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Evert Hoek's legacy in Rock Mechanics and Rock Engineering[1]

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Abstract

Dr. Hoek's contributions to the rock mechanics and rock engineering had made him one of the most established engineers in these fields. He graduated in mechanical engineering from the University of Cape Town with a B.Sc. in 1955 and an M.Sc. in 1957. In 1958 he moved to Pretoria, where he worked as a research engineer for the Council for Scientific and Industrial Research (CSIR). In 1966, he moved to London, where he was appointed originally as a reader and later on as a full professor of the Imperial College. During his stay in London, he published two classic books in rock engineering, one on „Rock Slope Engineering" with John Bray, and a second on „Underground excavations in rock" with his successor on Imperial Ted Brown. In 1975 Dr. Hoek left UK, and joined the industry with Golder Associates in Vancouver, Canada. In 1987 he joined University of Toronto as an industrial research professor when he was with P.K. Kaiser and W.F. Bawden published book „Support of Underground Excavations in Hard Rock". In 1993 Dr. Hoek returned to Vancouver and started his own consulting business. He is probably best known for his role in the development of the Hoek-Brown failure criterion. He retired in 2018. Dr. Hoek passed away on July 6, 2024, after a short illness at his home in Vancouver.

Keywords

Evert Hoek legacy, Failure criterion, Rock engineering, Rock mechanics.

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1 Education and first jobs in South Africa

Dr. Evert Hoek was born in 1933 in Southern Rhodesia, today Zimbabwe. His parents were farmers. He graduated with a degree in mechanical engineering from the University of Cape Town in 1955 and earned his master's degree in 1957[2]. During his master's studies, he researched stress distribution in threaded joints (bolts and nuts) using three-dimensional photoelastic techniques (Figures 1 and 2). At that time, all stress research in mechanical components was conducted on analog models by attaching strain gauges to the models, or by using two-dimensional and three-dimensional photoelastic models.

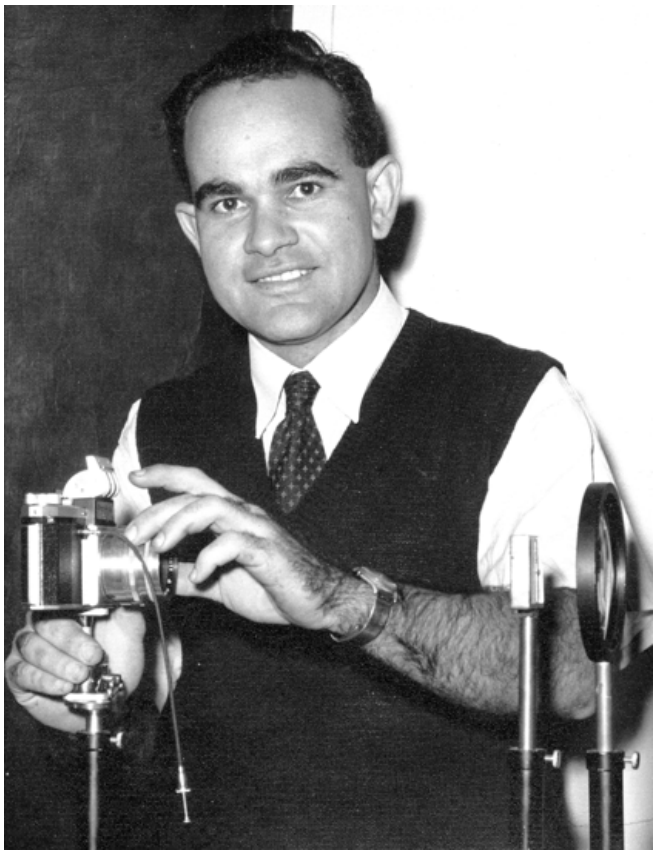


Fig. 1 Dr. Hoek during his master's research at the University of Cape Town (1956–1957) (Hoek, 2021).

While working as a mechanical engineer at the University of Cape Town, he was interested in jet engine design and aeronautical engineering. A friend's invitation to visit the National Research Institute for Mechanical Engineering, a branch of the South African Council for Scientific and Industrial Research (CSIR)[3], completely shaped his scientific and professional life. During the visit, he was offered a position as a research engineer in the field of stress analysis and material strength. He accepted the job and moved to Pretoria in 1958. There he encountered large-scale equipment for photoelastic stress analysis, which he immediately began to use. In this way, he continued working on stress analysis in mechanical elements.

However, circumstances soon forced him to abandon stress analysis in mechanical elements and turn to rock mechanics. The reason was that deep gold mines in South Africa were experiencing severe

[2] It is interesting to note that several well-known geotechnical engineers originally graduated in mechanical engineering. Alongside Hoek, these include Karl Terzaghi, Z.T. Bieniawski, and Robert Zimmerman (currently Head of the Rock Mechanics Department at Imperial College).

[3] The CSIR is South Africa's national organization for scientific research and development. Established in 1945 in Pretoria, it employs around 3,000 technical and scientific researchers (Wikipedia).

problems caused by rockbursts, and the mining industry engaged the Institute to investigate this phenomenon[4].

Dr. Hoek joined the team working on this problem from the very beginning. His mentor was Günter Denkhaus, the Institute's director, who was an excellent mathematician. Denkhaus made a significant contribution to the early development of rock mechanics through stress analysis around excavations of different shapes using elasticity theory. In an interview he gave to *Geostrata* in 2018, Dr. Hoek said: *"Naïvely assuming that rock is just another engineering material, but soon we realized that rock is quite unusual"* (Geostrata interview, 2018)[5].



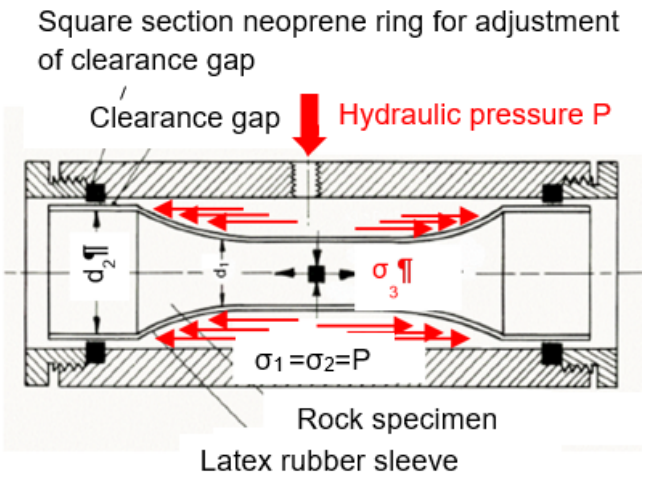
Fig. 2 Dr. Hoek with a large photoelastic polariscope and a photoelastic sample of a crane hook. Photographed in 1958 at the National Research Institute for Mechanical Engineering, a branch of the South African Council for Scientific and Industrial Research (Hoek, 2023).

Although South African mining at that time was leading in the development of innovative technologies for exploiting mineral resources, the health of miners and mining accidents were entirely neglected. In 1960, the progressive collapse of about 900 support pillars (domino effect) in the underground Coalbrook coal mine in Clydesdale killed 435 miners, the worst accident in South Africa's history. These disasters forced the government's Chamber of Mines to establish the Mining Research Laboratory, with Dr. N.G.W. Cook as director. CSIR joined the search for answers and appointed Dr. Hoek as team leader.

In his research project (Hoek, 1965) and doctoral thesis (Hoek, 1965a) on determining the strength of intact rock under triaxial conditions, Dr. Hoek collected results from numerous triaxial tests on different rock types. To determine tensile strength under triaxial conditions, he adapted a technique published by Brace (1964) and carried out many tests on dog-bone shaped samples (Figure 3). The pressure applied to the enlarged ends induced tensile stress in the reduced section. He presented the results in a diagram of maximum principal stress σ_1 and minimum principal stress σ_3, normalized by the uniaxial compressive strength σ_c. These results later contributed to defining the failure criterion that he published with Ted Brown in 1980.

4 Sudden explosive-like release of energy due to the failure of a brittle rock of high strength (ISRM, 1975).

[5]Reference: *GeoStrata Magazine*, ASCE – American Society of Civil Engineers. GeoStrata May–June 2018, Evert Hoek Interview (PDF)



$$\sigma_3 = P\frac{\left(d_2{}^2 - d_1{}^2\right)}{d_1{}^2}$$

Fig. 3 Equipment for testing tensile strength under triaxial conditions used by Dr. Hoek in his doctoral thesis (Hoek, 1965a).

He earned his PhD in 1965 at the Faculty of Engineering, University of Cape Town, with the thesis *Rock fracture under static stress condition*, thus obtaining the title Doctor of Philosophy in Engineering. He also holds a doctorate in engineering from the University of London.

At that time, rock mechanics was not yet an engineering discipline. Some rock mechanics problems were addressed by mechanical and civil engineers, as well as physicists working in material mechanics. Hoek's experience in stress analysis and material strength helped him to view rock as an engineering material. When Dr. Hoek went to the Imperial College of Science and Technology in London in 1966 (hereafter "Imperial"), his position as head of the rock mechanics department at CSIR was taken over by Richard (Dick) Bieniawski, known for his RMR rock mass classification.

2 Work in Europe (1996-1975) and Canada (1975-2022)

Professor Alastair Black, head of the Mining Department at the Royal School of Mines (RSM) in London, enrolled students Nick Barton (civil engineering), Peter Cundall (electrical engineering), and John Sharp (civil engineering) in postgraduate studies in rock mechanics, with the aim of expanding the program and firmly establishing RSM internationally as an interdisciplinary center for rock mechanics (Fairhurst, 2025)[6].At Professor Black's invitation, Dr. Hoek arrived at RSM in 1966, which was part of Imperial College, where he was appointed head of the first formal rock mechanics program at RSM[7]. That same year he was named reader, and in 1970 professor of rock mechanics. Dr. Hoek mentions that his academic career was significantly influenced by Professors Alan Bishop and Alec Skempton in soil mechanics, and Neville Price in geology (Geostrata interview, 2018). Nick Barton, whose contribution to rock mechanics was also enormous, recalls in his unpublished autobiography Dr. Hoek as his professor: *"It is here that I must also acknowledge Evert Hoek who had joined Imperial during our first year. He was first a Reader at IC but was soon nominated as our formal professor and academic link to the college. Evert was a well-established expert in rock mechanics and mining from South Africa, and was quite busy as a specialist international consultant, but also talented at keeping our project on track and with an expanding budget. Evert later surprised and impressed us with two classic texts in rock engineering, one on Rock Slope Engineering in 1974 with a talented lecturer at IC, Dr. John Bray, and a second on Underground Engineering in Rock in 1980 with an Australian successor at Imperial, Ted Brown"*.During his time at Imperial, Dr. Hoek led two major research projects sponsored by several international mining companies, which resulted in the publication of two books: *Rock Slope Engineering* (Hoek and Bray, 1974) and *Underground*

[6]Video recording of Professor Fairhurst's lecture was published by ISRM: ISRM Official Website: https://isrm.net/page/show/1765

[7] In 1907, the Royal College of Science, the Royal School of Mines, and the City and Guilds of London Institute merged to form the Imperial College of Science and Technology (today known as *Imperial College London*) (Wikipedia)

Excavations in Rock (Hoek and Brown, 1980). A year before leaving the U.K., the University of London awarded him a Doctor of Science (Engineering) degree based on his published work and research. His position as professor at Imperial was succeeded by another giant of rock mechanics and rock engineering, Ted Brown.

In 1975, he was appointed director of the international geotechnical consulting company Golder Associates in Vancouver, Canada. During twelve years at Golder Associates, he worked as a consultant on major civil and mining projects in more than twenty countries worldwide. In 1987, he was appointed professor of rock engineering in the Department of Civil Engineering at the University of Toronto. There he was involved in another industry-sponsored research project, which resulted in the publication of the book *Support of Underground Excavations in Hard Rock*, co-authored with P.K. Kaiser and W.F. Bawden (1995).He returned to Vancouver in 1993 to devote himself fully to consulting as an independent expert, working exclusively on advisory and review boards and in professional panels for civil and mining projects worldwide. He retired from these activities in 2018 and officially withdrew from professional work.

3 What is Dr. Hoek's Legacy in Rock Mechanics and Rock Engineering?

Dr. Hoek was a giant whose contributions have had a deep and lasting impact on the development of rock mechanics and rock engineering. He was a long-standing international leader in these fields. Throughout his career, he sought solutions to the problems faced by ordinary engineers in practice. That is why his analytical solutions were tailored to them—simple and clear. He was an excellent communicator. His lectures were clear, concise, and well-illustrated, whether delivered orally or in written form.

Dr. Hoek is perhaps best known for his contributions to the assessment of rock mass strength. Together with Ted Brown, he developed and continuously refined the Hoek–Brown failure criterion (hereafter, H–B criterion). However, he also contributed to many other aspects of rock mechanics and rock engineering.

The International Society for Rock Mechanics and Rock Engineering (ISRM) honored Dr. Hoek through a tribute prepared by former presidents Prof. Charles Fairhurst and Prof. E.T. Brown (Fairhurst and Brown, 2024). Among other things, they wrote: *„We have lost a world leader in our field, but we are all the better for his major contributions and for having known him.The rock mechanics community grieves the loss of a true giant in rock mechanics, rock engineering and in life"*.

Since Dr. Hoek constantly emphasized the importance of engineering geology in rock engineering, the International Association for Engineering Geology and the Environment (IAEG) also paid tribute to him during the First International Conference on Rock Classification. In the section *Scientific Farewell to Dr. Evert Hoek – A Rock Engineering Legend by the IAEG and ISRM*, speeches were given by Prof. John Harrison (University of Toronto), Prof. Vassilis Marinos (National Technical University of Athens, IAEG President 2023–2026), and Prof. Leandro R. Alejano (University of Vigo, Spain). A video recording of these presentations was published on the ISRM website.

The company Rocscience established in 1996 the so-called *Hoek's Corner*, which contains numerous Hoek publications, videos of his lectures, as well as the book *Practical Rock Engineering*. All of these materials are free and can be downloaded from its website.

3.1 The Hoek-Brown Failure Criterion

For any stress and deformation analysis in rock engineering (slopes, tunnels, foundations), it is essential to reliably estimate the strength and deformability of the rock mass. The ISRM was founded on May 25, 1962, in Salzburg. The day before, Professor Müller and his colleague Dr. Franz Pacher gave an interview to Salzburg radio. One of the questions was: *„Do we know the strength of rock?"* Müller replied: *For rock (specimens) tested in the laboratory, yes. For a rock mass, no. This is what we need todetermine. This is why we need an International Society for Rock Mechanics"* (ISRM, 2012). This concise statement defines what Müller considered the central question in rock mechanics: *What is the strength of the rock mass?*

Today, 63 years later, do we know how to determine the strength of the rock mass? Although great progress has been made in research and numerical analyses, this remains a key problem in rock mechanics. The failure criterion, which defines the peak strength of the rock mass, is a crucial element in every geotechnical stress analysis. Since it is impossible to perform triaxial or shear testing of rock masses at a scale corresponding to underground and surface excavations in mining and civil engineering, several authors developed empirical criteria. Among them were Hoek and Brown, who attempted to solve this problem, fully aware of its complexity. From the very beginning, they recognized all the limitations, but they sought to help practicing engineers obtain at least a rough estimate of rock mass strength.

While working at Imperial, Dr. Hoek encouraged the mining industry to fund a research project (1972–1976) involving postgraduate students at RSM. During the project, Hoek and Brown realized that there was no good method for assessing slope stability, particularly due to the problem of scale in observations. They understood that they lacked a criterion capable of linking geological observations with the strength properties of poorly or heavily fractured rock masses (Geostrata interview, 2018). This was the impetus for developing the rock mass failure criterion that we now recognize as the Hoek–Brown criterion. The final report of this project was published in the book *Underground Excavations in Rock*. In this book, the original form of the H–B criterion was presented for the first time (Hoek and Brown, 1980).



Fig. 4 Dr. Evert Hoek (right) and Dr. E.T. (Ted) Brown [8](left) at a dinner celebrating Dr. Brown's retirement, Brisbane, October 4, 2018 (Fairhurst and Brown, 2024).

In the interview he gave to *Geostrata* (2018), Dr. Hoek acknowledged that this method, although crude, was widely accepted due to the lack of suitable alternatives. The interview also provides insight into Dr. Hoek's views on the development and future perspectives of rock engineering, as well as advice for engineering students just beginning their careers in rock mechanics and rock engineering.

[8]Ted Brown has been Professor Emeritus at the University of Queensland since 2001. His academic career included studies at the University of Minnesota (USA) and the University of Cambridge (UK) before joining the staff of Imperial College in 1975, first as a Reader and, from 1979, as Professor. He served as Dean of the Royal School of Mines and Head of the Department of Mineral Resources Engineering.In 1987, he returned to Australia as the first permanent Dean of the Faculty of Engineering at the University of Queensland. He has had an impressive career spanning more than 55 years of international experience as a researcher, teacher, and consultant, with numerous publications on rock mechanics and rock engineering and their applications in mining, civil engineering, and energy resources.

3.1.1 A Brief Overview of the Main Modifications to the H-B Criterion

Based on Griffith's theory of brittle fracture (Griffith 1921, 1924), Hoek and Brown developed the original H–B criterion (Hoek and Brown, 1980, 1980a; Hoek, 1983). Before them, Griffith's brittle fracture theory had been applied to rocks by Murrell (1958). The H–B criterion was derived from Hoek's research on brittle fracture of intact rock (1965, 1965a) and Brown's model studies on the behavior of fractured rock masses (1970).The H–B criterion for intact rock was obtained by experimenting with a series of parabolic envelopes through a trial-and-error process. The Mohr envelope was derived by statistically fitting a curve to a number of pairs of normal and shear stresses (σ'_n, τ), using the method published by Balmer (1952). The H–B criterion belongs to the group of stress failure criteria defined by the relationship between the maximum (σ'_1) and minimum (σ'_3) principal stresses at the moment of rock failure. The influence of the intermediate principal stress (σ'_2) was neglected.

Since rock mass strength is the greatest challenge in rock mechanics and rock engineering, the authors adapted the original criterion for intact rock to make it applicable to rock masses, assuming the same parabolic equation form. Just as Bieniawski refined his RMR classification between 1973 and 1989, Hoek and Brown repeatedly modified their criterion in response to practical experience and to address specific limitations.

Hoek, Wood, and Shah (1992) published a revision of the original criterion to make it applicable to poor-quality rock masses. This modification became known as the *modified H–B criterion*.

Hoek (1994) and Hoek, Kaiser, and Bawden (1995) introduced the *general H–B criterion*. They argued that a system based more on geological observations was needed, and less on "numbers" such as RMR, which had been used in the original and modified criteria. They also realized that the 1992 modification produced overly conservative strength values for higher-quality rock masses. The general form included both the original criterion (for excellent to fair-quality rock masses) and the modified criterion (for poor to very poor-quality rock masses with increasing fine-grained content). In this version, the Geological Strength Index (GSI) was introduced as a replacement for Bieniawski's RMR. GSI classification is based on two main factors that strongly influence rock mass mechanical properties: structure (blockiness) and discontinuity conditions.

Hoek, Carranza-Torres, and Corkum (2002) published the last major revision, which included estimation of Mohr–Coulomb parameters (cohesion and friction angle). They developed new equations for m, s, and a, incorporating GSI and a new parameter D. The disturbance factor D was originally introduced to account for damage caused by blasting in large open pits. Over time, other effects were included, and today D is recognized as a *disturbance factor*, not merely a blasting damage factor. It now encompasses strength reduction due to weathering, long-term creep, and any other processes that may alter rock mass properties (Rocscience, 2022).

Hoek and Diederichs (2006) published a modification of the criterion that included the estimation of the deformation modulus of rock masses, based on numerous field tests in China and Taiwan. The authors realized that the commonly used exponential relationships in the general H–B criterion usually overestimated the deformation modulus of massive rock masses. Therefore, they proposed new equations for estimating the deformation modulus of rock masses.

The most recent, and probably final, version of the criterion was published by Hoek and Brown (2019).

As experience with the criterion accumulated, GSI diagrams for different rock types were published. For example, Hoek, P. Marinos, and V. Marinos (2005) presented GSI diagrams for molasse rocks. Marinos, P., Hoek, and Marinos, V. (2006) presented a geological model of ophiolitic deposits, their various petrographic types, and tectonics mainly resulting from thrusting. They showed GSI diagrams with ranges of GSI values for different qualities of peridotite–serpentinite rock masses in ophiolitic complexes, as well as a classification of the behavior of peridotite–serpentinite rock masses in ophiolitic complexes during tunneling.

Below is the general form of the H–B criterion (Hoek, Carranza-Torres, and Corkum, 2002) and commentary on the constants (parameters) in the equations:

$$\sigma_1' = \sigma_3' + \sigma_{ci}\left(m_b \frac{\sigma_3'}{\sigma_{ci}} + s\right)^a \quad (1)$$

$$m_b = m_i \exp\left(\frac{GSI-100}{28-14D}\right) \quad (2)$$

$$s = \exp\left(\frac{GSI-100}{9-3D}\right) \quad (3)$$

$$a = \frac{1}{2} + \frac{1}{6}\left(e^{-GSI/15} - e^{-20/3}\right) \quad (4)$$

where σ'_1 and σ'_3 are the maximum and minimum effective principal stresses, σ_{ci} is the uniaxial compressive strength of intact rock, m_b, s, a are material constants of the rock mass depending on composition, structure, and discontinuity properties ($m_b = m_i$ and s = 1 for intact rock).

In the above equation, σ_{ci} is the dominant parameter determining the position of the failure curve on the ($\sigma'_1 - \sigma'_3$) diagram. Constants (m_b) and (s) define the shape of the failure curve. It is assumed that intact rock fracture does not play a significant role in the overall failure process, that fracture distribution is "chaotic" with no preferred failure directions, and that the rock mass can be treated as isotropic and homogeneous. GSI, m_i, D are independent variables determined in the laboratory (m_i) or estimated in the field (D, GSI), m_b, s, a are dependent variables calculated from values of GSI, m_i, D.

It is essential to clarify the significance of the uniaxial compressive strength of intact rock, σ_{ci}. This parameter can be derived through two distinct methods. The first is the conventional laboratory procedure in which specimens are subjected to axial loading in the absence of lateral confinement (UCS, unconfined test). Alternatively, σ_{ci} can be determined by extrapolating the results obtained from triaxial compression tests on intact rock samples. In a $\sigma_1 - \sigma_3$diagram, $\sigma_{ci}$is defined as the value of σ_1 at the intersection of the intact rock failure criterion with the vertical axis (where σ_3=0).Values of σ_{ci}obtained from triaxial tests (confined test) are generally higher than those obtained from uniaxial compressive tests (UCS). Under triaxial stress conditions, pre-existing micro-cracks close, thereby enhancing the overall rock strength. Therefore, Hoek and Brown (2019) require that the H–B criterion use σ_{ci} determined from triaxial testing.

3.1.2 Warnings Dr. Hoek Addresses to Users of the Criterion

Dr. Hoek, in a letter to the editor of the *ISRM News Journal*, warns that the criterion was developed with very limited data of rather poor quality and was offered only as a temporary solution (Hoek, 1994a). For reliable use of the H–B criterion, it is essential to carry out geological and geotechnical investigations during the first phase of a project. Dr. Hoek cautions that design work is very often approached with scant investigative studies. Most often, only national power corporations generally have teams that understand the problems and accept recommendations regarding the need for proper site investigation, project review, and construction control (Rocscience, 2022).

Although the criterion has generally been found to provide satisfactory estimates, Hoek and Brown point out that there are several issues concerning its applicability and inaccuracies related to the quality of input data. Hoek (2023) warns of the difficulties in selecting mechanical parameters of rock masses in numerical analyses, stating: „*It is unlikely that 'accurate' methods for estimating rock mass properties will be developed in the foreseeable future. Consequently, the user of the Hoek-Brown procedure or of any other equivalent procedure for estimating rock mass properties should not assume that the calculations produce unique reliable numbers. The simple techniques described in this section can be used to explore the possible range of values and the impact of these variations on engineering design*".The ultimate responsibility always lies with the engineer, who cannot justify shortcomings by the results of calculations.

Hoek and Brown (2019) recommend: „Despite the revisions that have been made to the criterion and the experience gained in its use over almost 40 years, care must be exercised in seeking to apply the criterion to some rock masses, particularly those at the higher and lower ranges of GSI. It is essential that the geology of the site be well understood, and that the mechanics of the engineering problems involved be evaluated critically. When this has been done, the methods discussed in this paper may be

used to evaluate the parameters in the criterion for the intact rock and the rock mass".All these methods have been implemented in a Windows program called ***RocLab*.** Brown (2008) warns against using programs that too automatically calculate equivalent Mohr–Coulomb parameters without clear consideration of the range of effective normal stresses applied to the case under study.

In 2022, Dr. Hoek announced his withdrawal from all professional activities, stating: „I have now retired completely from all professional activities and research and so I will not be contributing any further to this topic. However, I am certain that there are others who will accept the challenge of improving existing failure criteria or developing new ones". (Rocscience, 2022)[9].

3.2 Equipment for Laboratory and Field Testing

Both in South Africa and at Imperial, Dr. Hoek developed a range of effective laboratory and field equipment. This was probably influenced by his education as a mechanical engineer. In South Africa, he designed and used a three-meter centrifuge, equipment for biaxial loading of plate models measuring 15 × 15 cm, large-scale field tests of uniaxial compressive strength (Figure 5), and other devices.

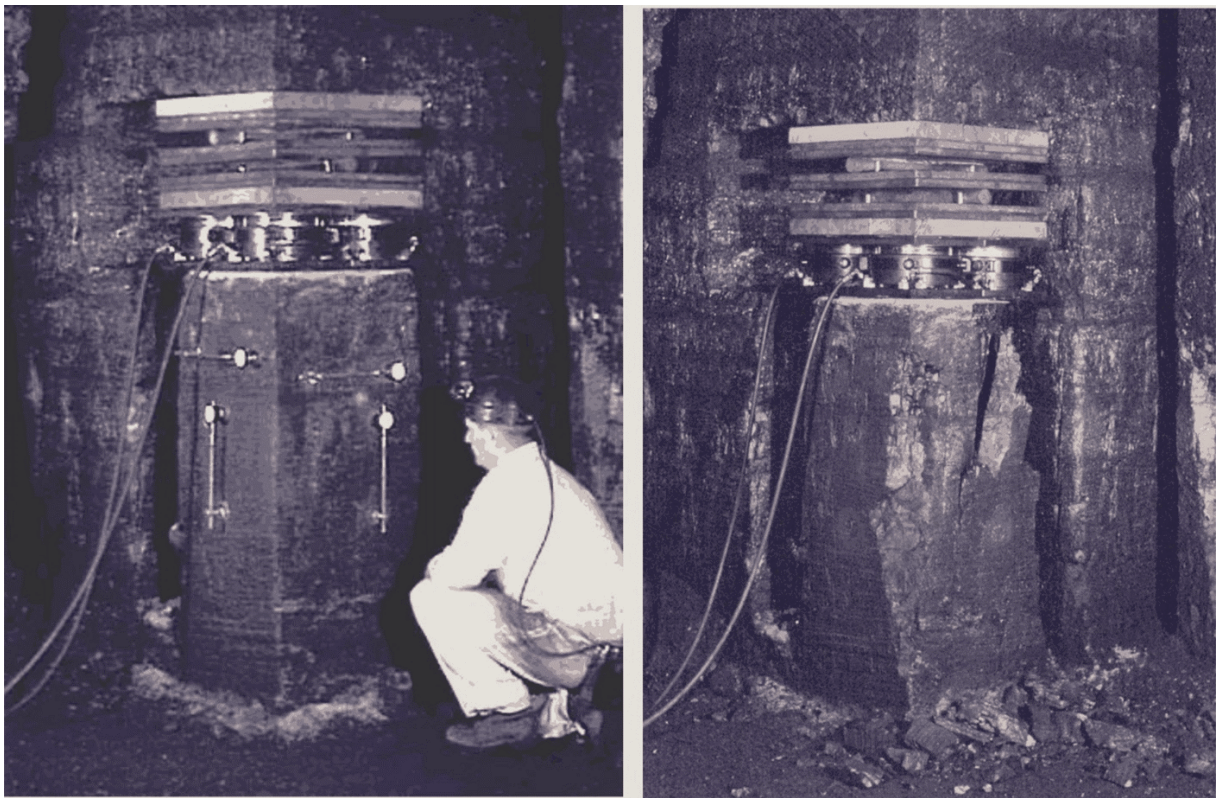


Fig. 5 Dr. Hoek was involved in the design and execution of the first phase of field tests on coal strength. After his departure from CSIR in 1966, the leadership of the project was taken over by Z.T. Bieniawski (Hoek, 2021).

During his time at Imperial, Dr. Hoek continued developing equipment. He always aimed to keep it inexpensive so that it would be accessible to a wide range of users. The equipment needed to be robust so it could also be used in laboratories located directly on construction sites. His most widely known invention is the triaxial cell, today referred to as the *Hoek triaxial cell*, for determining the strength and deformability of intact rock. The equipment is compact and portable, and it provides reliable results if the hydraulic press is dependable. Results from triaxial testing are used to determine the uniaxial compressive strength σ_{ci} and the parameter m_i in the Hoek–Brown criterion. The design details of this cell were published by Hoek and Franklin (1968) and Franklin and Hoek (1970) (Figure 6).

[9]www.rocscience.com

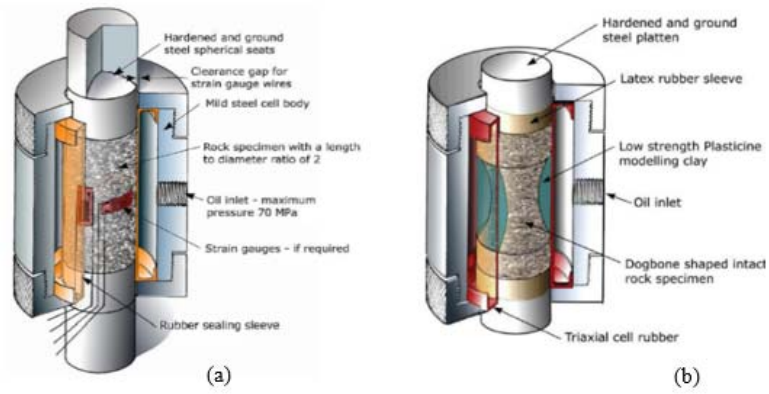


Fig. 6 Testing of triaxial compressive strength (a) and triaxial tensile strength (b) in the Hoek cell (Ramsey and Chester,2004).

Ramsey and Chester (2004) used the Hoek triaxial cell to determine tensile strength under triaxial conditions on dog-bone shaped samples, as already explained in the first chapter. They used a standard protective membrane, and the space between the membrane and the narrowed part of the sample was filled with modeling clay.

3.3 Published Books

Dr. Hoek is the author or co-author of four significant textbooks. He also published more than one hundred papers on stress analysis, brittle fracture, laboratory equipment design, rock slope stability, underground excavation design, and related topics (*Geostrata interview, 2018*).

The book by Dr. Hoek and John Bray, *Rock Slope Engineering*, was published in three editions (1974, 1977, and 1981) by the Institute of Mining and Metallurgy in London. As noted earlier, the book was the result of research carried out at Imperial. The mining industry sponsored the research, recognizing the need to develop design methods for increasingly deep open pits. Investigation and design techniques originally developed for mines were soon adopted in civil engineering, where slope heights are usually smaller than those in open pits. The fourth edition was published by Duncan C. Wyllie and Christopher W. Mah (2004) under the title *Rock Slope Engineering, Civil and Mining* (based on the third edition by E. Hoek and J. Bray). The authors dedicated this edition to Hoek and Bray in recognition of their pioneering work in rock slope engineering.

The book by Dr. Hoek and Dr. Ted Brown, *Underground Excavations in Rock*, was published by the Mining and Metallurgy Research Institution in London in 1980 (Hoek and Brown, 1980). Preparation of this book began as a four-year research project on the design of large underground excavations conducted at Imperial in London between 1972 and 1976. Several editions of this book have been published, either as reprints or revised versions.

The book *Support of Underground Excavations in Hard Rock* was the result of a four-year research project carried out by Dr. Hoek (Department of Civil Engineering at the University of Toronto), Peter K. Kaiser (Geomechanics Research Centre at Laurentian University), and William F. Bawden (Department of Mining Engineering at Queen's University) (Hoek, Kaiser, and Bawden, 1980). The results of this research also included the programs DIPS, UNWEDGE, and PHASES. As Dr. Walter Curlook stated in the book's foreword, this was the most complete and up-to-date manual for excavation and support design in underground mining. It was the product of close collaboration between the mining industry, which provided funding and advisory support, and universities. Around 40 engineers and graduate students participated in the research, gathering knowledge and experience worldwide. The book went through four editions: 1995, 1997, 1998, and 2000.

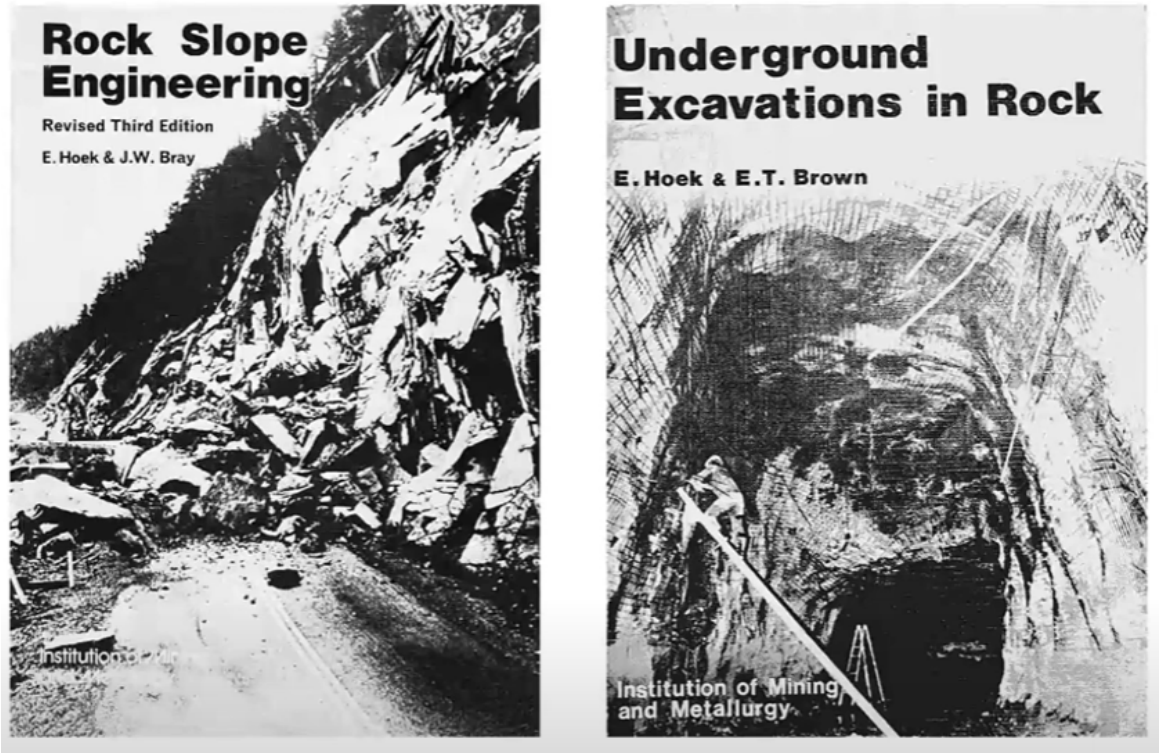


Fig. 7 Books as a result of scientific research at Imperial (1972–1976).

As Professor of Rock Engineering at the University of Toronto, Dr. Hoek prepared lecture notes (course scripts) for undergraduate and graduate studies between 1987 and 1993 under the title *Practical Rock Engineering*[10]. From time to time, these notes were supplemented and updated, but they remained in their original form for the last thirty years. In 2006, the notes were significantly revised to incorporate major advances in rock engineering since they were originally written. The notes were intended to provide insight into practical rock engineering for students, geotechnical engineers, and engineering geologists. Practical examples were used wherever possible to illustrate methods currently employed by engineers in practice. The notes did not include results of scientific research that had not yet found its way into everyday practical application.Hoek (2023) wrote: *„In 2020, I retired from all my consulting and academic activities and started the process of assembling material for a complete update and rewrite of these notes. In 2022 and 2023, I prepared several new chapters and re-wrote several of the original chapters to incorporate advances and practical applications in the field“*. Unfortunately, his sudden death in 2024 prevented him from fulfilling this intention.

4 Awards and Recognitions

For his contributions, Dr. Hoek received more awards and honors from major organizations connected with rock mechanics and rock engineering than anyone else in the field. A complete list of awards and recognitions is provided by Fairhurst and Brown (2024). Only some of them are shown here:

- Reader, later Professor of Rock Mechanics at the Royal School of Mines, Imperial College, London.
- Professor of Industrial Research in Rock Engineering at the University of Toronto.
- Honorary doctorates: University of Waterloo, Canada; University of Toronto, Canada; Polytechnic University of Catalonia, Barcelona, Spain.
- Rankine Lecture, British Geotechnical Society.

[10] https://www.rocscience.com/assets/resources/learning/hoek/Practical-Rock-Engineering-Full-Text.pdf

- Gold Medal, Institution of Mining and Metallurgy, UK.
- Müller Award, International Society of Rock Mechanics and Rock Engineering.
- William Smith Medal, Geological Society, UK.
- Fellow, Royal Academy of Engineering, UK.
- Fellow, ISRM.
- Glossop Lecture, Geological Society, UK.
- Terzaghi Lecturer, American Society of Civil Engineers.
- Member of the Royal Academy of Engineering (UK), the US National Academy of Engineering, and the Canadian Academy of Engineering.

Dr. Hoek officially retired in 2018, but until 2022 he was still engaged in some professional activities. The software company Rocscience, with which Dr. Hoek closely collaborated, organized several events in recent years to thank him for his global contributions to rock engineering. In 2021, Rocscience held the *Rocscience International Conference 2021*. In the *Lifetime Achievement Session – Dr. Evert Hoek*, he received the Lifetime Achievement Medal in recognition of his contributions to rock engineering. On that occasion, Dr. Hoek delivered his last major lecture: *Developments in Rock Engineering from 1958 to 2020*. A video recording of this lecture was published (Hoek, 2021). After the lecture, Hoek answered questions (Hoek, 2021a).

A year later, Rocscience published a major interview with Dr. Hoek titled: *Africa Geotechnical Legends: Dr. Evert Hoek Designs and Disasters in Rock Engineering Q&A*. In this interview, answering 95 questions, Dr. Hoek discussed all the important aspects of rock mechanics and rock engineering (Rocscience, 2022)[11].

In 2025, Rocscience introduced the Evert Hoek Legacy Medal, celebrating Dr. Evert Hoek's contribution to rock engineering. The medal and a monetary award will be presented to the best paper at each future international Rocscience conference.

5 How Dr. Hoek views Rock Engineering Studies and what he advises young engineers and students

Dr. Hoek saw the integration of geology and engineering as the most important challenge in education for rock engineering. As a mechanical engineer, he had no formal geological training and, as he himself admitted, it took him many years to realize that without geological knowledge it is impossible to solve rock engineering problems. Later, when working as a consultant, he always insisted on collaborating with a good geologist. As good practice, Dr. Hoek considered situations where engineering and geology professors teach together, providing students with the necessary knowledge from both disciplines, which are inseparable in rock engineering. He regarded insufficient geological education as the greatest challenge he faced, and believed that in the early stages of his career he should have devoted more time to learning geology (Hoek, 2021a).

Dr. Hoek was concerned about current university programs that do not prepare students for real situations they may encounter when solving rock engineering problems. In an interview with *Geostrata* (2018), when asked if he had any further advice for young engineers, Dr. Hoek urged students considering postgraduate study: *„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*

[11] https://www.youtube.com/watch?v=dy83dYaXHVY&t=5s

https://static.rocscience.cloud/assets/resources/learning/hoek/RIC2021-QAwithDrHoek_V2.pdf

https://static.rocscience.cloud/assets/resources/learning/hoek/Africa-Geotechnical-Legends-Questions-for-Evert_v4_2022-04-29-201059_fmvn.pdf

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".He repeated this advice in the closing minutes of his lecture *Developments in Rock Engineering from 1958 to 2020* (Hoek, 2021).

Dr. Hoek also shared his personal view on the future development of rock mechanics and engineering in the *Geostrata* interview (2018). Asked how rock mechanics had changed since he began working in the field, he replied: *„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"*.

6 Instead of a Conclusion

Dr. Hoek's contribution to rock mechanics and rock engineering is immense. He was the author or co-author of four major textbooks: *Rock Slope Engineering* with John Bray, *Underground Excavations in Rock* with Edwin Brown, *Support of Underground Excavations in Hard Rock* with Peter Kaiser and William Bawden. He independently prepared the e-book *Practical Rock Engineering*. He also published more than 100 papers on stress analysis, brittle fracture, laboratory equipment design, rock slope stability, underground excavation design, and other related topics.

As a mechanical engineer, Hoek did not receive formal education in rock mechanics. Major mining accidents in South Africa were the reason he began working in rock mechanics. Concluding his last major lecture (2021), Dr. Hoek emphasized how challenging rock mechanics and rock engineering had been throughout his career: *„However, having stumbled into this field by accident, I found it to be fascinating, challenging, and rewarding, because of the unpredictability of rock masses I found every problem to be uniquely challenging"*. Dr. Hoek attributed his success to the fact that from the very beginning he dealt with problems that were real, not theoretical. He believed that experience, common sense, and engineering intuition were just as important as formal knowledge of the fundamental principles of rock mechanics (Hoek, 2021).

I had the privilege and honor of being on friendly terms with Dr. Hoek for the last fifteen years. I began following his career back in my student days, keeping track of the publications he released. The book *Rock Slope Engineering* (1974) was embraced by the entire mining community to which I belonged at the time, and it was of great help in solving open-pit slope stability problems.I personally met Dr. Hoek when, at my invitation, he came to EUROCK 2009[12]. Dr. Hoek delivered a keynote lecture titled *Tunnelling in Overstressed Rock* (Hoek and Marinos, P., 2009).

In the last of several letters we exchanged, Dr. Hoek wrote to me in early January 2024: *„I am now 90 years old and fully retired but still in very good health. I am working on the print version of my last book on Practical Rock Engineering, which is already available on the Internet. I think that it will take me a few months to complete this edit and then I will be able to relax and enjoy the rest of my life"*.

The energy with which Dr. Hoek tackled rock mechanics and engineering problems is reflected in these words from the same letter: *„I have not done any serious consulting for some time now and I*

[12] 13th ISRM European Rock Mechanics Symposium, Dubrovnik, Cavtat, Croatia, 29-31 October 2009.

have to say that I do not miss the stress with the travel that was required to complete my commitments. However, I am happy with the overall results of my career and with the opportunities that it provided to meet people like you, who I would not have met otherwise".



Fig. 8 Dr. Hoek and the author in Dubrovnik, 2009.

Sadly, Dr. Hoek did not succeed in preparing his last book for print. He passed away six months later, on July 6, 2024, after a short illness at his home in Vancouver.

Thank you to him for the knowledge he shared with all of us and for the effort he invested in presenting the problems of rock mechanics and rock engineering in a simple and understandable way to "ordinary" engineers, designers, supervising engineers, and those working in difficult field conditions.

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