RESEARCH MECHANICAL CHARACTERISTICS OF THE CORAL ROCK MASS BY AUTOMATIC TRIAXIAL TEST SYSTEMS COMBINE WITH HOEK-BROWN FAILURE CRITERION

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Abstract

This paper introduces the determination method of mechanical characteristics of coral rock mass basing Hoek-Brown failure criterion by RocData software. The input parameters are determined by triaxial test results on coral rock specimen, the geological strength index GSI and disturbance factor D. The results of article have practical meanings to research and recommend the calculation values of the mechanical parameters of coral rock mass for designation and excavation the constructions.

Keywords: *Coral rock mass; triaxial test systems; Hoek-Brown failure criterion.*

1. Introduction

Coral rock is the new construction material that has not much data yet. This is a sedimentary rock, made up of the minerals aragonite and calcite (80%), which are different crystal forms of calcium carbonate unlike normal limestone with mostly calcite or dolomite. This rock is distributed at depths greater than 12,0 m offshore on the atolls. A borehole site reach as deep as 60 m, the relatively large layer thickness is about 44 m or more. This shows that the coral rock has different forming conditions, petrification and composition as compared to other limestone types in the continent.

When the building weight increases, the coral rock layer will be chosen to locate the foundation. In addition, the available data on uniaxial compressive strength of rock specimen did not make much meaning in assessing the mechanical properties of coral rock mass. Hence, the determination of mechanical properties of the coral rock mass is very necessary.

In construction, the most important issue that building work in or on the rock foundation must be stable during the time of exploitation and operation. Building stability is usually assessed by stress conditions, so the strength of the rock mass and its failure criterion are attentive. In recent years, rock mechanics still uses the familiar Mohr-Coulomb failure criterion. Besides, the Hoek-Brown failure criterion for rock mass is also being widely used. This is a closely and logical test criterion, the calculated

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parameters are quantified by mathematical functions, allowing the determination of correlation relations between stress components at the limiting state of the rock.

The article presents the method of determining the mechanical characteristics of coral rock mass according to Hoek-Brown criterion by RocData software. The input parameters were calculated by the triaxial test results of coral rock specimens and The estimating method of Geological strength Index GSI and disturbance factor D. Along with that is the relationship with the Mohr-Coulomb failure criterion to give cohesion and friction angle values for rock mass.

2. Hoek-Brown criterion

Hoek and Brown (1980) proposed this method for obtaining estimates of the strength of jointed rock masses and was modified over the years. The Generalized Hoek-Brown failure criterion is defined by (2002):

$$\sigma_1 = \sigma_3 + \sigma_{ci}(m_b\sigma_3 / \sigma_{ci} + s)^a \tag{2.1}$$

where σ_1 and σ_3 are the principal stresses at failure; σ_{ci} is the uniaxial compressive strength of the intact rock pieces; s and a are constants which depend upon the rock mass characteristics, with rock material s = 1, a = 0,5; m_b is the value of the Hoek-Brown constant, with rock material (rock specimen) replace m_b with m_i. The values of m_i should be determined by statistical analysis of the results of a set of triaxial tests on core samples.

$$m_b = m_i \exp[(\text{GSI} - 100)/(28\text{-}14\text{D})] \tag{2.2}$$

GSI is geological strengh index; D is disturbance factor.

The Hoek-Brown failure criterion should only be applied to intact rock specimens, many joint sets or heavily jointed rock mass, which be assumed isotropic rock.

3. The determination method of data input of RocData software

According to the User's Guide of Rocscience Inc., RocData is a software program for determining rock mass strength parameters through analysis of laboratory or field triaxial. RocData is designed to aid engineers, especially at the preliminary stages of design. The program can fit data to the linear Mohr-Coulomb model or to any of the following three non-linear failure criteria: the generalized Hoek-Brown, Barton-Bandis and Power Curve strength models. The program enables users to easily visualize the effects of changes in input parameters on rock failure envelopes [7].

3.1. The input and output parameters of the RocData software

The input and output parameters of the software are shown in Figure 3.1 and Figure 3.2:

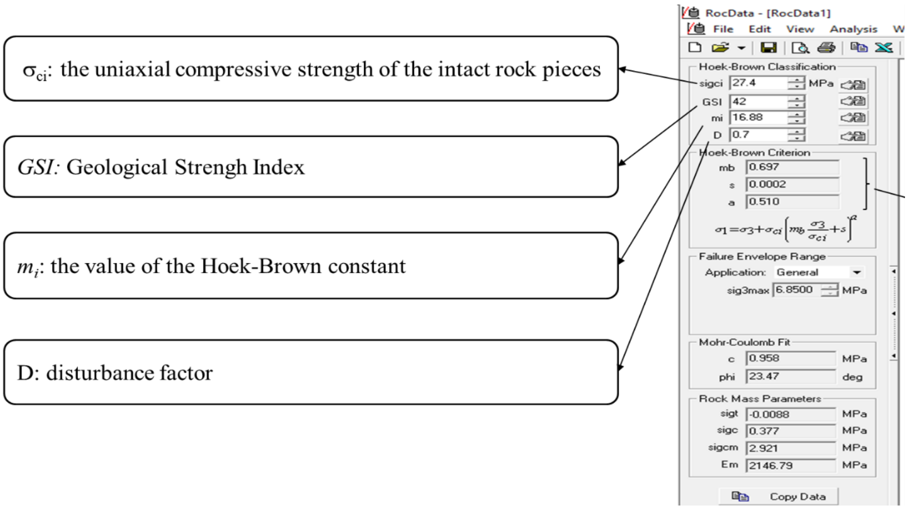


Figure 3.1. Input data of RocData software

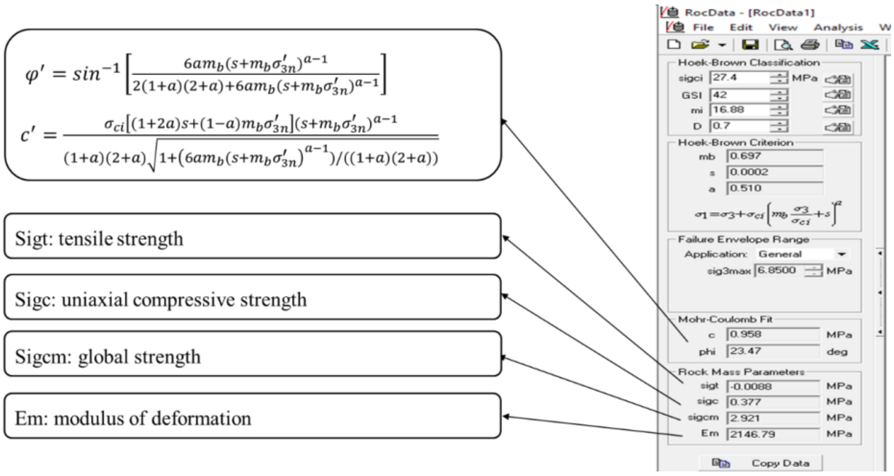


Figure 3.2. Output data of RocData software

3.2. Determining the Hoek-Brown material constant m_i and the uniaxial compressive strength of the coral rock by triaxial test systems

3.2.1. Automatic Triaxial test system

The material factor m_i is determined by Automatic Triaxial test system MCC - 3000 kN (Controls Group, Italy). This experiment was conducted at the geotechnical laboratories - Institute of Techniques for Special Engineering (ITSE). The system includes: Automatic Triaxial test for rock cores (Figure 3.3); Laboratory coring machine and bits, Core trimmer and cut-off machine (Figure 3.4); MCC8 - Multitest program and experimental result calculation software (Figure 3.5).

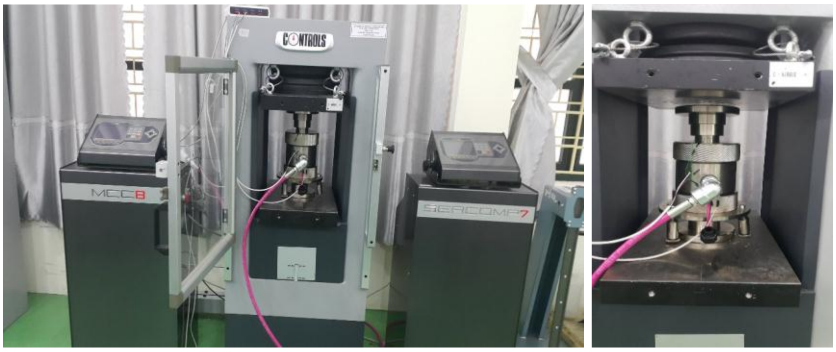
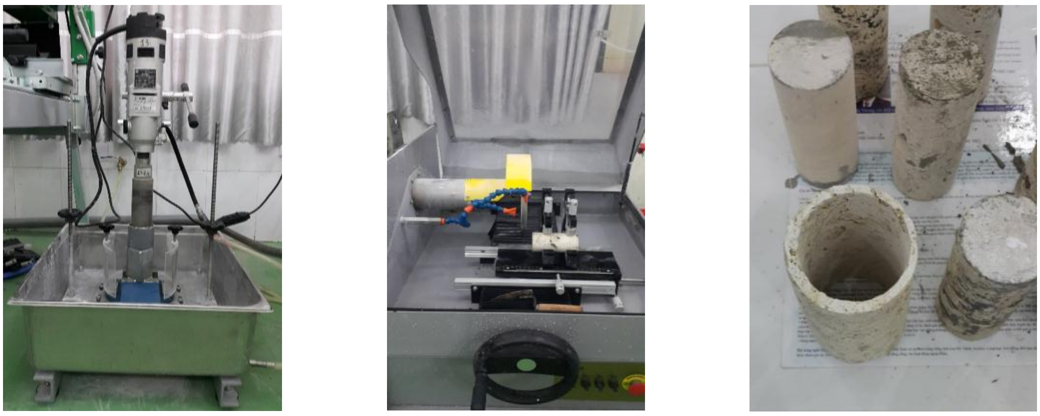


Figure 3.3. Automatic Triaxial test system MCC and Hoek cells



a) Laboratory coring machine and bits — *b) Core trimmer and cut-off machine* — *c) Prepared core samples*

Figure 3.4. Sample preparation equipment

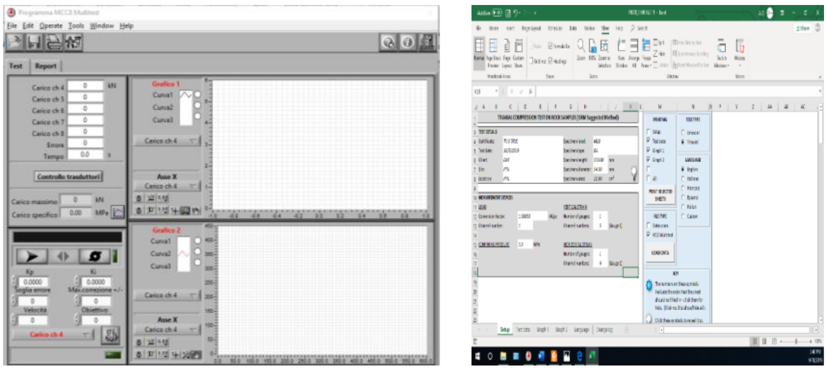


Figure 3.5. MCC8 Multitest program

The normal specimens preparation for laboratory testing, which they were taken in the borehole of 60m depth on the offshore coral islands area (Figure 3.6).

Figure 3.6. Coral rock specimens were 54×108mm in size

Rock core samples were sticked strain gauges and put into cells on the compression frames of triaxial test equipment and connected to the computer. When the communication between the PC and the console, the later sent all the system configuration data (channel settings, calibration, parameters) to the PC. The next was confining pressure levels control that corresponding to the sampling depth and increasing the axial load until the specimen was failure (Figure 3.7). This was carried out automatically.

Figure 3.7. Failure in rock specimen

3.2.2. The determination method of the Hoek-Brown material constant m_i and the uniaxial compressive strength σ_{ci} of the coral rock mass

The value of constant m_i should be determined by statistical analysis of the results of a set of triaxial tests on carefully prepared core samples [2]. The failure criterion defined by equation:

$$\sigma_1 = \sigma_3 + (m_i \sigma_{ci} \sigma_3 + s\sigma_{ci}^2)^{1/2} \tag{3.1}$$

According to Evert Hoek-Practical Rock Engineering (2006), at least five well spaced data points should be included in the analysis. In deriving the original values of σ_{ci} and m_i, Hoek and Brown (1980a) used a range of $0 < \sigma_3 < 0{,}5\sigma_{ci}$. In this analysis, equation (3.1) is re-written in the form:

$$y = m_i \sigma_{ci} x + s\sigma_{ci}^2 \tag{3.2}$$

where $x = \sigma_3$ and $y = (\sigma_1 - \sigma_3)^2$ and for intact rock, $s = 1$; For n specimens, the uniaxial compressive strength σ_{ci}, the constant m_i and the coefficient of determination r^2 are calculated from [1]:

$$\sigma_{ci}^2 = \frac{\sum y}{n} - \left[\frac{\sum xy - \sum x \sum y / n}{\sum x^2 - \left(\sum x\right)^2 / n} \right] \frac{\sum x}{n} \qquad (3.3)$$

$$m_i = \frac{1}{\sigma_{ci}} \left[\frac{\sum xy - \sum x \sum y / n}{\sum x^2 - \left(\sum x\right)^2 / n} \right] \qquad (3.4)$$

$$r^2 = \frac{\left[\sum xy - \sum x \sum y / n\right]^2}{\left[\sum x^2 - \left(\sum x\right)^2 / n\right]\left[\sum y^2 - \left(\sum y\right)^2 / n\right]} \qquad (3.5)$$

Note that high quality triaxial test data will usually give a coefficient of determination r^2 of greater than 0,9. A spreadsheet for the analysis of triaxial test data of coral rock specimen is given in Table 3.1. There are eight testing samples with pairs of σ_1, σ_3 at failure. The calculation results the constant m_i of coral rock mass are obtained from the formulas (3.3) to (3.5):

Table 3.1. The triaxial test results of coral rock

No,	Sample	Diameter (mm)	Height (mm)	$x = \sigma_3$ (MPa)	σ_1 (MPa)	$y = (\sigma_1\text{-}\sigma_3)^2$	xy	x^2	y^2
1	M1	54	108	0,5	28,26	770,618	385,309	0,25	593851,49
2	M2			1,0	30,01	841,580	841,580	1,00	708257,06
3	M3			1,5	31,89	923,552	1385,328	2,25	852948,48
4	M4			2,0	34,05	1027,203	2054,406	4,00	1055144,98
5	M5			3,0	37,58	1195,776	3587,328	9,00	1429881,20
6	M6			5,0	40,68	1273,062	6365,310	25,00	1620687,87
7	M7			10,0	53,77	1915,813	19158,130	100,00	3670339,07
8	M8			15,0	59,28	1960,718	29410,770	225,00	3844416,64
Total				38,0	38,0	315,52	9908,322	63188,161	366,5

Coral rock mass parameters are obtained as: n = 8; sigci = 28,3 MPa; m_i = 3,203; r^2 = 0,929.

3.3. The estimating method of Geological Strength Index GSI and disturbance factor D

Before 2002, the GSI was estimated directly from RMR and Q. However, this correlation has proved to be unreliable, particularly for poor quality rock masses and for rocks with lithological peculiarities that cannot be accommodated in the RMR classification. Consequently, it is recommended that GSI should be estimated directly and chosen based on interlocking and joint conditions of different rock from 2002 version.

Disturbance factor D which depends upon the degree of disturbance due to blast damage and stress relaxation. It varies from 0 for undisturbed in situ rock masses to 1 for very disturbed rock masses. The tables for estimating GSI and D have both been updated in RocData software (Figure 3.8 and Figure 3.9).

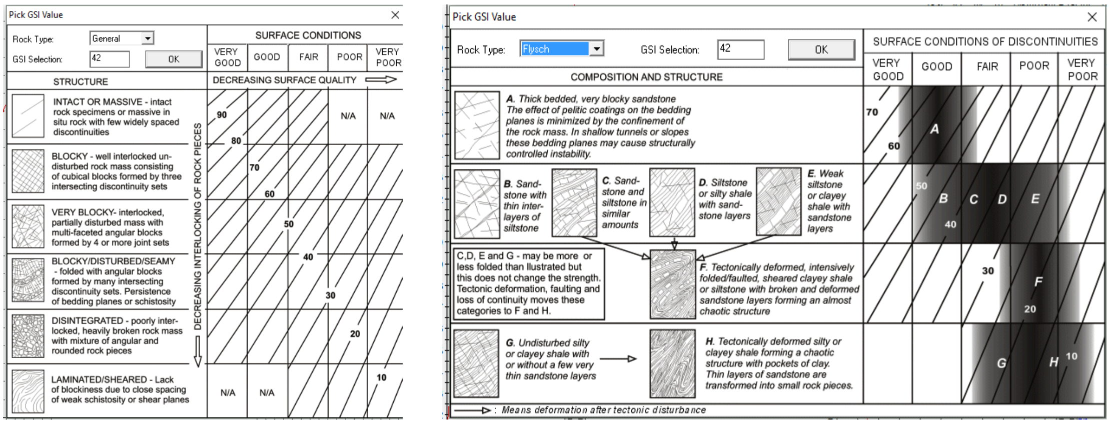


Figure 3.8. Estimate of GSI for blocky and heterogeneous rock masses

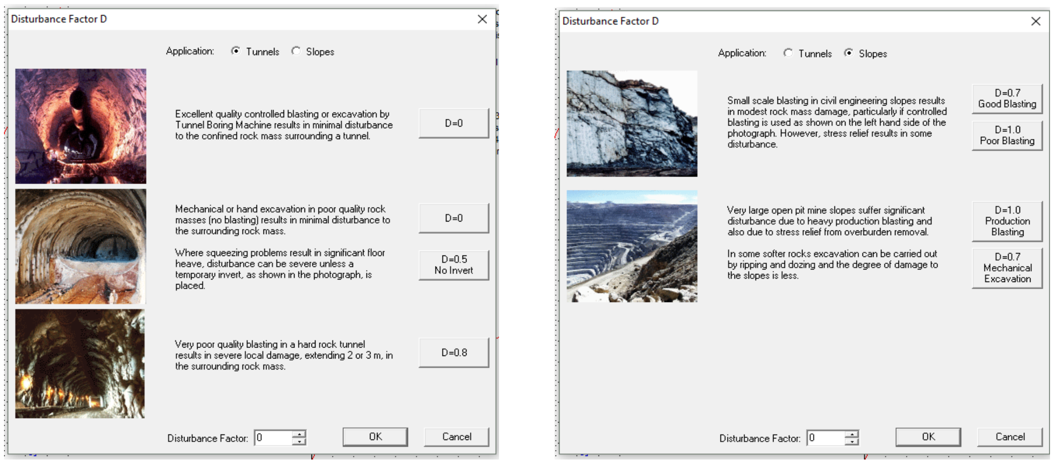


Figure 3.9. Estimate of D for Tunnels and Slopes

4. The application of RocData software for calculation values of the mechanical parameters of coral rock mass

4.1. The inputs value

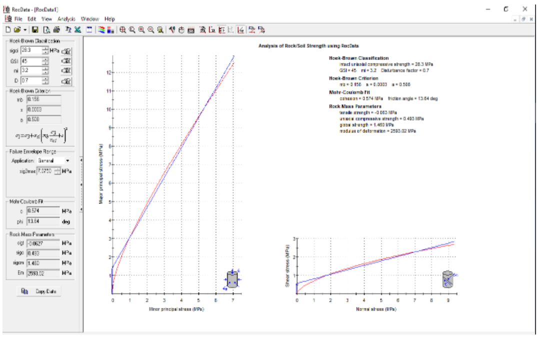
The inputs parameters are shown in Table 4.1 for cases: General (available only for the Generalized Hoek-Brown criterion). This is based on the empirical observation that the stress range associated with brittle failure, occurs when sigma3 is less than about one-quarter of sigci; Slopes, Tunnels and custom (may enter any value of sigma3max). The Failure Envelope Range option has a direct effect on the calculated Mohr-Coulomb parameters and no effect on the calculated parameters of a non-linear failure envelope.

Table 4.1. The inputs values

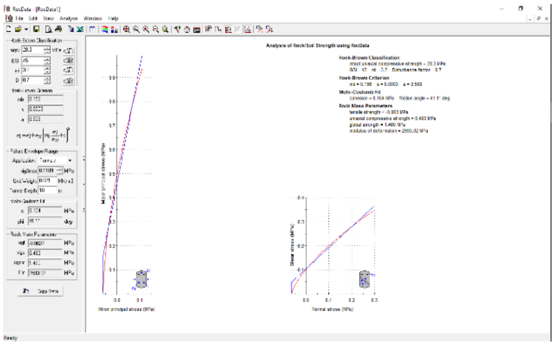
No.	Parameters	Unit	Value
1	The uniaxial compressive strength of the intact rock pieces Sigci:	MPa	28,3
2	Geological strength Index GSI:		45
3	the Hoek-Brown constant m_i:		3,2
4	Disturbance factor D for cases:		
	General		0,7
	Tunnels		0,8
	Slopes		0,7
	Custom		0,7
5	Unit weight	MN/m^3	0,021

4.2. The calculation results of mechanical properties of coral rock mass

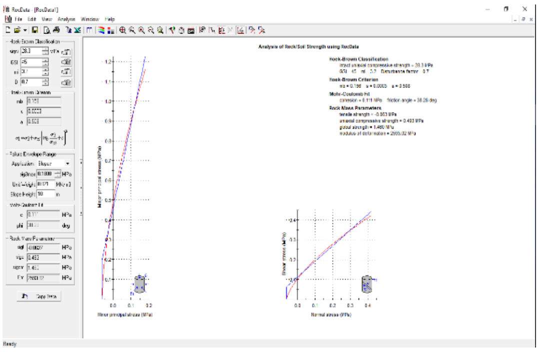
The calculation results of mechanical properties of coral rock mass by RocData software are shown in Figure 4.1:



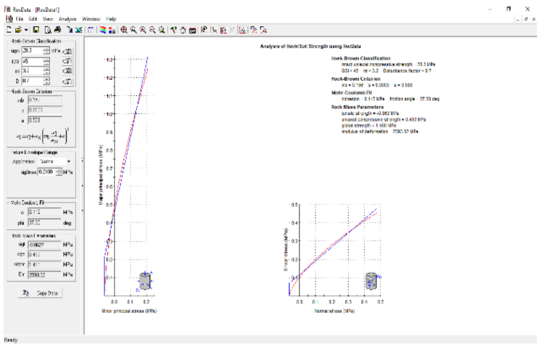
a) General



b) Tunnels (tunnel depth H = 10 m)



c) Slope (slope height H = 10 m)



d) Custom (sig3max = γH where H = 10 m)

Figure 4.1. The calculation results of mechanical properties of coral rock mass

The values of mechanical properties of coral rock mass for cases choosing on Figure 4.1 are summary in Table 4.2.

Table 4.2. Summary of mechanical properties of coral rock mass

No	Mechanical properties	Unit	Values			
			General	Tunnels	Slope	Custom
1	Cohesion c	MPa	0,574	0,104	0,111	0,115
2	Friction angle φ	deg	13,64	41,11	38,28	37,30
3	Uniaxial compressive strength sigc	MPa	0,493	0,493	0,493	0,493
4	Global strength sigcm	MPa	1,460	1,460	1,460	1,460
5	Modulus of deformation	MPa	2593,02	2593,02	2593,02	2593,02

5. Conclusions

The RocData software allows simultaneous calculation of the mechanical properties of rock mass in slopes and tunnels with different depths. The calculation data is highly reliable when using triaxial test systems to determine the input parameters.

From the results of triaxial test on eight rock specimens, the Hoek-Brown constant m_i of the coral rock mass was determined as 3,205. It is important to calculate values of the mechanical parameters of coral rock mass and adding the value of the constant m_i of coral rock mass into the estimating table for intact rock. The mechanical characteristic values of the rock mass have practical scientific meanings and reference for construction planning and design.

However, to improve the accuracy of the determination of the constant m_i, needing more the field tests with more large number of samples at different depths and survey areas.

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NGHIÊN CỨU ĐẶC TRƯNG CƠ HỌC CỦA KHỐI ĐÁ SAN HÔ BẰNG THÍ NGHIỆM BA TRỤC TỰ ĐỘNG KẾT HỢP VỚI TIÊU CHUẨN BỀN HOEK-BROWN

Tóm tắt: *Bài báo trình bày phương pháp xác định các đặc trưng cơ học của khối đá san hô theo tiêu chuẩn bền Hoek-Brown bằng phần mềm RocData. Các thông số đầu vào được xác định từ kết quả thí nghiệm ba trục trên mẫu đá san hô, chỉ số độ bền địa chất và hệ số xáo động của khối đá. Kết quả của bài báo có ý nghĩa thực tiễn trong việc nghiên cứu và đưa ra khuyến nghị về các đặc trưng cơ học của khối đá san hô phục vụ cho thiết kế và thi công công trình.*

Từ khóa: Đá san hô; thí nghiệm ba trục đá; tiêu chuẩn bền Hoek-Brown.

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