LIFETIME ACHIEVEMENT SESSION Q&A

Dr. Evert Hoek: Developments in Rock Engineering from 1958 to 2020

Q1: What do you think of dividing the uniaxial compressive strength of rock (coming from laboratory test results) by a factor safety when estimating rock parameters?

Atalay Turgut, Geotechnical Engineer @ Kasktaş A.Ş.

A1: You can change either the uniaxial compressive strength (UCS) or the Geological Strength Index (GSI) ratings in using the Hoek-Brown criterion. I would only change the UCS if there was some evidence of degradation of the intact rock because of weathering or alteration or, if you do not have any good laboratory UCS measured values, if you are doubtful about your choice of a UCS value. These changes will obviously have a significant impact on the calculated results. However, in general, I would recommend changing the GSI value if you are doing calculations of something like the factor of safety of a slope or the deformations in a tunnel. Changes in these situations are generally the result of rock mass properties, characterised by GSI, rather than of intact UCS values.

Q2: Rocks may provide great tensile strength and cemented to concrete retaining walls the tensile strength adds to the resistance. When do you think the available failure models may be extended to a considerable tension cut-off?

Ahmed Mufty, Geomechanics Specialist @ Rocscience

A2: Intact rock has significant tensile strength, which is generally higher than that of concrete. There are situations in which this tensile strength can be taken into account in designs, depending on the stress distribution generated by the loads or displacements applied to the structure. In the case of a concrete retaining wall, with rocks embedded in concrete applied to the outer surface, the tensile strength of the concrete would probably be the weakest link if the embedded rock has been well sorted, so that only intact pieces are embedded in the concrete. In this case, you could consider that the concrete retaining wall is simply thicker and that the embedded rocks have no impact on the tensile strength of the concrete. On the other hand, if weak rock or poorly sorted rock is embedded in the outer concrete layer, then I would recommend that the tensile strength of this outer layer should be reduced to zero if necessary.

Q3: What's your advice on the application of GSI to weathered environments such as those in tropical areas?

Allan Maia, Geotechnical Engineer @ VALE S.A.

A3: I have never considered the need to differentiate between GSI values for different climatic conditions. The GSI rating is based on direct observations of the condition of the joints, shear zones or other discontinuities in the rock mass. Obviously, in a tropical environment, weathering of these zones may occur faster and more severely but the geologist observing these need not be concerned since they see what they see. The rating applied for current conditions should be based on the observations at that time. If the designer is concerned about long-term changes in GSI, due to increased weathering, estimates of these changes can be built into the designs.

Q4: What are the challenges that professors face in the education process of rock engineering?

Martin Espitia, Professor @ UPTC

A4: The most important challenge that I see in rock engineering education is the integration of geology and engineering. I graduated as a mechanical engineer and it took me many years to recognize that my knowledge of geology, which was practically zero, was inadequate for me to operate effectively in rock engineering. I was fortunate to have had many colleagues and friends and who were kind enough to help me with the many questions that I had. In later life, when I operated mainly as a consultant, I almost always insisted that I worked with, or that I had access to, a good geologist who could deal with the geological components of the problems.

Some universities are very fortunate to have professors and lecturers who have studied both geology and engineering during their careers. A good alternative is to have both engineering and geology professors teaching in tandem. The goal should always be to give students an adequate and balanced exposure to both disciplines, which are inseparable in the work that they will deal with in their careers.

Q5: a. In rock masses with squeezing potential, could you share your experience and advice on using TBMs and segmental liner versus traditional rock mass support?

b. In rock masses with squeezing potential, would you recommend the Hoek-Brown model and use of GSI or would you consider an elasto-plastic model with a large deformation formulation?

c. In southern Ontario, bedrock consists of shale (thinly bedded rock) with interbeds of hard layer (limestone and sandstone) in various formations (Georgian Bay formation, Queenston formation, etc.). Do you see the H-B model and GSI system applicable to these types of rock masses?

Hossein Bidhendi, Tunnel Practice Regional Director @ Hatch

A5: a. In weak rock masses with significant squeezing potential, traditional support based on a combination of rockbolts, mesh and shotcrete, may not be effective and an Earth Pressure Balance TBM with segmental liners can operate effectively, provided that supplementary pressure can be applied at the working face, if required. (Babendererde, S., Hoek, E., Marinos, P and Silva Cardoso, A. 2004. Geological risk in the use of TBMs in heterogeneous rock masses – The case of "Metro do Porto" and the measures adopted. Presented at Course on Geotechnical Risks in Rock Tunnels, University of Aveiro, Portugal, 16-17 April 2004. — I can send you a copy of this paper if you are interested).

b. The most difficult tunnel that I have ever worked on is the Yacambu-Quibor tunnel in Venezuela. This tunnel squeezed to total closure in places and the history and design of the final solution is described in Hoek, E and Guevara, R. Overcoming squeezing in the Yacambu-Quibor tunnel, Venezuela. Rock Mechanics and Rock Engineering, Vol. 42, No. 2, 389-418, 2009. (I can send you a copy of this paper if you are interested). In this paper we used the Hoek-Brown criterion and justified its use in the following statement:

"The time-dependent behaviour of tunnels has been discussed extensively in geotechnical literature (e.g., Kaiser et al, 1982) and some authors, notably Wittke (2000) have used rheological models in analysing this behaviour. However, in considering the issues of time-dependency in the Yacambú-Quibor tunnel, the authors took the view that estimating the static properties of the rock mass was a difficult enough problem without adding rheological considerations. A pragmatic approach in which the long term strength was reduced to some proportion of the short term strength was therefore adopted. Where possible, back analysis of the tunnel behaviour was used as a basis for calibrating this reduction."

c. I have not done any work in the various formations in Ontario that you describe and so my answer would be rather unreliable. On the other hand, Dr. Mark Diederichs (diederim@queensu.ca) has done a large amount of work in this area and has published several papers on tunnel design in these rocks. I would like to ask that you contact him directly for an answer to your question.

Q6: How can one design an effective field stress investigation program for projects in which mining operations migrate from surface to underground operations?

Allan Maia, Geotechnical Engineer @ VALE S.A.

A6: In my experience, the transition from a surface to an underground operation is a process that takes many years of investigation and planning. Exploration boreholes from surface or from inside an open pit would almost certainly have been drilled to define the orebody and, in some cases, it may be possible to carry out three-dimensional stress measurements in some of these holes. However, by far the best solution would be to wait until an exploration shaft is put down to investigate the underground rock mass in detail. This would typically be done during the detailed design of the underground mine access tunnels and of the draw level excavations and it would only be at this point that a detailed knowledge of the in situ stress field would be required. Up to that point, preliminary designs can be based on estimates which can be made from information from adjacent mines or civil engineering projects or from general compilations such as the World Stress Map.

In my opinion, the only reliable in situ stress information is that derived from a well planned and carefully executed in situ stress measurement program based on measurements made by over-cored three-dimensional stress measuring cells, bonded into boreholes drilled from underground access. In some cases, large mining companies, with several underground mines, may have their own geotechnical teams who have the equipment and expertise to carry out these measurements. However, in most cases it would be more efficient to engage a specialist company to carry out this work since it is only carried out infrequently and it is not justified to establish an in house capability to carry out these measurements.

Q7: How can one effectively control consistent failures in open pit weak zones after trying all remedial measures?

Deogratias Laurent Shauri, Junior Mine Geotechnical Engineer @ Pecko Consult

A7: The answer to this question depends on the scale of the failure. In many open pit mines, it is possible to use wider benches or to control the traffic on narrow benches so that small scale failures in weak zones can be accommodated. Reducing the slope angle locally or the installation of drainage behind the slope, using boreholes or, in extreme cases, drainage tunnels, can certainly help in many cases. In civil engineering applications, it is sometimes possible to use long tensioned and grouted cables to stabilize these kinds of slopes but, in mining, it is seldom practical or economical to try this solution. In some extreme situations, where a significant portion of the open pit exhibits consistent instability, which is difficult to control, it may be practical to lay these slopes back as far as possible and then move the operating ramps, for transportation and progressive deepening of the pit, to the other side which, hopefully will have better rock.

In other words, there is no simple answer to your question. Such problems are normally dealt with by a team of managers, operators, and technical staff members, sometimes with the help of outside consultants, discussing the issue in a joint meeting. This is the only way in which all the constraints and potential solutions can be put on the table and discussed to find what we sometimes call the best of the worst solutions.

Q8: Question for Dr. Hoek: If you are monitoring movements of a landslide, what method or technical reference would you recommend for determining the threshold displacement velocity value at which catastrophic failure could be imminent?

Jorge Pachas, P.E., G.E., Lead Project Engineer @ USACE - U.S. Army Corps of Engineers

A8: Unfortunately, I have no direct experience of using displacement velocity monitoring to predict catastrophic landslide failure. However, I would like to recommend that you should contact either Dr. Suzanne Lacasse (suzanne.lacasse@ngi.no) in the Norwegian Geotechnical Institute, or Professor Jean Hutchinson (hutchinj@queensu.ca) at Queen's University in Canada. Both of these ladies have considerable experience in dealing with landslide hazard prediction and I am sure that they would be able to help you.

Q9: Dr. Hoek, where do you see Rock Engineering having the greatest impact on the future of Civil Engineering?

Helmut Wahanik, Applied Mathematician @ Rocscience

A9: Rock engineering plays, and will continue to play, an important role in civil engineering, particularly in urban environments. The design of foundations for buildings, bridges and dams, slopes for highways and railways, dams and water supply structures are all routine requirements for everyday life. Civil engineers are required to supervise and execute the design and construction of these structures.

The area in which I see rock engineering having the largest impact is in tunneling, particularly that for road and rail transportation and for the delivery of water. In some small countries, such as Singapore, practically all the infrastructure has been moved underground to leave the available surface land as space which the population can enjoy. On the other hand, in larger countries, such as Canada and the USA, our population densities have been low enough that there has not been a demand for major subsurface development. This will undoubtably change as population densities increase in urban centres.

In my experience, I have found that, in the larger countries discussed above, there is a reluctance to accept tunnels as an effective and obvious solution to some of the challenges that are emerging. Consequently, I consider that the of role rock engineers is to participate in the development of fast, safe and economical tunnelling methods and to persuade the public, our clients, that these make sense in the developments that are required to meet the needs of our future cities. The tools that we need to do this already exist, but we have to learn to use them properly, to provide adequate theoretical and practical information to our students and persuade our fellow engineers and clients that tunnels are not costly black holes that are too dangerous to incorporate into our urban development.

Q10: Thank you for the presentation. Can we use GSI for BIM rocks?

Emrah Sert, Geotechnical Engineer @ TCDD (Turkish State Railways)

A10: BIM rocks are defined by the originator of the name Dr. Ed Medley as "block in matrix" rocks in which mixtures of stronger rocks are surrounded by a matrix of weaker rocks. Typical bimrocks include faulted and weathered rocks and rock/soil mixtures. Incidentally, for those who are not familiar with the bimrock concept, Dr Medley's web site (www.bimrocks.com) contains a wealth of information.

The application of GSI to BIM rock presents many challenges. If the zone classified as a bimrock is small, such a fault zone with a thickness of 5 to 10 cm, it can be assigned an appropriately low GSI value and incorporated into the overall rock mass model. However, if the extent of the bimrock is large, compared the scale of the structure under consideration, then it would be wise to undertake some specific shear box or triaxial tests to try and categorize the strength more directly. Most numerical programs will allow multiple material models to be incorporated in the same overall model, such as the analysis of the stability of a slope of significant size.

Q11: Would you recommend junior engineers to get Master's degrees after gaining a few years of field experience first?

Robert Fuerderer, EIT @ Teck Resources Ltd

A11: My main recommendation is that someone working in rock engineering, or any similar discipline, should have exposure to field experience at some stage in their academic development. Given the generality of a first degree in either geology or engineering, it is almost a requirement that someone wishing to work in rock engineering or engineering geology should work for a Master's degree at some stage of their career.
I do not think that it matters a great deal whether the recommended practical experience component comes between the first and second degrees or after the Master's degree. Economic or domestic constraints will probably be more important in deciding the sequence, provided that the practical experience is incorporated somewhere in the sequence.

Q12: Have you adapted the Hoek-Brown criterion to bearing capacity applications? In particular, for massive foundations such as those for wind turbines?

Byron Mawer, Solid Waste & Geotechnical Engineer @ JG Afrika

A12: I have not done very much work in foundations and I have not adapted the Hoek-Brown criterion to any particular application. However, in the analyses that I have done I have found that there are no major differences between foundation design and the techniques that we use for slope or tunnel design. Fortunately, currently available software enables us to apply a variety of analytical approaches, several of which may be applied to the same problem and the results obtained can be compared. The conclusions reached from such an exercise should not be limited to a comparison between the precision of the answers provides by each solution, but rather to the different mechanisms revealed by each analysis. In some cases, it can happen that the failure mechanisms revealed by two parallel analyses have entirely different practical consequences. Hence, the difference between the analysis of a massive foundation and a tunnel, carried out with the same software, may not provide simple comparable answers, but both solutions may be correct when interpreted carefully.

Q13: I would like to know the biggest technical and professional challenges you faced in your career.

Edna Lizeth Ardila Montilla, Master's Student @ University of Sao Paulo

A13: The biggest technical challenge that I faced in my career was that, as a well educated mechanical engineer, I had an inadequate background in geology. This did not matter a great deal during the early part of my career, when most of my duties and research activities were related to stress analysis and strength of materials problems, with which I was very comfortable. When I moved to London in 1966 to become an academic at the Imperial College of Science and Technology, I was fortunate to be surrounded by many outstanding geologists who provided me with a great deal of help. However, when I moved into consulting, I found my lack of a geological background to be a significant disadvantage and I had to develop the methodology which ensured that I always had a geological colleague to work with. In retrospect and knowing what I now know, I should have made the time to learn more about geology at an early stage in my career.

Professionally, I do not think that I faced many major challenges. There were, of course, minor political issues in all the institutions in which I worked. These disappeared and I had very few significant professional challenges in the last 25 years of my career in which I operated as an independent consultant. ▪