A proposal to obtain a scale factor between rock masses and laboratory specimens

M.C. Torres-Suárez
National University of Colombia, Bogotá, Colombia

ABSTRACT
Five years ago a new proposal to obtain a scale factor between rock masses and their respective laboratory specimens had been development, showing good results in according to estimates from classification rock masses schemes (Q, GSI, RMR). In this paper are commented the fundamentals (Brillouin, 1946), step by step, and application for some real examples, in order to offering a wide spectrum of the proposed method, which stars with the characteristic wave length (λ) and their internal spatial dimension (a) that are in relationship and allows calculating an inherent scale factor firstly; then, from the proposal include here is possible to establish a relation between those inherent scale factors, each for rock masses and laboratory specimens. Recently was determined by the author (Utica – Colombia) a scale factor (mechanical properties as σ_c, E, G and Bk reduction factor) of 38%, high-lighting a deep gap between the laboratory specimen properties of and those assigned to the rock mass.

RESUMEN
Hace cinco años el autor presentó una propuesta para determinar un factor de reducción de propiedades físico – mecánicas entre macizos rocosos y especímenes de prueba en laboratorio, la cual ha arrojado resultados coherentes con los que provienen de sistemas de clasificación de macizos rocosos (Q, GSI, RMR). Se describen los fundamentos del procedimiento (Brillouin, 1946), paso a paso, y su aplicación en varios casos, ofreciendo así un espectro amplio de aplicaciones, iniciando con la determinación de la longitud de onda característica (λ) y la dimensión espacial interna (a), relacionadas entre sí, conllevando al cálculo de un factor intrínseco de escala; con dichos factores es factible relacionar las condiciones del macizo y laboratorio. Recientemente el autor determinó un factor de escala en un macizo rocoso (Útica – Colombia), que arrojó un resultado del 38% para sus propiedades mecánicas, respecto de las determinadas en el laboratorio.

1 INTRODUCTION

During decades rock mechanics researches had been proposing different approaches to obtain from rock masses mechanical properties as those σ_c, E, G, ν and Bulk between other, but several difficulties are presented; for example is required sets of flatting cats with pressure machines and measurement systems frequently so costs, resulting in the practice physically impossible for the developing countries to do these tests.

Using the Non Destructive Methods (NDM) as those including here, namely the acoustic wave velocities measuring on two forms of the same material, for this case, in-situ rock masses and testing rock specimens. By the first one is used low frequency shallow waves (seismic refraction, down-hole or cross-hole techniques) and by the second one is usually to use high frequency waves, as the ultrasonic and eco-impact techniques.

Many authors had proposed empirical relationships between wave's velocities from rock masses and rock samples, which combine with the outcrop characteristics, offer to the field engineers some tools in order to estimate physical and mechanical properties for the rock mass. The paper describes a new methodological proposal for to obtain a scale factor between rock mass and laboratory specimens based on intrinsic factors as the wave length (λ) and internal spatial dimension (a) determined on each of the presentations of the same litho-logical material.

2 FOUNDATIONS OF THE NON-DESTRUCTIVE METHODS (NDM)

The fundamentals of the non destructive methods had been widely explained at before works by the author of this paper and his co-workers (Torres, 2005; Torres and Puerto, 2006; Pedroza & Torres, 2007; Torres & Pedroza, 2008; Torres et al., 2010), on the base of Santamarina (2001). In essential consist of different energy forms, e.g. mechanical, chemical, thermal and electro-magnetic, that are induced by someone dispositive crossing the material and registered between the two faces of the element.

In our works we used acoustic waves because easy to apply directly on in-situ rock masses and the laboratory specimens; for the first one several waves trains are applied with techniques as seismic refraction or tests in the holes, e.g. down-hole when the impact is on the surface of the terrain and registered down in the hole, whereas cross-hole when the impact is in the hole and registered in another hole at the same depth; for the second one we use a PUNDIT (Pulse Ultrasonic Digital Unit) similar to that in the Figure 1, that was designed by both, the author and GCTS® equipment house which transducers (piezo ceramic elements) are made of high resistance steel in order to support the loads applied; the design referred has author's rights but its use is possible with the compression machine for ELE International®, known as the Hoek's cell in honour to its thinker.

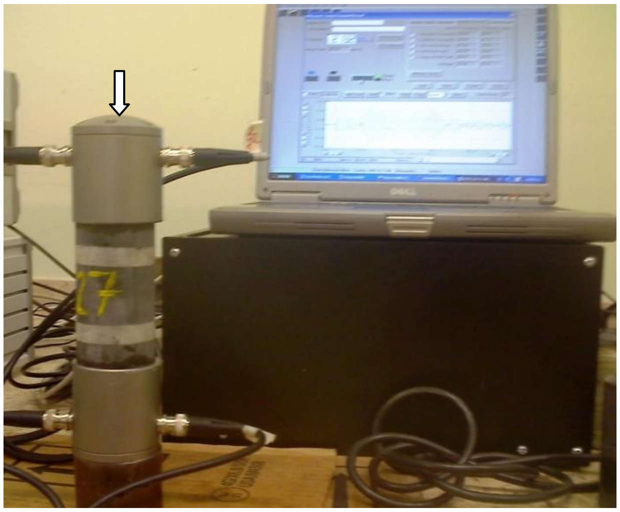


Figure 1. Ultrasonic equipment for laboratory specimens

3 FUNDAMENTALS OF THE PROPOSAL

The proposal has fundamental on the Brillouin finding (1946) that establish a relationship between the wave length (λ) of the pulses train and the internal spatial scale (a), when the medium is periodic inherently. By the one hand, wave length refers as the waver signal spatial scale, as the period T is its temporal scale; the relation between these two scales are known as phase velocity for the medium ($V_{ph} = \lambda / T$).

Due to wave velocity is a medium property and λ is related with the internal spatial scale according Brillouin, the frequency is selected to ensure properly measurement at both presentations of the same litho-logical medium; for the rock mass, where strata and thick litho-logical packs predominant, its internal spatial dimension (a_m) is huge (in the order of meters) and in consequence the λ_m is also great, so the frequency f is low (few hertz ≈ 10 Hz).

By the other hand, at the laboratory scale the internal dimension (a_l) is small, because a sand, silt and clay particles size predominant; in consequence the λ_l is few and the frequency is high (ultrasonic > 20 kHz). Inherent factor scales are established for each presentation of the same medium, according to the Equations 1 and 2.

$$fe_m = \lambda_m / a_m \quad [1]$$

$$fe_l = \lambda_l / a_l \quad [2]$$

It is not easy to determine the a_m and a_l parameters but there are some guidelines as follows: a_m obeys to the spacing between discontinuities (stratification planes, joints, etc) but the separation of litho-logical packs by central tendency measurements as modal or average is a good approaching; a_l is related with the characteristic size in the specimen, e.g. the particle or aggregate size that is more repeated inner, by sieve analysis or some technique for determining the predominant grain-metric size.

The wave length (λ_m and λ_l) can be determined by statistical analysis of data, of the characteristic frequency from signals registered during the tests and processed trough mathematics procedure as DTF (discrete transformed of Fourier), passing the signals from time domain to frequency domain; then, with characteristic frequency the predominant wave length is calculated. An analysis more simple but inaccurate is performed dividing V_{ph} into the equipment sampling frequency, but the level of accurate is minor (±85 – 95% about frequency analysis; Torres, 2005).

3.1 Antecedents of the scale factors

The simplest approaches to the scale factors between rock mass and laboratory specimens, in order to estimate some mechanical properties for in-situ condition are proposed by rock mechanics researches that made classification schemes, as follows:

a. Singh (2001) related the unconfined compression strength of rock mass with the Q (Barton, 1974) value, according the Equation 3.
b. Hoek (1997) established that $\sigma_c^{(m)}$ depends of $\sigma_c^{(l)}$ according to the Equation 4, which S parameter is function of RMR rating from (Bieniawski, 1989), according to the Equation 5.
c. For Barton et al. (1980; 1992; 1993) the elastic modulus of rock mass ($E^{(m)}$) is function of the Q value, as expressed by the Equation 6.
d. Bieniawski (1978) founded an empirical dependency between $E^{(m)}$ and RMR, Equation 7.
e. Similarly, Serafím & Pereira (1983) established this relation, but according with the Equation 8.
f. Hoek (2002) expressed this parameter depends of the rock mass classification index, Geological Strength Index (GSI), according to the Equation 9.

The equations are included in the Table 1 for the ease purpose, including the units for each; the superscript $^{(m)}$ equivalent to rock mass and $^{(l)}$ to laboratory specimen.

Table 1. Set of equations for empirical expressions about relations between rock mass and lab parameters

Equation*	Units	Author (year)	Number
$\sigma_c^{(m)} = 7 \cdot \gamma \cdot Q^{1/3}$	MPa	Singh (2001)	[3]
$\sigma_c^{(m)} = \sqrt{S} \cdot \sigma_c^{(l)}$	MPa	Hoek (1997)	[4]
$S = e^{\frac{RMR-100}{5}}$	-	Hoek (1997)	[5]
$E^{(m)} = 25\ logQ$	GPa	Barton et al. (1993)	[6]
$E^{(m)} = 2\ RMR - 100$	GPa	Bieniawski (1978)	[7]
$E^{(m)} = 10^{\frac{RMR-10}{40}}$	GPa	Serafím & Pereira (1983)	[8]
$E^{(m)} = \sqrt{\frac{\sigma_c^{(l)}}{100}} \cdot 10^{\frac{GSI-10}{40}}$	GPa	Hoek (2002)	[9]

*From ref. [1]

Although the previous equations relate rock mass parameters with both the lab parameters and rock mass parameters, other researches had proposed expressions that relate V_P^{lab} with V_P^{mass} directly, as showing next.

Goriaynov N.N. (1979) published the first book about seismic to geologic engineering applications, relating the porosity (η) with wave velocities according to Eq. 10.

$$\frac{1}{V_P} = \frac{1.7\eta}{V_P^{(2)}} + \frac{1-\eta}{V_P^{(1)}} \quad [10]$$

Where, V_P is the rock mass wave velocity, $V_P^{(1)}$ is the joint fill wave velocity and $V_P^{(2)}$ is the intact rock wave velocity.

Several relations had been proposing but applicability is questionable because the differences in litho-logies but most important are geomorphologic and environmental conditions that had prevalence during the geologic period.

3.2 Relations between rock mechanical properties and wave velocities

Similarly to before relations, several researches had proposed correlations between wave velocities measured on the specimens with yours own mechanical properties, as from Golodkovskaya (1986) who related the intact rock strength [in kg/cm^2] with V_P for Urals mountains sedimentary rocks, according to the Equation 11.

$$\sigma_c = 10^{0.33V_P+1.31} \quad [11]$$

Tugrul (2000), established a relationship between V_P and σ_c [MPa] for Turkey igneous rock, see Equation 12; Liajovskiy trough ultrasonic determined the Equation 13.

$$\sigma_c = 82.67 + 0.21V_P^3 - 35.11/V_P \quad [12]$$

$$\sigma_c = \frac{V_P^2\gamma(1-2\nu)^2}{140g(1-\nu)^2} \quad [13]$$

The static elastic modulus E_o [kg/cm^2] was related with V_P [km/s] by Golodkovskaya (1986) for intact rock specimen of sandstones, siltstones and argillaceous rocks, trough the Equation 14.

$$Log\ E_o = 2.44\ logV_P + 4 \quad [14]$$

For Colombian sedimentary rocks as conglomeratic sandstones, fine grain sandstones and claystones inter-bedded, Torres (2005) find correlations between V_P and mechanical parameters on lab specimens as follows: with σ_c Eq. 15; E_o [*10^4] Eq. 16 and I_S (punctual load) Eq. 17; E_o vs. E_d according Eq. 18; V_P in m·s^{-1} and stress in MPa.

$$V_P = 1900\ \sigma_c^{0.2} \quad (r=0.74) \quad [15]$$

$$V_P = 4042.3\ E_o^{0.09} \quad (r=0.64) \quad [16]$$

$$V_P = 3061\ I_s^{0.29} \quad (r=0.82) \quad [17]$$

$$E_o = (1.6\ E_d - 2.3) * 10^4 \quad (r=0.71) \quad [18]$$

In rock mechanics are common low correlation coefficient value due to the variability of properties and testing procedures, inclusive to 27% at standard deviation (SD) (Hoskins and Horino, cited by Correa, 2000, in [2]).

4 PROPOSED REDUCTION FACTOR APPLICATION

4.1 Rancheria Dam Project

The Universidad Pedagogica y Tecnologica de Colombia (UPTC), Tunja head, in 2003, realized a viability technical study for the hydraulic project construction at Paipa (Col) village to 4.5 km from its urban zone (see Figure 2). Jurassic rock formations as La Rusia and Arcabuco out-crop at zone, which are constituted by conglomeratic and fine grain sandstones, with thin inter-bedded low porosity siltstones; the thick varies between 200 and 600 m, modal value of 180 m, average of 304 m and SD equal to 230 m.

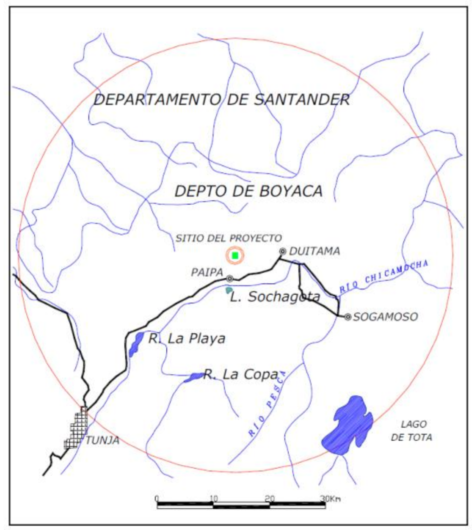


Figure 2. Project localization at the regional level

The quaternary thick range from 10 to 40 m and consist about colluvial, alluvial and fluvial-lakes deposits formed by sub-angular with variable dimensions immerse in clayey sandy matrix resting natural slopes blocks; soft silty clays with sand and gravel inter-bedded; also some talus and recent mass movements derived are present. The natural joints were determined trough geologic study establishing spaces between 0.30 to 1.00 m, with average value of 0.48 m and 30% of that value for the SD.

From a preliminary geo-morphological division was provided an exploration program consists about holes, shallow seismic refraction, vertical electric sounds and a down-hole test distributed by all area; from these in-situ tests the sub-soil profile was determined for seven strata, including a general description, V_P, V_S, ν, G, E, Bk and γ for each layer, as is shown in the Figure 3.

At the laboratory scale were advanced destructive test as ω, γ, sieve analysis, punctual load, Schmidt hardness, unconfined strength with measurements of deformation in order to find mechanical parameters (E_o and ν); also non-destructive measurements were made by ultrasonic wave velocities for the two extreme conditions, i.e., “intact” core and failure by simple compression stress, obtaining index values as those included in the Table 2. Data were processed and statistically analyzed, determining average values as well as the typical deviation, bias, probability density function and other statistical variables.

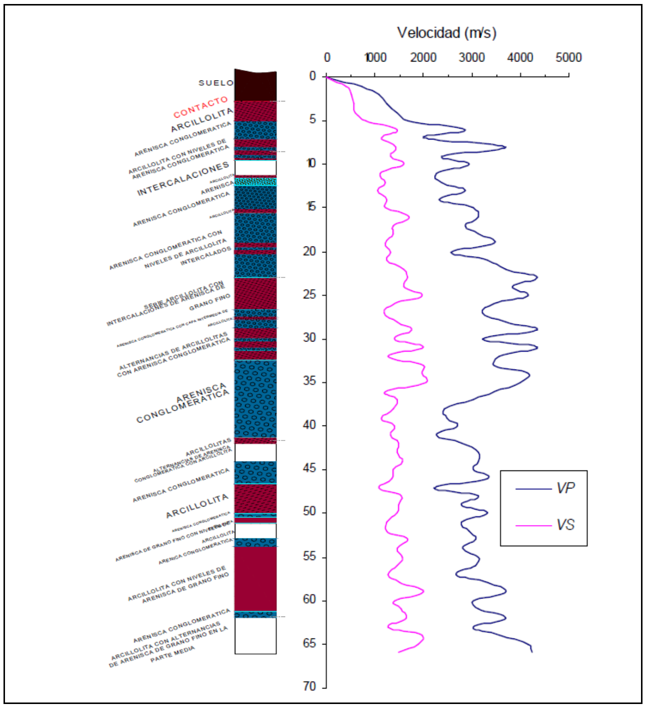


Figure 3. Litho-logical profile and V_P & V_S wave velocities from down-hole test for the hole number 2

As is seen in the Figure 3, the variability of V_P and V_S velocities is according with litho-logical characteristics, in special the presence of an alluvial deposit soil at the top of profile, sandstone and claystone interbedded layers and the relative rigidities associated to the material type. It was determined three different zones related to V_P / V_S ratio, which can be used as litho-logical indicator (Tatham, 1982; Doménico, 1984), varying between 2.0 to 2.2 for clayey materials, 2.2 to 2.5 for conglomeratic sandstone and 1.8 to 2.0 for colluvions, revealing its anisotropy.

4.2 Parameters to determine the scale factors

In order to do this were taking into account parameters from both scales of the material, as next:

4.2.1 Rock mass

The dominant layer thickness is related with the wave length, which is established by the relationship between average velocity and equipment fundamental frequency, according with the Equation 19. By the other hand, internal spatial scale was defined according mean spacing between discontinuities, i.e. a_m = 0.50 m.

$$\lambda_m = \overline{V_P} \cdot f_m^{-1} = 3430\frac{m}{s} \cdot \frac{1}{10}s = 350\,m \qquad [19]$$

Combining previous values under the Brillouin principle, inherent scale factor for the rock mass is finding by the Equation 20; medium behaviour is equivalent to a continuum because $\lambda_m >> a_m$, for repetitive structures but non un-periodical due to the internal organization.

$$fe_m = \frac{\lambda_m}{a_m} = \frac{350\,m}{0.5\,m} = 700 \qquad [20]$$

4.2.2 Laboratory specimens

Near of 40 testing specimens were subjected to the characterization activities, including index and physical as well as mechanical properties and the wave velocity was determined by ultrasonic technique, but only for the V_P measurements because the equipment used in that task has longitudinal transducers. The V_S wave velocities were estimated from V_P and ν relationship, which was find to be practically the same for the in-situ and the static in-lab conditions, in turn were determined by the Equation 21.

$$\nu = \frac{V_P^2 - 2V_S^2}{2(V_P^2 - V_S^2)} = \frac{V_L^2 - 2V_S^2}{2V_S^2} \qquad [21]$$

Where V_P corresponds to the in-situ condition and V_L corresponds to the in-lab condition, due to the typical rock testing specimen cylindrical shape, with high to diameter ratio ≥ 2.0 according to the ISRM suggested methods (2007). Some so interesting relations between V_P and wavering parameters as those related with amplitude, fundamental period and frequency and, of course, the wave length were determined; for the end parameter a statistical analysis was performed and we obtained average values for λ_l = 18.5 cm and T = 46.7 µs. Then, the phase velocity from before parameters is according with the Equation 22; although typical error on this determination is near to 20%, the density probability function respective is normally approaching.

$$V_{ph} = \lambda_l \cdot f_f = 0.185\,m * \frac{1}{46.7\,\mu s} = 3965\,m \cdot s^{-1} \qquad [22]$$

To determine the inherent spatial scale for laboratory scale, a_l, it's necessary the predominant grain size to be encountered but in practical terms this task is complex, due to the variety of sizes that occurrence in the rocks. For this purpose had been proposed techniques as the simple particles sieve analysis; at the Figure 4 is shown two grain size distribution curves, as normal distribution but don't cumulative distribution curve.

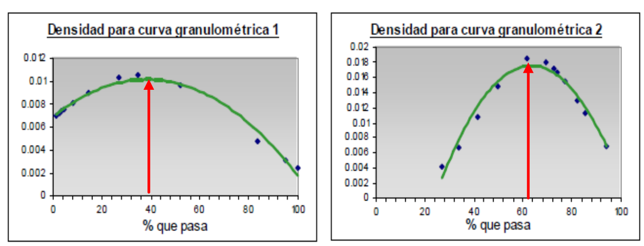


Figure 4. Determination of the characteristic dimension for the testing specimens

From the curves "the pass percentage" for each is used to determine grain sizes that represent the internal scale of the test specimen, indicating an average value of 1.0 cm as appropriated for next analysis. The inherent scale factor for hand samples in laboratory is determined from the Equation 23.

$$fe_l = \frac{\lambda_l}{a_l} = \frac{0.185\,m}{0.01\,m} = 20 \qquad [23]$$

To here, we had used only the Brillouin Principle, but the proposal don't yet; from the Eq. 24 is encountered a first approach which relate the both inherent scale factors, which is called laboratory specimens to rock mass scale factor, as similar when one drawing sketches a building, representing a scale between the plane and structure.

$$fe_{(l/m)} = \frac{fe_l}{fe_m} = \frac{\left[\lambda_l/a_l\right]}{\left[\lambda_m/a_m\right]} = \frac{20}{700} = 0.033\ (1:33\ 1/3) \qquad [24]$$

As a consequence of the previous approaching face clear that the rock mass properties represent a portion of the rock lab specimen properties; from this idea, the author proposed a simple, but very powerful conception for the reduction factor, as appears in the Equation 25.

$$fr_{(m/l)} = \left[1 - \frac{1}{100\cdot fe_{(l/m)}}\right] = \left[1 - \frac{1}{100\cdot 0.033}\right] = 0.67 = 67\% \qquad [25]$$

A brief description of the Eq. 25 is next: the reduction factor combines two medium scales dominant features in order to estimate physics-mechanical properties; its superior limit (1.0) is for the case when the properties are similar on rock mass and rock lab specimens, i.e. for $fe_{(l/m)}$ more than 0.1 (1:10), that in turn occurs when fe_l tends to high values ($\lambda_l >> a_l$, or a_l is very little, e.g. very fine or crystalline rocks) or fe_m tends to low values (if λ_m is very little, high frequencies and low resolution, or a_m is very huge, e.g. for a very competent or massive rock.

The reduction factor tends to 0.0 for $fe_{(l/m)}$ values less than 0.02 (1:50), when: fe_l tends to low values (if $\lambda_l \approx a_l$, or $\lambda_l / a_l \rightarrow 2.0$, in which case don't propagation occurs, or $a_l \rightarrow a_m$) or fe_m tends to high values (for frequencies very low that seismograms don't register, or a_m is very low, i.e., is soil). The analyses apply directly to all type of relationships between rock masses and rock specimens.

4.2.3 Reduction factor from empirical approaches

The average value for Poisson' ratio (ν) in-situ condition and in-lab is 0.34 and 0.36 respectively, for static and dynamic conditions; the reduction factor is 0.94. Similarly, the Young [E*10^4 MPa] and shear modulus [G*10^4 MPa], which average values in-situ conditions are 1.89 and 0.71 from down-hole test, whereas for in-lab are 3.08 and 1.15 respectively, in static loading but 3.19 and 1.23 from the ultrasonic wave velocities, demonstrate a reduction factor of 62[5]% and 60%, respectively for each case.

By the other hand, using some equations in the Table 1, σ_c^m corresponds to 68% of σ_c^l and E^m is the 64% determined on the rock lab specimens (E^l). According to the Hoek & Brown criteria, σ_c^m is 14% of σ_c^l and E^m is 20% of the laboratory data; these results are low compare with the before, because this criteria depends of GSI that is heavily subjective and have little application over soft rocks as sedimentary rocks.

In resume the reduction factor is possible to determine according waver parameters and internal size dominant for each of the litho-logical medium presentations, in-situ as well as in-lab conditions, from an objective point of view but don't subjective about observed characteristics.

4.3 The Utica site

The Utica site corresponds to a small village near to Bogota city, as is shown in the Figure 5. The geological composition at zone is from cretaceous sedimentary rocks of the Villeta and Olini Group, and the Utica Formation; the majority of the rocks are argillaceous inter-bedded by calcareous and sandstones rocks, cover in cases by quaternary deposits in special wet thick colluviums.

The Trincheras Formation forms part of the Villeta Group and is conformed by thin laminated claystones, grey to black and dark red brown colour due to weathering effects; this Unit has 600 m thick aprox., which occurred under depth waters during the Aptiano period.

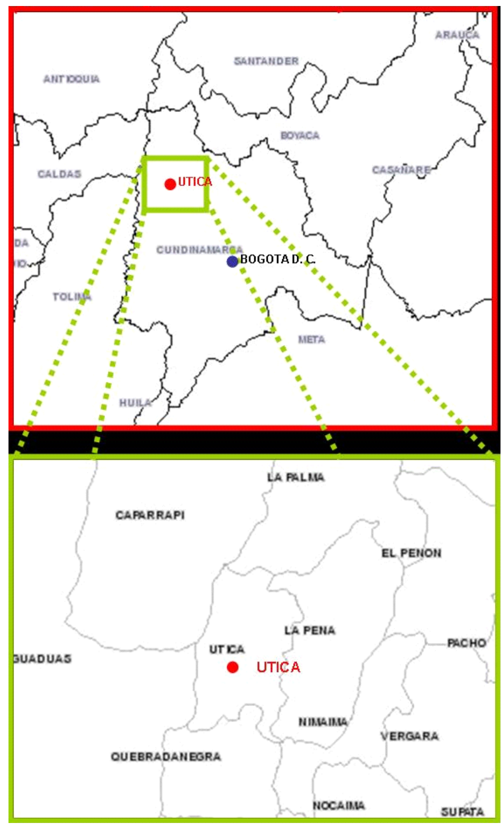


Figure 5. Localization map of the Quebradanegra basin and the Utica village, Cundinamarca department

This example is more recently evaluated and it was included in ref. [3] but the principal results are presented herein. The V_P^m average value was calculated from the Equation 26 according to the wave velocity curve equation for in-situ conditions, determined from a down-hole test.

$$\overline{V_{P\,in-situ}}\,(m\cdot s^{-1}) = \frac{\bar{z}\,(m)+3{,}6207}{0{,}0094} = \frac{16{,}5\,m/2+3{,}6207}{0{,}0094} = 1263\,m\cdot s^{-1} \approx 1300\,m\cdot s^{-1} \qquad [26]$$

The wave length (λ_m) for the rock mass is calculated from the Eq. 27, if the seismic equipment works to 10 Hz.

$$\lambda_m = \frac{\overline{V_{P\,in-situ}}}{f_m} = \frac{1300\,m\cdot s^{-1}}{10\,s^{-1}} = 130\,m \qquad [27]$$

The previous value is multiple of the rock mass thick that is near to 600 m; similarly for the λ_l is required firstly the medium rock lab specimen value, according the Equation 28, so that value is from the Equation 29.

$$\overline{V_{P\,in-lab}}\,(m\cdot s^{-1}) = \frac{\bar{z}\,(m)+32,602}{0,0122} = \frac{8,0\,m/2+32,602}{0,0122} = 3000\,m\cdot s^{-1} \quad [28]$$

$$\lambda_l = \frac{\overline{V_{P\,in-lab}}}{f_l} = \frac{3000\,m\cdot s^{-1}}{54000\,s^{-1}} = 0,056\,m \approx 5.6\,cm \quad [29]$$

Newly, the previous value is related with the specimen dimensions. To determine the inherent scales is required previously to calculate a_m and a_l parameters; for the first case, the value was 0.13 m and for the second one the average particle size according sieve analyses realized over seven series of previously degraded material, threw a measure of 0.0035 m. The sizes were obtained one time the material was subjected to wetting – drying cycles, but it is not in the scope of this article.

The Equations 30 and 31 are for inherent scale factors that apply to rock mass and laboratory conditions, respectively; in order to determine the scale factor between the two conditions, is proposed the Equation 32.

$$fe_m = \frac{\lambda_m}{a_m} = \frac{130\,m}{0.13\,m} = 1000 \quad [30]$$

$$fe_l = \frac{\lambda_l}{a_l} = \frac{0.056\,m}{0.0035\,m} = 16 \quad [31]$$

$$fe_{(l/m)} = \frac{fe_l}{fe_m} = \frac{[\lambda_l/a_l]}{[\lambda_m/a_m]} = \frac{16}{1000} = 0.016\,(1{:}\,36.5) \quad [32]$$

Finally as in the previous case referred the reduction factor is calculated according to the Equation 33 proposed firstly in this paper; the sensitivity for parameters included here is considered high and in consequence require that the determination to be a very carefully estimation.

$$fr_{(m/l)} = \left[1-\frac{1}{100\cdot fe_{(l/m)}}\right] = \left[1-\frac{1}{100\cdot 0.016}\right] = 0.38 = 38\% \quad [33]$$

For the results validation was revised in terms of deformation modulus relation between rock mass and laboratory specimens, according to the Equation 34.

$$fr_{(m/l)E_o} = \frac{E_o^m}{E_o^l} * 100\% = \frac{0.074*10^4\,MPa}{0.206*10^4\,MPa} * 100\% = 36\% \quad [34]$$

Unfortunately for this case the rock mass classification systems don't apply directly because the mechanical parameters on laboratory scale are very low, so the schemes as the GSI index exhibit values as 120% for the rock mass respect to the laboratory measurements.

With the same methodology before applied, σ_c^m is a fraction of σ_c^l average value, which is 7.3 MPa; then for the first one is 2.8 MPa approximately. With the RocLab® software, this value was 3.0 MPa, very near to the estimated value from the rocks software application.

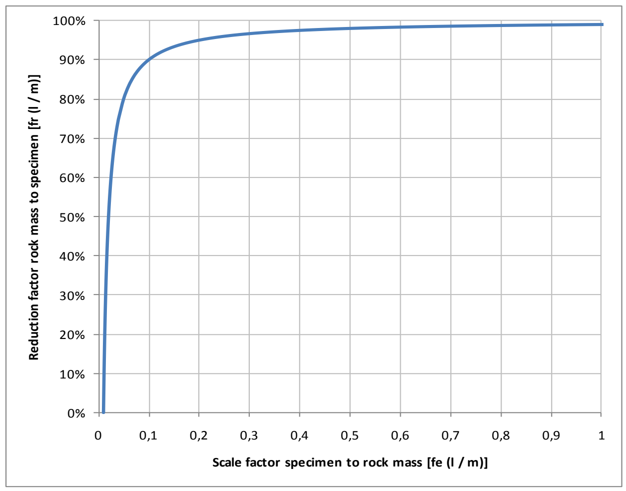
5 CONCLUSIONS

This report is about a proposal to obtain a scale factor between the mechanical rock mass properties and those obtained from the rock specimens. In order to do that is required firstly to obtain parameters about inherent scale factor for each scale and so to combining those properly is feasible establishing a reduction factor.

The author likes to invite colleagues and rock mechanics researches to validate the proposal, which with care and systematic procedures can help us in order to characterize the rock mass, from rock laboratory testing specimens and V_P & V_S wave velocities measurements on both scales of the same litho-logical medium.

The classification systems are good tool for this purpose, but have disadvantages because respond to subjective procedures and were development on other different latitudes. Q and RMR are the systems with the most reliable application in order to estimate mechanical properties as strength and rigidity for the rock mass scale.

With the aim to visualize some general tendency for the reduction factor and scale factor proposed, next is presented a curve that relate the $fe_{(m/l)}$ to $fr_{(l/m)}$.



ACKNOWLEDGEMENTS

The writer would like to acknowledge the contribution of a number of individuals to the paper, especially to the National University of Colombia and the Colombian Society for Geotechnics.

REFERENCES

[1] Hoek, E. 2006. Practical Rock Engineering. Course Notes. Downloaded from *The Hoek's Corner at* www.rocscience.com *web page*.

[2] Correa, A. Caracterización de rocas. Ensayos de laboratorio. Universidad Nacional de Colombia y Sociedad Colombiana de Geotecnia. 2000.

[3] Torres, M.C. et al. Mechanical behavior of the Colombian Andes mud rocks. Proceedings of XIII Colombian Congress of Geotechnics. Manizales, Col. 2010. ISBN 978-958-98770-2-9.