

Engineering Geological Characterization and Correlation Analysis of Sandstone from the Yazd, Iran

Mehdi Hosseini¹, Ali Shirmohammadi¹, Ali Jafari Rad^{1,*}

¹Department of Geology, Maragheh Islamic Azad University, Maragheh 5519747591, Iran

*Corresponding author: jali_geo1375@gmail.com

Received: 10 February 2026 / Accepted: 30 March 2026 / Published: 25 May 2026
© The Author(s) 2026

Abstract: This study presents an engineering geological assessment of sandstone formations in the Yazd region of central Iran. A total of 150 rock samples were systematically collected from various outcrops within a defined area near Yazd city. The aim was to investigate the physical and mechanical properties of the sandstones and to analyze correlations between these properties, with particular emphasis on uniaxial compressive strength (UCS). Laboratory testing included measurements of dry and saturated density, porosity, water absorption, and uniaxial compressive strength. The results revealed a significant range in UCS values, reflecting heterogeneity in the geological features of the sandstone units. Correlation analysis was conducted to evaluate relationships between UCS and other physical properties. The findings indicate that UCS is moderately to strongly correlated with porosity (negatively), dry density (positively), and water absorption (negatively). These correlations provide insights into the geomechanical behavior of the local sandstone and support predictive modeling for engineering applications. The outcomes of this study are relevant for geotechnical design and site investigation in central Iran, particularly for infrastructure projects involving excavation, slope stability, and foundation engineering. The research also contributes to a better understanding of the variability in mechanical behavior of sedimentary rocks under arid climatic conditions.

Keywords: Sandstone, UCS, Physical properties, Engineering geology, Yazd region.

I. INTRODUCTION

Sandstone is a common sedimentary rock composed mainly of sand-sized mineral particles or rock fragments, predominantly quartz and feldspar (Yang, 2013). Due to its wide distribution, variation in texture, and mineral composition, sandstone has diverse mechanical and physical properties, which are of particular interest in engineering geology and geotechnical studies (Peng & Zhang, 2007). Sandstones can exhibit a broad range of compressive strengths, porosity, and durability,

depending on factors such as grain size, cementation, and weathering (Hencher, 2024). From an engineering perspective, the geomechanical behavior of sandstone is influenced by both intrinsic properties (e.g., mineralogy, grain interlocking, and cement type) and extrinsic factors such as weathering state, moisture content, and in-situ stress conditions (Jingli et al., 2019). These properties determine its suitability for various construction applications, including tunnels, slopes, foundations, and retaining structures (Jeng et al., 2004). Sandstone is often considered favorable for construction if it has low porosity, high strength, and resistance to environmental degradation (Tating et al., 2013).

The uniaxial compressive strength (UCS) of sandstone is one of the most essential parameters for rock engineering (Farrokhrouz & Asef, 2017; Mao et al., 2024). UCS is often correlated with other physical parameters such as dry density, porosity, and water absorption to establish predictive relationships that can assist in preliminary site assessment and design (Mousavi et al., 2018). In practice, these correlations are highly useful in reducing the number of costly mechanical tests required, especially when dealing with a large number of samples or limited resources (Cemiloglu et al., 2023; Mao et al., 2023).

In arid and semi-arid environments like central Iran, sandstones are often subjected to physical weathering due to temperature fluctuations, which can significantly affect their engineering behavior (Jafarzadeh & Hosseini-Barzi, 2008). This makes localized studies necessary to characterize their properties accurately before construction activities (Naghadehi et al., 2010). Furthermore, the natural variability of sandstone demands a statistically significant number of samples to establish meaningful engineering conclusions (Mohammadi et al., 2020; Ghoreishi et al., 2021). The city of Yazd, located in central Iran, is surrounded by various geological units that include prominent sandstone formations. These formations are part of different lithostratigraphic units formed during different geological periods, notably the Paleozoic and Mesozoic eras (Bagi, 2022). The area exhibits complex geological structures such as faults, folds, and intrusions, reflecting its tectonic history within the Central Iranian microplate (Torabi-Kaveh et al., 2023a). This stratigraphic variety results in a wide range of rock masses with

varying mechanical behaviors, necessitating detailed geotechnical characterization before any major construction activity (Torabi-Kaveh et al., 2023b). A geological map of the studied area is provided in Figure 1.

One of the engineering geological challenges in Yazd is the frequent presence of weathered and fractured rock masses near the surface (Fookes & Knill, 1969). Due to long-term exposure to arid climate conditions and thermal fatigue, many outcrops exhibit near-surface disintegration, exfoliation, and microcrack development (Tajbakhsh et al., 2024). These features can significantly reduce the intact rock strength and increase permeability, leading to slope instability and reduced bearing capacity in shallow foundations (Torabi-Kaveh et al., 2023a). Moreover, surface weathering can result in misleading estimations of rock mass strength unless proper sampling depth and procedures are used (Jamshidi et al., 2021). Subsurface investigations in several infrastructure projects near Yazd have revealed that jointed and blocky sandstone units are often underlain by compacted siltstone and shale, which can exhibit swelling behavior when exposed to water (Beheshti et al., 2022). This stratigraphic arrangement poses engineering risks such as differential settlement or slope failure, especially where excavation cuts expose layered rock with contrasting mechanical properties (Mojtaba et al., 2016). The heterogeneity of the geological formations requires the use of classification systems such as RMR (Rock Mass Rating) and GSI (Geological Strength Index) to account for variable joint conditions and weathering grades (Torabi-Kaveh et al., 2023b).

Karst features, though more prominent in the nearby Bafq and Taft areas, are occasionally observed in limestone units close to Yazd and can introduce significant engineering concerns. Subsurface cavities and solution channels may remain undetected during routine geotechnical surveys, leading to foundation instability or collapse hazards (Chitsazan & Manshadi, 2021). Geophysical methods, including ground-penetrating radar (GPR) and seismic refraction, have proven valuable in detecting such voids and delineating competent rock zones in preliminary investigations (Ahmadi & Nejad, 2024). Groundwater conditions also influence the engineering geology of the region (Ahmadi & Ahangarani, 2021). Despite the arid climate, perched water tables can develop locally above relatively impermeable shale or marl layers, especially after rare but intense rainfall events (Fookes & Knill, 1969). These localized water zones can reduce the effective stress in the rock mass and trigger slope failures or piping phenomena in unconsolidated deposits (Bahadori et al., 2021). Proper drainage design and hydrogeological assessments are essential for long-term geotechnical stability, particularly in road embankments and cut slopes (Amin et al., 2019). Additionally, seismicity is a key consideration in the engineering geology of Yazd. Although the city itself is not located on an active fault, it lies within a tectonically active region bounded by several major fault zones (Asadi et al., 2014). Seismic hazard assessments consider the potential for strong ground shaking, especially in areas with loose alluvial or colluvial deposits that may amplify seismic waves in the region (Mehnahad, 2000). The geostructural zones map of Yazd block has been provided in Figure 2. Rock structures, including tunnels, dams, and retaining walls, require careful design against seismic loads, including

potential degradation of jointed rock mass behavior under dynamic conditions (Arefi et al., 2021).

One of the key sandstone-bearing units in the Yazd region is the Shah-Kuh Formation, which consists of well-cemented sandstones with interbedded siltstone and shale layers (Aghanabati, 2012). These rocks have undergone various degrees of diagenesis and tectonic deformation, affecting their mechanical performance (Mehnahad, 2000). Another notable unit includes younger sandstone layers within Quaternary alluvial fans that have been partly lithified and show weaker geotechnical properties (Mirjalili et al., 2023). The Yazd region lies within the Central Iran structural zone, bounded by major fault systems such as the Doruneh Fault and the Kuhbanan Fault. The geological setting includes crystalline basement rocks, Mesozoic sedimentary sequences, and Cenozoic volcanic and intrusive bodies. This complex geological framework makes the area an ideal case study for understanding the variability in sedimentary rock behavior, particularly sandstone (Aghanabati, 2012). Climatically, Yazd is characterized by arid to hyper-arid conditions, with low annual rainfall and high diurnal temperature variation (Keshtkaran, 2011). These environmental factors contribute to the physical weathering of exposed rock outcrops, including sandstone units (Wilmsen et al., 2015; Shirgholami & Yazdi, 2025). The desert climate also affects moisture retention and influences the long-term mechanical stability of surface and near-surface rocks (Nezhad et al., 2019). Previous geological mapping and stratigraphic studies have provided a broad understanding of the regional lithology around Yazd (Aghanabati, 2012). However, there is a lack of detailed engineering geological studies focusing on the mechanical properties of sandstone in this area. This research aims to fill that gap by evaluating 150 sandstone samples collected from various outcrops in the Yazd vicinity, subjecting them to physical and mechanical testing to evaluate their engineering behavior.

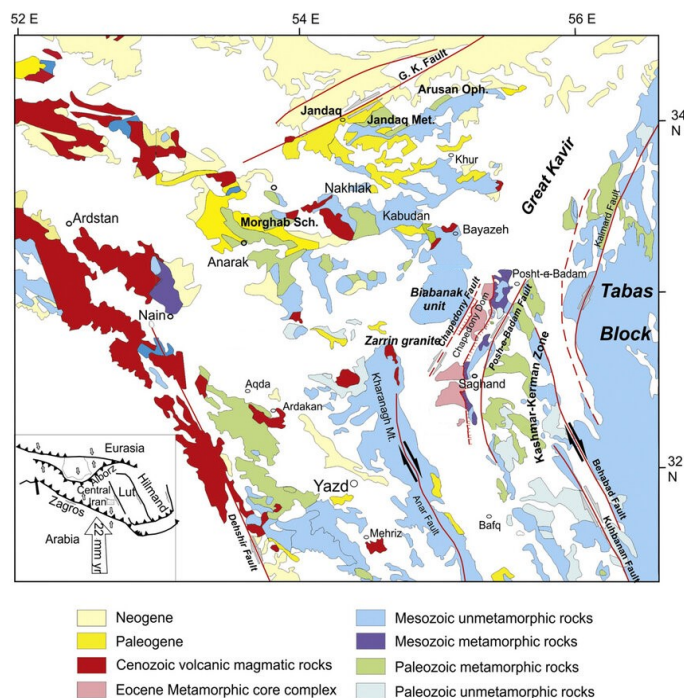


Fig. 1 Location and geological map of Yazd and studied region (Kargaranbafghi et al., 2015)

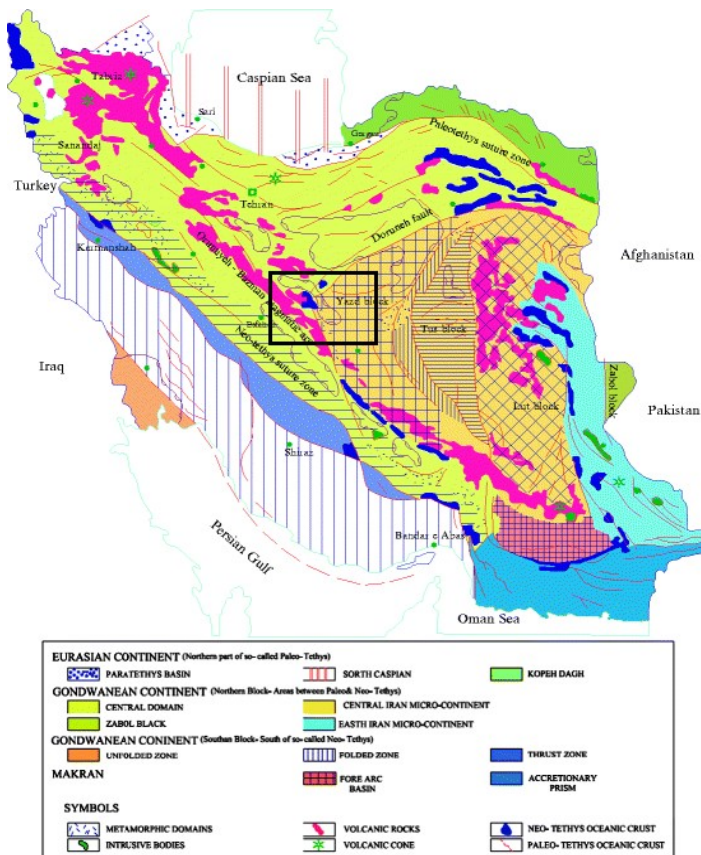


Fig. 2 Geotectonic zones map of Yazd block in Iran (Ghorbani, 2013)

The purpose of this study is to characterize the engineering geological behavior of sandstone formations around Yazd and to establish empirical correlations between uniaxial compressive strength (UCS) and key physical parameters. By systematically analyzing a representative set of sandstone samples, this research aims to identify the controlling factors that influence strength and deformability in these rocks. Particular attention is given to the relationships between UCS and properties such as porosity, density, and water absorption, which are commonly used as indirect indicators in geotechnical investigations. Understanding these relationships can improve the reliability of preliminary site assessments where direct strength testing may be limited due to time or cost constraints. Furthermore, the results provide a practical framework for estimating mechanical properties from easily measurable physical indices. This approach can significantly reduce the need for extensive laboratory testing while maintaining acceptable accuracy in engineering evaluations. In addition, this study seeks to enhance the existing geotechnical knowledge base for central Iran by providing locally derived data that reflect the specific geological and climatic conditions of the Yazd region. The findings are expected to support more accurate predictive models and contribute to safer and more economical engineering designs. This is particularly important for infrastructure projects involving excavation, slope stability, and foundation systems constructed on or within sandstone units. Ultimately, the outcomes of this research will assist engineers and geologists in making better-informed decisions by reducing uncertainty associated with the mechanical behavior of heterogeneous sandstone formations.

II. UNIAXIAL COMPRESSIVE STRENGTH

The concept of strength in rock mechanics is fundamental to understanding how rocks behave under applied stress (Cemiloglu et al., 2023). One of the most essential strength parameters in geotechnical and engineering geology is the UCS, which represents the maximum axial load a cylindrical rock sample can withstand before failure, without any lateral confinement (Mao et al., 2023; Nanehkaran et al., 2023). It is used extensively in engineering design, site characterization, and numerical modeling of rock behavior under stress conditions (Huang et al., 2019). UCS is defined as the compressive stress at which a specimen of rock fails in a controlled laboratory test when subjected to axial loading under zero confining pressure (Sheshde & Cheshomi, 2015). Mathematically, it is expressed as the peak axial load divided by the cross-sectional area of the specimen. UCS is often regarded as the most direct and reliable indicator of a rock's mechanical integrity, particularly for intact rock samples (Altındağ & Güney, 2010). It is typically expressed in units of megapascals (MPa).

The determination of UCS is of critical importance in rock engineering. It serves as a baseline input for numerous rock classification systems such as the Rock Mass Rating (RMR), Q-System, and Geological Strength Index (GSI) (Azarafza et al., 2017). UCS is also critical in calculating parameters like cohesion and internal friction angle through Mohr–Coulomb failure criteria and Hoek–Brown failure envelopes. These parameters directly affect the design of slopes, tunnels, foundations, and underground excavations (Bejarbaneh et al., 2015). Moreover, UCS plays a key role in estimating other rock properties that are difficult or expensive to measure directly, such as tensile strength, deformability modulus, and point load strength index (Cemiloglu et al., 2023).

Empirical relationships between UCS and these properties are widely accepted and used in practice, especially when only a limited amount of core material is available (Corkum et al., 2018). UCS also helps engineers assess durability and weathering susceptibility of rock types in various environmental conditions (Sadeghi et al., 2022). The UCS test involves subjecting a prepared rock specimen, typically a right cylindrical core with a length-to-diameter ratio between 2:1 and 2.5:1, to a gradually increasing axial load until failure occurs. The ends of the sample must be perfectly flat and parallel to ensure even distribution of stress (Nanehkaran et al., 2023). The loading is performed under controlled strain or stress rate conditions to avoid dynamic effects and to ensure consistent results. The failure mode, stress-strain behavior, and axial deformation are recorded throughout the test (Cemiloglu et al., 2023).

Figure 3 provides a schematic of the UCS test and its details. The equipment used for UCS testing is known as a uniaxial compression testing machine, or a uniaxial load frame (Bejarbaneh et al., 2015). This device consists of a hydraulic or mechanical actuator capable of applying high axial loads, a loading platen, displacement sensors, and a data acquisition system (Isah et al., 2020). Some machines also include high-resolution cameras for observing fracture development. Most modern systems are computer-controlled and allow precise load and displacement monitoring during the entire test (Cemiloglu et al., 2023).

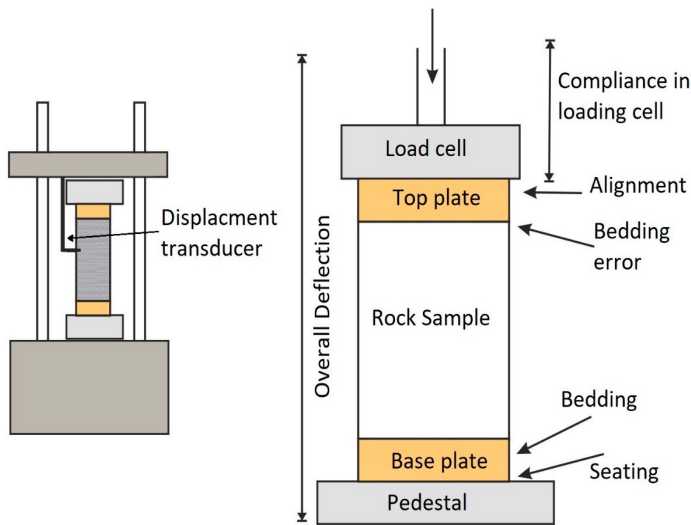


Fig. 3 A schematic of a regular UCS test (Isah et al., 2020)

In a standard UCS test, the rock specimen is placed vertically between the upper and lower platens of the testing machine (Nazir et al., 2013). Once aligned, a compressive load is applied at a constant rate (either stress-controlled or strain-controlled), until the sample fails (Mousavi & Rezaei, 2022). The axial load and corresponding displacement are recorded continuously, allowing for generation of a stress-strain curve (Rajabzadeh et al., 2012). Peak stress at failure corresponds to the UCS, while the slope of the linear portion of the curve gives the Young's modulus (Sheshde & Cheshomi, 2015). The failure patterns observed in UCS tests can provide additional insight into rock behavior (Nanehkaran et al., 2023). Brittle rocks often fail through axial splitting or shear fractures, while weaker or more ductile rocks may exhibit bulging, yielding, or crushing behavior (Cao et al., 2016). Observing these failure modes helps engineers understand the potential performance of rock under field conditions (Afifpour & Moarefvand, 2014). Additionally, variations in UCS across multiple samples from the same lithology can indicate degrees of weathering, anisotropy, or microstructural defects (Cemiloglu et al., 2023).

III. MATERIALS AND METHODS

This research employed a systematic and multidisciplinary approach to evaluate the engineering geological characteristics of sandstone formations in the Yazd region of central Iran. The methodology began with the selection of a representative study area near Yazd city, where sedimentary rock outcrops are prominently exposed. A total of 150 rock samples were collected through field mapping and stratified random sampling from various sandstone outcrops to ensure geological diversity and spatial representation. Fieldwork also involved initial observations regarding bedding orientation, weathering degree, and lithological variation. Following collection, the samples were transported to the laboratory for detailed physical and mechanical testing. Each specimen was first prepared according to ASTM and ISRM standards to ensure consistency and reliability in test results. Physical properties were determined through standard procedures, including measurements of dry density, saturated density, porosity, and water absorption. Subsequently, UCS tests

were performed using a universal testing machine to assess the mechanical resistance of the rocks under axial loading. Figure 4 provides the flowchart of the process for this study.

To interpret the results, statistical and correlation analyses were conducted. The relationships between UCS and other measured physical properties were examined using Pearson correlation coefficients. This allowed for the identification of significant trends, such as negative correlations between UCS and porosity or water absorption, and a positive correlation with dry density. These analyses were instrumental in understanding the internal structure and mechanical behavior of the sandstones. The methodology was designed to support predictive geotechnical modeling and provide practical insights for engineering applications, including slope stability analysis, excavation planning, and foundation design in arid environments. The integration of field data, laboratory testing, and statistical analysis ensured a comprehensive evaluation of the geomechanical variability within the local sandstone formations.

The implementation of this study began with defining the geographic boundaries around Yazd city where sandstone formations are prominently exposed. A reconnaissance visit was first carried out to identify suitable sampling locations based on accessibility, geological variability, and safety conditions. Subsequently, a total of 150 sandstone samples were manually extracted using a hammer and chisel, ensuring minimal disturbance to the surrounding environment. Each sample was labeled and logged with location coordinates, outcrop descriptions, and visible physical characteristics such as color, texture, and degree of weathering. In the laboratory, the samples were trimmed and prepared according to international standards to ensure consistent dimensions for testing. The preparation stage included cutting cylindrical specimens for UCS testing and determining volume and weight for density calculations.

The physical testing began with measurements of dry and saturated mass, followed by porosity and water absorption analysis using standard soaking and oven-drying methods. Once physical data were collected, the UCS test was performed using a hydraulic press machine, applying axial load until failure. After the tests, all data were compiled into a central database. The dataset was cleaned, and preliminary statistics were computed. A correlation analysis was then conducted to explore the relationships between UCS and the physical characteristics of the rocks. Finally, the interpreted results were used to derive conclusions regarding the mechanical behavior of the sandstones in arid climates and to provide practical recommendations for geotechnical design in the region. The entire process ensured a blend of field observation, precise lab work, and statistical analysis to support engineering decisions.

To further quantify the relationships between UCS and the measured physical properties, a detailed statistical analysis was carried out. Initially, descriptive statistical parameters (i.e., mean, standard deviation, and coefficient of variation) were calculated for all variables. The mean value was determined based on Eq. 1, which represents the average of the dataset, where X_i is the individual observation and n is the total number of samples:

$$\bar{X} = \frac{1}{n} \sum_{i=1}^n X_i \quad (1)$$

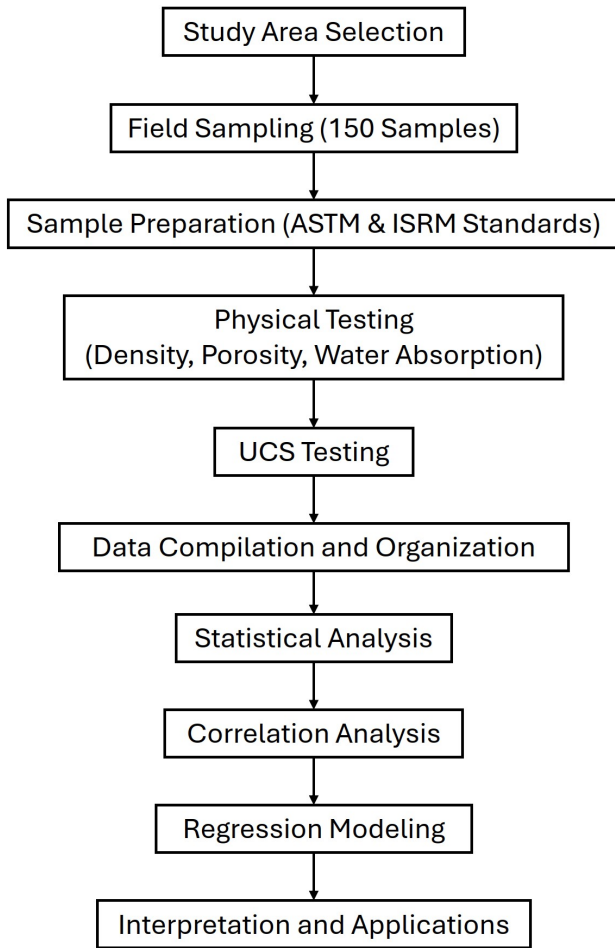


Fig. 4 Working flowchart used in this study

The dispersion of the data was evaluated using the standard deviation, calculated according to Eq. 2, where $\bar{X}$ is the mean value:

$$SD = \sqrt{\frac{\sum_{i=1}^n (X_i - \bar{X})^2}{n-1}} \quad (2)$$

Furthermore, the relative variability of the dataset was expressed using the coefficient of variation (CV), as defined in Eq. 3:

$$CV = \frac{SD}{\bar{X}} \times 100 \quad (3)$$

To assess the relationships between UCS and physical parameters such as porosity, dry density, and water absorption, Pearson's correlation coefficient was calculated using Eq. 4. In this equation, X and Y represent the paired variables, while $\bar{X}$ and $\bar{Y}$ denote their respective mean values:

$$r = \frac{\sum_{i=1}^n (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^n (X_i - \bar{X})^2 \cdot \sum_{i=1}^n (Y_i - \bar{Y})^2}} \quad (4)$$

Following the correlation analysis, regression modeling was performed to establish predictive relationships between UCS and the measured physical properties. A simple linear regression model was first applied based on Eq. 5, where UCS is the dependent variable, X is the independent variable, and a and b are regression coefficients:

$$UCS = a + bX \quad (5)$$

In addition, multiple linear regression analysis was conducted to improve prediction accuracy by incorporating more than one independent variable. The general form of the model is expressed in Eq. 6, where $X_1, X_2, \dots, X_n$ represent the physical parameters and $b_1, b_2, \dots, b_n$ are their corresponding coefficients:

$$UCS = a + b_1X_1 + b_2X_2 + \dots + b_nX_n \quad (6)$$

The regression coefficients were estimated using the least squares method, minimizing the difference between observed and predicted UCS values. Model performance was evaluated using the coefficient of determination (R^2) and adjusted R^2 , while statistical significance was assessed at a confidence level of 95% ($p < 0.05$). This analytical framework provided a robust basis for interpreting the relationships between physical and mechanical properties and for developing predictive models applicable to geotechnical engineering practice.

IV. RESULTS AND DISCUSSION

The results from the laboratory testing of 15 representative sandstone samples from the Yazd region reveal a significant variation in both physical and mechanical properties. The UCS values ranged between approximately 38 MPa and 117 MPa, reflecting the inherent heterogeneity in mineral composition, grain bonding, and porosity of the sandstones. In accordance with Figure 5, the relationship between UCS and the physical properties of the sandstone samples can be interpreted through the observed trends in the plotted relationships.

In the first graph (UCS vs. Dry Density) of Figure 5, there is a visible upward trend suggesting a positive correlation. This means that as the dry density of the samples increases, the UCS tends to rise as well. Denser sandstone samples are structurally more compact, which enhances their ability to resist compressive stress. Although the scatter of data points indicates some variability, the overall direction of the regression line supports this positive relationship. In the second graph (UCS vs. Porosity), the regression line trends downward, revealing a negative correlation between porosity and UCS. Sandstones with higher porosity values show lower UCS, which is consistent with geomechanical expectations. Higher porosity indicates more void space within the rock, reducing the contact area between grains and thereby weakening the rock's capacity to bear load. The third graph (UCS vs. Water Absorption) also exhibits a negative correlation, as represented by the descending trend of the regression line. This suggests that samples with greater water absorption tend to have lower UCS values. Water likely infiltrates pore spaces and microcracks, which can contribute to weakening the rock matrix and accelerating the onset of failure under stress.

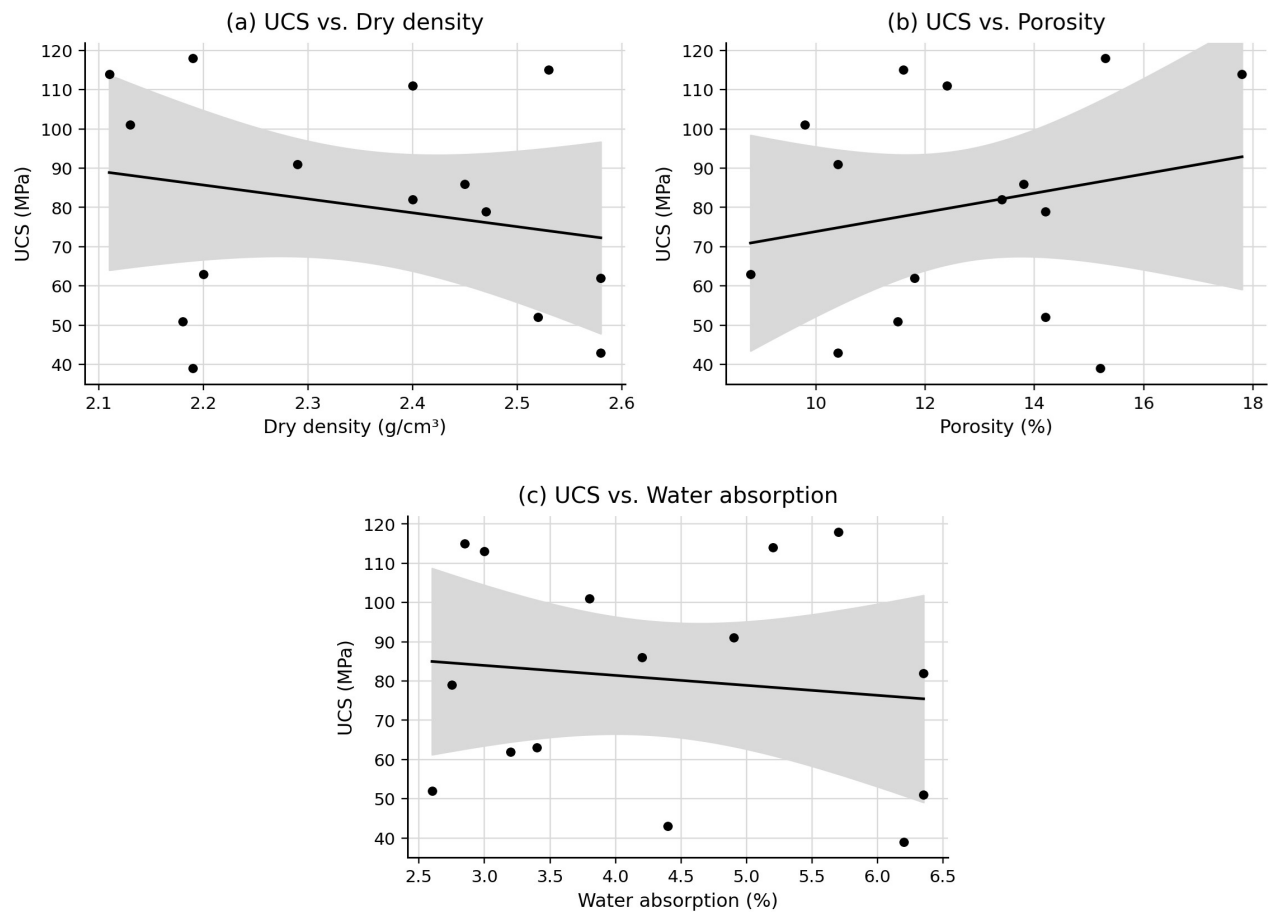


Fig. 5 Correlation of UCS with physical properties: (a) dry density, (b) porosity, (c) water absorption

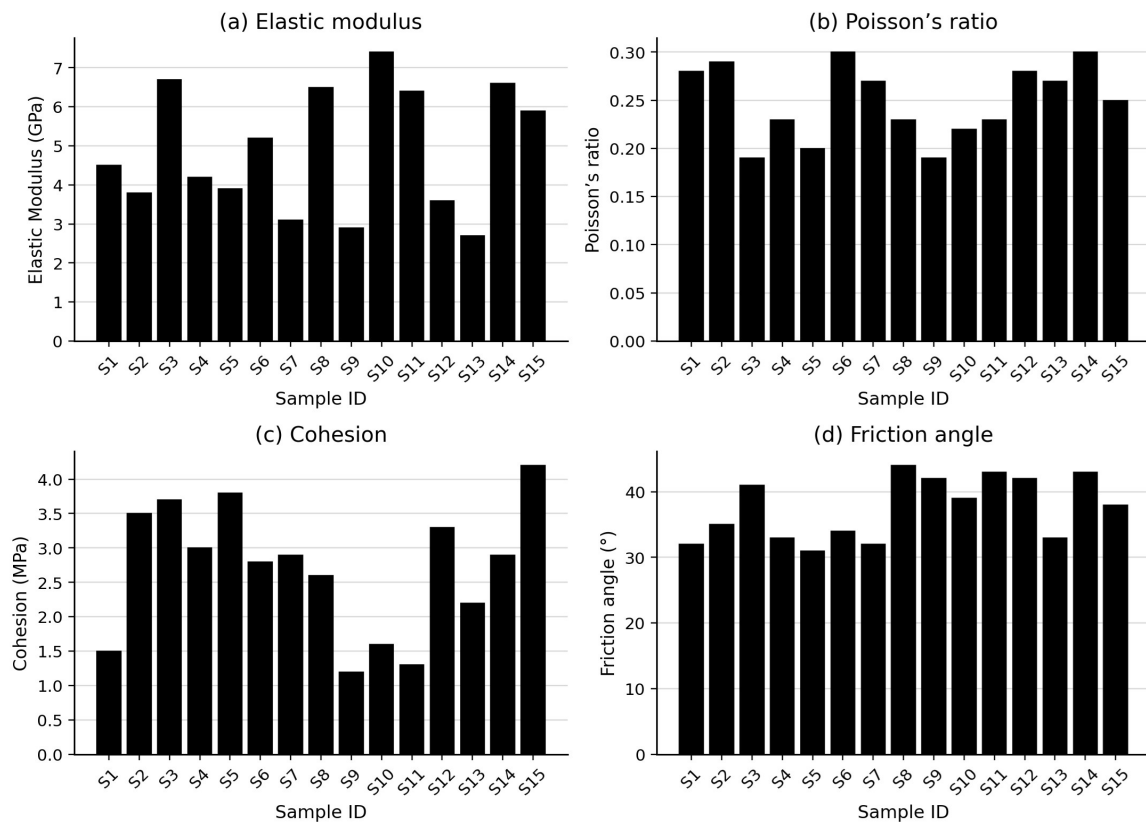


Fig. 6 Variability of mechanical properties: (a) elastic modulus, (b) Poisson's ratio, (c) cohesion, (d) friction angle

Table 1 Influence of microstructural characteristics on the mechanical behavior of sandstone

Parameter	Effect on UCS	Engineering Interpretation
Grain size	Variable	Controls packing and contact points
Cementation quality	Positive	Stronger bonding increases strength
Porosity	Negative	Higher void space reduces load-bearing area
Pore connectivity	Negative	Facilitates crack propagation

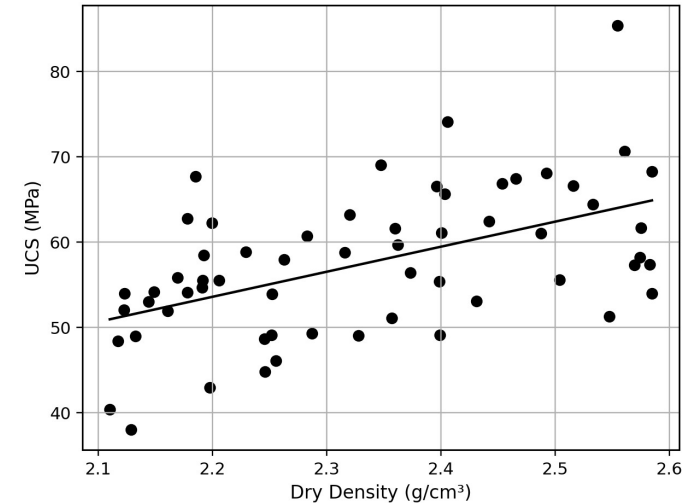


Fig. 7 Relationship between UCS and dry density, showing a positive linear trend

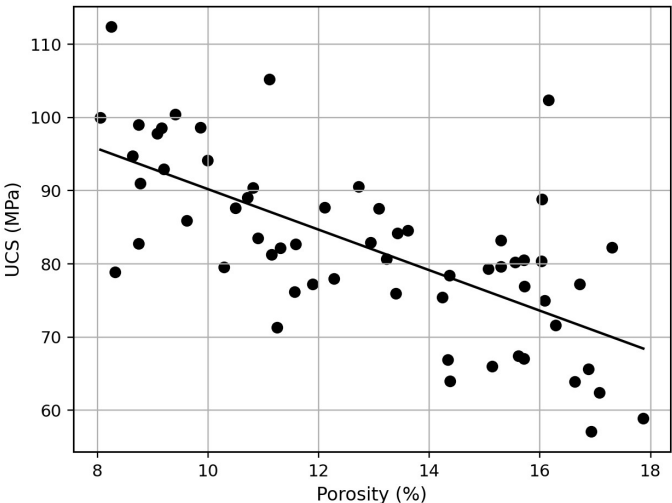


Fig. 8 Relationship between UCS and porosity, indicating a negative correlation

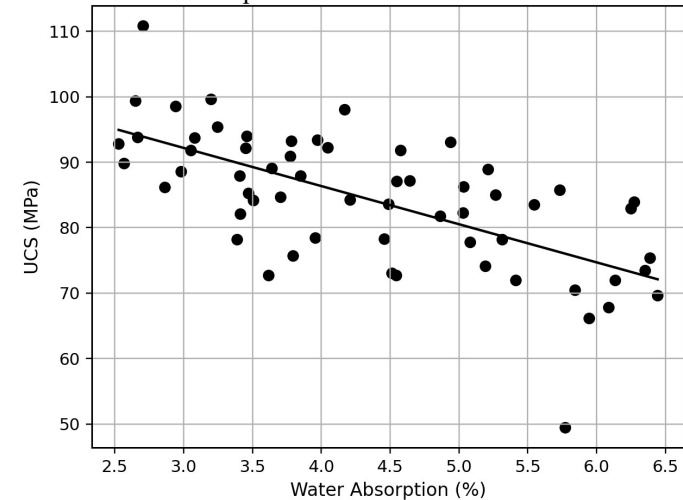


Fig. 9 Relationship between UCS and water absorption, demonstrating a decreasing trend

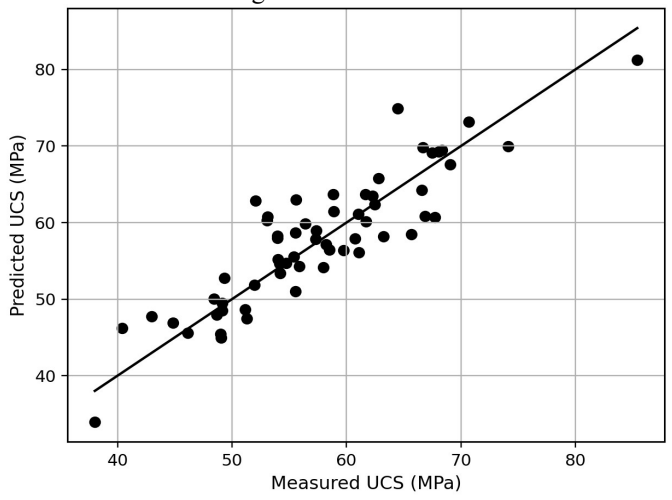


Fig. 10 Comparison between measured and predicted UCS, showing good agreement and model reliability

These trends collectively indicate that UCS is strongly influenced by the internal structure and moisture-related characteristics of the sandstone, and that these physical parameters can be used as reliable predictors of mechanical strength in geological assessments. The bar charts illustrate the distribution of key engineering properties across the sandstone samples, providing a clear picture of their mechanical diversity, as shown in Figure 6. In the Elastic Modulus chart (Figure 6a), noticeable variations are observed among the samples, with values ranging from around 2.5 to over 7 GPa. This visual spread suggests that some samples exhibit significant stiffness and resistance to deformation under load, while others are more flexible. Higher values in this chart indicate stiffer materials, likely due to better cementation and denser grain packing.

Poisson’s ratio chart (Figure 6b) shows values fluctuating between 0.18 and 0.32. The relatively consistent bar heights indicate that most samples exhibit similar lateral deformation behavior under axial stress. However, a few samples stand out with higher ratios, which implies more ductile behavior and possibly weaker grain interlock. The cohesion chart (Figure 6c) indicates that there is a moderate range in values from approximately 1.2 to 4.5 MPa. Some bars are significantly taller, indicating that those rock samples possess stronger internal bonding. These samples would likely perform better under shear stress conditions, making them more suitable for structural support in slopes and excavations. Finally, the friction angle chart (Figure 6d) reveals a range of values between 30° and 45°. This indicates varying degrees of resistance to internal sliding. The samples with taller bars (closer to 45°) have higher shear

strength and would be more stable under loading, especially in slope or foundation scenarios. Collectively, these visual representations emphasize the mechanical variability of sandstone in the Yazd region. The diversity in bar heights reflects the geological heterogeneity and underscores the importance of sample-specific assessments for geotechnical design.

In addition to the observed correlations, the variability in UCS values can be attributed to differences in the microstructural characteristics of the sandstone samples. Variations in grain size distribution, degree of cementation, and mineral composition play a fundamental role in controlling strength behavior. Samples exhibiting well-interlocked grains and strong cementation generally demonstrate higher UCS values, whereas poorly cemented or loosely packed grains result in reduced mechanical strength. To better illustrate this relationship, a conceptual diagram (Figure 7) is proposed, highlighting the influence of grain bonding and packing density on compressive strength. Furthermore, the relationship between physical properties and UCS is strongly influenced by pore structure characteristics. Not only the magnitude of porosity, but also pore geometry including size, shape, and connectivity, affects stress distribution within the rock matrix. Highly connected pore networks act as preferential pathways for crack propagation, leading to premature failure under load. This explains why samples with similar porosity values may still exhibit different UCS responses. To summarize these effects, Table 1 presents the qualitative influence of key microstructural features on mechanical behavior.

The effect of moisture on sandstone strength is also evident from the results. Although the Yazd region is characterized by arid climatic conditions, intermittent moisture exposure can significantly influence mechanical behavior. Water presence within pore spaces reduces effective stress and weakens intergranular bonding, leading to a decrease in UCS. This behavior aligns with the observed negative correlation between water absorption and UCS. A schematic representation (Figure 8) can be used to demonstrate the weakening effect of moisture on the internal structure of sandstone. Another key observation is the pronounced heterogeneity within the sampled sandstone units. Even within relatively محدود spatial extents, considerable variability in both physical and mechanical properties was observed. This heterogeneity has direct implications for geotechnical design, as it may lead to non-uniform performance of rock masses under loading conditions. To visualize this variability, a comparative boxplot diagram (Figure 9) is suggested to represent the distribution of UCS and associated physical parameters across all samples. Finally, the empirical relationships established between UCS and physical properties provide a practical framework for predictive modeling in engineering applications. These relationships enable the estimation of UCS using easily measurable parameters, reducing the need for extensive laboratory testing. However, it is important to consider that such models are site-specific and must be calibrated for local geological conditions. Figure 10 is proposed to present the regression-based predictive model, illustrating the relationship between measured and estimated UCS values.

Collectively, these analyses demonstrate that the mechanical behavior of sandstone in the Yazd region is governed by a

combination of microstructural features, pore characteristics, and environmental influences. The integration of these factors into a unified analytical framework enhances the reliability of geotechnical assessments and supports more informed engineering decision-making.

V. CONCLUSION

This study provided a comprehensive engineering geological assessment of sandstone formations in the Yazd region of central Iran. Through systematic field sampling and laboratory testing, key physical and mechanical properties of 150 sandstone samples were evaluated. The main focus was on UCS and its relationship with other measurable parameters such as dry density, porosity, and water absorption. The results revealed a wide range of UCS values, reflecting the geological heterogeneity and variable cementation among the sandstone units. Correlation analyses indicated that UCS is positively associated with dry density, and negatively correlated with both porosity and water absorption. These findings align with known geomechanical principles, where higher density typically contributes to greater strength, while higher porosity and moisture content tend to weaken rock materials. The visual representation of these trends further confirmed these relationships, highlighting their predictive value in assessing rock strength. In addition to UCS, engineering properties such as elastic modulus, Poisson's ratio, cohesion, and friction angle were evaluated. The charts showed considerable variation across samples, emphasizing the importance of site-specific testing. Higher cohesion and friction angles in some samples point to their potential suitability for use in structural foundations, slope stabilization, and excavation design. However, the variability in properties underlines the necessity of thorough site investigation before engineering implementation.

ACKNOWLEDGMENT

We sincerely thank the reviewers for their careful reading and constructive comments, which helped improve the clarity and quality of this manuscript.

DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are available within article. No publicly archived dataset was generated.

ETHICS APPROVAL

This study did not involve human participants, personal data, or animal subjects. No specific ethical approval was required.

FUNDING

This research received no external funding.

AUTHORS' CONTRIBUTIONS

Mehdi Hosseini and Ali Shirmohammadi conducted the main data analysis, contributed to the data collection, preprocessing, and interpretation, and were responsible for drafting the initial manuscript. Ali Jafari Rad performed supervision, conceptual guidance, critical revision of the manuscript, overall project administration and final approval of the version to be published. All authors read and approved the final manuscript.

CONFLICT OF INTEREST

The authors have not disclosed any competing interests.

USE OF AI

AI tools were not used in data generation, analysis, results, or decision-making.

OPEN ACCESS

This article is distributed under the terms of the *Creative Commons Attribution 4.0 International License*, which allows use, sharing, adaptation, distribution, and reproduction in any medium or format, provided appropriate credit is given to the original author(s) and the source. A link to the Creative Commons license must also be provided, and any modifications should be clearly indicated. Unless otherwise noted in a credit line, images or third-party materials included in this article are covered under the article's Creative Commons license. For material not included in the license or where statutory regulations do not apply, permission must be obtained directly from the copyright holder. To view the full license, visit <http://creativecommons.org/licenses/by/4.0/>.

Publisher's Note: This journal remains neutral with regard to jurisdictional claims in published maps, data, and institutional affiliations.

REFERENCES

- Afifipour M., Moarefvand P. (2014). Mechanical behavior of bimrocks having high rock block proportion. *International Journal of Rock Mechanics and Mining Sciences*, 65, 40-48. <https://doi.org/10.1016/j.ijrmms.2013.11.008>.
- Aghanabati A. (2012). *Geology of Iran*. Geological Survey and Mineral Exploration of Iran press, Tehran, Iran.
- Ahmadi R., Ahangarani M.L. (2021). Application of probabilistic neural network method for classification of Yazd, Ali-Abad copper deposit. *Iranian Journal of Engineering Geology*, 14(3), 124-126.
- Ahmadi R., Nejad, J.E. (2024). 3-D geophysical modeling using 2-D acquisition data and geostatistics for Yazd, Ali-Abad copper deposit to propose optimal drilling location. *Researches in Earth Sciences*, 15(2), 77-95. <https://doi.org/10.48308/esrj.2023.103818>.
- Altındağ R., Güney A. (2010). Predicting the relationships between brittleness and mechanical properties (UCS, TS and SH) of rocks. *Scientific Research and Essays*, 5(16), 2107-2118.
- Amin P., Ghalibaf M.A., Hosseini M. (2019). Land subsidence and soil cracks monitoring by surveying on the clayey plain soils in Central Iran (case study: Yazd City). *Arabian Journal of Geosciences*, 12, 1-11. <https://doi.org/10.1007/s12517-019-4241-3>.
- Arefi M.R., Ariyamanesh M., Mir Hosseini S.M. (2021). Presentation of Zoning Model of Land Subsidence Dangers in Yazd-Ardakan Plain. *Review of International Geographical Education Online*, 11(10), 35-46.
- Asadi A., Neshat S., Barkhordari M. K. (2014). Seismic hazard assessment and determination of maximum design base acceleration of Yazd. *Journal of Rehabilitation in Civil Engineering*, 2(2), 1-9.
- Azarafza M., Akgün H., Asghari-Kalajahi E. (2017). Assessment of rock slope stability by slope mass rating (SMR): a case study for the gas flare site in Assalouyeh, South of Iran. *Geomechanics and Engineering*, 13(4), 571-584. <https://doi.org/10.12989/gae.2017.13.4.571>.
- Bagi H. (2022). Geotechnical analysis of igneous rocks (Andesite) from west of Yazd for Engineering Uses. *Journal of Research in Civil Engineering and Architecture of Iran*, 26(3), 28-32.
- Bahadori M., Beiranvand P., Amnieh, H.B. (2021). Optimization of Sardasht Dam Sealing System Using UDEC Software. *Journal of Analytical and Numerical Methods in Mining Engineering*, 11(26), 23-34. <https://doi.org/10.22034/anm.2021.1827>.
- Beheshti S.H., Bafghi A.Y., Ghorbani A., Rezvanianzadeh M.R. (2022). Relationship between physical and mechanical properties of jointed rocks in Central Iran (Bafgh Block). *Journal of Analytical and Numerical Methods in Mining Engineering*, 12(31), 1-13. <https://doi.org/10.22034/anm.2022.2026>.
- Bejarbaneh B.Y., Armaghani D.J., Amin M.F.M. (2015). Strength characterisation of shale using Mohr–Coulomb and Hoek–Brown criteria. *Measurement*, 63, 269-281. <https://doi.org/10.1016/j.measurement.2014.12.029>.
- Cao R.H., Cao P., Fan X., Xiong X., Lin H. (2016). An experimental and numerical study on mechanical behavior of ubiquitous-joint brittle rock-like specimens under uniaxial compression. *Rock Mechanics and Rock Engineering*, 49, 4319-4338. <https://doi.org/10.1007/s00603-016-1029-6>.
- Cemiloglu A., Zhu L., Arslan S., Xu J., Yuan X., Azarafza M., Derakhshani R. (2023). Support vector machine (SVM) application for uniaxial compression strength (UCS) prediction: a case study for Maragheh limestone. *Applied Sciences*, 13(4), 2217. <https://doi.org/10.3390/app13042217>.
- Chitsazan M., Manshadi B.D. (2021). Role of Mehriz Fault in hydrochemical evolution and groundwater flow of Yazd aquifer, central Iran. *Arabian Journal of Geosciences*, 14(7), 560. <https://doi.org/10.1007/s12517-020-06395-3>.
- Corkum A.G., Asiri Y., El Naggar H., Kinakin D. (2018). The Leeb hardness test for rock: an updated methodology and UCS correlation. *Rock Mechanics and Rock Engineering*, 51, 665-675. <https://doi.org/10.1007/s00603-017-1372-2>.
- Farrokhrrouz M., Asef M.R. (2017). Experimental investigation for predicting compressive strength of sandstone. *Journal of Natural Gas Science and Engineering*, 43, 222-229. <https://doi.org/10.1016/j.jngse.2017.03.023>.
- Fookes P.G., Knill J.L. (1969). The application of engineering geology in the regional development of northern and central Iran. *Engineering Geology*, 3(2), 81-120.
- Ghorbani M. (2013). *A Summary of Geology of Iran*. In: The Economic Geology of Iran. Springer Geology. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-5625-0_2.
- Ghoreishi B., Esfahani M.K., Lushabi N.A., Amini O., Aghamolaie I., Hashim N. A.A.N., Alizadeh S.M.S. (2021). Assessment of geotechnical properties and determination of shear strength parameters. *Geotechnical and Geological Engineering*, 39, 461-478. <https://doi.org/10.1007/s10706-020-01504-1>.
- Hencher S. (2024). *Practical Engineering Geology*. CRC Press, Florida, USA.
- Huang F., Shen J., Cai M., Xu C. (2019). An empirical UCS model for anisotropic blocky rock masses. *Rock Mechanics and Rock Engineering*, 52, 3119-3131. <https://doi.org/10.1007/s00603-019-01771-2>.
- Isah B.W., Mohamad H., Ahmad N.R., Harahap I.S.H., Al-Bared M.A.M. (2020). Uniaxial compression test of rocks: Review of strain measuring instruments. *IOP Conference Series: Earth and Environmental Science*, 476(1), 012039. <https://doi.org/10.1088/1755-1315/476/1/012039>.
- Jafarzadeh M., Hosseini-Barzi M. (2008). Petrography and geochemistry of Ahwaz Sandstone Member of Asmari Formation, Zagros, Iran: implications on provenance and tectonic setting. *Revista Mexicana de Ciencias Geológicas*, 25(2), 247-260.
- Jamshidi A., Torabi-Kaveh M., Nikudel M.R. (2021). Effect of anisotropy on the strength and brittleness indices of laminated sandstone. *Iranian Journal of Science and Technology, Transactions A: Science*, 45, 927-936. <https://doi.org/10.1007/s40995-021-01080-w>.
- Jeng F.S., Weng M.C., Lin M.L., Huang T.H. (2004). Influence of petrographic parameters on geotechnical properties of tertiary sandstones from Taiwan. *Engineering Geology*, 73(1-2), 71-91. <https://doi.org/10.1016/j.enggeo.2003.12.001>.
- Jingli Y., Xiaopeng L., Huitao Z., Xuemei L. (2019). Characteristics of He 8th member tight sandstone gas reservoir and solution based on geology-engineering integration in Ordos Basin. *China Petroleum Exploration*, 24(2), 186.
- Kargaranbafghi F., Neubauer F., Genser J. (2015). The tectonic evolution of western Central Iran seen through detrital white mica. *Tectonophysics*, 651, 138-151. <https://doi.org/10.1016/j.tecto.2015.03.019>.
- Keshkaran P. (2011). Harmonization between climate and architecture in vernacular heritage: A case study in Yazd, Iran. *Procedia Engineering*, 21, 428-438. <https://doi.org/10.1016/j.proeng.2011.11.2035>.
- Mao Y., Azarafza M., Bonab M.H., Bascompta M., Nanekhan Y.A. (2023). Empirical correlation for in-situ deformation modulus of sedimentary rock slope mass and support system recommendation using the Qslope method. *Geomechanics and Engineering*, 35(5), 539-554. <https://doi.org/10.12989/gae.2023.35.5.539>.
- Mao Y., Li Y., Teng F., Nanekhan Y.A., Azarafza M., Zhang M. (2024). Predicting the elasticity modulus of sedimentary rocks using Deep Random

- Forest Optimization (DRFO) algorithm. *Environmental Earth Sciences*, 83(16), 487. <https://doi.org/10.1007/s12665-024-11768-y>.
- Mehnahad H.R. (2000). *Study of Seismicity, Seismotectonic and Estimate of Seismic Hazard in Yazd*. PhD dissertation, Shahid Beheshti University, Iran.
- Mirjalili T., Khamechian M., Nikoudel M.R. (2023). Engineering Geological Characteristics of Carbonate building stones in southwest of Yazd. *Iranian Journal of Engineering Geology*, 16(3), 109-130.
- Mohammadi M., Fatemi Aghda S.M., Talkhablou M., Cheshomi A. (2020). Introducing a comprehensive geological and geotechnical classification for urban planning and design, a case study in Isfahan (Iran). *Geotechnical and Geological Engineering*, 38, 6809-6826. <https://doi.org/10.1007/s10706-020-01471-7>.
- Mojtaba R.S., Fariba K., Mehdi M.S., Nima R. (2016). Engineering geological assessment of the Shahid dam site (Semirom, Iran). *Journal of Geotechnical Geology*, 12(2), 193.
- Mousavi E., Cheshomi A., Ashtari M. (2018). Estimating elasticity modulus and uniaxial compressive strength of sandstone using indentation test. *Journal of Petroleum Science and Engineering*, 169, 157-166. <https://doi.org/10.1016/j.petrol.2018.05.056>.
- Mousavi S.Z.S., Rezaei M. (2022). Correlation assessment between degradation ratios of UCS and non-destructive properties of rock under freezing-thawing cycles. *Geoderma*, 428, 116209. <https://doi.org/10.1016/j.geoderma.2022.116209>.
- Naghadehi M.Z., KhaloKakaie R., Torabi S.R. (2010). The influence of moisture on sandstone properties in Iran. *Proceedings of the Institution of Civil Engineers-Geotechnical Engineering*, 163(2), 91-99. <https://doi.org/10.1680/jeng.2010.163.2.91>.
- Nanehkar Y.A., Azarafza M., Pusatli T., Bonab M.H., Irani, A.E., Kouhdarag M., Derakhshani R. (2023). Deep learning method for compressive strength prediction for lightweight concrete. *Computers and Concrete*, 32(3), 327-337. <https://doi.org/10.12989/cac.2023.32.3.327>.
- Nazir R., Momeni E., Armaghani D.J., Amin M.M. (2013). Correlation between unconfined compressive strength and indirect tensile strength of limestone rock samples. *Electronic Journal of Geotechnical Engineering*, 18(1), 1737-1746.
- Nezhad E.M., Hosseini S.Z., Nezhad H.M., Asadi M.A. (2019). Study of effect of climate change on potential evapotranspiration in arid areas using geostatistics (case study: Yazd province). *Desert Management*, 6(12), 1-18.
- Peng S., Zhang J. (2007). *Engineering Geology for Underground Rocks*. Springer Science & Business Media, Berlin, Germany.
- Rajabzadeh M.A., Moosavinasab Z., Rakhshandehroo G. (2012). Effects of rock classes and porosity on the relation between uniaxial compressive strength and some rock properties for carbonate rocks. *Rock Mechanics and Rock Engineering*, 45, 113-122. <https://doi.org/10.1007/s00603-011-0169-y>.
- Sadeghi E., Nikudel M.R., Khamehchiyan M., Kavussi A. (2022). Estimation of unconfined compressive strength (UCS) of carbonate rocks by index mechanical tests and specimen size properties: Central Alborz Zone of Iran. *Rock Mechanics and Rock Engineering*, 55, 125-145. <https://doi.org/10.1007/s00603-021-02532-w>.
- Sheshde E.A., Cheshomi A. (2015). New method for estimating unconfined compressive strength (UCS) using small rock samples. *Journal of Petroleum Science and Engineering*, 133, 367-375. <https://doi.org/10.1016/j.petrol.2015.06.022>.
- Shirgholami M., Yazdi H.A. (2025). Spatiotemporal Analysis of Atmospheric Hazards in Arid and Hyper-Arid Regions: A Case Study of Yazd Province. *Desert Management*, 12(4), 21-40. <https://doi.org/10.22034/jdmal.2024.2041781.1483>.
- Tajbakhsh G., Pichon S., Majlisi F. (2024). Evaluation of stone weathering in urban environments using tombstones (case study: Yazd city). *Physical Geography Research*, 56(3), 77-94. <https://doi.org/10.22059/jphgr.2024.384132.1007847>.
- Tating F., Hack R., Jetten V. (2013). Engineering aspects and time effects of rapid deterioration of sandstone in the tropical environment of Sabah, Malaysia. *Engineering Geology*, 159, 20-30. <https://doi.org/10.1016/j.enggeo.2013.03.009>.
- Torabi-Kaveh M., Mehrnabad H., Mohammadi S., Moosavizadeh S. (2023a). Application of kinematic and distinct element methods to investigate instability mechanism of rock slopes containing weak and hard layers. *Modeling Earth Systems and Environment*, 9(2), 2757-2770. <https://doi.org/10.1007/s40808-022-01672-4>.
- Torabi-Kaveh M., Rizi F.S., Tajbakhsh G., Khodami M., Ménendez B. (2023b). The use of chemical and textural indices to predict geotechnical properties of granites with different degrees of weathering. *Bulletin of Engineering Geology and the Environment*, 82(9), 362. <https://doi.org/10.1007/s10064-023-03387-x>.
- Wilmsen M., Fürsich F.T., Majidifard M.R. (2015). An overview of the Cretaceous stratigraphy and facies development of the Yazd Block, western Central Iran. *Journal of Asian Earth Sciences*, 102, 73-91. <https://doi.org/10.1016/j.jseas.2014.07.015>.
- Yang H.X. (2013). Experimental Study on Engineering Geological Properties of Sandstone. *Applied Mechanics and Materials*, 256, 324-327. <https://doi.org/10.4028/www.scientific.net/AMM.256-259.324>.