Response to questions posed by Berk Demir, 12 September 2021.

- You have contributed a whole new perspective on understanding rock behaviour with Prof. Brown. I, personally, am always curious about the beginning of these studies. How did it start?

I graduated with a BSc in 1955 and an MSc in 1957 from the University of Cape Town in South Africa. In 1958, I was appointed as a research engineer at the National Mechanical Engineering Institute of the South African Council for Scientific and Industrial Research (CSIR), in Pretoria, South Africa. At that time, the gold mining industry was working at depths up to 3 km below surface and encountered frequent rockbursts. These were events in which the very highly stressed brittle quartzites failed by imploding into the excavations which had been mined to recover the gold. The CSIR was one of the research organizations engaged by the mining industry to study this problem. I soon found myself involved in a detailed study of the mechanics of fracture of highly stressed brittle rocks. I wrote a detailed report on this study in 1965, and I was permitted to include this report in my PhD thesis, submitted to the University of Cape Town in the same year.

In 1966, I moved to England to take up a position as a Reader and, in 1970, as a Professor of Rock Mechanics in the Royal School of Mines which is one of the three colleges of the Imperial College of Science and Technology. I spent nine years in London and it was during this time that many of the basic concepts of the Hoek-Brown failure criterion for rock masses were developed. Professor E.T. Brown, who succeeded me as Professor of Rock Mechanics in Imperial College, joined me in publishing the first version of this criterion in our book, *Underground Excavations in Rock,* in 1980.

The work on the failure of intact rock that I had carried out in South Africa in the 1960s formed the basis of the Hoek-Brown criterion. However, to describe the failure processes in rock masses, it was necessary to include the failure of the joints, shear zones and faults which divide the intact rock into the components which form the three-dimensional brick-work of rock pieces that make up a typical rock mass. The interaction between the intact rock blocks and the surrounding geological discontinuities was the key component of the Hoek-Brown failure criterion. It remains one of the few tools available for defining the properties of rock masses as engineering materials when subjected to the complex loading conditions encountered in the construction of caverns, tunnels, slopes and foundations.

- It is inevitable for our profession to be a part of a failure in our projects. Can you tell us a failure that you have experienced?

Rock Engineers deal with two types of failures. In civil engineering, the overall goal is the construction of safe and durable structures in which failures are unacceptable. In mining, controlled failure of mineral-rich rock masses is the mechanism which enables us to recover the metals which we require for the construction of stable civil engineering structures. I have been fortunate to have worked extensively in both civil and mining engineering projects and I have learned that there is a significant difference between preventing a failure and controlling a failure. An example of a controlled series of failures is the Chuquicamata copper mine in Chile, which is currently being transformed from an open pit to an underground block-caving mine. I worked as a consultant and member of the mine's geotechnical review board at various times between 1992 and 2017. I was heavily involved in the establishment of a program for the collection and interpretation of geotechnical data and guidance of the on-site geotechnical team responsible for the interpretation and analysis of this information for the design of the open pit slopes. I consider that the mining of the open pit was a tribute to all of those involved in the successful execution of this work, which involved controlling many unstable slopes by a process of monitoring slope displacements and adjusting the excavation process to maintain stability. The mine is currently in the early stages of the creation of a block-caving mine which will exploit the orebody located under the completed open pit.

Chuquicamata open pit copper mine in northern Chile. The pit is 4 km long, 3 km wide and was mined to a depth of 1 km before transitioning to an underground block-caving mine in 2019. Control of slope failures was a critical part of the successful completion of the open pit.

An example of a civil engineering failure is illustrated in the next photograph of the collapse of a 5 m diameter water tunnel for the Yacambú-Quibor project in Venezuela. This 24 km long tunnel was started in 1976. It was excavated in tectonically disturbed poor quality graphitic phyllite at depths of up to 1270 meters below surface. Breakthrough of the tunnel, driven from either end, was achieved in 2008, 32 years after commencement. Between 1991 and 1999, I was a member of the consulting board for the project until it was suspended because of construction and contractual problems. Work on the project re-commenced in 2003 and I was invited to return as an independent consultant.

The horseshoe shaped tunnel supported by steel sets and a concrete floor, based on the rock load tunnel design procedure proposed by Terzaghi in 1946, proved to be inadequate for the large displacements induced by the combination of weak rock and high stresses. Deformation of the steel sets and failure of the shotcrete lining, as well as failure of the concrete floor connections to the tunnel lining were common occurrences.

A support method, published by Rabcewicz in 1964, was used to overcome these problems. This method utilized sliding joints in the steel sets to allow the support system to yield a controlled amount before it is called upon to provide a support pressure. Yielding elements in the support system result in activation of the installed support at a greater distance from the face while providing security for the workers in the tunnel. The support pressure required to stabilize the tunnel is now much lower and the steel sets can provide support that is well within their capacity. In this case, a closure of the tunnel from 5.2 m to 5.0 m diameter was allowed before the sliding joints locked and the deformation of the surrounding rock mass was controlled by the support system. Details of the design of this support method are discussed in the paper by Hoek, E, and Guevara, R. Overcoming squeezing in the Yacambú-Quibor tunnel, Venezuela. *Rock Mechanics and Rock Engineering*, Vol. 42, No. 2, 389-418, 2009.

Repair of a concrete lining in the 5 m diameter, 24 km long Yacambú-Quibor project in Venezuela. Removal of the damaged original lining and re-mining the damaged rock enabled miners to install a new lining of circular steel arches, embedded in a 0.6 m concrete lining with sliding joints to absorb the squeezing of the surrounding rock mass. These sliding joints enabled the steel arches to absorb the energy of the squeezing rock mass sufficiently to permit the installation of a stable concrete lining.

- You are continuing to contribute to rock mechanics with papers and seminars. What is your incentive to be so active after all these years?

I am now 88 years old and have retired completely from all consulting, academic and publication activities. My remaining task is to update a set of notes entitled *Practical Rock Engineering* which are hosted on www.rocscience.com, which is the web site of the engineering software company Rocscience. My understanding is that these notes are heavily used by engineers and geologists working in the field. Some of the chapters in this collection date back to the 1980s and there are several missing chapters which remain to be written. I intend to complete this task as my final legacy to rock engineering.

- We are living in an age that reaching any knowledge takes less than a minute such as finding a paper. What do you feel about this difference when you compare it to 50 years ago? It is especially interesting for us, young engineers, to think about this.

When I started working in research on rock mechanics problems in South Africa in 1958, there were no books and very few papers dealing with this subject matter. The book *Fundamentals of Rock Mechanics* by Jaeger and Cook was published in 1969 which provided a very important compilation of the basics of the topic. Fortunately, I held a position which permitted world-wide travel. I made several trips to meet and work with professors and researchers in Europe and North America. With time, more and more papers were published in civil and mining engineering journals. These provided our main vehicles for the interchange of research information.

Eventually, the Internet developed and offered the opportunity for communication by email and a rapidly increasing ability to find information through services such as those offered by Google. Today, I find all the information that I require on the Internet and this represents an enormous increase in productivity. My main concern is that there is now too much information which has been published prematurely and which has not had the chance to be questioned and to mature as did the information generated before the Internet.

- Hoek Brown model is implemented in almost all finite element packages now. How do you feel about it? I am trying to focus on the sentimental value of this.

As described earlier in these comments, the Hoek-Brown criterion was developed to meet the practical needs of geologists and engineers working on the analysis and design of slopes, tunnels, and foundations. The development of the Geological Strength Index was based upon practical experience rather than on theory. It had to be, and still is, refined as more experience is gained. It has been satisfying to me that the overall criterion has proved to be practical and reliable when used with care in the field. However, I believe that more work is required to investigate its application to difficult rock mass conditions and that the results of this work should be published as clearly and concisely as possible.

- There are many different behaviours of researchers when it comes to interacting with readers. I often try to communicate with researchers about a question I had regarding a point, but to be honest, you were the best on this. Because you have replied to me in detail trying to cover everything I asked. Do you see yourself as a teacher first and consultant second or what is the reason behind this generous behaviour?

My early years were spent on a farm in Africa, working with my father in caring for and repairing the many problems associated with running a large farm. This hands-on experience set the tone for the remainder of my life. I have always been interested and concentrated on the practical rather than the theoretical. Whether consulting, researching, or teaching, I have always tried to deal with practical issues and to communicate my findings in simple and concise language. As I look back on my career, now at its end, I do not differentiate between my roles in teaching and consulting.