25th Edition of the Ingeokring Newsletter

No.25 Winter 2020-2021

Colophon

Ingeokring, founded in 1974, is the Dutch association of engineering geologists. It is the largest section of KNGMG (Royal Geological and Mining Society of The Netherlands). Ingeokring also forms the Netherlands National Group of the International Association for Engineering Geology and the Environment (IAEG).

*With **over 150 members** working in different organisations, ranging from universities and research institutes to contractors, from consultancy firms to various governmental organizations, Ingeokring plays a vital role in the communication between engineering geologists in The Netherlands.*

The objective of the Newsletter is to inform members of the Ingeokring and other interested parties about topics related to engineering geology, varying from detailed articles, book reviews and student affairs to announcements of the Ingeokring and current developments in the field of engineering geology. The Newsletter wants to make engineering geology better known by improving the understanding of the different aspects of engineering geology.

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Subscription to the Newsletter

Each member of the Ingeokring receives at least once a year a new edition of the Newsletter. Membership fee for the Ingeokring is **€18; student membership fee is €9.** Other membership alternatives can be found at:

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Issue

25th Edition of the Ingeokring Newsletter

Winter 2020-2021 (**digital copy**)

Cover photo

The cover is made from a selection of the past 25 Newsletter issues over the last 25 years. Made by Marco Bolognin.

Guidelines for authors of Newsletter articles and information about advertising in the Newsletter can be found at the inside of the back cover.

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Letter from the Chairman

Siefko Slob—Chairman of the Ingeokring

Dear Valued Ingeokring member,

I think it is safe to say that this has been a very challenging year for all of us. The Ingeokring started 2020 hopeful with many plans for interesting excursions, the autumn symposium, a visit from the Finnish national group and we had plans to attend the Eurengeo conference in Athens. Of course, all these ideas and initiatives came abruptly to a halt due to the Covid-19 outbreak. We still had hopes over the year that we could gather for the autumn symposium in honour of the retirement of Robert Hack and Wim Verwaal, but it soon became clear that this was also not feasible. Nevertheless, instead of the autumn symposium the Ingeokring organised a webinar on 3D geo modelling, which was attended by many of you.

We are happy though that we can publish this fully digital Newsletter before the Christmas holidays, already the 25th edition since 1995. In 1995 we started a new glossy version of the newsletter, which remained largely the same until now. This year we decided not to print the Newsletter anymore, to distribute only in digital form. The cover of this Newsletter shows a compilation of the 25 editions. All past editions can be downloaded from our website.

This newsletter contains diverse subjects and I think it provides enough reading material for some quiet moments during your Christmas break. Because we were not able to organise any activities, the board has decided not to ask for Ingeokring membership contribution for the year 2020. The Ingeokring is fortunately in healthy financial position to be able to do this. I would also like to take the opportunity here to ask our members to come forward to join the Ingeokring board. We need active members to support us in our future activities, especially now.

The Ingeokring has good hopes that 2021 will be better than 2020 and that soon we are able to see you again at our meetings, live events, and excursions. Keep track of our website and LinkedIN page for announcements and news. Next year for instance, the Ingeokring will issue a BSc award for the best student. More news on this will follow. On behalf of the entire board of the Ingeokring I would like to wish you a very nice Christmas holidays and a very good and healthy 2021!

Letter from the Editor

Marco Bolognin—Editor of the Newsletter

The editorial board of the Newsletter is happy to present to you the 25th edition of the Ingeokring Newsletter in 25 years in its current glossy form. Before 1995 the Ingeokring also issued regular Newsletters, but these were still partly or fully in Dutch ("Nieuwsbrieven") and printed in black-and-white. The first Issue of the Newsletter was in 1977 when Jan Nieuwenhuis was the chairman of the Ingeokring. You can find all the old issues for download on our website. This Newsletter serves as a bridge to transmit professional experiences (in The Netherlands or elsewhere) and provide others with technical or scientific articles on specific relevant projects we deal with through our profession. It also provides an overview of the latest postgraduate topics at TU Delft; summaries from fieldtrips, workshops or any other activities organized by Ingeokring. This Newsletter aims to promote and encourage colleagues disseminating technological activities and research. Suggestions to improve the format, content and quality of this Newsletter in the future are welcome. Looking forward for your contributions!

Save the date: Friday 25 June 2021!

The Ingeokring board will organize its first summer symposium on the degradation of soils and rocks in engineering time. The event will be the pretext for celebrating the combined 80+ years career of two of our most prominent Ingeokring members: Robert Hack and Wim Verwaal.

Hoping that the Covid crisis gets under control so that we can meet for Wim and Robert's farewell in Delft on 25-06-2021.

Dominique Ngan-Tillard and John Adrichem are the organizers of the symposium.

Wim Verwaal and Robert Hack. Photo courtesy of Marco Huisman.

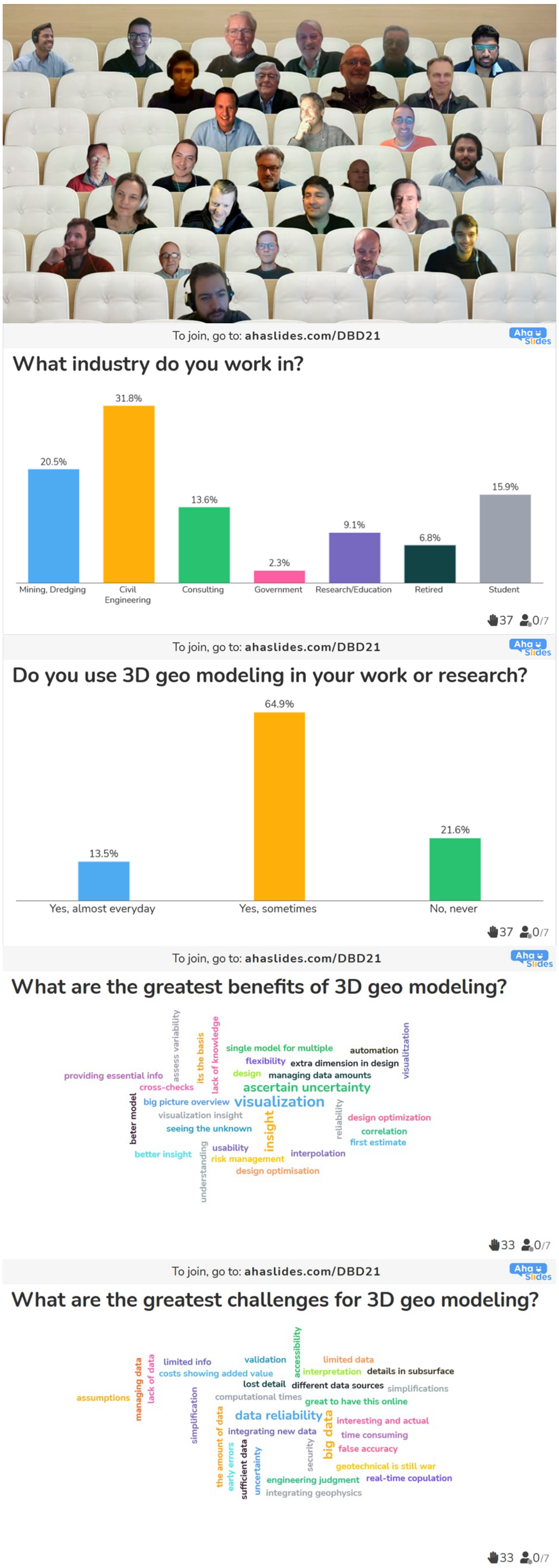
3D geomodeling webinar

Siefko Slob—Chairman of the Ingeokring

On Friday 20 November the Ingeokring hosted for the first time a webinar on 3D geo modeling. This webinar came instead of the planned autumn symposium. The webinar was a very interesting mix of presentations and online interactive Q&A sessions.

The first speaker was Keith Turner, our former and the last full professor in engineering geology from 1999-2002 in Delft. Keith provided a very nice overview of the development of 3D modeling over the years. Keith encountered 3D modeling when he was on a sabbatical with TNO in the late eighties. The title of his presentation was “Past, Present, and Future of Geological Modeling of the Shallow Subsurface”. The next speaker was Michiel van der Meulen, chief geologist of the Geological Survey of The Netherlands (TNO). Michiel is one of the driving forces behind the development of the comprehensive ground model of The Netherlands (GeoTOP). The title of Michiel’s presentation was: “Enabling Societal Access and Use of Geoscience Data.” The next presentation was by Robin Wimmer from Crux B.V. Robin is a geohydrological consultant and created a variety of tools to automate groundwater statistics and -calculations. His presentation was titled: “Automated Hydrogeological Modelling for Civil Engineering”. The final speaker was Mark Greatorex-Davies from RHDHV (UK) and his presentation was titled: “3D modeling for land reclamation in Pasay City, Philippines”. Mark is a geotechnical engineer and oversees the ground information management platform within the company. He is involved with improving existing data flows, innovating new ways to incorporate ground information and to optimise and improve geotechnical design process.

The interactive Q&A session were via a online platform called Aha slides, similar to Mentimeter where maybe more people are familiar with. Some of the sheets with the questions and answers are provided in the screenshots below. This is the first time that the Ingeokring hosted a webinar. It turned out to be a very successful event with over 60 attendees. Many students and attendees outside the typical Ingeokring network, which is encouraging. So, certainly a reason to organize this again anytime soon. Especially if due to the Covid measures, traveling and meetings will remain restricted. If you have missed the webinar, or if you want to see the presentations again, you can find the link on our LinkedIN page: https://www.linkedin.com/company/ingeokring. If you want to be updated on our activities and initiatives, please follow our LinkedIN page and you will be notified.



“Together view” of the participants from the webinar and interactive Q&A session results.

Susceptibility to weathering; overview

H. Robert G.K. Hack *(Bigbonzoconsulting, Leiden, The Netherlands)*

Abstract: Weathering is the chemical and physical change in time of ground under influence of atmosphere, hydrosphere, cryosphere, biosphere, and nuclear radiation. Quantities of weathered material do not need to be large to change the geotechnical properties of a groundmass, for example, weathering of discontinuity walls that reduces the shear strength. Weathering is the reason for many constructions and other engineering applications in which ground is used, to become a disaster during project lifetime. Hence, accounting in the design for the degradation of geotechnical materials in the future is necessary to ensure a stable structure for the full lifetime.

Keywords: Ground, Weathering; Susceptibility to weathering; Geomechanical properties; Degradation

1. Introduction

Weathering takes place everywhere around us; wood rots, concrete get stained or worse, falls apart, plastics dissolve, and also soil and rock weather. Groundmass materials change under influence of the Earth atmosphere, hydrosphere, cryosphere, biosphere, and by nuclear radiation, mostly causing a groundmass to become less strong. Under some conditions weathering may have a reverse effect and cause an increase in ground strength when forming 'hard' layers. Most groundmasses weather in a fairly slow process taking long (geological) times to weather noticeable volumes of ground, but even changes in properties of very small quantities of ground may jeopardize an engineering construction. For example, the rock on both sides of a joint plane after excavation being exposed to a new environment may weather by a depth of tens of a millimeter in a short time after excavation. Then the shear strength of the joint plane may reduce significantly due to weathering of the asperities on the joint plane and weathered material may form a thin layer of low shear strength infill material, e.g. clay, in the joint. Such reduction in shear strength is often enough to allow sliding of a rock block that would not have been the case along the unweathered joint plane. 'Loss of structure' of ground is also a consequence of weathering. The geotechnical properties of a groundmass depend to a certain extent on a tight structure of particles and blocks of ground material. Weathering causing removal of material or decreasing the strength of particles or blocks reduces the tightness. The reduction in tightness allows displacements, relaxation of stresses in the groundmass, reduction of shear strength between particles and blocks, and, hence, the overall geotechnical quality of the groundmass.

Weathering has a major influence on the geotechnical and engineering properties of the ground (Anon., 1995; Fookes, 1997; Hack, 1998, 2020; Hencher, 2015; ISO 14689-1:2017; Miščević and Vlastelica, 2014; Price et al., 2009; Tating et al., 2013). Therefore, weathering and the change of geotechnical properties with time during the lifetime of an engineering construction should be incorporated in the design of any construction on or below the Earth surface.

Weathering is often assumed to be restricted to the Earth surface, but active weathering may take place deep under the surface, for example, around faults with percolating groundwater down to thousands of meters deep, and at surface weathered material may have moved down into the Earth crust by tectonic and sedimentary processes. Moreover, weathered material may be a relic of weathering under a past climate or environment that has changed since long (Harris et al., 1996; Olesen et al., 2007). Hence, any weathered material can be encountered anywhere at the surface or in the subsurface of the Earth. This article is an overview on susceptibility to weathering partially based on 'Weathering, erosion and susceptibility to weathering' (Hack, 2020).

2. Weathering rate and depth of weathering

The rate of weathering, i.e. the weathering per time unit, is highly variable and strongly depends on the type of groundmass, environment, climate, and local circumstances, such as erosion, the accessibility of the groundmass for (ground-) water and air, minerals dissolved in (ground-) water and in vapor in air, and nuclear radiation. The influence of weathering on engineering structures can be within years but it may also take centuries before any influence is noticeable (Cabria, 2015; Hack et al., 2003; Huisman et al., 2006; Tating et al., 2013; Tran et al., 2019). The depth of weathering into a groundmass is dependent on the same factors. In-situ weathering from surface may go down to tens and often more than one hundred meters below surface in warm and humid environments (Fig. 1) (Fookes, 1997; Lumb, 1983; Qi et al., 2009). In dry climates, however, the in-situ weathered zone is often just a few decimeters or meters deep. The depth of the weathered zone is less where weathered material is removed by erosion or by solution into (ground-) water.

2.1 Environment and climate

The environment and climate have a major influence on rate and depth of weathering. In a tropical humid climate chemical weathering is dominant and minerals fall apart very rapidly under influence of chemical reactions. In more temperate climates physical weathering becomes dominant, whereas in arid polar or dry mountain climates physical weathering will be virtually the sole mechanism of weathering (Lamp et al., 2017). Solution of material, also a form of weathering, may reduce very rapidly geotechnical properties of materials soluble in water in a climate with rain (Fig. 2).

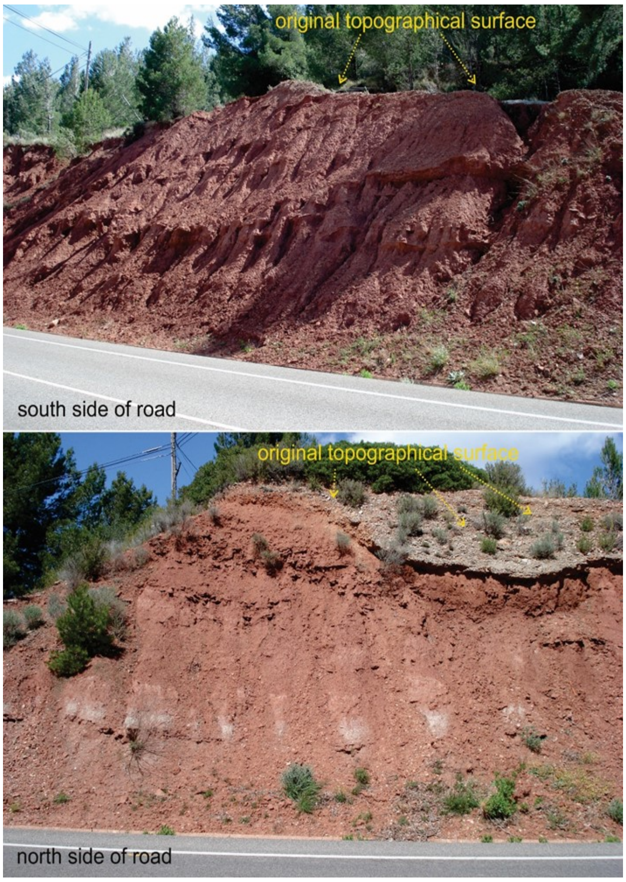


Figure 2 Road cut slopes excavated in gypsum-cemented siltstone about 5 years after excavation. The slopes were excavated as a plane surface with a slope angle of about 60°. The slopes are instable and eroded due to solution of gypsum after excavation. The north side is less affected than the south side, likely due to more direct sunlight on the north side and the prefailing wind direction. The protrusive banks in the south side and greyish areas in the north side are layers mainly consisting of gypsum with little silt that are slightly more resistant to solution and erosion (Road C44 near Vandellòs, Catalunya, Spain)

Figure 1 Deep mainly chemical weathering in a cut slope in gneiss and schist in a tropical climate (weathering grades follow ISO 14689-1:2017 (2017) for rock masses) (Yên Bái City, Vietnam; photo courtesy D. Alkema, 2010)

2.2 Erosion

Erosion predominantly occurs at the Earth surface and is generally less relevant in underground works. However, underground water flows, including water leaking from sewage and water mains, may transport soil or infill materials. Erosion by itself may lead also to effects similar as those in weathering, for example, the saltation of sand that reduces particle size of sand grains and creating dust particles in wind (Shao et al., 1993). Grinding of rock blocks over the bedrock in rivers and glaciers reducing block size of a moving block, and also fracturing, loosening, and unlashing rock blocks and particles from the bedrock ('plucking') by moving water, ice or wind are other examples (Anderson and Anderson, 2010; Singh et al., 2011). Weathered materials often form a good insulation of the underlying groundmass from the influence of the atmosphere, hydrosphere, cryosphere, and often also biosphere. This de-accelerate weathering, slows further weathering in depth, and when the layer of weathered material is thick enough effectively stops further weathering. Inversely, erosion causes the insulation to be removed, exposing the groundmass to the environment, accelerates weathering, and allows further progressive weathering in depth of new fresh ground. Erosion thus increases the rate of weathering of the underlying material (Huisman et al., 2011; Tating et al., 2019).

2.3 Accessibility of groundmass for weathering agents

Weathering of soil-type material mostly progresses through intact material and discontinuities, if present. The weathering agents, such as water and air, percolate through the pores and channels between pores in intact ground, and through discontinuities. The permeability of intact rock-type material is normally quite low and therefore weathering of rock masses mostly starts from the discontinuities through which the weathering agents circulate and develops further into the intact rock material from the discontinuities. In many groundmasses discontinuities give thus the access to the groundmass for weathering agents, and the number of permeable discontinuities determines for a considerable extent the rate of weathering in groundmasses. Discontinuities, such as faults, with percolating groundwater may exist at any depth below surface and groundmasses at large depth of thousands of meters may be subject to active in-situ weathering (Katongo, 2005).

Man-made influences such as the damage caused by the tools and means used for making an excavation may allow faster and deeper weathering. The excavation method may create fractures, widen existing discontinuities, and change incipient into mechanical discontinuities, collectively denoted 'backbreak', that allow water and air to infiltrate easier and deeper into the groundmass (Fig. 3) (Hack et al., 2003).

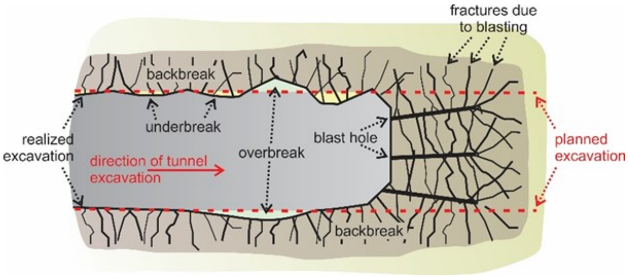


Figure 3 Discontinuities in a groundmass due to blasting and present as backbreak in the walls, roof, and floor of a tunnel give access for weathering agents

Generally, more backbreak is caused when higher energy levels are used in shorter timespans, i.e. blasting gives a high energy peak with many backbreak fractures, while scouring by a river creates an exposure virtually without any backbreak as energy is applied over many hundreds or thousands of years. Table 1 illustrates the damaging influence of excavation methods in use for surface and underground excavations with quantitative factors for the damage. The factors are correction factors applied to groundmass properties.

2.4 Nuclear radiation effects

Few research is done on the influence of nuclear radiation on groundmasses on Earth. In facilities for long-term storage of radioactive nuclear waste, degradation of the surrounding groundmass, brines, and groundwater is a subject of limited research (Lainé et al., 2017; Lumpkin et al., 2014; Soppe and Prij, 1994). Changes of atoms and minerals under influence of radiation is also occurring in natural nuclear reactions, for example, the Oklo fossil nuclear fission reactor in Gabon (Bracke et al., 2001; Gauthier-Lafaye et al., 1996; Meshik, 2009). Weathering rates due to nuclear radiation are likely very low compared to the rates under other influences, but may be of importance for stability of rooms, tunnels and shafts guaranteeing access to underground radioactive-waste repositories over very long timespans of tens

Table 1 Excavation damage ('backbreak') factors for groundmasses

SSPC [a] (slope)		FRHI [b] (slope)		Hoek - Brown [3][c] (GSI disturbance factor)				MRMR [d] (underground mining)		MBR [e] (underground mining)	
Excavation	Factor	Excavation	Rating	Excavation (slope)	D	Excavation (tunnel)	D	Excavation	Factor	Excavation	Factor
Natural/hand-made [1]	1.00	Smooth excavation	-1	In some softer rocks excavation can be carried out by ripping and dozing and the degree of damage to the slope is less (mechanical excavation)	0.7	Mechanical or hand excavation in poor quality rock masses (no blasting) results in minimal disturbance to the surrounding rock mass	0	Boring	1.00	Boring	1.00
Pneumatic/hydraulic hammer [2]	0.76	Regular cut Manual cut	3 4								
Controlled blasting	0.99	Controlled blasting	1			Excellent quality controlled blasting or excavation by Tunnel Boring Machine results in minimal disturbance to the confined rock mass surrounding a tunnel	0	Controlled blasting	0.97	Controlled blasting	0.94-0.97
				Small scale blasting in civil engineering slopes results in modest rock mass damage, particularly if controlled blasting is used. However, stress relief results in some disturbance: Good blasting	0.7						
Blasting with result: Good	0.77							Good blasting	0.94	Good blasting	0.90-0.94
Blasting with result: Open discontinuities	0.75	Regular blasting	5			Where squeezing problems result in significant floor heave, disturbance can be severe unless a temporary invert is placed: With invert	0				
Blasting with result: Dislodged blocks	0.72			Small scale blasting in civil engineering slopes (…): Poor blasting	1.0	Where squeezing problems (…): No invert	0.5				
Blasting with result: Fractured intact rock	0.67										
		Poor blasting	8	Very large open pit mine slopes suffer significant disturbance due to heavy production blasting and also due to stress relief from overburden removal (production blasting)	1.0	Very poor quality blasting in a hard rock tunnel results in severe local damage, extending 2 or 3 m, in the surrounding rock mass	0.8	Poor blasting	0.80	Poor blasting	0.90-0.80
Blasting with result: Crushed intact rock	0.62										

Notes: SSPC, MRMR and MBR factors range from 1.00 for negligible damage to 0.62 respectively 0.80 for maximum damage, FRHI is expressed as point rating from -1 for no damage to 8 for maximum damage, GSI disturbance factor ranges from 0 for undisturbed to 1.0 for maximum disturbance. (1) Care should be taken that discontinuities due to stress relief are not considered excavation damage. (2) This value is based on hammer sizes up to 5 m length with a diameter of 0.2 m. (3) The description of D is referenced with example photographs of excavation damage. Data from: (a) Hack et al. (2003) (b) Singh (2004) (c) Rocscience (2011) & Hoek and Brown (2018) (d) Laubscher and Jakubec (2001) (e) Cummings et al. (1984).

Table 2 Examples of differences in engineering properties due to weathering

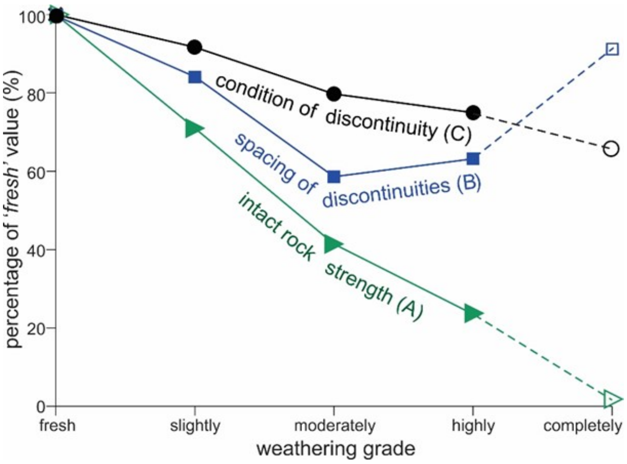
Grade [1]	In-situ unit weight	Porosity	Permeability	Unconfined compressive strength	Unconfined tensile strength	Static deformation modulus	Seismic velocity Longitudinal wave	Seismic velocity Shear wave	Schmidt hammer number	Rock mass friction	Rock mass cohesion
	kN/m³	%	cm/s	MPa	MPa	GPa	m/s	m/s	-	degrees	kPa
Dolorite [a]											
0 – 1	28.0	0.4		170	45	16.5	4,500		64		
2	27.6	0.5		122	27	3.3	3,250		53		
3	27.0	1		71	13		2,150		45		
4	26.2	3.2		41	7		1,600		25		
Granodiorite [b]											
0	26.3	1.5		138		33	4,359	2,567		47	17
1	25.9	4.6		79		15	2,057	1,693		46	16
2	25.4	1.9		41		10	1,693	1,111		38	14
3	24.0	5.7		32		4.9	973			17	8
4	19.8	24		0.1		0.008				6	3
5	14.7	44									
Basalt [c]											
0	26.1 [2]	2	1×10^{-9}	110	9	58					
1											
2	25.7 [2]	4	1×10^{-8}	75	7	48					
3	23.0 [2]	10	5×10^{-8}	30	3	23					
4	21.6 [2]	36	1×10^{-5}	8		10					
5	16.5 [2]	45	1×10^{-4}								
Sandstone [d]											
0	25.0 [3]			101							
1	26.3 [3]			58							
2	23.6 [3]			21							
3	23.8 [3]			8							
Gneiss & schist [4][e]											
4	16.8	53	3×10^{-5}	0.36						32	5
5	16.3	54	1×10^{-5}	0.29						21	22

Notes: (1) Grade follows the classification in ISO 14689-1:2017 (2017) for rock masses. (2) Dry unit weight (3) Values may be influenced by precipitation of iron in particular weathering grades. (4) Values for two years after excavation. Data: (a) Dolerite at Stirling Castle, UK (Price, 2000) (b) Granodiorite data from Krank (1980), except rock mass friction and cohesion. Granodiorite rock mass friction and cohesion from slope back analysis in Granodiorite in the Falset area, Spain, from Hack (1998) (c) Tu□rul (2004) (d) Tating et al. (2013) (e) Tran et al. (2019).

of thousands of years.

3. Quantitative influence of weathering on geotechnical properties

Table 2 shows examples of properties of intact ground and groundmasses indicating how ground properties change with increasing grade of weathering. The table shows the considerable changes in material properties as a consequence of weathering. Quantification of the grades of weathering in terms of the reduction of geotechnical properties of rock masses is shown in Fig. 4. The graph is based on data from various authors and from different rock types and rock masses. The influence of weathering is quite clear in the decrease of intact rock strength over the complete sequence from fresh to completely weathered rock masses and for the decrease in discontinuity spacing and condition of discontinuities (determining the shear strength) down to moderately weathered rock masses. The influence of weathering on spacing and condition of discontinuities de-accelerate or invert from moderately to highly weathered which may be attributed to cementation processes in discontinuities often happening in higher grades of weathering.



Notes: Data averaged after normalization with values for fresh equal 100 %. Standard deviation around 15 to 23 %p (percent point) for slightly through highly weathered; data for completely weathered are few and average not reliable. Weathering grade refers to rock mass weathering following ISO 14689-1:2017 (2017). '*Spacing of discontinuities*' based on rock block size and form following Taylor (1980) in Hack et al. (2003) or on discontinuity spacing. '*Condition of discontinuity*' (determining the shear strength) following sliding criterion (Hack et al., 2003) or friction and cohesion properties for discontinuities. Data: A: 1, 5, 6, 7 & 10; B: 2, 3, 4 & 5; C: 5, 8 & 9. (1) Begonha and Sequeira Braga (2002) (2) Ehlen (1999) (3) Ehlen (2002) (4) GCO (1990) (5) Hack and Price (1997) (6) Marques et al. (2010) (7) Pickles (2005) (8) Reißmüller (1997) (9) Snee (2008) (10) Tugrul (2004).

Figure 4 Influence of weathering on intact rock and rock mass properties

Quantification of grades of weathering in terms of the reduction of geotechnical properties of a groundmass have been done by various authors (Bieniawski, 1989; Hack and Price, 1997). Table 3 gives an example in which the factors are based on the weathering at surface of a wide range of rock masses such as limestone, sandstone, shale, granodiorite, and slate in the Mediterranean climate of northeast Spain. The factors in the table are multiplied with the geotechnical property to give the weathered property in a particular grade of weathering.

Table 3 Adjustment factors (WE) for different geotechnical properties of a rock mass (Hack and Price, 1997; Hack et al., 2003). Factor for overall spacing of discontinuities does not increase from moderately to highly weathered material here.

Grade (1)	Description	Intact rock strength	Overall spacing of disconti-nuities	Overall condition of disconti-nuities	Rock mass friction	Rock mass cohesion
0	Fresh	1.00	1.00	1.00	1.00	1.00
1	Slightly	0.88	0.93	1.00	0.95	0.96
2	Moderately	0.70	0.89	0.99	0.90	0.91
3	Highly	0.35	0.63	0.89	0.59	0.64
4 (2)	Completely	0.02	0.55	0.80	0.31	0.38

Notes: (1) Grade follows the classification in ISO 14689-1:2017 (2017) for rock masses. (2) 'Completely weathered' is assessed in granodiorite only.

4. Susceptibility to weathering

To guarantee the safe and sound design for the whole lifetime of an engineering structure it is important to know what the geotechnical properties of the groundmass are going to be during and at the end of the lifetime, i.e. 'what is the susceptibility to weathering of the groundmass?' Comparing the condition of the groundmass in similar exposures but with different excavation dates is the most common method to establish susceptibility to weathering. Preferably the exposures should be on short distance from each other and from the construction site. The weathering processes should be the same and be the same as those going to act around and influence the future engineering structure, hence, geomorphological and environmental setting should be the same.

Published quantitative data on future changes in properties due to weathering and the rate of weathering for engineering purposes are only sparsely known. Laboratory studies are not very reliable for forecasting in-situ weathering rates as these depend on the local circumstances and environment, and the tests are limited in groundmass volume and time (section 5.1). How groundmasses deteriorate over long (geological) periods over large areas (landscape development) is reasonably well investigated by geological, geomorphological, denudation, and soil forming studies (section 4.1). The influence of weathering on intact rock used as building material or gravestones has been extensively studied in-situ and rates for loss of material due to weathering have been established by many researchers ('tomb- or gravestone geology', section 4.2). However, few studies are published for 50 to 100-year time spans over areas from tens up to a couple of hundreds of meters, the typical engineering lifetime and size (Fig. 5). This is understandable, as in-situ testing is virtually impossible while local variations and inhomogeneity make geological methodologies complicated and unreliable for this scale and timespan. Some rock mass classification systems have factors that quantitatively assess the future weathering and some recent studies to weathering rates are presented in section 4.3

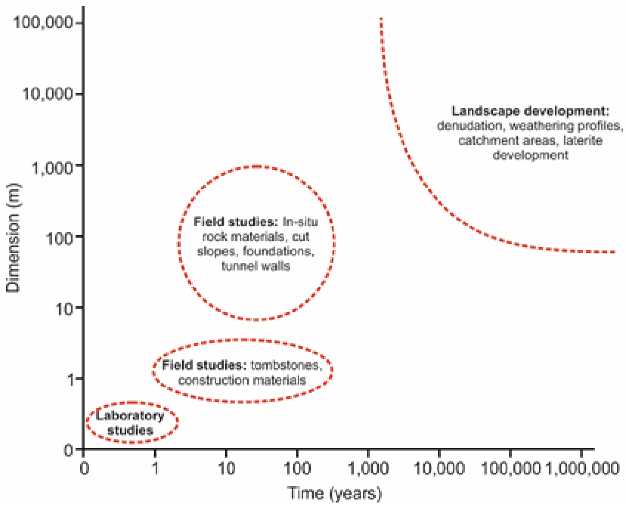


Figure 5 Research to weathering and erosion as function of space and time (modified from Huisman, 2006)

4.1. Loss of material, denudation studies over long (geological) timespans

Loss of material due to weathering resulting in denudation over relatively large areas and long (geological) timespans is extensively studied as it may reveal data over past climates and CO_2 presence in the atmosphere, hydrosphere, and cryosphere (Ahnert, 1994; Lebedeva et al., 2010). Denudation is mostly established by measuring the differences in quantities of chemical elements in rivers and streams flowing into and out of an area. The differences are a measure for the loss of material. Denudation over large areas and large timespans is dependent on active tectonic uplift and mountain forming, vegetation, and influences by man, such as land use and (de-) forestation. It should be realized that the climate and environment may have undergone major changes during the periods over which the denudation rates are established. Table 4 lists various denudation rates for different lithologies under different present-day climates.

4.2. Loss of material, tombstone geology studies over short timespans

Loss of material of various intact rock types over short timespans and tested on relatively small samples is done mainly on building and construction stones (Doehne and Price, 2010; Fookes et al., 1988; Morgan, 2016; Selby, 1993; Winkler, 1986). The amount of intact rock material lost under influence of weathering in a temperate climate on a forested slope in Japan is 1.3 %/yr for tuff material, 0.1 for limestone, 0.025 for crystalline schist, and 0.01 %/yr for granite. The samples were exposed directly at the Earth surface (Matsukura and Hirose, 2000). Trudgill et al. (2001) measured 0.01 to 0.07 mm/yr loss of material of mainly limestone exterior building

Table 4 Examples of denudation rates

Lithology	Area	Denudation rate [1] mm/yr	Present-day climate [2]	
Granitic [a]	Chile	0.02 - 0.07	Bsk/Csa	Semi-arid, Mediterranean
Granitic [b]	Boulder, USA	0.022	Dfc/Dfd	Boreal, mountain
Granulites, migmatites, gneisses, schists, phyllites, granitoids, and alluvial beds [c]	Ambato range, Sierras Pampeanas, Argentina	0.038 - 0.12	Bsk/Bsh/ Cwb	Arid/warm temperate
Mica schist, phyllite [d]	Sierra de las Estancias, Betic Cordillera, Spain	0.034	Bsk	Semi-arid, mountain
Mica schist, phyllite [d]	Sierra de los Filabres, Betic Cordillera, Spain	0.054	Csa/Csb/ Bsk	Humid to semi-arid, mountain
Mica schist [d]	Sierra Cabrera, Betic Cordillera, Spain	0.164	Bsk/Bwh	Semi-arid, mountain
Granitic, carbonate and quartz-bearing metasedimentary rocks [e]	Ganges, Northern Himalayas	0.5	Cwa/Cwb	Humid; warm temperate, mountain
Quaternary sediments [e]	Ganges, main stem	0.17	Cwa	Humid, warm temperate
Quaternary sediments [e]	Ganges, southern tributaries	0.03	Cwa/Aw	Humid, warm temperate/tropical
Basalt [f]	Paraná, Brazil	0.006	Csb	Humid, warm temperate

Notes: (1) Rates based on 10Be cosmogenic radionuclide (CRN) analysis, if reported. (2) Climate according Kottek and Rubel (2017). Data: (a) Vázquez et al. (2016) (b) Dethier and Lazarus (2006) (c) Nóbile et al. (2017) (d) Schoonejans et al. (2016); Vanacker et al. (2014) (e) Rahaman et al. (2017) (f) Da Conceição et al. (2015).

stones of St Paul's Cathedral in London over a period of 20 years. The results are influenced by air pollution (i.e. SO2) in London that decreased over the measuring period. Tombstone geology has also been used to establish changes in environment, climate, and air pollution (Meierding, 1993). Feddema and Meierding (1987) report values of 0.001 to 0.067 mm/yr for carbonate building stones in areas with varying quantities of air pollution, and Meierding (1993) established weathering rates of over 0.03 mm/yr for carbonate rocks in heavily air-polluted areas in the USA. The striking similarity in order of magnitude between rates for loss of material of small building stones over short timespans and loss of material over large areas over long timespans is remarkable (section 4.1).

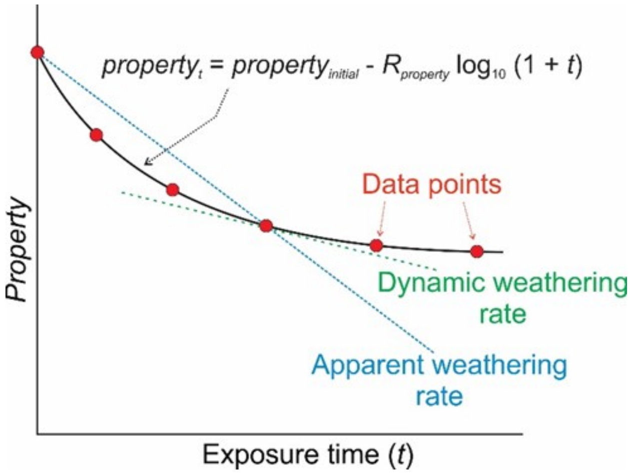


Figure 6 Property vs exposure time (modified from Huisman, 2006)

4.3. Geotechnical rate of weathering

The influence of weathering on geotechnical properties over timespans from 50 to 100 years is thought to be expressed by a logarithmic decrease of properties with time (Colman, 1981; Hachinohe et al., 2000; Huisman, 2006; Ruxton, 1968; Selby, 1980; Tating et al., 2013; Utili and Crosta, 2011), for example (Huisman, 2006):

$$property_t = property_{initial} - R_{property} \log_{10}(1+t) \qquad (1)$$

in which propertyt is the value of a particular geotechnical property at time t, propertyinitial is the value of the property initially at time of exposure, i.e. at t = 0, Rproperty is the 'weathering rate' which is property, material, and environment dependent, and t is the time in years (Fig. 6). This relation describes the change in time of a property over the full weathering range from fresh groundmass to residual soil. Huisman (2006) incorporated the WE (weathering) factors of Table 3 in eq. 1, and established the weathering rates (RWE) for different groundmasses in the Mediterranean climate of Spain (Table 5). Table 5 lists also the dynamic weathering rates and total decrease of property values for various groundmasses after 30 years of exposure in various climates. Table 5 clearly shows the large influence of different climates on the rate of weathering of geotechnical properties and the influence of differences in bedding spacing and presence of soluble materials.

Table 5 Weathering rate examples

Lithology [1]	Property [2]	Initial value	R_{we} [3]	Dynamic weathering rate (at 30 years after exposure as percentage of initial value) [4]	Decrease in 30 years after exposure (as percentage from initial value) [4]	Indicative timespan	Climate [5]	
			1/log [yr]	%pt./yr	%	yr		
Clay-containing limestone (bedding spacing < 0.1 m) [a]	*WE*	1	0.052	-0.073	7.8	40	Csa	Mediter-ranean
Clay-containing limestone (bedding spacing > 0.1 m) [a]	*WE*	1	0.042	-0.059	6.3	40		
Limestone (medium-thick bedded) [a]	*WE*	1	0.067	-0.094	10	40		
Calcareous shale (clay-/mudstone) [a]	*WE*	1	0.169	-0.24	25	40		
Gypsum-cemented siltstone [a]	*WE*	1	0.325	-0.46	48	40		
Gypsum (beds consisting of gypsum) [a]	*WE*	1	0.133	-0.19	20	40		
Sandstone [b]	*IRS*	105 MPa	34	-0.45	48	30	Am	Tropical
Gneiss/schist [6][c]	*Index prop* [7]			-1.15	35	35	Aw	
Gneiss/schist [6][c]	*Strength* [8]			-1.14	34	35	Aw	
Tuffaceous sandstone [d]	R_S	863 N/mm		-0.34	60	3,000	Csb	Tempe-rate
Mudstone [d]	R_S	235 N/mm		-0.17	21	3,000		

Notes: (1) Data (a-c) from cut slopes, (d) from natural terraces. (2) WE: weathering factor from SSPC (Hack et al., 2003); IRS: Intact Rock Strength, RS0: Penetration strength based on needle penetration hardness. (3) RWE: (Weathering rate) follows eq. 1. (4) Dynamic weathering rate and total decrease follow logarithmic relation for data from (a,b), linear relation for (c), and exponential relation for (d). (5) Climate according Kottek and Rubel (2017). (6) Completely weathered material and residual soil only. (7) Various index properties of soil, such as Unit Weight, porosity, and saturated conductivity. (8) Various shear and unconfined strength properties. Data: (a) Huisman et al. (2006) (b) Tating et al. (2013) (c) Tran et al. (2019) (d) Hachinohe et al. (2000).

5. Tests to establish the state of weathering and susceptibility to weathering

The state of weathering as is can be estimated in laboratory and in-situ field tests by comparing test values for the weathered ground material or groundmass to the same but unweathered material or mass. This may give an indication how weathering has influenced the material or mass. Susceptibility to weathering can be established to a certain extent in laboratory tests, however, the long timespan in reality has to be simulated within a timespan suitable for laboratory testing. For example, cyclic freeze-thaw tests in which freeze and thaw conditions change within days to simulate seasons. Chemical and physical processes in the ground such as diffusion, may be accelerated in time by using centrifuges. Sample size is limited and effectively restricted to testing of disturbed intact ground material only. Whether the samples and simulated conditions in laboratory tests are representative for reality is often questionable.

5.1. Laboratory testing

Laboratory ultrasonic velocity measurements may give an idea about the state of weathering as is of a piece of intact ground by referencing to the measured ultrasonic velocities in a piece of the same but unweathered ground (ASTM D2845-08, 2008; Chawre, 2018). Higher velocities indicate less weathering and vice versa. It should be noted that there is no direct relation between the state of weathering and ultrasonic velocity. Also, the ultrasonic velocity does not give information on the susceptibility to weathering.

Climate chambers are used to simulate the influence on ground of a changing environment, for example, day – night temperatures, changing seasons, freezing and thawing, and regular wetting and drying due to rainfall (ASTM D5312/D5312M-12, 2013; ASTM D5313/D5313M-12, 2013; Barros De Oliveira Frascá and Yamamoto, 2006). These may be combined with centrifuges (Tristancho et al., 2012). Humidity cells are used to simulate weathering of solids for among other weathering of and chemical changes in mine waste material (ASTM D5744-18, 2018). The influence of salt, for example, from sea spray, can be tested by regularly spraying samples with water with dissolved salts (ASTM D5240/D5240M-12e1, 2013). Crystallization tests determine the resistance of intact ground to crystallization processes of, for example, salt in pores in rock (BS EN 12370:1999, 1999).

Slaking tests are often used to indicate the susceptibility to weathering of intact ground material, for example, the slake durability and the Los Angeles abrasion tests; the later mostly used for determining the durability of toughness and abrasion resistance of aggregate for road pavement (ASTM C131/C131M-14, 2014; ASTM D4644-16, 2016; Dick and Shakoor, 1995; Franklin and Chandra, 1972; Hack, 1998; Hack and Huisman, 2002; Nicholson, 2000; Nickmann et al., 2006; Ulusay and Hudson, 2007). The tests submerge material in water in a rotating drum and the volume of material that falls apart in a particular timespan is a measure for the durability.

Dropping a block of rock from a certain height to investigate how the intact rock fractures under impact ('Drop Test', CIRIA, 2007), and cyclic stressing-destressing tests (Lagasse et al., 2006) may be useful for establishing intact rock integrity. These tests may indicate indirectly the ease with which intact rock fractures due to weathering or how easy incipient discontinuities change into mechanical discontinuities.

5.2. In-situ testing

Indirectly an indication on the state of weathering of a groundmass may be derived from seismic wave characteristics such as wave velocity or amplitude (Table 2). Measured seismic wave velocities and amplitudes are higher if the wave travels through fresh ground and slower through weathered masses, partially because the measured waves may have travelled around weathered parts of the mass or around discontinuities and thus have a longer ray path. The wave amplitude is a function of among others, the absorption of energy in the ground which is higher in weathered than fresh unweathered ground. The wave velocity and amplitude should be correlated to states of weathering established on borehole cores. Seismic waves do not directly give information on the susceptibility to weathering but may give depth of weathering and the thickness of weathered layers. The depth of weathering may in turn give an idea on the rate of weathering as larger depth of weathering in the subsurface often also implies a higher rate.

Other geophysical methods that indirectly give an idea about the state of and susceptibility to weathering are resistivity and electro-magnetic measurements as these react to the presence of clay that in many grounds will be more present in weathered than unweathered parts of the ground.

6. Conclusion

Weathering is a process that governs many engineering applications on and in the Earth. It often transforms originally sound ground into soft ground. Quantities of weathered material do not need to be large as small volumes of ground weathered in a brief time span drastically can change geotechnical properties. Weathering is the reason for many constructions and other engineering applications in which ground is used, to become a disaster. Tests to determine the susceptibility to weathering representative for realistic volumes of groundmass do not exist and published data on time-weathering-degradation relations for groundmasses are few. Therefore, forecasting the influence of weathering on geotechnical properties has to be done by the design engineer based on experience and a-priori knowledge without much or no hard data at all. Many engineers do not realize the importance of weathering or are hesitant in taking decisions based on own expertise and a-priori knowledge alone. They may assess the state of weathering as is, may mention the existence of future or susceptibility to weathering in general terms in the reporting, but do nothing to implement the consequences in design and construction. Fortunately, the safety factor used in civil engineering instigates excess in design to accommodate for uncertainties in the construction. One of these is ground and future behavior of ground, and therefore not all constructions fail even if susceptibility to weathering is not but should have been taken into account.

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A sinkhole above a historical shaft in Kerkrade required immediate action

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It was in december 2011 that the formation of a large sinkhole at the shopping center Het Loon in Heerlen revealed again the coal mining history of the South Limburg region between Geleen and Kerkrade. While many inhabitants of this region are still familiar with the mine closure in the 1970s, the knowledge about the historical dimension of the coal mining was no more prevalent in public. This large sinkhole with serious consequences on the shopping mall was the starting point of a process that intended to systematically investigate and classify the potential risks of post mining effects in South Limburg. In 2016 the Ministry of Economic Affairs (EZ) invites tenders for a research project in which the potential risks of industrial and historical coal mining in this region should be analysed. The german engineering office IHS was ordered by EZ; the results of the study (GS-ZL-study) have been presented at the end of 2017 in several reports.

One important result of this GS-ZL-study was the statement that, restricted only to the area of Kerkrade, altogether 59 so-called historical shafts were identified from a few thousand historical documents. In many cases the rough position of these shafts is shown in old maps or sometimes rather in sketches. All of these old shafts were classified to be quite risky as nearly no information is available about dimensions, depth, filling and other conditions. Hence it was recommended to check all of these shafts with respect to their actual positions and their actual conditions. Where necessary, further remediation work should be done.

Soon after the GS-ZL-study a program on these historical shafts was started, consisting in general for each shaft of three stages:

1. Prospection: In this first stage, based on a detailled desk study, the shaft position was defined by low-cost on-site-investigations with small hammer drivings.
2. Inspection: In this second stage the deeper parts of the prospected shafts were inspected by inclined core drillings that were sunken through the shaft column from a safety distance.
3. Remediation: If necessary and if technically feasible a shaft should be remediated by vertical drillings and cement injections into the

Figure 1 Sinkhole at shaft DOM 37 on 23.07.2020

shaft column.

Until summer 2020 this program was progressed according to plan. Stage 1 was finished for about 26 shafts, the inclined core drillings of stage 2 were performed on 12 shafts and 5 shafts were already remediated or in process of remediation. It was just after the completion of the last core drilling of stage 2 at the shaft named DOM 37 when the shaft itself took over the leadership of the project for a few weeks.

Figure 2 Tube-shaped voids in front of the residential building at the sinkhole shaft DOM 37

Figure 3 Filled-up voids in front of residential building at the sinkhole shaft DOM 37

In april 2020 the shaft DOM 37 was prospected by small hammer drivings at the Franciscanerstraat in Kerkrade directly in front of a residential building. According to stage 2 the shaft was inspected by two core drillings that were sunken through the shaft from a safety distance. These core drillings were completely finished and re-filled by cohesive material („Dämmer“). At this point in time the shaft was intended to be remediated „sometime in the near future“, but things changed.

It was over night that a large sinkhole with 8 m diameter and a depth of 1 to 1.5 m appeared above the shaft (see fig. 1). As can be seen in Fig. 1 the sinkhole was quite close to the building and also affected the pavement in which a number of service pipes (gas, water and electricity) was installed. Because of this special situation, the responsible insti-

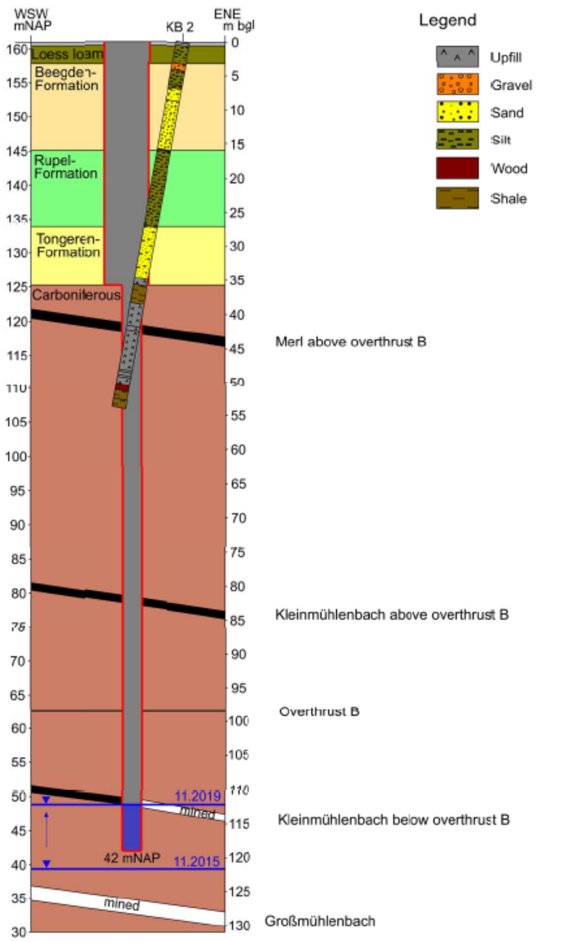

Figure 4 Cross-section through shaft DOM 37. The mine water has recently invaded the bottom of the shaft.

tutions were informed by the municipality of Kerkrade, the nearby residential buildings were evacuated, the pipes were locked by the suppliers.

During these first measures, aiming at public safety, some preparations were performed in order to carefully remove the pavement and investigate the underground situation by excavating the upper parts of the sinkhole area.

The excavation work first revealed rather strange results, as the bearing layer of the Franciscanerstraat right below the center of the sinkhole was still completely intact and even the filling material of the old shaft below this bearing layer was showing no cavities at all. Everything was according to the results of the small hammer drivings and the inclined core drillings. But the scene changed as the excavation work was extended to the pavement. Here, at the outer border of the old shaft, several tube-shaped voids were revealed. These voids reached to the cellar walls of the residential building and extended also below the neighboured garden wall. Fig. 2 shows the situation in front of the

residential building. All of these first investigations led to the result that action was urgently necessary.
As the inspection of shaft DOM 37 was not a singular action but instead one part of a large program it was possible to react quite fast on this challenge. About 100 m west of the sinkhole the two historical shafts DOM 33 and DOM 34 are located and these shafts were already in stage 3 with remediation work by cement injections going on. Therefore the basic equipment for mixing and pumping cohesive material was available. It was late in the evening of the first day (23.07.2020) that nearly 7.5 t of cement were pumped as water/cement-suspension into the voids. In the next morning 3 t more were pumped until the visible tube-shaped voids were filled totally. Fig. 3 shows the situation shortly before the filling was completed.
After this first stabilisation of the underground conditions the authorities decided that the remediation of shaft DOM 37 should start as soon as possible. As one part of the planning a cross section through the shaft was constructed (see fig. 4). This cross section shows that the shaft was sunken through three coal seams and also through the tectonic overthrust B. But the most important feature of this shaft is the assumed depth of 120 m. Taking the actual minewater level in this area it is quite obvious that the lower parts of the shaft column are already flooded by the rising minewater and momentarily the minewater level is at the same level than the mined coal seam „Kleinmühlenbach below overthrust B“.
Therefore it can be assumed that the flooding with minewater partially led to a destabilisation of soil material in the lower parts of the shaft column. Therefore an unstable situation was created which sooner or later might lead to a sinkhole at the ground surface.
Meanwhile the remediation work on shaft DOM 37 has started. For safety reasons, a 18 m-steel-bridge was placed above the area of the sinkhole. Fig. 5 shows the situation on site using two heavy-duty cranes to install the steel-bridge (20 tons) above the sinkhole. Also for safety reasons the first drilling was only drilled down to a depth of about 45 m and then filled with a „Dämmer-mixture“. Nearly 63 tons of „Dämmer“ were filled into this first drillhole aiming at a first stabilisation of the loose soil material inside of the shaft column.
For the complete remediation of this historical shaft altogether about ten drillings will be needed in which cement injections will be performed. This work is estimated to last until spring 2021. Based on experiences from other shaft remediations it is expected that about 400 t more of cohesive material (cement and “Dämmer”) will be needed until the work is done.

Figure 5 Installing the 18 m-steel-bridge above shaft DOM 37 (Picture by GbE, Grundbau Essen GmbH)

A lost Dutchman in Arizona

***Leon van Paassen** (Associate Professor, Arizona State University ASU)*

It has been almost about four years now, since I left my hometown Delft and made the big move with the family to Arizona. When I signed my contract at Arizona State University, America was preparing for the election in which everybody expected to see Hillary Clinton become the first women president, after Barack Obama had been the first black president in the history of the United States. With positive anxiety I watched the Democratic National Convention, while preparing for the move. And what a shock it was when Donald Trump got elected. Michael Crow, ASU's president, tried to ease the unrest on campus a bit by referring the university charter "ASU is measured not by whom it excludes, but by whom it includes and how they succeed assuming fundamental responsibility for the economic, social, cultural, and overall health of the communities it serves." A message in stark contrast with Trump's divide and conquer strategy, providing some hope it was going to be ok.....

The first year after the big move felt like a holiday. Everything was new and different: a different climate: every day it is sunny and warm, and the few occasions it rains, you celebrate it by going outside and getting soaked to the bone. A house with a pool in the backyard. Every weekend making hiking or biking trips to explore the mountains in the city and its surroundings. One of my recent favorites "the Flat Iron" starting at the Lost Dutchman State Park (named after the legendary goldmine, found by the German prospector 'Jacob Waltz', but which was never found again). Climbing up over the alluvial fans near the footslopes covered by blooming wildflowers, to continue on all fours up the steep slopes of the uplifted caldera of the Superstition Mountains east of Phoenix, is a huge effort, but the views from the top are worth it.

In terms of geology, the contrast between the swampy green lowlands in a temperate climate and the rocky mountainous dry hot desert of Arizona and the southwest of the United States cannot be bigger. The geologic record in and around Phoenix ranges from the early Proterozoic to recent Quaternary and includes all possible rock types.

Figure 1 Hiking the Flat Iron, the steep slopes of an uplifted caldera in the Superstition Wilderness from the Lost Dutch Man State Park

Every fall when I teach geotechnical engineering for the undergraduate students, I take them during the first week for a geological excursion on campus up to A-mountain, an andesite intrusion on top of tilted sedimentary rocks, to teach them about rock types, discontinuities, orientation and climate and their relation to weathering soil formation and slope stability.

Figure 2 Teaching students the basics of Engineering Geology on A-mountain at the ASU Campus.

In terms of research it was not such a big change. As I managed several projects in Delft on bio-based geotechnics through the STW Biogeocivil program in Delft, joining the NSF funded engineering research Center on Bio-mediated and Bio-inspired Geotechnics (CBBG) I felt like a fish in the water and with my expertise I could help many students making progress with their research. On the other hand, I realized that with our research in Delft we were working at the frontier of science on bio-based and in terms of Dunning-Kruger effect I saw many students fall down from their peak of excitement into their valley of despair, before they could crawl out and make some impact. Also, I found realized the network I build up and gathered within and outside Delft University was far away and I had to start again building new connections. Still the old connections proved useful, as through collaboration with Dutch colleagues from TUDelft, Deltares and Groundwater Technology we managed to perform a large scale field trial in the summer of 2018 on bio-mediated ground improvement in Toronto, Canada, where we aimed to increase the shear strength of silty soils by stimulating Microbially induced Carbonate precipitation (MICP) through hydrolysis of urea and cementing the silty soils with calcium carbonate minerals. At the same location we also tried an alternative process stimulating nitrate reducing bacteria to produce calcium carbonate minerals. Since we got a site to test are treatment strategies, we obtained a supplementary research grant from NSF, to mobilize T-Rex, a big shaker from the University of Texas, Austin, which could trigger small earthquakes, while measuring shear and pressure wave velocities and pore pressure build up and ground accelerations, to measure the potential of bio-treatment for mitigating earthquake-induced liquefaction. The cementation results of the field trial were not immediately promising as it was hard to quantify the amount of cementation through cone penetration testing, calcium carbonate analysis or shear wave velocity measurements. However, the plots where we stimulated nitrate reducing bacteria showed a significant reduction in pressure wave velocities, indicating the soils were desaturated due to the production of nitrogen gas, a by-product from nitrate reduction. Through laboratory experiments we proved that desaturation of soils could be useful to mitigate the risk of earthquake-induced liquefaction of loose granular soils as the compressibility of trapped gas dampens pore pressure build up during cyclic loading (Wang et al., 2020). The results in Toronto triggered interest throughout the research us and in 2019 we teamed up with researchers at Portland State University to perform a second field trial focusing on the bio-

Figure 3 Professor Ken Stokoe from University of Texas, Austin, explaining how the big shaker T-Rex induced shear waves to induce small earthquakes and test the potential of bio-based treatment for liquefaction mitigation in Portland, Oregon.

mediated desaturation of silty sands for mitigating liquefaction triggering (Moug et al. 2020).
In terms of teaching there were some differences, but I soon found my routine. I developed a new course on Biogeotechnics, in which I can integrate my research experience and ask students to prepare a proposal for a bio-based ground improvement project, which involves interpreting site investigation data, develop a simple numerical reactive transport model to determine treatment strategy (nr and location of wells, flow rates, substrate concentrations and treatment duration), develop a monitoring strategy for quality and control and assessment and estimate the costs and time planning. The results are presented and evaluated by an jury of colleagues from industry and academia. I also still teach a course on engineering geology, in which I still use the structural geology exercises from Jan-Kees Blom and the Site investigation games developed by Professor Price. They may be old, but the lessons like geology wear very slowly and students still like them.
One of the large differences between TU Delft and ASU is the amount of tuition students need to pay. Where European students in Delft only pay 2060 euro and non-European students 10384 euro, at ASU the in-state tuition starts at 11338 USD, while out-of-state students pay 29428 USD, which is actually relatively cheap for a university in the US)
On the other hand, there are many ways in which (particularly local) undergraduate students can get scholarships or university jobs, which typically include tuition waivers. Other students first go to smaller and cheaper community colleges, taking only the last few years at ASU. A consequence of the high tuition is that many students have side jobs, which may affect their focus on their studies. Also the number of graduate students is relatively low as scholarship opportunities for graduate students are limited. In fact many graduate students do their M.S. on a parttime basis or after having worked several years in the industry. As students have so many side activities they have limited time to work on a thesis. Typically, they start their thesis in the first year of a two-year Master program and work on it several hours per week. You could argue whether that is good or bad, as on the one hand they learn how to distribute their time over multiple tasks, which is useful in daily life after graduation, but on the other hand they are often not able to get very deep into a topic.
Another big difference between the TUDelft and ASU (or in fact any respectable American university) is their fascination with sports. The most important event at ASU every year is when

Figure 4 When the Sun Devils College Football plays at home everyone on campus wears ASU Gold.

Figure 5 Visiting Meteor Crater during the geological road trip through Arizona and surrounding states.

Figure 6 Black Lives Matter mural near my home in Tempe, Arizona.

the Arizona State Sun Devils play their rivals from University of Arizona for the Territorial Cup. A fully packed stadium with over 50000 people, complete with fireworks, brass band and cheerleaders is something different then I remember from my own rugby matches with Thor against DSR-C.

Then 2020 came and turned out to be quite a challenge. Like everywhere around the world everything closed down mid-march, and suddenly teaching had to be online and research at home, conferences were postponed or canceled as all non-essential travel was prohibited. But then they opened everything too early, just before Memorial Day weekend when students were just graduated and pictures of partying students in Arizona even reached the Dutch news as the increase in number of COVID-cases became the highest in the country. As we were not able to travel to the Netherlands, we took the opportunity to make a road trip to visit the National Parks of the Southwest. With the new editions of the “Roadside Geology” books of Arizona, Colorado, Utah and Wyoming on my lab we revisited some sites of the Engineering Geology Study Tour of 1999.

While I am writing this, we are still in the middle of the pandemic. All public schools remain closed and my kids are now better trained in online education then I am. The university has reopened for students who wish to follow courses in person, but every student and employee is tested and needs to wear a facemask being indoors. With public protests on the streets and the election coming up it is still going to be a hectic year.

So, I do not know what the future will bring. The move to Arizona has enabled me to participate in challenging projects and brought me to many places throughout the US and around the world. The CBBG research center recently got funded for another 5 years, so there is enough work to do with guaranteed funding. Also Sometimes I literally miss the ‘green, green grass of home’ but as my position at ASU only supports me for 9 months a year, I can still escape the heat in Arizona during the summer, visit my family and friends in Delft once or twice a year and enjoy the cloudy skies and smell of freshly mowed grass in The Netherlands. So I am privileged and if you happen to be in the neighbourhood, you are welcome to come and take a dive in the pool!

Ioannis Vardoulakis PhD Prize

***Dr. Stefano Muraro, Geo-Engineering** (Delft University of Technology)*

Stefano Muraro is the 2020 recipient of the Ioannis Vardoulakis PhD Prize created by ALERT Geomaterials in 2016 to commemorate Prof. Vardoulakis and his contributions to research and teaching in the field of Geomechanics.

Vardoulakis (1949-2009) is known for his work on shear band modelling and its applications to geological and geotechnical processes.

ALERT Geomaterials (alertgeomaterials.eu) is a Doctoral School born from the **A**lliance of **L**aboratories in **E**urope for **E**ducation, **R**esearch and **T**echnology.

TU Delft geo-engineering section is proud to count two recipients of the Vardoulakis PhD Prize: Stefano Murari and Anne-Catherine Dieudonné.

Dr. Stefano Muraro, Assistant Professot of Experimental soil mechanics at TU-Delft.

I am Stefano Muraro and from next January I will be joining the Geo-Engineering section at TU Delft as the new tenure track assistant professor of experimental soil mechanics. I obtained my MSc in Environmental & Civil Engineering at the University of Trento (Italy). After a short experience in the industry, I decided to go back to academia and I embarked in a PhD at TU Delft dedicated to the geotechnical behaviour of dykes and embankments on soft soils and in particular on peat. My research focuses on the comprehension of the physical processes ruling the multiphase behaviour of soils and on the proposal of innovative measures to mitigate complex challenges in deltaic areas such as environmental and anthropogenic loads. I like adopting a versatile research methodology which combines laboratory testing and numerical modelling to serve geotechnical applications as slopes stability, earth retaining structures and soil-structure interaction.

An example of a recent research activity I have been involved is the Leendert de Boerspolder field stress-test, a full scale test on a regional dyke in the Kagerplassen, north of Leiden, which included observation of the pre-failure response and the design of its failure. The research was a joined initiative of HH Rijnland, TU Delft in the framework of the STW research project Reliable Dykes, STOWA, and Deltares.

Figure 1 Pictures from geotechnical investigation of laboratory and field experiments. Photo courtesy of C.Jommi.

Understanding the effect of underground excavations on existing buildings

Dr. Giorgia Giardina *(Assistant Professor in Geo-Monitoring and Data Analytics, Delft University of Technology)*

My name is Giorgia Giardina, and this year I have joined the Geo-Engineering Section at TU Delft as Assistant Professor in Geo-Monitoring and Data Analytics. A big part of my research has been so far dedicated to understanding the effect of underground excavations on existing buildings. Soil-structure interaction mechanisms, and their dependence on geology, are therefore very relevant aspects of my work.

Dr. Giorgia Giardina, Assistant Professor in Geo-Monitoring and Data Analytics.at TU-Delft.

After a MSc in Civil Engineering at the University of Brescia, in Italy, I moved to the Netherlands for my doctoral research. During my PhD at TU Delft, I studied the impact of underground excavation on surface structure trough numerical modelling and experimental testing. Later on, at the University of Cambridge, I used advanced computational models to reproduce the results of centrifuge tests performed on 3D-printed scale models of buildings undergoing tunnelling in sand. Prior to coming back to TU Delft, I was a Lecturer at the University of Bath, where I became interested into the use of satellite data to assess the conditions of civil engineering structures.

My current research at the Geo-Engineering Section aims at increasing urban resilience through the evaluation of buildings and infrastructure vulnerability. By integrating remote sensing data, experimental testing and computational modelling, I analyse the response of existing structures to urbanisation, earthquakes and climate change effects. In collaboration with NASA, I developed an integrated satellite monitoring and structural assessment procedure for the evaluation of tunnelling-induced damage to structures. I am currently looking at new ways to combine satellite-based observations with engineering assessment methods to understand the effect of multiple hazards on infrastructure networks.

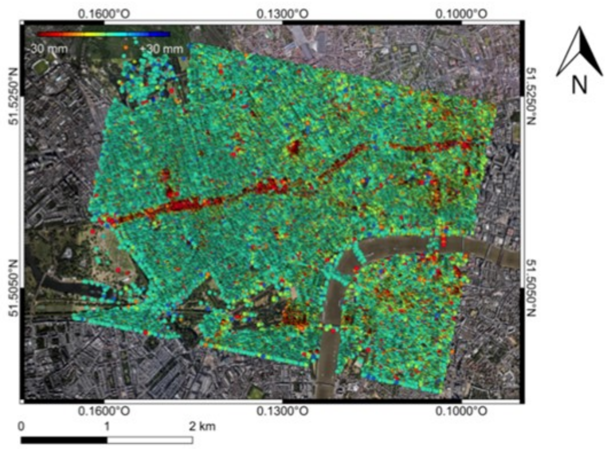

Figure 1 Example of satellite-based map of ground movement: Crossrail tunnel excavation in London, UK.

Quantification of uncertainties in geotechnical modelling

Dr.ir. Bram van den Eijnden *(Assistant Professor of Geotechnical Uncertainty, Delft University of Technology)*

As assistant professor of geotechnical uncertainty I recently joined the academic staff of the department of Geoscience and Engineering to strengthen the GeoEngineering Section. A new position at a familiar place, since I have an engineering geology background in Delft.

Dr.ir. Bram van den Eijnden, Assistant Professor of Geotechnical Uncertainty at TU-Delft.

My educational background is at TU Delft, where I obtained an MSc in Applied Earth Since with a specialisation in Engineering Geology. A doctoral degree at Université Grenoble Alpes and Université de Liège then formed the backbone of my academic profile, with a solid basis in numerical modelling of geomaterials. The main application of this work has been the numerical modelling of the excavation damaged zone around drifts of deep geological disposal facilities for radioactive waste. After four years abroad, I joined TU Delft in 2015 as a post-doc, working on stochastic analysis of dyke stability. The interplay between numerical modelling, stochastic characterisation and probabilistic methods has been my main line of research since then, mostly in the context of slope (i.e. dyke) stability.

My current research is on the development of numerical modelling techniques accounting for spatial variability and multiscale heterogeneity in soil behaviour, with application in the stochastic modelling of geotechnical structures. In parallel, I work on stochastic characterisation and quantification of uncertainty in model input data (e.g. site investigation data), and its propagation through the numerical models into their reliability-based output. With the combination of these topics I cover the quantification of uncertainty in geotechnical modelling, from data uncertainty to reliability-based assessment of structures.

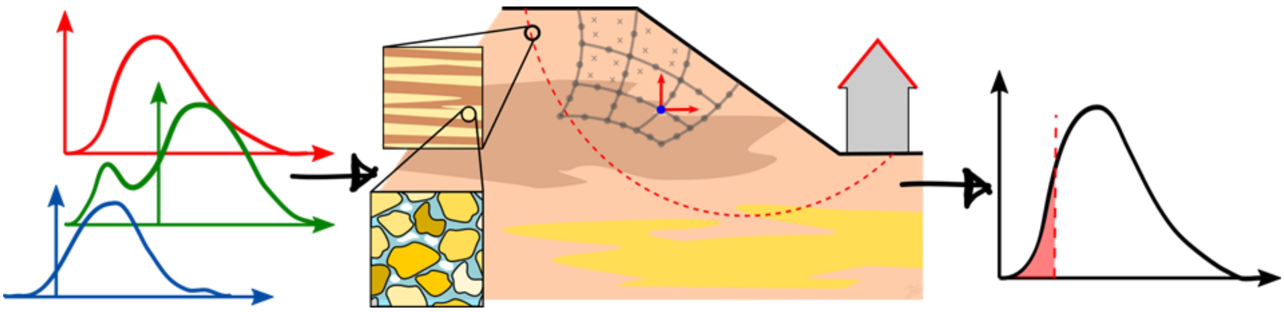

Figure 1: Uncertainty propagation in stochastic modelling of geotechnical stability as the basis for reliability-based assessment.

Best graduate from CITG

MSc. Frans Liqui Lung, Applied Physics and Remote Sensing *(Delft University of Technology)*

In order to gain a better insight into the atmospheric processes taking place nearer the ground, Frans Liqui Lung developed a simulation model showing small-scale interactions between sand and wind The resulting Master's thesis earned him the title of Best Graduate of the faculty of Civil engineering and Geosciences for year 2019-2020.

Frans holds a BSc in AES and a double MSc degree in Applied Physics and Remote Sensing.

See:
https://www.tudelft.nl/en/stories/articles/creating-order-in-the-chaos-of-sand-and-wind/

New board of De Ondergrondse

Bertie Rietema, Chair of De Ondergrondse *(Delft University of Technology)*

I am proud to present five students that will be on the board of De Ondergrondse from the end of 2020 until November 2021. De Ondergrondse is the student association of the Master Geo-Engineering at the Faculty of Civil engineering and Geosciences of the TU Delft. We all started the master Geo-Engineering this year and each have our own interest: tunnelling, foundations or rock mechanics. Although we started our board year in a quite challenging time, we are enthusiastic to get the most out of this year. We will try to make sure that the members and partners of De Ondergrondse remain connected to the association and organise as many activities as possible. Our first activity is a Christmas-themed Quiz with also questions on geo-engineering, for students and the academic staff. Hopefully, this will be a large success!
In October 2021, the 3rd Lustrum of De Ondergrondse will take place. We all hope that the pandemic will influence our festivities as little as possible. If the measures allow it, we will organise geo-related activities that will be open to students and staff.

From left to right: Jur Peerden, Shlagha Thapa, Bertie Rietema, Edin Memić, Lauran de Jong.

Working abroad: “Shaping Islands in the Middle East”

Omar Barghouthi *(Dredging Production Engineer at NMDC)*

Since graduating from my geo-engineering Master’s program at TU Delft, I have been working at the leading dredging and marine contractor in the Middle East, the National Marine Dredging Company or NMDC. NMDC was founded in 1976 and played a large role in shaping the landscape of Abu Dhabi by dredging and reclaiming its islands, beaches and ports. In the last decade the company has expanded with projects across several counties including UAE, Egypt, India, Bahrain and the Maldives.

Although I started off with more of a geotechnical design role, I slowly transitioned into the world of dredging production and estimation. Dredging was a world I knew very little about during my time in Delft but it’s one I’m fully immersed in at the moment. I am now a part of the dredging estimation team where we are responsible for calculating production of our dredgers for all of our tenders and

Figure 1 NMDC's Trailing Suction Hopper Dredger "Arzana"

projects as well as estimating the costs anticipated for these dredging tenders. In order to do so, a sound knowledge of geotechnical and geological aspects is definitely an advantage.

Due to its distinct features, the Arabian Gulf has a unique geological history that plays a major role in how dredging and reclamation projects are approached in this region. Shallow sea levels and warm water temperatures combined as the ideal deposition environment for Calcium Carbonate. These unique conditions in combination with carbonate sedimentation led to the accumulation of a thick sedimentary lens compromising of carbonate sands, carbonate rocks and evaporates.

An example of how the marine environment of the region directly affects the dredging process is evident in most geotechnical/geophysical investigations. In the shallow waters of Abu Dhabi, a thin caprock layer is usually encountered. The occurrence of this layer is attributed to the presence of carbonate sands that slowly morph into a thin rock layer in shallow warm waters. This caprock layer is underlain by sand deposits and

Figure 2 Corniche Beach, Abu Dhabi

typically has higher strength values than the stable bedrock beneath it, which means its harder to dredge and harder to reach the valuable sand deposits below.

On the other hand, Carbonate soils create a unique problem when used as reclamation fill. Three main features of these soils are crushability, angularity and cementation. As a result of these features, the soils are more compressible than silicieous soils under the same loading conditions. This however does not mean that carbonate soils are not suitable as reclamation fill but rather that these properties need to be accounted for in both design and construction phases.

When combining the variability of the geological/geotechnical conditions in this region with the wide range of projects that NMDC are a part of, the outcome is a highly challenging but equally rewarding working environment. Working with a dredging/marine contracting company, you literally get to play a role in shaping the future of our cities.

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  - Figures, drawings, and pictures should be produced in one of the common image formats: GIF, TIFF, JPEG.
  - Figures, drawings, pictures, and tables should be submitted separately; named and numbered in a logical order according to their placement in the main text. Submissions should be preferably in digital format. The print size should be selected by considering possible reduction for the final version.
  - Each article must include the author(s) name(s), affiliations and address, and a short abstract of preferably less than 100 words.

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