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Article

Study of the relationship between uniaxial compressive strength vs non-destructive testing and specific weight in bank rocks from the Seybaplaya Campeche Mexico

Estudio de la relación entre resistencia a compresión uniaxial vs ensayo no-destructivo y peso específico en rocas del banco en Seybaplaya Campeche México

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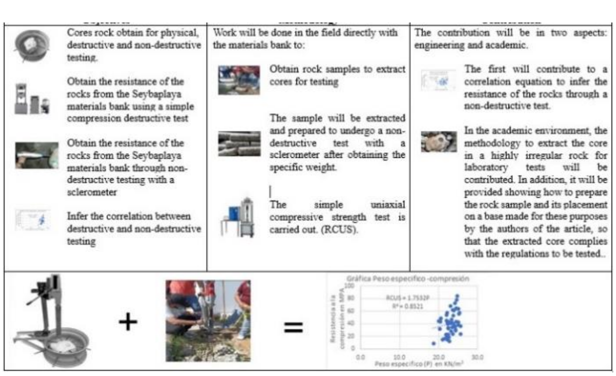
Abstract

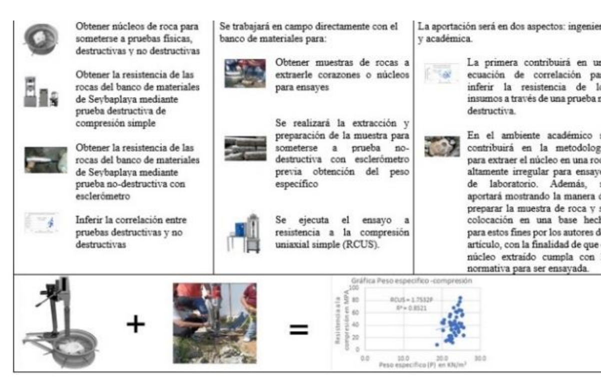
This research study focuses on analyzing the uniaxial compressive strength of rocks and its correlation with non-destructive testing (Schmidt hammer) and specific gravity. It is important to note that Seybaplaya, located in Campeche, Mexico, is known for its fishing, industrial, and commercial activities. Samples from one of the main active quarries in the state of Campeche were used for the investigation. As a result, equations were developed to predict the simple uniaxial compressive strength based on values obtained from the Schmidt hammer and specific gravity. It is relevant to highlight that these relationships are only valid for rocks with lithological characteristics similar to those used in this study. The results of the analysis and the conclusions demonstrate the non-linearity of the relationships between simple uniaxial compressive strength, non-destructive testing, and specific gravity.



Simple uniaxial compressive strength, Rock specific gravity, Schmidt hammer test

Resumen

La presente investigación se enfoca en analizar la resistencia a la compresión uniaxial de las rocas y su relación con ensayos no destructivos mediante esclerómetro y peso específico. Es importante señalar que Seybaplaya, ubicado en Campeche México, es reconocido por sus actividades pesqueras, industriales, comerciales y en la que se localiza un banco activo y principal de materiales de la que se obtuvieron muestras para llevar a cabo el estudio. Como resultado, se desarrollaron ecuaciones que permiten predecir la resistencia a la compresión uniaxial simple basándose en los valores obtenidos del esclerómetro y el peso específico. Es relevante destacar que estas relaciones son válidas únicamente para rocas con características litológicas similares a las utilizadas en este estudio. Los resultados del análisis y las conclusiones demuestran la no linealidad de las relaciones entre la resistencia a la compresión uniaxial simple, el ensayo no destructivo y el peso específico.



RCUS, Peso específico de la roca, Prueba de esclerómetro en roca

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Introduction

Every construction project sits on soil or rock, and every construction site requires aggregates, rocks being the raw material for these. For this reason, it is fundamental to consider the resistance of rocks in any location when analysing and designing structures that are fundamental for human progress, as this parameter will guarantee stability from their foundations. In other words, rock strength is the determining factor for the structural design. Rocks are hard and compact natural aggregates composed of mineral particles with strong permanent cohesive bonds, which are commonly considered as a continuous system. The proportion of different minerals, the granular structure, the texture and the origin of the rock serve for its geological classification (Gonzalez, 2002).

The behaviour of a block or mass of rock in its original location differs from a rock material, as the latter is significantly more resistant. In addition, a block of rock often has systems of structural weaknesses known as cleavages, which include fractures, fissures, joints, discontinuities and faults of different sizes. Virtually all the rocks that make up the kilometres of the Earth's crust are traversed by fissures and cracks of short extent (Iriondo, 2006).

The diversity of structure, rock types and their spatial distribution impact on the structural damage that engineering works can experience. Therefore, it is essential to detect these phenomena before they occur, to adjust land use according to their level of affectation and to reduce the vulnerability of constructions. This problem is the subject of this research focused on the characterisation and mitigation of geological risks originated by geomorphology, specifically in karst areas, such as those found in the state of Campeche (Palacio, 2013).

Due to the high cost and complexity associated with performing the Resistance to Uniaxial Simple Compression (RCUS) test to evaluate the behaviour of rocks, it is recommended to use tests that allow classifying the physical properties of the rocks involved (Naal-Pech *et al*., 2023).

This classification will facilitate the grouping and subsequent characterisation of the rocks by assigning mechanical behaviour parameters obtained from tests on representative samples. Finding out the simple compressive strength of a rock is important because it allows the rock to be classified according to its strength, it is an important parameter in the most commonly used fracture criteria (Delgado, 2013).

The observation of these conditions is crucial, as it is sometimes very difficult to comply with them or increases the cost of the test too much. Sometimes, it is necessary not to follow the recommendations of the standards because discontinuities in the rock mass may make it difficult to obtain rock cylinders with lengths equal to or greater than twice their diameter. In some cases, the corresponding sample dimensions are impossible to obtain for rocks whose grains or clasts exceed one centimetre (such as some granites or pegmatites), and if they are obtained, the sample could not be broken with a conventional press. To address these difficulties, researchers such as (Galván, 2011) have developed an experimental correlation between rock compressive strength and indirect test results or physical characteristics of the rock under study, allowing indirect estimates of rock strength to be obtained cheaply and quickly.

Equations have been formulated from the test results, which establish relationships between parameters using statistical methods of correlation and linear regression. To estimate the simple compressive strength of a rock, methods and tests are available that can be carried out both in the field and in the laboratory. Obtaining this strength can range from subjective estimation to indirect measurement. One of the methods used is to obtain the Resistance to Uniaxial Simple Compression (RCUS) through the index properties of the rock (Galván, & Restrepo, 2016).

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The above correlations originate from several investigations in rocks such as sandstones, shales, limestones and dolomites. These correlations emerged from multiple tests and analyses of rock cores, making it possible to characterise and correlate parameters for specific rock formations. Researchers have done their best to obtain all these equations were examined in laboratory and field and their RCUS was obtained, (Aggıstalıs *et al*., 1996) see Table 1.

Box 1

Table 1

Relationship between Schmidt hammer hardness. Where RCUS is simple uniaxial compression in MPA, R is rock sclerometer impact rebound value, ɣ is the density of the rock in (g/cm^3)

Type of rock	Autor	Correlation Equation	Relation
Three types of bedrock	Deere and miller (1966)	$RCUS=10^{(0.00014\gamma R+31.6)}$	0.94
Three types of bedrock	Aufmuth (1973)	$RCUS=6.9\ x10^{[1.348\log(\gamma R)+1.86]}$	
Three types of bedrock	Beverly et al. (1979)	$RCUS=12.74\exp[0.0185\ \gamma R]$	
Rock coal	Kidybinski (1980)	$RCUS=0.447\exp[0.045(R+3.5)+\gamma]$	0.72
30 sedimentary units	Singh et al. (1983)	$RCUS=2R$	0.94
20 sedimentary units	Shorey et al. (1984)	$RCUS=0.4R-3.6$	0.7
10 unidades sedimentarias	Haramy and DeMarco (1985)	$RCUS=0.994R-0.383$	0.87
Coal	Ghose and Chakraborti (1986)	$RCUS=0.88R-12.11$	0.77
Sandstone, siltstone, limestone and anhydrite	O' Rourke (1989)	$RCUS=702R-11040$ (psi)	0.88
30 lithological units (marble, limestone, dolomite, dolomite, etc.)	Sachpazıs (1990)	$R=0.2329RCUS+15.7244$	0.81
Sandstone	Cargill and Shakoor (1990)	$RCUS=4.3x10^{-2}(R\gamma)+1.2$	
Carbonated	Cargill and Shakoor (1990)	$RCUS=1.8x10^{-2}(R\gamma)+2.9$	
Marga	Gokceoglu (1996)	$RCUS=0.0001R^{3.2658}$	0.84
Graphite and basalt	Aggıstalıs (1996)	$RCUS=1.31R-2.52$	0.55
10 lithological units	Kahraman (1996)	$RCUS=4.5X10^{-4}(R\gamma)^{2.46}$	0.93
7 different types of rocks	Katz et al. (2000)	$LnRCUS=0.792+0.067R\pm0.231$	0.96
48 different type of rock	Kahraman (2001)	$RCUS=6.97\exp(0.014R\gamma)$	
Plaster	Yılmaz and Sendir (2002)	$RCUS=\exp(0.818+0.059R)$	0.98
Two types of limestone rock, two types of marble, sandstone and basalt	Yasar and Erdogan (2004)	$RCUS=4X10^{-6}R^{4.2917}$	
6 igneous rocks, 3 metamorphic rocks and 2 sedimentary rocks	Fener et al. (2005)	$RCUS=4.24\exp[0.059R]$	
19 different type of rock	Kılıc and Teymen (2008)	$RCUS=0.0137R^{2.2721}$	0.97

Study area

The state's main source of wealth is due to the existence of important hydrocarbon deposits on its marine shelf. In addition, Campeche has significant deposits of non-metallic minerals, mainly limestone (calcium carbonate), gypsum, clays, salt and stone aggregates (Servicio Geológico Mexicano, 2021).

Seybaplaya is located on the geological plate known as the "Yucatan Platform", which is an extension of sedimentary rock on the Yucatan Peninsula in Mexico. This platform was formed millions of years ago by the accumulation of marine sediments and has a depth of about 200 metres. As for the specific geological characteristics of Seybaplaya, its soil is composed mainly of sedimentary rocks such as limestone and clay. The area also has oil and natural gas deposits, which have been important for the local economy.

It is of great interest to examine the characteristics of the rocks in and around the Seybaplaya bench known as Mary Carmen, where a quarry is located. Refer to Figure 1 for the geographic location of the rock bench, the type of material and the volume in Table 2.

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Box 2

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Figure 1
Location of rock bank at Seybaplaya in the state of Campeche, Mexico

Source: http://b.materiales.siac.gob.mx/

Box 3

Table 2
Characteristics of the Bank in seybaplaya called Mary Carmen

State:	Campeche		
Name of the bank:	Mar and Carmen		
Kilometre:	1000		
Location:	PAYUCAN		
UTM coordinates	X 741570.00		Y 2174740.00
Deviation:	Right	Metres:	0
Type of property:			
Type of material:	TEZONTLE		
Treatment:			
Volume x 1000 (m³):	500	Thickness of the trimming (m):	0.2
Likely uses:			
Use of explosives:	Unrestricted		They do not exist
Economic aspects:	Convenient	Quality report:	report

Methodology

The most commonly used non-destructive test on rocks is the sclerometer and the specific gravity is the most commonly used physical test.

A systematic framework is provided to address the relationships between uniaxial compressive strength with non-destructive testing and specific gravity in rocks from the Mary Carmen bench at Seybaplaya Campeche.

To achieve this objective and to ensure that a structured and logical process is followed, the following steps are listed below:

Bench mining.

Sample extraction and preparation.

Non-destructive test (sclerometer).

Specific gravity test.

Single uniaxial compressive strength test (RCUS).

Each phase is broken down in this section:

Bench mining

The open pit, post hole and auger methods are commonly used to explore soils. Typically, expensive drilling methods are used in rock bench exploration.

Laboratory benches must be sampled randomly, although some institutions determine the number of boreholes per number of cubic metres of material to be exploited, without taking into account the homogeneity or heterogeneity of the formation.

Sample extraction and preparation

A standard procedure is established for the preparation of rock core samples and the evaluation of their dimensions and shape. According to ASTM 2012 D4543.370238-1 (ASTM, 2010; 2012), the samples to be analysed should be straight circular cylinders that meet the specified tolerances. It is necessary that the samples have a length to diameter ratio between 2.0 and 2.5, and that the diameter is at least 47 mm. Finally, the end surfaces must be polished to flatness, with a maximum tolerance of 0.001 inch.

Non-destructive test (sclerometer)

The USBR Field Index Test (1998) states the following methodology; take ten readings at various locations on each surface. Discard the five lowest values and average the five highest.

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As the hammer we have is type N which is concrete and we need type L which is rock we apply the equation of (Poole & Farmer 1980) we propose the following correlation formula (1) for the position and vertical downwards, in the respective, being eσ the standard error that is committed when estimating any value.

$$R=1.838+0.813RN;\ e\sigma = 2.9 \tag{1}$$

Where:

RN= rebound value of the concrete type hammer.

R= rebound value already correlated for rock type.

Specific gravity test.

The specific weight test on rock is carried out in accordance with ASTM D 854. This procedure is used to calculate the actual density and by multiplying it by gravity we obtain the specific weight of the rocks, where density is the ratio between the actual mass of the sample and its actual volume. The value of this parameter is calculated using a specific formula, density formula (2) and specific gravity formula (3), as follows.

$$ɣ = m/V \tag{2}$$

$$P = ɣg \tag{3}$$

Where:

ɣ = the actual density

m = the mass of the rock

V = the total volume of the sample.

g = gravity

P = specific gravity.

The procedure for performing the actual density test on rock according to ASTM is as follows:

The process of determining the true density of a rock sample involves obtaining a representative sample, drying it in an oven, weighing the dried sample, measuring the volume of water displaced by submerging it, and finally calculating the true density by dividing the weight of the sample by the volume of water displaced

Resistance to uniaxial simple compression test (RCUS)

The uniaxial compression test according to ASTM D7012-10. The method used to calculate the uniaxial compressive stress, Poisson's ratio and Young's modulus of a rock core (Peng and Zhang, 2007). See simple uniaxial compressive strength formula (4).

$$\sigma = RCUS = P/A \tag{4}$$

Where:

σ = RCUS = resistance to simple uniaxial compression.

P = axial load

A = Cross sectional area

Procedure for simple compression test.

Take note of the dimensions to evaluate the cross-sectional area.

Verify that the universal machine is in the proper condition (at zero).

Place the specimen centred on the compression platens of the universal machine.

Using the control software, program the machine to perform the compression test.

Proceed with the test until the specimen is observed to fail (observing cracks).

Apply the load progressively.

Remove the specimen from the machine and proceed to place a new sample, repeating the procedure described above (Nieto & Avendaño, 2015).

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Results

In this research, 50 sample tests were carried out and the following results were obtained: compression, moisture content, density (see **Table 3**).

Box 4

Table 3

Results of the 50 samples: where ID is the sample identification number, Rcus in MPA, R is rebound value already correlated by using concrete hammer and P is specific gravity x103 in N/m^3

ID	RCUS in MPA	Adjusted R = 1,838 + 0,813RN	Specific gravity in KN/m^3
1	31.6	30	20.2969
2	28.6	36	23.2406
3	46.8	27	23.3416
4	15.2	31	22.1972
5	18.3	29	22.0139
6	11.7	35	22.7956
7	22.7	33	21.9463
8	42.1	19	23.3876
9	53.4	38	23.7025
10	14.9	30	21.0619
11	68.6	32	22.9992
12	8.6	32	18.7118
13	23.2	22	22.5369
14	40.7	38	22.9663
15	43.5	20	24.4967
16	28.7	40	24.3683
17	43.6	30	22.4521
18	55.5	42	25.2793
19	32.3	37	22.4442
20	61.3	43	23.8702
21	78	40	24.5744
22	61.9	36	23.5791
23	42.4	44	25.0202
24	49.1	37	20.6647
25	84.7	44	24.7480
26	72.8	34	24.1366
27	38.1	29	25.1228
28	33.2	34	22.4872
29	58	31	22.1556
30	23.9	43	23.6929
31	21.3	28	22.2322
32	40	35	22.2586
33	34.8	33	23.4224
34	43.6	32	22.2384
35	18.5	39	22.5979
36	54.1	40	22.0043
37	45.5	27	22.0671
38	44.1	36	20.0185
39	22.4	35	22.2381
40	35.1	27	24.1842
41	43.4	31	20.4987
42	37.4	36	24.1049
43	31	39	24.3428
44	36.5	40	25.5866
45	63.7	43	25.0749
46	15.7	37	21.3591
47	57.6	33	25.3142
48	40.5	35	23.5603
49	65.1	45	24.5425
50	23.3	41	25.6597

Using information from **Table 2** to correlate RCUS and Sclerometer Rebound Value in rock samples from the Seybaplaya bench, we obtain the results shown in **Figure 2**. It is observed that the sclerometer rebound value (R)-compression has an acceptable trend correlation of 0.8454.

Box 5

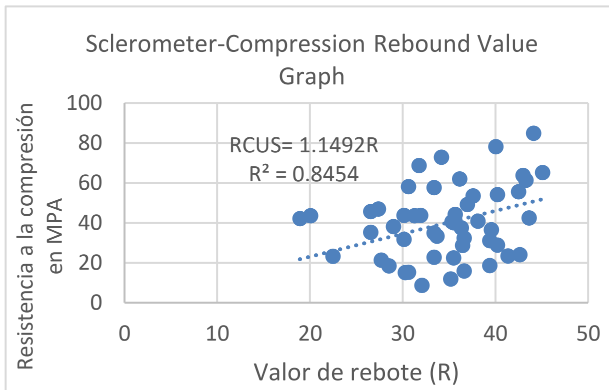

Figure 2

Correlation between RCUS and Sclerometer Bounce Value in rock samples

From Table 2 the correlation between RCUS-Specific gravity in rock samples from the Seybaplaya bench is shown (see **Figure 3**). It is observed that the specific gravity (P)-compression there is an acceptable trend correlation of 0.8521.

Box 6

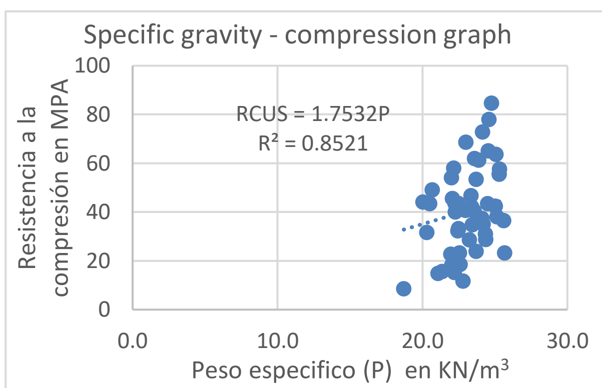

Figure 3

Correlation between RCUS-Specific gravity in rock samples

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Discussion

With the assistance of an expert, explosives were used to mine the bench and rock fragments of considerable diameter were randomly selected for sampling. During the extraction phase, it was noted that the drilling rate varied according to the hardness of the rocks, a fact that was confirmed by compression tests and the identification of the samples by their ID. It was also observed that when water was injected into the drill hole, a white liquid was generated, indicating the presence of limestone in the rock.

The samples were then measured with a vernier caliper and cross-sections were made, which was complicated in some cases due to the disintegration of the samples, resulting in the length or the ratio of 2 to 2 1/2 times their diameter not being met and another sample having to be drilled to meet the requirements.

To carry out the surface hardness test, the remaining fragments of the rock from which the core was extracted were taken and a concrete sclerometer was used. In this process, equation (1) takes care of converting the concrete hit RN to the rock hit (R). The remaining part of the rock fragment is immobilised in the direction of coring, and the surface is polished with an abrasive stone to remove irregularities in the rock, thus ensuring that the hammer blow is as uniform as possible and in a direction parallel to coring. On this surface, 10 blows were made with the equipment at different points, recording the 5 highest values, which were averaged to obtain a representative value. It could be observed that the faster the polishing stone is polished, the softer it is, while the harder it is polished, the harder it is, the harder it is. It was also noted that, as the rock is polished, it gives off a whitish-coloured powder representative of limestone.

Compression tests were carried out on the universal machine with the dried samples, obtaining the expected results. In addition, tests were carried out with the concrete sclerometer, adapting them by means of a formula to correlate them with a rock sclerometer, observing consistent results during the following process.

a) It is observed that the rocks have numerous discontinuities.

b) When examining the RCUS-Specific gravity graph, it can be seen that there is an acceptable relationship.

c) When analysing the RCUS-Sclerometer Rebound Value graph, it is noted that there is an acceptable relationship.

d) It is shown that the dynamite bench mining method also creates micro-cracks that continue to damage the resistors.

e) The sclerometer is used to determine the uniformity of the rock.

f) Despite being widely used and sought after, the use of the sclerometer to measure in situ rock strength is not very reliable.

g) The sclerometer test alone does not measure the compressive strength of rock.

h) The sclerometer test complements, but does not replace, coring for compression testing.

i) In general, the sclerometer reports higher values than actual values.

j) The sclerometer is a hardness tester that measures surface hardness.

k) The measurement made with the sclerometer is superficial and does not reflect what is happening inside the rock.

l) Sclerometer graphs should not be used to report the f'c of the rock without first mentioning the corresponding correlation coefficient.

m) The sclerometer correlation with compression obtained in this investigation shows an optimal linear behaviour.

Conclusion

The results obtained in this study represent a significant advance in rock mechanics in the state of Campeche. It is crucial to keep in mind that the regression models presented in this paper are applicable and representative for rocks with similar characteristics to those used in this research.

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As general conclusions of the research, the following considerations stand out: The physico-mechanical parameters of the rock samples considered in the study were determined. A summary of the ranges of these values is presented below, see **Table 4**.

Box 7

Table 4

Range of values of RCUS, Surface Hardness, True Density ($^{g/cm3}$) in rock samples from the Seybaplaya bench.

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Concept	Range	Mean value	Standard deviation	units
RCUS en MPA	8.6 <> 84.7	40.14	17.9977663	Mpa
Rebound Value (VR)	19<>45	34.6	6.132	
Specific gravity	18.712<> 25.6597	23.07	1.56	x10^3 en N/m^3

Declarations

Conflict of interest

The authors and co-authors declare that they have no conflicts of interest. They have no known competing financial interests or personal relationships that could have influenced the article reported in this paper.

Authors' contribution

The author performed the testing, analysis and interpretation of the results; the first co-author contributed to the extraction of samples; the second co-author performed the processing of raw data generated from the tests and the third co-author performed the discussion, conclusion and revision of the whole article by generating the graphs of each correlation.

Availability of data and materials

The data obtained from this research are available for consultation at any time as required.

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Abbreviations

ASTM American Society for Testing and Materials.

RCUS Compressive Strength Uniaxially Simple Compressive Strength.

USBR United States Bureau of Reclamation.

References

Background

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