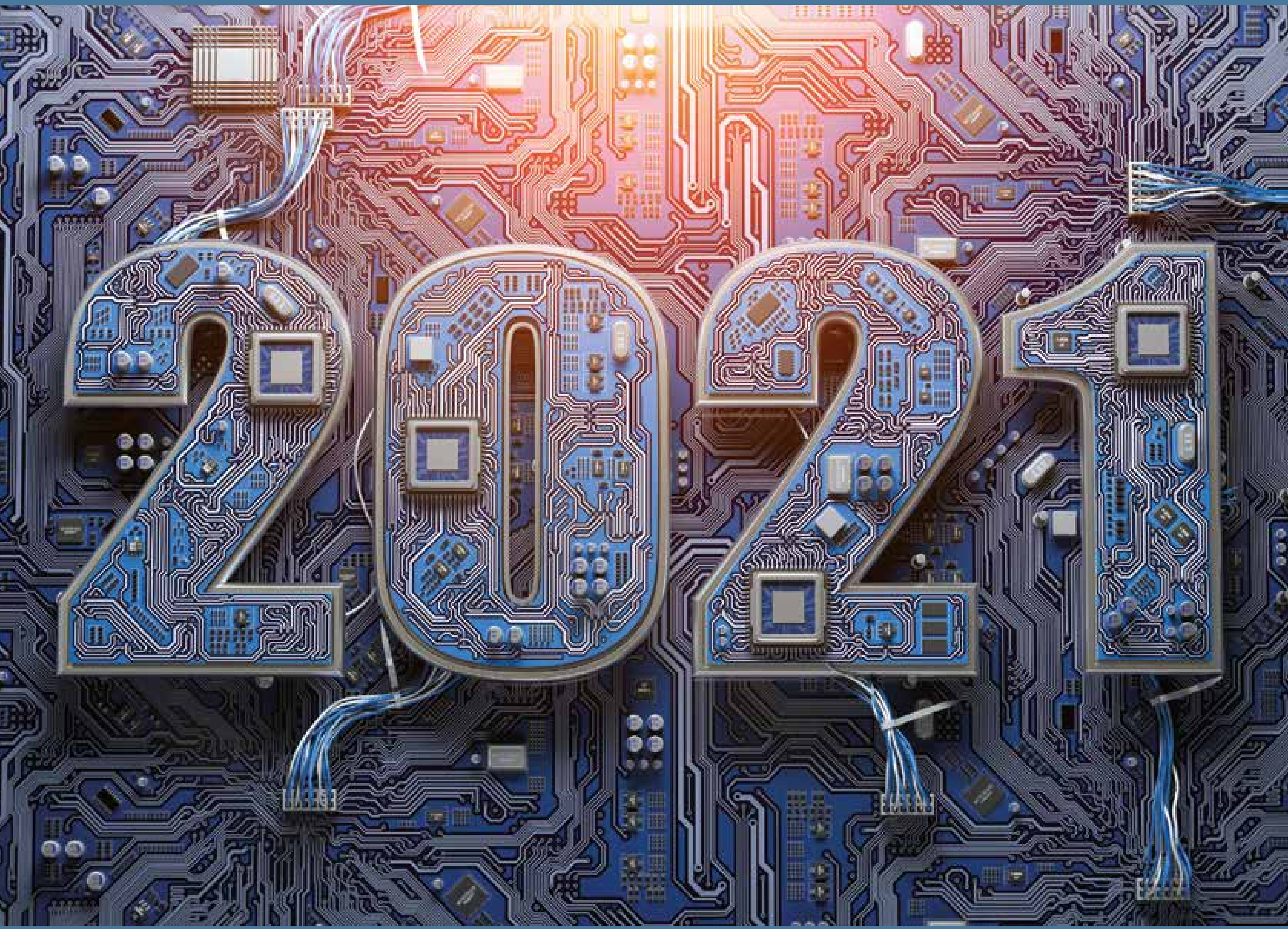
N° 51 May 2021

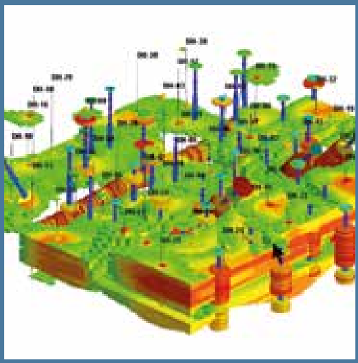
European Geologist

Journal of the European Federation of Geologists

Geotechnics – Building sustainable foundations

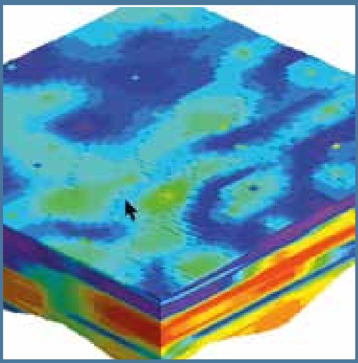
RockWorks 2021®





Geoscience Software,
Consulting & Training.

For over 37 Years.



RockWare®
Since 1983

www.RockWare.com

Contents

Foreword
M. Komac 4

Topic - Geotechnics – Building sustainable foundations

Policy trends and business opportunities for sustainability in geotechnics
I. Fernández Fuentes & J. Estaire 5

Deepening an old, verticalised pit: rock slope instability hazard assessment using a digitally augmented structural database (Flône limestone quarry, Belgium)
E. C. Frets, A. Gauffriau, N. Coussaert & J. Vanneste 15

Geotechnical challenges at Adriatic offshore gas platforms: Subsidence due to exploitation at the Izabela Exploitation Field
R. Vasiljević 20

Slope protection with an earth retaining system: respectful of natural resources and the landscape
S. Gruslin & D. Nola 25

Site appraisal in fractured rock media: coupling engineering geological mapping and geotechnical modelling
H. I. Chaminé, M. J. Afonso, J. F. Trigo, L. Freitas, L. Ramos & J. Martins Carvalho 31

News

News corner
EFG Office 39

Book review 42

Peer review:
We would like to express a particular thanks to all those who participated in the peer reviewing of this issue and thus contribute to the improvement of the standards of the European Geologist journal. The articles of this issue have been reviewed by Arda Arcasoy, David Champness, Paul Evins, Tamás Hámor, Éva Hartai, Isabel Fernandes, Magnus Johansson, Christos Karkalis, Petros Koutsovitis, Péter Pál Scharek, Roberto Alvarez de Sotomayor Matesanz, Simon Wheeler and Eoin Wyse.

Copyright and licensing:
Authors retain the copyright and full publishing rights without any restrictions for articles published in the European Geologist journal. Articles are licensed under an open access Creative Commons CC BY 4.0 license

Advertisement:
Rockware (pages 2 and 44).

Cover photo:
© Alabi Adefemi, EAGE/EFG 2016, Erosion vs Geomatics.

No responsibility is assumed by the Publisher for any injury and/or damage to persons or property as a matter of products liability, negligence, or otherwise, or from any use or operation of any methods, products, instructions or ideas contained in the material herein. Although all advertising material is expected to conform to ethical standards, inclusion in this publication does not constitute a guarantee or endorsement of the quality or value of such product or of the claims made by its manufacturer.

ISSN: 1028 - 267X
e-ISSN: 2294-8813

EUROPEAN GEOLOGIST

is published by the
European Federation of Geologists
C/O Service Géologique de Belgique
Rue Jenner 13
B-1000 Bruxelles, Belgium
Tel: +32 2 7887636
info.efg@eurogeologists.eu
www.eurogeologists.eu

EFG BOARD

PRESIDENT
EurGeol. Marko Komac
efg.president@eurogeologists.eu

VICE-PRESIDENT
EurGeol. Iris Vukovic
efg.vicepresident@eurogeologists.eu

SECRETARY-GENERAL
EurGeol. Gabriele Ponzoni
efg.secretarygeneral@eurogeologists.eu

TREASURER
EurGeol. Ruth Allington
efg.treasurer@eurogeologists.eu

EXTERNAL RELATIONS OFFICER
EurGeol. Pavlos Tyrologou
efg.externalrelations@eurogeologists.eu

EDITORIAL BOARD
Pavlos Tyrologou (Editor in chief)
Pierre Christe
Vitor Correia
Isabel Fernández Fuentes
Hans-Jürgen Gursky
Éva Hartai
Michael Neumann
Edmund Nickless

Translations by
Keyla Ramirez
Erwin Frets

COPY EDITOR
Robin Lee Nagano
robin.nagano@eurogeologists.eu

STAFF AND LAYOUT EDITOR
Anita Stein
anita.stein@eurogeologists.eu

Foreword

EurGeol. Marko Komac, EFG President

Welcome to the 51st issue of the *European Geologist* journal! *Tempus fugit* and in front of you is yet another issue of our great journal. It is my pleasure to welcome the newly appointed Editor-in-Chief, Dr. Pavlos Tyrologou, who I am certain will do a great job and will successfully lead the EGJ in the future by delivering relevant societal contents.

With these pertinent contents in mind, we bring you interesting and informative contents in this issue, which is devoted to a very practical branch of geology –geotechnics. In a way, geotechnics is the link between geology or engineering geology and civil engineering and hence plays an important role in bringing the geological knowledge to the end user, the society.

At the beginning, the contributors exploit the opportunities and possibilities of the geotechnics in the new European Green Deal programme. Following this general overview, articles address real cases that experts faced during their work and present various solutions. These include either the integration of novel computer-based approaches like GIS with geovisualisation to digitally augment geotechnical maps for solving small to medium-scale problems, or advanced approaches, based on mechanical-technical or bio-technical solutions that are focused on solving medium to large-scale problems. Undoubtedly there are more approaches that could be presented under this topic and based on the huge pool of experts working on various geotechnical applications, I'm strongly convinced there will be more articles to be published in the EGJ in the future.

Dear Reader, the 51st issue of the *European Geologist* brings you again insights in novel, interesting, and innovative approaches in geotechnics. Take the time to read this issue of the European Geologist and dive into the presented challenges and proposed solutions. They might spark some new ideas for your future endeavours. Very best regards!

Marko Komac

Policy trends and business opportunities for sustainability in geotechnics

Isabel Fernández Fuentes[1] and José Estaire[2]*

European Green Deal, the EU growth policy to become the first climate-neutral continent by 2050, opens huge opportunities to geotechnics related activities, mainly focused in four of its nine policy areas: Clean energy, Sustainable industry, Building and renovating, and Climate action. This paper explains firstly the legal and regulation framework in which European Green Deal policies will be developed. As a second step, for each of these policy areas, topics related to geotechnics and its studies and projects will be presented, including related European EN standards, regulations and examples.

Le 'European Green Deal', la politique de croissance de l'UE à devenir le premier continent neutre en carbone d'ici 2050, ouvre d'énormes opportunités aux activités liées à la géotechnique, principalement axées sur quatre de ses neuf domaines politiques : énergie propre, industrie durable, construction et rénovation, et action climatique . Cet article explique tout d'abord le cadre juridique et réglementaire dans lequel les politiques européennes du Green Deal seront développées. Dans un deuxième temps, pour chacun de ces domaines politiques, des sujets liés à la géotechnique et à ses études et projets seront présentés, y compris les normes européennes EN, réglementations et exemples associés.

El Pacto Verde Europeo, "European Green Deal" en su versión original, la principal política de crecimiento de la UE, abre enormes oportunidades a las actividades relacionadas con la Geotecnia, basadas fundamentalmente en cuatro de sus nueve áreas temáticas (policy áreas): Energía Limpia, Industria Sostenible, Construcción y Renovación, y Acción Climática.
Este artículo explica primeramente el marco legal y regulatorio en el que se desarrollarán las políticas del Pacto Verde Europeo. Posteriormente, para cada una de las áreas temáticas, se presentarán temas relacionados con los estudios y proyectos de Geotecnia, incluyendo algunas normas EN europeas, regulaciones y ejemplos.

Introduction

Global overview of the European Green Deal

In December 2019, the European Union presented its new European Green Deal as its main growth policy. In September 2020, the Commission president, Ursula von der Leyen, proposed to the European Parliament that Europe's policy lead it to become "the first climate-neutral continent by 2050". In that line, the Commission proposed to increase the 2030 target for emissions reduction from 32% to at least 55%. ***Figure 1*** illustrates the key initiatives within the European Green Deal.

The EU aims to be climate neutral in 2050 and, to reach this target, it calls for action in all sectors of the economy, including mainly:

- investing in environmentally-friendly technologies,
- supporting industry to innovate,
- rolling out cleaner, cheaper and healthier forms of private and public transport,
- decarbonising the energy sector,
- ensuring buildings are more energy efficient, and
- working with international partners to improve global environmental standards.

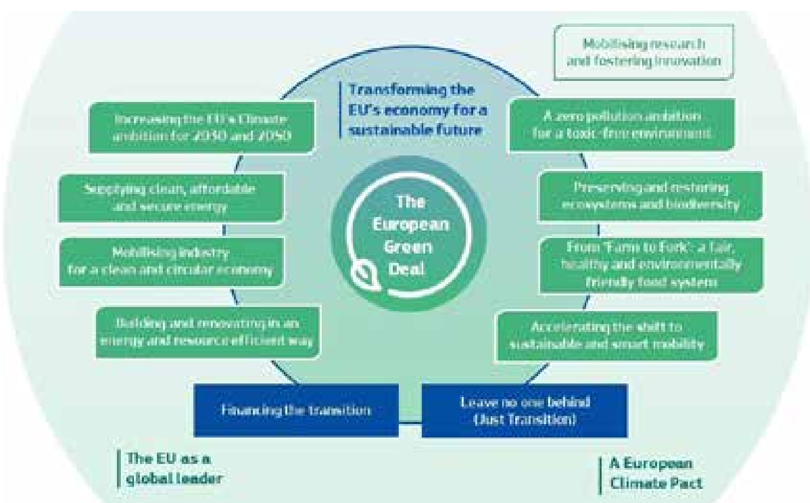


Figure 1: Key initiatives within Green Deal (COM(2019) 640).

[1] European Federation of Geologists – (EFG), Brussels, Belgium
[2] Laboratorio de Geotecnia – CEDEX, Madrid, Spain
* isabel.fernandez@eurogeologists.eu

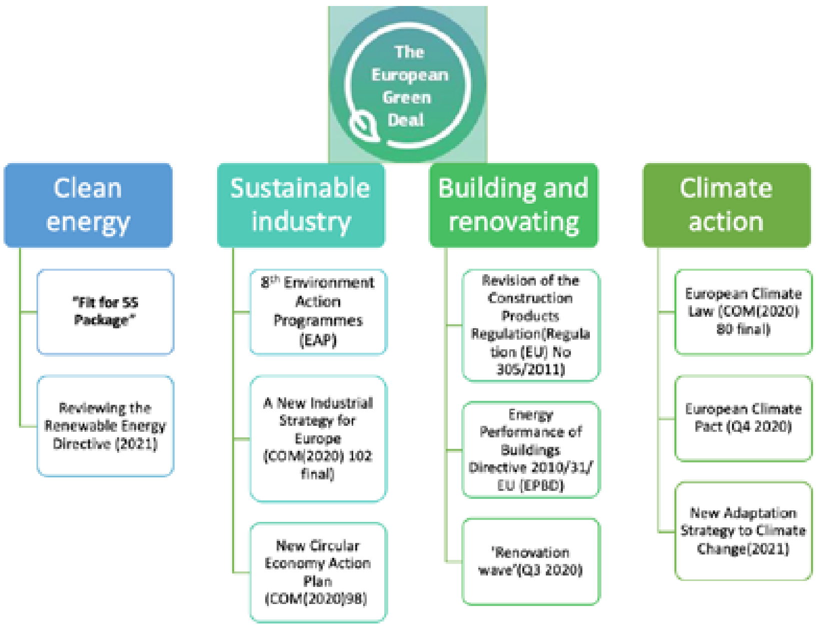


Figure 2: Green Deal policy areas and regulations relevant for geotechnical studies.

Figure 3: Mission-oriented innovation policy centred on the European Green Deal.

The EU will also provide financial support and technical assistance to help those countries and regions which are most affected by the move towards the Green Economy. EU investment in the recovery to a green and digital economy and society amounts to € 1.81 trillion over the next seven years (Recovery Plan for Europe, 2021), which is ten times greater than the Marshall Plan to reconstruct Europe after WW II (European Budget, 2021-2027)

This comprehensive policy of regulations, investment and reforms affects almost all industrial sectors, i.e. energy, manufacturing and circular economy, transport, agricultural/food industries, and real estate and construction. EU focuses its industrial policy for SMEs (small and medium-sized enterprises) on creating business opportunities from the current green and digital transition. This includes new legal instruments to build European relevant value chains linking EU-wide firms to local SMEs in strategic sectors (e.g. batteries, hydrogen, circular economy, and bioeconomy). This package also includes a new European skills agenda.

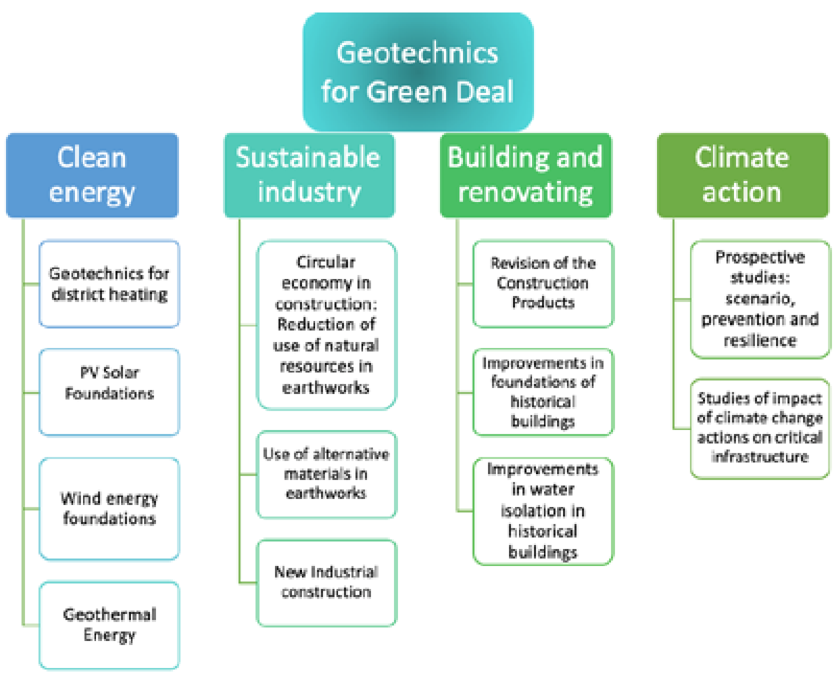


Figure 4: Relevant topics for geotechnics in each Green Deal policy area.

The European Green Deal centres on nine policy areas: biodiversity, from farm to fork, sustainable agriculture, clean energy, sustainable industry, building and renovating, sustainable mobility, eliminating pollution, and climate action. Among these policy areas, geotechnics has a relevant role in four areas: clean energy, sustainable industry, building and renovating, and climate action.

This article will examine the objectives for these policy areas and will establish the relevant contribution of geotechnical studies to obtain such goals. ***Figure 2*** illustrates, in more detail, the four main Green Deal policy areas and regulations relevant for geotechnics.

Besides the regulatory instruments, the EU is also launching a new mission-oriented innovation policy with a clear focus on sustainability. Five EU missions are under elaboration, expected to be fully operational at the end of 2021. Four of these five missions are linked to the European Green Deal: Clean soil, Clean oceans and inland water, Climate adaptation, and 100 Climate-neutral cities as seen in ***Figure 3***. These missions will open up new funding for technological development, innovations and deployment across EU. Two of these missions are particularly relevant for the geotechnical studies. The mission on "100 climate-neutral cities" will accelerate sustainable construction and energy systems in these cities, while the mission on Climate adaptation will stimulate technological innovation and deployment of new solutions to resilience and climate-stress such as flooding or landslide prevention in 200 regions and communities across EU. Industry will be directly involved in the missions as well as public actors such as regulators, planners and policy administrators of investment projects in innovation and new infrastructures.

Green Deal policy areas relevant for geotechnics

For each of the selected political areas, the article presents topics of relevance to geotechnics, as shown in ***Figure 4***. The list of selected topics is not exhaustive, but it does emphasise relevant topics in our days and has great capacity for employment, innovation and research.

Additionally, ***Table 1*** summarises the ground properties needed in geotechnics activities related to the selected topics. The ground properties selected are based on the classification used in the second generation Eurocode 7 (to be delivered around 2025). The Green Deal topics and the ground properties are presented in a matrix connected for four levels of needs, from compulsory to low relevance. The objective of this matrix is not intended to be exhaustive, and exclusive of other relevant issues, but it does help to visualise the important role of geotechnics in the implementation of the Green Deal.

Professionals in geotechnics studies and their contribution to the Green Deal

It will be necessary to ensure high quality in the geotechnics studies that will contribute to the Green Deal. Second generation Eurocode 7, EC7 (to be delivered around 2025) establishes, in its draft Annex D, one possible way for verifying the assumption that the design and collection of information is performed by competent persons. This document provides guidelines on requirements for competence of persons responsible for either geotechnical design or ground investigation process.

Based on this document, the persons responsible for ground investigation and geotechnical design should have appropriate qualifications and experience within their respective field that includes:

- A diploma demonstrating successful completion of tertiary studies in a relevant field;
- Professional experience in ground engineering;
- Continuous Professional Development (CPD) in ground engineering;
- Membership of a relevant Professional Register, if available or required in individual countries.

These elements plus the Code of Ethics are the pillars for the European Geologist title, (Fernández Fuentes, 2015). The applicants for the title of European Geologist must demonstrate their professional experience through the application form, supporting documentation, a professional practice report and a professional interview. They must demonstrate that they have obtained sufficient knowledge and experience, over

Table 1: Summary of the ground properties needed in geotechnics activities related to the different policy areas defined in the European Green Deal.

Ground properties needed	Clean Energy				Sustainable industry			Building and renovating			Climate action	
	District heating	PV Solar foundations	Wind energy foundations	Geothermal energy	Circular economy in construction	Use of alternative in materials earthworks	New industrial construction	Revision of construction products	Historical buildings foundations	Historical buildings water isolations	Prospective studies	climate change impact on critical infrastructures
Ground investigation	C	C	C	C	C	C	-	-	C	C	C	C
Groundwater conditions and Geohydraulic	H	H	H	H	H	H	-	-	H	H	H	H
Geohydraulic properties	H	H	H	H	M	M	-	-	H	H	H	H
Ground description and classification of ground	H	M	M	H	H	H	-	-	H	H	M	M
Ground physical and chemical properties	H	H	H	H	H	H	-	-	H	H	M	M
Ground strength properties	L	H	H	L	L	L	-	-	H	H	H	H
Ground stiffness properties	H	H	H	H	H	H	-	-	H	H	H	H
Cyclic response and seismic properties	H	H	H	M	H	H	-	-	H	H	H	M
Ground geothermal properties	H	H	M	H	L	L	-	-	M	M	M	L
Properties of material for reuse	M	L	L	M	H	H	H	H	L	L	L	L
Contaminated or aggressive ground	M	H	H	L	H	H	M	M	H	H	L	L

Legend: C = Compulsory; H = High relevance; M = Medium relevance; L = Low relevance

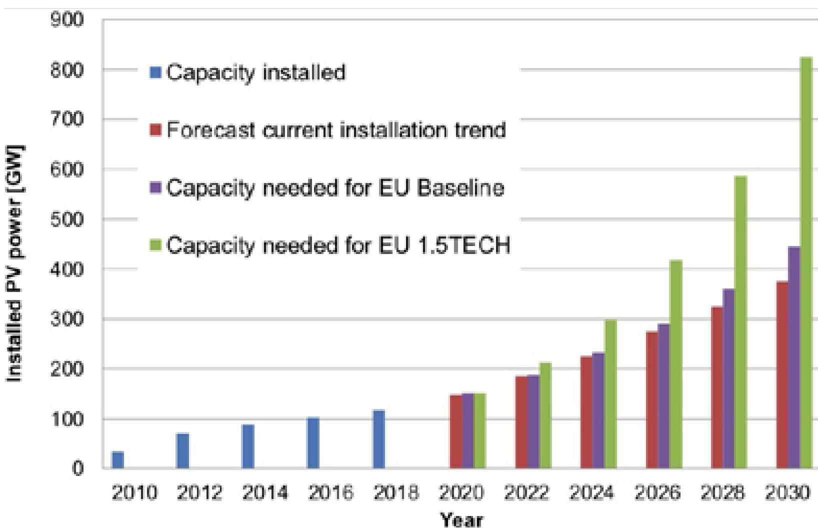


Figure 5: Actual and projected photovoltaic installations from 2010 to 2030 (EC JRC, PV status report 2019).

a combined minimum total of nine years (education and professional practice combined), to be able to work independently and to be capable of supervising others. An applicant who is only able to undertake routine activities or who requires extensive supervision would not meet the requirements for the award of the title of European Geologist. The mobility of geologists enabled by the EurGeol title is now boosted by a web platform launched in 2019. It allows companies and organisations to search for EurGeols active in one specific country and/or one specific professional geology domain (Fernández Fuentes *et al.*, 2021). This instrument could be a great support to guarantee qualified and competent people in the future context of specialised geotechnics jobs to support the Green Deal.

Geotechnics and clean energy

Specific regulations

Decarbonising the energy system is critical to reach EU's climate objectives. The European Commission proposed to increase the 2030 target for emission reduction to at least 55%. Relevant energy legislation will be reviewed and where necessary revised by June 2021. EU Member States will subsequently update their national energy and climate plans in 2023, to reflect the new climate ambition. The "Fit for 55 Package" will review three European Directives: the Renewable Energy Directive; Energy Efficiency Directive; and Energy Performance and Building Directive, in line with the increased 2030 target for emission reduction.

EU's ambition is to develop a power sector based largely on renewable sources. The revision of the Renewable Energy Directive in the European Green Deal states that the targets and measures set in the directive should be ambitious enough to reduce greenhouse gas emissions by at least 55% by 2030. This policy is backed by a more energy efficient and circular energy system. It facilitates renewables-based electrification, and promotes the use of renewable and low-carbon fuels including clean hydrogen in those sectors where electrification is not yet a viable option, such as transport. The Commission planned to adopt the revised Renewable Energy Directive in the second quarter of 2021. EU countries are required to draft National Energy and Climate Plans (NECPs) for the period 2021–2030, outlining how they will meet the new 2030 targets for renewable energy and for energy efficiency.

Geotechnical studies have an important role to ensure good quality in the development of some crucial renewal sources. From the different clean energy supplies we have selected four areas relevant for geotechnical studies: district heating; solar energy; wind energy; and geothermal energy.

Geotechnics for district heating

District heating (DH) has been for many decades a well-established industry for supplying heat in several countries. Surplus heat from power plants and industrial processes is used as well as renewable heat sources such as solar thermal, geothermal and heat from biomass combustion. The success of heating distribution to the final users depends significantly on the pipeline network (Villalobos *et al.*, 2018). The interaction between underground district heating pipelines and the surrounding soil is fundamental to avoid problems of ruptures, leaks, and as a consequence a decrease in the effectiveness of the DH system. There are different conditions being tested such as thickness of insulation materials, temperature ranges and bedding soil type. Details of the piping and instrumentation arrangements as well as soil geotechnical characteristics are very important for an efficient DH system (Villalobos *et al.*, 2019b). For example, it was found that when temperature increased from ambient conditions up to 90 °C, pipes were moving all along their length. Moreover, after a temperature drop from 90 to 20 °C during 20 days and subsequent increase to 90 °C again, axial displacements did not return to the same values as before (Villalobos *et al.*, 2019a).

DH plays an important role in the implementation of future sustainable energy systems. However, the present district heating system must be transformed into low-temperature district heating networks, interacting with low-energy buildings as well as becoming an integrated part of smart energy systems (Mathiesen *et al.*, 2015). According to Mathiesen et al. we are looking now at the fourth generation of DH, whose different phases of development were the following:

- First generation, 1880–1930 - steam
- Second generation, 1930-1970 – hot water > 100 °C
- Third generation, 1970–present – Hot water < 100 °C
- Fourth generation, < 70 °C

Denmark is aiming for a 100% fossil-free heating sector for buildings by 2035 where DH with a supply temperature of 55–50 °C is central to the solution (Brand & Svendsen, 2013). Sweden is betting on the new generation of DH that will allow integrated smart energy systems (Klemetz, 2019)

Until now, the effect of seismic loading has not been contemplated in the design standards of District Heating and Cooling (DHC) networks, since this technology was originally adopted in northern Europe, which I characterised by low earthquake vulnerability. Nevertheless, an increasing number of countries, including those in seismic areas, are using DHC solutions due to the higher energy efficiency compared to individual heating systems. Seismic regions are one of the most hostile environments for buried pipelines due to the effects of transient ground deformation (TGD) caused by seismic wave propagation, and permanent ground deformation (PGD) like faulting, landsliding, lateral spreading and buoyancy due to liquefaction (Banushi *et al.*, 2018). Geotechnical studies will support the prevention of this kind of risk.

A very important ground property to take into consideration in DH projects is ground thermal conductivity. In an enhanced study in the Ljubljana DH system, which includes 245 km of highly diversified pipelines, the effect of the soil thermal conductivity coefficient (λs) on the heat loss from pre-insulated pipes during operation was demonstrated (Perpar *et al.*, 2012). In this respect, it is interesting to highlight that the DH second generation, Eurocode 7, includes a table with the test standards to be used to measure both thermal conductivity and thermal diffusivity, two of the main geothermal properties of the ground, as a signal of the importance of these ground properties in geotechnics coming in the near future.

Geotechnics for solar energy

Foundation selection is critical for the cost-effective installation of photovoltaic (PV) solar panel support structures. The installation of large areas of solar PV has led to the development of geotechnical companies specialised in surveys for solar PV. In Europe the capacity is expected to triple before 2030 (***Figure 5***).

Europe's solar PV grew 104% in 2019, according to statistics published in December 2019 by SolarPower Europe, (Simon, 2019) an industry association. The increase in solar PV capacity in Europe is expected to create new job opportunities. Geotechnics professionals will be required for the energy transition working with solar PV.

Lack of proper investigation of subsurface conditions can lead to selection of inappropriate foundation types and can result in costly change orders and delays to the job completion date (Perez, 2019).

Each PV solar site is unique in its geological complexity. A solar PV site should first be checked by digging test pits at approximately 5 to 10 locations for each megawatt of installation. Enough test pits should be dug so that the number is statistically relevant.

A complete geotechnical study will include a limited number of test bores noting soil type, refusal, and water table. Also the geotechnical report will note corrosive factors to help in selecting the correct type of corrosion protection needed for the foundations.

Geotechnical reports often tend to be conservative in their embedment depth recommendation, so some pull tests should be conducted before beginning foundation construction in order to attempt to minimise embedment depth and thus the length and cost of screwed or driven foundations. A pull test uses a strain gauge to measure vertical and lateral resistance up to the forces required by the PV support structure engineer's calculations for wind and snow load requirements.

There are four principal types of foun-

Figure 6: Example of a toppled wind turbine (Nova Scotia Power's Nuttby Mountain) ***https://ontario-wind-resistance.org/2011/02/03/nearly-all-22-turbine-foundations-cracked/***.

dations commonly utilised in this kind of application: driven piles, helical piles, earth screws, and ballasted foundations. The site's geotechnical properties will determine the most appropriate type of foundation (Bushong, 2014).

Geotechnics for wind energy

The wind energy sector is given a very important role in order to meet some very ambitious targets with respect to usage of renewable energy by 2020 and 2030. According to Wind Europe's Central Scenario, 323 GW of cumulative wind energy capacity will be installed in EU by 2030, 253 GW onshore and 70 GW offshore. That would be more than double the capacity installed at the end of 2016 (160 GW). With this capacity, wind energy would produce 888 TWh of electricity, equivalent to 30% of EU's power demand (Wind Europe, 2017). This prediction of 2030 is based on the previous European challenge of 32% decarbonisation. The current decarbonisation increase of the Green Deal to 55% will substantially increase the energy capacity of wind energy.

It is worth noting that both onshore and offshore wind farms require extensive foundations and consequently specific geotechnical studies.

Onshore Wind Energy projects require geotechnical exploration. Wind energy projects are often fast-paced and cover large terrains. Such conditions result in increased geotechnical risks and require specially adapted geotechnical exploration and data analysis techniques that are designed to manage risks at different stages of project development. Ben-Hassine & Griffiths (2013) mention some general geotechnical studies according to the different wind energy project phases:

- *Development Phase:* the initial environmental permitting process presents an opportunity to identify geotechnical conditions that carry cost implications, as most environmental permitting applications include an evaluation of geo-environmental conditions.
- *Design Phase:* a full ground investigation must be carried out to finalise the design. The full investigation should confirm and refine the assessment of the risks identified during the preliminary investigation and should assess any additional risks that may be uncovered, such as: groundwater level; flooding conditions; bedrock depth; slope stability and landslide; mine subsidence; karst subsidence; expansive soils; frost heave; permafrost; collapsible soils; corrosion (high sulphates, high salinity); seismicity/liquefaction; and the soil's electrical and thermal conductivity.
- *Construction Phase:* geotechnical activity is typically limited to quality assurance testing which serves to confirm and ensure that the design assumptions remain valid.

On the other hand, Offshore Wind Energy has a special focus in the cost-reduction of the overall process from planning to design and maintenance phases. In terms of efficiency, during the design phase, the wind turbine foundation faces different geotechnical challenges. In order to determine and provide an accurate characterisation of the subsurface soils, an extensive site investigation must be performed. The anticipated geology and the overall background description of the area play an important role in the pre-assessment of the ground conditions (Kellezi, 2015).

Geothermal foundations

The "Fit for 55% package" in 2030 will overhaul Europe's energy sector, especially the heating and cooling market, which is poised to deliver the needed additional carbon emission reductions. In a heating and cooling sector that locks out fossil fuel consumption and is focused on mainstreaming renewable heating and cooling, it is essential to have a robust framework to allow the market uptake of renewable heating and cooling technologies.

Geothermal energy provides renewable heating, cooling and electricity for sustainable building, agriculture and industry. Geothermal energy can be produced anywhere. The average temperature at shallow depth is constant at around 10–15 °C. The various shallow geothermal methods to transfer heat out of or into the ground are horizontal ground heat exchangers; borehole heat exchangers; energy piles; and groundwater wells (Geotrainet, 2011). The use of geothermal methods in foundations is related to the shallow geothermal energy supported by heat pumps.

Geothermal heat pumps provide the most efficient and cheapest energy in Europe, because they operate using constant underground temperature. The geothermal heat pump or ground source heat pump (GSHP) market has hit the milestone of 2 million heat pumps installed in Europe; the undeniable success of Sweden is a powerful example that geothermal heat pumps can be a mainstream solution for heating and cooling. It is also a testimony of how policies can shift the heating and cooling market away from fossil fuels towards renewable sources such as geothermal heat pumps (EGEC, 2019).

GSHP is already a well-known technology in some European countries like Sweden, Germany or Switzerland, but still emerging in many others, as shown in ***Figure 7***. To support the Renovation Wave Initiative (see the following section), shallow geothermal based heating systems can also be part of a stable and efficient catalogue of heating and cooling solutions.

One of the strategies for designing geo-

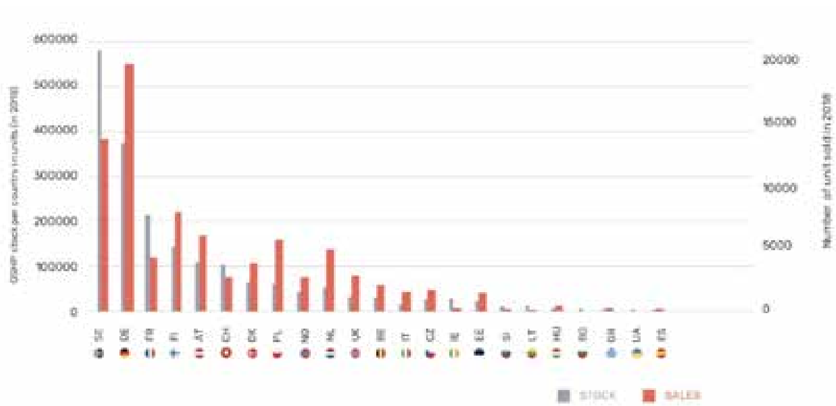


Figure 7: Number of GSHP units sold in 2018 (EGEC, 2019).

technical structures for enhanced sustainability should include geothermal elements in the geotechnical structure. The structures linked to the reinforcement of building construction are being used for GSHP. The principle of a GSHP integrated in the geotechnical structure is to transfer heat to and from the ground. In cool weather, the ground natural heat is collected through the loops and carried by heat transfer fluid to a heat pump in the building. In warm weather, the process is reversed in order to cool the building.

One of the best-known geothermal foundation structures is the so-called "geothermal pile". Piles used in foundations are long, slender, columnar elements that are installed into the ground to transfer structural loads to competent grounds. They are typically made from steel or reinforced concrete or less often timber. Geothermal piles consist of pile foundations combined with closed-loop ground source heat pump systems. Structural piles are turned into heat exchangers by adding one or more loops of plastic pipes down their length, as shown in ***Figure 8***.

In the field of standardisation, it is worth highlighting the efforts done by CEN through its technical committee CEN/TC 451 "Water wells and borehole heat exchangers" to deliver the standard EN17522, 2020Design and construction of borehole heat exchangers. This document covers standardisation in the field of geological and environmental aspects, design, drilling, construction, completion, operation, monitoring, maintenance, rehabilitation and decommissioning of borehole heat exchangers for uses of geothermal energy. Other CEN committee documents related to this topic is the committee CEN/TC 341 "Geotechnical Investigation and Testing" that in collaboration with ISO, in 2015 delivered the standard EN-ISO 17628:2015- "Geotechnical investigation and testing - Geothermal testing - Determination of thermal conductivity of soil and rock using a borehole heat exchanger".

Geotechnics and sustainable industry

Specific programmes

One of the aims included in the European Green Deal action plans is to boost the efficient use of resources by moving to a clean and circular economy. The paths to obtain these objectives are diverse and among others, a sustainable industry based on the circular economy and focused on the use of recycled materials must be highlighted.

From the point of view of the construction sector, the reduction of non-renewable natural resource extraction has encouraged the increase in waste valorisation, taking into account that this sector is responsible for 50% of the consumption of natural resources (European Commission, 2001). Another issue is the concentration of waste from industrial activities and urban expansion, which are concerning from an environmental point of view.

The EU has set itself the objective of becoming sustainable, and this is tackled by Environment Action Programmes (EAP). The 8th EAP will guide European environmental policy until 2030. The list of policy areas of this programme includes "Waste and recycling", which aims to contribute to the circular economy by extracting high-quality resources from waste, as much as possible.

The circular economy in construction

All these factors make it necessary to propose alternatives to the use of natural resources, and the valorisation of wastes, even, it is possible to mix these two goals by using the wastes as construction materials. A good example of this kind of measures is the rate for recovering Construction and Demolition Wastes (CDW), which reached 89% in 2016 (Eurostat 39/2019).

Despite these high recycling rates, on average only 12% of material resources used in the EU in 2016 came from recycled products and recovered materials, thus saving extraction of primary raw materials (Eurostat 39/2019). The high amounts of material consumption needed in the construction field seem to be a good opportunity to increase recycling rates, as has already been achieved for CDW.

Use of alternative materials in earthworks

Nowadays, inside the European Committee for Standardization (CEN), the Committee CEN/TC396/WG7 is formed by a group of experts who are developing a Technical Report on "Alternative materials in earthworks". The main goal of this document is to list the recycled materials resulting from the processing of inorganic mineral material previously used in construction, that are used in earthworks across Europe. The report will also include the most relevant geotechnical properties, examples of applications and environmental issues. Although this document is not available yet, it is a liaison with another CEN group, CEN/TC154/WG12 "Aggregates for secondary sources". The Technical Committee CEN/TC154 has prepared the document CEN/TS 17438:2020 (E) "Source materials considered in the development of the Aggregate standards of TC 154" (CEN/TS 17438). It includes an inventory list with source materials for aggregates that is almost the same as that to be included in the Technical Report elaborated by CEN/TC396/WG7. ***Table 2*** shows some of the sources and specific materials that will be

Table 2: Examples of some alternative materials to use in earthworks and their sources.

Source	*Specific materials*
Construction and demolition recycling industries	*Reclaimed concrete*
	Reclaimed bricks, masonry
	Mix of reclaimed concrete, masonry, asphalt, and hydraulically bound materials
Municipal solid waste incineration industry	*Municipal incinerator bottom ash*
	Municipal incinerator fly ash
Coal power generation industry	*Coal fly ash*
	Coal bottom ash
Iron and steel industry	*Granulated blast furnace slag*
	Electric arc furnace slag
Non-ferrous industry	*Copper slag*
	Zinc slag
Mining and quarry industry	*Red coal shale*
	Black coal shale
Excavated natural materials	*Tunnel arisings*
	Dredge spoil
Other combustion residues	*Biomass ash*
	Oil shale ash
Other	*Shredded tyres*

Figure 8: Demolition of Atletico de Madrid Stadium and CDW pile waiting to be re-used (Credit: Pedro Juan García Guzmán).

included in the Alternative Material list for their use in earthworks.

New industrial construction

EU new industrial policy focuses on two drivers which will transform European industry: the Green Transition, supported by the European Green Deal, and the Digital Transition, supported by EU's digital strategy and global competitiveness leveraging the single market to set global standards ((COM(2020) 102 final). Within this policy frame, EU is launching several concrete initiatives in the period 2020- 2022. Here are some examples:

A relevant example is related to modernising and decarbonising energy-intensive industries. The European Green Deal sets the objective of creating new markets for climate neutral and circular products, such as steel, cement and basic chemicals. The EU Emissions Trading System Innovation Fund will help deploy other large-scale innovative projects to support clean products in all energy-intensive sectors.

Geotechnics in building and renovating

The construction, use and renovation of buildings require significant amounts of energy and natural resources, such as sand, gravel and cement. The Green Deal policy action "Building and Renovating" aims to double the current rates of renovation of public and private buildings in the next decade.

To reduce the resources for construction, the design of buildings should be in line with the circular economy. The European Commission will review the Construction Products Regulation (Regulation (EU) No 305/2011). The use of alternative materials and the circular economy approach mentioned in the precedent item should be implemented in order to achieve this objective. Geotechnical studies will evaluate the behaviour of these materials to achieve the sustainable construction objectives.

In October 2020, the Commission presented its Renovation Wave strategy as part of the European Green Deal. The strategy contains an action plan with specific regulatory, financing and enabling measures to boost building renovation. Its objective is to at least double the annual energy renovation rate of buildings by 2030 and to foster so-called "deep renovation", which combines energy efficiency with more sustainable heating and cooling, and when relevant digital applications.

The revision of the Energy Performance of Buildings Directive 2010/31/EU (EPBD) is therefore an essential part of the renovation wave strategy, as it focuses on the central aims while also contributing to the decarbonisation of buildings, in line with the enhanced climate ambition of the European Green Deal, "Fit for 55 Package". Nowadays, following the introduction of energy performance rules in national building codes, buildings today consume on average only half as much energy as typical buildings from the 1980s. The building sector is crucial for achieving the EU's energy and environmental goals. At the same time, better and more energy efficient buildings improve the quality of citizens' lives while bringing additional benefits to the economy and the society.

A refurbished and improved building stock in the EU will help pave the way for a decarbonised and clean energy system, as the building sector is one of the largest energy consumers in Europe and is responsible for 40% of the EU's emissions. But only 1% of buildings undergo energy efficient renovation every year, so effective action is crucial to making Europe climate-neutral by 2050. Currently, roughly 75% of the building stock is energy inefficient, yet almost 85–95% of today's buildings will still be in use in 2050. Renovation of both public and private buildings is an essential measure in this context.

Given the labour-intensive nature of the building sector, which is largely dominated by local businesses, renovation of buildings also plays a crucial role in the European recovery from the COVID-19 pandemic. To kick-start the recovery, the Commission has identified doubling the renovation rate in its dedicated recovery plan (Renovation Wave, 2020).

Geotechnical studies relevant for the Renovation Wave could be:

- Climate resilience standards for buildings
- Sustainable remediation technologies: Considering the depth and volume of renovation Europe needs, this task ultimately requires a strong and competitive construction sector, embracing innovation and sustainability to increase quality and reduce costs.
- Study of geotechnical problems in historical buildings, mainly focused on:
  - Improvements in foundations.
  - Improvements in water isolation

In this context, it is worth noting the current activity to develop a new Eurocode focused on the Assessment and Retrofitting of Existing Structures, in which geotechnics should be part of the main core of the document, given its key role in solving many of the problems faced by existing structures. Furthermore, the activities of the Technical Committee TC 301 "Preservation of Historic sites" of the International Society of Soil Mechanics and Geotechnical Engineering must be also highlighted.

Geotechnics and climate action

Climate action is at the heart of the European Green Deal – an ambitious package of measures ranging from ambitiously cutting

Figure 9: Landslide in Castell de Ferro, A7, Spain, 13/3/2021 (EU Riskcoast _Sudoe project).

greenhouse gas emissions through investing in cutting-edge research and innovation to preserving Europe's natural environment.

First climate action initiatives under the Green Deal include: European Climate Law 2020, to enshrine the 2050 climate-neutrality objective into EU law; European Climate Pact, to engage citizens and all parts of society in climate action; 2030 Climate Target Plan, to further reduce net greenhouse gas emissions by at least 55% by 2030; and the new EU Adaptation Strategy to Climate Change, 2021.

The European Commission adopted its new EU Strategy on Adaptation to Climate Change on 24th February 2021. The new strategy sets out how the European Union can adapt to the unavoidable impacts of climate change and become climate resilient by 2050.

The Strategy has four principal objectives:

- Data and risk assessment tools: Adaptation actions must be available to all, from families building homes, businesses in coastal regions and farmers planning their crops. To achieve this, the strategy proposes actions that push the frontiers of knowledge on adaptation so that we can gather more and better data on climate-related risks and losses.
- Faster adaptation: The effects of climate change are already being felt, and so we must adapt more quickly and comprehensively. The strategy therefore focuses on developing and rolling out adaptation solutions to help reduce climate-related risk, increase climate protection and safeguard the availability of fresh water.
- More systematic adaptation: Climate change will have impacts at all levels of society and across all sectors of the economy, so adaptation actions must also be systemic. The Commission will continue to actively mainstream climate resilience considerations in all relevant policy fields.
- Stepping up international action for climate resilience: The EU will increase support for international climate resilience and preparedness through the provision of resources, by prioritising action and increasing effectiveness, through the scaling up of international finance and through stronger global engagement and exchanges on adaptation.

Geotechnical studies are relevant for data and risk assessment (prospective studies, scenarios, prevention and resilience), and faster adaptation, (adaptation solutions to help reduce climate-related risk). Natural risks such as flooding, coast erosion and landslides have an important impact on society and the economy, as shown in the example of ***Figure 9***. The prevention and mitigation of projects in collaboration with other natural science disciplines will allow the economic burden of potential climate scenarios to be more accurately assessed.

Climate change and the concomitant increase in extreme weather and geo-hazards events are placing additional pressures on the existing Critical Infrastructure (CI) of Europe in the water, energy, urban and transport sector as seen in ***Figure 10***. These are systems that are often already weakened by aging.

In an increasingly interconnected, globalised world, society heavily relies on CI for safety, quality life and economic success. Strengthening and enhancing CI resilience to meet present and future challenges and demands should therefore be at the forefront of societal goals.

One example of EU interest in this kind of actions is the project GEOLAB funded by H2020: The main objective of the INFRAIA project is to create a net among 11 unique installations in Europe aimed to study ground behaviour and the interaction with structural CI elements and the environment. These installations represent the best of the state-of-the-art available today in Europe.

An additional signal of the importance of geotechnics in Climate action is the fact that Critical Infrastructures formed by geotechnical structures will be considered as CC4 Consequence Class (the top class) in the future Eurocode 7, as a signal of their importance in EU society. As examples of these CI, levees must be highlighted as they play a key role in land protection under heavy floods. The International Levee Handbook (CIRIA Report C731, 2013) is a very useful document for designing such structures based on theoretical and practical geotechnics principles that should be considered an example of state-of-the-art documents that need to be produced in the near future to face these climate challenges.

Conclusions

Geotechnical studies have an important role to ensure good quality in the development of some crucial policies areas of the European Green Deal. The EU will provide financial support and technical assistance to help those that are most affected by the move towards the Green Economy. The creation of jobs and business related to the Green Deal will be an important engine of transformation in Europe in the coming years. The identification of the relevant areas for geotechnics can shed light on employment and business in this sector in the coming years.

To ensure high quality in the contribution of geotechnical studies to the European Green Deal, it will be necessary to certify professional competence. The second-generation Eurocode 7 is working in a frame, at European level, to certify appropriate qualifications and experience within their

	Critical Infrastructure (CI):
Energy	Oil, gas production and related pipelines
	Electricity generation and transmission
	Distribution electricity, oil, gas
Water	Drinking water and sewage system
	Surface water, flood protection
Urban	Public buildings, offices
	Monuments, historic buildings
	Resident housing
	Underground construction
Transport	Road & rail infrastructure
	Airports
	Ports and inland waterways
	Pipelines

Figure 10: Different types of Critical Infrastructures (GEOLAB project, 2020).

respective fields. The applicants for the title of European Geologist must demonstrate their professional experience, knowledge and experience, over a combined minimum total of nine years. In this context the European Geologist title could be a great support in guaranteeing qualified and competent people in the future context of specialised geotechnics jobs to support the Green Deal.

References

Banushi, G. & Weidlich, I. 2018. Seismic analysis of a district heating pipeline. *Energy Procedia*, 149. 216–225. DOI: 10.1016/J.EGYPRO.2018.08.186

Ben-Hassine J. & Griffiths D.V. 2013. Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris, 2319-2322

Brand, M., & Svendsen, S. 2013. Renewable-based low-temperature district heating for existing buildings in various stages of refurbishment, Energy, Volume 62, 1 December 2013, Pages 311-31 Bushong, S, 2014, White Paper: Foundation Selection For Ground Mounted Solar PV Systems ***https://www.solarpowerworldonline.com/2014/07/white-paper-foundation-selection-ground-mounted-pv-solar-systems/***

COM(2019) 640 final. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions, The European Green Deal. ***https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0002.02/DOC_1&format=PDF***

Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives

CEN/TS 17438. 2020. European Committee for Standardization (CEN): Source materials considered in the development of the Aggregate standards of TC 154. June 2020.

Clean Energy, the European Green Deal: ***https://ec.europa.eu/commission/presscorner/detail/en/fs_19_6723***

CIRIA C731. 2013. The International Levee Handbook. CIRIA, Ministère de l'Ecologie, du Développement Durable et de l'Energie, and the US Army Corps of Engineers. CIRIA, London.

Commission Decision 2000/532/EC. 2000. European List of Waste.

EC7 (Eurocode 7), CEN-TC250-SC7_N1436_M515_SC7PT6_1997-1- Geotechnical design, M515 SC7.PT6 1997-1 Geotechnical design - General rules (PT6) Oct-2020.

EN17522. 2020. Design and construction of borehole heat exchangers.

EN-ISO 17628:2015. Geotechnical investigation and testing. Geothermal testing. Determination of thermal conductivity of soil and rock using a borehole heat exchanger. ***https://www.en-standard.eu/bs-en-iso-17628-2015-geotechnical-investigation-and-testing.-geothermal-testing.-determination-of-thermal-conductivity-of-soil-and-rock-using-a-borehole-heat-exchanger/***

Energy Performance of Buildings Directive 2010/31/EU (EPBD). ***https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en***

European Climate Law, 2020. ***https://ec.europa.eu/info/sites/info/files/commission-proposal-regulation-european-climate-law-march-2020_en.pdf***

EU Adaptation Strategy to climate change, 2021. ***https://ec.europa.eu/clima/policies/adaptation/what_en***

European Commission, 2001. Competitiveness of the Construction Industry, A Report Drawn up by the Working Group for Sustainable Construction with Participants from the European Commission, Member States and Industry. European Commission

European Green Deal: ***https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en#actions***

EU Strategy on Climate Adaptation, 2021, ***https://ec.europa.eu/clima/policies/adaptation/what_en***

EGEC. 2019. Geothermal market report, Key Findings, European Geothermal Energy Council, Brussels. ***https://www.egec.org/wp-content/uploads/2020/06/MR19_KeyFindings_new-cover.pdf***

European Budget, 2021-2027. ***https://ec.europa.eu/info/strategy/eu-budget/long-term-eu-budget/2021-2027_en***

Eurostat 39/2019. Circular economy in the EU. Record recycling rates and use of recycled materials in the EU. ***https://eeas.europa.eu/delegations/china_en/59123/Circular%20economy%20in%20the%20EU:%20Record%20recycling%20rates%20and%20use%20of%20recycled%20materials%20in%20the%20EU***

EC JRC, PV status report 2019, PV status report 2019, JRC118058 ***https://ec.europa.eu/jrc/sites/jrcsh/files/kjna29938enn_1.pdf***

Fernández-Fuentes, I., Correia, V., & Neumann, M. 2021. The importance of professional regulation of geoscientists and their role in a fast-changing world. Geological Society, London, Special Publication

Fernández-Fuentes, I. 2015. EurGeol as Competent Person. *European Geologist*, 39. 8-13

GEOLAB project: Science for enhancing Europe's Critical Infrastructure. IMPLEMENTATION PLAN GEOLAB contract # 101006512. Call: H2020-INFRAIA-02-2020.

Geotrainet Training Manual for Designers of Shallow Geothermal Systems, GEOTRAINET, EFG, BRUSSELS, 2011, ***http://geotrainet.eu/wp-content/uploads/2015/10/Geotrainet-Manual-for-Designers-on-Shallow-Geothemal.compressed.pdf***

Kellezi, L. 2015. Offshore wind energy & geotechnical engineering design of foundations for different wind farm structures. Keynote lecture, European Conference in Geo-Environment and Construction, Copenhagen Denmark. ***https://www.geo.dk/media/1790/offshore-wind-energy-geotechnical-engineering-design-of-foundations-for-different-wind-farm-structures_lkellezi.pdf***

Klemetz, D. 2019. Subsurface Energy Storage and Buffering (ATES and Shallow Geothermal Plants). Euroworkshop: Geology and the energy transition, Delft, Netherlands. ***https://eurogeologists.eu/wp-content/uploads/2019/06/10_david_klemetz_delft-20190523.pdf***

New Industrial Strategy for Europe (COM(2020) 102 final. ***https://knowledge4policy.ec.europa.eu/publication/communication-com2020102-new-industrial-strategy-europe_en***

Mathiesen, B.V., Lund, H., Connolly, D., Wenzel, H., Østergaard, P.A., Möllerd, B., Nielsen, S., Ridjan, I., Karnøe, K., Sperling, K. & Hvelplund, F.K. 2015. Smart energy systems for coherent 100% renewable energy and transport solutions. Applied Energy 145, pp139-154. DOI: 10.1016/j.apenergy.2015.01.075

Perez, R. 2019. Geotechnical surveying and soil testing for solar projects. EuroWorkshop Geology and Energy Transition, Delft, Netherlands, ***https://eurogeologists.eu/wp-content/uploads/2019/06/12_Perez_Ramon_TecsolGeo_Delft.pdf***

Perpar, M., Rek, Z., Bajric, S. & Zun, I. 2012. Soil thermal conductivity prediction for district heating pre-insulated pipeline in operation. *Energy*, 44(1), 197-210. DOI: 10.1016/j.energy.2012.06.037.

Recovery Plan for Europe, 2021: ***https://ec.europa.eu/info/strategy/recovery-plan-europe_en***

Regulation (EU) No 305/2011 - construction products, ***https://osha.europa.eu/en/legislation/directives/regulation-eu-no-305-2011-construction-products***

Renovation Wave, 2020, ***https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en***

Renewable energy in the European Green Deal: ***https://ec.europa.eu/energy/topics/renewable-energy/renewable-energy-directive/overview_en#renewable-energy-in-the-european-green-deal***

Simon, F., 2019, Europe's solar PV sector reports 104% growth in 2019, EurActiv, ***https://www.euractiv.com/section/energy/news/europes-solar-pv-sector-reports-104-growth-in-2019/***

Villalobos F., Hay S. & Weidlich I. 2019a. Monitoring in a District Heating Pipeline System. In: Ferrari A., Laloui L. (eds.) *Energy Geotechnics*. SEG 2018. (pp. 132-139). Springer Series in Geomechanics and Geoengineering. Springer, Cham. DOI: 10.1007/978-3-319-99670-7_17

Villalobos, F., Hay, S., Weidlich, I. & Wolf, I. 2019b. Design, Construction, and Operation of a Monitored District Heating Pipeline System. *Journal of Pipeline Systems Engineering and Practice*, 10(3). DOI: 10.1061/(ASCE)PS.1949-1204.0000388

Wind Europe report. 2017. Wind Energy in Europe, Scenarios for 2030 ***https://windeurope.org/about-wind/reports/wind-energy-in-europe-scenarios-for-2030/***

Deepening an old, verticalised pit: rock slope instability hazard assessment using a digitally augmented structural database (Flône limestone quarry, Belgium)

E. C. Frets[1], A. Gauffriau[1], N. Coussaert[1] and J. Vanneste[2]*

We present a rock slope instability hazard study of the Flône pit (Belgium) by means of a deterministic kinematic stability analysis. The specificity of this study resides in the "digital augmentation" of the field mapping structural database (x 5) by semi-automatic point cloud analysis. Results show that the main instability hazards in the actual pit are flexural toppling and, to a lesser extent, wedge sliding. Planar sliding, although minor, will constitute a significant hazard for interbench rupture during future excavation due to the presence of an anticline structure at depth. The augmented - and georeferenced - structural database has enabled us to generate a synthetic rock slope instability hazard map that constitutes the basis for the recommendation of targeted monitoring solutions during future excavation works.

L'aléa d'instabilité des fronts rocheux de la carrière de Flône (Belgique) a été étudié par analyse cinématique déterministe. L'augmentation numérique (x5) de la base de données structurales par analyse semi-automatique en nuages de points a permis de montrer que les principaux aléas d'instabilité sont le basculement et, en moindre mesure, le glissement en coin. Le glissement planaire, bien que mineur actuellement, constituera cependant un aléas important de rupture inter-bancs lors de l'approfondissement, de par la présence d'une structure anticlinale identifiée en profondeur. Enfin, notre base de données structurale géoréférencée et augmentée a permis de générer une carte synthétique des aléas d'instabilité des talus rocheux, qui constitue la base de recommandations de solutions de surveillance ciblées lors des futurs travaux d'excavation.

El peligro de inestabilidad de las paredes rocosas de la cantera de Flône (Bélgica) se estudió mediante análisis cinemático determinista. El aumento numérico (x5) de la base de datos estructural mediante el análisis semiautomático de nubes de puntos ha demostrado que los principales peligros de inestabilidad son la caída por volteo y, en menor medida, el deslizamiento en cuña. El deslizamiento plano, aunque actualmente menor, constituirá sin embargo un gran peligro de ruptura interbancos durante la profundización, debido a la presencia de una estructura anticlinal identificada en profundidad. Finalmente, nuestra base de datos estructural georeferenciada y aumentada ha hecho posible generar un mapa sintético de peligros de inestabilidad, que forma la base de recomendaciones para soluciones de monitoreo específicas durante la excavación futura.

Introduction

With increasing environmental awareness, optimising the extraction of readily available resources - prior to searching for new ones - is key to ensure future sustainable extraction activities. Nonetheless, optimising resources by deepening a pit and/or verticalising its fronts goes along with increased instability hazard and may endanger the personnel working at a given site.

Lhoist Group plans to optimise the exploitation of the Hermalle site pure limestone resource. The Hermalle quarry is located in a very narrow and steep location at the border of the Meuse River in Belgium (***Figure 1***).

It is a 2.5 km long, 300 m large elongated pit whose westernmost part (the "Flône" pit) has not been exploited since 2007. Since then, the 3 upper benches have been already set in their "final" position (i.e. 20 m vertical each, with 5 m interbench distance - ***Figure 2***), making it inaccessible for geological-structural mapping. Although no major instability hazard has occurred since this time, it was imperative for security reasons to:

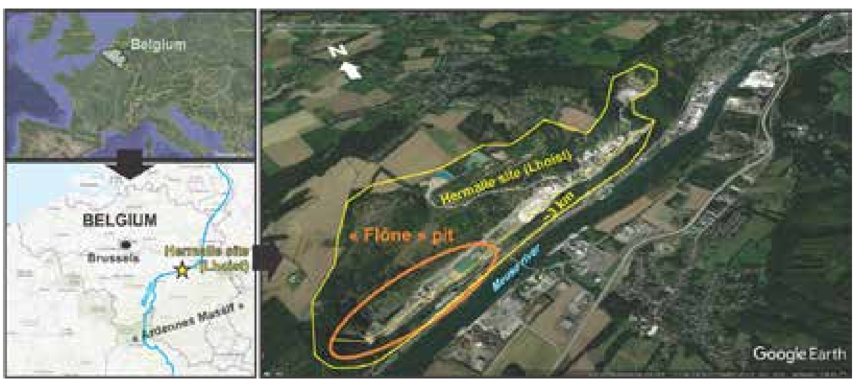


Figure 1: Context of the Flône pit (orange), object of the present instability hazard assessment study by means of a digitally augmented structural database.

[1] Tractebel Engie, Boulevard Simón Bolívar 34-36, 1000 Brussels, Belgium
[2] Lhoist Western Europe, Rue Granbonpré 11, 1435 Corbais, Belgium
* erwin.frets@tractebel.engie.com

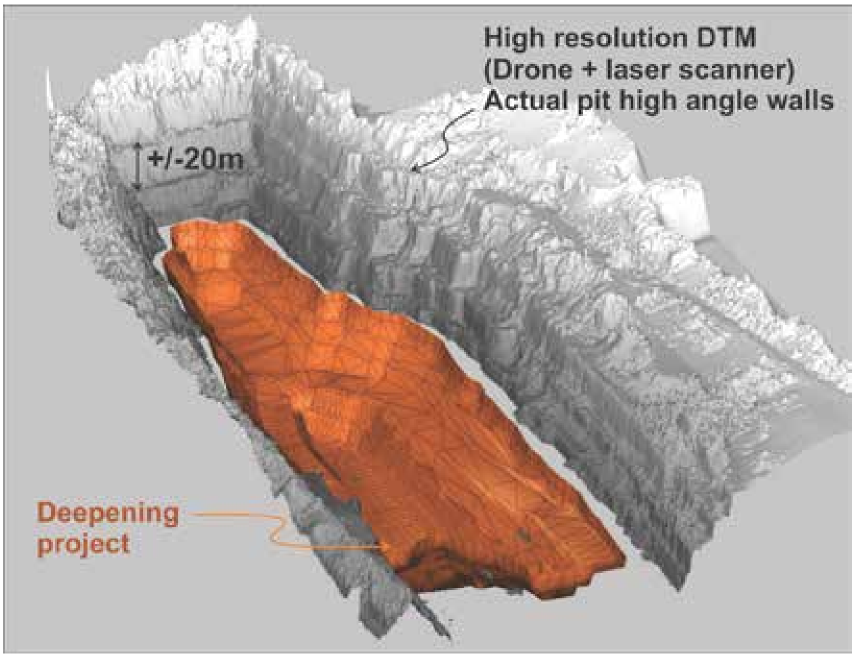


Figure 2: Flône actual pit geometry (grey) and deepening project (orange).

i. assess the instability hazard in such narrow and steep conditions,
ii. gain a view of the resource at depth, prior to restarting extraction activities in the Flône pit.

Although geological interpretation of “virtual outcrops” has been successfully tested to map inaccessible areas such as cliffs (e.g. Xu *et al.*, 2001, Trinks *et al.*, 2005) or caves (Triantaphyllou *et al.*, 2019) or for detailed structural mapping at outcrop scale (Martin *et al.*, 2019), to our knowledge only few studies (Smith & Holden, 2020) have attempted to integrate a deterministic kinematic stability analysis into such mapping. In addition to this, here we also link this kinematic stability analysis with hazard mapping of the quarry.

Geological context

The Hermalle quarry exploits Visean limestones and dolomites along the Midi-Eifel thrust zone, the Belgian part of the Variscan Front Thrust that delimits the European Variscides to the south, with the Caledonian basement to the north. The exploited rocks pertain to the lower to middle Visean Terwagne, Lives and Neffe formations. Below and above these formations occur the Tournaisian dolomites of the Engihoul formation and the Namurian shales of the Chokier formation, respectively. This folded sedimentary succession crops out in the quarry as steeply S-dipping strata with normal stratigraphic polarity, or steeply N-dipping with reverse polarity in the south and the north of the pit, respectively. The northern front also shows a tight, upright fold, with an axial surface dipping towards the pit (see also cross-section of ***Figure 5***, section 4).

Methodology

Digitally augmented structural database

The high-density point cloud has been constructed by merging a fix station laser scanning acquisition from the base of the pit with an aerial (drone) photogrammetric survey. This dual acquisition has allowed us to increase and homogenise point density, especially in scanning dead angles for geological and geotechnical study purposes.

Our structural database, based on:

i. Field mapping: 157 DGPS stations, 211 planes – S0, S1, fractures, faults – and 24 lines – slickensides, fold axes, and
ii. Archive integration: Lhoist pit photographs and structural database,

has then been digitally ‘augmented’ by semi-automatic, point-cloud based picking of ~1000 plane orientations using CloudCompare software (***Figure 3***).

The georeferenced point cloud not only allows us to retrieve data from inaccessible areas such as each of the three 20 m high, verticalised fronts of the Flône pit, but also enables us to refine the geological model and perform targeted detailed kinematic slope stability analyses, precisely locating the subsets of problematic structures directly in GIS. Remote data measurement is reliable, efficient and a powerful methodology for both geological and geotechnical studies.

Interpretative geological cross-sections

In order to evaluate simultaneously the evolution of the limestone resource at depth and the instability hazard during excavation of the future pit, four interpretative cross-sections (see ***Figure 4*** for their location) have been produced, of which two are presented in ***Figures 5 and 6***. These sections allowed discussion of the instability hazard to be integrated with the future design of the pit and hence served as a basis for making recommendations for monitoring and additional investigations, as well as general recommendations regarding future excavation works.

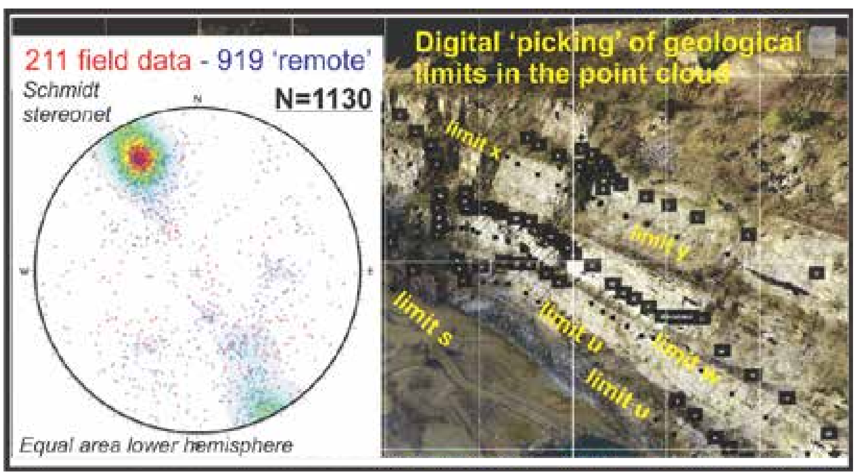


Figure 3: 3D point cloud geological limits picking and results of field & remote structural database.

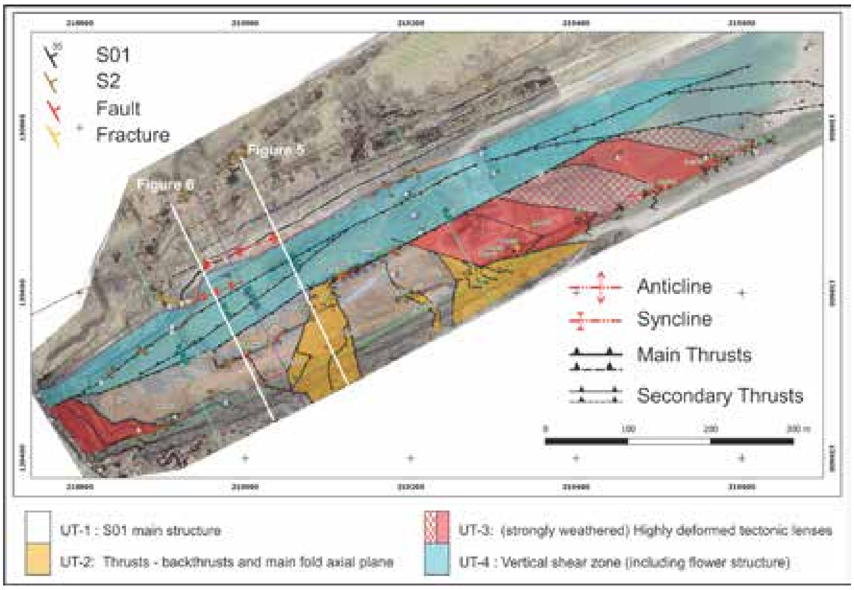


Figure 4: Structural map showing Tectonic Units UT-1 to UT-4, and location of the cross-sections presented in Figures 5 and 6.

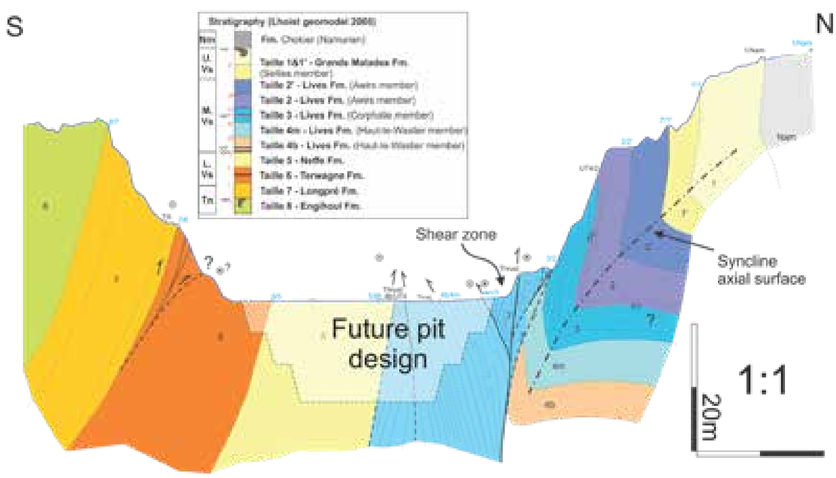


Figure 5: Digitally augmented structural cross section with remote structural data (see Figure 4 for cross-section location).

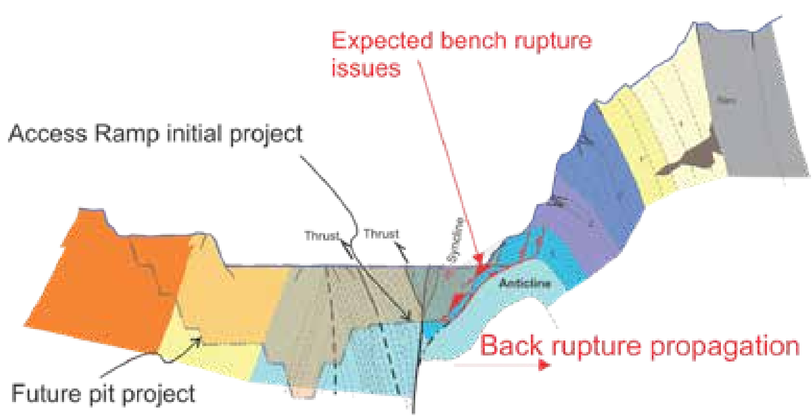


Figure 6: Planar sliding hazard along the main anticline flank (see Figure 4 for cross-section location).

Rock slope kinematic stability analysis

Three rock slope instability hazards have been investigated by means of rock kinematic stability analysis using the Rocscience software suite (Dips 5.0): planar sliding, wedge sliding and flexural toppling. Investigation of general failure mode was not part of this study, considering the overall strong character of the exploited limestones and dolomites as deduced from our field mapping.

For each actual front (south, north, west and east) of the Flône pit, we have computed plane, wedge and flexural toppling kinematic stability analysis based on >1000 planes covering the 4 mapped tectonic units. To perform the kinematic stability analyses based on Markland's test (Hoek & Bray, 1981), we have considered an average slope dip of the quarry fronts of 75°, a friction angle of 30°, and the georeferenced structural database that enabled detailed instability hazard maps to be produced.

Results

Geological – Structural mapping and cross-sections

Based on our new field structural mapping and augmented structural database, we were able to distinguish four tectonic units in the Flône pit (***Figure 4***), each characterised by a different degree of deformation: UT-1 is composed by dominant S0/1 planes, UT-2 is in addition crosscut by one family of high angle (back-)thrust faults, UT-3 shows complex (recumbent) fold geometries and is cut by two or more fracture/fault orientations, and UT-4 corresponds to decameter scale, steeply dipping deformation zones (e.g. inverted flower structures) where S0/1 is no longer visible.

The presence of high angle thrusts and backthrusts crosscutting the S0/1 and recumbent folds and intense shearing affecting the westernmost and easternmost part of the pit was previously unrecognised (Lhoist, 2008), and this new information allowed us to draw a more consistent tectonic interpretation of the Flône pit. The cross-section shown in ***Figure 5*** draws a representative view of the structure across the pit.

Instability hazard assessment

Rock slope instability hazard of the future pit based on our interpretative cross-sections (***Figure 6***) and rock kinematic stability analysis (deterministic approach) based on

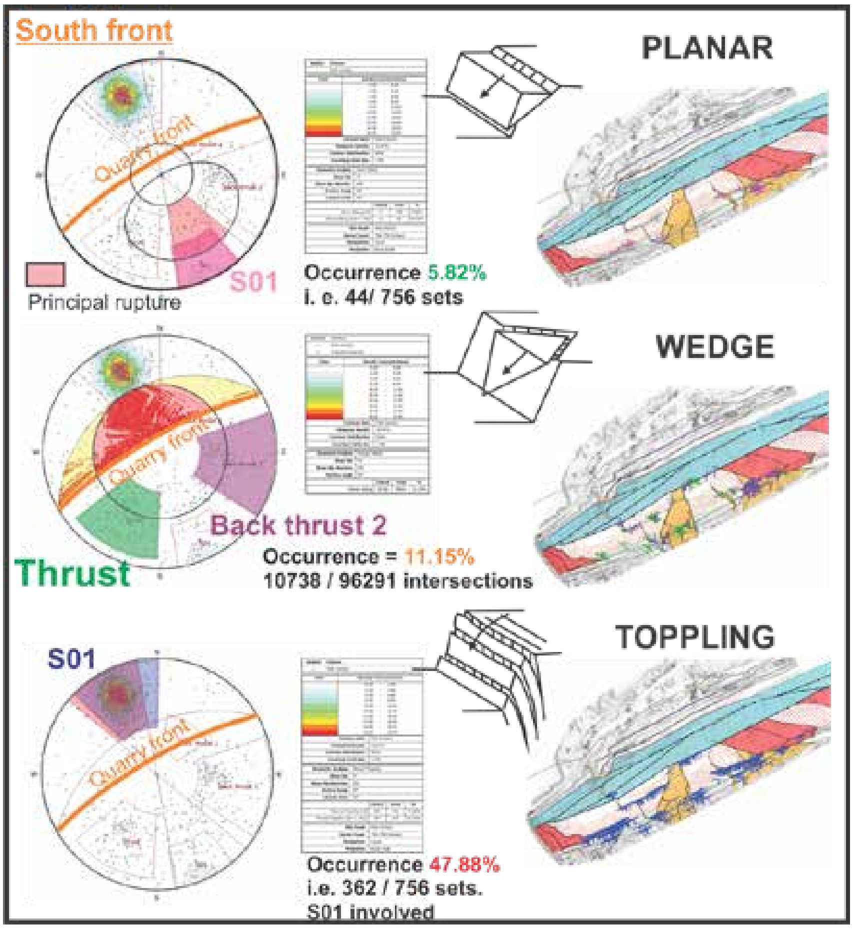


Figure 7: Rock kinematic deterministic analysis of the south front: results and GIS mapping of the involved planes.

a near comprehensive georeferenced structural database (see ***Figure 7*** for the case of the south front) have shown that the main rock instability hazard in the Flône pit concerns flexural toppling on the north and south fronts (46% and 47% respectively). The east and west fronts, which are dominated by UT-2 and UT-3, only show moderate wedge failure hazard (11%), mainly where S0/1 intersects (back-)thrusts. Planar sliding hazard is generally low (2% to 10%) on all fronts, but our interpretative cross-sections have highlighted that this hazard may significantly increase during future excavations. In particular, on the northern front, deepening of the pit could generate significant inter-bench failure due to the presence of the anticline flank dipping moderately downwards through the future pit (see example cross-section).

Discussion

Point cloud based structural data acquisition has enabled augmenting our field mapping database by a factor of 5 in the Flône quarry to re-assess the geological model and support our rock instability hazard assessment. The virtually augmented structural database makes it possible to largely reduce the uncertainty related to the usually poor representativity of structural data at the scale of a quarry where the majority of the outcrop surface is inaccessible. Similar structural data acquisition based on point clouds has been successfully conducted in other inaccessible environments, such as rock slopes (Tiruneh *et al.* 2013; Bordehore *et al.*, 2017; Tung *et al.*, 2018), caves (Triantaphyllou *et al.*, 2019), road cuttings (Riquelme *et al.*, 2016) or for geological model development (Cawood *et al.*, 2017). However, these works did not integrate deterministic kinematic stability analysis in their assessment. Only very recently, Smith & Holden (2020) provided a similar analysis, but these authors looked at the different mechanisms one by one, without finally integrating or mapping the hazard results. For our study, the georeferenced structural database then enabled us to extract and map the subsets of planes that were prone to failure, providing an integrated instability hazard map necessary for safe extraction activities of the pit.

Whilst this geometric approach is very powerful, it should nevertheless always be complementary to – and not be replaced by – geological/geotechnical field expertise, as instability hazard not only relies on geometric parameters, but also on mechanical parameters that can be estimated directly in the field (e.g. Marinos & Hoek, 2000; Marinos *et al.*, 2005). Our combined geological and geotechnical surface analysis has enabled us to anticipate future hazards in defining a targeted monitoring programme depending on the locations of the instability hazards identified across the pit.

Conclusion

Digitally augmented structural databases based on georeferenced point cloud analyses now enable deterministic rock kinematic stability analysis to be performed even at the scale of a pit with a high degree of confidence due to the enormous amount of robust structural data that can be gathered in an efficient way, but field geological mapping and rock mass characterisation should be integrated to make a consistent stability assessment.

Acknowledgements

We thank two anonymous reviewers for their constructive comments that contributed to improving the manuscript.

References

Bordehore, L., Riquelme, A., Cano, M., & Tomas, R. 2017. Comparing manual and remote sensing field discontinuity collection using in kinematic stability assessment of failed rock slopes. *International Journal of Rock Mechanics and Mining Sciences*, 97. 24–32

Cawood, A.J., Bond, C.E., Howell, J.A., Butler, R.W.H. & Totake, Y. 2017. LiDAR, UAV or compass-clinometer? Accuracy, coverage and the effects on structural models. *Journal of Structural Geology*, 98. 67–82. DOI: 10.1016/j.jsg.2017.04.004

CloudCompare (version 2.11) [GPL software]. (2019). Retrieved from ***http://www.cloudcompare.org/***

Dips 5.0 Rocscience Inc. 1998, Dips Version 5.0 - Graphical and Statistical Analysis of Orientation Data. ***www.rocscience.com***, Toronto, Ontario, Canada.

Hoek, E. & Bray, J.W. 1981. *Rock Slope Engineering*. The Institute of Mining and Metallurgy, London, England.

Lhoist (2008). Flône quarry revision and extension of the geomodel. Limelette, April 4th 2008 (by Pirotte, N.)

Marinos, P. & Hoek, E. 2000. GSI: a geologically friendly tool for rock mass strength. In: Proceedings GeoEng 2000, International conference on geotechnical and geological engineering, p. 1422-40. Melbourne, Australia, Lancaster, PA: Technomic Publishing Co.

Marinos, V., Marinos, P. & Hoek, E. 2005. The geological strength index: applications and limitations. *Bulletin of Engineering Geology and the Environment*, 64(1):55-65. DOI: 10.1007/s10064-004-0270-5

Martín, S., Uzkeda, H., Poblet, J. & Bulnes, M.. (2019). Geological interpretation of two virtual outcrops of deformed Palaeozoic rocks (NW Iberian Peninsula) using 3D stereo VDT in a computer assisted virtual environment (CAVE™). *Journal of Iberian Geology*, 45. 565–584. DOI: 10.1007/s41513-019-00110-2.

Riquelme, A.J., Tomás, R. & Abellán, A. (2016). Characterization of rock slopes through slope mass rating using 3D point clouds. *Int J Rock Mech Min Sci* 84:165–176

Smith, J. & Holden, L. 2020. Rock slope kinematic instability controlled by large-scale variation of basalt column orientation. *Bulletin of Engineering Geology and the Environment*, 80. 239–250. DOI: 10.1007/s10064-020-01917-5.

Tiruneh, H.W., Stetler, L.D, Oberling, Z.A., Morrison, D.R., Connolly, J.L. & Ryan, T.M. 2013. Discontinuity mapping using ground-based LiDAR: case study from an open pit mine. American Rock Mechanics Association, ARMA-2013-663

Triantafyllou, A., Watlet, A., Le Mouélic, S., Camelbeeck, T., Civet, F., Kaufmann, O., Quinif, Y. & Vandycke, S. 2019. 3-D digital outcrop model for analysis of brittle deformation and lithological mapping (Lorette cave, Belgium). *Journal of Structural Geology*, 120. 55–66. DOI: 10.1016/j.jsg.2019.01.001.

Trinks, I., Clegg, P., McCaffrey, K., Jones, R., Hobbs, R., Holdsworth, B., Holliman, N., Imber, J., Waggott, S. & Wilson, R. 2005. Mapping and analysing virtual outcrops. *Visual Geosciences*, 10. 13–19 DOI: 10.1007/s10069-005-0026-9.

Tung, W., Nagendran, S., Mohamad, I. & Mohd, A.. 2018. 3D rock slope data acquisition by photogrammetry approach and extraction of geological planes using FACET plugin in CloudCompare. IOP Conference Series: *Earth and Environmental Science*. 169. 012051. DOI: 10.1088/1755-1315/169/1/012051.

Xu, X., Bhattacharya, J., Davies, R. & Aiken, C. 2001. Digital geologic mapping of the Ferron Sandstone, Muddy Creek, Utah, with GPS and reflectorless laser rangefinders. *GPS Solutions*, 5. 15–23. DOI: 10.1007/PL00012872.

Geotechnical challenges at Adriatic offshore gas platforms: Subsidence due to exploitation at the Izabela Exploitation Field

Ratko Vasiljević [1*]

The "Izabela" Exploitation Field is in the central part of the northern Adriatic. It consists of two gas exploitation platforms anchored directly onto the seabed. The seabed of the exploitation field is an alluvial plain where sandy, dusty and clay sediments were deposited during the Quaternary. The dominant reservoir rocks are Pliocene and Quaternary sands and loosely bound sandstones. Gas-bearing deposits are shallowly located (between 500–1000 m depth). One of the main challenges was the question of seabed subsidence due to gas exploration and its cross-boundary influence on the Italian coastline. The current research aims to present the response to this challenge at gas field Izabela, focusing on a subsidence model of the seabed as a consequence of the pressure drop in the reservoir due to exploitation.

Le champ d'exploitation "Izabela" se trouve dans la partie centrale de l'Adriatique nord. Il se compose de deux plates-formes d'exploitation gazières ancrées directement sur le fond marin. Le fond marin y est constitué d'une plaine alluviale où des sédiments sableux, limoneux et argileux se sont déposés au cours du Quaternaire. Les roches réservoirs dominantes sont les sables pliocènes et quaternaires et les grès faiblement liés. Les gisements gaziers sont situés à faible profondeur (entre 500 et 1 000 m). L'un des principaux défis était la question de subsidence des fonds marins en raison de l'exploration du gaz et de son influence transfrontalière sur le littoral italien. La recherche actuelle vise à présenter la réponse à ce défi, en se concentrant sur un modèle de subsidence des fonds marins induit par la chute de pression dans le réservoir dûe à l'exploitation du champ Izabela.

El campo de explotación "Izabela" se encuentra en la parte central del norte del Adriático. Consta de dos plataformas de explotación de gas ancladas directamente al fondo marino. El fondo marino del campo de explotación es una llanura aluvial donde se depositaron areniscas, sedimentos finos y arcillas durante el Cuaternario.
Las rocas dominantes del yacimiento son areniscas del Plioceno y Cuaternario así como areniscas friables.
Los depósitos que contienen gas están ubicados a poca profundidad (entre 500 y 1000 m de profundidad). Uno de los principales desafíos fue la subsidencia del lecho marino debido a la exploración de gas y su influencia transfronteriza en la costa italiana. La presente investigación tiene como objetivo presentar la respuesta a este desafío en el campo de gas de Izabela, centrándose en un modelo de subsidencia del fondo marino como consecuencia de la caída de presión en el yacimiento debido a la explotación.

Introduction

The Izabela exploitation field is located within the North Adriatic exploration area. Its southern edge borders the North Adriatic exploitation field, where offshore research has lasted over 40 years and natural gas exploitation started in 1998. The gas in the gas fields is of biogenic nature, occurring in the shallow Pliocene-Quaternary sands and sandstones.

The northern Adriatic offshore area can be considered a submarine continuation of the Po river basin on the continental shelf, where about 7,000 meters of sand and clay deposits were deposited during the Pliocene. Most of these sediments were formed by the erosion of the Alps and the Apennines. This material is brought to the northern Adriatic along the Po River and several smaller streams (Adige, Brenta and Reno). Currently, the Po River brings most of the sediment, about 20 million tonnes per year (Colantoni *et al.*, 1979). Coarse-grained material is deposited closer to the shore, while the finer fraction is transported further. The location of the gas field is an alluvial plain where sandy, dusty clay sediments were deposited during the Quaternary mixed with terrestrial organic matter, with prevailing remains of terrestrial plants.

The gas in the gas fields is of biogenic nature, occurring in the shallow Pliocene-Quaternary sands and sandstones mixed with terrestrial organic matter, rich with cellulose and lignin. This kind of material is a precursor for kerogen type III (also known as gas prone) in late phases of diagenesis. According to geochemical facies, the gas in the reservoirs of the exploitation fields in North Adriatic is generated by bacterial decomposition, fermentation and reduction of carbon dioxide or acetate, under the influence of methanogenic bacteria during the Quaternary period. In bacterial-derived gas, the dominant component is methane and the content of higher hydrocarbon homologs is less than 1% and belongs to the class of dry gases (Barić, 2006). The formation of bacterial methane occurs in non-marine and marine environments after sulphate reduction has been completed (Vasiljević, 2018).

Considering the relatively small surface of the Adriatic Basin and possible trans-boundary influence of the subsidence of sea bottom, it was necessary to estimate any

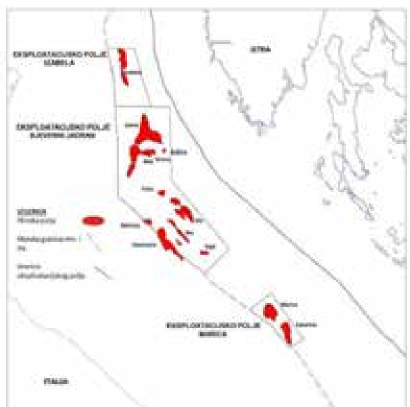


Figure 1: Exploitation fields in the northern Adriatic (Režić, 2016).

[1]ECOINA Ltd, SR Njemačke 10,
10 020 Zagreb, Croatia.
* rvcro@yahoo.co.uk

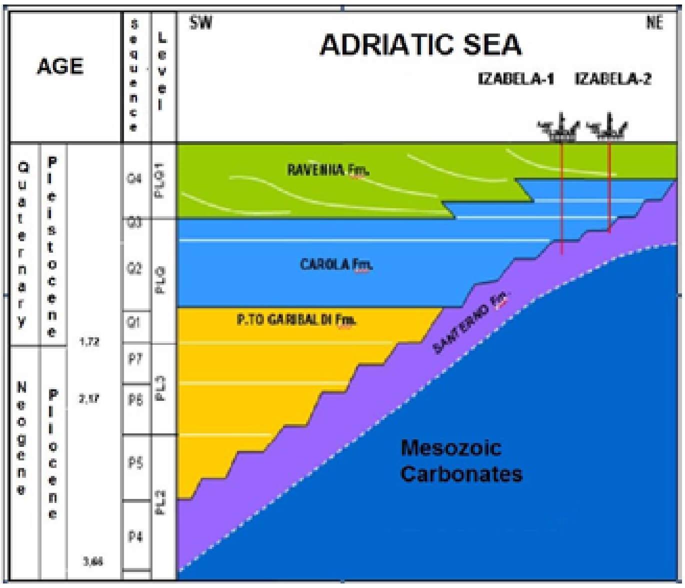


Figure 2: Schematic representation of the lithostratigraphic units of the Pliocene-Quaternary deposits of the northern Adriatic according to AGIP (Modified after ECOINA Ltd, 2007).

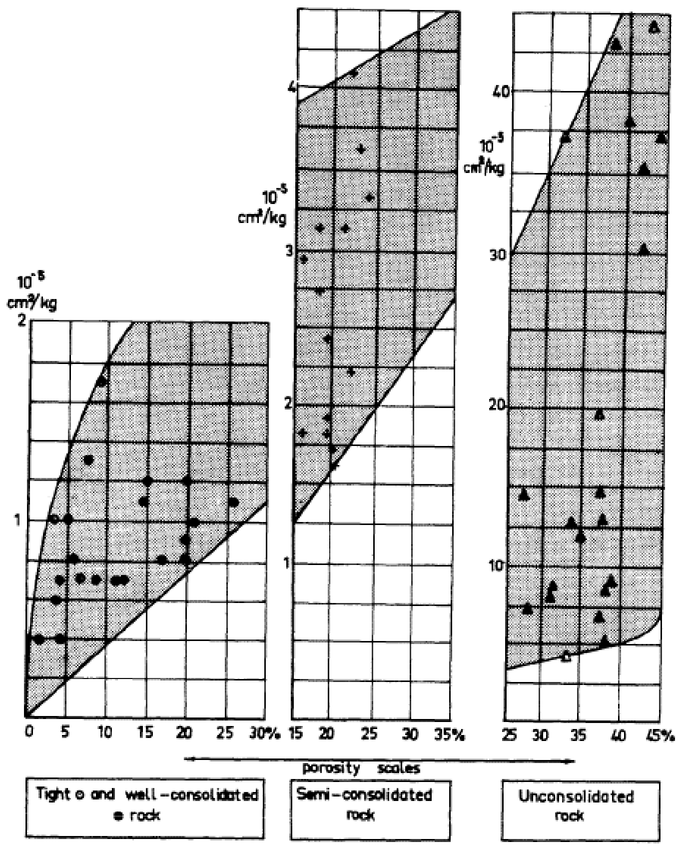


Figure 3: Uniaxial compaction coefficient (Cm) vs. porosity, for sandstone reservoirs (Geertsma, 1973).

Table 1: Production profile for the Izabela field (Modified after ECOINA 2007).

	Production per year $10^6 \times Sm^3$/year		
Year	Izabela South	Izabela North	Total
1st	204	137	341
2nd	204	137	341
3rd	214	191	405
4th	167	150	317
5th	134	121	255
6th	109	96	205
7th	89	80	169
8th	72	67	139
9th	60	56	116
10th	49	47	96
11th	42	38	80
12th	36	32	68
13th	31	26	57
14th	27	21	48
15th	23	18	41
16th	20	16	36
17th	18	14	32
18th	14	12	26
19th	11	8	19
20th	10	3	13
	1534	1270	2804

possible negative influence on the Italian coastline. This paper presents a theoretical approach to estimation of subsidence in the environmental impact assessment from exploration and exploitation of gas at the Izabela gas field (ECOINA, 2007).

The expert committee of the competent authority approved the proposed methodology (MZOPUG, 2007) and it was used in further Environmental Impact Assessment studies for the gas exploitation fields IKA, IDA, Andreina and Ravenna (ECOINA, 2008), for new production platforms at the fields Ivana, Irina IKA (Oikon, 2011), and results of modelling were also accepted for the new development exploitation field Irena at the Izabela gas field (ECOINA, 2016).

Gas bearing properties and production forecast

The Izabela exploitation field, located within the North Adriatic exploration area, just north of the exploitation field North Adriatic. The Izabela gas field is placed approximately 60 km northwestern of Pula, 21 km north of the Ivana gas field and 40 km east of Italy (***Figure 1***). The depth of the sea at the location of the Izabela gas field is 38 metres. The Izabela gas field was discovered by the Izabela 1 exploration well, drilled through clays of Santerno Formation. The well was located at the southwestern edge of the structure and drilled hydrocarbon-containing layers in the Carola Formation (***Figure 2***).

The stratigraphic column drilled at the Izabela exploitation field consists of Middle and Upper Pliocene and Upper Pleistocene deposits. A detailed division of the stratigraphic column was made according to the zoning performed by the General Italian Oil Company AGIP (*Azienda Generale Italiana Petroli*), subsidary of the Italian National

Hydrocarbons Authority – ENI (*Ente Nazionale Idrocarburi*) (***Figure 2***).

According to this zoning, the oldest formation in the northern Adriatic is the Santerno Formation (Middle Pliocene to Middle Pleistocene). The Santerno Formation is followed by the Garibaldi Formation (Middle Pliocene to Lower Pleistocene). Concordant on the Garibaldi Formation, there is the Carola Formation (Middle Pleistocene). The youngest member is the Ravenna Formation (Upper Pleistocene).

The Santerno, Carola and Ravenna formations were developed on the Izabela exploitation field. Gas-bearing deposits in the Izabela exploitation field are in Pleistocene sands and loosely bound sandstones of the Ravenna and Carola formations at depths of 300 to 900 m.

Prediction of production from the Izabela field was given in the Plan of Development (EDINA, 2006). The field was planned to be developed by one satellite platform with one well. It was assumed that the well would be vertical and would be completed with 2 7/8′′ tubing. The field was supposed to be put in production in 2010, but it started production in 2020 (INA, 2020). The production profile is presented in ***Table 1***.

During 20 years of production, 280 × 10^6 Sm^3 of gas is expected to be produced yearly (INA d.d., 2020). Field pressure is expected to fall from the initial pressure of approximately 45.6 bar to approximately 8.5 bar. Although simulation was extended beyond the planned production time, due to the relatively fast extension of pressure drop through the aquifer, there is practically no reservoir pressure increase after production stops. This is due to still relatively high aquifer transmissibility, and since the largest subsidence is expected to occur in the last year of production when the reservoir pressure is lowest, possible pressure buildup after production does not seem important for maximum subsidence evaluation (EDINA, 2006).

Subsidence modelling

In order to simulate the possible transboundary impact by subsidence of the seabed due to the exploitation of natural gas under pressure on the Italian part of the Adriatic continental shelf, a subsidence model was developed.

To create the model, the numerical simulator Eclipse was used to simulate the pressure drop in the reservoir, with the following parameters and settings:

- Cell size 100 × 100 m
- Grid dimensions 60 × 90 × 31 m
- 167,400 cells, of which 51,937 are active
- Water pressure mode simulated by analytical aquifer. Aquifer surface is 3 times larger than the reservoir. Larger aquifers have not yet been observed in currently producing gas fields in the Croatian offshore Adriatic area so assumption of aquifer size seems justified.
- The total (external) dimensions of the model are 6 km × 9.1 km
- 2 platforms - 6 wells
- Sand backfill - Skin factor = 10
- qgmin = 10,000 m^3/day
- Depression Dp = 20 bar
- Max WGR = 100 cm^3/m^3
- Period of production: 20 years
- Simulated period: Seventy years after start of production

A nucleus of strain, semi-analytical model was used in order to evaluate the subsidence induced by the gas production from Izabela field. The hypothesis of this theory is that the reservoir can be assumed as contained in an infinite half-space with linear porous-elastic behaviour and that the whole medium, inside and outside the reservoir itself, is characterised by two mechanical parameters, uniaxial compaction coefficient cm and Poisson's ratio

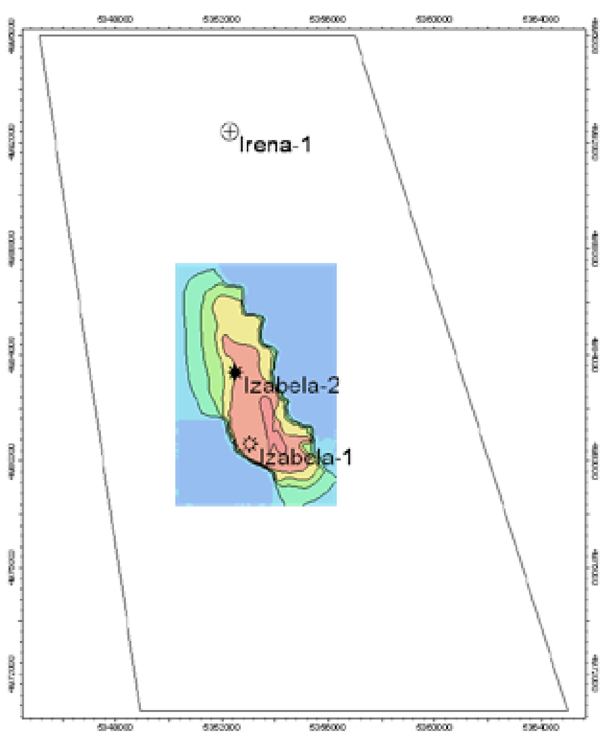


Figure 4: Size and location of the initial numerical model of the Izabela gas field within the production concession (ECOINA, 2007).

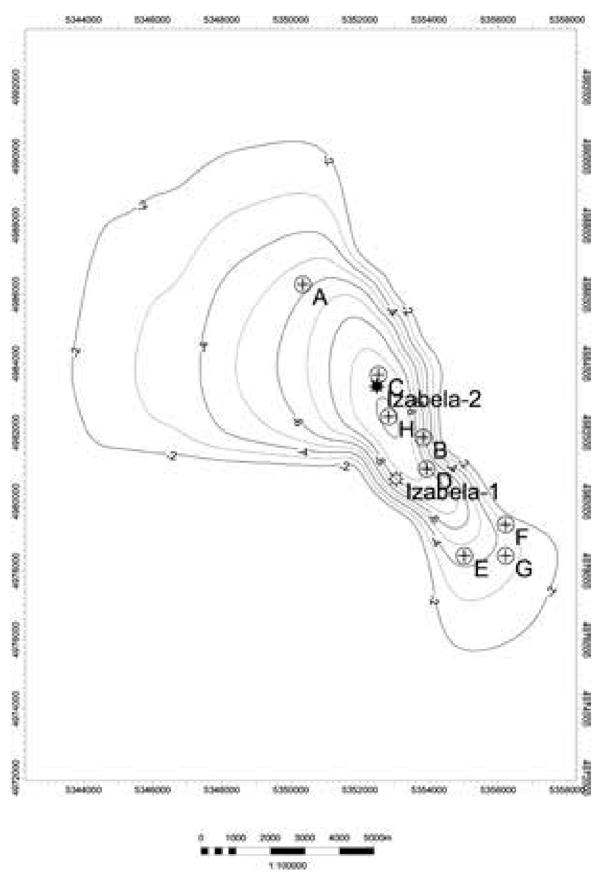


Figure 5: Disposition of observation points in the model (ECOINA, 2007).

Table 2: Coordinates of observation points in the model (shown in Figure 3).

	x	Y
Observation point A	*5350346*	*4986291*
Observation point B	*5353627*	*4985081*
Observation point C	*5353826*	*4981856*
Observation point D	*5352534*	*4983670*
Observation point E	*5353925*	*4980949*
Observation point F	*5355019*	*4978429*
Observation point G	*5356212*	*4979336*
Observation point H	*5352832*	*4982461*

(Geertsma & van Opstal, 1973).

From the nucleus of strain concept, it follows that the subsidence at position x, y above reservoir – i.e., the displacement perpendicular to the free surface, due to nucleus of strain of small but finite volume ($V = l_{xn} \cdot l_{yn} \cdot l_{zn}$) positioned at ξ_n, η_n, c_n, under the influence of a pore pressure reduction Δpn amounts to:

$$u_z(x,y,0) = -\frac{c_m \cdot (1-\nu)}{\pi} \cdot \sum_{n=1}^{N} \Delta p_n \cdot \frac{c_n \cdot l_{xn} \cdot l_{yn} \cdot l_{zn}}{\left[(x-\xi_n)^2 + (y-\eta_n)^2 + c_n^2\right]^{3/2}}$$

Information relevant to equation (1), mainly reservoir geometry data and pressure evolution maps, have been directly obtained from a dynamic model carried out with Eclipse software. Each cell into which the reservoir in the dynamic model is discretised represents a single nucleus of strain and contributes to the surface subsidence as a function of its volume, its depletion and location with respect to the observation point.

The uniaxial compaction coefficient (c_m) used in the model has been determined using published correlations (Geertsma, 1973; Geertsma & Opstal, 1973) for unconsolidated sandstones (***Figure 1***) and amounts to 1.41 × 10^{-4} bar^{-1}. Poisson's ratio (ν) has been assumed equal to 0.3.

As a matter of technical resolution – reliability of the modelling techniques and accuracy of geodetic measurement – we believe that a 2 cm contour from the centre of the subsidence bowl is the minimum reliable contour we can estimate.

Disposition of the observed points in the model is given in ***Figure 3***, where the model is shown in relation to the exploitation field Izabela (the western border represents the border of the continental shelf) and in ***Table 2***. ***Figure 4*** shows the dynamics of subsidence of isolated points on the seabed as a function of time.

In ***Figure 4***, it can be seen that the most significant subsidence is expected in the area of the middle of the deposit, in the amount of 10.4 cm, 12 years after the planned start of production. Since production started in 2020, the most significant subsidence can be expected in 2032. The reservoir is protected by ridges to the southwest and northeast that prevent the spread of subsidence in the vicinity of the reservoir, while to the northwest and southeast it is open for subsidence, which at a distance of 9 km west will be a maximum of 2 cm at the lowest reservoir pressure.

The model gave the following numerical results:

- Maximum settlement: 10.4 cm 12 years after the start of production.
- There is no subsidence at the edges of the model, the largest radius of the subsidence area is 10 km, and subsid-

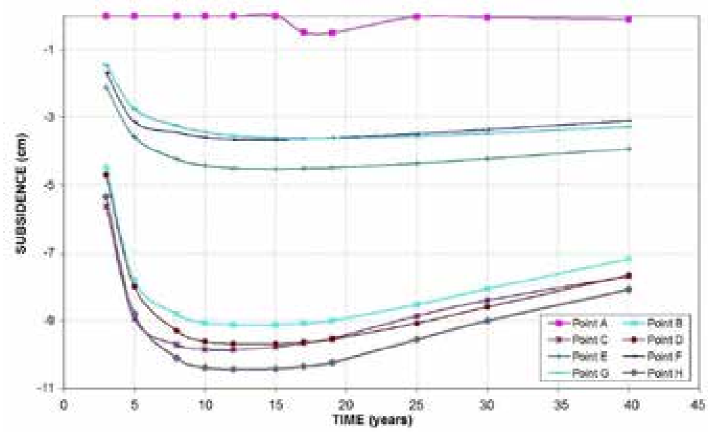


Figure 6: Seabed subsidence dynamics (ECOINA, 2007).

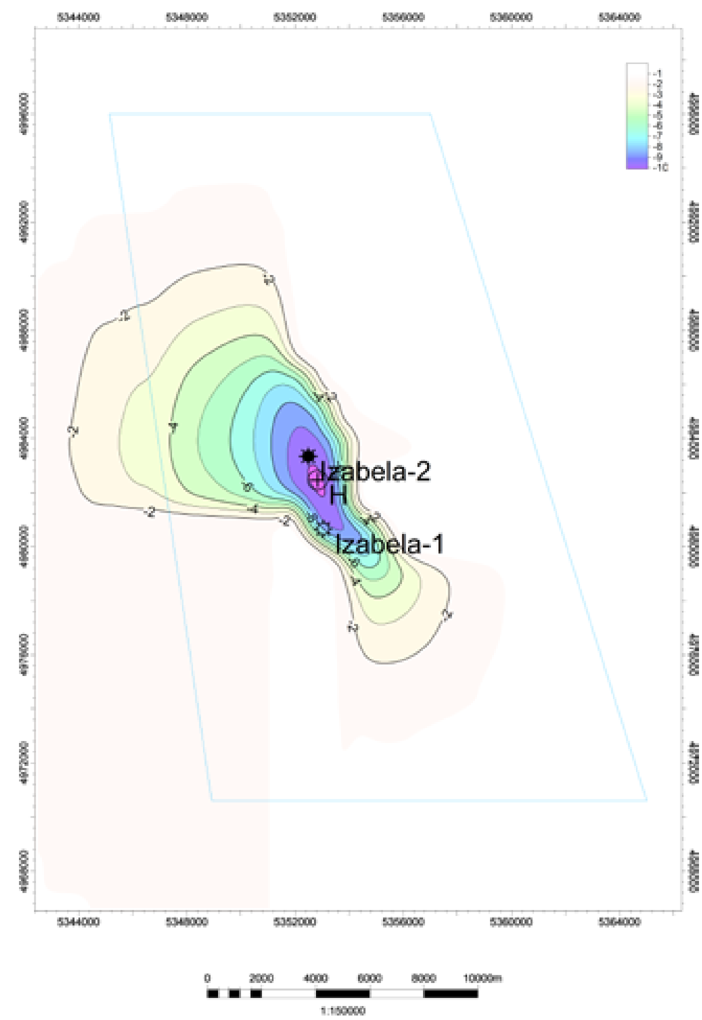


Figure 7: Simulated seabed subsidence 12 years after start of production (ECOINA, 2007).

ence of the reservoir can in no way affect the Croatian or Italian coast.

According to Geertsma (1973) and the Dutch Institute of Applied Technologies, subsidence of less than 10 cm has practically no impact on the seabed.

Figure 5 displays the maximum subsidence of the seabed, 12 years after the start of production.

Conclusion

The present study has the aim to estimate subsidence caused by production from the gas field Izabela. It was estimated that gas production would be 2.804 × 10^6 Sm^3 in 20 years of production, during which reservoir pressure would decline from 45.6 bar to approximately 8.5 bar (19% of initial pressure). The grid of the numerical model incorporates the aquifer in order to evaluate propagation of the pressure disturbance and resulting subsidence.

The nucleus of strain semi-analytical model was used in order to evaluate the subsidence induced by gas production from Izabela field. Each active cell of the numerical model represents a single nucleus of strain and contributes to the surface subsidence as a function of its volume, depletion and location with respect to the observation point. The uniaxial compaction coefficient (c_m) used in the model has been determined using published correlations for unconsolidated sandstones and amounts to 1.41 × 10^{-4} bar^{-1}. Poisson's ratio (ν) has been assumed equal to 0.3.

Results of the subsidence modelling indicate that the largest subsidence will occur at the middle of the production period and will amount to -10.4 cm. Considering that subsidence of less than 10 cm has practically no impact on the seabed, even the largest value of subsidence is still well below any significant value. The extent of the -2 cm subsidence contour never exceeds a radius of 5.5 km from the centre of the reservoir, so it is safe to assume that gas production from the Izabela field will not have any impact on Croatian or Italian coastlines.

References

Barić, G. 2006. *Naftna geokemija (Petroleum Geochemistry)*, INA Industrija nafte d.d. Zagreb.

Colantoni P., Gallignani P. Lenaz R. 1979. Late Pleistocene and Holocene evolution of the North Adriatic continental shelf. *Marine Geology*, 33. 41-50.

ECOINA 2007. Eksploatacija plina iz eksploatacijskog polja "Izabela", Studija utjecaja na okoliš (Gas exploitation from the "Izabela" exploitation field, Environmental Impact Assessment). ECOINA, Zagreb.

ECOINA 2008. Studija o utjecaju na okoliš eksploatacije plina iz eksploatacijskog polja 'Sjeverni Jadran' (Environmental impact assessment on the gas exploitation from the North Adriatic exploitation field), ECOINA, Zagreb., ***http://stariweb.istra-istria.hr/fileadmin/dokumenti/novosti/SUO_PUO/SUOSjeverniJadran.pdf*** (Consulted: April 7 2020).

ECOINA 2016. Eksploatacija prirodnog plina iz plinskog polja Irena na području Eksploatacijskog polja ugljikovodika Izabela Elaborat o utjecaju zahvata na okoliš (Screening on the Environmental Impact or the Exploitation of natural gas from the Irena gas field in the area of the Izabela exploitation field). ***https://mingor.gov.hr/UserDocsImages/ARHIVA%20DOKUMENATA/ARHIVA%20---%20OPUO/2017/elaborat_zastite_okolisa_744.pdf*** (Consulted: April 7 2020).

EDINA 2006. Gas field Izabela, Plan of Development (In ECOINA 2007.).

Geertsma, J (1973): Land Subsidence Above Compacting Oil and Gas Reservoirs, JPT, June *Journal of Petroleum Technology*, 25(6): 734–744.

Geertsma, J. and van Opstal, G. 1973. A Numerical Technique for Predicting Subsidence above Compacting Reservoirs, Based on the Nucleus of Strain Concept, Verhandelingen Koninklijik Nederlandsch Geologisch Mijnbowkundig Genootschap, 28, 63–78.

INA, d.d. 2020. Production on North-Adriatic field Izabela launched, July 4 2020.***https://www.ina.hr/en/announcement/zapocinje-proizvodnja-sa-sjevernojadranskog-polja-izabela/*** (Consulted: April 7 2021).

MZOPUG 2007. Rješenje Ministarstva Zaštite Okoliša, Prostornog Uređenja i Graditeljstva o prihvatljivosti zahvata eksploatacije plina iz Eksploatacijskog polja „Izabela", Klasa: UP/I-351-03/07-02/92; Ur.broj: 531-08-3-1-1-6-07-8 od 30. listopad 2007. (Decision of the Ministry of Environmental Protection, Physical Planning and Construction on the acceptability of the project of gas exploitation from the Exploitation Field "Izabela", Class: UP/I-351-03/07-02/92; No: 531-08-3-1-1-6-07-8, October 30, 2007)

Oikon 2011. Elaborat o utjecaju zahvata na okoliš za izgradnju novih platformi napostojećem polju za eksploataciju ugljikovodika "Sjeverni Jadran" (Screening on the Environmental Impact of for the Construction of New Platforms at the Existing Gas Exploitation Field "North Adriatic").

Režić M. 2016. Opći model za izračun geološke vjerojatnosti novih otkrića plina u sjevernom Jadranu uz primjer plinskog polja Ika, (General Model for the Calculation of Geological Probability Associated With New Gas Discoveries in the Northern Adriatic with An example of the Ika Gas Field), Master's Thesis, University of Zagreb Faculty of Mining, Geology and Petroleum Engineering.

Vasiljević, R. 2018. Environmental issues of gas exploitation platforms in the North Adriatic offshore Croatia, *European Geologist*, 46. 6–11.

Slope protection with an earth retaining system: respectful of natural resources and the landscape

Steve Gruslin[1] and Domenico Nola[1]*

Heavy rains in June 2018 damaged a road between Echternach and Berdorf (Luxembourg) so severely that it had to be closed. The river along the road below it destroyed the existing stabilisation structures, such as retaining walls and gabion walls, and severely eroded the natural slope covering the underlying Luxembourger Sandstone. Water infiltrated the embankment, causing landslides extending in several places to below the body of the roadway. After clarifying the geological situation and determining the geotechnical parameters of the materials, renovation was carried out using natural materials present on the site, which were used to recreate load-bearing structures reinforced by geogrids and adapted to the landscape in topographically very difficult conditions. From a sustainability standpoint, landslide materials and locally excavated materials were reused in a resource-saving manner.

Les fortes pluies de juin 2018 ont gravement endommagé une route entre Echternach et Berdorf (Luxembourg) au point que celle-ci a dû être fermée. La rivière le long de la route en contrebas a détruit les structures de stabilisation existantes, telles que les murs de soutènement et les murs en gabions, et a érodé la pente naturelle recouvrant le grès luxembourgeois sous-jacent. L'eau s'est infiltrée dans le remblai, provoquant des glissements de terrain s'étendant à plusieurs endroits jusqu'en dessous du corps de la chaussée. Après avoir clarifié la situation géologique et déterminé les paramètres géotechniques des matériaux, la rénovation a été réalisée avec des matériaux naturels présents sur le site, qui ont permis de recréer des structures porteuses renforcées par des géogrilles et adaptées au paysage dans des conditions topographiquement très difficiles. Du point de vue de la durabilité, les matériaux des glissements de terrain et les matériaux excavés localement ont été réutilisés de manière à économiser les ressources.

Las fuertes lluvias caídas en junio de 2018 dañaron una vialidad entre Echternach y Berdorf (Luxemburgo) tan gravemente que tuvo que ser cerrado. A lo largo y debajo de la carretera, el río destruyó las estructuras de estabilización existentes, como muros de contención y muros de gaviones, erosionando severamente la pendiente natural que cubría la subyacente arenisca de Luxenburgo. El agua percoló en el terraplén, provocando deslizamientos de tierra que se extendieron en varios lugares por debajo de la calzada. Tras esclarecer la situación geológica y determinar los parámetros geotécnicos de los materiales, se procedió a la rehabilitación utilizando materiales naturales presentes en el área, que sirvieron para recrear estructuras portantes reforzadas por geomallas y adaptadas al paisaje en condiciones topográficamente complejas. Desde el punto de vista de la sostenibilidad, los materiales del deslizamientos de tierra y los materiales excavados localmente se reutilizaron de manera de optimizar los recursos.

During the night of 31 May to 1 June 2018, several parts of the Grand Duchy of Luxembourg were severely affected by violent thunderstorms, which were sometimes accompanied by floods. This was particularly the case for the Mullerthal region, nicknamed "Luxembourg's Little Switzerland", which is a popular tourist and hiking destination. The road linking Echternach to Berdorf and Beaufort (CR364), which runs along the Aesbach Valley on the south side, was particularly affected (***Figure 1***).

Due to heavy rains, with rainfall of up to 90 litres per square metre, several land-

[1] GEOCONSEILS S.A.
Parc d'Activité de Capellen, 2-4, L-8308 Capellen, Luxembourg
* steve.gruslin@geoconseils.lu

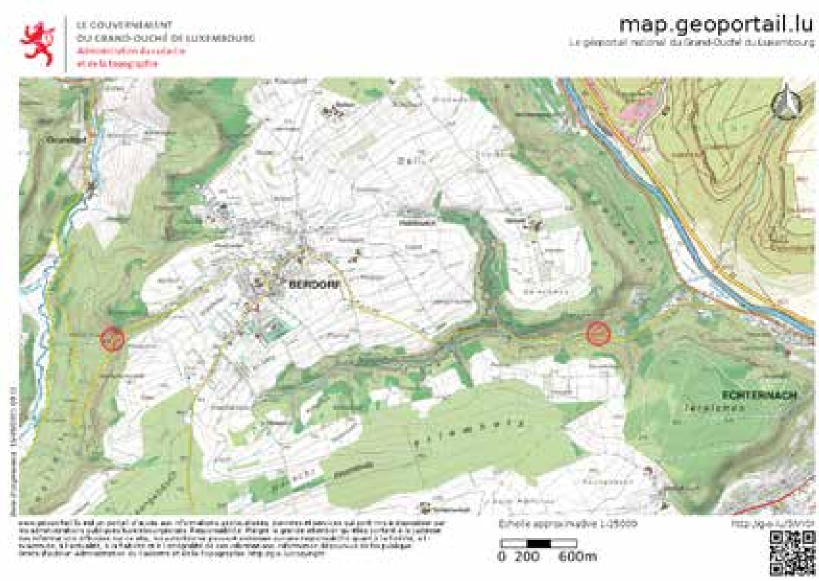


Figure 1: Location of the two zones on the topographic map (zone 1 on the right, zone 2 on the left).

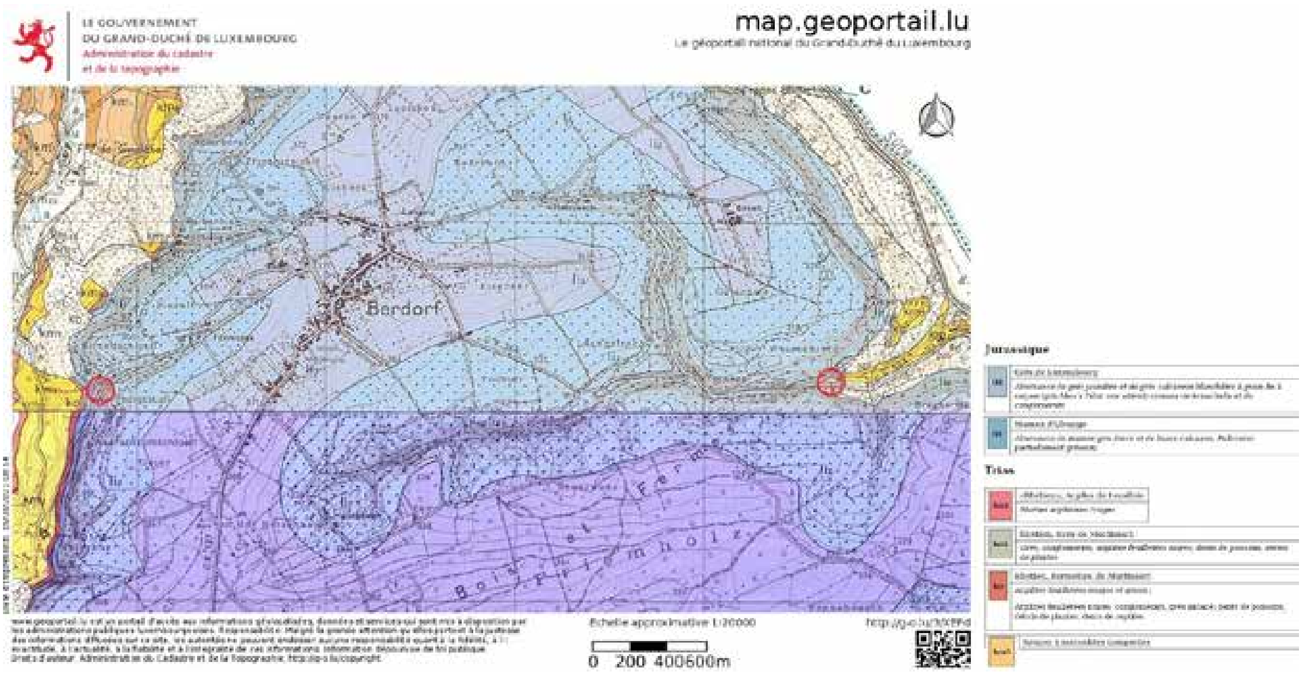


Figure 2: Location of the 2 zones on the geological map (zone 1 on the right, zone 2 on the left).

slides occurred. In addition, the Aesbach flood caused considerable damage to the embankments and protective structures of the roadway, consisting of retaining walls, gabion walls and backfills. Many buildings were also severely affected by the floods, and several bridges and walkways were completely destroyed. Given the geology and the topography of the area, the occurrence of small landslides is not uncommon in the region, but never with the magnitude of these which occurred due to the bad weather, so the road had to be closed immediately.

The damage that occurred and the corrective measures implemented are described below for two areas in particular, but many other areas required emergency measures to be put into place. In addition to the measures described below, a large number of renovation measures such as retaining supports, installation of drainage systems, etc. were carried out on the entire road, but they are not the subject of this article.

The geotechnical studies and the planning of the measures allowing the rehabilitation of a portion of approximately 1.1 km of the CR364 road were carried out by the design office Géoconseils S.A. on behalf of the "Administration des Ponts & Chaussées du Luxembourg".

Geological situation

According to the geological maps of Luxembourg (***Figure 2***), the section of the road concerned is located on sandstones from the Lower Liassic (Jurassic), indicated as "li$_2$" on the maps. Due to the presence of the river, this geological layer has been eroded in places, giving outcrop or approaching underlying geological layers such as marls and limestones (Lower Liassic: li$_1$), clay and clayey marls (Upper Keuper: ko$_2$), sandstones and argillites (Upper Keuper: ko$_1$) and variegated marls (Middle Keuper: km$_3$).

- The li$_2$ (more commonly known as "Luxembourg Sandstone") is composed of calcareous sandstones of whitish color alternating with sandstones, of which the calcareous cement is less present or totally absent, of yellowish color.
- The li$_1$ ("Elvange Marls"), is made up of alternating dark gray marls and partially sandy limestone beds.
- The ko$_2$ ("Rhaetian: Argile de Levallois – Levallois Clay") are clays and red clayey marls, the presence of which strongly influences the risk of landslides (by acting as a soap layer).
- The ko$_1$ ("Rhaetian: Mortinsart Sandstone") is composed of sandstones, conglomerates and black laminated argilites.
- Finally, the km$_3$ ("Keuper with compact marnolites") is made up of motley marls with thin dolomitic beds that may contain gypsum.

Due to the topography and the steep slopes, all these geological formations are covered by non-cohesive slope screes, composed of sandstone boulders in a sandy-silty matrix. These screes are the result of the weathering of the sandstone and the placement by gravity of the weathering materials along the slopes.

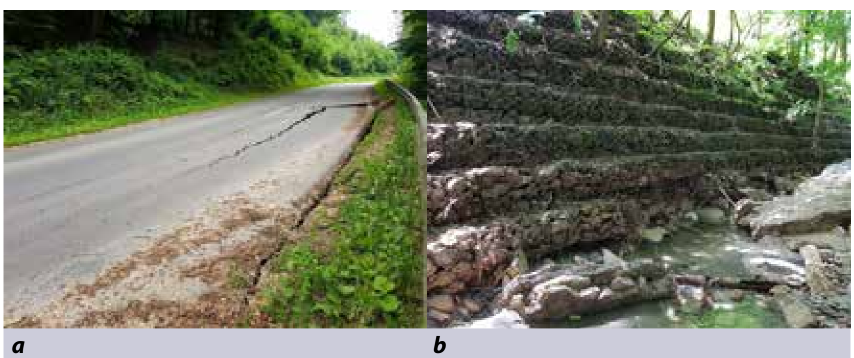


Figure 3: Examples of damage: cracks on the road (a); damaged gabion retaining wall (b).

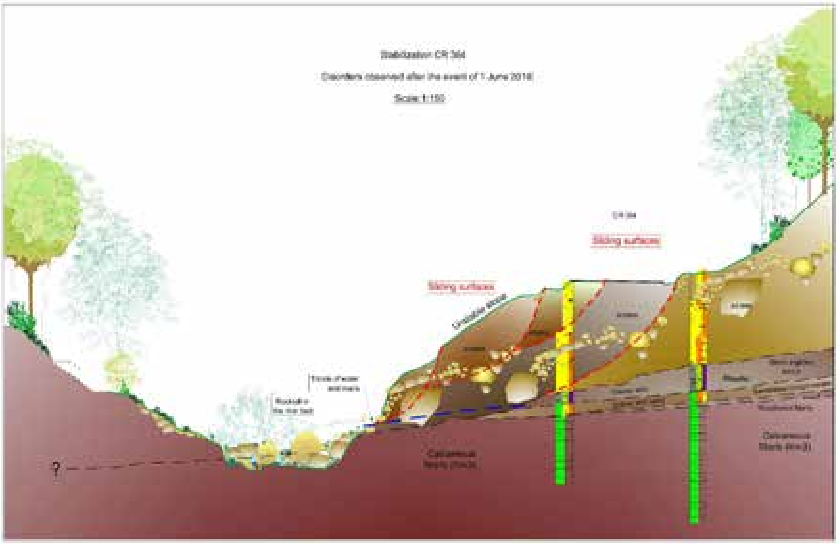


Figure 4: Interpretation of the situation based on the results of the boreholes.

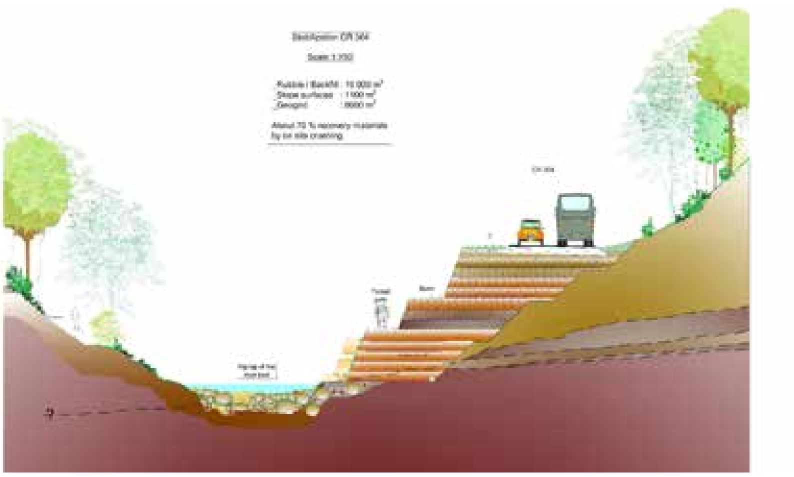


Figure 5: Principle of stabilisation with the Reinforced Earth System.

Zone 1

Damage and its causes

Damaged area 1 is located in the eastern part of the affected site. At this point, the Aesbach River is in the immediate vicinity of the CR364 road.

This area suffered a significant slip of the slope under the road (***Figure 3a***), causing it to crack. In addition, a bridge on the hiking trail over the Aesbach was completely destroyed. The lower part of the slope also shows strong traces of scour and erosion due to the force of the stream.

West of the site the slope was stabilised by gabions. Because of the speed and increased density of the stream due to sediment, floating debris and boulders that were transported, the gabion wall present over part of the area was undermined and considerably damaged (***Figure 3b***). The lower layer, which forms the basis of the entire retaining structure, was particularly affected. The road was affected by numerous longitudinal cracks due to the loss of wall integrity and landslides.

Geological and geotechnical surveys

For the geotechnical survey, three reconnaissance boreholes of 11 m, 12 m and 15 m depth, respectively, were carried out. To determine the geotechnical characteristics of the various layers required for geotechnical calculations and sizing, laboratory tests were carried out on representative core samples: classification tests (water content, Atterberg, particle size analysis) and uniaxial compressive strength tests.

The geotechnical investigations carried out encountered stony and gravelly backfills under the road over thicknesses of up to 3 m. Below there is slope scree consisting of sand and gravel with encrusted and partially altered layers of the Upper Triassic (Rhaetian) and the layers of the Middle Keuper. Rhaetian layers have high consistency in the dry state, but they are very sensitive to water. They soften very quickly on contact with water, thus playing the role of a "soap layer" which, in combination with the inclination of the layer, can constitute a potential sliding surface for overlying materials that are not very cohesive.

The water masses resulting from the heavy rains coming from the hill above the site reached the road, ran off on the embankment and caused significant erosion on the surface. The water which penetrated under the road quickly crossed the permeable layers (backfills and scree) and mobilised the sliding surface constituted by the Rhaetian layers, so that all the embankments and scree slipped, which led to the appearance of cracks in the roadway. Reconnaissance boreholes allowed us to estimate that around 10,000 m^3 of underground materials had slipped. ***Figure 4*** shows the cause of the damages, interpreted using the results of the exploration boreholes and the position of the cracks (GEOCONSEILS S.A., 27/09/2018; 2019).

Corrective actions undertaken

In order to find a sustainable solution and to protect the road against future heavy rains, the damaged existing embankment, which already had very steep slopes, was replaced by a steep embankment made of natural materials reinforced by geogrids that fits perfectly into the landscape.

Extensive geotechnical studies and calculations have shown that landslides can reoccur in affected areas if only limited corrective measures are put in place near the surface. To avoid long-term instabilities, it was necessary to excavate the entire body of the slip over the entire width of the roadway and down to the layers of Rhaetian at risk of slipping (***Figure 5***). The curved path of the Aesbach created additional requirements by limiting the space available for the basis of the reinforced earth construction

From a sustainability standpoint, most of the excavated material could be reused for backfilling in a way that saved resources. In this context, the excavated material, which consisted of stones, boulders, sand and gravel, was prepared on site with a crusher to produce backfill material with a grain size of 0/45 mm, which was temporarily stored on the road outside the damaged area. In this way, about 70% of the required backfill material could be obtained, which also had a positive effect on the ecological balance.

To provide the support structure for the earth retaining system fill sections, the steep slope system TensarTech GreenSlope

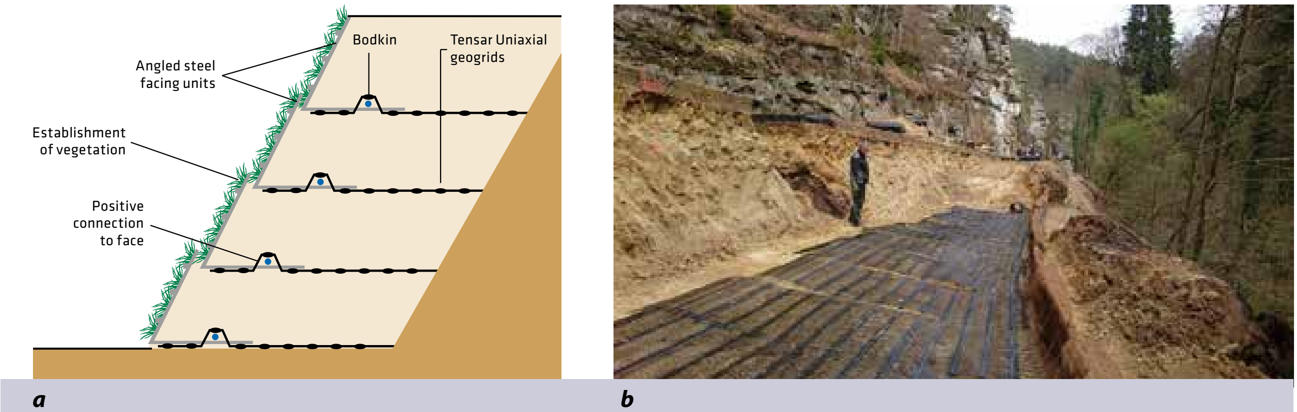


Figure 6: The TensarTech GreenSlope system: its principle (a) [reproduced with the permission of Tensar] and on site (b).

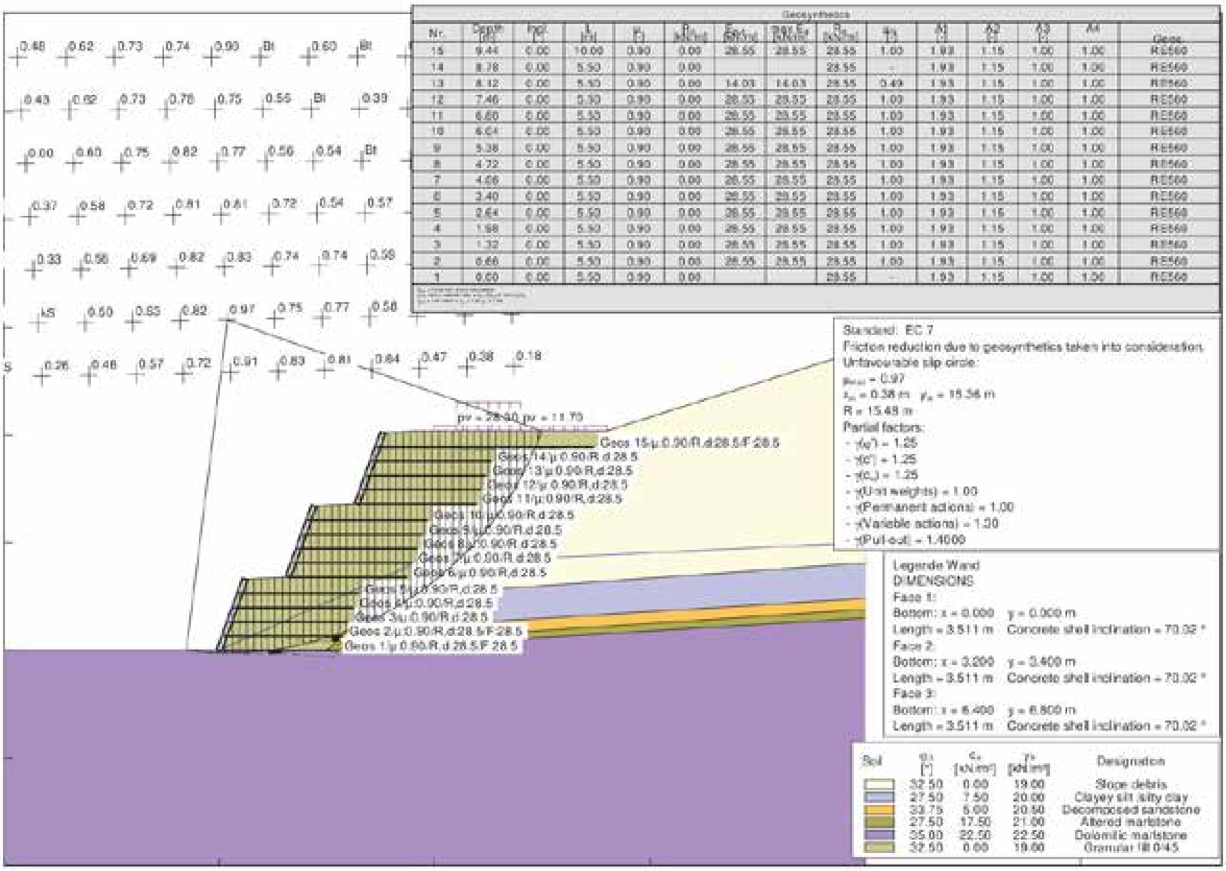


Figure 7: Stability calculations of the reinforced earth system.

was chosen, which allows slopes between 45° and 70° to be created. This system chosen for reinforcement is an adaptable, settlement insensitive securing system made up of steel grid elements in the front and horizontally laid geogrids, so that the backfill material results in a composite load-bearing body with a high degree of ductility.

Based on stability calculations using geotechnical software, the inclination of the elements made of steel grid is 70° and the distance between the layers of the horizontal geogrids is 66 cm. The reinforcement consists of expandable, uniaxially stretched, node-rigid and dimensionally stable geogrids in order to ensure optimal nesting of the backfill material and high long-term strength. To ensure good grip and sufficient stability of the backfill vis-à-vis the existing slope, steps were made in the natural land, with a slope of 5° outwards to allow good drainage of infiltration water.

The lengths of the geogrid were adapted to the geometry of the supporting body and

Figure 8: Stabilisation system under construction.

Figure 9: Landslide at the "Preacher's Chair".

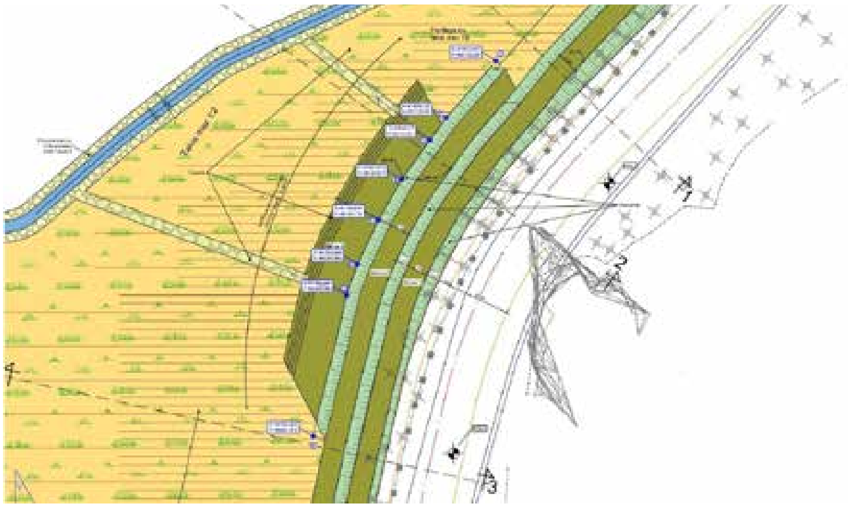


Figure 10: Situation map of the reinforced earth construction at the "Preacher's Chair".

to the constraints of the road and the land and were between 5 m and 8 m. In total, around 8,000 m² of geogrids were installed in this section. Control of the compaction of the backfill material was carried out by means of plate loading tests on each layer.

For protection against erosion, a mat was placed behind the face of the steel grid element which also allows rapid revegetation. As an additional protective measure, blocks of natural rocks were placed at the Aesbach as protection against erosion in the event of flooding.

To take into account the uneven topography of the site, the reinforced earth construction was built to heights of between 3 m and 9 m. In order to obtain a uniform landscape, berms of about 2 m in width were built every 3 m high. Thanks to the combination of the green construction in reinforced earth, the section of road blends harmoniously into the landscape since the end of the works in summer 2019. ***Figure 8*** shows the reinforced earth construction under construction in April 2019 (Meyer *et al.*, 2019).

Zone 2

The 2nd zone is located in the western part of the damaged road, approximately 50 m higher than damaged zone 1. In this area, the road embankment was also considerably eroded by heavy rains and water seeping into the embankment destabilised the road and caused landslides in several places. The largest landslide affected the tourist area known as the "Preacher's Chair".

In this location, the waters of the stream are channeled under Route CR364. Due to the debris carried during the storm, the existing pipes were blocked and could not handle the volume of water associated with the severe weather. Consequently, the water overflowing from the pipeline seeped into the embankment of the road, creating a large landslide which locally washed away all the CR364 road. Each subsequent rainfall further accentuated the instabilities created by the June 2018 storm.

For the geotechnical survey, 2 core boreholes of 11 m and 14 m were carried out, in combination with laboratory tests.This made it possible to highlight a geological situation different from that encountered for the first zone. The sloping scree here has thicknesses of up to 7 m. We then find the Luxembourg sandstone, both weath-

Figure 11: Stabilisation system under construction.

Figure 12: Rock outcrop integrated into the stabilisation system.

a *b*

Figure 13: Situation before (a) and after (b) stabilisation.

ered and unweathered. The landslides were therefore caused by the large amounts of water seeping through the non-cohesive screes, which, combined with the steep slope, created the movement (GEOCONSEILS S.A., 17/10/2018).

Earth retaining system

Similarly to the Zone 1 renovations described above, the entire slip body was excavated, and a geogrid reinforced earth system (Tensar Tech GS System) was implemented (***Figure 10***).

Here also, material excavated from the slipping zone was treated on site and reused as backfill material. The variable geometry of the valley required an adjustment of the height, which results in different heights of the reinforced earth structure and the creation of 2 m wide berms. The retaining structure therefore fits harmoniously into the landscape.

In addition to the topography of the valley, the highly variable geometry of the rock that outcropped after the excavation of the landslide zone created an additional constraint. In several places, rock points protruded into the retaining structure, similar to those visible above road level at the "Preacher's Chair". ***Figure 12*** shows the state of construction in April 2019. A rock outcrop integrated into the exterior face of the backfill is visible (Meyer *et al.*, 2019).

A comparison between the initial situation after the landslide and the final situation is visible in ***Figure 13***. The entire slope will be covered in vegetation soon, because the TensarTech GreenSlope system will promote vegetation growth on the surface, helping it to blend in with its surroundings.

Drainage systems

The damage repairs had to take into account the causes of the damage. Here, it was the heavy rains and the water infiltrated into the embankment, associated with a very particular geological and topographical situation, that led to the landslides. It is therefore imperative to collect the water through appropriate drainage systems and discharge it without damage.

Two issues had to be taken into consideration:

- the risk of erosion from the river
- the risk of runoff and infiltration into the backfills

Regarding erosion, it was decided to protect the lower parts with a stone facing to avoid direct contact with water. In addition, riprap was placed in the riverbed to reduce the speed of the stream.

To manage the surface water, drainage has been put in place to prevent water infiltrating into the backfills from softening sensitive geological layers, and also to prevent erosion. A drainage ditch was dug at the foot of the load-bearing structure in order to be able to evacuate surface water which flows through the structure. The berms have a slope of 5% towards the outside.

To drain the water coming from the slope, a drainage layer of at least 30 cm thick of 8/16 mm gravel was installed between the excavation slope and the supporting structure, separated from the existing soil by a geotextile. The water is discharged via a DN 200 drainage system and can be discharged at 2 points through solid pipes under the supporting structure. The water is then diverted to the receiving water via constructed drainage ditches (see also ***Figure 10***). Fortified drainage and overflow ditches have also been created in other areas where high water flow could be expected during heavy rains.

Conclusion

The roads and the steep slopes of the embankments present in the Mullerthal require special attention due to their topographical characteristics and the resulting demands on stability and drainage conditions. Two examples were used to show how landslides that have occurred can be remedied economically and safely. Reinforced earth constructions are particularly suitable for this because they can be integrated very well into the landscape thanks to their design options. The possibility of reusing the materials excavated on site ensures a good ecological balance. At the end of the work, the green support structures fit harmoniously into the landscape and, at least in these areas, future damage from heavy rains is likely to be avoided.

References

GEOCONSEILS S.A., 27/09/2018. Assainissement inondations CR364, Berdorf (Renovation after flood damage CR364 Berdorf) – SGP-218-009. Geotechnical study report.

GEOCONSEILS S.A., 17/10/2018. Assainissement inondations CR364, Beaufort (Renovation after flood damage CR364 Beaufort) – SGP-218-009. Geotechnical study report.

GEOCONSEILS S.A. 2019. CR364 Echternach-Berdorf; „Rutschungen und Erosionsschäden infolge der Regenereignisse vom 1.6.2018"(Landslides and erosion damage as a result of the rain event of the 1 June 2018). Report.

Meyer, N., Nola, D. and Scherbina, E. 2019. Ressourcen- und landschaftsschonende Hangsicherungen mit Kunststoff-Bewehrte-Erde (KBE)-Konstruktionen (Resource and landscape-friendly slope stabilization with plastic-reinforced earth (KBE) constructions). Proceedings Fachsektionstage Geotechnik Wurzburg, pp. 504–508.

Site appraisal in fractured rock media: coupling engineering geological mapping and geotechnical modelling

Helder I. Chaminé, Maria José Afonso, José Filinto Trigo, Liliana Freitas, Luís Ramos, and José Martins Carvalho*

Geotechnical surveys are based on collecting data from fieldwork and are a key element of rock-mass quality assessment in rock engineering. The lessons learned in several engineering projects underline the value of the accuracy of the basic geological and geotechnical data information related to the rock masses description and evaluation. An evaluation based on engineering geosciences, hydraulic and geotechnical features of rock masses involves combining parameters to derive quantitative geomechanical classifications for engineering design. In the present work, two selected sites are highlighted to demonstrate the importance of GIS mapping and models. Mapping and quantifying the on-site measurements' information content and building a geo-database is vital for decision-making processes and risk assessment on sustainable engineering design with nature and hazards.

Les levés géotechniques sont basés sur la collecte de données provenant de travaux de sur le terrain et sont un élément clé de l'évaluation de la qualité de la masse rocheuse dans l'ingénierie des roches. L'enseignement tiré de plusieurs projets d'ingénierie souligne la valeur de l'exactitude des informations géologiques et géotechniques fondamentales liées à la description et à l'évaluation des masses rocheuses. L'évaluation basée sur les géosciences de l'ingénieur, les caractéristiques hydrauliques et géotechniques des masses rocheuses implique la combinaison de paramètres de manière à obtenir des classifications géomécaniques quantitatives pour la conception en ingénierie. Dans le présent travail, certains sites ont été sélectionnés pour mettre en évidence l'importance de la cartographie SIG et des modèles. De cette façon, la cartographie et la quantification du contenu informatif des mesures sur le terrain et la construction d'une géo-base de données sont vitales pour être utilisées dans les processus de prise de décision et l'évaluation des risques sur la conception technique durable en rapport avec la nature et les risques.

Las investigaciones geotécnicas se basan en la adquisición de datos de campo, y son elemento clave para evaluar la calidad del macizo rocoso, en la ingeniería de rocas. Las lecciones aprendidas, en varios proyectos de ingeniería, resaltan el valor de la precisión de la información de los datos geológicos y geotécnicos fundamentales, relacionados con la descripción y evaluación de los macizos rocosos. La evaluación basada en la ingeniería de las geociencias, las características hidráulicas y geotécnicas de los macizos rocosos, implica la utilización de parámetros combinados, para obtener clasificaciones geomecánicas cuantitativas para el diseño ingenieril. No presente trabajo, se han seleccionado algunos lugares elegidos para demostrar la importancia de la cartografía SIG y modelos. Es así que cartografiar y cuantificar el contenido de información de las mediciones in situ, y construir una base de datos geológicos, es vital para utilizarla en los procesos de toma de decisiones y de evaluación de riesgos, en el diseño de ingeniería sostenible con la naturaleza y los riesgos.

Introduction

Barton and Quadros (2015) argue the following: "Anisotropy is everywhere. Isotropy is rare. Round stones are collectors' items, and any almost cubic blocks are photographed, as they are the exception. The reasons for rock masses to frequently exhibit impressive degrees of anisotropy, with properties varying with direction of observation and measurement, are clearly their varied geological origins. Origins may provide distinctive bedding cycles in sedimentary rocks, distinctive flows and flow-tops in basalts, foliation in gneisses, schistosity in schists and cleavage in slates, and faults through all the above. We can add igneous dykes, sills, weathered horizons, and dominant joint sets. Each of the above are rich potential or inevitable sources of velocity, modulus, strength and permeability anisotropy — and inhomogeneity." (p. 1323).

This impressive quotation outlines the key role of an accurate geology assessment in field site investigations for rock engineering purposes. Also, it highlights the complexity of heterogeneous rock-mass nature and behaviour. Lessons learned in geotechnical practice emphasise the importance of comprehensive acquisition of the fundamental geological and geotechnical data related to rock mass description and evaluation (Chaminé *et al.*, 2013).

A site appraisal in fissured rock media is an essential step to gather reliable information concerning structural geology and the petrophysical, hydrogeomechanical, and geotechnical features of the intact rock and rock masses, either in boreholes or exposed rock surfaces (***Figure 1***).

Site characterisation for engineering purposes should be outlined based on Earth systems analysis, which forms the core for developing models to create scenarios using various approaches (e.g., Griffiths and Stokes, 2008; Chaminé *et al.*, 2013; Griffiths, 2014; Fookes *et al.*, 2015, Norbury 2021, and references therein), such as: i) geological models (lithological and structural models with basic geology information for engineering purposes); ii) ground models (geological and/or geomorphological models with engineering parameters based on ground investigations

* Laboratory of Cartography and Applied Geology, School of Engineering (ISEP), Polytechnic of Porto, Portugal, hic@isep.ipp.pt

Figure 1: Geotechnical site appraisal and its main technical-scientific fields and applications.

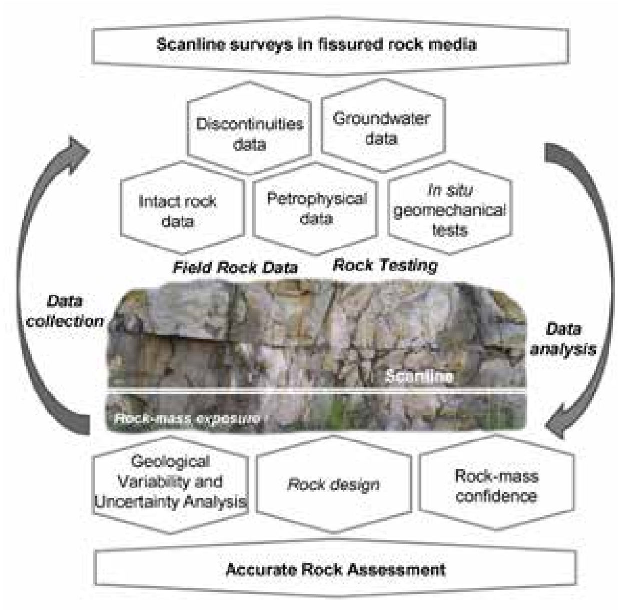


Figure 2: Scanline surveys in fissured rock media: a reliable technique to reduce the geologic variability and uncertainty.

and other available data); iii) geotechnical models (ground models with predicted performance based on design parameters); iv) geomechanical models (geotechnical models based on mathematical modelling focused on material behaviour). All the models must be robust, calibrated and supported on a permanent back-analysis scale based on a logical understanding of real ground behaviour (Chaminé *et al.*, 2013). Particularly, rock engineering deals with jointed/faulted anisotropic material and fluid-bearing media, the so-called rock mass (Barton and Quadros, 2015).

Scanline surveys are based on collecting rock data from fieldwork and are an essential component of rock-mass quality assessment in rock engineering practice (e.g., Priest 1993, Chaminé *et al.* 2013, 2015), ***Figure 2***. The strength, deformability, and permeability features of a rock mass are greatly affected by its discontinuities network and nature. Evaluation based on engineering geosciences and the geotechnical features of rock masses includes combining parameters to develop multi-parametric geomechanical classifications and or geotechnical indexes for engineering design purposes (***Figure 3***).

Selected Sites: engineering geoscience maps on geotechnics practice

A thorough study of applied geology was carried out at two selected NW Portugal sites: Mourilhe road slope, Cinfães, and Luriz cemetery, Valongo. The Mourilhe road slope study coupled GIS-based engineering

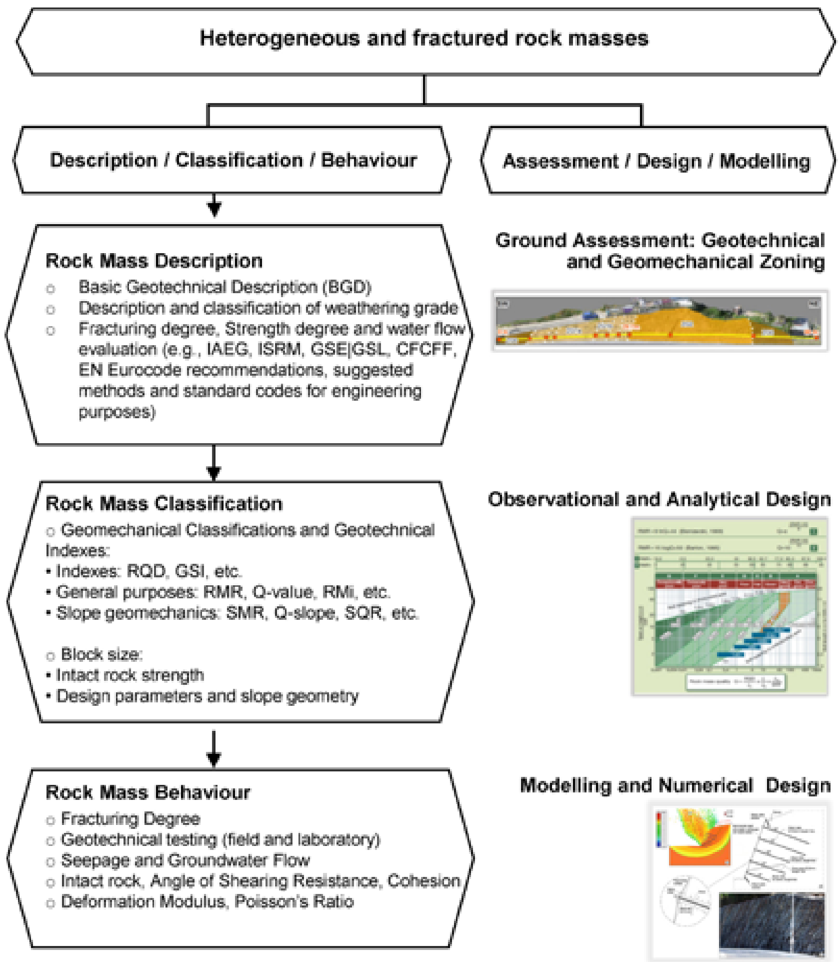


Figure 3: An overview of heterogeneous and fractured rock masses focussed on geotechnical slopes: from rock mass description to rock mass behaviour.

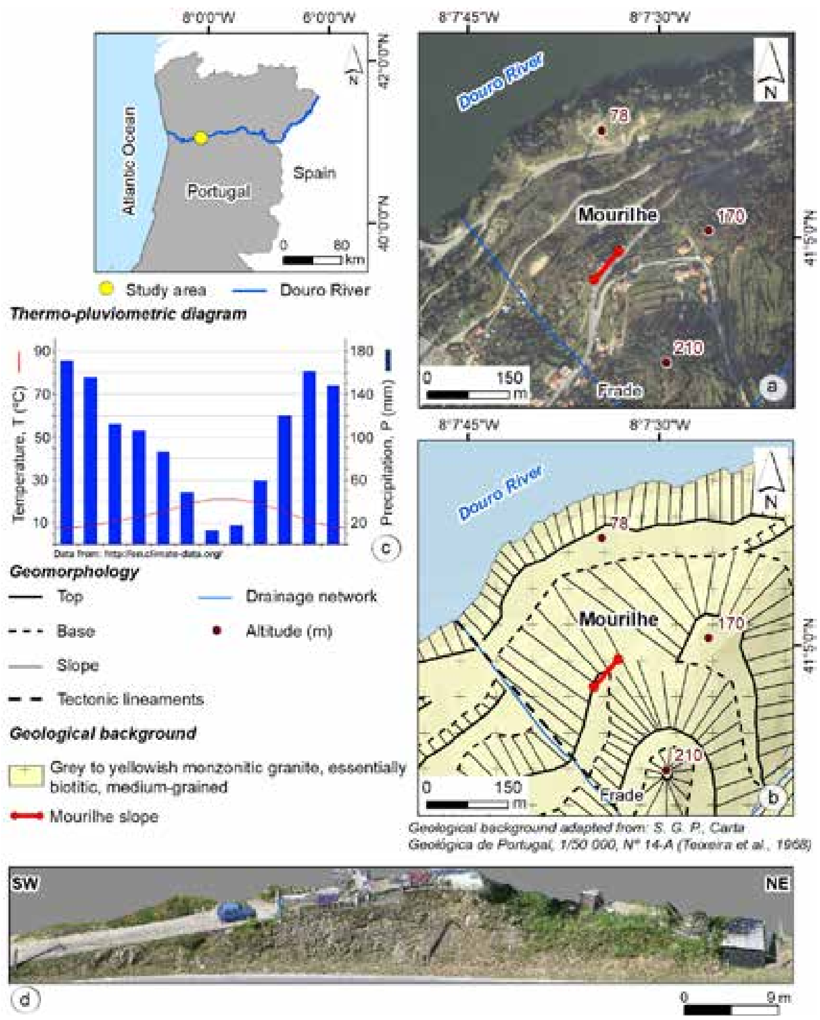


Figure 4: Mourilhe road slope setting (Cinfães, N Portugal): (a) Geographic location (Google Earth Pro); (b) Geomorphological and geological background; (c) Thermo-pluviometric diagram; (d) General view of the slope.

Table 1: Summary of the basic geotechnical parameters for the Mourilhe rock slope.

Basic Geotechnical Description of the Rock Mass Parameters (BGD after ISRM codes)	
Slope (length/height, m)	*70 / 10 m*
Weathering Grade (W)	*Moderately to Highly Weathered (dominantly W_3 to W_{4-5}, but occurred W_6 - residual soil)*
Discontinuity type	*Predominantly joints, but faults also mapped*
Main Discontinuity sets	*N170°-200°E; 80°-88°NW/SE N90°-130°E; 64°-84°SW/NE N30°-50°E; 40°-70°NW/SE (n = 36)*
Aperture (mm)	*Open to Closed [median value = 4.8 mm]*
Fracture Intercept, F (cm)	*Wide Spacing (F_{1-2}) [median value = 75 cm]*
Persistence (m)	*Medium to High (3 - 10 m)*
Roughness (R)	*Smooth (R_3), Undulating*
Filling	*Mostly Absent; 22% are filled with fault gauge*
Seepage	*Dry*
Uniaxial Compressive Strength, S (σc, MPa)	*Moderate to Low (S_3 to S_4) [median value = 22 MPa]*

geological mapping with slope geotechnics, whilst the Luriz graveyard study combined GIS-based mapping with hydrogeotechnical assessments. Thematic maps and cross-sections were prepared from multi-source geodata, particularly remote sensing, morphotectonic and geological mapping, and geotechnical and hydrogeological field surveys. All the data were combined and analysed in a GIS platform to elaborate detailed cross-sections to support the geotechnical modelling and solution. The mapping techniques, engineering geosciences, applied geomorphology, and applied hydrogeology were applied at the study sites (e.g., Dearman, 1991; Griffiths, 2002; Gustafson, 2012, and references therein).

Field inspection and surveys were performed to outline the geological, morphotectonical and geotechnical constraints of the rock mass in the study sites and nearby areas. This approach intends to highlight the essential aspects, such as: i) regional and local geology and morphostructure, ii) geo-structural description and mapping; iii) identification and mapping of the weathering zones; iv) definition of weathering profiles; v) characterisation of the seepage and hydrological features; vi) a timeline record of all geotechnical aspects, such as rock falls. A complete geotechnical description of the rock mass was developed, and in situ strength rock testing (Schmidt hammer, type L) was performed. Besides, the scanline sampling technique was applied to the study of free faces on rocky slopes. This approach was also supported by: i) georeferenced data using high-precision GPS for the fieldwork survey and high-resolution digital imagery acquired by an unmanned aerial vehicle (UAV), ii) structural geology data collected were analysed with stereo-nets and rose diagrams in Dips version 7 (Rocscience) software, iii) the use of geo-calculator applications (particularly "GeoTech|CalcTools" and "MGC-RocDesign|Calc") to support the analysis, design, and modelling (Chaminé *et al.*, 2015), iv) GIS-based mapping and application tools. In order to classify the quality of the rock mass, the geomechanical classification systems and indexes were applied, namely Rock Mass Rating (RMR) (Bieniawski, 1989), Slope Mass Rating (SMR) (Romana *et al.*, 2015), and the Geological Strength Index (GSI) (Hoek *et al.*, 2013). Finally, the site was evaluated using the Rockfall Hazard Rating System (RHRSM2) and Slope Quality Index (SQI) (Pinheiro *et al.*, 2015).

The evaluation of the studied sites followed the basic description of rock masses and recognised engineering geoscience maps, following the recommendations of

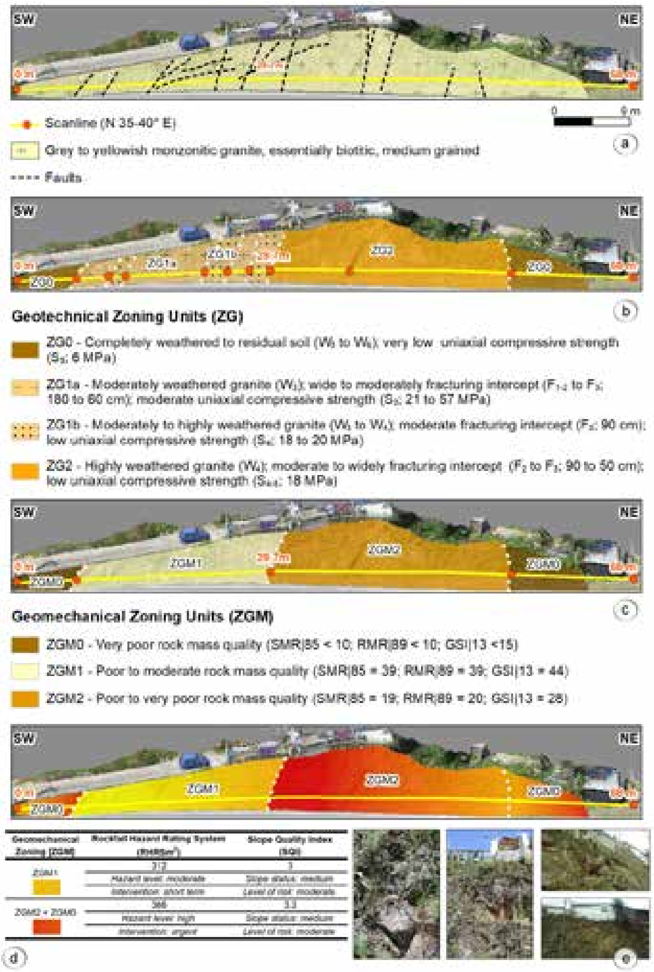


Figure 5: Geotechnical and geomechanical assessment: geotechnical and geomechanical zoning (the dots mark the zoning units' boundaries) and rock slope hazard zoning based on rockfall rating system and slope quality index. (a) Scanline and geological cross-section; (b) Geotechnical zoning; (c) Geomechanical zoning; (d) Rockfall hazard features; (e) Several aspects of the rocky slope instability.

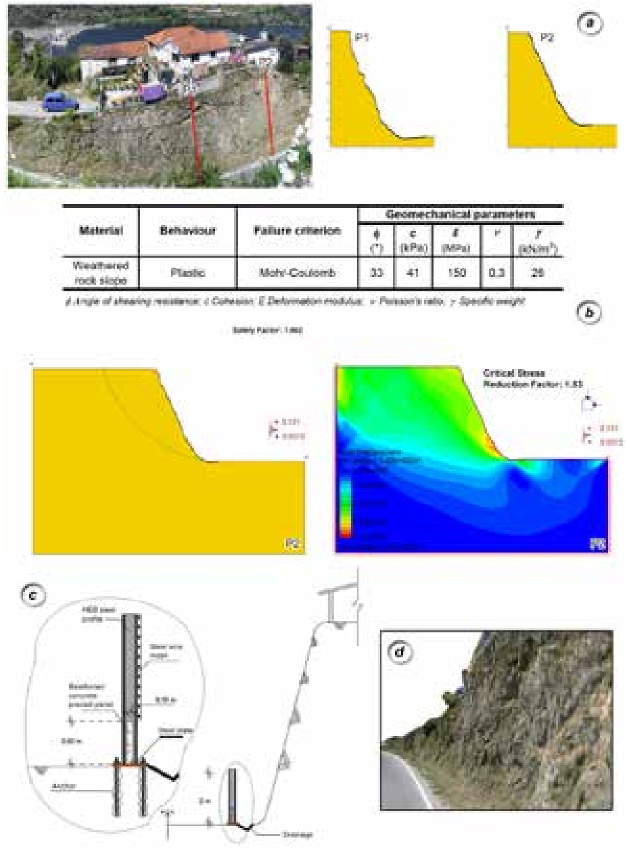


Figure 6: Geotechnical modelling and protection solution design adopted for Mourilhe road slope. (a) Profiles P1 and P2 and the geomechanical parameters used; (b) Minimum safety factor and critical SRC for P2 (Slide and RS2 software from Rocsience); (c) Schematic cross-section with the proposed protection features; (d) 3D slope model resulting from UAV aerial surveys.

several associations: IAEG – International Association for Engineering Geology and the Environment (***www.iaeg.info***); GSE|GSL –Engineering Geology Group of the Geological Society of London (***www.geolsoc.org.uk***); ISRM – International Society for Rock Mechanics and Rock Engineering (***www.isrm.net***); CFCFF – Committee on Fracture Characterization and Fluid Flow (***www.nap.edu***) and European Eurocodes, particularly geotechnical design standards (***https://eurocodes.jrc.ec.europa.eu***). The geotechnical parameters used for the rock mass characterisation are fracture spacing (F_1 to F_5), weathering grade (W_1 to W_6), roughness (R_1 to R_5) and uniaxial compressive strength of rock material (S_1 to S_5) as recommended in the Basic Geotechnical Description (BGD) of rock masses classification from ISRM.

Mourilhe Road Slope Case Study

The selected study site, Mourilhe rocky slope, is located in S. Cristóvão de Nogueira (Cinfães, Northern district of Viseu, Portugal), close to the Douro River. This study's main goal was to inspect, survey and evaluate safety conditions of the rocky slope and, subsequently, to present a proposal for a stabilisation and protection solution. The studied road slope is in a hillside area, with altitudes ranging from 50 m (Douro riverside) to 218 m (Frade settlement) (***Figure 4a,b***). The Mourilhe area fits in the so-called Alto Minho–Beira granite belt, trending NW-SE. The Mourilhe outcrop is a medium-grained, biotite-rich, grey to yellowish monzonitic granite (***Figure 4b***). It is characterised by up to 15 m thick weathering horizons of sandy and clayey materials. The regional morphotectonic context is dominated by a large network of structures that control the landforms. The fracture system that occurs in the directions NNE-SSW to NE-SW are parallel to the Verín– Régua–Penacova fault zone and Tâmega fault, respectively. Also, a NW-SE fracture system is represented. These deep crustal structures control some of the sections of the Douro River and some smaller streams.

Air temperature and precipitation are dependent on altitude variations. They show strong thermo-pluviometric contrasts, particularly between the areas located in the Douro Valley and the surrounding highest relief, the Montemuro Mountains. The Mourilhe area has an average annual temperature of 14 °C and average annual precipitation of 1200 mm. The minimum and maximum values for temperature are 7.5 °C (January) and 20.8 °C (July and August). For precipitation, the minimum and maxi-

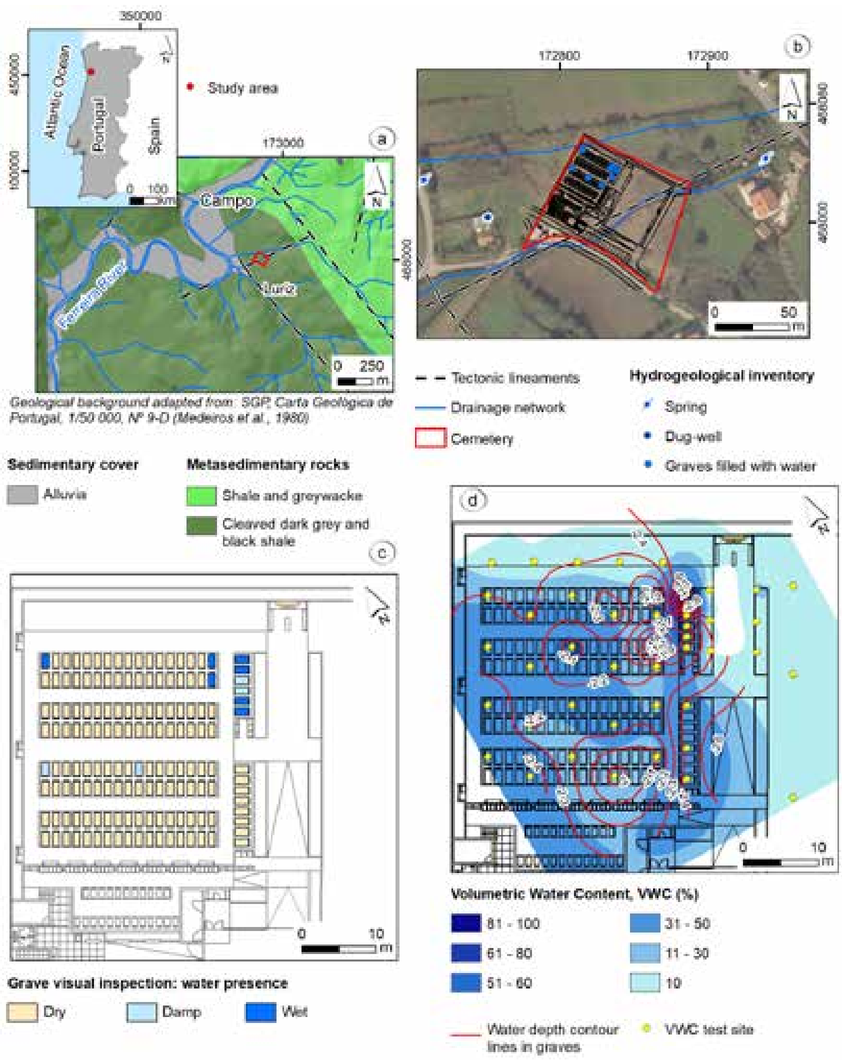


Figure 7: Luriz cemetery (Valongo, NW Portugal): (a), (b) geological and geographical setting (Google Earth Pro from 2005); (c) visual inspection and hydrological inventory of the graves (cemetery layout in 2010); (d) volumetric water content (%) mapped on the ground (adapted from Chaminé et al., 2016).

mum values are 13 mm (July) and 171 mm (January). The dry period corresponds to July and August (***Figure 4c***).

The Mourilhe slope has a smooth curvilinear shape with general NNE-SSW orientation and a steep dip angle (80°). The average height is 10 m, the length is 70 m, and the rock mass exposure area is about 140 m^2 (***Figure 4d***). The studied road slope is mainly constituted by a dominantly medium-grained, biotite-rich granite (***Figure 5a***) that crops out as moderately weathered (W_3) to highly weathered (W_{4-5}). Thirty-six discontinuities (mainly joints and some faults) were mapped, and Schmidt's hammer rebound tests were performed at 10 locations (***Figure 5b***).

Table 1 summarises the most important in situ geological and geotechnical parameters collected and analysed from the Mourilhe rock slope.

The rock mass has dominantly a poor to moderate geomechanical quality based on SMR, RMR and GSI schemes (***Figure 5c***). The slope was classified (RHRSM2 and SQI) as unstable, with a moderate to high susceptibility to and a moderate hazard of rockfall (***Figure 5d***).

The geomechanical parameters adopted for the stabilisation evaluation are synthesised in ***Figure 6***. The evaluation of the slope stability was carried out with Slide and RS2 software (Rocscience). For these analyses, two geometrically accurate cross-sections (P1 and P2) were selected from the 3D slope model obtained from UAV aerial surveys (***Figures 6a and 6d***). Based on the geomechanical characterisation resulting from the fieldwork developed, equivalent values of the resistance parameters, φ and c, corresponding to the Mohr-Coulomb yield criterion, were determined (***Figure 6a***). ***Figure 6b*** shows the minimum safety factor calculated with Slide software for the vertical slope cross-section profile P2. It also presents the Strength Reduction Factor (SRF) critical value obtained with the RS2 software, using the Shear Strength Reduction (SSR) functionality. The values are similar in both calculations, and a reasonable safety reserve was identified concerning the global instability of the slope. An engineering protection solution was proposed after the geological, geotechnical and geomechanical studies and implemented. The protection solution is composed of high tensile wire mesh connected to steel profiles on the slope base, and a gutter was also installed near the base of the slope (***Figure 6c***).

Luriz cemetery case study

This case study is related to hydrogeotechnical issues found in the final stage of constructing a new cemetery located in Luriz, Valongo city (NW Portugal), particularly the severe groundwater inflow in some graves that prevented their use (details in Chaminé *et al.*, 2016). No burials were permitted until this problem was solved. Due to Portuguese legal restrictions for cemeteries, it is forbidden to install permanent or seasonal dewatering non-gravitic systems and solutions, which means that natural drainage must prevail (Nascimento and Trabulo, 2008). That is mainly because of potential geoenvironmental issues, particularly due to the discharge of hazardous substances and non-hazardous chemical and biological pollutants to groundwater (Dent *et al.*, 2004). The Luriz cemetery occupies an approximate area of 5000 m^2. It is grounded in organic soil that overlays a highly weathered (W_{4-5}) to residual soil (W_6) of dark shale, covering the metasedimentary bedrock. The dominant regional fracture network is NNW-SSE to NW-SE and NE-SW sets. The valley of the Ferreira River is subordinated to the mentioned fracturing systems. The bedrock consists of slightly weathered slaty and clayey fine-grained shales (W_{1-2}), dark grey to black, compact, with well-marked schistosity (N160°E; 70°NE). Milky quartz veins crosscut the shales. Joints were also recorded, with a sub-perpendicular orientation to regional schistosity (N60°E; subvertical). Joints are usually close to open (<0.5 mm), slightly rough (R_{1-2}), close to very close spacing (F_{4-5}: 6-15 cm), continuous, poorly filled (silty-clayey), and damp.

The Luriz cemetery is partly located on ground where the water table is at the subsurface, at a depth of less than 3.5 m, with minor seasonal variations. The topographic surface is partly flooded since a local stream cannot contain periods of intense precipitation. Moreover, the bedrock provides some level of imperviousness related to its

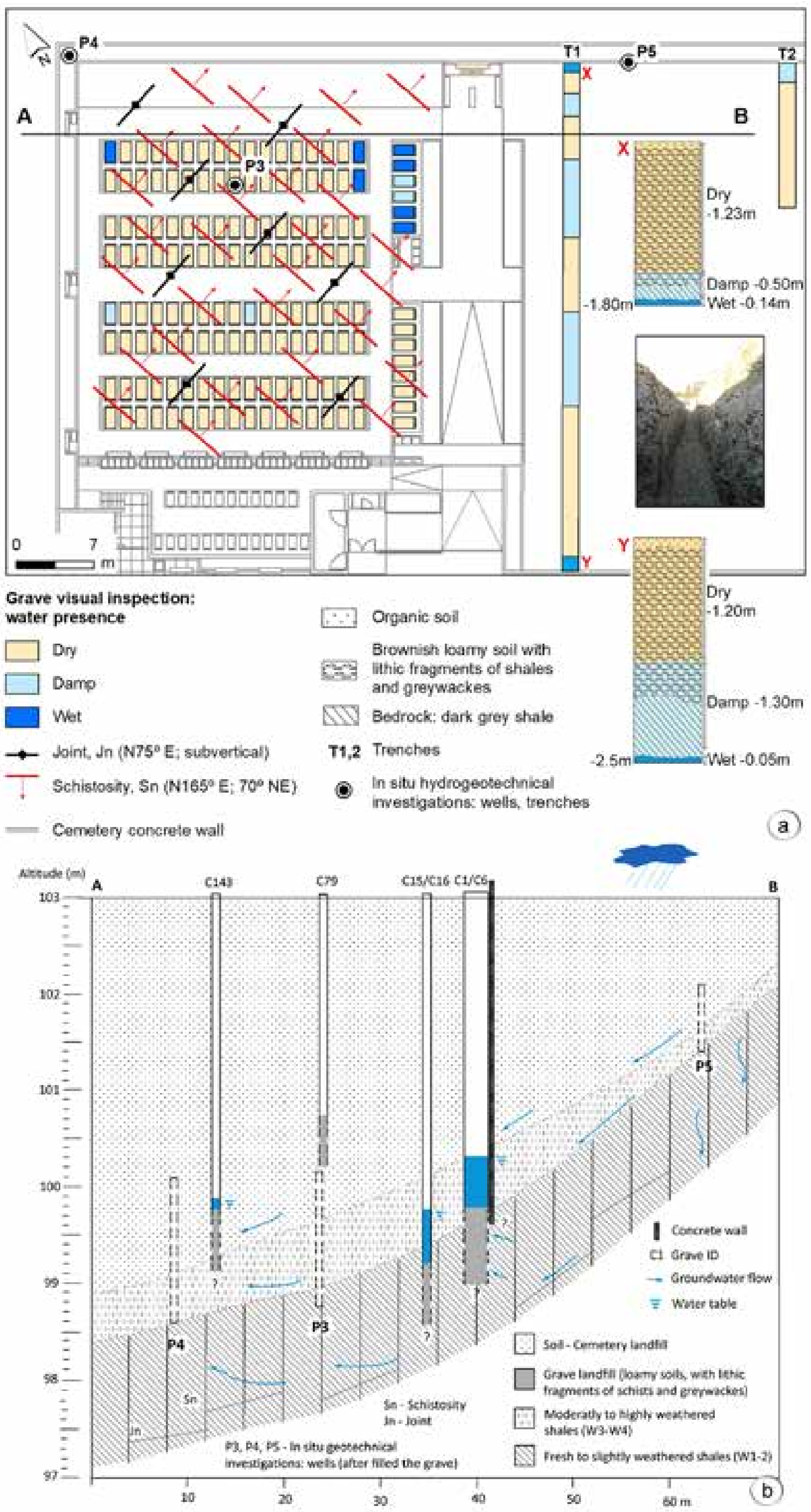


Figure 8: Inputs to the conceptual hydrogeological site model (adapted from Chaminé et al., 2016): (a) schematic mapping of the structural geology constraints of the rock mass and hydrogeotechnical logs (X, Y) and trenches mapped (T1, T2); (b) Interpretative hydrogeological cross-section (AB) with conceptual site model.

silty-clay nature. Precipitation is, in general, profuse, presenting an uneven distribution throughout the year. There is a water deficit from June to September, particularly in July and August. The average annual precipitation is around 1240 mm/year, reaching circa 180 mm in the wettest month (December) and 20 mm in the driest month (July). The actual evapotranspiration is about 50% of the precipitation, and the direct groundwater recharge is about 10–15%. ***Figure 7*** shows that the local hydrographic network drains into the Ferreira River, located SW of the cemetery. One of these streams crosses the cemetery area diagonally with a direct impact on its use. During the cemetery construction, this stream was diverted to a ditch located next to its NE-SW limit.

Several studies have been conducted to solve the inflow problem into the Luriz cemetery graves. The first one consisted of a hydrogeological inventory of the groundwater manifestations in the cemetery's vicinity and several cemetery graves. Twelve points were inventoried, including one well, two springs and nine graves. Each point was assigned an inventory number, and several characteristics were recorded. For the well, springs and the graves that contained water, in situ physicochemical properties of water were recorded: temperature, pH, and electrical conductivity (EC, μS/cm). The degree of soil moisture and the bedrock's depth for the remaining graves were evaluated whenever possible. The wells and springs' pH values are lower (ca. 5) than those of the cemetery graves (7–9). As for EC, the values are in the range 250–700 μS/cm.

A visual inspection of all the cemetery graves was made to check the water level at a later stage. It was noticed that most of them were dry, except Graves 1, 2, 6, 15, 16 and 143, which contained water, and Graves 75 and 147, which were wet. A more accurate definition of the water content at the soil moisture in the graves' base and some locations on the cemetery's surface was obtained by a capacitance probe (Theta Probe; Delta-T Devices, Cambridge), which assesses the volumetric water content of soil moisture. Based on these data, a map of isolines of volumetric water content (%) was elaborated, which verified that the highest level of water content was clustered in the zone of Graves 1 to 6, especially in Graves 1, 2 and 6. Besides, based on that data, the groundwater flow seems to be from NE to SW. That agrees with the main joint sets orientation and the stream that crosses transversely the cemetery site, grounded, and redirected.

To better understand the in situ geotechnical site conditions, two trenches were excavated with a backhoe: Trench 1 (T1), 45 m long and with a depth of 1.80–2.50 m, and Trench 2 (T2), 12 m long (see ***Figure 8a***). Both trenches have reached the metasedimentary bedrock. The analysis of the ground profile in T1 allowed the establishment of the following horizons: a superficial horizon of organic soil; a grave landfill level consisting of loamy soils, with heterometric lithic-supported schists and greywackes, with a silty-clayey matrix and a yellowish-brown tone; a lower level corresponding to the dark grey shale bedrock. Along with T1, the water content presence was mapped, which verified the presence of alternating dry and damp/wet areas, highlighting the trench's edges, where there is a clear presence of water. Along almost the total length of T2, the outcropped bedrock was recorded. It is important to note that no precipitation occurred in a couple of weeks before developing the fieldwork.

All the gathered data permitted us to conceptualise the groundwater circulation in the cemetery site. ***Figure 8a*** highlights the structural bedrock constraints, namely schistosity trending to NNW-SSE (and dipping to 70ºNE), and joint sets system with ENE-WSW orientation and sub-vertical dip. ***Figure 8b*** presents a hydrogeological cross-section that illustrates the geo-hydraulic conditions and the grave excavation positioning with water presence (Graves 1–6, 15, 16, 143). The graves acted as natural discharge points and were excavated in the bedrock and/or in the residual soil. Also, the remaining graves are positioned to a reasonable depth of the bedrock, set up in the cemetery landfill and/or in the slaty residual soil and with no water presence. A final remark is that the entire cemetery is bordered by a concrete wall founded in the bedrock. This infrastructure may, in part, contribute to confinement and disturbance of the underground hydraulic circuit.

Concluding remarks

GIS mapping is one of the techniques currently in use to support geotechnical studies such as slope stability analyses or hydrogeotechnical assessments. Additionally, the hydrogeological site conditions are of keen importance in any geotechnical study. The main advantage of using engineering geoscience mapping is that it is a simple and effective way to communicate geological, hydrogeological, geotechnical, geomechanical, and geoenvironmental information. Several methods and techniques are currently being used to assess slope stability (e.g., Romana *et al.*, 2015; Wyllie, 2018). Rock slope instabilities constitute a significant hazard for human activities and ecosystems, frequently affecting socioeconomic losses, property damages and maintenance costs, as well as for injuries and or casualties (e.g., Pantelidis, 2009; Pinheiro *et al.*, 2015). The combined geotechnical and geomechanical studies based on mapping, the rock classification schemes and indexes prove to be efficient tools in supporting the geotechnical evaluation and engineering design.

Finally, interdisciplinary methodology provides a crucial view to better understanding the studied sites' potential hazards. That approach is decisive to a balanced and safe solution in sustainable design with nature and geo-hazards (McHarg, 1992; González de Vallejo, 2012) and contributing to building a comprehensive site model based on reliable data and incorporating inherent ground variability and uncertainty (e.g., Griffiths, 2014; Chaminé *et al.*, 2015; Fookes *et al.*, 2015).

In summary, the geotechnical engineer John Neville Hutchinson stated an inspiring thought: 'To appraise a site properly, identifying the nature, structure and boundaries of its component materials, the locations and nature of discontinuities present and any relevant changes in conditions, and thence to establish a sufficiently correct geological model to form the basis of the geotechnical model for design of the proposed works, is undoubtedly one of the more demanding tasks that we face.' (Hutchinson, 2001:7). Last but not least, as highlighted by the engineering geologist Peter Fookes, that approach shall be rigorous straightforward, i.e., the field geologists or engineers shall use the KISS principle: *'Keep It Simple, Stupid!'* (Fookes *et al.*, 2015:8).

Acknowledgements

Some projects partially supported this study: LABCARGA|ISEP re-equipment program (IPP-ISEP| PAD'2007/08), and Centre GeoBioTec|UA (UID/GEO/04035/2020). We are grateful to J. Teixeira and J. Espinha Marques for the fieldwork inputs on the Luriz site. Our thanks to Cinfães municipality and Valongo municipality for their kind support in some stages of fieldwork. Special thanks are due to Nicole Devy-Vareta and Rafael Fernández-Rubio for kindly reviewing the French and Spanish version of the abstract, respectively. Our appreciation to our colleague I. Fernandes and reviewers for their valuable comments that helped improve the manuscript focus. The paper is dedicated to Professor Luís Ribeiro e Sousa, an outstanding Portuguese geotechnical engineer who promotes high standards in rock mechanics and rock engineering research, teaching, and practice.

References

Barton, N. & Quadros, E. 2015. Anisotropy is everywhere, to see, to measure and to model. *Rock Mechanics and Rock Engineering*, 48. 1323–1339. DOI: 10.1007/s00603-014-0632-7

Bieniawski, Z.T. 1989. *Engineering Rock Mass Classifications: A Complete Manual for Engineers and Geologists in Mining, Civil, and Petroleum Engineering*. Interscience, Wiley: New York

Chaminé, H.I., Afonso, M.J., Carvalho, J.M., Teixeira, J. & Espinha Marques, J. 2016. Considerações hidrológicas sobre o novo cemitério de Luriz, Valongo (NW de Portugal) (Hydrological remarks about the new graveyard of Luriz, Valongo (NW Portugal)). In Chaminé, H.I., Afonso, M.J., Galiza, A.C. (eds.), *Eduardo Gomes: Engenheiro, Docente, Empreendedor – Uma Homenagem, Porto, Portugal.* (pp. 133–142) Colecção LABCARGA-Geo|2, Instituto Superior de Engenharia do Porto, Porto.

Chaminé, H.I., Afonso, M.J., Ramos, L. & Pinheiro, R. 2015. Scanline sampling techniques for rock engineering surveys: insights from intrinsic geologic variability and uncertainty. In Giordan, D., Thuro, K., Carranza-Torres, C., Wu, F., Marinos, P., Delgado, C. (eds.), *Engineering Geology for Society and Territory – Applied Geology for Major Engineering Projects*, IAEG, Springer, 6.357-361. DOI 10.1007/978-3-319-09060-3_61

Chaminé, H.I., Afonso, M.J., Teixeira, J., Ramos, L., Fonseca, L., Pinheiro, R., Galiza, A.C. 2013. Using engineering geosciences mapping and GIS-based tools for georesources management: Lessons learned from rock quarrying. *European Geologist*, 36. 27-33.

Dearman, W.R. 1991. *Engineering Geological Mapping.* Butterworth-Heinemann: Oxford

Dent, B.B., Forbes, S.L. & Stuart, B.H. 2004. Review of human decomposition processes in soil. *Environmental Geology*, 45. 576–585. DOI_ 10.1007/s00254-003-0913-z

Fookes, P., Pettifer, G. & Waltham, T. 2015. Geomodels in Engineering Geology: An Introduction. Whittles Publishing: Dunbeath

González de Vallejo, L.I. 2012. Design with geo-hazards: an integrated approach from engineering geological methods. Soils and Rocks, *International Journal of Geotechnical and Geoenvironmental Engineering* 35(1).1–28. ***http://www.abms.com.br/links/soilsandrocks/solos-e-rochas-vol35-n1.pdf***

Griffiths, J.S. (ed.) 2002. Mapping in Engineering Geology. *Key Issues in Earth Sciences Series*, Vol. 1. The Geological Society of London: London

Griffiths, J.S. 2014. Feet on the ground: engineering geology past, present and future. *Quarterly Journal of Engineering Geology and Hydrogeology*, 47(2). 116-143. DOI 10.1144/qjegh2013-087

Griffiths, J.S. & Stokes, M. 2008. Engineering geomorphological input to ground models: an approach based on earth systems. *Quarterly Journal of Engineering Geology and Hydrogeology*, 41.73-91. DOI 10.1144/1470-9236/07-010

Gustafson, G. 2012. *Hydrogeology for Rock Engineers*. BeFo and ISRM Edition: Stockholm

Hoek, E., Carter, T.G. & Diederichs, M.S. 2013. Quantification of the geological strength index chart. In Pyrak-Nolte, L.J. (ed.), Proceedings of the 47th US Rock Mechanics and Geomechanics Symposium, ARMA 13–672, San Francisco, p. 1–8

Hutchinson, J.N. 2001. Reading the ground: morphology and geology in site appraisal. *Quarterly Journal of Engineering Geology and Hydrogeology*, 34.75–50. DOI 10.1144/qjegh.34.1.7

McHarg, I.L. 1992. *Design with Nature*. 25th anniversary edition. Wiley Series in Sustainable Design, John Wiley & Sons: New York

Nascimento, E., Trabulo, M. 2008. *Cemitérios* 3.ª edição (*Cemetaries*, 3rd ed.). Almedina: Coimbra

Norbury, D. 2021. Ground models: a brief overview. *Quarterly Journal of Engineering Geology and Hydrogeology*, 54(2). DOI: 10.1144/qjegh2020-018

Pantelidis, L. 2009. Rock slope stability assessment through rock mass classification systems. *International Journal of Rock Mechanics and Mining Sciences*, 46, 2. 315–325. DOI: 10.1016/j.ijrmms.2008.06.003

Pinheiro, M., Sanches, S., Miranda, T., Neves, A., Tinoco, J., Ferreira, A. & Correia, A.G. 2015. A new empirical system for rock slope stability analysis in exploitation stage. *International Journal of Rock Mechanics and Mining Sciences*, 76. 182-191. DOI: 10.1016/j.ijrmms.2015.03.015

Priest, S.D. 1993. *Discontinuity Analysis for Rock Engineering*. Chapman and Hall: London.

Romana, M., Tomás, R. & Serón, J.B. 2015. Slope Mass Rating (SMR) geomechanics classification: thirty years review. In Hadjigeorgiou, J., Archibald, J. (eds.), Proceedings of the 13th International Symposium on Rock Mechanics, ISRM, Quebec, p. 1-9.

Wyllie, D.C. 2018. *Rock Slope Engineering: Civil Applications.* Fifth Edition. CRC Press, Taylor & Francis Group: Boca Raton.

News corner:
Compiled by Anita Stein, EFG Office

EFG Annual report 2020

EFG is glad to present its Annual Report for 2020 which introduces the Federation's main activities throughout the past year.

The Report is structured around the six strategic action areas of the EFG Strategic Plan "Towards a sustainable future": Members, Network, Professional Expertise, Projects, Communication, Panels of Experts.

The report is available at the following link: ***https://bit.ly/3wgrNQV***

EFG Employment survey

In the annual EFG Employment Survey, the European Federation of Geologists (EFG) aims at taking a snapshot of the current labour market for geologists in Europe and beyond:

- Which industries are professional geologists working in?
- What is their current employment state and job security?
- Do their professional activities align with their training?
- Are they exploiting job opportunities in other European countries?
- What are the prospects for the future?

To help us produce a comprehensive report about the evolution of our profession, we would appreciate if you could take our short survey. This report will be published later this year and provide a clear overview of work opportunities in Europe, helping (future) geoscientists to orientate their studies or career decisions and providing professional associations with a steer on which services to offer to their members.

The survey is available here and answering it will take approximately 10 minutes: ***https://bit.ly/3aUc7do***

Thank you in advance for your time!

The results of the 2020 survey are available here: ***https://eurogeologists.eu/results-efg-employment-survey-2020/***

EU projects

Horizon 2020 is the biggest EU research and innovation programme ever, with nearly €80 billion of funding available to secure Europe's global competitiveness in the period 2014–2020. EFG is currently involved in five active Horizon 2020 projects: INTERMIN, ROBOMINERS, CROWDTHERMAL, REFLECT and SUMEX. In addition, EFG is also participating in two projects under the EIT RawMaterials initiative: ENGIE and PROSKILL. Below you will find descriptions of the topics and aims of these projects.

ROBOMINERS

ROBOMINERS

820971 – ROBOMINERS
Resilient Bio-inspired Modular Robotic Miners
START DATE: 1 June 2019
DURATION: 48 months
http://robominers.eu

Objectives:

ROBOMINERS will develop a bio-inspired, modular and reconfigurable robot-miner for small and difficult-to-access deposits. The aim is to create a prototype robot that is capable of mining underground, underwater or above water, and can be delivered in modules to the deposit via a large diameter borehole. In the envisioned ROBOMINERS technology line, mining will take place underground, underwater in a flooded environment. A large diameter borehole is drilled from the surface to the mineral deposit. A modular mining machine is delivered in modules via the borehole. This will then self-assemble and begin its operation. Powered by a water hydraulic drivetrain and artificial muscles, the robot will have high power density and environmentally safe operation. Situational awareness and sensing is provided by novel body sensors, including artificial whiskers, that will merge data in real-time with production sensors, optimising the rate of production and selection between different production methods. The produced high-grade mineral slurry is pumped to the surface, where it will be processed. The waste slurry could then be returned to the mine where to backfill mined-out areas.

ROBOMINERS will deliver proof of concept (TRL-4) of the feasibility of this technology line that can enable the EU have access to mineral raw materials from otherwise inaccessible or uneconomical domestic sources. This proof of concept will be delivered in the format of a new amphibious robot Miner Prototype that will be designed and constructed as a result of merging technologies from advanced robotics, mechatronics and mining engineering. Laboratory experiments will confirm the Miner's key functions, such as modularity, configurability, selective mining ability and resilience under a range of operating scenarios. The Prototype Miner will then be used to study and advance future research challenges concerning scalability, swarming behaviour and operation in harsh environments.

REFLECT

850626 - Redefining geothermal fluid properties at extreme conditions to optimize future geothermal energy extraction
START DATE: 1 January 2020
DURATION: 36 months
https://www.reflect-h2020.eu/

Objectives:

The efficiency of geothermal utilisation depends heavily upon the behaviour of the fluids that transfer heat between the geosphere and the engineered components of a power plant. Chemical or physical processes such as precipitation, corrosion, or degassing occur as pressure and temperature change, with serious consequences for power plant operations and project economics. Currently, there are no standard solutions for operators to deal with these challenges. The aim of REFLECT is to avoid the problems related to fluid chemistry rather than treat them. This requires accurate predictions and thus a thorough knowledge of the physical and chemical properties of the fluids throughout the geothermal loop. These properties are often only poorly defined, as in situ sampling and measurements at extreme conditions are hardly possible to date. As a consequence, large uncertainties prevail in current model predictions, which will be tackled in REFLECT by collecting new, high quality data in critical areas. The proposed approach includes advanced fluid sampling techniques, the measurement of fluid properties in in-situ conditions, and the exact determination of key parameters controlling precipitation and corrosion processes. The sampled fluids and measured fluid properties cover a large range of salinity and temperature, including those from enhanced and super-hot geothermal systems. The data obtained will be implemented in a European geothermal fluid atlas and in predictive models that both ultimately allow operational conditions and power plant layout to be adjusted to prevent unwanted reactions before they occur. That way, recommendations can be derived on how to best operate geothermal systems for sustainable and reliable electricity generation, advancing from an experience-based to a knowledge-based approach.

ENGIE

Encouraging Girls to Study Geosciences and Engineering
START DATE: 1 January 2020
DURATION: 36 months
https://www.engieproject.eu/

Objectives:

ENGIE aims to turn the interest of 13-to-18-year-old girls towards studying geosciences and related engineering disciplines. As career decisions are generally made in this period of life, the project aims to improve the gender balance in the fields of these disciplines. During the implementation of the three-year-long project an awareness-raising strategy will be developed and an international stakeholder collaboration network will be established for the realisation of a set of concrete actions. These actions include family science events, outdoor programmes, school science clubs, mine visits, mentoring programmes, international student conferences, competitions, publication opportunities, summer courses for science teachers and production of educational materials. The actions will be carried out in more than twenty countries throughout Europe.

PROSKILL

Development of a Skill Ecosystem in the Visegrád Four countries
START DATE: 1 January 2020
DURATION: 36 months
www.proskillproject.eu

Objectives:

The European Union puts emphasis on raising productivity as an important factor in maintaining economic growth. In order to improve productivity, it is vital to offer products and services with a high added value, and for that purpose highly qualified employees are required. Companies and professional organisations in the raw materials industries have stressed the need to improve the soft skills of students in order to meet the requirements of the labour market. The engineers of the future have to accept that engineering problems – as well as their solutions – are embedded in complex social, cultural, political, environmental and economic contexts. Engineers have to access, understand, evaluate, synthesise, and apply information and knowledge from engineering as well as from other fields of study. They have to find and achieve a synergy between technical and social systems. ProSkill has a double purpose. From the one side it adopts a 'skill ecosystem' concept, looking at what (hard and soft) skills are missing in the raw materials sector, which areas are affected by skill problems (shortages, mismatches and gaps) and what strategies can work. A high-skill ecosystem strategy supplemented with an action plan is developed. To ensure sustainability, the project focuses on lecturers in higher education ('train the trainer'). The main goal is to develop their knowledge about new and innovative educational techniques and to reshape outdated curricula. On the other side, a pilot project is launched involving the colleges for advanced studies in partner HEIs. Short-term and long-term programmes help to implement the strategy with the targeted development of selected soft skills.

SUMEX

101003622 - SUstainable Management in EXtractive industries
START DATE: 1 November 2020
DURATION: 36 months
https://www.sumexproject.eu/

Objectives:

SUMEX is a 36-month project funded by the European Commission that started on 1 November 2020. The project supports the set-up of a European sustainability framework to improve the permitting procedure along the extractive value chain (prospecting, exploration, extraction, processing, closure, post-closure activities), to guarantee timely decisions, a transparent governmental regulatory regime, appealing financial and administrative conditions and sustainable natural environmental and social conditions. The main mission of SUMEX is to assist policymakers and other stakeholders in seizing this opportunity.

In order to foster more extensive but sustainable mineral production in the EU, SUMEX (SUstainable Management in EXtractive industries) will establish a sustainability framework for the extractive industry in Europe. It does so by considering the Sustainable Development Goals, the European Green Deal, as well as EU Social License to Operate considerations and will involve stakeholders from industry, government, academia and civil society backgrounds from all across the EU.

INTERMIN

776642 – INTERMIN
INTERNATIONAL NETWORK OF RAW MATERIALS TRAINING CENTRES
START DATE: 1 February 2018
DURATION: 36 months
http://interminproject.org

Objectives:

INTERMIN is intended to create a feasible, long-lasting international network of technical and vocational training centres for mineral raw materials professionals. Specific objectives:

- Develop common metrics and reference points for quality assurance and recognition of training;
- Develop a comprehensive competency model for employment across the primary and secondary raw materials sectors;
- Introduce an international qualification framework for technical and vocational training programmes;
- Create a conceptual framework for the development of joint educational training programmes based on present and future requirements by employers;
- Create and launch a joint international training programme by a merger of competences and scope of existing training programmes.

CROWDTHERMAL

857830 – CROWDTHERMAL
Community-based development schemes for geothermal energy
START DATE: 1 September 2019
DURATION: 36 months
http://crowdthermalproject.eu

Objectives:

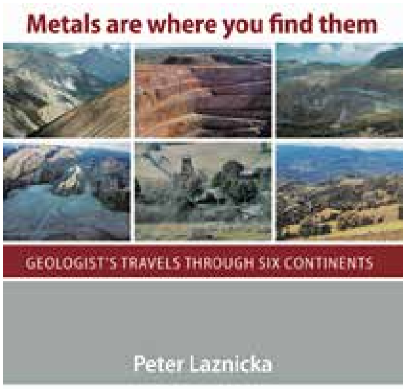
CROWDTHERMAL aims to empower the European public to directly participate in the development of geothermal projects with the help of alternative financing schemes (crowdfunding) and social engagement tools. In order to reach this goal, the project will first increase the transparency of geothermal projects and technologies by creating one-to-one links between geothermal actors and the public so that a Social Licence to Operate (SLO) could be obtained. This will be done by assessing the nature of public concerns for the different types of geothermal technologies, considering deep and shallow geothermal installations separately, as well as various hybrid and emerging technology solutions. CROWDTHERMAL will create a social acceptance model for geothermal energy that will be used as baseline in subsequent actions for inspiring public support for geothermal energy. Parallel and synergetic with this, the project will work out details of alternative financing and risk mitigation options covering the different types of geothermal resources and various socio-geographical settings. The models will be developed and validated with the help of three case studies in Iceland, Hungary and Spain and with the help of a Trans-European survey conducted by EFG Third Parties. Based on this feedback, a developers' toolbox will be created with the aim of promoting new geothermal projects in Europe supported by new forms of financing and investment risk mitigation schemes that will be designed to work hand in hand with current engineering and microeconomic best practices and conventional financial instruments.

Book review by Zdeňka Petáková, CAEG

Metals are where you find them: Geologist´s travels through six continents

by Peter Laznicka

ISBN: 978-80-7075-957-8



This is one of the most extensive monographs about global ore deposits recently published. It is focused on in-depth introductions of ore deposits: their description and geological setting, a discussion of origin, with vivid, mostly field photodocumentation. The author has visited more than 3,500 ore deposits in 80+ countries during the past 60 years, of which the most interesting examples are included in the book. Ore deposits situated on six continents are described: North America, Central and South America, Australia, Asia, Africa and Europe. There is a brief history of the regions described, and prospecting methods and case histories of the ore deposits' discoveries are also included. The descriptions are not strictly dry and encyclopaedic, but are animated by author's travel experiences, the story of his life and professional career ("I have sold my soul to ores", declares Laznicka) and his philosophy of life.

The book has twelve chapters, as follows:

- From Czech Meadows and Woods, 1945-1967
- In the Land of the Maple Leaf; Canada, 1967-1999
- North and Central America: The Warehouse of Metals
- South America
- Project Data Metallogenica: How I ended up Down Under
- Australia Encore
- Western Pacific and Indian Ocean Archipelagos
- Southern and SE Asia
- North Africa, Western and Central Asia
- Africa South of Sahara
- Europe
- Back in Prague after 25 years

The author, Peter Laznicka (born 1936 in Prague), is an economic geologist. He studied, worked and lived 32 years in Canada and now calls Australia home. As professor of geosciences at the University of Manitoba he lectured about metallic deposits around the world. He is the author of eight economic geology monographies. The most recent book, Giant Metallic Deposits: Future Sources of Industrial Metals (2010, Springer), is widely used as a university textbook. Peter Laznicka is also the founder of the expert system Data Metallogenica, which is one of the most complete "rock solid" information resources about world's ores: some 70,000 miniaturised samples of ores and host rocks, systematically cemented to aluminium plates, can actually be visited (and nondestructively tested) in Adelaide, and are displayed at *https://dmgeode.com/* with descriptions and thousands of photos.

Although primarily targeted at students and geo-professionals, the author makes a case in the preface as to why lay travelers might also benefit from reading it. "People travel for recreation, fun and to learn about the world. The sights to see include general geography, nature, culture, history, folklore. How many people travel to the often-messy places from where came the iron that holds their car together, or gold in their rings and jewels? Few do, but many readers might like to learn about such places, even without going anywhere. These are the intended readers of this book, and also the geological and industry professionals and students interested to venture beyond the dry technical facts offered by the professional literature and specialized higher education."

This book is marketed as an e-book in pdf format to economise on price, although purchasers are permitted to have the book printed locally. The book has 519 pages, 11 maps, 184 picture plates and 1,034 photos and the author, as copyright owner, allows free reproduction of photos and short paragraphs (with standard acknowledgment of source), a service appreciated by students. The book can be downloaded from the link (*https://obchod.geology.cz/metals-are-where-you-find-them-geologist-s-travels-through-six-continents?search=metals*) or from *www.payhip.com/b/tWLm*. The price is USD 52; for personal and student half-price discounts e-mail the author for a discount coupon at *plaznicka41@gmail.com*.

The Engineering Group of the Geological Society

Upcoming Events 2021

Date	Title (Theme)
12th April	Joint EGGS-EC and BGA-EC Event **Unknowable Risks : Health and Safety on Site** *Jim Gelder and Alejandro Zapata*
4th May	Joint EGGS and SERG Event **Harwich Formation in the London Basin** *Justyna Edgar*
2nd to 4th July	Engineering Group: Annual Field Meeting 2021 **The Engineering Geology of Canals, Somerset – the William Smith legacy** *Vicky Corcoran and Matthew Webb*
14th July	**Ian Higginbottom Memorial Event** *David Giles and Julian Murton*
15th September	**Engineering Geology of Egyptian Tomb Stability** *Martin Ziegler*
13th October	Groundwater Working Party TBC
24th November	**24th Annual Glossop Award and the 21st Glossop Medal Lecture** *David Shilston*

Follow us

Submission of articles to European Geologist Journal

Notes for contributors

The Editorial Board of the European Geologist journal welcomes article proposals in line with the specific topic agreed on by the EFG Council. The call for articles is published twice a year in December and June along with the publication of the previous issue.
The European Geologist journal publishes feature articles covering all branches of geosciences. EGJ furthermore publishes book reviews, interviews carried out with geoscientists for the section 'Professional profiles' and news relevant to the geological profession. The articles are peer reviewed and also reviewed by a native English speaker.
All articles for publication in the journal should be submitted electronically to the EFG Office at ***info.efg@eurogeologists*** according to the following deadlines:

- Deadlines for submitting article proposals (title and content in a few sentences) to the EFG Office (***info.efg@eurogeologists.eu***) are respectively 15 July and 15 January. The proposals are then evaluated by the Editorial Board and notification is given shortly to successful contributors.
- Deadlines for receipt of full articles are 15 March and 15 September.

Formal requirements

Layout
- Title followed by the author(s) name(s), place of work and email address,
- Abstract in English, French and Spanish,
- Main text without figures,
- Acknowledgements (optional),
- References.

Abstract
- Translation of the abstracts to French and Spanish can be provided by EFG.
- The abstract should summarise the essential information provided by the article in not more than 120 words.
- It should be intelligible without reference to the article and should include information on scope and objectives of the work described, methodology, results obtained and conclusions.

Main text
- The main text should be no longer than 2500 words, provided in doc or docx format.
- Figures should be referred in the text in italic.
- Citation of references in the main text should be as follows: 'Vidas and Cooper (2009) calculated…' or 'Possible reservoirs include depleted oil and gas fields… (Holloway *et al.*, 2005)'. When reference is made to a work by three or more authors, the first name followed by '*et al.*' should be used.
- Please limit the use of footnotes and number them in the text via superscripts. Instead of using footnotes, it is preferable to suggest further reading.

Figure captions
- Figure captions should be sent in a separate doc or docx file.

References
- References should be listed alphabetically at the end of the manuscript and must be laid out in the following manner:
- Journal articles: Author surname, initial(s). Date of publication. Title of article. Journal name, Volume number. First page - last page.
- Books: Author surname, initial(s). Date of publication. Title. Place of publication.
- Measurements and units
- Measurements and units: Geoscientists use Système International (SI) units. If the measurement (for example, if it was taken in 1850) was not in SI, please convert it (in parentheses). If the industry standard is not SI, exceptions are permitted.

Illustrations
- Figures should be submitted as separate files in JPEG or TIFF format with at least 300dpi.
- Authors are invited to suggest optimum positions for figures and tables even though lay-out considerations may require some changes.

Correspondence

All correspondence regarding publication should be addressed to:
EFG Office
Rue Jenner 13, B-1000 Brussels, Belgium.
E-mail: ***info.efg@eurogeologists.eu***

Note

All information published in the journal remains the responsibility of individual contributors. The Editorial Board is not liable for any views or opinions expressed by these authors.

Subscription

Subscription to the journal:
15 Euro per issue

Contact

EFG Office
Rue Jenner 13, B-1000 Brussels, Belgium.
E-mail: ***info.efg@eurogeologists.eu***

Advertisements

EFG broadly disseminates geology-related information among geologists, geoscientific organisations and the private sector which is an important employer for our professional members, but also to the general public.

Our different communication tools are the:
- EFG website, ***www.eurogeologists.eu***
- GeoNews, a monthly newsletter with information relevant to the geosciences community.
- European Geologist, EFG's biannual journal. Since 2010, the European Geologist journal is published online and distributed electronically. Some copies are printed for our members associations and the EFG Office which distributes them to the EU Institutions and companies.

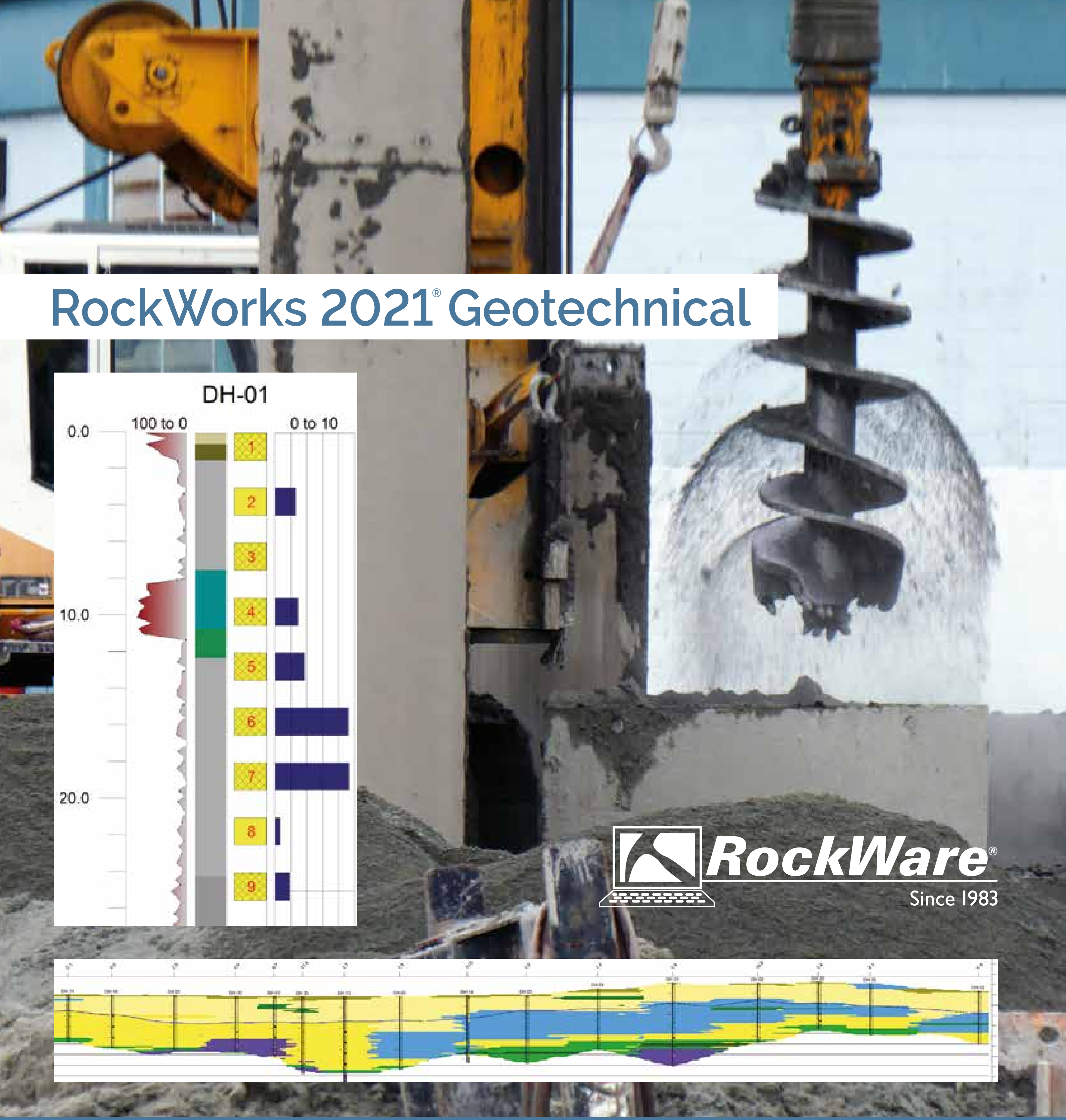
By means of these tools, EFG reaches approximately 50,000 European geologists as well as the international geology community.

With a view to improving the collaboration with companies, EFG proposes different advertisement options. For the individual prices of these different advertisement options please refer to the table.

Prices for advertisements

EGJ	**One Insertion**	**Two Insertions**
Full page (colour)	820 Euro	1320 Euro
Half page (colour)	420 Euro	670 Euro
Quarter page (colour)	220 Euro	350 Euro
Full page (black and white)	420 Euro	670 Euro
Half page (black and white)	220 Euro	350 Euro
Quarter page (black and white)	120 Euro	200 Euro
Business card size	90 Euro	150 Euro
Preferential location	25% plus	
Price for special pages:		
Outside back cover (colour)	1200 Euro	1900 Euro
Second page (colour)	1000 Euro	1600 Euro
Second last page (colour)	1000 Euro	1600 Euro

Geonews	**Annual Price**
Ad and regular newsfeed	1500 Euro
EFG Homepage	
Ad and regular newsfeed	1500 Euro
University ad	
Ad for training opportunities in the job area of the homepage	500 Euro
Annual package	
Business card size ad in EGJ, GeoNews and homepage.	3000 Euro



RockWorks offers geotechnical and civil engineers graphical and analytical tools for evaluating construction and excavation sites. Create borehole logs and cross sections, dozens of different types of maps, structural diagrams, geological/geotechnical/fracture/color models, volume reports and more.

Download FREE Trial at RockWare.com

37th ANNIVERSARY