Effect of soaking time on the geotechnical behavior for different types of sedimentary rocks in Egypt

Mona Afifi and Abeer Heikal

Ministry of Water Resources and Irrigation, Researcher, Construction Research Institute, National Water Research Centre, Cairo, Egypt

ABSTRACT
Weathering problems of weak sedimentary rocks, especially when subjected to water immersion, are considered one of the serious geotechnical engineering issues. Examples of rock water submersion include foundations subject to seepage, regular irrigation, residence daily activities, service water, frequent plant watering, an increase in groundwater level and heavy rain, in addition to numerous urban and rural water use consequences; hence, it is necessary to quantify the effect of water on the physical and mechanical characteristics of sedimentary rocks. The objective of this study is to assess, evaluate and estimate the strength and stiffness of deterioration of sedimentary rocks in Egypt subject to freshwater soaking in three states (natural/presoaking state, after 48 h and after 30 days of soaking). An extensive laboratory testing program including slake durability, uniaxial compression and point load tests was conducted in the three states on sandstone and limestone specimens collected from Galala, Attaka-Suez Governorate, Egypt. The influence of water immersion on the physical and mechanical characteristics such as rounding, stress–strain envelope, strength and stiffness was studied. The results showed a reduction of up to 87% and 93% in the uniaxial compressive strength and elastic modulus, respectively, post 30 days of freshwater soaking. The limestone showed more resistance to deterioration compared to the sandstone. The stiffness and strength of sedimentary rocks decrease with long contact with water. This paper results provide guidance when assessing, planning and preliminarily evaluating similar rock formation/s considered as a candidate for engineering projects.

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Introduction
Over decades, rock is known as one of the preferred geological materials in engineering projects all over the globe. However, in practice, rocks can be significantly affected by erosion and weathering such as moisture content fluctuations and daily and seasonal changes of water level [1]. These effects
occur due to the presence of various scales of discontinuities within the rock mass, and this becomes more prominent in sedimentary rocks, where the interbedding discontinuities are generic distinct features.

In various engineering applications, such as tunneling, mining, railway and embankment construction, oil and gas exploration, cut and fill and excavation, the deformation and failure of the rock are usually accompanied by water content change. Many failure incidents reported worldwide recently were associated with water–rock interactions, such as geological disasters like earthquakes, debris flow, landslides and ground subsidence. Water–rock interactions can result in a significant deterioration of the physical and mechanical properties of the rock. These interactions have been identified as significant factors influencing the stability and safety of structures in rock-tunnel engineering [2]. Slope instability, landslide, tunnel spalling, embankment cracking, mining pit collapse, etc., are typical problems that result when the rock strength is jeopardized.

In recent years, several experimental research has been carried out exploring the softening characteristics of different rocks after water immersion [3]. For soft rocks such as mudstone and coal rock, the increase in the water content was found to negatively affect the rock compressive strength. The reason for the decrease in the compressive strength with water immersion is that the rock preexisting (natural) discontinuities extend and the internal pressure of the discontinuity increases as the rock gets increasingly saturated [3]. Auvray et al. in 2004 [4] reported that, if the saturated rock mass under stress does not discharge the discontinuity water, the pore water pressure will generate reducing the rock effective stress, consequently jeopardizing the rock shear strength [5]. This phenomenon is characterized by weakened rigidity and enhanced flexibility. Increasing the water content could significantly degrade the mechanical properties of rock materials [2]. An experimental study was conducted on the strength degradation of sandstone under the action of water saturation, and it was found that the sandstone strength decreases with increasing water saturation.

Zhu et al. in 2019 [3] studied the effect of water on the physical and mechanical parameters of a natural gypsum rock, where gypsum rock samples of a gypsum mine were prepared with different immersion times. Uniaxial compression tests were performed on the gypsum rock samples. Compression and scanning electron microscopy experiments were carried out to analyze the effects of immersion time on the uniaxial compressive strength ($q_u$), elastic modulus ($E$), Poisson’s ratio ($\nu$) and gypsum microstructure. The results showed that $q_u$ and $E$ of gypsum are inversely proportional to the water content. However, $\nu$ was found to be directly proportional to the water content [3].

Hua et al. in 2019 [2] found that periodic water–rock interactions can remarkably affect the fracture resistance of sandstone. It was found that the physical and mechanical properties of rock samples were degraded to varying
degrees in most of the tests, but even the same type of rock differed significantly in different tests due to its different composition [1]. The reaction mechanism analysis of an eroded sandstone shows that the fillings in joints and fissures of sandstone are frequently decomposed, resulting in changes of interior molecular structure and framework composition and decrease in cohesion (C) and angle of internal friction (φ) between rock structure interfaces [6].

Okoro et al. in 2015 [7] stated that civil engineering works on watersensitive rocks fail after many cycles of soaking. Results published by Liang et al. in 2021 [8] showed that soaking duration significantly impairs the peak and residual strengths and other mechanical properties (e.g. cohesion, friction angle and shear stiffness). Similarly, Yu et al. in 2019 [9] showed that the peak strength and elastic modulus of a red sandstone decreased with not only water content but also immersion time, which they found it is better to be expressed by an exponential function, sandstone’s shear strength. The results provided in that study revealed that the stability of rock engineering changes in water levels [8].

There is a paucity in literature concerning the evaluation and quantification of the effects of freshwater soaking on sandstone and limestone rocks in Galala, Attaka-Suez Governorate, Egypt. Therefore, this study pertains investigation, analysis and discussion of the rocks’ degradation issue by examining the influence of freshwater soaking duration on the physical and mechanical properties such as compressive strength and secant Young’s modulus of these two types of sedimentary rock.

**Geological location and site map**

The purpose of this study is to examine how two types of sedimentary rocks are influenced by water–rock interactions and freshwater immersion using specimens collected from a site located at Galala, Attaka-Suez Governorate, in the direction of Ain Sokhna, Egypt. The latitude and longitude coordinates of the site are 29.435437 North and 32.490559 East. The site was chosen as it is planned to be a vital area for constructing highways, universities, residence, service facilities and resorts [10].

The stratigraphic succession in the study area consists of Precambrian basement complex overlain unconformable by Phanerozoic sequence as illustrated in Figure 1. The Phanerozoic sequence was composed of siliciclastic-dominated rocks superimposed by carbonate-dominated rocks. The carbonate-dominated rocks cover most of the surface area, while the siliciclastic-dominated rocks exposed along the eastern and southern foot slope of the Northern Galala Plateau. The observed palaeokarst surfaces, fissures, caves, sink-holes and fault zones within the carbonate rocks may cause geological hazards in the area. The source depths range from 500 to 4000 m, which were resulted from the Precambrian basement complex [10].
As a part of the framework of this study, bulk samples of sedimentary rocks, namely sandstone and limestone, were collected from a natural hill deposit located at Galala site, Attaka-Suez Governorate, Egypt. The rock samples were collected by a disturbed sampling method at a height 1.0–5.0 m above sea level. The total number of samples collected in-situ was 18; 11 of them were big sized blocks and 7 of them were (weathered) rock samples of a smaller size. The block dimensions were \( \approx 50 \text{ cm} \times 50 \text{ cm} \times 50 \text{ cm} \). Specimens for testing were cut off the blocks to a rectangular cuboid with dimensions of 6 cm \( \times \) 6 cm \( \times \) 12 cm. Select samples as prepared in the laboratory are shown in Figure 2, and all the 18 samples were labeled as listed in Table 1.

(1) Eleven block samples cut to rectangular cuboids and labeled from S1 to S11.
(2) Seven smaller samples of rock and their labeling was from ID# S12 to S18.

Figure 1. Structural and stratigraphic setting of lithological succession beneath New Galala City, Northern Galala Plateau, Egypt [11].

Materials

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Figure 2. Collected sedimentary rock samples from the studied area.
Visual description

The rock preliminary visual description following British Standards is listed in Table 1. The visual description included color, texture and approximate hardness estimation.

Laboratory testing and results

In the present study, a series of physical, chemical and mechanical testing was conducted. Water content (W.C.), specific gravity (G_s), absorption, bulk unit weight (γ_b), dry unit weight (γ_d), porosity (n), slake durability, unconfined compressive strength (UCS) tests and point load test were carried out. The UCS tests were performed on limestone and sandstone specimens, under three water soaking conditions: natural W.C., after 2 days of freshwater immersion and after 30 days of freshwater immersion.

Physical testing

Multiple physical tests were conducted according to the ASTM such as bulk (γ_b) and dry (γ_d) unit weights, specific gravity (G_s), moisture/water content (W.C.) and porosity (n). The physical properties were calculated for the sedimentary rock samples, and Table 2 shows all the physical testing results. The natural W.C. ranged from 1.61% to 2.90% as seen in Figure 3. The G_s ranged from 2.536 to 2.864. The γ_b values ranged from 20.4 to 23.6 kN/m³ for the sandstone, which is classified as medium to high unit weight rock (20.0–23.1 kN/m³). For the dolomitic limestone, the γ_b values ranged from 23.3 to 26.4

Table 1. Sedimentary rock sample visual description (following British Standards).

| ID# | Visual description – Color – Texture – Hardness |
|-----|-----------------------------------------------|
| 51  | Carbonate sandstone, whitish yellow, medium to coarse grains, weak |
| 52  | Carbonate sandstone, light yellow, medium to coarse grains, weak |
| 53  | Carbonate sandstone, whitish yellow, medium to coarse grains, weak |
| 54  | Sandstone, white to reddish brown, medium to coarse grains, weak |
| 55  | Sandstone, purple, medium to coarse grains, medium hardness |
| 56  | Sandstone, multi-color dark brown to light yellow with some purple interbeds medium to coarse grains, weak |
| 57  | Sandstone, purple, medium to coarse grains, medium hardness |
| 58  | Sandstone, pale yellow, medium to coarse grains, weak |
| 59  | Sandstone, pale yellow to brown, medium to coarse grains, weak |
| 60  | Sandstone, dark brown, medium to coarse grains, medium hardness |
| 61  | Limestone, dark gray, medium hardness |
| 62  | Limestone, dark gray, medium hardness |
| 63  | Limestone, gray, medium hardness |
| 64  | Limestone, dark gray, medium hardness |
| 65  | Limestone, yellowish white, medium hardness |
| 66  | Limestone, dark gray, medium hardness |
| 67  | Limestone, pale gray, medium hardness |
| 68  | Limestone, dark gray, medium hardness |
Table 2. Physical tests results.

| ID# | Units | Rock type          | Bulk unit weight ($\gamma_b$) (kN/m$^3$) | Dry unit weight ($\gamma_d$) (kN/m$^3$) | Water content (WC) (%) | Specific gravity ($G_s$) | Porosity (n) (%) | Water absorption ($A_b$) (%) | Slaking index ($I_d(2)$) (%) |
|-----|-------|--------------------|------------------------------------------|----------------------------------------|------------------------|------------------------|-----------------|-------------------------------|-------------------------------|
| S1  |       | Sandstone (SS)     | 20.39                                    | 20.03                                  | 1.83                   | 2.567                  | 20.4            | Collapsed                     | 30.70                         |
| S2  |       |                     | 21.78                                    | 21.37                                  | 1.94                   | 2.561                  | 14.8            | Collapsed                     | 31.40                         |
| S3  |       |                     | 21.32                                    | 20.93                                  | 1.88                   | 2.634                  | 18.9            | Collapsed                     | 33.50                         |
| S4  |       |                     | 20.86                                    | 20.53                                  | 1.61                   | 2.666                  | 21.4            | Collapsed                     | 30.90                         |
| S5  |       |                     | 23.64                                    | 23.11                                  | 2.30                   | 2.718                  | 13.3            | 0.744                         | 68.40                         |
| S6  |       |                     | 20.86                                    | 20.47                                  | 1.88                   | 2.562                  | 18.4            | 33.764                        | 68.40                         |
| S7  |       |                     | 22.64                                    | 22.04                                  | 2.70                   | 2.688                  | 16.3            | 13.366                        | 56.96                         |
| S8  |       |                     | 21.92                                    | 21.36                                  | 2.60                   | 2.536                  | 14.0            | Collapsed                     | 32.22                         |
| S9  |       |                     | 21.54                                    | 21.10                                  | 2.10                   | 2.603                  | 17.3            | 25.252                        | 39.33                         |
| S10 |       |                     | 22.30                                    | 21.67                                  | 2.90                   | 2.552                  | 13.4            | 10.245                        | 76.30                         |
| S11 |       | Dolomitic limestone (DL) | 25.49                                  | 25.01                                  | 1.95                   | 2.796                  | 8.8             | 0.014                         | 97.20                         |
| S12 |       |                     | 26.42                                    | 25.86                                  | 2.18                   | 2.852                  | 7.5             | 1.034                         | 96.20                         |
| S13 |       |                     | 25.72                                    | 25.22                                  | 2.02                   | 2.793                  | 7.9             | 0.211                         | 96.80                         |
| S14 |       |                     | 26.19                                    | 25.63                                  | 2.18                   | 2.759                  | 3.6             | 0.826                         | 92.30                         |
| S15 |       |                     | 23.27                                    | 22.84                                  | 1.88                   | 2.538                  | 8.2             | 7.133                         | 91.80                         |
| S16 |       |                     | 25.77                                    | 25.19                                  | 2.30                   | 2.714                  | 10.3            | 0.005                         | 95.01                         |
| S17 |       |                     | 24.98                                    | 24.37                                  | 2.50                   | 2.864                  | 7.8             | 1.252                         | 94.00                         |
| S18 |       |                     | 24.19                                    | 23.74                                  | 1.90                   | 2.696                  | 12.2            | 0.015                         | 96.00                         |

Figure 3. Natural water content.

kN/m$^3$ which is specified as high weight rock (22.8–25.9 kN/m$^3$) according to the classification scheme, and it is higher than the sandstone values. The $G_s$ values for the sandstone samples ranged from 2.536 to 2.718, which indicates a rock with a medium $G_s$. However, for the dolomitic limestone, the $G_s$ values ranged from 2.538 to 2.864, which implies medium to high specific gravity rock.
Porosity

To calculate rock porosity, the Egyptian Code of Soil Mechanics and Foundation Design and – Part (10) – bulletin 10/4/3/2 classification limits were used to classify the rock samples under investigation. Studying the porosity ($n$) plot in Figure 4(a), it is found that the $n$ values ranged from 13.26% to 21.44% for sandstone (SS) samples, and this implies a medium to high porosity rock. However, for the dolomitic limestone (DL), the $n$ ranged from 3.64% to 12.21-%, which indicates low to medium porosity rock, and this value is lower than the values measured for the sandstone samples.

Water absorption

Tests were conducted on the collected samples to estimate the rock water absorption as illustrated in Figure 4(b) and listed in Table 2. The absorption values ranged from 10.24% to 33.76% for the sandstone samples, which indicates high absorption rock. It is worth noting that the light yellow color samples with an ID S1, S2, S3, S4 and S8 collapsed shortly after water soaking.

An odd low absorption value was recorded for rock sample ID S5 (reddish purple color) of 0.744%. For the dolomitic limestone samples, the absorption values ranged from 0.01% to 1.25%, which implies a low absorption rock and lower than the sandstone values. The yellowish white color sample ID S15, however, showed a higher absorption value of 7.133%.

Mechanical testing

The influence of water on stress–strain responses and peak compression strength envelopes was investigated.
**Slake durability testing**

Slake durability classification tests were carried out on the collected sedimentary rock samples according to ASTM D 4644 to determine the durability of rocks subjected to cycles of wetting and drying. In this test, the specimens and the drum are dried at the end of the rotation cycles (10 min at 20 rpm) and weighed. After two cycles of rotating and drying, the weight loss and the shape and size of the remaining rock fragments are recorded. The following equation was used to calculate the slaking index:

\[
Id(2) = \frac{\text{Dry weight retained (after two cycles)}}{\text{Dry weight (before test)}} \times 100
\]

Photos of rock samples showing typical rounding post slake testing are given in Figure 5. The slake index values are plotted in Figure 6 and listed in Table 2. The slake index values for the (light yellow color) sandstone samples ranged from 30.70% to 56.96%, which indicates low slaking resistance rock. However, two samples (S5 (purple color) and S10 (dark brown)) showed medium slaking resistance with slake index values of 68.40% and 76.30%. Also, the

![Figure 5. Sedimentary rock post slake showing typical rounding – samples S7, S8, S9 and S10.](image)

![Figure 6. Slake durability results.](image)
slake durability was affected by bulk and dry density, and the relation is directly proportional. For the dolomitic limestone, the slake index values ranged from 91.80% to 97.206%, which implies high slaking resistance rock.

In order to classify the rock samples’ durability under investigation, the classification scheme based on recommendations from Gamble 1971, Dick 1994 and Gautam 2012 is used. Figure 6 shows that the majority of the sandstone samples fall in the low slake durability zone, while all of the dolomitic limestone samples are located in the medium to high slake durability zones due to the presence of dolomite which is characterized by its high strength and durability.

**Unconfined compression test**

Unconfined compressive strength tests were carried out to determine the compressive strength of the rock samples according to ASTM D2938-95. By increasing soaking time, the strength of the sedimentary rock decreases [12,13]. The water causes significant reductions in the peak, residual compressive strength and the secant Young’s modulus for all the tested samples. In order to explore how this applies to sedimentary rock types under investigation in Egypt, mechanical tests were performed on the two sedimentary rock types at three different water soaking conditions: before (pre-soaking), after two days and after 30 days.

As listed in Table 3, unconfined compression testing was conducted on 11 rock specimens (ID# S1–S11) to estimate the unconfined compressive strength ($q_u$) at three freshwater soaking states:

- Natural moisture content (no or pre-soaking),
- After soaking in freshwater for 2 days, and
- After soaking in freshwater for 30 days.

### Table 3. Uniaxial compression test results.

| ID# Units | Rock type                  | Natural WC |           | After 2 days of soaking |           | After 30 days of soaking |           |
|-----------|----------------------------|------------|-----------|-------------------------|-----------|--------------------------|-----------|
|           |                            | $q_u$ (MPa)| $E$ (MPa) | $q_u$ (MPa)             | $E$ (MPa) | $q_u$ (MPa)              | $E$ (MPa) |
| S1        | Sandstone                  | 1.42       | 130       | 1.10                    | 57        | 0.58                     | 19        |
| S2        |                            | 5.67       | 315       | 1.87                    | 74        | 0.88                     | 27        |
| S3        |                            | 9.22       | 425       | 1.42                    | 50        | 1.81                     | 32        |
| S4        |                            | 5.67       | 429       | 4.26                    | 243       | 1.25                     | 66        |
| S5        |                            | 60.99      | 7446      | 31.22                   | 2407      | 29.81                    | 2402      |
| S6        |                            | 2.84       | 227       | 1.85                    | 111       | 0.38                     | 15        |
| S11       | Dolomitic limestone        | 75.17      | 3604      | 72                      | 3569      | 73.09                    | 2092      |
| S12       |                            | 83.68      | 8370      | 75                      | 3813      | 72.38                    | 3638      |
| S13       |                            | 24.11      | 4255      | 20                      | 2246      | 11.35                    | 1195      |
| S14       |                            | 59.57      | 8935      | 38                      | 3575      | 18.45                    | 1747      |
| S15       |                            | 32.62      | 2986      | 30                      | 1881      | 12.77                    | 584       |
Figures 7 and 8 show the stress–strain relationships for select sandstone and dolomitic limestone samples, respectively. These figures show that the dolomitic limestone possesses higher UCS and E compared with the sandstone.

Figure 9 and Table 3 illustrate the results of the uniaxial compressive strength (UCS) and the modulus of elasticity (E) for the sandstone and dolomitic limestone rock samples at different soaking periods in fresh water. Interpreting the results leads to the following findings:

For sandstone samples, at their natural water content, the results indicate that the rock's $q_u$ ranges from 1.42 to 9.22 MPa. These values typically refer to very weak to weak rock. Also, Figure 9 shows that when soaking the sandstone samples in freshwater for two days, the $q_u$ dropped to a range from 1.1 to 4.26 MPa, moving these rock sample classification to the very weak rock category. The $q_u$ values even dropped further as the samples were left soaking for 30 days in freshwater to a range from 0.38 to 1.81 MPa, placing these rocks in the very weak rock category. It is worth noting that the
sandstone rock samples studied in this paper were sensitive to freshwater soaking as they degraded after freshwater soaking. Also, the compressive strength was affected by bulk and dry density, and the relation is directly proportional in the dry condition and affected also by saturation coefficient in wet condition. However, sandstone sample S5 (reddish purple color) possessed a $q_u$ of 61 MPa, which was dropped after 2 days of freshwater submerging to 31.22 MPa and to 29.81 MPa after submerging for 30 days, keeping this rock within the medium hard rock category due to the presence of iron oxide that gives it more strength than other sandstone samples.

**Point load test**

Point load test was carried out according to ASTM D 5731 to determine the strength classification of the rock through an index test. Rock specimens in the form of core (diametric and axial), cut blocks or irregular lumps were

**Figure 9:** Uniaxial compressive strength (UCS) and modulus of elasticity (E) at different soaking durations in fresh water.
tested by applying a concentrated load through a pair of spherically truncated, conical platens. Test specimens were typically tested at their natural water content. Size corrections are applied to obtain the point load strength index, $I_{S(50)}$, of a rock specimen. A strength anisotropy index, $I_{S(50)}$, is determined when $I_{S(50)}$ values are measured perpendicular and parallel to planes of weakness. The point load tests’ results are plotted in Figure 12, where the compressive strength was calculated using Bieniawski (1975) per the following equation:

$$q_u = 23 I_{S(50)}$$

Figure 12 shows that SS sample S10 has the maximum strength and the minimum value recorded for S8. In the case of DL, S18 has the maximum strength, and S17 has the minimum value. Dolomitic limestone generally possessed higher strength than sandstone, and also higher bulk and dry density indicate higher point load values. Also, for the slake durability, the compressive strength from the point load was affected by the bulk and dry density, and the relation was found to be directly proportional.
Indication of colors in the rock samples due to the presence of oxides and how this influences the rock strength, stiffness and resistance to freshwater soaking were assessed through the chemical testing on the collected rock samples. The chemical testing conducted included determining the acidity and basicity index/power of hydrogen (pH), total dissolved solids (TDS), chloride ion (Cl\(^-\)), sulfur trioxide (SO\(_3\)), silicon dioxide (SiO\(_2\)), alumina (R\(_2\)O\(_3\)), calcium oxide (CaO) and magnesium oxide (MgO), as given in Table 4. All the samples have alkaline tendency; all the samples have a small TDS except sample no. S2; and samples S3, S11, S12, S13, S17 and S18 have a higher value of MgO, which indicates that the durability of this samples is high. The MgO values affect the durability of dolomitic limestone more than the sandstone.

### Table 4. Chemical test results.

| Sample ID | pH   | TDS (%) | Cl\(^-\) (%) | SO\(_3\) (%) | SiO\(_2\) (%) | R\(_2\)O\(_3\) (%) | CaO (%) | MgO (%) |
|-----------|------|---------|--------------|--------------|---------------|------------------|---------|---------|
| S1        | 8.91 | 0.058   | 0.023        | 0.019        | 96.50         | 1.73             | 1.56    | 0.11    |
| S2        | 8.93 | 0.210   | 0.014        | 0.062        | 94.48         | 2.41             | 2.59    | 0.19    |
| S3        | 9.00 | 0.047   | 0.021        | 0.011        | 91.50         | 2.30             | 3.35    | 1.52    |
| S4        | 9.11 | 0.038   | 0.013        | 0.005        | 93.00         | 3.82             | 2.55    | 0.36    |
| S5        | 8.54 | 0.048   | 0.022        | 0.003        | 89.10         | 8.55             | 1.15    | 0.35    |
| S6        | 8.48 | 0.040   | 0.014        | 0.005        | 83.47         | 11.91            | 3.30    | 0.53    |
| S7        | 8.00 | 0.080   | 0.043        | 0.023        | 86.00         | 10.09            | 3.28    | 0.13    |
| S8        | 8.12 | 0.043   | 0.018        | 0.003        | 93.00         | 1.98             | 4.40    | 0.24    |
| S9        | 8.00 | 0.043   | 0.014        | 0.003        | 90.34         | 2.18             | 4.31    | 0.91    |
| S10       | 8.70 | 0.038   | 0.011        | 0.002        | 90.19         | 1.95             | 3.46    | 1.04    |
| S11       | 8.86 | 0.062   | 0.028        | 0.015        | 2.90          | 11.32            | 5.94    | 3.00    |
| S12       | 8.84 | 0.068   | 0.036        | 0.017        | 21.00         | 16.73            | 34.00   | 2.85    |
| S13       | 9.00 | 0.050   | 0.021        | 0.006        | 2.35          | 14.75            | 34.80   | 5.12    |
| S14       | 8.77 | 0.062   | 0.028        | 0.014        | 3.42          | 12.85            | 32.70   | 4.00    |
| S15       | 8.89 | 0.072   | 0.036        | 0.020        | 7.22          | 16.80            | 33.66   | 0.29    |
| S16       | 8.62 | 0.071   | 0.029        | 0.019        | 7.17          | 18.53            | 5.00    | 0.81    |
| S17       | 8.73 | 0.066   | 0.036        | 0.015        | 2.08          | 9.17             | 30.10   | 3.19    |
| S18       | 8.85 | 0.073   | 0.037        | 0.021        | 1.63          | 11.39            | 31.92   | 3.86    |
Results discussion and analyses

Multiple correlations between various physical properties of two sedimentary rock types are plotted in Figures 13 and 14. The relation between the bulk unit weight versus the water absorption is inversely proportional for the two rock types, which matches the literature. The water absorption is directly proportional to porosity. Water absorption versus the specific gravity looks typical, inversely proportional, for both the sandstone and limestone samples. Dry unit weight versus the natural water content looks typical for the two rock types as what have been reported in the literature.

Derived correlations

Colback and Wild in 1975 [14] reported that the uniaxial compressive strength of saturated rock reduced by approximately 50%. In this study, it was found that the weakest rock sample is S6 (sandstone), as it lost ≈87% of
its strength (UCS) and ≈93% of its stiffness (E) after been submerged in freshwater for 30 days. When revisiting this rock physical characteristic results, it is found that this sample has high porosity and high water absorption, as seen in Figure 4, and it possesses low bulk and dry unit weights as listed in Table 2, and it showed low slaking durability as depicted from Figure 6. Moreover, this SS sample contains low magnesium oxide (MgO) as indicated from the chemical analysis results in Table 4. The strongest and more resisting sample is S11 (dolomitic limestone), as it only suffered a loss of 4% of its strength (UCS) and 42% of its stiffness (E) after been submerged in freshwater for 30 days.

When revisiting S11 physical characteristic results, it is found that this sample has low porosity and extremely low water absorption as seen in Figure 4, and it possesses high or heavy bulk and dry unit weights as mentioned in Table 2; moreover, it showed high slaking durability as depicted from Figure 6. This sample contains high MgO as indicated from the chemical analysis and per the results listed in Table 4. Comparative experiments between all the original and submerged sedimentary rock samples studied in this paper generally show a significant deterioration in the uniaxial compressive strength and elastic modulus by up to 87% and 93%, respectively, post freshwater soaking.

**Conclusion**

Water–rock interactions can significantly deteriorate the physical and mechanical properties of sedimentary rocks, and this has been identified as one of the serious issues influencing the stability and safety of structures in civil engineering, such as foundations subject to underground seepage from continuous surface irrigation. In the current study, the properties of sedimentary rocks examined at three water-contact conditions, natural state, after 48 h and after 30 days of soaking, have been studied. The results
show that with increasing soaking time, the elastic modulus and the unconfined compressive strength decreased for all the sedimentary rock samples investigated in this study. Both sandstone and limestone found to be dissolute in water. However, the drop in sandstone stress–strain is much more significant compared to the dolomitic limestone. Dolomitic limestone is more resisting and durable to deterioration when submerged in fresh-water compared to the sandstone samples, and it depends on the dolomite percent in it. Moreover, the most competent and stable sandstone sample is S10 (deep brown color) and the second best is S5 (purple color) due to the presence of iron oxide that gives the rock more stiffness than other sandstone samples. However, for the dolomitic limestone samples, the most competent and stable sample is S11 (dark gray) and the second best is S12 (dark gray).

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