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Article

Study of the relationship between uniaxial compressive strength and the indirect tensile test (BTS) in rocks from the bank in Seybaplaya Campeche Mexico

Estudio de la relación entre la resistencia a la compresión uniaxial y el ensayo de tracción indirecta (BTS) en rocas del banco de Seybaplaya Campeche México

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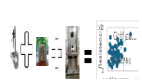
Abstract

The present research focuses on analyzing the uniaxial compressive strength of rocks and its relationship with the indirect tensile test (the Brazilian method). It is important to note that Seybaplaya, located in Campeche, Mexico, is known for its fishing, industrial and commercial activities, and is home to a rock bank from which samples were obtained for this study. As a result, an equation was developed that allows predicting the simple uniaxial compressive strength from the values obtained in the indirect tensile test. It should be noted that this relationship is valid only for rocks with similar lithological characteristics of the samples analyzed. The results of the analysis and conclusions show the linearity of the relationship between the simple uniaxial compression resistance and the indirect tensile test.

Objectives: Analyse the linear correlation between the results of the direct test and the indirect test.

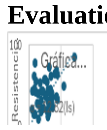
Method: Data acquisition

Processing



Model

Evaluation



Results: $\sigma = 11.057(\sigma\ t)$ $R^2=0.7885$

Contributions: A RCUS-BTS correlation equation for predicting input resistance using an indirect test.

Simple uniaxial compressive strength and indirect tensile strength in rock

Resumen

La presente investigación se centra en analizar la resistencia a la compresión uniaxial de las rocas y su relación con el ensayo de tracción indirecta (el método brasileño). Es importante destacar que Seybaplaya, ubicado en Campeche, México, es conocido por sus actividades pesqueras, industriales y comerciales, y alberga un banco de roca del cual se obtuvieron muestras para este estudio. Como resultado, se desarrolló una ecuación que permite predecir la resistencia a la compresión uniaxial simple a partir de los valores obtenidos en el ensayo de tracción indirecta. Cabe resaltar que esta relación es válida únicamente para rocas con características litológicas similar de las muestras analizadas. Los resultados del análisis y las conclusiones evidencian la linealidad de la relación entre la resistencia a la compresión uniaxial simple y el ensayo de tracción indirecta.

Objetivos: Analizar la correlación lineal entre los resultados de la prueba directa y la prueba indirecta.

Método: Adquisición de dato

Procesamiento

Modelo

Evaluación

Resultados: $\sigma = 11.057(\sigma\ t)$ $R^2=0.7885$

Contribuciones: Una ecuación de correlación RCUS-BTS para predecir la resistencia de los insumos mediante una prueba indirecta

Resistencia a la compresión uniaxial simple y resistencia a la tracción indirecta en roca

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Introduction

The durability and sustainability of brittle materials is a topic of growing interest for civil engineering. Assessing their strength is crucial when analysing and designing structures, as this ensures stability from the foundation. In summary, the strength of rocks is a key factor in structural design, as they are hard, compact, natural aggregates, consisting of mineral particles held together by permanent cohesions. The proportion of different minerals, the granular structure, the texture and the origin of the rock serve for its geological classification (González, 2002).

Rock masses are complex geological environments with cracks and faults that affect the performance of engineered structures. These discontinuities can initiate new cracks under external forces, which can grow and combine, resulting in a non-linear degradation of rock strength and stiffness. Therefore, it is necessary to know the fracturing behaviour of the rock mass of multiple faults in order to accurately interpret and predict the deformation behaviours of rocks (Zhou, Lian, Wong, & Berto, 2018).

The variety of rock structure and rock types, as well as their geographical distribution, influences structural damage in engineering works. It is therefore essential to identify these factors in advance, adapt land use and reduce the vulnerability of constructions. This problem is the reason for 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 assess the behaviour of rocks, it is recommended to use tests that allow classification of the physical properties of the rocks involved (Naal-Pech *et al.,* 2023). This classification will facilitate the grouping and characterisation of rocks, allowing the assignment of mechanical behaviour parameters obtained from tests on representative samples. Determining the simple compressive strength of a rock is important because it allows the rock to be classified according to its strength and is an important parameter in the most commonly used fracture criteria (Delgado, 2013).

Rocks exhibit linear and/or non-linear relationships between the forces applied and the deformations produced, resulting in different models of stress vs. strain curves for different rock types (Secretaría de Comunicaciones y Transporte, 2016). Furthermore, for rocks with grains larger than one centimetre, such as granites or pegmatites, it may be impossible to obtain suitable samples. Even if they can be obtained, they cannot be fragmented with conventional presses. 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, which allows indirect estimates of rock strength to be obtained cheaply and quickly.

Equations relating parameters through statistical methods of correlation and linear regression have been developed to estimate the simple compressive strength of a rock. There are methods and tests applicable in the field and in the laboratory, ranging from subjective estimates to indirect measurements. 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). These correlations, derived from numerous tests and analyses of rock cores, make it possible to characterise and relate specific rock parameters. Several researchers have worked to obtain these correlation equations, evaluated in the laboratory and in the field, which relate the uniaxial compressive strength (RCUS) to the indirect tensile test. See Table 1.

Box 1

Table 1
Correlation equations between single uniaxial compression (RCUS) in MPA and indirect tensile test (BTS)

Authors and year	Correlation Equation	Type of rock
Gokceoglu and Zorlu (2004)	RCUS=6.8*BTS+13.5	-----------------------------
Altindag and Guney (2010)	RCUS =12.38*[BTS]$^{1.0725}$	Different types of rocks including limestone
Tahiretal (2011)	RCUS= 7.53 * BTS	Limestone samples
Farah (2011)	RCUS=5.11*BTS-133.86	Weathered limestone
Kahraman et al. (2012)	RCUS=10.61*BTS	Different types of rocks including limestone
Nazir et al. (2013)	RCUS=9.25*[BTS]$^{0.947}$	Limestone
Kahraman et al. (2015)	RCUS=24.30+4.87*BTS	Different types of rocks

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Study area

The main wealth of the state of Campeche comes from hydrocarbon deposits on its marine shelf and significant deposits of non-metallic minerals, such as limestone, gypsum, clays, salt and stone aggregates (Servicio Geológico Mexicano, 2021). Seybaplaya is geologically located on the Yucatan Platform, a large area of sedimentary rock on the Yucatan Peninsula, which was formed by the accumulation of marine sediments over millions of years and reaches a depth of approximately 200 metres. The region's soil is predominantly composed of limestone and clay, and also contains deposits of oil and natural gas, which are crucial to the local economy. It is essential to analyse the characteristics of the rocks of the bench located in and around Seybaplaya, known as Mary Carmen, where a quarry is located. Figure 1 shows the geographic location of the rock bank, while Table 2 details the type of material and its volume.

Box 2

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

Status:	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	Clearance thickness (m):	0.2
Likely uses:			
Use of explosives:	Unrestricted		There are no
Economic aspects:	Convenient	Quality report:	Informe

Methodology

The simplest indirect destructive test on rocks is the indirect tensile test, while the most commonly used direct destructive test is the simple uniaxial compressive strength test. A systematic framework is presented to analyse the relationship between the uniaxial compressive strength and the indirect tensile test (Brazilian method) on rocks from the Mary Carmen bench, located in Seybaplaya, Campeche. To achieve this objective and to ensure a structured and logical process, the steps to be followed are detailed below:

- Exploration and bench exploitation.
- Sample extraction and preparation.
- Indirect Tensile Test (BTS).
- RCUS (Resistance to Uniaxial Compression Single Strength) test.

This section breaks down each phase:

Exploration and bench mining In soil exploration, methods such as the open pit, post hole and auger are commonly used. However, for rock bank exploration, drilling methods are used which are often quite expensive. The material banks must be sampled randomly; however, some institutions determine the number of boreholes according to the volume 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 in accordance with ASTM 2008 D4543.370238-1. Samples shall be straight circular cylinders with a length to diameter ratio of 2.0 to 2.5 and a minimum diameter of 47 mm. In addition, the ends shall be polished and flat, with a maximum tolerance of 0.001 inch.

Indirect Tensile Test (BTS)

The Brazilian test is a simple indirect test method (ASTM D3967-08) used to determine the tensile strength of brittle materials, such as rocks. This test consists of applying a compressive load along the diameter of a cylindrical rock specimen until it breaks, there are several types of load plates as shown in Figure 2.

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Box 4

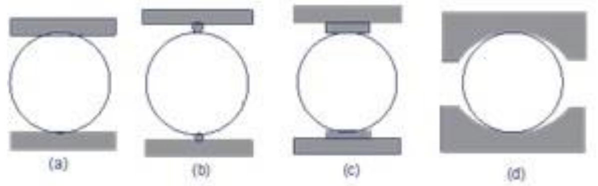

Figure 2

Typical loading configurations for the Brazilian tensile test: (a) flat load plates, (b) flat load plates with two small diameter steel rods, (c) flat load plates with cushion and (d) curved load jaws.

The indirect tensile strength shall be calculated by means of equation 1:

$$\sigma_t=2P/(\pi*L*D)=0.6366*P/(L*D) \qquad (1)$$

Where:

P= Applied load in (N)

L= Sample thickness in (mm)

D=Sample diameter in (mm)

σ_t = Indirect tensile strength (Mpa)

Procedure for the indirect tensile test.

- The desired vertical orientation is marked on the sample, according to the specification to be indicated, by a diametric line at each end of the sample.

- The lines shall be used to centre the sample in the universal machine to ensure proper orientation. They shall also serve as references for thickness and diameter measurements.

- If the sample is anisotropic, it is important to ensure that the lines marked on each sample correspond to the same orientation.

- The test sample is positioned so that the diametral plane formed by the two lines marked on the ends aligns with the centre of the test cylinder.

- Good line loading should be achieved by rotating the sample on its axis until there is no visible light between the sample and the load plates.

Backlighting facilitates this observation

- A continuously increasing compression load shall be applied. The load shall be generated to maintain an approximately constant loading rate or deformation such that failure occurs over a small time interval.

- Remove the load from the tested specimen.

- Remove the specimen from the machine and proceed by placing a new specimen, repeating the procedure described above.

Single uniaxial compressive strength test (RCUS)

The uniaxial compression test is performed in accordance with ASTM D7012-10. The method used to calculate the uniaxial compressive stress, Poisson's ratio and Young's modulus of a rock core is based on the work of (Peng and Zhang, 2007). The simple uniaxial compressive strength is calculated using equation (2).

$$\sigma = RCUS = P/A \qquad (2)$$

Where:

σ = RCUS = simple uniaxial compressive strength in Mpa

P = Axial load N

A = Cross-sectional area mm ^{2}

Simple compression test procedure.

Note the dimensions to assess the cross-sectional area. Ensure that the universal machine is calibrated correctly and in optimum condition, with the reading at zero before starting any measurements. Position the specimen so that it is perfectly centred between the compression platens of the universal machine. Use the control software to program the machine and run the compression test properly. Carry out the test until failure of the specimen is detected, watching carefully for cracks. Remove the load from the specimen. Remove the specimen from the machine and proceed to place a new specimen, repeating the procedure described above (Nieto & Avendaño, 2015).

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Results

In this investigation, 50 simple uniaxial compressive strength tests (RCUS) and 50 indirect tensile tests (BTS) were carried out, and the following results were obtained (see Table 3).

Box 5

Table 3
Results of the 50 samples: where ID is the sample identification number, RCUS in MPA, BTS in MPA

ID	Brazilian Test σt=0.6366*P*1000/(D*L)	RCUS single uniaxial compressive strength in MPA
1	3.829	31.6
2	1.150	28.6
3	4.239	46.8
4	2.732	15.2
5	1.631	18.3
6	2.374	11.7
7	1.907	22.7
8	0.972	42.1
9	1.859	53.4
10	0.672	14.9
11	4.373	68.6
12	2.386	8.6
13	3.722	23.2
14	4.222	40.7
15	4.149	43.5
16	1.702	28.7
17	2.893	43.6
18	5.562	55.5
19	2.057	32.3
20	2.285	61.3
21	3.125	78
22	3.192	61.9
23	2.746	42.4
24	3.464	49.1
25	10.839	84.7
26	4.788	72.8
27	6.858	38.1
28	5.475	33.2
29	3.906	58
30	3.865	23.9
31	2.246	21.3
32	2.435	40
33	5.101	34.8
34	2.501	43.6
35	1.586	18.5
36	3.154	54.1
37	1.333	45.5
38	3.872	44.1
39	1.459	22.4
40	1.951	35.1
41	2.915	43.4
42	3.767	37.4
43	2.280	31
44	4.435	36.5
45	1.612	63.7
46	0.711	15.7
47	1.643	57.6
48	2.065	40.5
49	3.633	65.1
50	1.404	23.3

Using information from Table 3 to correlate RCUS and (BTS), in rock samples from the Seybaplaya bench, we obtain the graph, see Figure 3. It is observed that the indirect tensile and compression test value has an R^2 of 0.7885.

Box 6

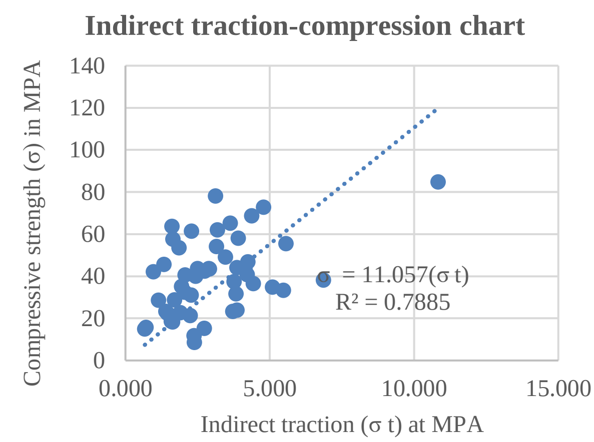

Figure 3
Correlation plot between RCUS and indirect tensile strength (BTS) in rock simples

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 observed 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. In addition, it was noted that when water was injected into the borehole, a white liquid was generated, indicating the presence of limestone in the rock. Two samples were extracted from the same fragment: one for the point load test and the other to assess the compressive strength.

The samples subjected to compression tests were measured with a vernier caliper and cross-sections were made. This process was complicated in some cases due to the disintegration of the specimens. The length to diameter ratio of 2 to 2.5 was met; in cases where it was not, another sample was drilled to meet the requirements. On the other hand, the samples for the indirect tensile test were also measured with a vernier caliper, complying with the diameter to length ratio of 0.25 to 0.75, as established in the standard.

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a) For the indirect tensile test on rock samples, diametrically shaped tests were carried out on cylindrical samples. The indirect tensile strength (BTS) was determined. This strength was obtained by subjecting a rock sample to a compressive load, applied through a pair of flat plates, until fracture occurred in the sample. The compression tests were performed on a universal machine using dry samples, which allowed for consistent results throughout the process.

b) It is observed that the rocks present numerous discontinuities.

c) When examining the RCUS-BTS graph, it is appreciated that there is an acceptable relationship.

d) When analysing the RCUS-BTS graph it is observed the linearity of the correlation.

e) It is demonstrated that the method of exploitation of banks with dynamite also creates micro cracks that continue damaging the resistances.

f) It was observed that the material bank is of limestone rock type.

g) The load plate was used in the Brazilian test was flat.

Conclusion

The results obtained in this study represent a significant advance in rock mechanics in the state of Campeche. It is essential to point out that the regression model presented in this paper is applicable and representative for rocks with similar characteristics to those used in this research. Among the general conclusions, the following considerations stand out: the physico-mechanical parameters of the rock samples analysed 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 RCUS and BTS values in rock samples from the Seybaplaya bench

Concept	Range	Mean value	Standard deviation	Units
RCUS in MPA	8.6 <> 84.7	40.14	17.998	Mpa
BTS value	0.672<>10.839	3.062	1.768	Mpa

Declarations

Incompatibility

The authors and co-authors declare that they have no conflicts of interest. They have no competing financial interests or personal relationships that could influence the content of this article.

Availability of data and materials

Data obtained from this research are available for consultation at any time as needed.

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Authors' contribution

The contribution of each researcher in each of the points developed in this research was defined based on the following:

Naal-Pech, José Wilber: Contributed significantly to the conceptualization of the project, as well as to the development of the research method and technique. Supported the design of the field instrument and carried out the data analysis, systematizing the results. In addition, he was in charge of writing the article.

Palemón-Arcos, Leonardo: Carried out the background research for this article and provided support in the design of the field instrument. In addition, he contributed to the writing of the article.

El Hamzaoui, Youness: Contributed to data processing and the generation of correlation graphs, as well as the development of the approach, method and writing of the article.

Gutiérrez-Can, Yuriko: Contributed to the research design, defining the type and focus of the study, as well as the development of the method and writing of the article.

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Abbreviations

ASTM American Society for Testing and Materials.

RCUS Compressive Strength Uniaxially Simple Compressive Strength.

BTS Brazilian Tensile Strength

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Background

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