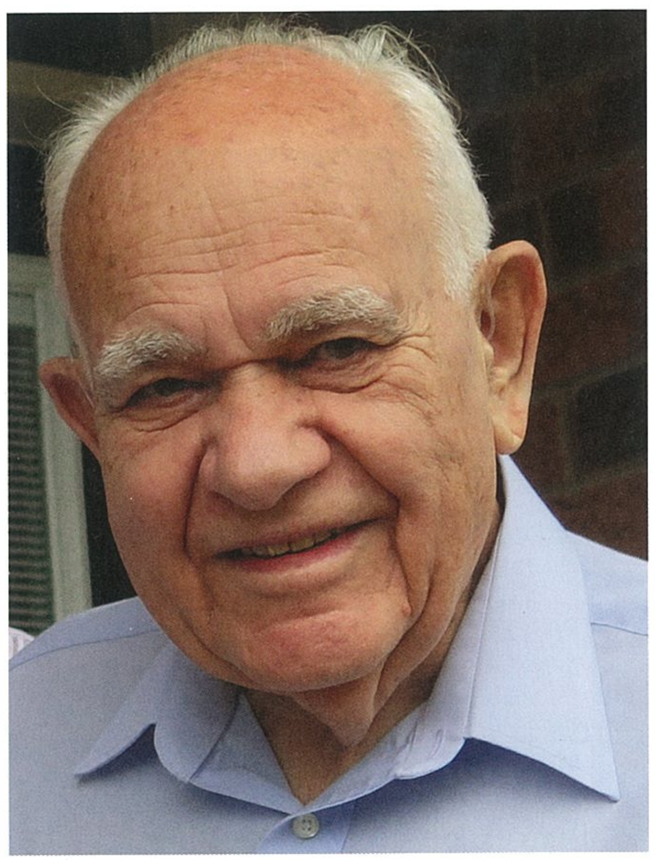
// Lessons Learned from GeoLegends

Evert Hoek, D.Sc, F.RAE, F.CAE, NAE

By Shane Markus, Alex Grant, PhD, and William Pollock



Evert Hoek

Evert Hoek is a world-renowned contributor to the fields of engineering geology and rock mechanics. He has contributed to academia as a graduate researcher and professor, has worked in industry, and has been a member of numerous civil and mining engineering consulting boards. Hoek is perhaps best known for his contributions in estimating the strength of jointed rock-masses with the Hoek-Brown Criterion and Geological Strength Index (GSI), but has contributed to countless other understandings, techniques, and methodologies for the analysis of the behavior of rock as an engineering material.

Hoek was born in Southern Rhodesia (now Zimbabwe). He moved to South Africa in 1951 and was granted the prestigious Beit Scholarship to attend the University of Cape Town. There, he obtained B.Sc and M.Sc degrees in mechanical engineering and studied the behavior of materials. In 1958, he was employed by the South African Council for Scientific and Industrial Research, where he investigated rock as an engineering material. In 1965, he was awarded a PhD in mechanical engineering by the University of Cape Town, where he studied rock fracture under static stress conditions. In 1966, Hoek was appointed a reader, and eventually a full professor, at the Imperial College of Science and Technology in London. He was awarded a D.Sc in engineering by the University of London in 1975.

In 1975, Hoek left academia to join Golder Associates in Vancouver, Canada. In 1987, he returned to academia as an industrial research professor at the University of Toronto. In 1993, he returned to Vancouver as an independent consultant, serving as a member of consulting boards, an advisory consultant, and an expert witness on projects around the world.

Hoek's contributions to the field of rock mechanics have been enormous. He authored or co-authored four landmark textbooks: *Rock Slope Engineering* with John Bray, *Underground Excavations in Rock* with Edwin Brown, *Practical Rock Engineering*, and *Support of Underground Excavations in Hard Rock* with Peter Kaiser and William Bawden. He has also published more than 100 papers on stress analysis, brittle fracture, laboratory equipment design, rock-slope stability, underground excavation design, and other related topics.

The Chuquicamata open pit copper mine, Chile, 2013. In this photograph, the pit is 4-km long, 3-km wide, and 1-km deep. The vehicles at the bottom of the pit are 400-ton capacity trucks.

Hoek has received numerous prestigious awards for his work, including the Consolidated Goldfields Gold Medal (1970), the AIME Rock Mechanics Award (1975), the E. Burwell Award (1979), the Gold Medal of the Institution of Mining and Metallurgy (1985), the Müller Award (1991), and the William Smith Medal (1993). He was elected a Fellow of the Royal Academy of Engineering (1982), a Fellow of the Canadian Academy of Engineering (2001), and a Foreign Associate of the U.S. National Academy of Engineering (2006). Hoek has also presented several named lectures, including the Sir Julius Werhner Memorial Lecture (1982), the Rankine Lecture (1983), the Perez Guerra Lecture (1996), the Glossop Lecture (1998), the Terzaghi Lecture (2000), and the Kersten Lecture (2008).

Q: What led you to pursue a career in rock mechanics?

I started as a mechanical engineer at the University of Cape Town, initially interested in jet-engine design and aircraft engineering. In fact, my master's degree specialized in strength of materials and stress analysis. In those days, before the advent of computers, we used physical models, such as photoelasticity, for the analysis of stresses in materials. Unsure where I should go to develop my skills in aircraft engineering, I accepted an invitation from a friend to visit the National Mechanical Engineering Research Institute, a branch of the South African Council for Scientific and Industrial Research. During the visit, I was offered a position as a research engineer, to

Excavation for the right abutment of the Sykia Dam in Greece.

work in the field of stress analysis and strength of materials. I accepted the job and moved to Pretoria in 1958.

The research institute had been approached by the gold-mining industry for assistance with rock burst issues in their deep excavations. We accepted the work, naïvely assuming that rock is just another engineering material, but soon we realized that rock is quite unusual. I was part of a team of about 10 people working in geophysics and mining engineering that had assembled in South Africa. Most of my work, until I left the institute in 1966, was related to brittle failure of intact rock.

Q: How did your background in mechanical engineering help shape your perspective as a rock mechanician?

In those days, rock mechanics was not an engineering discipline. Looking back, people came from many different fields. In fact, rock mechanics drew on expertise from mechanical engineers, civil engineers, and physics experts who dealt with the mechanics of materials. It was really my background in stress analysis and strength of materials that equipped me to look at rock as an engineering material.

Q: Who were your mentors?

My earliest mentor in South Africa was Günter Denkhaus, the Institute director when I was there. He was a fine mathematician in his own right, and contributed significantly to some of the early work in rock mechanics like calculating stresses around excavations of different shapes using elastic theory. This was before the development of models for failure propagation, so the work was simplistic.

In 1966, I started at Imperial College as chair in the first formal rock mechanics program. My principal mentor was Professor Alistair Black, head of the Department of Mining, who was responsible for setting up the rock mechanics program. I also worked with people like Professors Alan Bishop and Alec Skempton in soil mechanics, and Neville Price in geology, all of whom had a significant impact on my academic career.

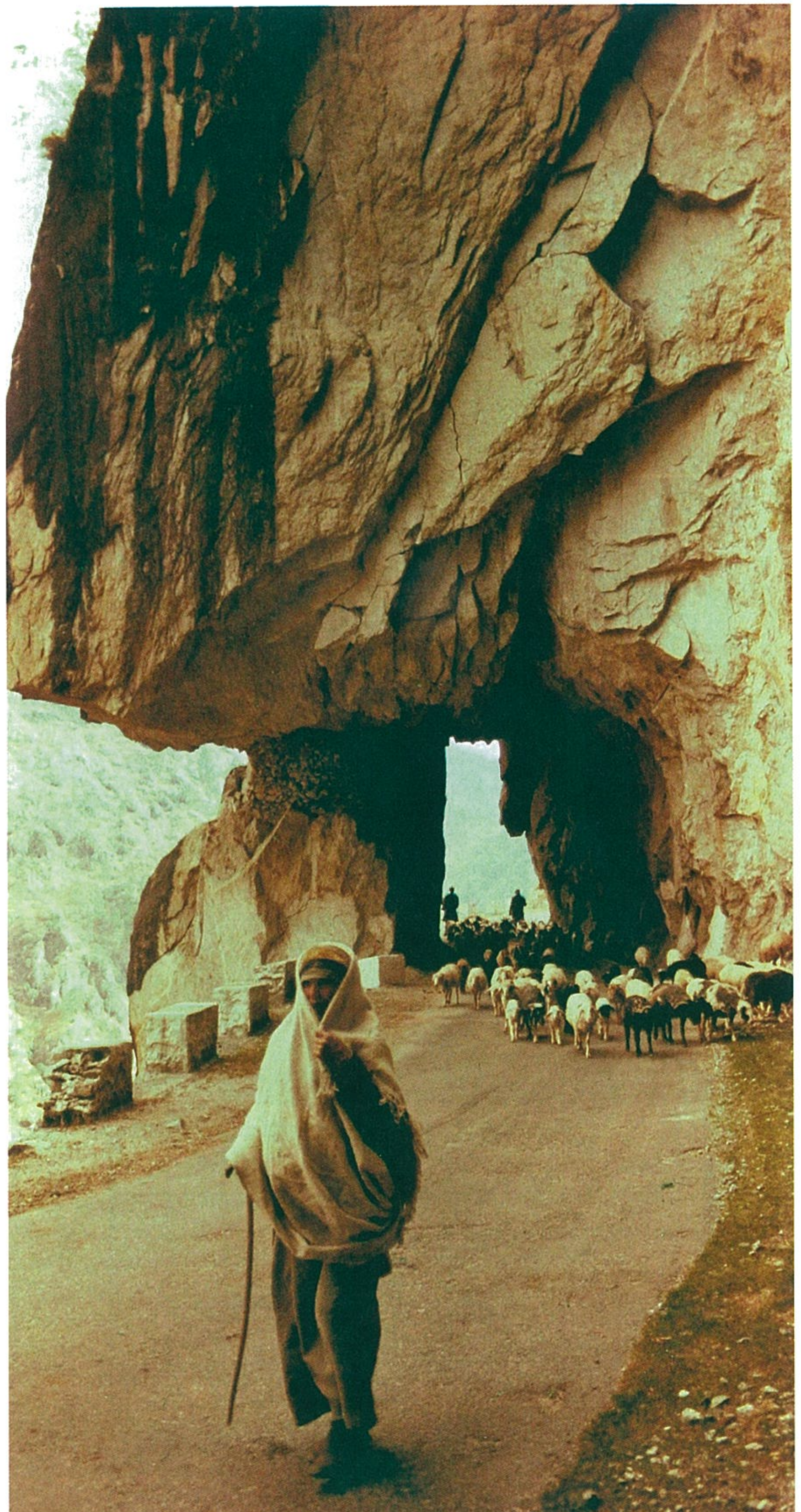
Q: What's the most interesting or challenging project you've worked on?

One of my most interesting projects was the Chuquicamata copper mine in Chile, which has been operating for nearly 100 years. When I left the Geotechnical Advisory Board a few years ago, the mine was 1-km deep, 4-km long, and 3-km wide. It was one of the largest open-pit copper mines in the world.

This project was fascinating because of the challenges of the scale of the project. In the early days, we recommended setting up high-level computing capabilities on site, and that appropriate site investigation and laboratory testing be undertaken to establish a comprehensive database of rock and rock-mass properties. We also recommended that the mine slopes be monitored to check that the stability calculations were meaningful. They set up electro-optical distance devices, still in the relatively early days of lasers. When I left, there were 1,000 targets around the site, and six monitoring stations automatically tracking movements every 20 minutes. The mine was probably the best monitored at the time, but today many mines have similar systems. With the advance of satellite technology, they now do a lot of monitoring by GPS rather than by precision surveying. For me, this project was extremely challenging and rewarding. This project is still ongoing, and is now being transformed from open-pit to an underground mine.

Q: Did you ever work on a project that didn't go well, and what lessons did you learn from it?

Problems in engineering are more often related to people rather than technical issues. One such problem arose on a hydroelectric project overseas. It was a massive project, with a 27-km-long intake tunnel, a very large underground powerhouse, and a lower dam. Because of high monsoon rainfalls, flash flooding of sediment- and debris-laden rivers was common. To avoid damaging the turbines, the project's consulting board (of which I was a member) decided that four underground settling chambers were required. Technically, the chambers were reasonably straightforward, but the politicians decided they wanted this scheme operating by a certain date before all of the settling chambers would be ready. The consulting board disagreed with this decision, but was overruled. A German colleague and I resigned from the consulting board because we could not accept being party to this decision. The project went ahead, and my understanding is that there was significant turbine damage. While not a technical failure, the project was certainly a people failure. Technical problems can usually be worked out, but people problems are often more challenging.



A challenging highway cut in Highway 22 in the Himalayan foothills in Northern India.

Q: How has rock mechanics changed since you began working in the field?

Obviously, much more knowledge has been gained, but the technology change has been particularly phenomenal. From having practically zero computing power when I started (my "computer" was a slide rule), to having enormously powerful programs, tools, and instrumentation, has been an enormous change. We had strain gauges and a few other instruments at the time, but we did not have the ability to compile and process the data, and then interpret the results, as we do today. While I'm impressed with these tools and what they can accomplish, there's a danger that this technology can get out of control. The tools are so powerful that most people have no idea what the programs are actually doing, so they put their faith into the program and assume that the results are correct. This line of thinking can be dangerous and requires senior-level oversight.

Q: How will the methods and practices you've developed adapt with advances in technology?

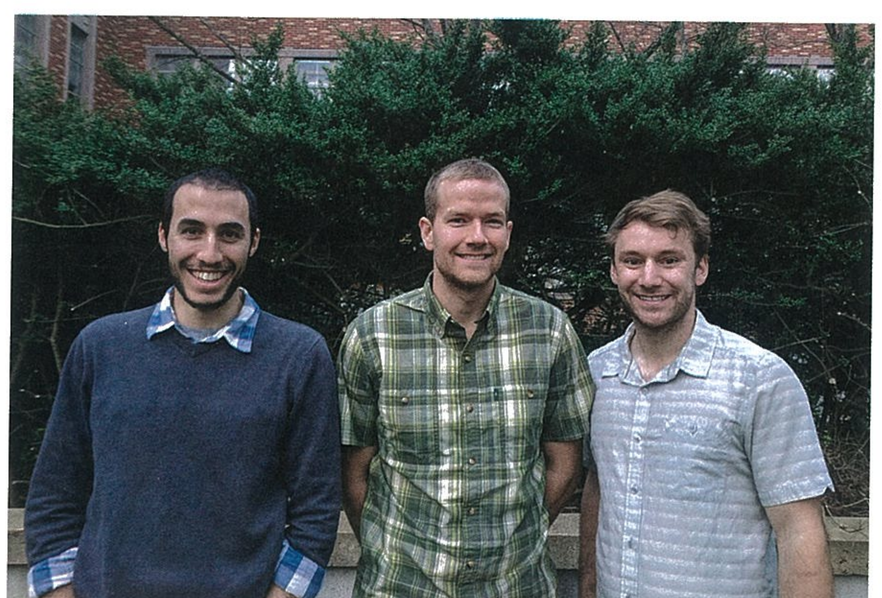
I'm probably best known for my approach to estimating rock-mass properties. Between 1975 and 1980, I co-authored a textbook on underground excavation engineering with Professor Ted Brown. While writing the chapter on rock-slope engineering, it occurred to us that a good method for rock-mass stability didn't exist. These analyses are easy if the rock-mass has distinct blocks with definable 3D geometries and strength along the surfaces. But when you stand back and look at a 1,000-m-high slope, you can see the big faults, but everything else looks like gravel. To help tackle this problem of scale, we decided we needed a criterion that could link geological observations to strength properties of poor or closely jointed rock. This became known as the Hoek-Brown Criterion, and the Geological Strength Index. While I consider this method to be crude, it has been widely adopted and used because of the lack of suitable alternatives.

I see things progressing in the evolution of numerical modeling. With models like Itasca's 3DEC, you can create models using input from field geologists to calculate the reactions needed for design. I see much room for advancement here. Some work's already been done, but it's at the limit of our computing abilities. As technology improves, I see us taking geological observations and observed rock-mass properties, plugging them into a model, and seeing what's likely to happen in large, complicated rock-masses. Geologic observations could be much more detailed and factual as well, like with LiDAR measurements, so that

An underground powerhouse for the Mingtan hydro-electric project in Taiwan. The final cavern is 22-m wide, 46-m high, and 158-m long.

Today's tools are so powerful that most people have no idea what the programs are actually doing, so they put their faith into the program and assume that the results are correct. This line of thinking can be dangerous and requires senior-level oversight.

Top heading and bench excavation in poor-quality rock for a 40-ft span tunnel on the Egnatia Highway in Northern Greece.



Left to r: The authors: Will Pollock, Shane Markus, and Alex Grant.

statistical properties of discontinuities and intact rock properties could be incorporated in the models. This would be a huge advance over the empirical models currently used.

Q: Are there any fundamental issues in rock mechanics that should be addressed in the next 5 or 10 years?

I see a progression. You solve one problem, which leads to solving others. I'm reminded of our very early slope-stability calculations. The first time I did a wedge analysis, I used an engineering drawing approach that would not be used today. Later, calculators simplified this task. Now, we've got programs that perform these tasks very easily and quickly. There's a definite progression that I see going forward. For example, software is available to conduct 3D wedge analyses, and future advancements will allow incorporation of earthquake loading in a much more realistic manner.

Q: What mistakes have you witnessed young engineers make, and how can they better avoid them?

I've noticed that young engineers are unfamiliar with broad subject matter and applications. It's too easy that someone can pick a solution and go with it, whether or not it actually fits the problem. That's how students are taught, and it's a mistake I commonly see, but fortunately it's usually recognized quickly by experienced people who oversee the work. Again, it's a consequence of the overemphasis on computing rather than on exposure. This problem is particularly prevalent in less developed countries. I'm contacted by builders in these places to help with tunnels, and it's clear to me they sometimes haven't the slightest idea what they're doing. I often advise them to hire a consultant to help out. The problems we've discussed with education in the developed world are not nearly as large as in third-world countries.

Fortunately, there is a growing tendency to incorporate practical exposure in academia by means of co-op programs. In these, students are teamed up with companies or consulting organizations. These students work and get mentored for periods of up to six months during their undergraduate degree programs.

Q: Do you have any other advice for young engineers?

Get out there! Take a break from school and get out into the real world! I can't think of any other way to overcome the constraints that the university system has imposed on itself. It's sad for me, as a former academic, having come through universities in a different era, to see this happening. The tendency is, today, to treat the university as a machine to pump out students, hoping that they'll all be employed and useful, but you don't maintain quality with mass production. Students must recognize this problem and make this happen themselves. All too often I see students go straight from their BS and MS degrees into a PhD program, into academia as a junior lecturer, work their way up to associate professor, and finally, professor. I know many professors who have never worked in the field, and that perturbs me.

▸ **SHANE MARKUS** is a master's student in civil engineering at the University of Washington, where he investigates rock-mass stability assessment. He can be contacted at *markussh@u.washington.edu*.

▸ **ALEX GRANT, PhD**, is a research civil engineer at the USGS. He recently completed his PhD at the University of Washington, where he focused on regional-scale, co-seismic landslide-hazard forecasting. He can be contacted at *agrant@usgs.gov*.

▸ **WILLIAM POLLOCK** is a PhD candidate in civil engineering at the University of Washington, where he studies regional-scale, quantitative landslide-risk assessment. He can be contacted at *wpollock@u.washington.edu*.