Study on the relationship between uniaxial compressive strength and elastic properties of limestone with various sample diameter

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ABSTRACT: Uniaxial compressive strength (UCS), elasticity modulus (E) and Poisson's ratio (υ) are critical design parameters in engineering. This study investigates the relationship between the UCS, Et (slope of the line tangent at 50% of the UCS) and υ of limestone core with various diameters. Core samples with a diameter of 25, 38, 48, 54 and 63mm were prepared for the UCS tests with strain gauges. The results were analyzed using linear regression between UCS and Et and υ with different sample diameters. The regression analysis results show that the Et has weak to strong positive and negative correlations with the UCS for sample diameter. The correlation between the υ and UCS is variably weak to strong for sample diameters of 38, 63, 25, 48 and 54mm. In general, the mean Et and υ decrease with increasing sample diameter increments, however, no meaningful trends are found for the UCS case.

Keywords Uniaxial compressive strength, Modulus of elasticity, Poisson's ratio, Limestone, Sample diameter.

1 INTRODUCTION

To build and maintain safe and reliable structures in various engineering disciplines, such as civil and mining engineering, it is necessary and critical to determine uniaxial compressive strength (UCS), modulus of elasticity (E) and Poisson's ratio (υ) of rock as material parameters. In the literature, there is a number of published studies that have proposed correlation equations between UCS, E and υ for different rock types (e.g., Sachpazis 1990, Arslan et al. 2008, Karagianni et al. 2010, Yagiz 2011, Arman et al 2014). Various researchers have also reported that UCS of a rock is influenced by grainsize and grain shape, rock fabric anisotropy, degree of cementation, rock density, porosity, etc. (e.g., Fahy and Guccione 1979, Shakoor & Bonelli 1991, Ulusay et al. 1994). However, only a few studies have investigated how UCS, E_t (slope of the line tangent at 50% of the UCS) and υ are influenced by core sample diameter, and what the relationships between those parameters may be (e.g., Jamshidi et al. 2014, Al-Rkaby & Alafandi 2015, Arman & Paramban 2021 and 2022). Therefore, there is room for further improve and insights into the effects of core sample diameter on the relationships between UCS, E_t and υ.

The aim of this study is to assess the effects of core sample diameter on the quantitative relationships between UCS, E_t and υ, and also to clarify the relations between UCS and elastic properties of limestone, E_t and υ, for different core sample diameters.

2 ROCK UNITS AND EXPERIMENTAL STUDIES

In the study area, the Dammam Formation is the youngest well-exposed stratigraphic unit. It is easily accessible and comprises gypsiferous mudstone, Nummulitic marly limestone, chalk, dolomitic limestone and marl (Arman et al. 2014) (Figure 1a). A number of limestone rock blocks of various dimensions were collected from the targeted study area at Jabal Hafit, Al Ain city, Abu Dhabi, United Arab Emirates (Figure 1a). All rock blocks were carefully examined in the field and laboratory to ensure that they were free of visible defects, such as fractures, veins, alteration zones, etc. This is important to avoid testing substandard rock specimens.

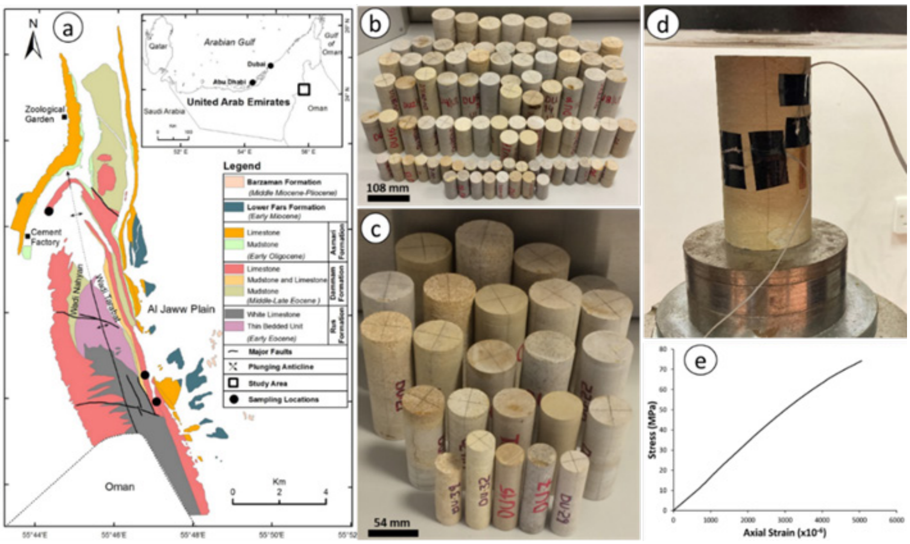

Figure 1. a) Sampling locations and geological map of the study area, b) Core samples prepared in different diameter for various mechanical and physical tests, c) Selected core samples in different diameter for UCS tests, d) Example of the UCS test with strain gauges setup, e) Example of stress (σ)–strain (ε) curve of a UCS test.

One hundred and ninety core samples with 25, 38, 48, 54 and 63mm diameter were extracted from limestone blocks. All core samples were prepared according to sample standards (ASTM 2019) (Figure 1b). Only 5 core samples were obtained for each diameter (except for diameter 64 mm, for which 4 samples were obtained) to be used for UCS tests (Figure 1c). The selected core samples were tested with strain gauges to construct stress– strain curves for each test sample, and for calculation of E_t and υ (ASTM 2014) (Figure 1d and e).

The statistical distributions of calculated values for the mechanical properties of the limestone (UCS, E_t and υ), along with core diameters and numbers of tested core samples, are given in Table 1.

3 RESULTS AND DISCUSSION

The relationships between the UCS and E_t for the five different core diameters were analyzed using simple linear regression techniques, which provide the most reliable empirical equations for the best fit line, along with the 95% confidence limit, and correlation coefficient R–value (Figure 2a–e). Although the data are limited and scattered, the regression analyses results indicate that the E_t illustrated weak to strong positive correlations with the UCS, with the correlation coefficient (R) values ranging from 0.21 to 0.87, except for core diameter 38 mm which showed a negative weak correlation, with the R−value of 0.17.

Table 1. Descriptive statistical results of mechanical properties of limestone.

Sample diameter and number	Descriptive statistics	UCS (MPa)	E_t x10^3 (MPa)	Y
25 mm, 5	Minimum	13	25	0.17
	Maximum	146	130	0.5
	Mean	72	60	0.34
	Standard deviation	62	43	0.12
38 mm, 5	Minimum	47	43	0.17
	Maximum	166	175	0.32
	Mean	100	76	0.23
	Standard deviation	52	56	0.06
48 mm, 5	Minimum	50	2	0.05
	Maximum	160	56	0.25
	Mean	106	33	0.16
	Standard deviation	50	25	0.09
54 mm, 5	Minimum	33	10	0.06
	Maximum	138	76	0.46
	Mean	94	48	0.26
	Standard deviation	45	32	0.16
54 mm, 4	Minimum	35	12	0.04
	Maximum	109	50	0.33
	Mean	71	33	0.18
	Standard deviation	31	19	0.12

UCS = Uniaxial Compressive Strength (MPa), E_t = Tangent Young's Modulus (MPa), υ = Poisson's Ratio

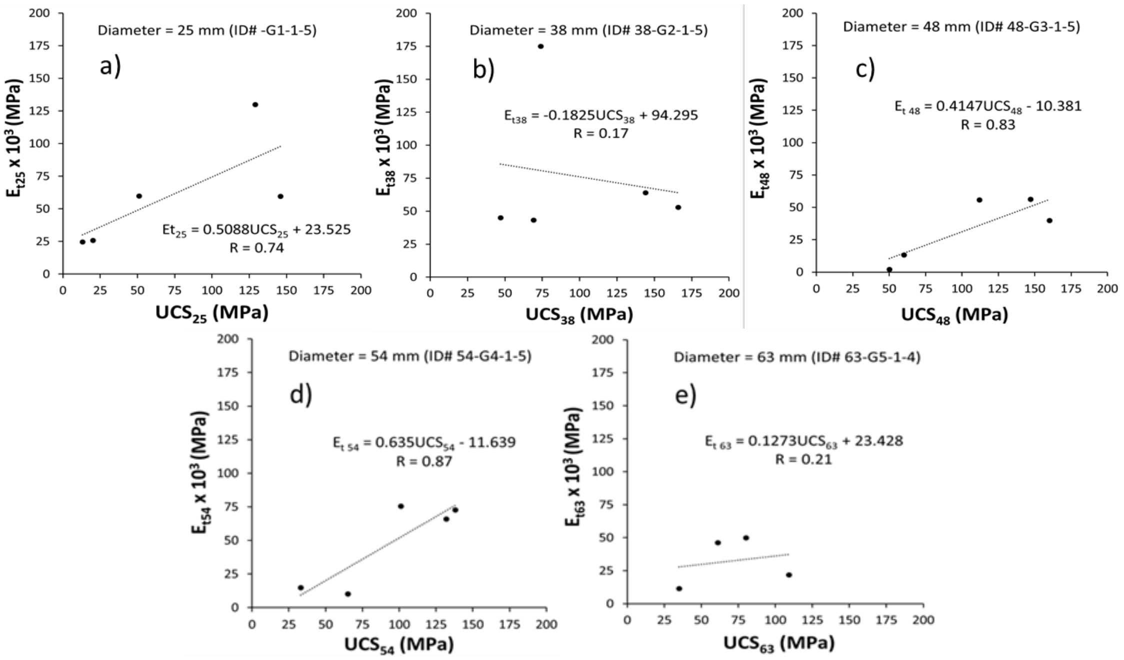

Figure 2. Relationships between the UCS and the E_t for different core sample diameter of a) 25 mm, b) 38 mm, c) 48 mm, d) 54 mm, e) 63 mm.

Similarly, the correlation between UCS and υ was strongly positive for core diameters of 25, 48, and 54 mm, with the R−value of 0.76, 0.77 and 0.9, respectively. For core diameters of 38 and 63 mm, the relationships between the plotted pairs of parameters vary from weak to moderate with negative linear correlations and the R−values of 0.41 and 0.24 (Figure 3a-e).

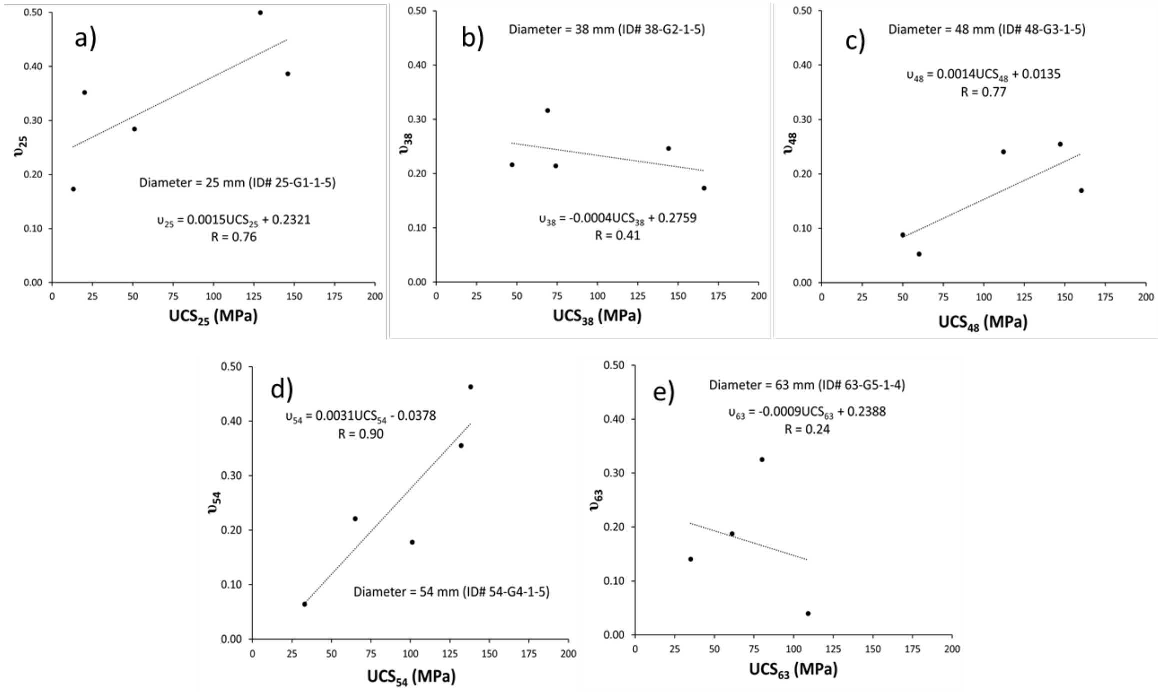

Figure 3. Relationships between the UCS and the υ for different core sample diameter of a) 25 mm, b) 38 mm, c) 48 mm, d) 54 mm, e) 63 mm.

Furthermore, the relationships between the core sample diameters and the mean UCS and the mean elastic properties, E_t and υ, were analyzed using a simple linear regression approach. The analyses showed that there were strong negative correlation trends, decreasing with increasing core sample diameter increments, for the mean E_t and υ, with the R−value of 0.70 and 0.79. However, there were no meaningful trend for the UCS case (Figure 4a-c).

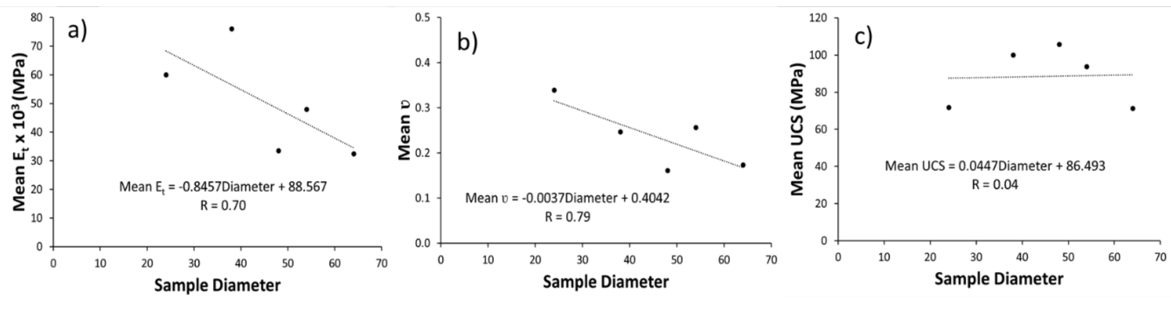

Figure 4. Relationships between sample diameter and a) the mean E_t, b) the mean υ, c) the mean UCS.

4 CONCLUSIONS

The possible effects of core sample diameter on relationships between the UCS and the elastic properties of limestone, E_t and υ, were investigated on 24 limestone core samples with diameters of 25, 38, 48, 54 and 63mm diameter. According to the analyses, the following conclusions can be drawn:

1. The linear regression analyses indicate weak to strong positive correlations between the UCS and the E_t with an exception for core diameter 38 mm, for which there is a negative weak correlation. Therefore, the UCS of limestone can be used to predict E_t, which requires tedious, more expensive and time-consuming efforts than the UCS test, within the corresponding correlation coefficient R–values.
2. The correlation analyses between the UCS and the υ exhibit positive strong relationships for core diameters 25, 48 and 54mm, however, the correlation was moderate to weak for core diameters 38 and 63mm. Thus, the υ can be estimated within certain accuracy limit using the UCS test results of limestone.
3. A strong relationship between core diameter and the mean E_t and the mean υ is evident, such that the E_t and the υ values decrease for increasing core diameters. In case of the mean UCS, there are no noticeable relationships.

Compositional and textural variations within the limestone core samples may cause the observed data scattering. Hence, the presented linear equations must be used with caution, and only for limestone. To generalize these equations to other rock types requires more extensive research and testing program. In addition, 54 mm core diameter (NX size) provides the best correlation coefficient value (R-value) for the first two analyses, and this study shows that 54 mm core diameter should be used as regular core diameter for coring samples, as suggested and recommended in standards.

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