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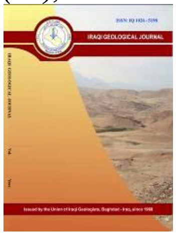

The Effect of Geotechnical Factors in Road of Basrah, Southern Iraq

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Abstract

Most Basrah roads are conducted to a major failure in their layers and bases, which appears in the form of cracking, crushing, landing, as well as massive holes. The influence of geotechnical factors on the performance of Basrah roads has been studied. Sixteen sites were selected for sampling, which are Al-Medaina, West Qurna, Al-Hartha, Al-Dir, Shatt Al-Arab, Al-Tuwaisa, Hayy-Al-Hussein, Al-Shuaiba, Al-Maqal, Al-Gazara, Abu-Al-Khaseeb, Al-Ashar, Umm Qasser, Al-Zubair Petrochemical factory, and Al-Faw. The soil properties were studied up to 3 meters of depth at each location to find out the effect of geotechnical properties on roads. Laboratory tests were carried out on the samples, which included grain size analysis, Atterberg limits, gypsum content, total soluble salts, swelling potential, organic content, and standard penetration test. The results presented that the percentage of gypsum exceeded the allowable limit in the standard specifications at the sites (S_7, S_8, S_{13}, S_{14}, S_{16}). Also, the percentage of total soluble salts exceeded the allowable limit in the standard specifications at the sites (S_5, S_8, S_{16}). The results showed that the soils in S_1, S_2, S_3, S_4, S_7, S_{11} have medium swelling potential, which requires treating before building roads on them. The results also showed that the percentage of organic materials exceeded the permissible limit in the standards specifications at the sites S_1, S_2, S_3, S_4, S_5, S_9, S_{10}, S_{11}, S_{12}, S_{15}. The results also showed that the cohesive soils in the first meter of the sites (S_2, S_5, S_{11}), the second meter of the sites (S_2, S_7, S_{12}) and the third meter of the sites (S_5, S_9, S_{10}, S_{11}, S_{12}) are medium stiff soils, which requires treating before building roads on them. While the non-cohesive soils at the two sites (S_8, S_{13}) are medium dense soils, in two sites (S_{14}, S_{16}) are loose sandy soils in the first meter, while the second meter in sites (S_8, S_{13}, S_{14}, S_{16}) are medium dense soils, and the third meter at the site (S_{14}) is medium dense soils.

Keywords: Basra roads; Gypsum content; Organic soils; Swelling potential; Weak soils

1. Introduction

The main input for all road design methods is a measure of the resistance of soil and rocks to bear the stress imposed on them by traffic movement, which is required in the design of new roads and partial or total reconstruction of damaged existing roads (Razouki et al., 2005). Road engineers face problems in using soils when they are gypseous, organic, weak, or swelling soils. These soils lead to a lot of problems for engineering foundations, including roads, and this appears in the form of cracks, slackening, swelling, shrinkage, and subsidence in pavement and walls (Rahmat & Kinuthia, 2011). Problems occur when water reaches these soils, causing swelling of swelling and organic soils and reducing the resistance of weak soils, as well as gypseous soils due to the melting of salts in them and thus losing their bearing capacity, especially in winter and early spring. Even if the road is properly

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designed, this will negatively affect its safety and sustainability (Hopkins et al., 1994). Road construction requires a geotechnical study of the properties of the foundation soil to provide a safe and stable platform for the construction of road layers and provide adequate support for it (Razouki et al., 1994). In Basrah Governorate, within a year after construction or less, deformations appear in some roads, which calls for studying the reasons leading to this and determining the impact of different soils in Basrah on-road performance.

Many researchers in the world have studied the effects of problematic soils (gypseous, swelling, organic, and weak) on roads. Cooper & Saunder (2002) explained melting gypsum in some areas in England caused dangerous deformations and subsidence of roads and bridges. Sobhan et al. (2012) reported many of the pavements in Florida built on high organic content soils have been damaged and suffered from early failure in the form of cracking, rutting and subsidence. Wanyan et al. (2015) studied the reason for the subsidence of roads built on swelling soils, and he indicated that the reason for the failure and emergence of longitudinal cracks on the shoulders of the road is that the foundation soil is swelling soil with high moisture content. Xing et al. (2019) reported Through his study of the reasons for the failure of roads in the city (Lungui) in China, the failure occurred due to the weakness of the foundation soil, which was weak clay soil, which caused a rise in the pavement to 14 mm due to the penetration of this water into the foundation soil and the occurrence of Shrinkage and drops to 76 mm due to water evaporation. Abdulnabi et al. (2020) studied the effect of saline soils on the resilience of the road between the city of Samawah and Lake Sawa and showed that the main road damage was caused by the infiltration of artificial lakes water into the saline base soil with low bearing capacity and high compressibility. Sorsa et al. (2020) indicated some highways in Guangsan city in China were severely damaged in the form of longitudinal cracking, fractures, according to the geological survey report, the failure occurred due to the excessive additional load on the road and because the base soil was weak clay soil with high moisture content and high compressibility. This research aims to study the effect of the geotechnical properties of the soils of the study area on the stability of the road in the Basra Governorate. Basrah Governorate is located in southern Iraq within two longitudes (E 47° 36' 29.48"–E 48° 22' 35.11") and two latitudes (N 31°7'14.3"–N 30°6'27.22"), where sixteen locations were chosen for the study as shown in Fig. 1 and Table 1.

2. Materials and Methods

To achieve the aim of the study, previous soil investigation reports were reviewed in thirteen sites in Basra Governorate, which are West Qurna, Al-Medaina, Al-Dir, Al-Hartha, Shatt Al-Arab, Al-Tuwaisa, Al-Shuaiba, Al-Maqal, Al-Gazara, Al-Ashar, Umm Qasser, Petrochemical factory, and Al-Faw investigated by Basra Construction Laboratory, Al-Faw Construction Laboratory, and Al-Mamas Construction Laboratory, to a depth of 3 meters. Another three boreholes were drilled with a depth of 3 meters in the locations of Hayy-Al-Hussein, Abu-Al-Khaseeb, and Al-Zubair, and the nine samples were kept in tightly closed bags until geotechnical tests were conducted on them in the Al-Mamas Construction Laboratory including the following tests:

- Grain size analysis: The test was carried out using the dry sieving method and hydrometer on soil samples for the study sites. The test was carried out according to the American Standard (ASTM D-421, D-422).
- Atterberg's limits: The tests were conducted according to the American Standard (ASTM -423). The results were used to calculate the swelling potential of the soil.
- Chemical tests: The gypsum content, total soluble salts, and organic content of soil samples were calculated. These tests were conducted according to the British Standard (BS 1377: 1990).

- Standard penetration test: The standard penetration resistance values were calculated for the first three meters of the study sites. The test was conducted according to the American Standard (ASTM D-1586).

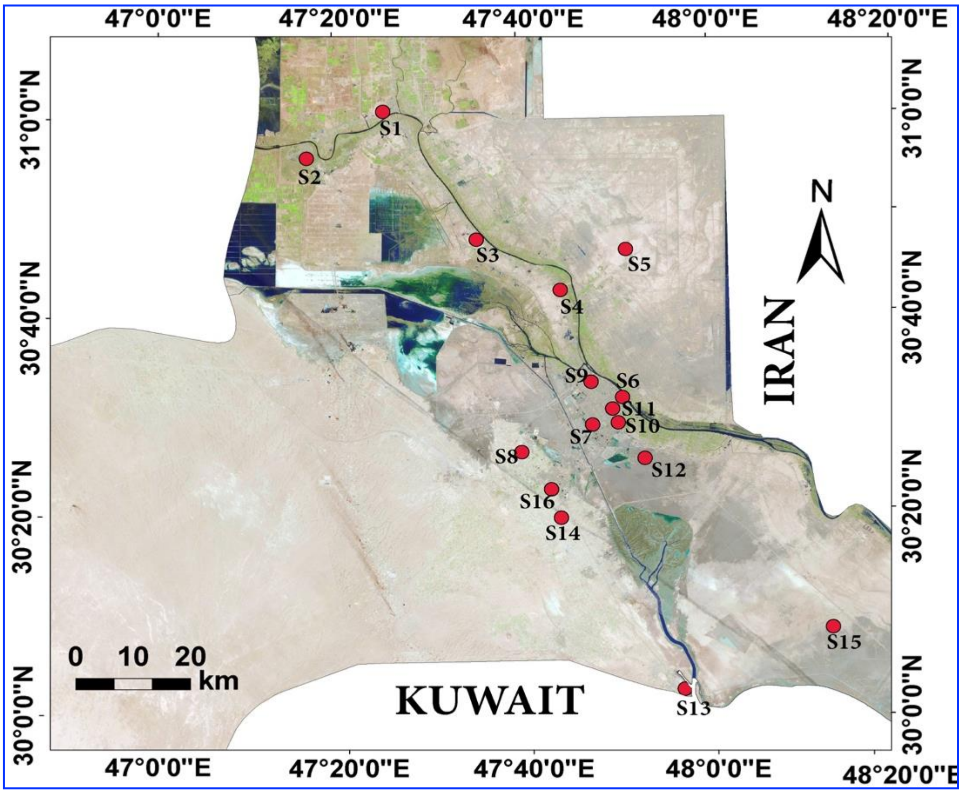

Fig. 1. Map of the study area

Table 1. Study area locations relative to latitude and longitude

Sample No.	Names	Latitude	Longitude
S_1	West Qurna	31˚ 00' 58"	47˚ 24' 28"
S_2	Al-Medaina	30˚ 56' 26"	47˚ 15' 30"
S_3	Al-Dir	30˚ 47' 47"	47˚ 34' 35"
S_4	Al-Hartha	30˚ 42' 32"	47˚ 43' 29"
S_5	Shatt Al-Arab	30˚ 46' 38"	47˚ 50' 39"
S_6	Al-Tuwaisa	30˚ 31' 06"	47˚ 49' 25"
S_7	Hayy-Al-Hussein	30˚ 29' 34"	47˚ 46' 45"
S_8	Al-Shaiba	30˚ 26' 14"	47˚ 39' 47"
S_9	Al-Maqal	30˚ 33' 23"	47˚ 46' 55"
S_{10}	Al-Gazara	30˚ 29' 46"	47˚ 49' 19"
S_{11}	Al-Ashar	30˚ 31' 21"	47˚ 50' 02"
S_{12}	Abu-Al-Khaseeb	30˚ 26' 03"	47˚ 52' 32"
S_{13}	Umm Qasser	30˚ 1' 32"	47˚ 56' 34"
S_{14}	Petrochemical	30˚ 19' 50"	47˚ 43' 18"
S_{15}	Al-Fao	30˚ 8' 41"	48˚ 12' 16"
S_{16}	Al-Zubair	30˚ 22' 44"	47˚ 42' 17"

3. Discussion

3.1. Distribution of Gypseous Soils and the Percentage of Soluble Salts in the Study Sites

Table 2 and Fig. 2 show the percentages of gypsum in the study area, where the percentages in the first meter ranged between 0.01% in Al-Dir (S3) and 16.45% in Al-Shuaiba (S8), with an average of 6.85%. The results showed that the percentages of gypsum in the sites S7, S8, S13, S14, and S16 were high and did not conform to the specifications, as the permissible percentage of gypsum is 10 % according to the general Iraqi specification for roads and bridges. For the second meter, the percentages of gypsum ranged between 0.03% in Al-Dir and 18.45% in Al-Shuaiba, with a rate of 5.27%. The results displayed that the sites S8, S14, and S16 had a high gypsum content that did not conform to the specification. While the results of the third meter showed that the percentages of gypsum ranged between 0.01% in Al-Dir and 17.07% in Al-Shuaiba, with a rate of 4.64%. The results exhibited that sites S7, S8 have high gypsum content.

The reason for the low values of gypsum in some study areas is due to the exposure of modern clay and silt sediments brought by the Tigris, Euphrates, and Karun rivers, as well as the wind to water saturation due to their low levels with compared to sea level and the continuation of washing processes in them as a result of the overlap of the Basra Governorate river network that is saturated in it, in addition to The periodic fluctuation in the level of groundwater near the surface due to the tides, which leads to a decrease in the concentration of salts, which reduces the chance of gypsum crystallization in it, while gypsum rates rise in the western regions of the governorate, where the groundwater is relatively deep and the absence of rivers and the lack of rain, which helps in the crystallization of gypsum (Albadran & Mahmood, 2006).

Table 2 and Fig. 3 also illustrate the percentage of total soluble salts (TSS) in the study sites. The percentages in the first meter ranged between 0.4% in Al-Tuwaisa (S_6) and 15.75% in Shatt al-Arab (S_5), with an average of 3.95%. The results show that the study sites had acceptable salt content, except for sites S_5, S_8, and S_{16} that have high percentages and are not in conformity with the standard specifications, as the permissible percentage is 10% of the Iraqi General Standard for Roads and Bridges. In the second meter, the percentages ranged between 0.4% in Al-Faw (S_{15}) and 12.25% in Shatt Al-Arab (S_5), with a rate of 2.94%, and the results showed that the sites had acceptable salt content except for the site (S_5), which had a high percentage of salt. The results also presented that the percentage of salts in the third meter ranged between 0.4% in Al-Faw and 11.5% in Al-Zubair (S_{16}) with a rate of 2.35% and that the study sites had acceptable salt contents except for the site (S_{16}) in which the percentage of salts was high.

The results display in two sites (S_8, S_5) that the salts rise in the first meter and decrease with depth. It may be due to the high rates of evaporation and drought, especially in the summer, or as a result of groundwater fluctuations, or due to poor sewage drainage and its remaining on the surface of the earth, all of these factors helped to concentrate the salts on the surface (Jafar, 2012). For the site (S_{16}), the results show the percentage of salts is high in the first meter, then decreases in the second meter, and returns to rise in the third meter. This may be due to groundwater fluctuations as well, or as a result of water leakage from sewage pipes buried underground. As for the decrease in salinity in some locations, it is attributed to the fact that they are residential areas where soil washing, irrigation, and tidal operations increase in the lower meters.

The salty soils are considered as problematic soils that cause many damages to the engineering foundations built on them. When constructing roads on these soils, the melted salt causes many problems such as low loading capacity and soil subsidence. The damage can also be transferred to the sub-base, the base, and the basic materials for the road upwards due to the capillary property and the high-temperature rates. Therefore, when these salts are accumulation will lead to the failure of the road and bubbles, reflection cracks, and rutting with form.

Table 2. Grain size analysis, Atterberg limits, organic content, gypsum content, total soluble salts, and Standard Penetration Test (SPT) N-values for the soils of the study sites

Location	**Depth (m)**	**Grain size analysis**				**Atterberg Limits**		**ORG %**	**GYS %**	**TSS %**	**SPT N-Value**
		Clay %	Silt %	Sand %	Gravel %	LL %	PI %				
West Qurna (S1)	0-1	50	45	5	---	40	21	1.46	2.11	2.16	50
	1-2	42	56	2	---	32	10	1.51	1.26	2.5	41
	2-3	54	46	---	---	43	10	2.11	0.75	1.50	37
Al- Medaina (S2)	0-1	28	57	15	---	45	20	1.50	2.40	3.9	7
	1-2	48	51	1	---	40	12	2.9	1.78	2.89	6
	2-3	49	50	1	---	41	12	2.14	2.30	2.71	12
Al-Dir (S3)	0-1	50	48	2	---	40	11	2.2	0.01	0.5	30
	1-2	63	35	2	---	44	21	1.82	0.03	0.92	28
	2-3	49	50	1	---	40	17	1.52	0.01	0.7	23
Al-Hartha (S4)	0-1	35	56	9	---	44	19	1.61	7.05	0.79	15
	1-2	10	87	3	---	40	10	2.11	6.03	0.70	14
	2-3	11	85	4	---	41	11	2.30	0.73	0.63	13
Shatt Al-Arab (S5)	0-1	50	45	5	---	35	11	1.77	10.24	15.75	6
	1-2	37	59	4	---	33	10	2.93	2.88	12.25	4
	2-3	45	54	1	---	36	10	2.61	2.58	2.25	6
Al-Tuwaisa (S6)	0-1	77	15	8	---	45	10	2.9	8.3	0.4	15
	1-2	54	42	4	---	43	13	2.15	7.8	0.5	13
	2-3	67	32	1	---	40	8	2.2	7.4	0.9	15
Hayy-Al-Hussein (S7)	0-1	61	39	---	---	32	10	0.83	11.43	6.54	10
	1-2	50	49	1	---	44	22	1.77	8.60	5.7	8
	2-3	49	50	1	---	36	13	1.20	14.13	5.58	11
Al-Shuaiba (S8)	0-1	28		71	1	NP	NP	0.06	16.45	15.62	22
	1-2	14		79	7	NP	NP	0.08	18.45	8.58	27
	2-3	21		71	8	NP	NP	0.88	17.07	6.81	>50
Al-Maqal (S9)	0-1	18	80	2	---	44	10	2.80	0.70	0.10	12
	1-2	19	79	2	---	45	9	2.72	0.64	0.25	10
	2-3	20	78	2	---	47	11	2.53	0.61	0.40	8
Al-Gazara (S10)	0-1	22	63	15	---	41	10	2.09	0.54	0.32	16
	1-2	18	81	1	---	37	9	2.14	0.60	0.21	18
	2-3	20	79	1	---	40	10	2.20	0.61	0.18	6
Al-Ashar (S11)	0-1	29	21	38	12	41	10	4.18	1.30	2.76	7
	1-2	60	39	1	---	47	21	2.47	1.07	2.2	10
	2-3	51	37	12	---	44	18	2.06	2.35	1.50	8
Abu-Al-Khaseeb (S12)	0-1	10	82	8	---	40	10	2.40	3.10	1.12	7
	1-2	16	82	2	---	43	12	3.11	2.71	0.90	8
	2-3	12	86	2	---	42	12	2.6	1.41	0.50	6
Umm Qasser (S13)	11	0-1	20	71	9	NP	NP	0.01	15.48	1.39	11
	15	1-2	8	82	10	NP	NP	0.09	3.78	3.89	15
	48	2-3	9	89	2	NP	NP	0.10	6.45	1.50	48
Petro-chemical (S14)	5	0-1	37	61	2	NP	NP	0.02	14.41	0.7	5
	30	1-2	30	70	---	NP	NP	0.01	15.48	0.40	30
	27	2-3	3	94	3	NP	NP	0.07	6.70	0.66	27
Al-Faw (S15)	0-1	58	39	3	3	42.5	15	2.99	2.30	0.6	18
	1-2	55	45	---	---	40.9	13	2.32	2.93	0.4	16
	2-3	39	61	---	---	39	15	1.30	1.60	0.3	13
Al-Zubair (S16)	5	0-1	3	90	7	NP	NP	0.19	13.9	10.55	5
	30	1-2	4	89	7	NP	NP	0.15	10.30	4.80	30
	22	2-3	28	71	1	NP	NP	0.06	16.45	15.62	22

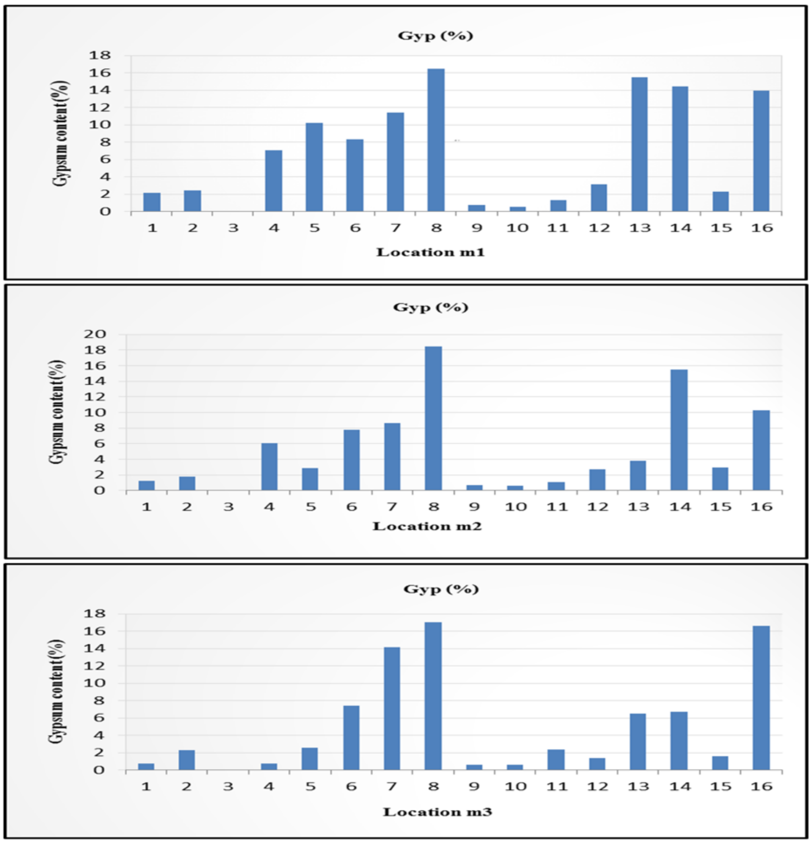

Fig. 2. Gypsum content in the first three meters of the study sites

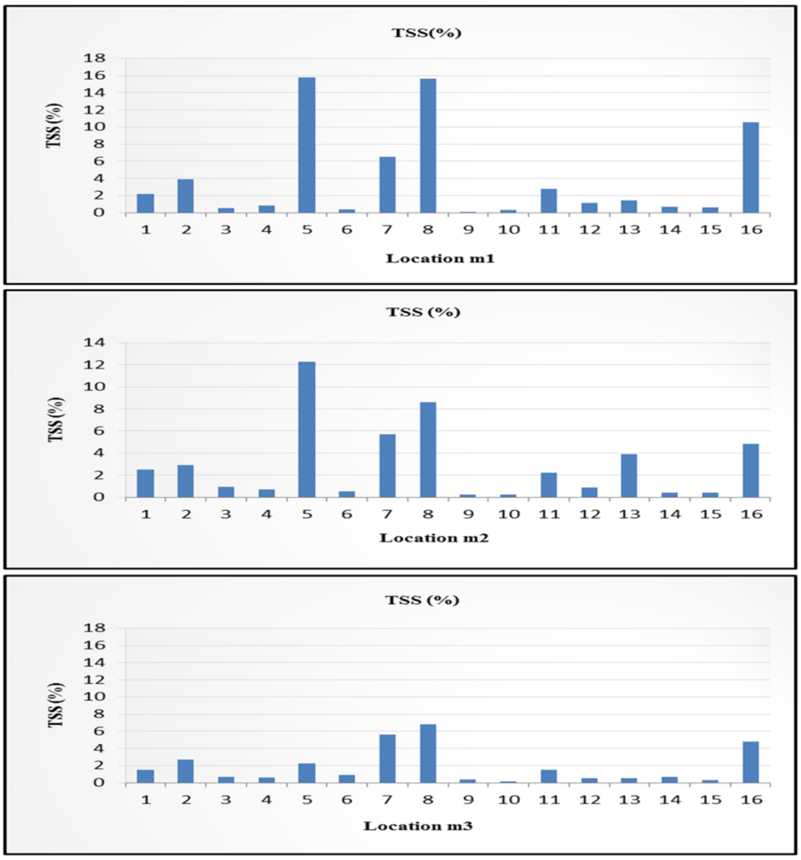

Fig. 3. The percentages of total soluble salts (TSS) in the first three meters of the study sites

3.2. Distribution of Swelling Soils in the Study Sites

The swelling was calculated in the soils of the study sites based on indirect methods, as follows:

- The values of the free swelling potential were calculated using the plasticity index values from the following equation (Seed et al., 1962):

$$S = 60K (PI) 2.44 \qquad (1)$$

- Where S = free swelling potential, PI = plasticity index, K = a constant of 3.6 x 10-5.
- As shown in Table 3. The results show that the free swelling potential ranged between 0.34% in the Al-Tuwaisa (S6) in the third meter, and 4.07% in Al-Maqal (S8) in the second meter. The results also showed that 6 samples have medium swelling potential, which includes sites S1, S2, and S4 in the first meter and sites S2, S7, and S10 in the second meter, and 30 models have low swelling potential.
- The results of swell calculation from Van der Merwe (1964) diagram in Fig. 4, which depended on the relationship between clay content and plasticity index in soil samples, showed that two soil samples for two sites S2 and S4 in the first meter are of medium swelling potential and 34 samples have a low swelling potential.
- The classification of Terzaghi & Peck (1967), which depends on the values of the plasticity index in determining swelling potential shows that 10 samples are of medium swelling potential in the first meter at sites S1, S2, S4, and S12 and in the second meter at sites S3, S7, and S10 and in the third meter at sits S3, S10, and S12, whereas 25 samples are of low swelling potential. The average of readings shows that 6 samples are of medium swelling potential, while 30 samples are of low swelling potential.
- The swelling soils are clayey soils that have a high ability to swell and shrink when the moisture content changes, and thus provide pathways for the infiltration and spread of moisture under the road, which leads to swelling and shrinkage of the soil in wetting and drying cases, and then the spread of cracks, heaving, and subsidence, then leading to the failure of the road. These soils cause many problems for engineering projects constructed on them, so they must be investigated first and treated before building on them.

3.3. Distribution of Organic Soils in the Study Sites

Table 3 and Fig. 5 show the distribution of the percentages of organic materials in the study area. The percentages in the first meter ranged between 0.01% in Umm Qasser (S13) and 4.18% in Al-Ashar (S11), with an average of 1.68%, the results showed that the sites S9, S10, S11, S12, and S15 had high organic content and did not conform to the standards. In the second meter, the percentage of organic matter in the study area ranged between 0.01% in the Petrochemical factory (S14) and 3.11% in Abu-Al-Khasib (S12), with an average of 1.76%, the results showed that the sites S2, S4, S5, S9, S10, S11, S12, and S15 had high organic content that did not conform to the standards. While the results of the third meter showed that the percentage of organic matter in the study area ranged between 0.07% in the petrochemical factory (S14) and 2.61% in the Shatt Al-Arab (S5), with an average of 1.71%, and the results showed that the sites S1, S4, S5, S9, S10, and S11 had high organic content that did not conform to the standards.

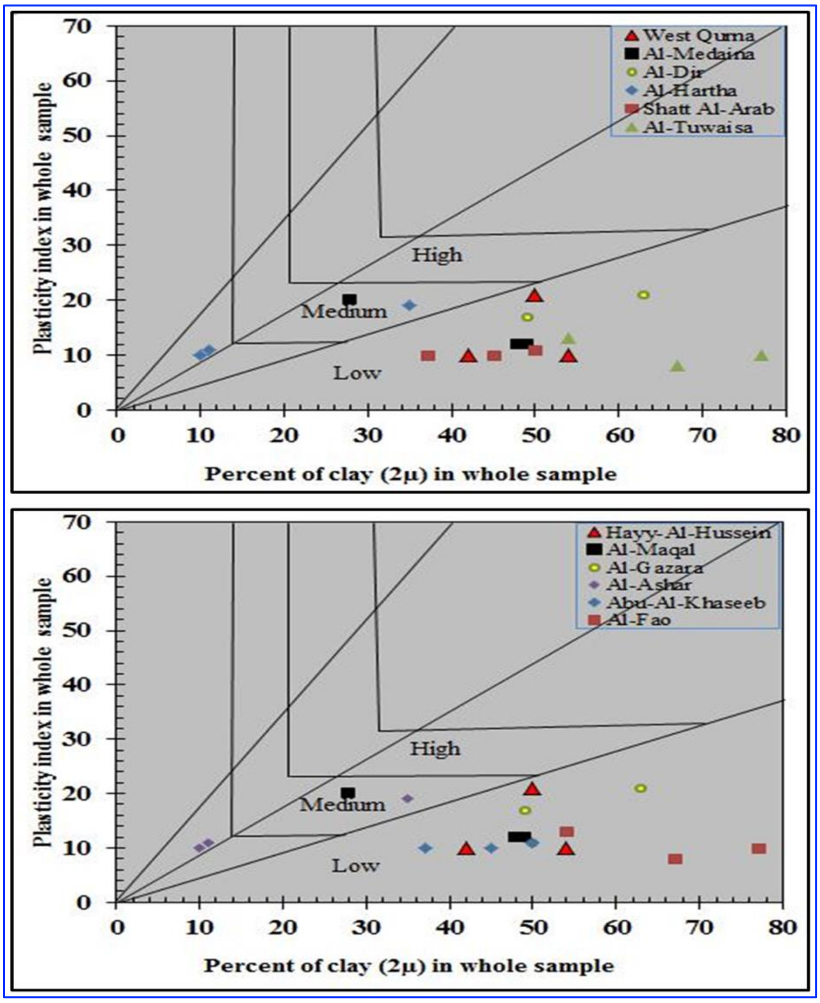

Fig. 4. Classification of the soils of the study sites according to their ability to swelling according to Van der Merwe (1964)

Soil classification in the plasticity diagram in Figs. 6 and 7 show that the soils of West Qurna, Al-Medaina, Al-Dir, Al-Hartha, Shatt Al-Arab, Al-Tuwaisa, Al-Maqal, Al-Gazara, Al-Ashar, Abu-Al-Khaseeb, and Al-Faw sites are organic because they are located below the A-Line and with a high organic content that did not conform to the standards, and therefore more care must be taken and treatment to these soils be necessary when roads constructed on these sites.

There is a great variation in the percentage of organic matter from one site to another and from one meter to another in the same site, also in some sites, there is a gradual increase in the percentages with depth, while in some sites the percentages fluctuated between increase and decrease with depth. The reason for this difference is due to many factors including sedimentation conditions, the nature of the environments of sedimentation, washing, and irrigation, groundwater movement, and its effect on the dissolution and removal of organic matter. Most of the soils of the study sites are fine-grained (contain high percentages of clay and silt), which have a high water-holding capacity, which makes these areas suitable for plant growth, and thus helps to collect organic matter and retain it in the spaces between the soil grains (Khalaf, 2019). Recent studies have determined the maximum allowable limit of organic matter in the base soil is not to exceed 2% (Chen et al., 2012). When the presence of organic matter in the soil is higher than the permissible limit, these soils are considered unsuitable for building and road works. This is because these materials will decompose over time and cause an increase in the percentage of voids between the soil particles and will affect and change the physical and chemical properties of the soil (Fig. 5).

Table 3. Swelling classification of soils at the study sites

Depth (m)	Swell by classification of Seed et al. (1962)	Swell by classification of Van Der Merwe (1964)	Swell by classification of Terzaghi & Peck (1967)	Rate of swell
Location 1: West Qurna				
0-1	Med.	Low	Med.	Med.
1-2	Low	Low	Low	Low
2-3	Low	Low	Low	Low
Location 2: Al-Medaina				
0-1	Med.	Med.	Med.	Med.
1-2	Low	Low	Low	Low
2-3	Low	Low	Low	Low
Location 3: Al-Dir				
0-1	Low	Low	Low	Low
1-2	Med.	Low	Med.	Med.
2-3	Low	Low	Med.	Low
Location 4: Al-Hartha				
0-1	Med.	Med.	Med.	Med.
1-2	Low	Low	Low	Low
2-3	Low	Low	Low	Low
Location 5: Shatt Al-Arab				
0-1	Low	Low	Low	Low
1-2	Low	Low	Low	Low
2-3	Low	Low	Low	Low
Location 6: Al-Tuwaisa				
0-1	Low	Low	Low	Low
1-2	Low	Low	Low	Low
2-3	Low	Low	Low	Low
Location 7: Hayy-Al-Hussein				
0-1	Low	Low	Low	Low
1-2	Med.	Med.	Med.	Med.
2-3	Low	Low	Low	Low
Location 8: Al-Maqal				
0-1	Low	Low	Low	Low
1-2	Low	Low	Low	Low
2-3	Low	Low	Low	Low
Location 9: Al-Gzar				
0-1	Low	Low	Low	Low
1-2	Low	Low	Low	Low
2-3	Low	Low	Low	Low
Location 10: Al-shar				
0-1	Low	Low	Low	Low
1-2	Med.	Med.	Med.	Med.
2-3	Low	Low	Low	Low
Location 11: Abu-Al-Khaseeb				
0-1	Low	Low	Low	Low
1-2	Low	Low	Low	Low
2-3	Low	Low	Low	Low
Location 12: Al-Fao				
0-1	Low	Low	Low	Low
1-2	Low	Low	Low	Low
2-3	Low	Low	Low	Low

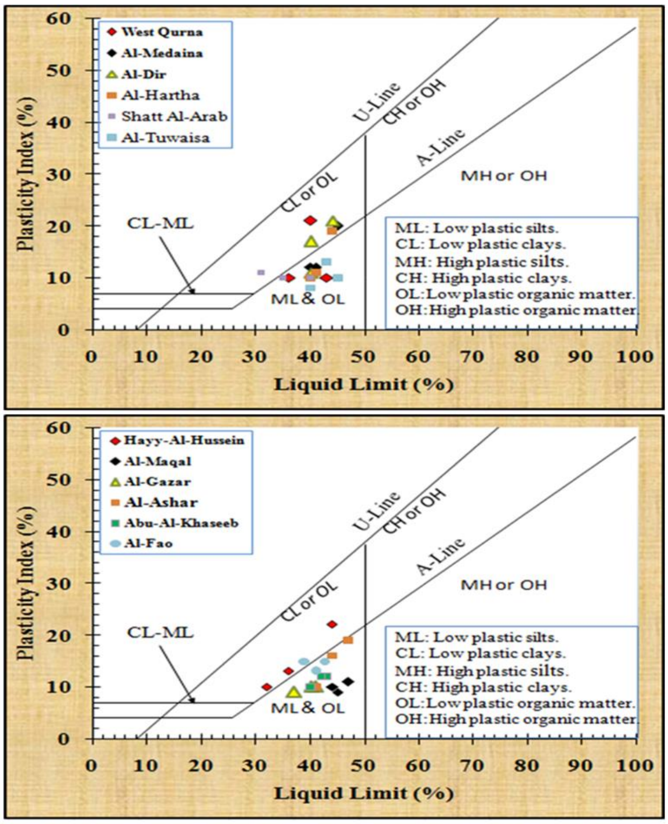

Fig. 5. Plasticity diagram of the soils for study sites

3.4. Distribution of Weak Soils in the Study Sites

The soils in the study area were classified according to the consistency of the cohesive soils and the compactness of the non-cohesive soils relative to the N-values of the standard penetration test (SPT). Table 2 and Fig.6 show the N-values at the first 3 meters of the study area. The results of the first meter of cohesive soils showed that the soil in the S10 site is hard and in S3, S10, and S15 are very stiff and in S4, S6, S7, S9, S10, and S12 sites are stiff, while in the sites S2, S5, and S11are medium-stiff soils. The results of non-cohesive soils in the first meter at sites S8 and S13 showed that they are medium dense sandy soils and in sites S14 and S16 they are loose sandy soils. As for the second meter, the results of cohesive soils showed that the soil in site S1 is hard, and in sites, S3, S5, and S10 are very stiff soils, and in sites, S4, S6, S9, S10, and S11 are stiff soil, and in sites, S2, S7, and S12 are medium stiff soil, while in site S5 the soil is soft. While the results of non-cohesive soils showed that the soils at sites S8, S13, S14, and S16 are medium dense sand. As for the third meter, the results for cohesive soils showed that the soil at site S1 is hard, and at the site, S3 is very stiff, and at sites, S2, S4, S6, S7, and S15 are stiff soils, and at sites, S5, S9, S10, S11, and S12 are medium stiff soils. While the results of non-cohesive soils showed that the soils of two sites S8 and S16 are very dense sandy soils, site S13 has dense sandy soil, and site S14 has medium dense sandy soil. The results show that the surface soils are weak in some locations, which requires treatment and improvement of these soils by various means of improvements methods. The cohesion of clay and silty soils gradually decreases in the direction from north to south, as the increased cohesion of surface clay soils is due to high evaporation, and therefore the reason for the weakness of these soils in the southern section may have occurred because these areas were exposed to water inundation, especially in periods of high tide. In addition to the general slope of the surface of the area towards the sea, which makes the groundwater level in the northern part is less than the southern part (Mahmoud, 1997).

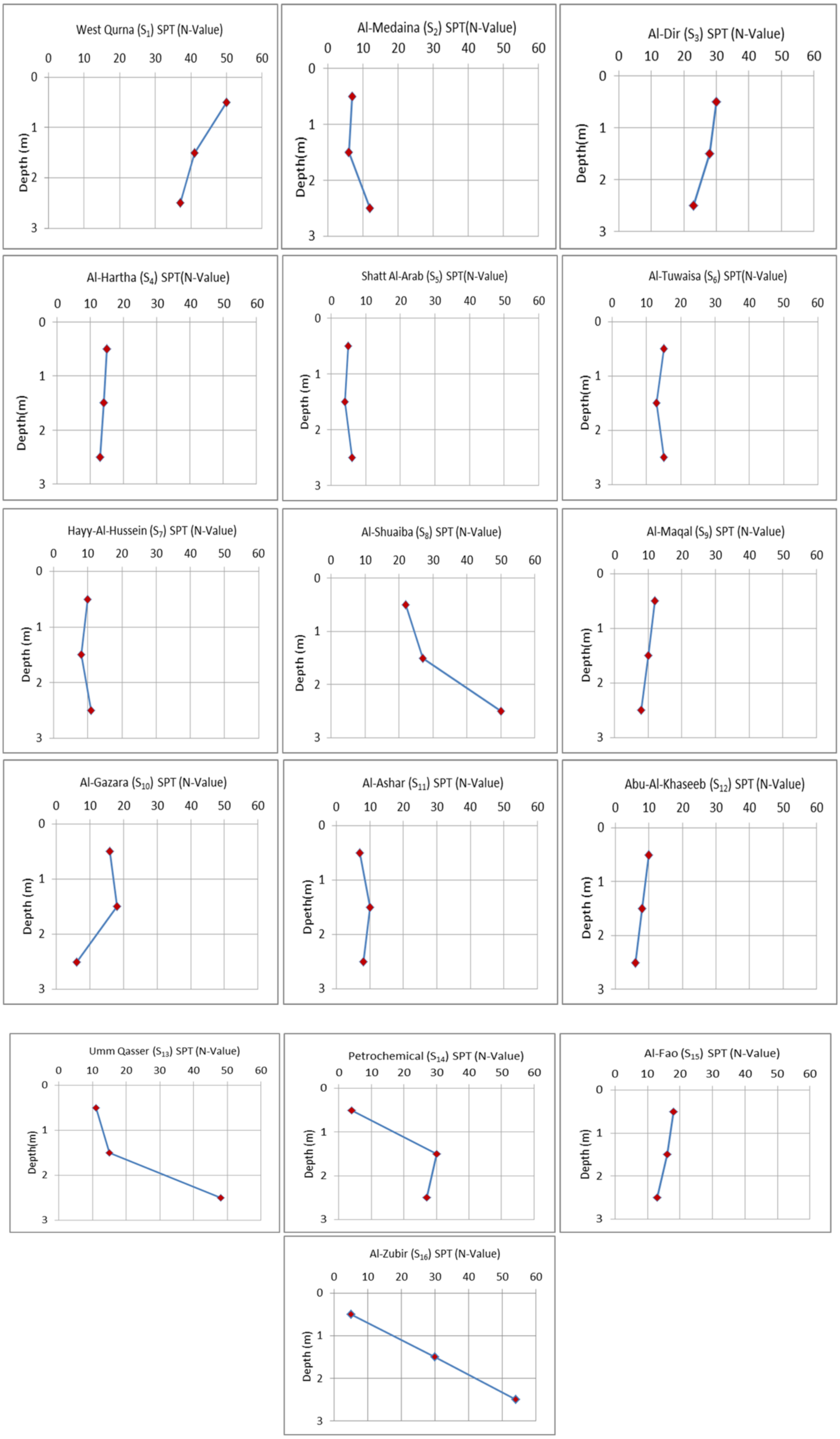

Fig. 6. Standard penetration test (SPT) N-values for soil study sites

4. Conclusions

According to the results of geotechnical tests, the following conclusions are:

- The percentage of gypsum exceeded the permissible limit in the standard specifications in the sites (S_7, S_8, S_{13}, S_{14}, S_{16}). Also, the percentage of total soluble salts (TSS) exceeded the permissible limit in the standard specifications in the sites (S_5, S_8, S_{16}).
- The results showed that the soils in S_1, S_2, S_3, S_4, S_7, S_{11} have medium swelling potential, which requires treating before building roads on them.
- The results also showed that the percentage of organic materials exceeded the permissible limit in the standards specifications in the sites (S_1, S_2, S_3, S_4, S_5, S_9, S_{10}, S_{11}, S_{12}, S_{15}).
- The results also showed that the cohesive soils in the first meter of the sites (S_2, S_5, S_{11}) and the second meter of the sites (S_2, S_7, S_{12}) and the third meter of the sites (S_5, S_9, S_{10}, S_{11}, S_{12}) are medium stiff soils, which requires treatment before building roads on them. While the non-cohesive soils in two sites (S_8, S_{13}) are medium dense soils, in sites (S_{14}, S_{16}) are loose sandy soils in the first meter, while the second meter in sites (S_8, S_{13}, S_{14}, S_{16}) are medium dense soils, and the third meter the site (S_{14}) is medium dense soils, which requires treatment before building roads on them. This requires conducting geotechnical investigations of the path of the road before its implementation to determine the nature of the foundation soils and the presence of soils with problems in them to be treated and improved before construction.

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