Method Article

An empirical classification method for South Pars marls by Schmidt hammer rebound index

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A B S T R A C T

The presented article provides an experimental classification for South Pars marls (SPM), southwest of Iran, using the Schmidt hammer rebound index, marl geological classes, and SPM geo-engineering characteristics. In this regard, 45 samples of marls (rock) are selected on the studied site and tested by geotechnical in-situ and laboratory tests such as Schmidt hammer, uniaxial compressive strength (UCS), laboratory direct-shear (LDS) to estimate the geo-engineering characteristics of SPM. These specimens are categorised by Pettijohn’s marl classification in 3 main groups (concluded argillaceous lime, calcareous marl, and marlstone) and established the geologic class and geo-engineering properties as well as Schmidt hammer rebound index. In the meantime, the geologic classes and the Schmidt index show the logic classification. Thus, this work attempted to prepare the experimental classification based on Pettijohn’s marl classification and Schmidt rebound index for SPM. According to geotechnical experiments results, the Schmidt index shows 3 main group variations like Pettijohn’s marl classification.

• This method can be used to prepare the geologic status based on the Schmidt rebound index.
• This method can be useful for detailed decryption of geo-engineering characteristics of different type of marls in the studied area.
• This method can be used as a quick link for marl geologic status and geo-engineering features.

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**Specifications Table**

| Subject Area                   | Earth and Planetary Sciences |
|--------------------------------|-------------------------------|
| More specific subject area     | Rock mass classification      |
| Method name                    | Empirical classification for SPM by using the Schmidt hammer rebound index |
| Name and reference of original method | Original method name: Schmidt hammer ASTM C805, 2018. Standard Test Method for Rebound Number of Hardened Concrete. ASTM International, West Conshohocken, PA. https://doi.org/10.1520/C0805_C0805M-18 |
|                                | ASTM D5873, 2014. Standard Test Method for Determination of Rock Hardness by Rebound Hammer Method. ASTM International, West Conshohocken, PA. https://doi.org/10.1520/D5873-14 |
| Resource availability          | There are no special resources and field investigation data is presented within the article. |

**Method details**

The Schmidt hammer (Swiss hammer), developed in the late 1940s as an indexing apparatus for non-destructive testing of concrete which has been used in rock mechanics practice since the early 1960s, mainly for estimating the uniaxial compressive strength (UCS) and Young’s modulus (E_r) of rock materials where it was invented by Ernst Schmidt. Considering its long history and widespread application, the standard methods for the Schmidt hammer test have been reformed and improved by ASTM [1,2] and ISRM [3] which might be expected to ensure consistent and reliable values and reproducible correlations for a given rock type [1]. Many published scientific reports have focused on improving data gathering procedures and developing new correlations for different rock types and geo-engineering characteristics. In Schmidt hammer index utilisation, several issues such as hammer type, rebound values normalization, specimen dimensions, surface smoothness, weathering, and moisture content, hammer orientation, data reduction, and analysis procedures continue to undermine the Schmidt hammer reliability results. In this regard, the Schmidt hammer charts are introduced to quick access to appropriate evaluations [4].

It consists of a spring-loaded mass released against a plunger when the hammer is pressed onto a hard surface. The plunger impacts the surface and the mass recoils; the rebound value is measured either by a sliding pointer or electronically. Hammer rebound readings are considered consistent and reproducible. In such fact, non-destructive tests help rock mass/intact properties evaluation and reduce the expenses for sample collection and laboratory testing. Consequently, it can determine the geo-mechanical characteristics in dense arrays of field measurements that reflect rock masses’ real inherent heterogeneity. According to the reports, there are several versions of the Schmidt hammer which is classified as N-type (used to provide data on rock types, weakness and rock compressive strengths), L-type (used to provide data on weak rocks and thin weathering crusts), and P-type (is pendulum hammer for testing materials of very low hardness). The N-type prepares data from 20 to 250 MPa. The L-type has an impact three times lower than the ‘N’ type (0.735 compared to 2.207 Nm). Also, the P-type prepares data of materials with compressive strengths of less than 70 kPa. When the hammer is pressed against a surface, its piston is automatically released onto the plunger. Part of the piston’s impact energy is consumed by absorption (i.e., the work done in plastic deformation of the rock under the plunger tip), and is transformed into heat and sound. The remaining energy represents the impact penetration resistance (e.g., the hardness) of the surface. It enables the piston to rebound which the distance traveled by the piston after it backfires is called the rebound value (R) [4]. From a geological perspective, harder rocks have higher R values, and weak rock provides low R values representing rock masses’ geological condition. Rebound values are influenced by gravitational forces to varying degrees so that non-horizontal rebound values must be normalised regarding the horizontal direction which comprehensively described in ASTM instructions which s shown by a pointer on a scale on the side of the instrument (range 10–100). Therefore, the Schmidt Hammer must be used with care and adequately calibrated [5]. Aydin and Basu [6] suggest that the reason for force direction is that the manufacturer’s correlations are derived empirically for a particular material (mostly concrete) with a relatively narrow range of mechanical properties and are often limited to two or four impact directions. The proposed alternative normalisation methods remain a wide variation
in the recommended testing procedures employed by different researchers [7] particularly regarding the number of impacts used to obtain ‘R’ values. For example, the ISRM [3] recommended that one record 20 rebound values from single impacts separated by at least a plunger diameter, and average the upper ten values. Matthews and Shakesby [8] recommended 15 rebound values for each sample, with five values that deviate most from the mean being discarded. Katz et al. [9] performed 32–40 individual impacts and averaged the upper 50%. Abnormally low values are omitted for various reasons: they may relate to the fact that the rock was weakened by the hammer’s actual impact on the rock surface or too small rock flaws that were not spotted visually before the effect was applied. Nevertheless, the extent of variation in the Schmidt index on rocks has led various scholars to use this index to assess the rock types (igneous, sedimentary and metamorphic) and provide a suitable variation pattern based on geological aspects. Table 1 presents several tasks utilised on different rocks, which leads to developing classification on rock mass strengths. One of these classifications was introduced by Goudie to categorise the geologic base rock types by R values [4] which is illustrated in Table 2. As can be seen from these tables’ sedimentary rocks (especially marlstones and claystones) have always had the lowest R values and wide variations, which indicate the low strength of these geo-materials.

The presented study used this idea to provide the empirical classification for marlstones’ located in South Pars (Assalouyeh) region, southwest of Iran were named SPM. The geo-engineering characteristics of South Pars are comprehensively investigated by Azarafza et al. [10–12]. This article tried to establish the link between the geo-engineering characteristics, geological origin, and Schmidt index for SPM. The SPM geotechnical properties are presented in Table 3, an estimate by geotechnical in-situ and laboratory tests such as UCS, LDS, and carbonate content. The carbonate content test results were based on Pettijohn’s classification system for marls which is presented in Table 4 [13].

By considering the provide data in Tables 2 to 4, the comparative Schmidt hammer test was performed on SPM samples. A hammer strike is perpendicular to the surface to provide accurate results. Then the results obtained from the experiment are recorded and plotted in the standard Schmidt chart. In this regard, the SPM samples were tested by UCS, and variations are plotted vs R-value and present in Fig. 1. Then, having information about the R and UCS values, the Schmidt chart is prepared for each of the marl categories were presented by Pettijohn. Fig. 2 is presented the results of SPM on Schmidt’s chart. As shown in these figures, the results have demonstrated logical trends that explain that the Schmidt index increases almost linearly with increasing UCS in the studied region. By placing the geological type, UCS and R values in Schmidt chart can be used to separate the marls type in South Pars. Fig. 3 is presented with the SPM classification chart in the studied area. According to this figure, the carbonate content of the SPM directly controls the UCS and R (rock mass strength indicators) which can be stated that by increasing the carbonate content from Marlstone (35-65%) to Argillaceous lime (75-85%), the UCS and R will be increased.
Table 1
The range of UCS and R value changes in different sedimentary rocks.

| Scholar                    | Geo-materials          | Location       | Schmidt index (R) | UCS (MPa) | Ref. |
|---------------------------|------------------------|----------------|-------------------|-----------|------|
| Day and Goudie (1977)      | Hardpan limestone      | England        | 42                | 67        | [14] |
|                           | Dolomite               | Bahrain        | 50                | 85        |      |
|                           | Calcareous marl        | Bahrain        | 14.5              | 38        |      |
|                           | Limestone              | Mallorca       | 52.7              | 94        |      |
| Day (1980)                 | Limestone (weathered to dense) |                 |                |           |      |
|                           | Argillaceous lime      | Yucatan        | 35.9              | 63        |      |
|                           | Limestone              | Jamaica (Browns town) |            | 48        |      |
|                           | Dolomite               | Guatemala      | 39.7              | 66        |      |
|                           | Dolomite               | Belize         | 39.8              | 66        |      |
|                           | Limestone              | Sarawak        | 56.4              | 47        |      |
|                           | Limestone              | Mulu           | 59.9              | 43        |      |
|                           | Calcareous marl        | Barbados       | 29.8              | 41        |      |
| Gökçeoğlu and Aksoy (2000)| Calcareous marl        | Turkey (Ankara) | 27.1 - 38.6       | 30–40     | [16] |
|                           | Marlstone              | Turkey (Istanbul) | 17.15 - 44.6     | 20–35     |      |
| Andrade et al. (2002)     | Marlstone              | Portugal       | 25                | 30        | [17] |
|                           | Limestone              | Portugal       | 38                | 55        |      |
| Hayakawa and Matsukura (2003) | Marlstone           | Japan          | 10.5 - 32         | 15–25     | [18] |
| Basarir and Karpuz (2004)  | Calcareous marl        | Turkey         | 20 - 51           | 33–47     | [19] |
|                           | Marlstone / Claystone  | Turkey         | < 18              | < 20      |      |
| Kahraman et al. (2004)    | Calcareous marl        | Turkey         | 35.2 - 57         | 27–45     | [20] |
| Dickson et al. (2004)     | Calcareous marl        | Lord Howe Island | 19.8 - 28.6     | 25        | [21] |
| Lyew-Ayee (2004)          | Limestone              | Jamaica (Montpelier) | 25.5            | 20        | [22] |
|                           | Limestone              | Jamaica (Troy) | 41.87 - 55.23    | 35–50     |      |
|                           | Limestone              | Jamaica (Moneague) | 43.67 - 44.57   | 40        |      |
|                           | Argillaceous lime      | Jamaica (Chapelton) | 38.04 - 38.74   | 35        |      |
|                           | Limestone              | Jamaica (Somerset) | 41.76           | 37        |      |

(continued on next page)
| Scholar                  | Geo-materials                  | Location                     | Schmidt index (R) | UCS (MPa) | Ref   |
|-------------------------|-------------------------------|------------------------------|-------------------|-----------|-------|
| Goktan and Gunes (2005) | Shale Marl                     | Turkey                        | 30 - 46           | 25 - 35   | [5]   |
| Güney et al. (2005)     | Limestone                      | Turkey (Burdur)              | 62 - 64           | 21 - 138  | [23]  |
|                         | Travertine                     | Turkey (Konya)               | 45 - 62           | 58 - 81   |       |
|                         | Travertine                     | Turkey (Bilecik)             | 59 - 85           | 6 - 92    |       |
|                         | Travertine                     | Turkey (Burdur- Karamanly)   | 44 - 62           | 24 - 110  |       |
|                         | Travertine                     | Turkey (Antalya-Finnke)      | 33                | 49 - 52   |       |
|                         | Travertine                     | Turkey (Burdur-Yeşilova)     | 25 - 62           | 91 - 131  |       |
| Torabi et al. (2010)    | Sandstone                      | Iran (Coal seam)             | 16 - 67           | 25 - 224  | [24]  |
|                         | Siltstone                      | Iran (Coal seam)             | 16 - 67           | 25 - 224  |       |
|                         | Shale                          | Iran (Coal seam)             | 16 - 67           | 25 - 224  |       |
|                         | Fossiliferous Shales          | Iran (Coal seam)             | 16 - 67           | 25 - 224  |       |
|                         | Argillaceous sandstone        | Iran (Coal seam)             | 16 - 67           | 25 - 224  |       |
| Nazir et al. (2013)     | Limestone                      | Malaysia                      | 28.9 - 39         | 52.2 - 85.6| [25]  |
| Saptono et al. (2013)   | Sandstone                      | Indonesia (Tutupan)          | 10 - 26           | 6.53 - 23.2| [26]  |
|                         | Mudstone                       | Indonesia (Tutupan)          | 10 - 28           | 6.53 - 25.6|       |
| Selçuk and Yabalak (2014)| Calcareous Marl               | Turkey (Van)                 | 27 - 29.7         | 38.6 - 41.3| [27]  |
|                         | Marlstone                      | Turkey (Van)                 | 20 - 26           | 4.3 - 9.5 |       |
|                         | Claystone / Argillaceous Marl | Turkey (Van)                 | 10 - 22           | 2.5 - 4.5 |       |
| Kesimal and Kesimal (2015)| Limestone                     | Turkey (Trabzon)             | 37.6 - 39.5       | 75 - 120  | [28]  |
|                         | Sandy limestone                | Turkey (Trabzon)             | 30.6 - 31         | 22.5      |       |
|                         | Biomicritic limestone         | Turkey (Trabzon)             | 13.5 - 17.5       | 7.7 - 18.9|       |
| Jobli et al. (2016)     | Marlstone                      | Sungai Buloh                 | 25.85             | 20 - 25   | [29]  |
|                         | Calcareous Marl               | Sungai Buloh                 | 37.38             | 30 - 35   |       |
|                         | Calcareous Marl               | Sungai Buloh                 | 59.51             | 38 - 43   |       |
|                         | Limestone                      | Sungai Buloh                 | 59.2              | 42 - 46   |       |
| Azimian (2017)          | Limestone                      | Iran (Shiraz)                | 59 - 22           | 28.7 - 118.4| [30]  |
| Rajabi et al. (2017)    | Limestone                      | Iran (Saveh)                 | 21.3 - 29.6       | 33.5 - 42.6| [31]  |
| Török (2018)            | Oolitic limestone              | Hungary (Budapest), Austria  | 37 - 17           | 18.7 - 35 | [32]  |
|                         | Porous Miocene limestone      | Hungary (Budapest), Austria  | 19                | 22        |       |
|                         | Compact limestone              | Hungary (Gerecse Mountains)  | 45                | 35        |       |
|                         | Travertine                     | Hungary                      | 45 - 38           | 35 - 42   |       |
|                         | Sandstone                      | Iran (Qom)                   | 39 - 57           | 46.6 - 77.3| [33]  |
| El Shinawi et al. (2020)| Mudstone                       | Egypt (May City)             | 31 - 32           | 34.2 - 43.2| [34]  |
|                         | Wackestone                     | Egypt (May City)             | 24 - 33           | 33.5 - 41.5|       |
|                         | Grainstone                     | Egypt (May City)             | 23 - 25           | 29.1 - 34.6|       |
| Aly Abdelhamid et al. (2020)| Limestone                | China (Hubei)               | 34 - 55.1         | 47.6 - 92 | [35]  |
Fig. 2. Schmidt hammer hardness index test results for SPM.

Table 2
The experimental rock mass classification by Schmidt index [4].

| Rock classification      | Schmidt index (R) | UCS (MPa) | Rock decryption                                      |
|--------------------------|-------------------|-----------|------------------------------------------------------|
| Very weak rock           | 10–35             | 1–25      | Weathered sediment rocks, Marls, Claystone          |
| Weak rock                | 35–40             | 25–50     | Marlstone, Calcareous marl, Argillaceous lime        |
| Moderate rock            | 40–50             | 50–100    | Limestone, Sandstone                                |
| Strong rock              | 50–60             | 100–200   | Metamorphic rocks                                   |
| Very strong rock         | > 60              | > 200     | Dense metamorphic rocks, Igneous rocks               |

Table 3
Geomechanical properties of SPM [10].

| Parameter                | Number of tests | Mean     | Standard Deviation |
|--------------------------|-----------------|----------|--------------------|
| Water content (%)        | 45              | 6.123    | 3.061              |
| Specific gravity (Gs)    | 45              | 2.759    | 1.107              |
| γt (kN/m3)               | 45              | 22.97    | 1.330              |
| γd (kN/m3)               | 45              | 21.63    | 1.386              |
| Porosity (%)             | 45              | 13.82    | 6.060              |
| Cohesion (kPa)           | 45              | 208.5    | 55.661             |
| Friction (°)             | 45              | 25       | 3.991              |
Table 4
Sedimentary rocks classification by Pettijohn (1983) [13].

| Categories  | Classification               | Main ingredients (%) |          |
|------------|------------------------------|----------------------|----------|
|            |                              | Carbonate            | Clay     |
| Carbonate  | Lime/Limestone               | 95–100               | 0–5      |
|            | Slightly argillaceous lime   | 85–95                | 5–15     |
|            | Argillaceous lime            | 75–85                | 15–25    |
| Marls      | Calcareous marl              | 65–75                | 25–35    |
|            | Marl/marlstone               | 35–65                | 35–65    |
|            | Argillaceous marl            | 25–35                | 65–75    |
| Clay       | Calcareous mud               | 15–25                | 75–85    |
|            | Slightly argillaceous mud    | 5–15                 | 85–95    |
|            | Mudstone/Claystone           | 0–5                  | 95–100   |

![Image](image.jpg)

Fig. 3. Empirical classification for SPM by using Schmidt chart.

Declaration of Competing Interest

None.

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