Study of the relationship between uniaxial compressive strength, water content, porosity and density in bank rocks in Seybaplaya Campeche

Estudio de la relación entre resistencia a compresión uniaxial, contenido de agua, porosidad y densidad en rocas del banco en Seybaplaya Campeche

NAAL-PECH, José W†. PALEMÓN-ARCOS, Leonardo*, EL HAMZAOUI, Youness and GUTIÉRREZ-CAN, Yuriko

Universidad Autónoma del Carmen, Facultad de Ingeniería, México

ID 1st Author: *José Wilber, Naal-Pech* / **ORC ID**: 0009-0006-2955-0382, **CVU CONAHCYT ID**: 1231951

ID 1st Co-author: *Leonardo, Palemón-Arcos* / **ORC ID**: 0000-0002-8361-8249, **CVU CONAHCYT ID**: 49334

ID 2nd Co-author: *Youness, El Hamzaoui* / **ORC ID**: 0000-0001-5287-1594, **CVU CONAHCYT ID**: 292367

ID 3rd Co-author: *Yuriko, Gutiérrez-Can* / **ORC ID**: 0000-0001-6358-2130

DOI: 10.35429/JME.2023.20.7.9.16 Received: September 30, 2023; Accepted: December 30, 2023

Abstract

This research work focuses on the evaluation of the uniaxial compressive strength of rocks and its relationship with three significant physical properties: water content, porosity and true density. It is important to mention that Seybaplaya is a port located in Campeche, Mexico, well known for its fishing, industrial and commercial activities. Samples from one of the main active banks in the state of Campeche were used for the research. As a result, equations were established to predict the simple uniaxial compressive strength, based on the values obtained for porosity, wet content and actual density. It is important to note that these relationships are valid only for rocks with lithological characteristics similar to those used in this study. The results of the analysis and conclusions show the non-linearity of the relationships between simple uniaxial compressive strength, porosity, moisture content and true density.

Simple uniaxial compressive strength, Rock water content, Rock porosity, Relationships between simple uniaxial compressive strength, Water content, Porosity and true density

Resumen

Este trabajo de investigación se centra en la evaluación de la resistencia a compresión uniaxial de las rocas y su relación con tres propiedades físicas significativas: contenido de agua, porosidad y densidad real. Es importante mencionar que Seybaplaya es un puerto ubicado en Campeche, México, reconocido por sus actividades pesqueras, industriales y comerciales. Para la investigación se emplearon muestras provenientes de uno de los principales bancos activos del estado de Campeche para llevar. Como resultado, se establecieron ecuaciones que permiten predecir la resistencia a la compresión uniaxial simple, basándose en los valores obtenidos por la porosidad, contenido húmedo y la densidad real. Es importante destacar que estas relaciones son válidas únicamente para rocas con características litológicas similares a las utilizadas en este estudio. Los resultados del análisis y conclusiones muestran la no linealidad de las relaciones entre la resistencia a la compresión uniaxial simple, porosidad, contenido de humedad y densidad real.

Resistencia a compresión uniaxial simple, Contenido de agua de la roca, Porosidad de la roca, Relaciones entre resistencia a la compresión uniaxial simple contenido de agua, Porosidad y densidad real

Citation: NAAL-PECH, José W. PALEMÓN-ARCOS, Leonardo, EL HAMZAOUI, Youness and GUTIÉRREZ-CAN, Yuriko. Study of the relationship between uniaxial compressive strength, water content, porosity and density in bank rocks in Seybaplaya Campeche. Journal of Mechanical Engineering. 2023. 7-20: 9-16

* Correspondence to the Author (e-mail: lpalemon@pampano.unacar.mx)
† Researcher contributing as first author.

Introduction

Every executive project is built on soil or rock, in addition, every work requires aggregates where the raw material for the aggregates are the rocks, for this reason, it is essential to take into account the resistance of these in any place to analyse and design important structures for human evolution, because this parameter will give stability from its foundation. In other words, the strength of rocks is the determining factor for the structural project. Rocks are hard and compact natural aggregates of mineral particles with strong permanent cohesive bonds, which are usually 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 rock mass or massif in situ is different from a rock material, because the rock material is much stronger and a rock massif almost always presents systems of structural weaknesses called diaclases, such as: fractures, fissures, joints, discontinuities and faults of various sizes. Virtually all the rocks that make up the kilometres of the earth's crust are traversed by fissures and cracks of short extension (Iriondo, 2006).

The variability of their structure, the lithological types of rocks and their spatial distribution are factors that influence the structural damage that engineering works can suffer. This makes it necessary to consider the initial detection of the phenomena, the adaptation of land use to their degree of affection and to reduce the vulnerability of the constructions. This problem is the reason for this research focused on the characterisation and mitigation of geological risks caused by geomorphology, specifically in karst areas, such as those found in the state of Campeche (Palacio, 2013).

Given that the Resistance to Simple Uniaxial Compression (RCUS) tests to evaluate the behaviour of rocks are costly and complicated, it is advisable to use tests that allow the classification of the rocks involved by their physical properties. 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 copressive 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).

Consideration of these requirements is essential, as they are sometimes very difficult to meet or make the test too expensive. Sometimes it is necessary to go beyond the recommendations of the standards because discontinuities in the rock mass may prevent the production of rock cylinders of lengths equal to or greater than twice their diameter. In some cases, the dimensions of the corresponding specimen 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 specimen could not be broken with a conventional press.

To solve these problems, researchers such as (Galván, 2011) have established an experimental correlation between the compressive strength of the rock and the results of indirect tests or the physical characteristics of the rock studied, which makes it possible to obtain indirect estimates of the rock strength in an economical and fast way.

From the test results, equations relating the parameters have been formulated using statistical methods of correlation and linear regression.

To estimate the simple compressive strength of a rock, there are methods and tests that can be carried out in the field or in the laboratory. Obtaining this strength can vary from a subjective estimation to an 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).

The researcher (Peng and Zhang, 2007). presents correlations obtained from different investigations in rocks of the Gulf of Mexico, such as sandstones, shales, limestones and dolomites. These correlations are the result of multiple tests and analyses of rock cores, which allow the parameters to be characterised and correlated for specific rock formations.

With the exception of the first equation, all equations for sandstone present poor prediction of strength data for high travel times $\Delta t > 100$ μs/ft and lower $\Delta t < 3000$ μs/ft, as reported by (Peng and Zhang, 2007), see Table 1.

In relation to this research, the following can be observed:

a. The strength of a rock decreases as its porosity increases.

b. The strength of a rock increases as its density increases.

Type of rock	Autor	Correlation (MPa)	Nomenclature
Thuringian Sandstone, Germany	Freyburg, 1972	$UCS = 0,035vp - 31,5$	speed ultrasonic speed (P) vp (m/s)
Fine-grained, consolidated and unconsolidated sandstone in the Bowen Basin of Australia	McNally, 1987	$UCS = 1200exp(-0,036\Delta t)$	Δt (μs/ft)= 1/vp
Weak, unconsolidated sandstones in the Gulf Coast of the USA.	Chang et al. 2006	$UCS = 1,4138 \times 10^{7}\Delta t^{-3}$	
Sandstone in the Gulf of Mexico	Chang et al. 2006	$UCS = 3,87exp(1,14x10^{-10} \rho v_p{}^{2})$	density - ρ (g/cm^3):
Shale	Lal, 1999	$UCS = 10(304,8/\Delta t - 1)$	
North Sea shales	Horsrud, 2001	$UCS = 0,77v_p{}^{2,93}$ $UCS = 243,6\ \phi^{-0,96}$	Vp(km/s) Φ: Porosity as a percentage
North Sea shales	Horsrud, 2001	$UCS = 243,6\rho_0 -0,96$	ρ_0: Porosity as a percentage
Limestone and dolomite	Milizer and Stoll, 1973	$UCS = (7682/\Delta t)^{1,82}/145$	
Limestone and dolomite	Golubev and Rabinovich , 1976	$UCS = 10^{(2.44+109,14/\Delta t)}/145$	
Limestone and dolomite Middle East	Chang et al. 2006	$UCS = 143,8\ ex(-6,95\Phi)$	Φ: Porosity in fraction.

Table 1 Correlation of compressive strength (MPa) with rock physical properties (Peng and Zhang, 2007)

1.1. Study area

According to the new Mining Law, which came into force on 24 September 1992, most of the substances are already considered as concessionable (Servicio Geológico Mexicano, 2021). The registration and control of mining concessions is carried out in the offices of the Regional Delegation of the General Directorate of Mines in the city of Puebla, Pue., which controls a mining agency in the city of Campeche, Campeche.

The main wealth of the state is due to the existence of important hydrocarbon deposits in its marine platform, Campeche also has important 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", 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 particular interest to examine the characteristics of the bedrock in and around Seybaplaya, which are areas where a quarry is located, Figure 1 and its geographic location of the bedrock, type of material and volume. Table 2 (http://b.materiales.siac.gob.mx/).

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

Status:	Campeche		
Bank Name:	Sea 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

Table 2 Characteristics of the bench called Seybaplaya

ISSN-2531-2189

December, 2023 Vol.7 No.20 9-16

1.2 Soil in the state of Campeche

A soil survey was carried out in Campeche, Mexico, using geomorphological landscape and relief mapping as a basis. The objective was to classify soil types and to determine the occupied surfaces by means of mapping. For this purpose, 115 soil profiles were made, distributed in different reliefs and classified at the level of soil units according to the World Resource Base (WRB) 2007 version. The soils of the state of Campeche are classified into the following groups (Palma-López & Zavala-Cruz, J. 2017): Leptosols (48.05%), Gleysols (16.56%), Nitisols (8.49%), Vertisols (6.93%), Luvisols (6.26%), Stagnosols (2.71%), Histosols (1.93%), Solonchaks (1. 83%), Calcisols (0.97%), Cambisols (0.71%), Phaeozems (0.69%), Arenosols (0.52%), Fluvisols (0.35%) and Regosols (0.23%); 45 units are derived from these. See Figure. 2.

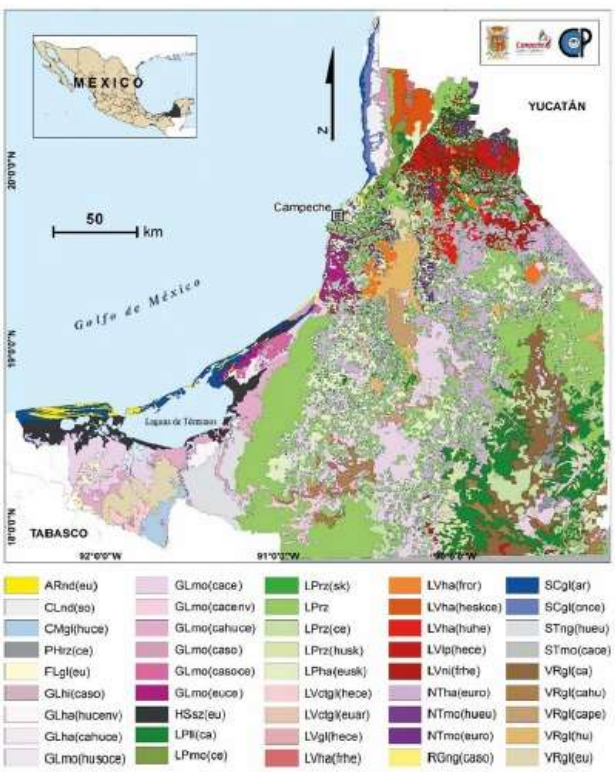

Figure 2 Map of soil units of the state of Campeche, Mexico

2. Methodology

The most important physical properties of rocks are: water content, porosity, density, specific weights, permeability and texture.

A systematic framework is provided to address the relationships between uniaxial compressive strength with the following properties water content, porosity and density in rocks from the Seybaplaya Campeche bench. To achieve this objective and to ensure that a structured and coherent process is followed, the following steps are listed below:

1. Bench exploitation
2. Sample extraction and preparation
3. % porosity test
4. Water content test
5. True density test
6. Single uniaxial compressive strength test (RCUS).

2.1 Bench mining

The open pit, post hole and auger methods are generally used for soil exploration. In general, rock bench exploration uses drilling methods which are very expensive.

The laboratory benches must be sampled in a random manner, some institutions determine numbers of boreholes per number of cubic metres of material to be exploited, which does not take into account the homogeneity or heterogeneity of the formation.

2.2 Sample extraction and preparation

The ASTM 2012. D4543.370238-1. establishes a standard test method for the preparation of rock core specimens and the determination of dimensional and shape tolerances.

According to this standard, the specimens to be tested must be straight circular cylinders that comply with the established tolerances. For this, the specimen must have a length to diameter ratio of 2.0 to 2.5 and a diameter of not less than 47 mm. In addition, the ends of the specimen are required to be smooth and free of irregularities, with all elements within 0.020 inches over the total length of the specimen.

The ends must be cut parallel to each other and at right angles to the longitudinal axis. Finally, the end surfaces shall be polished to flatness with a maximum tolerance of 0.001 inch.

ISSN-2531-2189

2.3 % Porosity Test

ASTM D4404 establishes the standard method for determining porosity in rocks. The calculation of porosity in rocks according to this standard is carried out using the following formula:

$$Porosidad\,\% = \frac{Vol.de\ poros}{Vol.total\ de\ la\ muestr}\ x\ 100 \qquad (1)$$

Where:

Pore volume = volume of water absorbed by the rock sample.
Total volume = total volume of the rock sample.

It is important to follow the detailed instructions in ASTM D4404 to obtain accurate and reliable results.

2.4 Water Content Test

Percent Actual Moisture (ASTM 2010b D2216-10) The objective of this test is to determine the moisture content of a rock in its natural state; which is an indicator of the accumulated water content of the aggregate either due to bank conditions, ambient moisture, interconnected pores, etc. The procedure consists of sampling the bank of materials, numbering the samples and weighing each one of them, drying them in the oven at a temperature of 110 °C ± 10 °C for 24 hours; the samples are then removed from the oven and allowed to cool to room temperature, and the weight is determined (Navarro L., 2011). The value of this parameter is determined using the formula.

$$\%\ Humedad\ Actual = \frac{p_i - p_f}{p_f}\ \text{x}\ 100 \qquad (2)$$

Where:
Pi= Initial weight of the sample, in g.
Pf= Final weight of the sample, in g.
An average of the representative rock samples is determined.

2.5 True density test

The actual density test on rock is performed according to ASTM D 854. This test is used to determine the true density of the rocks, which is the ratio of the actual mass of the sample to its actual volume. The value of this parameter is determined using the formula.

$$\delta = \frac{m}{V} \qquad (3)$$

Where
δ = the actual density
m = the mass of the rock
V = the total volume of the sample.

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

Sample preparation: A representative sample of the rock must be obtained and any loose material or foreign particles removed. The sample must be of adequate size to fit the container used in the test.

Sample drying: The sample should be dried in an oven at a constant temperature until it reaches a constant weight. This ensures that the sample is completely dry and contains no moisture.

Weighing of the sample: The dried sample is weighed and its weight recorded.

Volume measurement: The sample is immersed in water and the volume of water displaced is measured. This can be done using a pycnometer or other volume measuring device.

Calculation of the actual density: The actual density is calculated by dividing the weight of the sample by the volume of water displaced.

2.6 Single uniaxial compressive strength test (RCUS) ASTM D7012-10

The uniaxial compression test is the procedure by which the uniaxial compressive stress, Poisson's ratio and Young's modulus of a rock core are determined (Peng and Zhang, 2007).

$$\sigma = RCUS = \frac{P}{A} \qquad (4)$$

Where:
$\sigma = RCUS =$ $simple\ uniaxial\ compressive\ strength$
P= Axial load
A= Cross sectional área

ISSN-2531-2189

2.7 Procedure for the simple compression test.

a) Note down the dimensions to evaluate the cross-sectional area.

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

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

d) Through the control software, program the machine to execute the compression test.

e) Proceed with the test until the specimen fails (observe cracks).

f) Apply the load progressively

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

3. Results

In this research, 50 sample tests were carried out and the following results were obtained: compression, moisture content, density. see table 2

Table 2. Results of the 50 samples: where ID is the identification number of the sample, Rcus in MPA, Water content in %, Porosity in % and real Density in (g/cm^3)

ID	RCUS en MPA	Water Content %	Porosity %	Actual Density (g/cm3)
1	31.6	7.792207792	16.12205818	2.068997466
2	28.6	7.076923077	*16.76577419*	2.369076788
3	46.8	7.092198582	16.87494012	2.379366557
4	15.2	9.236947791	20.90051767	2.262708217
5	18.3	8.43373494	18.92553269	2.244027448
6	11.7	6.956521739	16.16494518	2.323710869
7	22.7	8.011869436	17.92366931	2.237139466
8	42.1	5.97826087	14.25253947	2.384061147
9	53.4	5.785123967	13.97777529	2.4161583
10	14.9	11.25	*24.15360977*	2.146987535
11	68.6	7.492795389	17.56662105	2.344468271
12	8.6	9.187279152	17.52400411	1.907420448
13	23.2	6.306306306	14.48774749	2.297342816
14	40.7	6.722689076	15.73859362	2.341115801
15	43.5	3.957783641	*9.883036448*	2.497113876
16	28.7	4.191616766	10.4120679	2.484021913
17	43.6	7.5	17.16525119	2.288700159
18	55.5	4.281345566	11.03257508	2.576894323
19	32.3	8	18.30313824	2.28789228
20	61.3	5.706521739	13.88539198	2.433249642
21	78	4.50928382	11.29591636	2.505035568
22	61.9	6.197183099	14.89542382	2.403579753
23	42.4	4.232804233	10.79569156	2.550482132
24	49.1	11.32075472	23.84710504	2.106494278
25	84.7	5.80474934	14.64380468	2.52272817
26	72.8	5.376344086	13.22802521	2.46041269
27	38.1	4.312668464	11.04448568	2.560940118
28	33.2	7.220216606	16.55073747	2.29227714
29	58	7.236842105	16.34421181	2.258472904
30	23.9	5.494505495	13.2702205	2.415180131
31	21.3	7.570977918	17.15798357	2.266283663
32	40	6.140350877	13.93226202	2.268968386
33	34.8	5.940594059	14.18378637	2.38760404
34	43.6	6.017191977	13.64046038	2.266914606
35	18.5	6.269592476	14.44239674	2.30356228
36	54.1	7.288629738	16.34874525	2.243047849
37	45.5	8.02919708	18.06123303	2.249444478
38	44.1	12.66233766	25.83910344	2.04062663
39	22.4	6.686046512	15.15645552	2.266878564
40	35.1	4.385964912	10.81254026	2.46525918
41	43.4	13.62007168	28.46017989	2.089576366
42	37.4	5.39083558	13.24624732	2.457178877
43	31	4.266666667	10.58742211	2.481427056
44	36.5	3.731343284	9.73213367	2.608211824
45	63.7	4.081632653	10.43286327	2.556051502
46	15.7	11.81818182	25.73151847	2.177282332
47	57.6	4.736842105	12.22317786	2.580448659
48	40.5	4.972375691	11.94193888	2.401656396
49	65.1	5.09383378	12.74369038	2.501787638
50	23.3	3.947368421	10.32499308	2.615664913

Table 2 shows the correlation between RCUS-Porosity in rock samples from the Seybaplaya bench. See Fig. 3. It is observed that porosity-compression there is no acceptable correlation type

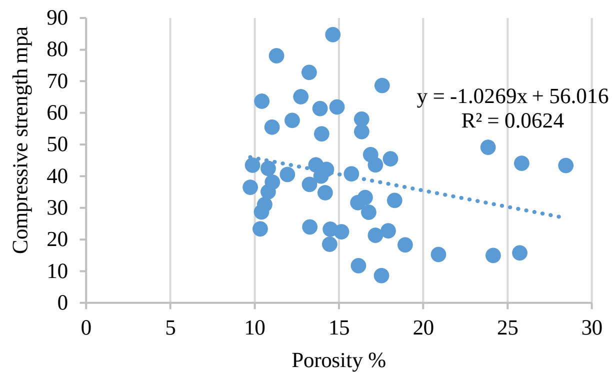

Figure 3 Of porosity - compression correlation

Table 2 shows the correlation between RCUS - water content in rock samples from the Seybaplaya bench. See Fig. 4. It can be seen that the water content - compression correlation is not acceptable.

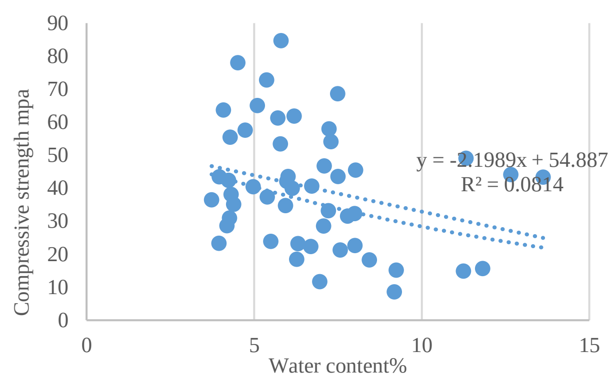

Figure 4 Of water content - compression correlation

ISSN-2531-2189

Table 2 shows the correlation between RCUS-Density in rock samples from the Seybaplaya bench. See Fig. 5 It is observed that density - compression there is no acceptable correlation type.

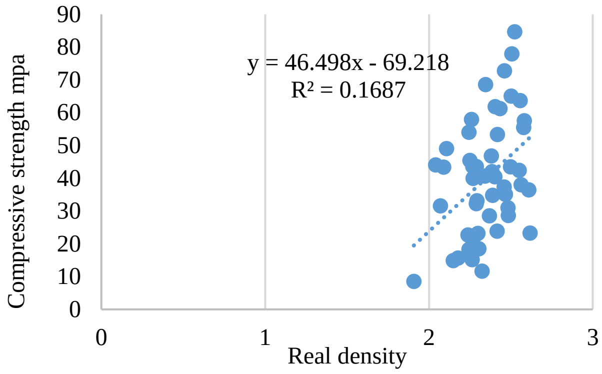

Figure 5 Real density-compression correlation

4. Discussion

With the help of an expert, explosives were used to mine the bench and rock fragments of considerable diameter were randomly selected to extract samples. During the extraction process, it was observed that the speed of the auger varies over time depending on the softness or hardness of the rocks, which was confirmed by compression tests and the identification of the samples by their ID. In addition, it was noted that injecting water into the barrier produced a white liquid indicating the limestone content of the rock.

Subsequently, the samples were measured with a vernier and cross-sections were made on the samples, which was difficult on some samples due to their disaggregation, resulting in the length or ratio of 2 to 2 1/2 times their diameter not being met and another sample had to be bored to meet the requirements.

The prepared samples were taken to the materials laboratory where they were weighed dry and then immersed in water for 24 hours to absorb moisture. The drying and wetting process was repeated three times until the ideal moisture content and drying for moisture content, porosity and density testing was achieved. Finally, compression tests were performed on the universal machine with the samples already dried, and the corresponding results were obtained.

a. It is observed that the rocks present many discontinuities.
b. The humidity-compression graph shows that due to the discontinuity there is not an acceptable relation.
c. The water content-compression graph shows that because of the discontinuity there is not an acceptable relationship.
d. It can be observed that the method of bench mining by dynamite also creates micro cracks and continue to damage the strengths.

5. Conclusion

The results obtained in this research are an important advance in rock mechanics in the state of Campeche. It is important to remember that the type of regression models presented in this paper are applicable and representative for rocks with similar characteristics to those used in the present investigation. As general conclusions of the investigation, the following considerations are highlighted: Physical-mechanical parameters were determined for the rock samples considered in the research. Below is a summary of the ranges of these values, see Table 3.

	Range	Mean value	Standard deviation	unidades
RCUS in MPA	8.6 <> 84.7	40.14	17.9977663	Mpa
Water content %	3.7313<>13.62	6.706	2.33509456	%
Porosity % Porosity % (g/cm3)	9.7321<>28.46	15.45	4.37665274	%
Actual density (g/cm^3)	1.9<>2.615	2.351	0.15899849	g/cm^3

Table 3 Range of values of RCUS, Water content %, Porosity %-, Real density (g/cm^3) in rock samples from the Seybaplaya bench

Acknowledgements

The authors José Naal-Pech, Leonardo Palemón-Arcos and Youness El Hamzaoui gratefully acknowledge the support of the Consejo Nacional de Humanidades, Ciencias y Tecnologías (CONAHCYT) through the Universidad Autónoma del Carmen. Yuriko Gutiérrez-Can acknowledges the support of the Programa para el Desarrollo Profesional Docente (PRODEP), through the Universidad Autónoma del Carmen.

Article Journal of Mechanical Engineering
December, 2023 Vol.7 No.20 9-16

References

ASTM 2010a. Standard Test Method for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures. D7012-10

ASTM 2010b. Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass1. D2216-10.

ASTM 2012. Standard Practices for Preparing Rock Core as Cylindrical Test Specimens and Verifying Conformance to Dimensional and Shape Tolerances. D4543.370238-1.

González de Vallejo L. I., Ferrer M., Ortuño L., Oteo C., (2002) Ingeniería Geológica, Editorial Pearson Educación, Madrid, ISBN84-205-3104-9.

M. Iriondo, Introducción a la Geología. Córdova. Argentina: 2006.

Palacio Aponte A. G., 2013. Identificación y Caracterización de la Subsidencia y/o Colapso de Terrenos Kásrticos. P. 169-181. En: Posada Vanegas G., B.E. Vega Serratos, y Silva Casarín (eds), Peligros Naturales en el Estado de Campeche. Cuantificación y Protección Civil. Universidad Autónoma de Campeche, cenecam-Gobierno del Estado de Campeche, cenapred.

C. Delgado, Evaluación de un cambio Tecnológico para el Procesamiento de Minerales de Alta Dureza. Tesis. Universidad de Chile: 2013.

Galván, M., Correlación entre la resistencia a compresión simple y el índice a carga puntual Is (50) en calizas de la Comunidad Valenciana (España). Tesis Doctoral, Universidad Politécnica de Valencia, España, 2011.

M. Galván, I. Restrepo, «Correlación de la resistencia a compresión uniaxial con la humedad y porosidad eficaz en rocas». DYNA,. 2016.

Peng, S. and Zhang, J., Rock properties and mechanical behaviors. Engineering Geology for Underground Rocks. Springer Berlin Heidelberg, 2007.

Servicio Geológico Mexicano (sgm)., 2021 Panorama Minero del Estado de Campeche. (http://b.materiales.siac.gob.mx/

Palma-López, D.J.- Zavala-Cruz, J. “Clasificación Y Cartografía De Suelos Del Estado De Campeche, México” Agro productividad 2017)

Navarro L., Martínez W., Espinoza A. (2011), “Análisis de Materiales”, Libro de Análisis de Materiales, Resistencia de Materiales, FIC – UMSNH, tercera edición.

Nieto, G. C., & avendaño, D. P. (2015). Guía de laboratorio de Resistencia de materiales. Bogota D.C: Inimagdalena