

*Full Length Research Paper*

# The geotechnical properties of the oolitic ironstone formation, Wadi Halfa, North Sudan

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**Wadi Halfa Oolitic Ironstone Formation (WHOIF) covers large areas around Wadi Halfa border town in Northern Sudan. The detrital framework grains of sandstone of WHOIF are composed of sub-angular to sub-rounded quartz grains followed by feldspars, lithic fragments, micas and heavy minerals. The dominant cementing materials are iron oxides, carbonate cement, and some clay minerals. Twelve block samples were carefully selected and collected from six sites to represent different parts of vertical lithofacies sections of the studied formation. The petrographical characteristics of the specimens were first studied and the specimens were then subjected to laboratory tests to determine some of their basic physical and engineering properties. The physical tests constituted unit weight, specific gravity and water absorption. The measured engineering properties included uniaxial compressive strength (UCS) and ultra-sonic pulse velocity (UPV). The UCS and UPV were measured for specimens parallel and perpendicular to the bedding planes of the studied samples. The geotechnical study shows that the UCS values of WHOIF generally range from strong 83.7 MPa to very strong 153.7 MPa for perpendicular direction to bedding planes. Very good statistical correlation coefficient was developed between UCS and UPV. Good correlation was obtained between water absorption, porosity and UPV. These relations indicated that a decrease in void ratio and porosity resulted in an increase in UCS and UPV. An increase in water absorption of sandstone yielded a decrease in ultrasonic pulse velocity and uniaxial compressive strength.**

**Key words:** Wadi Halfa Oolitic ironstone formation, lithofacies, uniaxial compressive strength, ultrasonic pulse velocity.

## INTRODUCTION

The term Nubian Sandstone Formation or Nubian Formation (NF) is applied in the Sudan to those bedded and usually flat-lying sandstones, conglomerates, grits,

sandy mudstones and mudstones that rest unconformably on the Basement Complex (Vail, 1978). These formations occupy about 25.7 to 28.1% of the area of Sudan before

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separation of South Sudan (Yousif, 1985). The Nubian Formation in Wadi Halfa area is known as Wadi Halfa Oolitic Ironstone Formation (WHOIF) and is composed of highly consolidated beds of sandstone, siltstone, mudstone and marked by thin beds of oolitic ironstone. The WHOIF was named based on the region of Wadi Halfa and by marked three beds of oolitic ironstone.

The WHOIF is rich in different types of clastic sediments consisting of multi-coloured sandstones which can be used as building materials and/or ornamental stones, and oolitic ironstone which could be utilized in steel industry and as industrial minerals.

Almost all the ancient buildings and pyramids in Sudan were built using the Nubian Sandstone and several large civil engineering projects are either founded on or built using products from these formations. The knowledge of their physical and engineering properties is necessary for design and construction engineers. Studies were carried out for the determination and prediction of the physical and engineering properties of basically the sandstone and mudstone components of the NF in Khartoum state (Yousif, 1985; Elsharief et al., 2015; Abdul and Mutasim, 2018), whereas very little is known about those of the WHOIF.

The study area is one of the most remote areas in the Sudan; most of the previous studies about the WHOIF are concentrated on the general geology stratigraphy and sedimentology and did not include any geotechnical study. This is the first study that deals with the geotechnical properties of the WHOIF.

The determination of the physical and engineering properties of rock formations require field sampling, sample preparation in the laboratory and laboratory testing. The laboratory tests require skilled personnel and advanced equipment for sample preparation and testing. An alternative to laboratory testing is to use indirect means for predicting the required engineering properties of interest such as the uniaxial compressive strength using ultrasonic pulse velocity data and/or simple physical rock parameters. Many researchers (Altindag, 2012; Sarkar et al., 2012; Kainthola et al., 2015; Asci et al., 2017; Abdi et al., 2018) developed correlation equations for important rock-engineering properties using geotechnical properties and pulse velocity for different rock types. The present study deals with the geotechnical properties of Wadi Halfa Oolitic Ironstone Formation and attempts to develop correlation equations between the measured geotechnical properties and some simple physical properties of these rocks.

### **The geology of the study area**

The geology of the region of Wadi Halfa is relatively simple. It consists of the oldest basement complex rocks of Precambrian age overlain by the Nubian Sandstone Formations (Vail, 1978; Stern et al., 1994). The term

"Nubian Sandstone" was first introduced in Egyptian stratigraphy by Russegger (1837). It includes sandstone of varying ages and types overlapping the edge of the Pre-Cambrian Arabo – Nubian Shield from Algeria to Saudi Arabia. Recently sedimentological and stratigraphical studies discarded the term "Nubian Sandstone" and separated into several formations with local names. The long range of age time and the wide distribution to what is called Nubian sandstone become meaningless.

Recent sedimentological study around Wadi-Halfa divided the so-called Nubian Sandstone of northern Sudan based on stratigraphical and paleontological evidence into the Wadi Halfa Oolitic Ironstone Formation to those sediments of Upper Carboniferous Permo-Triassic Upper Jurassic age which contains three layers of oolitic ironstone (Nafi et al., 2009; Nafi et al., 2010 and Nafi et al., 2011) (Figure 1).

The NF in the study area is composed of yellowish, brownish to whitish fine medium to coarse grained sandstone layers that are intercalated with oolitic ironstone and covers more than 500 km<sup>2</sup>. The lithofacies of Wadi Halfa Oolitic Ironstone Formation include trough cross bedded sandstone, planner cross bedded sandstone, horizontally stratified sandstone, fine mudstone facies, massive mudstone facies, massive sandstone facies, rippled sandstone facies and horizontally shallow marine sandstone facies as shown in Figure 2 (Elamein, 2015; Nafi et al., 2015).

The study area is situated in northern Sudan in the vicinity of Wadi Halfa town and close to Sudan-Egypt border.

It is bounded by latitudes (21° 25' and 21° 59' N) and longitudes (31° 18' and 31° 40' E) as shown in Figure 3.

### **Scope of the study**

In the present study, 12 large block sandstone samples were carefully selected and collected from six locations in the study area to represent the vertical lithofacies sections of Wadi Halfa Oolitic Ironstone Formation. The petrographical characteristics of the specimens were first studied and the specimens were then subjected to laboratory tests to determine some of their basic physical and engineering properties. The physical tests constituted unit weight, specific gravity and water absorption. The measured engineering properties included uniaxial compressive strength test and ultra-sonic pulse velocity.

### **The petrographical study**

The petrographic characteristics of the 12 selected samples were determined using Optical Polarized Microscope (PL) as well as Cross Nicol (C.N) to determine the rock constituents using Gazzi Dickinson method (1985) and to classify the sandstone according to

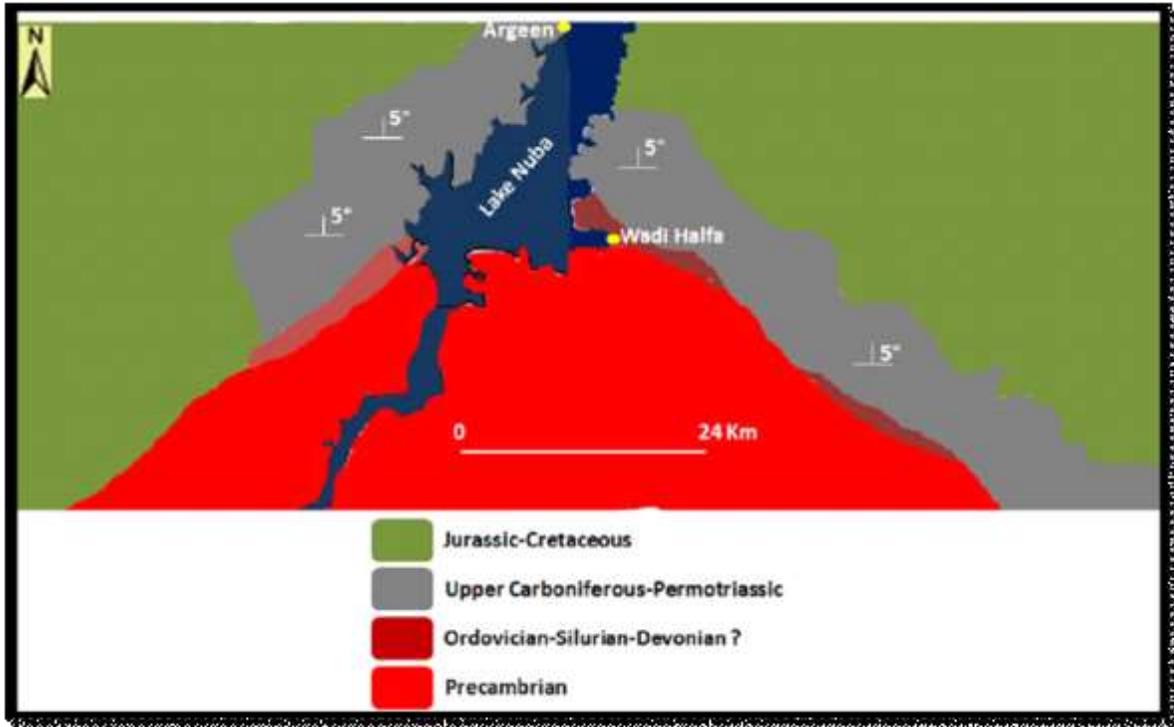


Figure 1. Sketch geological map of the study area (After Nafi et al., 2009).

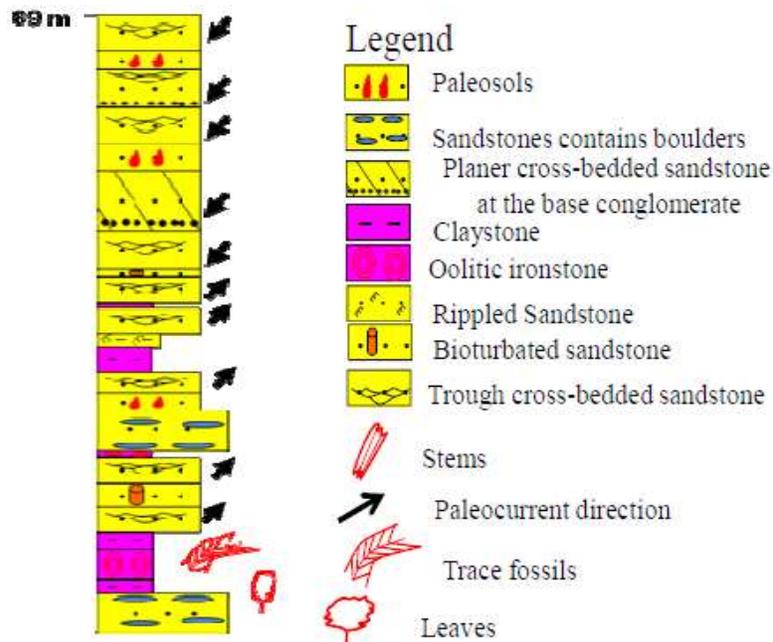
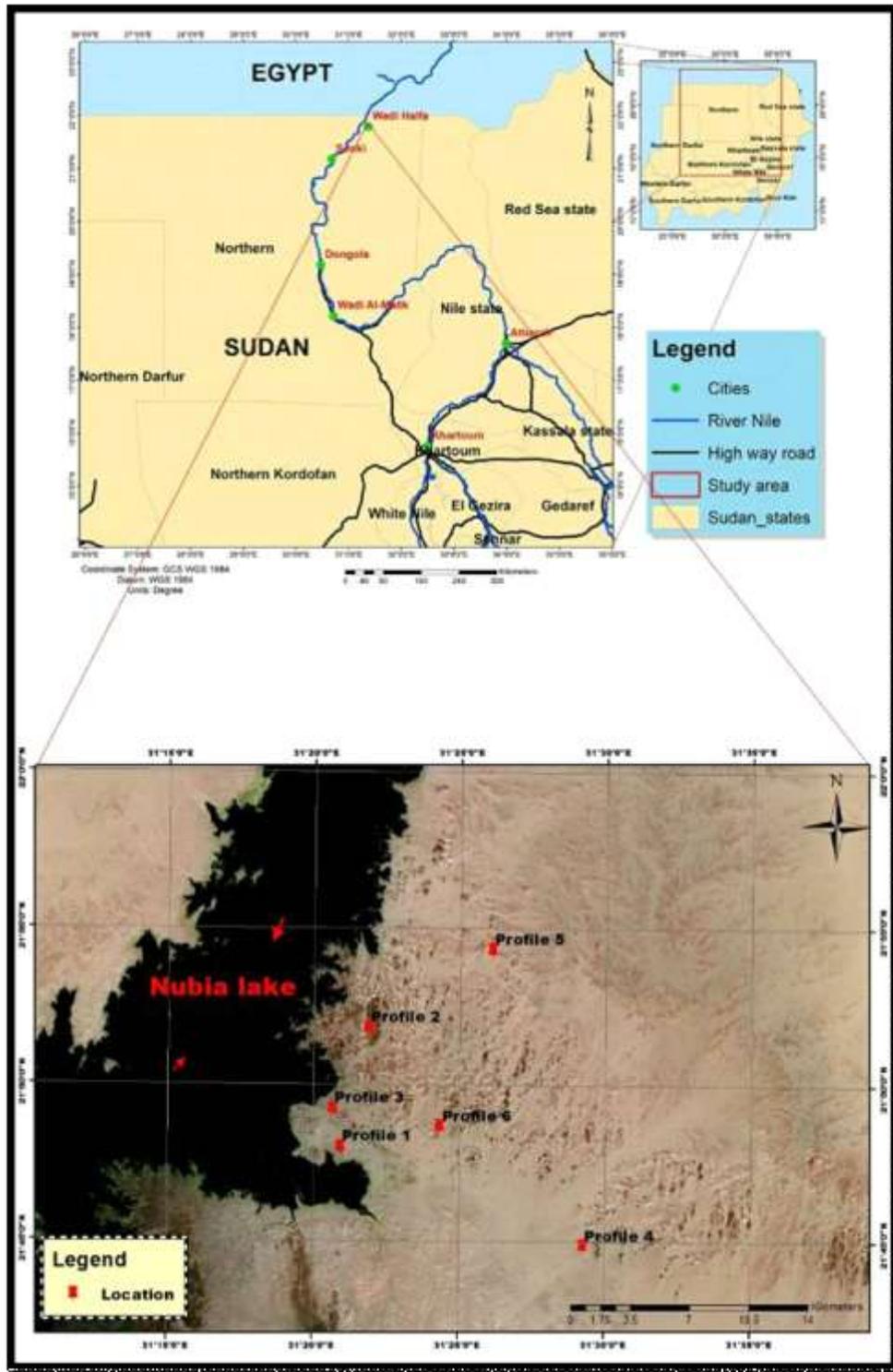


Figure 2. Lithofacies of Wadi Halfa Oolitic Ironstone Formation. (Nafi et al., 2015).

Folk (1974). The test results are summarized in Table 1. The detrital framework grains, pores and cementing

materials of WHOIF samples were calculated using the petrographic microscope and the results are summarized



**Figure 3.** Location map of the study area showing the location of selected samples and the region of Wadi Halfa.

in Table 2.

Petrographically, the detrital framework grains of the sandstone of Wadi Halfa Oolitic Ironstone Formation are

composed of monocrystalline, polycrystalline quartz grains followed by feldspars, lithic fragments, micas and heavy minerals. The main types of cementing materials

**Table 1.** Petrographical classification of the studied sandstone samples using Gazzi-Dickenson method.

Samples	Qz %	F %	LF%	Classification
A1	97	0	3	Quartz arenite
A2	94	1	5	Sublithic arenite
A3	96	3	1	Quartz arenite
A4	92	6	2	Subarkose
A5	94	5	6	Sublithic arenite
A6	94	5	1	Subarkose
A7	96	3	1	Quartz arenite
A8	97	2	1	Quartz arenite
A9	96	1	3	Quartz arenite
A10	99	1	0	Quartz arenite
A11	96	4	0	Quartz arenite
A12	95	4	1	Subarkose

**Qz**, Quartz include monocrystalline and polycrystalline quartz grains; **F**, Feldspars include plagioclase and microcline; **LF**, Lithic fragments include metamorphic, igneous and sedimentary rock fragments.

**Table 2.** The percentage of quartz grains, cement, matrix and pores of the studied samples calculated using the petrographic microscope.

Samples	Grains	Cementing material	Matrix	Pores
A1	50	16	4	30
A2	74	11	4	11
A3	66	23	2	9
A4	74	14	7	5
A5	64	21	10	4
A6	61	24	1	14
A7	66	9	2	23
A8	64	26	3	7
A9	60	9	3	28
A10	68	22	2	8
A11	65	19	9	7
A12	67	18	7	8

Grains include, Quartz, Feldspars, Rock Fragment, Micas and Heavy minerals; Cementing Material, Iron Oxides, Carbonates, Clay Minerals; Matrix, Clays and Opaque Minerals; Pores, Intergranular and Oversized Pores.

are iron oxides, carbonates and some clay minerals.

### ***The physical properties***

The physical property tests performed on the specimens constituted unit weight, specific gravity and water absorption. These tests were carried out for all the collected samples using test methods described in ASTM (1981) and Cheng and Jack (2009). The water absorption test is intended to measure the capacity of the tested rock samples to absorb water. It gives an indirect

measure of the quality of rock materials and a basic idea about the rock strength and its water holding capacity. Summary of the test results is given in Table 3.

### ***The engineering properties***

Twenty-four representative cylindrical test specimens were prepared for the laboratory tests by coring. The cores were prepared to give test specimens about 35 mm diameter and 70 mm core length, considering the orientation of the bedding planes of the sandstone

**Table 3.** Results of physical tests.

Samples	$\gamma$ g/cm <sup>3</sup>	G <sub>s</sub> (%)	W (%)	e (%)	n (%)	WA (%)
A1	2.24	2.67	0.12	0.34	25.1	7.97
A2	2.38	2.65	0.10	0.23	18.7	6.10
A3	2.23	2.71	0.10	0.26	20.7	9.54
A4	2.20	2.74	0.20	0.49	32.9	5.80
A5	2.76	2.66	0.13	0.09	8.18	5.28
A6	2.40	2.66	0.20	0.34	25.4	8.15
A7	2.30	2.66	0.15	0.33	24.8	8.91
A8	2.20	2.66	0.03	0.24	19.4	8.89
A9	2.27	2.67	0.11	0.31	23.7	14.3
A10	2.13	2.67	0.15	0.44	30.6	8.33
A11	2.36	2.66	0.10	0.24	19.4	9.55
A12	2.33	2.66	0.24	0.41	29.1	12.2

$\gamma$ , Unit weight; G<sub>s</sub>, Specific gravity; W, Water content; e, Void ratio; n, Porosity; WA, Water absorption.

**Table 4.** The ultrasonic pulse velocity and uniaxial compressive strength test results.

Samples	UPV (m/sec)		UCS (MPa)		Classification
	90°	0°	90°	0°	
A1	2750	2430	25.5	24.6	Moderately Strong
A2	3500	3110	111.7	97.3	Very Strong
A3	2660	2880	153.7	120.9	Very Strong
A4	2540	2500	87.4	65.8	Strong
A5	2630	2560	53.7	47.3	Strong
A6	2650	2550	66.4	50.0	Strong
A7	2380	2280	83.7	50.0	Strong
A8	2840	2800	86.4	55.5	Strong
A9	1830	1570	28.2	13.6	Weak
A10	2060	1860	80.7	59.1	Strong
A11	2050	1960	82.8	79.1	Strong
A12	2170	1940	58.2	49.1	Strong

samples (anisotropy). For each test sample one specimen was cored in a direction parallel (0°) to the bedding plane and the other one perpendicular (90°) to the bedding plane following ASTM (2009) and Ramamurthy et al. (1993) procedures.

The ultrasonic pulse velocity was measured, for each test specimen, at room temperature in dry state according to ASTM (1995b). The UPV values were computed by dividing the length of the tested specimen by the travel time of the ultrasonic pulse. The results are shown in Table 4.

The same specimens were mounted on the compressive test machine to determine their uniaxial compressive strength. Each specimen was loaded to failure. The uniaxial compressive strength was obtained by dividing the maximum failure load by the cross-

sectional area of the tested sample. The corrected compressive strength value with respect to different values of L/D ratios (L: Length and D: diameter) was calculated using the formula suggested by ASTM (1995a):

$$CS = CS_m / \left( 0.778 + 0.222 \left( \frac{D}{L} \right) \right) \quad (1)$$

Where, CS (MPa) is the corrected compressive strength, CS<sub>m</sub> (MPa) is the measured compressive strength, D is the specimen's diameter in mm and L is the length of the tested specimen in mm.

The UPV and UCS test results are presented in Table 4 for the orientations parallel (0°) and perpendicular (90°) to

the bedding planes.

## RESULTS AND DISCUSSION

Table 1 presents the results of the petrographical study. The petrographic classification of sandstone samples of Wadi Halfa Oolitic Ironstone Formation according to mineral composition (quartz, lithic fragments, and feldspars) is as follows: quartz arenite 58.3%, sub lithic arenite 16.7% and subarkose 25%.

The percentages of grains, cements, matrix and pores are calculated from petrographic microscope (Table 2) to show the relationship between the strength of sandstone and the angularity of quartz grains and different types of cementing materials (iron oxides, clays and carbonates). The detrital framework grains of sandstone of WHOIF representing an average of 68% of the rock volume and composed of sub angular to sub rounded quartz grains followed by feldspars, lithic fragments, micas and heavy minerals. The main cementing materials of most of the studied samples are iron oxides, carbonate cement, and different types of clay minerals also may occur as pore filling. The cementing materials represent an average of 24% of the rock volume.

The uniaxial compressive strength is the most important engineering parameter for assessment of the strength of a rock sample. Normally, the UCS tested sample is either obtained from coring operations during rotary drilling or by coring from a representative block sample. For the first case, the sample is extracted in the direction of drilling, which is vertically downward in most cases. However, for block samples, test specimens could be obtained for different orientations. For this study, laboratory test specimens were obtained from representative block samples by coring parallel (0°) and perpendicular (90°) to the bedding planes. The UCS values obtained for the two orientations, ranges from 120 to 28.2 MPa with an average value 74.6 MPa for parallel direction and ranges from 153.7 to 13.6 MPa with an average value 83.7 MPa for perpendicular direction.

According to the results of the uniaxial compressive strength tests the WHOIF can generally be classified as very strong to strong according to classification suggested by Hoek and Brown (1997). Only samples A1 and A9 are moderate to weak.

Samples A2 and A3 measured the highest UCS (111.7 to 153.7 MPa). These samples are cemented by iron oxides and clays; whereas samples (A1 and A9) measured the lowest values of UCS (13.6 and 28.2 MPa) due to the weathering effects, high porosity (30%) and weak cementing element (carbonates). It is clear to some extent that the UCS increases with cementing material and decreases with increasing pore volume.

Compared with other rock types (Johnson and DeGraff, 1989; Lockner, 1995; Lama and Vutukuri, 1978) the sandstone samples of the studied area show high

compressive strength due to the high content of iron oxides and probably the presence of some clay minerals. According to Fjaer et al. (2009) the strength of medium to fine sandstone cemented by iron oxides ranges from 35 MPa to 153.7 MPa, which are similar to the sandstone of the study area.

Figure 4 shows the UCS parallel vs UCS perpendicular to the bedding planes for all the tested specimens. As expected, the UCS perpendicular is higher than UCS parallel for the tested specimens and very good relationship is established between parallel and perpendicular with very good correlation coefficient; the correlation is significant at the 0.01 level (2 – tailed) with coefficient ( $R^2 = 0.91.03$ ).

$$UCS (Perpendicular) = 1.1397 UCS (Parallel) + 8.8809 MPa \quad (2)$$

The UCS was plotted against UPV for all the tested specimens. Figure 5 shows that UCS could be estimated or predicted with very good accuracy from the UPV values for perpendicular and parallel orientations. Since the UPV is nondestructive and easy to perform its data could be used to predict the strength of the investigated Wadi Halfa Oolitic Ironstone Formation with very good accuracy with  $R^2 = 0.992$ .

$$UCS (Perpendicular) = 83.823 UPV (Perpendicular) - 136.05 \quad (3)$$

Porosity is an important rock parameter that measures the voids within unit volume. Porosity was plotted against UPV. Good negative correlation was found between porosity and UPV of parallel and perpendicular orientation with  $R^2 = 0.7548$ . This means that porosity could be estimated with acceptable accuracy from the UPV test results (Figure 6).

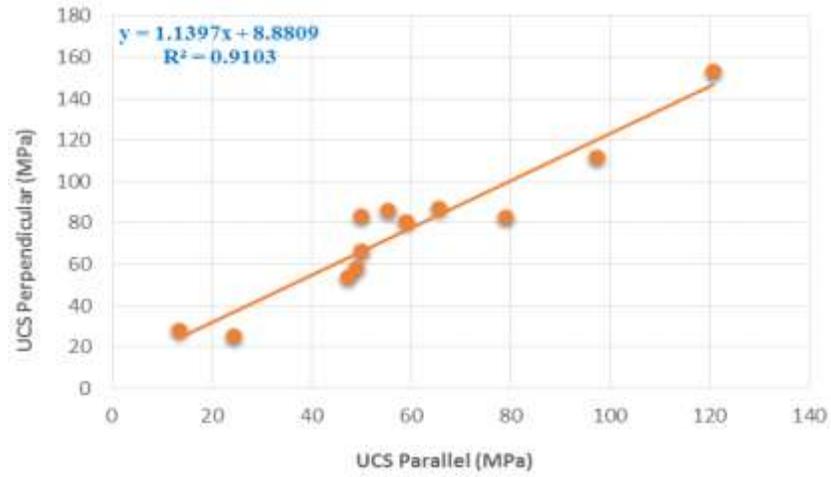
$$n = -0.0074 UPV + 42.834 \quad (4)$$

Water absorption was plotted against porosity and ultrasonic pulse velocity (Figures 7 and 8). Acceptable relationship was found ( $R^2 = 0.5122$  and  $0.5536$ ) respectively:

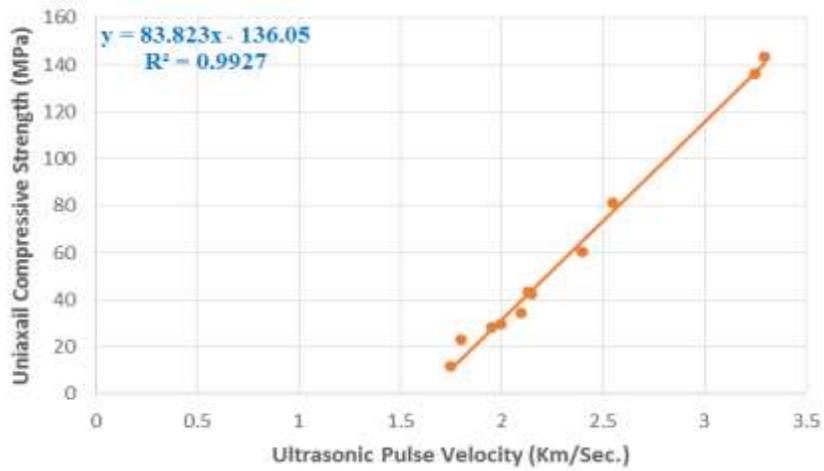
$$WA = 0.2094 (n) + 4.1793 \quad (5)$$

$$WA = -0036 (UPV) + 18.014 \quad (6)$$

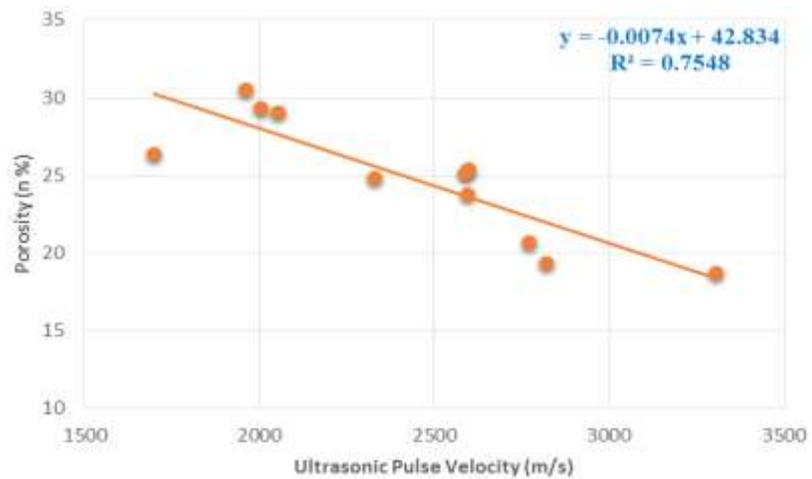
These relations indicated that a decrease in void ratios and porosity resulted in an increase in uniaxial compressive strength and ultrasonic pulse velocity and an increase in water absorption of the sandstone yielded a decrease in ultrasonic pulse velocity and hence uniaxial compressive strength.



**Figure 4.** The relationship between uniaxial compressive strength parallel and perpendicular to bedding planes.



**Figure 5.** UCS perpendicular vs UPV perpendicular.



**Figure 6.** Porosity vs ultrasonic pulse velocity.

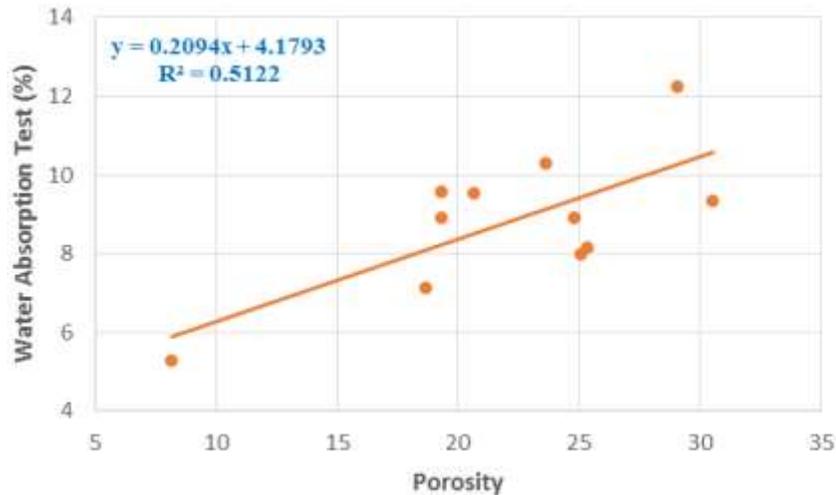


Figure 7. Water absorption vs porosity.

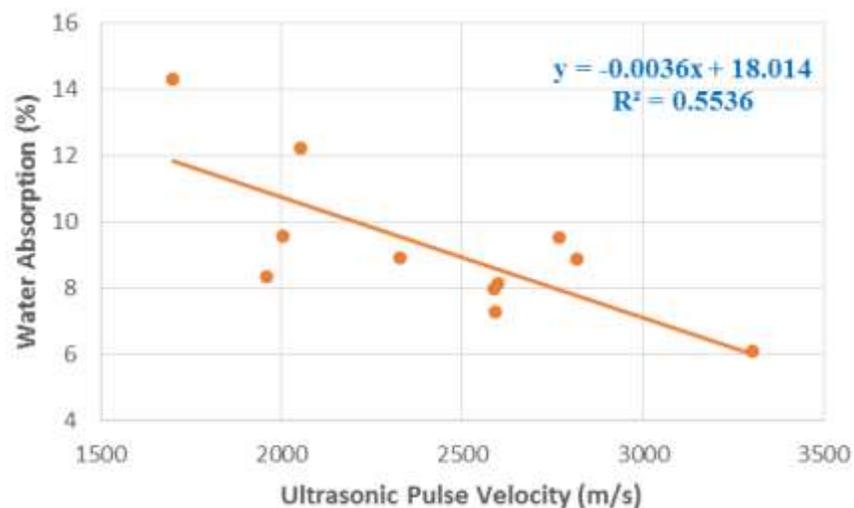


Figure 8. Water absorption vs ultrasonic pulse velocity.

## Conclusion

The knowledge of the geotechnical properties of Wadi Halfa Oolitic Ironstone Formation is important for engineers working on the design and construction of civil engineering projects founded on or constructed with them. According to the field investigation of WHOIF; twelve representative block samples were carefully selected to represent the investigated formation. The samples were petrographically studied first. Afterwards intensive laboratory testing program was performed on the obtained rock samples. The tests included determination of the unit weight, specific gravity, moisture content, porosity, void ratios, water absorption, uniaxial compressive strength and ultrasonic pulse velocity. The

compressive strength and ultrasonic velocity were measured for specimens parallel and perpendicular to the bedding planes of the studied samples. An attempt was made to develop correlation equations for the prediction of UCS, WA and porosity of WHOIF.

Good to very good statistical correlation was developed between uniaxial compressive strength and ultrasonic pulse velocity of different anisotropy of the sandstone. The compressive strength, porosity, and water absorption could be estimated or predicted with very good accuracy from the ultrasonic pulse velocity values.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

## REFERENCES

- Abdi Y, Khanlari GR, Amin J (2018). Correlation between Mechanical Properties of Sandstones and P-Wave Velocity in Different Degrees of Saturation. *Geotechnical Geological Engineering* 37(157):1529-1573.
- Abdul Karim MZ, Mutasim AS (2018). Estimation of the strength of Nubian Sandstone Formation from point load test index and other simple parameters. *MATEC Web of Conferences* 149(02024):1-6.
- Altindag R (2012). Correlation between P-wave velocity and some mechanical properties for sedimentary rocks. *The Journal of the Southern African Institute of Mining and Metallurgy* 112:229-237.
- Asci M, Kaplanvural I, Karakas, Sahin OK, Kurtulus C (2017). Correlation of physical and mechanical properties with ultrasonic pulse velocities of sandstones in Cenedag, Kocaeli-Turkey. *International Journal of Advance Geosciences* 5(2):109-115.
- American Society for Testing and Materials (ASTM) D854-02 (1981). Standards C127 Test Method for Specific Gravity and Absorption of Coarse Aggregate. American Society for Testing Materials 04(08).
- American Society for Testing and Materials Materials (ASTM) (1995a). Standard Test Method for Unconfined Compressive Strength of Intact Rock Core Specimens. Test Designation D2938, Annual book of ASTM standards Philadelphia 14(2).
- American Society for Testing and Materials (ASTM) (1995b). Standard test method for laboratory determination of pulse velocities and ultrasonic elastic constants of rock. D2845 American Society for Testing Materials USA.
- American Society for Testing and Materials (ASTM) (2009). D 7012-04 Standard test method for compressive strength and elastic modulus of intact rock core specimens under varying states of stress and temperatures. West Conshohocken USA.
- Cheng L, Jack BE (2009). Soil properties testing, measuring and evaluation. Sixth edition Pearson education New Jersey: 39- 71. <https://www.scribd.com/doc/242719518/Soil-Properties-Lab-Cheng-Liu-pdf>
- Dickinson WR (1985). Interpreting provenance relations from detrital modes of sandstones. In: *Provenance of sandstones* pp. 333-361.
- Elamein AM (2015). Sedimentology and stratigraphy of Upper Carboniferous Permo-Triassic clastic sediments around Wadi Halfa and Argeen areas, northern Sudan. PhD Thesis University of Khartoum Sudan (Unpub.)
- Elsharief AM, Zein AK, Elarabi HM, Abulgasim R (2015). Design practice of bored piles in Nubian Formation, Sudan. *Engineering Society Journal* 60(1):1-19.
- Fjaer E, Holt RM, Horsrud P, Raaen AM, Rines, R (2009). *Petroleum Related Rock Mechanics*. Elsevier Science Amsterdam.
- Folk RL (1974). Petrology of sedimentary rocks. Austin pp. 182-194.
- Hoek E, Brown ET (1997). Practical estimation of rock mass strength. *International Journal of Rock Mechanics and Mining Science* 34(8):1165-1186.
- Johnson RB, DeGraff JV (1989). *Principles of Engineering Geology*. John Wiley and Sons New York.
- Kainthola A, Singh PK, Verma D, Singh Sarkar RK, Singh TN (2015). Prediction of strength parameters of Himalayan rocks: a statistical and ANFIS approach. *Geotechnical and Geological Engineering* 33(1255).
- Lama RD, Vutukuri VS (1978). *Handbook on Mechanical Properties of Rocks*. Trans Tec Publications Clausthal Germany 481 p.
- Lockner DL (1995). Rock failure, rock physics and phase relations-a handbook of physical constants. AGU Reference Shelf 3, American Geophysical Union.
- Nafi M, Awad Z, Abdel Rahman EM, Elamein AM, El Dawi M, Brugg N, Babikir A, El Faki A, El Badri O, El Hag A, Abou A, El Doma A, Abakar A (2009). Significance of Paleozoic Paleogeographic Reconstruction in North Sudan. The First International Symposium on the Petroleum Systems and Geological Resources in the Tethys (ABSTRACT) Cairo University Egypt pp. 17-25.
- Nafi M, Elamein AM, El Dawi M, Awad MZ, Abdel Rahman EM, El Badri O, El Faki EM, Salih K, Ismail O, ElBahi O, Brügge N, Kheirelseed EE, Babikir OE, Babikir O, El Hag O, Abou A, El Doma A, Abakar A (2010). New evidence of Upper Carboniferous – Early Permian glaciation in northern and northwestern Sudan and its relation to hydrocarbon accumulations. Fifth International Conference on the Geology of the Tethys Realm South Valley University Qena Egypt.
- Nafi M, Elamein AM, El Dawi M, Awad MZ, Abdel Rahman EM, El Badri O, El Faki EM, Salih K, Ismail, ElBahi O, Brügge N, Kheirelseed EE, Babikir, Babikir OE, Abou A, El Doma A, Abakar A (2011). New evidence of Upper Carboniferous – Permian Strata in north Sudan. *Sudanese Association of Petroleum Engineering Geology Journal* First Issue pp. 29-43. [https://www.researchgate.net/publication/270881621\\_New\\_Evidence\\_of\\_Upper\\_Carboniferous-Permian\\_Strata\\_in\\_Northern\\_Sudan](https://www.researchgate.net/publication/270881621_New_Evidence_of_Upper_Carboniferous-Permian_Strata_in_Northern_Sudan)
- Nafi M, Elamein AM, El Dawi M, Salih K, ElBahi K, Abou A (2015). Wadi Halfa Oolitic Ironstone Formation. *International Journal of Environmental Chemical Ecological Geological and Geophysical Engineering* 9(10):1271-1276.
- Ramamurthy T, Venkatappa RG, Singh J (1993). Engineering Behavior of Phyllite. *Engineering Geology Journal* 33:209-225.
- Russeger J (1837). Kreide und sandstein Ein von. *Granit ant letzteren: Neues Jahrb. Mineral* pp. 665-669.
- Sarkar K, Vishal V, Singh TN (2012). An empirical correlation of index geomechanical parameters with the compressional wave velocity. *Journal of Geotechnical and Geological Engineering* 30(2):469-479.
- Stern RJ, Kroner A, Bender R, Reischmann T, Dawoud AS (1994). Precambrian basement around Wadi Halfa, Sudan: a new perspective on the evolution of the East Saharan Craton. *Geological Rundschau* 83:564-577.
- Vail JR (1978). Outline of the geology and mineral deposits of the Democratic Republic of Sudan and adjacent areas. *Overseas Geology and mineral Resources* 49:66.
- Yousif HO (1985). Geotechnical properties of the Nubian mudstone and weak Sandstone. M. Sc. Thesis Building and Road Research Institute University of Khartoum Sudan.