COMPARISON OF GYPSIFEROUS SOILS IN SAMARRA AND KARBALA AREAS, IRAQ

Mou'taz A. Al-Dabbas*, Tom Schanz and Mohammed J. Yassen*****

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ABSTRACT

A proposed engineering gypsiferous soil classification is given using: soil texture, mineralogy, geochemistry, engineering properties, and chemical analyses of soils water-extract. The results reflect that these soils consist of different percentages of sand, silt, clay, and some gravel. Analyses also detected secondary gypsum, quartz, calcite, feldspar and different types of rock fragments and different types of heavy minerals in trace amounts. Clay minerals are dominated by palygorskite. Hydrochemical analyses results of soils water-extract show that the calcium and sulphate ions are most common, followed by sodium, bicarbonate, chloride, magnesium and potassium. Bicarbonate and chloride show high values in Karbala area. Gypsum content ranges from (0.9 – 67.5) % in Samarra area, while in Karbala it ranges from (0.4 – 28.9) %. The physical and engineering properties of the studied soils were determined, such as specific gravity, density, shear strength parameters, unconfined compressive strength, and compression and shear wave velocities, compression index, swelling index, initial void ratio, and collapse potential. Samples, which were allowed to soak water show a sudden drop in unconfined compressive strength and compression and shear values immediately after soaking, then were decreased gradually.

The proposed engineering classification of gypsiferous soils includes two classes: "Gypsiferous Soil" and "Highly Gypsiferous Soil"; according to the gypsum content (< 25% and > 25%, respectively), initial void ratio, coefficient of curvature, coefficient of uniformity, collapse potential, compressive strength, cohesion, plasticity index, content of fines, and the T.D.S of the soils water-extract. It is believed that this proposed classification for Iraqi soils can be applied to other locations, therefore, will be useful for other soil scientists and engineers as well, worldwide.

مقارنة بين الترب الجبسية في منطقتي سامراء وكربلاء، العراق

معتز عبد الستار الدباس، توم شخانز و محمد جاسم ياسين

المستخلص

تم اقتراح تصنيف هندسي للترب الجبسية باستخدام نسيج ومعدنية وجيوكيميائية الترب الجبسية، إضافةً إلى خواصها الهندسية ونتائج التحاليل الكيميائية لمياه مستخلصات تلك الترب. عكست النتائج بأن نسيج الترب الجبسية المدروسة يتكون بصورة رئيسية من الرمال ونسب مختلفة من الغرين والطين والحصى. باستثناء منطقة سامراء، حيث تتكون من الغرين والطين والحصى ونسب مختلفة من الرمال. أظهرت الدراسة المعدنية أن هذه الترب تتكون بصورة رئيسية من الجبسم الثانوي، الكوارتز، الكالسايت، الفيلدسبار، أنواع مختلفة من القطع الصخرية ونسب نزرة من المعادن الثقيلة بكميات قليلة جداً، وان معدن الباليكورسكايت يكون من المعادن الطينية الشائعة فيها، وتتراوح نسبة الجبسم من (0.9 – 67.5) % في سامراء وتكون نسبته في كربلاء بين (0.4 – 28.9) %. أظهرت الدراسة الهيدروكيميائية لمستخلصات التربة أن أيوني الكالسيوم والكبريتات أكثر شيوعاً، تليها أيونات الصوديوم، البيكربونات، الكلورايد، المغنيسيوم والبوتاسيوم وان أيوني البيكربونات والكلورايد يظهران تزايداً في منطقة كربلاء.

* College of Science, University of Baghdad. e-mail: profaldabbas@yahoo.com
** Ruhr University of Bochum, Germany. e-mail: tom.schanz@ruhr-uni-bochum.de
*** College of Engineering, University of Mustansyriya, Baghdad, Iraq

تمت دراسة الصفات الفيزيائية والهندسية وتحديدها ومثل الكثافة والكثافة النسبية ومعاملات قوة القص والتماسك ومقاومة الانضغاط غير المحصور وسرعة الموجات الإنضغاطية والقصية وجهد الانهيار ومعامل الانضغاط والانتفاخ ونسبة الفجوات الأولية.

إن التصنيف الهندسي المقترح للترب الجبسية في هذه الدراسة يتكون من مجموعتين استناداً إلى محتواها من معدن الجبسم الثانوي، حيث المجموعة الأولى تسمى الترب الجبسية وبنسب اقل من 25% من الجبسم والمجموعة الثانية تسمى الترب الجبسية ذات المحتوى العالي من الجبسم وبنسب أعلى من 25% من الجبسم إضافة الصفات الهندسية المذكورة سابقا.

INTRODUCTION

Gypsiferous soils represent serious problems in many fields of human activity. They have dramatic impacts on buildings and infrastructure. The gypsiferous soils consist of a secondary gypsum-rich crust within the soil, developed after sedimentation of the soil material by increasing evaporation of saline and sulphate-rich groundwater in arid and warm regions. Infact, gypsiferous soils retain most of the original soil components (clay, silt and sand) but, impregnated by variable amounts of gypsum; as nests or disseminations. Fine-grained soils contain more gypsum than coarse grained soils. Almost, all gypsum accumulates above capillary water zone; in dry areas at which water table is located at about 3 m below ground surface. The soil distribution map in Iraq represents that secondary gypsum is concentrated in the middle third and southern parts of Iraq (Buringh, 1960). Structures built on gypsiferous soils in Iraq suffer from many engineering problems as cracks, tilting, or differential settlements in buildings or as structure collapse and breakage of water and sewage network due to solubility of gypsum within the soil. The main cause of these problems is the collapse of the gypsiferous soils and/ or their decrease in compressibility in case of saturation of the site by rain water or irrigation.

The study areas of this research are situated within Mesopotamian Plain, and included two sites, namely: Samarra and Karbala, which are located between latitudes 32º 30' and 34º 00', and longitudes 43º 45' and 44º 30' (Fig.1). They are covered by Quaternary sediments and Tertiary rocks. The exposed Tertiary rocks are represented by Fatha Formation, consists of marl, claystone, limestone and gypsum, with rare siltstone and sandstone. Injana Formation (consists mainly of sandstone, siltstone and claystone). Mukdadiya Formation, consists mainly of pebbly sandstone, sandstone, siltstone, and claystone, and Dibdibba Formation, consists mainly of sand, gravel and gravelly sandstone with lenses of clay, which is composed of compacted clay balls interfered with some sand and gypsum as cementing material (Fig.1).

Quaternary sediments cover the underlying Tertiary formations; involve Pleistocene and Holocene sediments that include river terraces, gypcrete, flood plain sediments and Aeolian sediments; as constituents of almost all the soil of the studied area.

Little work has been carried out; so far in studying the engineering characteristics of gypsiferous soils in Iraq; among them are Al-Mohammadi and Nashat (1987); Al-Layla (1993) and Abdulla (2005). Work has been limited mostly to Soviet field tests (Petrukhin and Boldyrev, 1978 and Petrukhin and Arakelyan, 1985). Also there are some Iraqi studies dealing with different properties of the gypsiferous soil, such as dry gypsiferous soils behavior in compression and rebound, collapsibility of a gypsiferous soil under different stress levels, the mineralogy and geochemistry of gypsiferous soils (Sirwan *et al*., 1989; Al-Mohammadi *et al*., 1987; Seleam, 1988; Al-Qaissy, 1987; Al-Ani and Seleam,1993; Al-Layla, 1993; Al-Badran, 2001; Al-Bassam and Dawood, 2002, and Yassin, 1988 and 2006).

The effect of gypsum content on collapsibility and compressibility of gypsiferous soils as indicated from different areas in Iraq and for different soils (silty clay, sand, silty sand) have been studied by many researchers (Al-Khuzaie, 1985; Al-Mohammadi and Nashat, 1987; Seleam, 1988; Al-Qaissy, 1987; Al-Aithawi, 1990; Zakaria, 1995; Al-Busoda, 1999 and Al-Beiruty, 2003).They noticed that the coefficient of compressibility and the in-situ void ratio increase with increasing gypsum content. Also they found that wetting of gypsiferous soils contributes in increasing of compressibility due to gypsum removal and collapse.

Many soil scientist and engineers have studied the gypsiferous soils in variable locations of the world and for different purposes, i.e. agriculture, surveying, civil engineering etc. Among those scientists and engineers, some have given different gypsiferous soils classification systems (A Barzanji, 1973; BSI, 1975; FAO – UNESCO, 1975; Petrukhin and Boldyrev, 1978; ASTM, 1986; Yassin, 1988 and 2006; Seleam, 1988 and Maharaj, 1995 and Nashat, 1990).

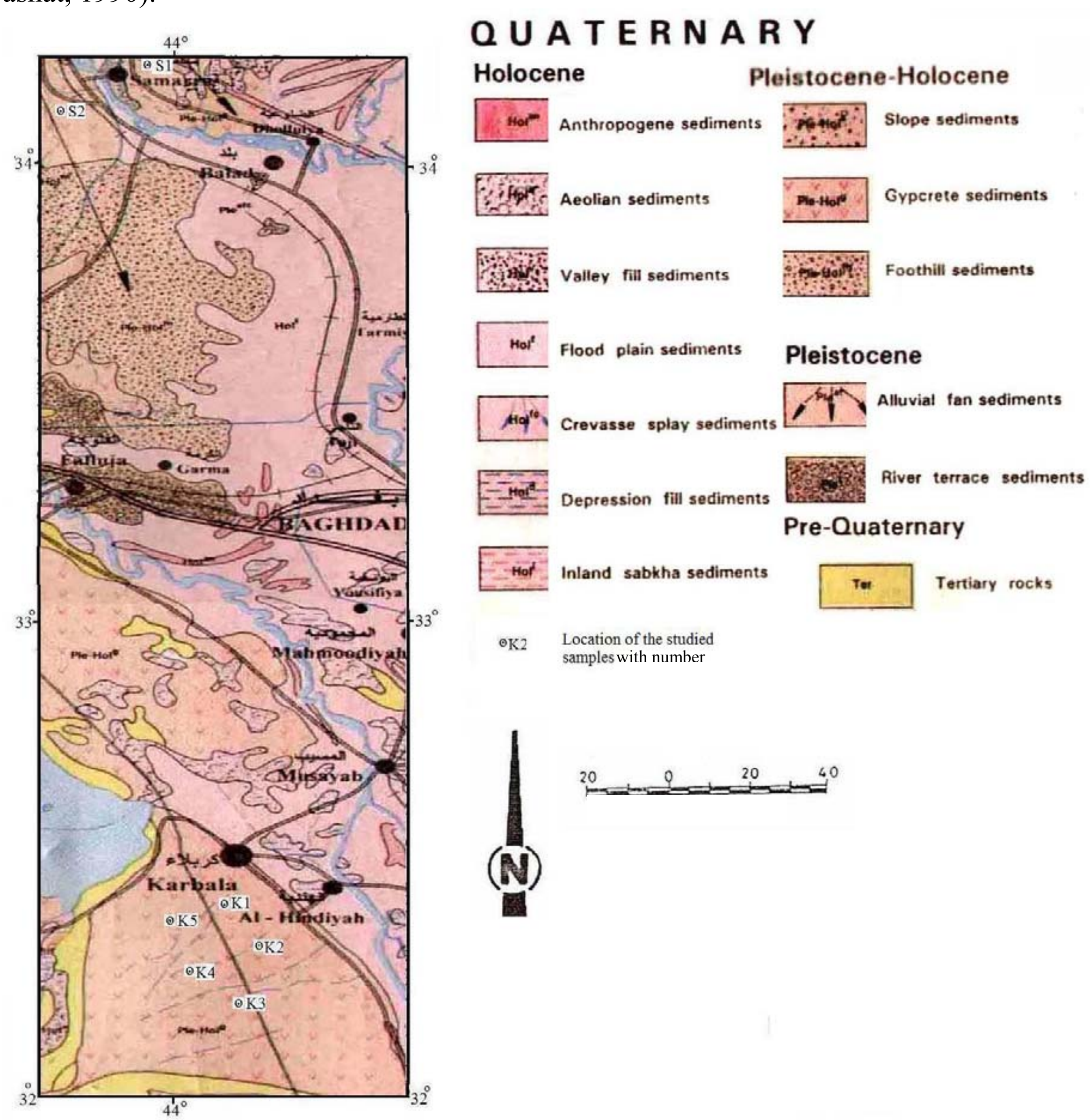

Fig.1: Quaternary sediments and sampling location map of the studied area (after Barwary *et al*., 2002)

These classifications are limited to their own specialization and to solve limited engineering problems. Therefore, it is very important to study the gypsiferous soils in Iraq, in order to find solutions for engineering properties in the gypsiferous soils and to have soil classification that combine not only gypsum content in the soil, but also involves many physical, chemical, climatological and engineering properties.

In this study, a gypsiferous soil classification is proposed that deals with the soil texture, mineralogy, chemistry and engineering properties such as: plasticity index, cohesion, unconfined compressive strength and collapse potential. It takes into consideration the most reliable, simple and widely used soil classifications of Barazanji (1973) and Boyadgiev (1974), which are believed after modification will give better, more reliable and comprehensive classification for Iraqi gypsiferous soils that could be used widely by all the pedologists, geologists and engineers in Iraq.

METHODS OF THE RESEARCH

The field work included collection of disturbed and undisturbed samples from earth surface, or existing hand-dug water wells of wide diameter and existing quarries within Samarra and Karbala areas (Fig.1). Samples were taken at a maximum depth of 5 m. Twenty samples were taken, 9 from Samarra area; distributed on two sites, and 11 from Karbala area; distributed on five sites (Tables 1 and 2). The laboratory tests included the following:

- **Standard classification tests:** These tests were performed on disturbed and undisturbed samples and included the following: grain size analysis, Atterberg limits (liquid limit and plastic limit). These tests were performed using Casagrande and Cone Penetration methods, specific gravity, moisture content and dry and wet densities.
- **Advanced standard soil mechanical tests:** These tests were performed on undisturbed and remolded samples, which include; single collapse test, direct shear test, unconfined compression test, point load test, and ultrasonic velocity test.
- **Chemical analyses:** These included analyses of Ca, Mg, K, Na, SO_4, Cl, CO_3 and HCO_3, also TDS from soils water-extract were determined.
- **Mineralogical analyses:** Clay minerals and non-clay minerals analyses were performed on 11 soil samples, which contain relatively high content of fines (silt + clay) using X-ray diffraction method. Also, petrographic study of the gypsiferous soils was performed on 13 samples using thin sections (microscopic study).

Table 1: Grain size distribution of gypsiferous soils in Samarra area

Site No.	Sample No.	Depth (m)	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	Gypsum (%)*	T.D.S* (soil water-extracts) (in ppm)
1	S1a	0.2 – 1.2	33	40	27	–	26.05	820
	b	1.2 – 2.4	34	20	46	–	44.77	1108
	c	2.4 – 3.2	28	26	43	3	29.55	792
	d	3.2 – 4.2	8	13	33	46	9.79	199
	e	4.2 – 5.7	11	19	9	61	0.93	48
2	S2a	0.2 – 1.4	36	32	32	–	67.52	1284
	b	1.4 – 2.2	45	25	30	–	43	944
	c	2.2 – 3.2	53	41	6	–	39.25	712
	d	3.2 – 4.7	7	8	13	72	10.87	240

* From the chemical analysis

Table 2: Grain size distribution of gypsiferous soils in Karbala area

Site No.	Sample No.	Depth (m)	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	Gypsum (%)*	T.D.S* (soil water-extracts) (in ppm)
1	K1a	0.1 – 0.5	33	37	30	–	3.22	56
	b	0.5 – 1.1	29	66	5	–	0.41	85
	c	1.1 – 1.9	11	29	60	–	2.61	50
2	K2a	0.1 – 1.3	–	–	100	–	2.74	172
	b	1.3 – 2.8	–	–	100	–	8.79	396
	c	2.8 – 3.6	–	–	100	–	0.84	112
	d	3.6 – 4.6	–	–	100	–	24.84	392
3	K3a	0.1 – 1.1	3.4	–	96.6	–	2.36	86
	b	1.1 – 1.7	8	15	77	–	19.93	565
4	K4	0 – 1.2	14	59	27	–	6.95	140
5	K5	0 – 1.5	–	14	86	–	28.92	556

***** From the chemical analysis

- **Mineralogical analyses**

Five thin sections from the soils of Samarra area and eight thin sections from the soils of Karbala area were studied in order to indicate their petrographical and mineralogical characteristics. The minerals that were recognized in the soil samples were: gypsum, quartz, orthoclase, microcline, plagioclase, calcite, rock fragments and heavy minerals, with little amount of muscovite and dolomite; in general. Comparing the soils within the two sites of Samarra area; it is remarkable that the upper 3 m in both sites consists of alternation of highly gypsiferous clayey silt and silty clay of ML and CL Groups, respectively. The lower 2.5 m in Site 1 is of silty gravel type of GM Group; whereas the lower 1.5 m in Site 2 is of clayey gravel type of GC Group. Also the results of thin section description show that gypsum content ranges from (20 – 63.7) % of the soil; clay comprise (10 – 24.2) %, while calcite is up to 4%. Quartz grains are of detrital origin, existing from trace amount to 1%. Chert, feldspar, igneous fragments occur in trace amounts, too. Minor other accessory minerals detected in trace amounts; such as: hornblende, grains of iron oxide, biotite, chlorite, epidote, muscovite and tourmaline.

Comparing the soils within the five sites of Karbala area, it was found that the upper 1 m is fine-grained, yellowish light brown, slightly gypsiferous very hard, clayey silt of low plasticity of ML Group. In Site 1, gypsum content decreases generally downward, whereas in Sites 2, 3, 4 and 5 it increases, with medium hard highly gypsiferous, silty sand of SM group.

Additionally, the results of thin section analysis show that gypsum content ranges form (0.7 – 74.3) %, quartz ranges form (0.3 – 23.6) %, calcite and dolomite occur abundantly from (38.7 – 82.1) %, feldspar is represented by orthoclase, albite, and microcline range from (1.3 – 3.1) % and chert fragments range form (1 – 4.7) %. Igneous rock fragments range from trace amount up to 2%, the metamorphic rock fragments are of quartzite, mica quartzite, and epidote and form (1.3 – 4.4) %. Biotite and muscovite, with other accessory minerals; such as: heavy minerals, mica, iron oxide, epidote, amphibole, pyroxene, hornblende and zircon, are present as inclusions.

▪ X-Ray Diffraction

The soil of the study area is examined by X-Ray diffraction method (XRD). Samples were prepared as bulk samples in order to study clay type and non-clay minerals. The results reflect that non-clay type minerals, in the studied soils are: quartz, calcite, dolomite, gypsum and feldspar; while the clay minerals are: chlorite, montmorillonite, kaolinite, illite and palygorskite. The dominant presence of palygorskite among the clay minerals reflects the arid and semi-arid climatic conditions. These clay minerals require alkaline environment and high to moderate Mg-salinity. The aridity and hot climate are obvious in the whole study area indicated by the gypsiferous soils in Samarra area and by the gypsiferous aeolian sand in Karbala area.

▪ Geochemistry of Water-Extracts of Gypsiferous Soils

The soil pore water-extracts were analyzed for major cations and anions in order to throw some light on the hydrochemistry of the salt-bearing soil that caused post depositional enrichment; of these sediments with gypsum and other salts. Gypsum occurs within the study areas as secondary gypsum of different sizes; or as crystals formed as a result of leaching rocks of Fatha Formation by rain water or capillary action of the groundwater.

Twenty disturbed samples were collected from two areas; of which 9 samples are distributed on two sites from Samarra area and 11 samples are distributed on five sites from Karbala area. Gypsum content of the samples was estimated from the chemical analysis of the water-extracts and the major cations and anions concentration for soil-water extract from the study areas were determined.

▪ Total Dissolved Solids (TDS)

In Samarra area, TDS range from (48 – 1284) mg/l, averaged 683 mg/l, whereas in Karbala area, TDS range from (50 – 565) mg/l, averaged 237.3 mg/l. It is noticeable that soil salinity in Karbala area is considerably lower than that of Samarra area.

▪ Major Ions

– Cations: The Calcium (Ca^{2+}) has the widest occurrence among other elements in the soil. In the study area at Samarra, the Calcium (Ca^{2+}) ranges from (52.4 – 99.7) epm %, averaging 65.4 epm %, whereas in Karbala, the Calcium (Ca^{2+}) ranges from (42.3 – 89.3) epm %. Magnesium (Mg^{2+}) in Samarra ranges from (0.2 – 5.9) epm %, averaging 1.9 epm %, while in Karbala, the Magnesium (Mg^{2+}) ranges from (0.5 – 21.7) epm % averaging 5.6 epm %. The Sodium (Na^{+}) ranges in Samarra from (0 – 46.5) epm %, averaging 32.5 epm %, whereas in Karbala ranges from (0 – 46.9) epm % averaging 30.6 epm %. The Potassium (K^{+}) ranges in Samarra from (0 – 1.5) epm %, averaging 0.3 epm %, whereas in Karbala ranges from (0.1 – 4.8) epm %, averaging 1.3 epm %.

– Anions: The Sulphate (SO_4^{2-}) in Samarra ranges from (0 – 97.1) epm %, averaging 82.0 epm %, whereas in Karbala ranges from (0 – 92.8) epm %, averaging 62.1 epm %. The Chloride (Cl^{-}) in Samarra ranges from (0.8 – 29.4) epm %, averaging 6.0 epm %, whereas in Karbala ranges from (3.7 – 36.2) epm %, averaging 14.7 epm %. The Carbonate (CO_3^{2-}) ions in the study areas are totally absent, while bicarbonate (HCO_3^{-}) ions in Samarra ranges from (1.6 – 70.6) epm %, averaging 12.0 epm % and in Karbala ranges from (3.4 – 76.2) epm %, averaging 23.2 epm %.

It is remarkable that calcium is the dominant cation in the whole studied areas, followed by sodium ion, whereas potassium and magnesium ions are of low content. On the other hand, sulphate is the prevailing anion followed by bicarbonate ion, while Chloride ion is of low concentration. Ca^{2+} and SO_4^{2-} dominate the ionic composition of the water-extracts in sections of Samarra and Karbala areas. Na^{+} is the second cation in all samples, whereas Cl^{-} or HCO_3^{-}

is the second anion. The latter is more dominant than the former, especially at the lower parts of both sections. However, Na^+, HCO_3^- and Cl^- show higher concentrations in the lower parts, where Ca^{2+} and SO_4^{2+} are decreased. Moreover, gypsum is present almost in all fractions of the soil, which increases with increase of the fine fractions. Obviously, Ca^{2+} and SO_4^{2-} amounts in the soil water-extract also (generally) increases with increase of gypsum content.

GEOTECHNICAL PROPERTIES

Geotechnical properties of the soil represent the physical and the engineering properties of the soil as well, these properties were studied and determined in Samarra and Karbala areas, the results are discussed hereinafter:

- **Physical Properties of the Soil**

The following two parameters were studied:

– Grain size distribution: Twenty samples were examined according to ASTM (1986), to find weight percentages of different sizes of dry soil samples. The results indicate that in Samarra area, clay fraction ranges from (7 – 53) %, averaging 28.3%. Silt fraction ranges from (8 – 41) %, averaging 24.9%. Sand ranges from (6 – 46) %, averaging 26.6%. Gravel ranges from (0 – 72) %, averaging 20.2%. While, in Karbala area, clay ranges from (0 – 33) %, averaging 8.7%. Silt ranges from (0 – 66) %, averaging 20.2%. Sand ranges from (5 – 100) %, averaging 71.1%. It was found that the fine sand fraction is the prevailing size within the studied samples. Grading was determined by estimating two parameters from the grain size distribution curves, which are the uniformity coefficient, Cu = D 60/ D 10, and the coefficient of curvature Cc = D10 x D60/ (D30). It was found that the samples are entirely poorly graded.

– Atterberg Limits: Atterberg limits were determined for soils of the studied area, according to Casagrande method and the Cone Penetrometer Test (ASTM, 1986 and BSI, 1975). In Samarra area, liquid limit values of the soil range from (28.7 – 56.6) %, averaging 38.6%, indicating low to high plasticity. In Karbala area, liquid limit values of the soil ranges from (27.8 – 33.6) %, averaging 30.7%, indicating low plasticity, few samples are non-plastic.

The soils of the studied area were classified according to the liquid limit depending on Clayton and Jukes (1978) classification. In Samarra area, 66.67% of the samples are of low plasticity, 11.11% of intermediate plasticity and 22.22% of high plasticity. In Karbala area, 100% of the samples are of low plasticity. The Plastic Limit, in Samarra area, ranges from (20.5 – 44.2) %, averaging 28.1%, while in Karbala area ranges from (19.5 – 26.4) %, averaging 22.7%, few samples are non plastic. The Plasticity Index in Samarra area ranges from 5.3 – 27.1, averaging 10.5, therefore, indicating low to high plasticity. In Karbala area, the Plasticity Index, ranges from 1.4 – 14.1, averaging 8.0, indicating almost plastic to medium plasticity, few samples are non plastic. According to Al-Asho (1991) classification it was found that in Samarra area, 66.67% of the samples are of low plasticity, 22.22% of medium plasticity, and 11.11% of high plasticity. In Karbala area, 45.45% of the samples are of low plasticity, 36.36% are non-plastic, and 9.09% are plastic and 9.09% of medium plasticity. The plasticity index of the majority of the samples is less than 15.

The specific gravity values of the soil samples revealed that in Samarra and Karbala areas, they range from 2.18 – 2.56, averaging 2.3, and from 2.38 – 2.73, averaging 2.5, respectively. The unit weights or dry densities were calculated from partly undisturbed samples in the studied areas; the results show that in Samarra area, ranges from (1.26 – 1.87) g/cm^3, averaging 1.5 g/cm^3, while in Karbala area, ranges from (1.66 – 2.07) g/cm^3, averaging 1.8 g/cm^3.

▪ The Engineering Properties of the Studied Soils

Engineering properties of the soils were studied within two areas (Samarra and Karbala), which included single collapse test, direct shear test, unconfined compressive strength test, ultra sonic velocity test and point load test. The results are mentioned hereinafter.

– Shear Strength: In this study, unconsolidated – undrained (**UU**) direct shear test was performed (Das, 1985). The **ø** and **c** values were estimated by plotting normal stress values (100, 200 and 400 KN/m^2) against shear strength (KN/m^2) measured from the test represented by two components, the cohesion (**c**) and the angle of internal friction (**ø**). However, direct shear test results revealed that in the study areas, at Samarra, cohesion varies between (8 – 42) KN/m^2, averaging 23 KN/m^2, whereas internal friction angle ranges from (31– 45)°, averaging 39°. At Karbala area, cohesion ranges from (3 – 31) KN/m^2, averaging 14.8 KN/m^2, whereas internal friction angle varies between (27 – 45)°, averaging 36°.

The relatively high cohesion values in Samarra area are attributed to the relatively higher gypsum and fines (silt and clay) contents, as compared to Karbala area, as cohesion and grain size are inversely proportional (Maharaj, 1995). On the other hand, the relatively higher sand content and lower gypsum content of the latter seems to have minor effect on the internal friction angles, as their average values are almost identical or very close.

Also internal friction angle ($ø_u$) is affected by soil density as it increases with interlocking of particles, which means a higher density. Moreover, the presence of clay minerals like illite, chlorite and montmorillonite decreases the internal friction angle ($ø_u$), as they cause sliding and decreases resistance at contact points from microstructure during shearing (Mitchell, 1993).

– Unconfined Compressive Test: The unconfined compressive strength for undisturbed samples collected from block samples, was measured. Samples were tested in both dry and soaked states. Different soaking periods were used, varied from few minutes, hours and days. As wetting fluid, distilled water was used. Eleven samples were tested in unconfined compressive strength, of which 8 were in dry condition, as they have low compressive strength values, while 3 samples were tested and have disintegrated at soaking. Unconfined compressive strength values, in dry condition ranges from (0 – 21.3) MN/m^2, averaging 1.4 MN/m^2; for Karbala soils, while it was found to be 0.0 for Samara soils.

– Ultrasonic Wave Velocity Test: This non-destructive dynamic test was performed to determine the dynamic properties of gypsiferous soils involving compressional wave velocity (**Vp**) and shear wave velocity (**Vs**). Samples were tested in both dry and soaked states; the same soaking periods as in unconfined compressive test were used. Eight samples were tested, of which 5 were in dry condition, as they have low compressive strength and have disintegrated at soaking, 3 were tested in both dry and soaked conditions. Compression wave velocities in dry condition range from (1.56 – 2.53) Km/sec, averaging 2.1 Km/sec for Karbala soils, while it is zero for Samara soils. Shear wave velocities in dry condition range from (0.93 – 1.43) Km/sec, averaging 1.2 Km/sec for Karbala soils and is zero for Samara soils.

– Collapsibility and Compressibility: The method of Kezdi (1980) is followed in the present study, except that the samples were dried due to their remolded nature and water was added at 200 and 400 KPa soaking pressure. The soils of the studied areas were tested using remolded cylindrical samples of 19 mm height and 75 mm or 50 mm diameter (B.S.I., 1975). Initial void ratio (e_o) is determined and the change in void ratio with applied pressure was computed from which collapse curves were plotted and collapse potential (**CP %**) was estimated, with compression index (**Cc**) and swelling index (**Cr**). Pressures of 50, 100, 200, 400 and 800 KPa were used. In the study area, at Samarra, **CP** values range from (1.07 – 6.83) %, averaging

3.8%. Compression index ranges from (0.0299 – 0.28), averaging 0.1158, swelling index ranges from (0.0036 – 0.0202), averaging 0.0117. **CP** values range suggests a severity of problem (Moderate Trouble – Trouble) averaging Moderate Trouble. In Karbala, **CP** values range from (0.09 – 2.8) %, averaging 0.8%. **CP** values range suggests a severity of problems (No problem – Moderate Trouble) averaging to No problem.

– Void Ratio (e): The Void ratio (**e**) in the study areas, was studied, it ranges at Samarra from (0.35 – 0.73), averaging 0.53, whereas at Karbala ranges from (0.206 – 0.598) averaging 0.4. The variation in void ratio may be attributed to overburden pressure and differences in fine and coarse fractions of the soil.

– Compression Index (C_c): In the study area, at Samarra, C_c values range from (0.03 – 0.28), averaging 0.116 and at Karbala range from (0.03 – 0.31), averaging 0.11. The change in compression index values is related to the changes in void ratio of the soil, which in turn depends on the soil type. It is noticeable that as sand content increases, compression index decreases, therefore, clayey soils are more compressible than sandy soil.

– Swelling Index (Cr): In the study area, at Samarra, **Cr** values range from (0.004 – 0.02), averaging 0.012 and at Karbala range from (0.002 – 0.03), averaging 0.012. Swelling index depends on the soil type, as clayey soils have higher swelling ability than sandy soils.

DISCUSSION

Many soil scientist and engineers, worldwide have studied the gypsiferous soils in variable locations of the world and for different purposes, i.e. agriculture, surveying, civil engineering, etc., among those scientists and engineers, some had suggested different gypsiferous soils classifications. Those classifications often are limited to their own specialization and to solve limited engineering problems. Therefore, it is essential to have a soil classification that combines not only gypsum content in the soil, but also involves relevant physical, chemical, climatological and engineering properties. In this research, a new gypsiferous soil classification is proposed that invokes soil texture, mineralogy, chemistry and engineering properties, such as plasticity index, cohesion, unconfined compressive strength and collapse potential. These parameters were indicated by the results of this research for the studied areas, taking into consideration the most reliable, simple and widely used soil classification of Barzanji (1973). Therefore, it is believed that modifying the classification of Barzanji (1973) will give better, more reliable and comprehensive classification for Iraqi gypsiferous soils that could be used widely by all pedologists, geologists and other scientists and engineers (Table 3).

Concerning the relationship between silt and clay percentage, and plasticity index, it is noticed that there are positive relationships between them. The relation of collapsibility, void ratio, collapsibility index, compression index and swelling index with TDS, soil constituents, compression index and swelling index show significant relations. Also, it was noticed that as density increases, void ratio decreases.

Collapsibility index is affected by void ratio showing a positive relation. This depends on fine and coarse materials content, water content, and also on gypsum content. Also liquid limit and plasticity index values affect the collapsibility index, as their values increase the collapsibility index decreases. Variation in compression index relates to variation in void ratio, which in turn depends on soil type. There is a significant relation between shear strength, cohesion (**C**), friction angle (**ø**), sand content, dry density and gypsum content of the soils, in the study area. Silt and clay show also positive weak relations as cohesion increases with increase of the fine materials.

There is a positive weak relation between friction angle and dry density of the soils in the study areas, similar relation occurs with gypsum content, as gypsum increases the friction in the dry condition. With silt and clay, the relation is negatively weak; as increase of the fine materials decreases the friction.

Table 3: The proposed applied classification for gypsiferous soils, in Iraq

Gypsum (%)	Class	Initial void ratio	Coeff. of Curvature	Uniformity Coeff.	Collapse Potential (%)	Comp. Strength (MN/m^2)	Cohesion (KN/m^2)	Plasticity Index (%)	Fine Grained Soils (%)	TDS of Soil Water-Extracts (ppm)
0.5 – 25	Gypsiferous Soil	< 0.45	< 2.5	< 25	< 1.5	< 1	< 15	< 10	< 50	< 350
25 – ≥50	Highly Gypsiferous Soil	> 0.45	> 2.5	> 25	> 1.5	> 1	> 15	> 10	> 50	> 350

CONCLUSIONS

- The analysis of different geotechnical properties of the gypsiferous soils show significant relations between clay, silt, gypsum contents and Atterberg limits, as gypsum increases with increase of clay, while Atterberg limits increase with increase of fines (silt and clay).
- Sand shows negative significant relation with silt, clay and Atterberg limits; as increase in the former leads to decrease in the latter.
- Positive significant relation exists between dry density and specific gravity; collapse potential similarly reveals positive significant relation with porosity and void ratio; as any increase in the latter will increase the former.
- The results of liquid limit, plastic limit, plasticity index, and dry density and specific gravity values of the gypsiferous soils show significant relations of these parameters with TDS, gypsum and soil constituents.
- The studied climatic factors, such as temperature, evaporation and rainfall did show a significant relationship with the physical, chemical and engineering properties either in Samara or Karbala areas. But, it is believed that such differences are not essential in a small geographical extinction; such as in the study area, but it should be taken into consideration in regional scale with much more significant climatological variations.

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About the authors

Dr. Mou'taz A. Al-Dabbas graduated from University of Baghdad in 1974 with B.Sc. degree in Geology, he got his Ph.D. degree in Marine Geology Environment from Dundee University in 1980. He was nominated as Full Prof. Earth Science Dept., College of Science, University of Baghdad in 1999 and directed many scientific bureaus and committees. He is a member of IUGS Global Geosciences Workforce Taskforce committee member since 2010. During his career, he published 75 scientific articles and supervised 25 M.Sc. and Ph.D. postgraduate students. Beside, publishing two text books in Sedimentology (in Arabic Language).
e-mail: prof_aldabbas@yahoo.com

Dr. Tom Schanz graduated from University of Stuttgart in 1988 with Diploma degree in Civil Engineering and Geology. He got Dr. Sc. degree in 1994 and Venia Legendi for Geotechnics in 1998 from the same university. He was University Professor, BAUHAUS-Universitt Weimar since 10/1998. Currently he is University Professor, Ruhr-Universitt Bochu since 04/2009.