Geomechanical Assessment of Limestone Deposits Using Uniaxial Compressive and Brazilian Tensile Strength Tests for Engineering Applications.

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Abstract: Geomechanical characterization of limestone is critical for assessing its suitability in engineering and construction applications. This study evaluates the mechanical properties of limestone from five locations (A1–A5) using uniaxial compressive strength (UCS) and Brazilian tensile strength (BTS) tests. Representative samples were prepared in accordance with ISRM standards and tested under controlled laboratory conditions. The UCS results range from 31.19 MPa to 68.06 MPa, indicating moderate to high strength variability across the study area. Locations A2 and A5 exhibit relatively higher compressive strength, suggesting more competent and well-cemented limestone, while A3 and A4 show greater variability due to heterogeneity in rock properties. BTS values range from 3.11 MPa to 7.24 MPa, confirming that limestone is significantly weaker in tension than in compression. A consistent relationship between UCS and BTS was observed, with tensile strength representing a small proportion of compressive strength. The results highlight the influence of geological variability on rock strength and emphasize the need for site-specific evaluation. This study provides useful data for geotechnical design, material selection, and rock mass classification in engineering applications.

Keywords: *Limestone, UCS, BTS, Geomechanical Properties, Engineering Applications.*

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I. INTRODUCTION

Limestone is one of the most widely utilized sedimentary rocks in civil engineering, mining, and construction due to its abundance, workability, and suitability as a raw material for cement, aggregates, and building stones. Its engineering performance is largely controlled by its physical and mechanical properties, which influence its behavior under loading conditions in geotechnical and structural applications. Limestone has been extensively used in engineering structures such as dams, tunnels, and foundations due to its favorable strength and durability characteristics (Zhang et al., 2023). Among the various mechanical parameters, uniaxial compressive strength (UCS) is regarded as the most fundamental property for evaluating the strength of intact rock. UCS plays a critical role in rock mass classification, excavation design, and stability analysis of engineering structures. It is widely used in geotechnical design because it provides a direct measure of the load-bearing capacity of rock materials. However, laboratory determination of UCS can be expensive, time-consuming, and requires carefully prepared specimens (Khanlari et al., 2024). In addition to compressive strength, the

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tensile strength of rocks, commonly determined using the Brazilian tensile strength (BTS) test, is equally important in understanding rock failure mechanisms. Rocks are generally much weaker in tension than in compression, making tensile strength a controlling factor in crack initiation and propagation. The Brazilian test is widely adopted due to its simplicity and effectiveness in indirectly determining tensile strength, especially for brittle rocks such as limestone (Erarslan and Williams, 2024). Furthermore, tensile strength plays a significant role in engineering problems such as blasting, drilling, and slope stability, where tensile failure often governs rock behavior (Li et al., 2024). Recent studies have emphasized the importance of integrating UCS and BTS measurements to better understand the mechanical behavior of rocks. Several researchers have developed empirical correlations between UCS and BTS, enabling prediction of compressive strength from tensile strength data. These correlations have proven useful in engineering applications, although their reliability depends on rock type and geological conditions (Singh and Rao, 2023). In addition, modern approaches such as regression analysis and machine learning techniques have improved the prediction accuracy of rock strength parameters (Liu et al., 2024). Limestone deposits often exhibit significant spatial variability in their geomechanical properties due to differences in mineral composition, porosity, grain size, and depositional environment. Such variability can significantly influence their suitability for engineering applications. Recent investigations have shown that both compressive and tensile strengths of limestone can vary widely across locations, highlighting the need for site specific characterization (Yilmaz and Yuksek, 2023). Despite the growing body of research on limestone characterization, there remains a need for localized studies that integrate both compressive and tensile strength properties, particularly in regions where geological variability is pronounced and data are limited. Many existing studies focus on either compressive or tensile strength independently, limiting a comprehensive understanding of rock behavior. Therefore, this study aims to evaluate the variability and relationship between uniaxial compressive strength and Brazilian tensile strength of limestone from selected locations. By conducting systematic laboratory testing and comparative analysis, the study seeks to provide insights into the mechanical behavior of limestone and its suitability for engineering applications. The findings are expected to contribute to improved rock characterization, support the development of predictive correlations, and enhance decision making in geotechnical and construction practices.

II. LITERATURE REVIEW

➢ *Importance of Geomechanical Characterization of Limestone*

Limestone is one of the most widely used geomaterials in civil engineering, construction, and mining due to its availability, workability, and mechanical competence. However, its engineering performance varies significantly depending on mineralogical composition, porosity, and diagenetic history. Recent studies emphasize that accurate geomechanical characterization is essential for evaluating its suitability in structural foundations, slope stability, tunneling, and aggregate production (Aladejare et al., 2021). The uniaxial compressive strength (UCS) remains one of the most critical parameters for assessing rock strength and is widely used in rock mass classification systems and engineering design. It directly influences excavation performance, blasting efficiency, and load-bearing capacity of rock materials (Aladejare et al., 2021). Recent investigations highlight that limestone exhibits considerable variability in strength properties due to heterogeneity in texture, microstructure, and environmental conditions, making localized geomechanical assessment necessary for reliable engineering applications.

➢ *Uniaxial Compressive Strength (UCS) of Limestone*

The uniaxial compressive strength (UCS) test is the most widely adopted laboratory method for determining the compressive strength of intact rock, providing a direct measure of the maximum axial stress a rock can withstand before failure under unconfined conditions (ISRM, 2007; Hoek and Brown, 1997). Several studies have shown that the UCS of limestone is strongly influenced by intrinsic properties such as porosity, grain size, degree of cementation, and mineral composition (Aladejare et al., 2021; Yilmaz and Yuksek, 2023). For instance, Hadi and Nygaard (2022) developed predictive models demonstrating that petrophysical parameters, including porosity and ultrasonic wave velocity, can reliably estimate UCS in carbonate rocks.

Recent experimental studies have further shown that integrating UCS with other physical and durability indices, such as slake durability index and P-wave velocity, significantly improves the classification and engineering characterization of limestone (Kahraman et al., 2023; Liu et al., 2024). Additionally, environmental factors such as temperature, moisture, and weathering conditions have been found to significantly affect compressive strength. Studies on thermally treated limestone indicate that UCS decreases with increasing temperature due to the development of microcracks, thermal expansion mismatch between minerals, and mineralogical alterations (Zhang et al., 2023; Erarslan and Williams, 2024).

➢ *Brazilian Tensile Strength (BTS) of Limestone*

While compressive strength is critical, tensile strength is equally important because most rock failures in engineering structures occur due to tensile stresses. However, direct tensile testing of rocks is difficult; hence, the Brazilian splitting test is widely used as an indirect method. The Brazilian tensile strength (BTS) test involves applying diametral compression to a cylindrical disc, inducing tensile stresses perpendicular to the loading direction. It is favored due to its simplicity, cost-effectiveness, and reproducibility (Yousefi and Fereidooni, 2020). Recent studies indicate that BTS values are sensitive to testing conditions, including loading configuration, specimen geometry, and moisture content. For example, water saturation has been shown to reduce tensile strength due to weakening of grain bonds and increased pore pressure (Rabat et al., 2022). Furthermore, tensile strength is typically much lower than compressive strength, often ranging between 5–15% of UCS in limestone, highlighting its vulnerability to cracking and failure under tensile loading conditions (general rock mechanics consensus supported by multiple studies).

➢ *Relationship Between UCS and BTS*

A strong correlation exists between UCS and BTS, which has been widely explored to develop predictive models for rock strength. Studies have demonstrated that BTS can be used to estimate UCS when direct compressive testing is not feasible. For example, Iyare et al. (2021) established empirical relationships between UCS and BTS using additional parameters such as elastic properties and wave velocities, showing that tensile strength can serve as a reliable predictor of compressive strength. Similarly, recent machine learning approaches have improved prediction accuracy by integrating multiple variables such as density, porosity, and ultrasonic velocity to estimate tensile strength and its relationship with UCS. The development of such predictive models is particularly useful in reducing laboratory costs and enabling rapid assessment of rock properties in field conditions.

➢ *Factors Influencing Limestone Strength*

The geomechanical behavior of limestone is controlled by several intrinsic and extrinsic factors, including:

- Mineralogy and texture: Grain size, cementation, and recrystallization influence strength properties.
- Porosity and density: Higher porosity generally reduces both UCS and BTS.
- Moisture content: Water weakens tensile strength and promotes crack propagation.
- Temperature: Elevated temperatures reduce mechanical strength due to thermal cracking.
- Testing conditions: Sample size, loading rate, and boundary conditions affect measured strength values.

Recent studies emphasize the need for integrated characterization approaches combining mechanical, physical, and mineralogical properties to better predict limestone performance in engineering applications.

➢ *Advances in Predictive Modeling and Engineering Applications*

Modern research trends focus on developing predictive models for uniaxial compressive strength (UCS) and Brazilian tensile strength (BTS) using statistical and artificial intelligence techniques. Regression-based approaches, artificial neural networks, and other machine learning models have demonstrated high accuracy in predicting rock strength parameters from easily measurable properties such as density, porosity, and ultrasonic wave velocity (Singh and Rao, 2023; Liu et al., 2024). These approaches significantly reduce the need for extensive laboratory testing while maintaining reliable predictive capability. These advancements are particularly relevant in large-scale engineering projects where rapid and cost-effective estimation of rock strength is required (Aladejare et al., 2021). Furthermore, recent studies have shown that hybrid models combining multiple input parameters outperform traditional empirical correlations in predicting UCS and BTS (Khanlari et al., 2024). In addition, integrated classification frameworks that combine UCS, BTS, and durability indices are increasingly being adopted to rank limestone quality and assess its suitability for construction applications (Yilmaz and Yuksek, 2023). Such frameworks provide a more comprehensive understanding of rock behavior and improve decision-making in geotechnical design and material selection.

III. METHODOLOGY

➢ *Study Area and Sampling*

Limestone samples were collected from five distinct locations designated as A1, A2, A3, A4, and A5, representing spatial variability within the study area. The sampling locations were selected to capture variations in lithology, texture, and structural characteristics of the limestone deposits. Block samples were obtained from fresh, unweathered outcrops to minimize the influence of surface alteration. Care was taken to ensure that samples were representative of in-situ conditions.

➢ *Sample Preparation*

Laboratory specimens were prepared in accordance with the standards of the International Society for Rock Mechanics (ISRM, 2007). Cylindrical specimens were prepared for UCS testing with a length-to-diameter ratio of 2:1. Disc-shaped specimens were prepared for Brazilian tensile strength (BTS) testing and the ends of samples were ground smooth and parallel to ensure uniform load distribution Defective samples with visible cracks or irregularities were discarded.

➢ *Uniaxial Compressive Strength (UCS) Test*

The UCS test was conducted using a compression testing machine under controlled loading conditions. Axial load was applied continuously until failure occurred. The UCS was determined using Equation (1).

(1)

Where;
P is the Maximum load at failure (kN);
A is the Cross-sectional area (mm²)

➢ *Brazilian Tensile Strength (BTS) Test*

The Brazilian tensile strength test was performed on disc-shaped specimens by applying diametral compression until failure. The BTS was determined using Equation 2.

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Where;
P is the Failure load
D is the Diameter
L is the Thickness

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IV. RESULTS AND DISCUSSION

Table 1 present the uniaxial compressive strength (UCS) results for limestone samples obtained from Locations A1 to A5. It indicates noticeable spatial variability in mechanical behavior despite uniform sample dimensions (40 mm diameter). The UCS values range from approximately 31.19 MPa to 68.06 MPa, reflecting differences in lithological characteristics, degree of cementation, and possible microstructural discontinuities within the rock mass. Location A1 exhibits moderate strength values, with UCS ranging between 35.15 MPa and 53.63 MPa, suggesting relatively consistent but moderately competent limestone. In contrast, Location A2 records the highest UCS value of 68.06 MPa and generally higher strength distribution (42.48–68.06 MPa), indicating stronger and more competent rock material, likely due to better consolidation and lower porosity.

Location A3 shows the widest variability, with UCS values spanning from 31.19 MPa to 59.63 MPa. This spread suggests heterogeneity in the rock fabric, possibly due to variations in mineral composition or the presence of fractures and weathered zones. Similarly, Location A4 demonstrates moderate to high strength (32.03–52.87 MPa), reflecting fairly competent limestone with some degree of variability. Location A5 presents consistently high UCS values (46.48–56.11 MPa), indicating relatively uniform and strong limestone deposits, which may be suitable for engineering applications requiring high load-bearing capacity. The results suggest that limestone from Locations A2 and A5 possesses superior mechanical properties, while Locations A1, A3, and A4 show moderate to variable strength characteristics. These findings are significant for geotechnical design and engineering applications, as they highlight the need for site-specific evaluation of limestone deposits prior to construction or mining activities.

Table 1 UCS of Limestone at Location A1 to A5

Location ID	Diameter of the Sample (mm)	Maximum Load (KN)	UCS (MPa)
	40	67.10	53.63
	40	43.98	35.15
A1	40	51.61	41.25
	40	53.80	42.99
	40	53.78	42.98
	40	85.15	68.06
A2	40	53.15	42.48
	40	55.68	44.50
	40	69.09	55.22
	40	65.15	52.07
	40	54.78	43.78
A3	40	52.21	41.73
	40	39.78	31.79
	40	74.61	59.63
	40	39.02	31.19
	40	49.52	39.58
	40	41.63	33.27
A4	40	50.71	40.53
	40	40.07	32.03
	40	53.42	42.70
	40	66.15	52.87
	40	60.81	48.60
A5	40	70.20	56.11
	40	68.21	54.52
	40	58.16	46.48

The Brazilian tensile strength (BTS) results for limestone samples from Locations A1 to A5 presented in table 2 reveal significant variations in tensile behavior, despite relatively consistent specimen dimensions (diameter ≈ 49.8 mm and thickness ranging from ~23.9 to 26.6 mm). The calculated tensile strength values range from 3.11 MPa to 7.24 MPa, reflecting differences in microstructural integrity, grain bonding, and the presence of micro-cracks within the rock matrix. At Location A1, tensile strength values vary between 3.99 MPa and 5.99 MPa, indicating moderate tensile resistance with some variability likely due to minor heterogeneities in the limestone fabric.

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Location A2 exhibits the highest tensile strength values, ranging from 4.83 MPa to 7.24 MPa, suggesting a more competent and well-cemented rock structure with improved resistance to tensile failure. In contrast, Location A3 shows a broader spread of values (3.79–5.92 MPa), indicating variability in rock quality, possibly associated with localized weaknesses such as micro-fractures or compositional differences. Similarly, Location A4 records the lowest tensile strength values overall (3.11–5.59 MPa), suggesting comparatively weaker rock material that may be more susceptible to tensile cracking and failure under stress. Location A5 demonstrates relatively high and consistent tensile strength values (4.58–6.88 MPa), indicating fairly competent limestone with good structural integrity. The results indicate that Locations A2 and A5 possess superior tensile strength characteristics, while Locations A3 and A4 exhibit relatively lower and more variable tensile performance. These findings are important for engineering design considerations, particularly in applications where tensile failure mechanisms such as cracking, blasting response, and slope stability are critical. The observed variability further emphasizes the necessity for site-specific geomechanical characterization of limestone deposits prior to their utilization in construction and mining projects.

Table 2. Brazilian Tensile Strength for Location A1 to A5

Location	D (MM)	L (MM)	P(kN)	Tensile Strength (MPa)
	49.86	24.93	9.51	4.87
A1	49.86	25.41	11.93	5.99
	49.86	25.89	8.10	3.99
	49.84	25.60	11.81	5.89
A2	49.84	26.08	14.80	7.24
	49.84	26.56	10.05	4.83
	49.85	24.56	9.25	4.81
A3	49.85	25.04	11.60	5.92
	49.85	25.52	7.88	3.94
	49.81	24.91	7.39	3.79
A4	49.81	25.39	9.26	4.66
	49.81	25.87	6.29	3.11
	49.79	23.90	10.45	5.59
A5	49.79	24.38	13.12	6.88
	49.79	24.86	8.92	4.58

V. CONCLUSIONS

This study presents a comprehensive geomechanical assessment of limestone deposits from five locations (A1–A5) using uniaxial compressive strength (UCS) and Brazilian tensile strength (BTS) tests. The results demonstrate that the limestone exhibits moderate to high strength characteristics, with UCS values ranging from 31.19 MPa to 68.06 MPa and BTS values from 3.11 MPa to 7.24 MPa. The observed variation in both compressive and tensile strengths reflect the influence of geological factors such as mineral composition, porosity, and microstructural features. Locations A2 and A5 consistently show higher strength values, indicating more competent and durable limestone suitable for demanding engineering applications. In contrast, Locations A3 and A4 display greater variability and relatively lower strength, suggesting heterogeneity and potential structural weaknesses that may affect performance under load. The study also confirms that tensile strength is significantly lower than compressive strength, with BTS representing a small fraction of UCS, highlighting the susceptibility of limestone to tensile failure. The findings emphasize the importance of integrating UCS and BTS measurements for reliable rock characterization. The study underscores the need for site-specific geomechanical evaluation to support safe and cost-effective design in construction, mining, and infrastructure development. These results provide valuable input for rock mass classification and contribute to improved decision-making in engineering practice.

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