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Soil Compaction Characteristics of Selected Sites in Diyala Governorate

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ABSTRACT

Soil compaction is essential to improve the geotechnical properties of soil such shear strength and load bearing capacity and to decrease subsequent soil settlement. This study aims to evaluate compaction characteristics of thirty four soil samples collected from four selected sites in Diyala governorate and to provide preliminary geotechnical data base for future studies. Firstly, Basic Index properties tests were carried out to characterise and to classify the soils according to USCS classification. Secondly, Standard and Modified compaction test were performed to determine the compaction characteristics namely Optimum Moisture Content OMC and Maximum Dry Density MDD. Thirdly, compaction ratio is calculated to examine field compaction specifications. All tests were carried out per ASTM (American Society for Testing and Materials) standards. The results revealed that the soil type was; SM at Qarattapa (Q) site, CL, SC at Khanaqin (Kh) site, CL, CL-ML at Baqubah (B) site, and ML, CL at Muqdadiya (M) site. From compaction tests, OMC and MDD for Standard Proctor compaction tests were average, respectively, 16.05%, 1.56 gm/cm³ for Q site samples, 17.10%, 1.69 gm/cm³ for B site samples, 16.30% 1.59 gm/cm³ for Kh site samples, and 16.30%, 1.59 gm/cm³ for M site samples. For Modified Proctor compaction tests, OMC and MDD were, respectively, 12.50%, 1.69 gm/cm³ for Q site samples, 13.65%, 1.80 gm/cm³ for B site samples, 12.90%, 1.71 gm/cm³ for Kh site samples, and 15.05%, 1.66 gm for M site samples. All collected soil samples have plasticity index less than 15% indicating moderately plastic soils. Calculated compaction ratio Q varies in the region. Q of 95% is recommended for future field compaction.

Keywords: Soil Compaction; Qarattapa ; Khanaqin; Baqubah; Muqdadiya; Diyala

1. Introduction

Soil characterisation and classification are essential to identify the soil for all engineering projects. In addition, geotechnical properties of soils are commonly enhanced for almost all engineering works such as dams, roads, and buildings using compaction process. Therefore, it is vital to determine soil compaction characteristics namely OMC and MDD often calculated from compaction curves acquired through laboratory standard and modified Proctor tests, and used as criteria to evaluate the field compaction specifications. (Budhu, 2015).

The determination of OMC and MDD of soil is important for assessing their engineering suitability and to avoid future settlement and reduce future mitigation expenditures. This can be done through calculation of compaction Ratio R which can be defined as the ratio between field dry density and MDD determined from laboratory compaction tests, expressed as:

$$R = \rho_d(\text{field}) / \rho_{d-\max}(\text{Lab}) \dots(1)$$

Where; R is the Compaction Ratio; $\rho_d(\text{field})$ is the field dry density of soil, and $\rho_{d-\max}(\text{Lab})$ is the MDD obtained from laboratory compaction tests.

Numerous field and experimental studies dealing with geotechnical evaluation of soils in different parts of Iraq have been published. For instance, Al-Naimi (1996) assessed the shear strength parameters of soil Baghdad city. Bakir (1998) presented geotechnical maps illustrating soil properties variation for southern region of Iraq. Similarly, Al-Ani (2001) provided geotechnical maps showing geotechnical properties of soil in Diyala governorate. Alshakarchi, and Turkie (2005) also presented geotechnical maps for soils in Baghdad, Diyala, Wasit and Babylon. Alhadad, (2012) evaluated the geotechnical properties of soil from selected in Tikrit and indicated the poor geotechnical characteristics gypseous soil. Hassan, (2021) evaluated the compaction characteristics of soil at a construction site in Al- Khalis city, Diyala governorate based on laboratory standard compaction tests and field dry density determination. Hassan et al., (2022) analyzed some physical and mechanical properties of soil collected the location of the University of Diyala, and according to USCS classifications, the soil in the region was fine-grained soil type CL of low to medium plasticity.

An extensive campaign of engineering projects has been taken place recently in Diyala governorate. Soil identification and characterisation, therefore, are significant to evaluate its suitability for different engineering works. Thus, the current work aims to characterise and classify the soil at selected sites in Diyala governorate with primary focus on soil compaction characteristics at these sites. The data presented here is part of an ongoing research work carried out in the region.

2. Location of Study Area

Diyala Governorate, is located in the central region of Iraq's eastern side between about 45° to 46° E longitudes and 33° to 35° N latitudes. Thirty four soil samples are collected from four sites shown in Figure (1). The first site is located in south of Baquba city.

The site is covered by clayey soil that extends up to a depth of 13.0 meters (Al-Ebdaa, 2015). The second site is in Khanaqin northeast of Diyala. Upper Jurassic to recent geological formations have been revealed in the Khanaqin Area. The primary formation in the Khanaqin basin is the Quaternary deposit, which is composed of loam, clay, sand, and gravel (Said,1992). The third site is Al-Muqdadiya located in center of Diyala Governorate. The soil in the area is characterized as being part of Quaternary alluvial plain deposits delivered by the Diyala River Al Obaidy et al (2014). The last site is Qara Tappa. The U. Fars, Lower, and Upper Bakhtiari Formations, were exposed throughout the region, were composed primarily of sandstone, siltstone, marl, clay, and conglomerate (Hanna, 1974).

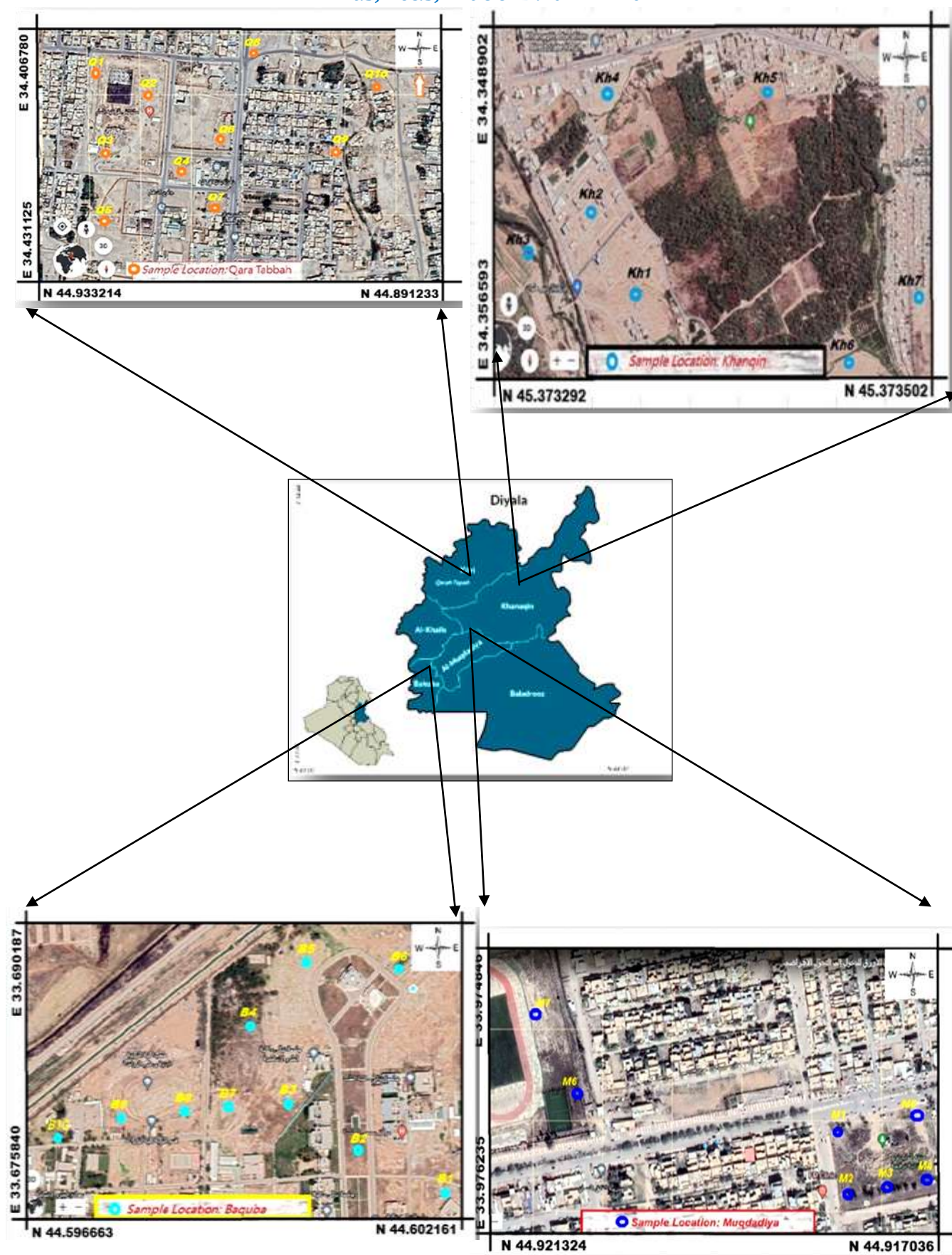


Fig. 1: locations of studied sites in Diyala

3. Materials and Methods

Thirty-four soil samples were manually augured at (1-1.25m) depth using a hand auger from the four selected sites in Diyala Governorate Fig.(1). Basic index geotechnical tests were carried out first to identify and classify the soils According to the following ASTM standards, Table (1);

Table 1: Laboratory tests performed in the current study and the corresponding ASTM standards

Laboratory Test	ASTM Standard
Grain size analysis	(ASTM D422)
Water content	(ASTM D221)
Atterberg limits	(ASTM D4318)
Soil Classification	ASTM D2487)
Standard and Modified Compaction	(D 689 & D1557)

3.1. Field Dry Density

The core cutter method is used to determine field bulk and dry density. A sharp tube of known volume is inserted in the soil. Knowing soil mass, its field water content, and the tube volume, the field dry density can be obtained (Powrie, 2004).

3.2 Sieve Analysis

First, dry sieve analysis was carried out to determine the particle size distribution. The aim was to obtain the relative quantity of constituent fractions (gravel, sand, and fine content). Second, wet sieve analysis using the hydrometer was performed to determine the ratio of silt and clay (ASTM D422,1972). The samples were finally classified according to the unified soil classification system (USCS) based on plasticity chart

3.3 Water Content

Water content of the soil is a significant indicator to explain its behavior and consistency features (Fredlund and Rahardjo,1993) The oven drying method is used to calculate the soil's water content (ASTM D2216-05,2005).

3.4 Specific Gravity

To estimate the phase relationship of air, water, and solids for a specific volume of soil, it is essential to calculate the specific gravity of the soil. The specific gravity of soil samples was determined using the pycnometer method (ASTM D854-05,2005). The ratio of the mass of a unit volume of soil solids at a specific temperature to the mass of a unit volume of

water at that same temperature is used to calculate soil specific gravity (Bowles, 1984).

3.5 Atterberg Limits

Atterberg Limits is used to describe and categorize fine-grained soils, Atterberg Limits tests (Liquid Limit LL, Plastic Limit PL, and Plasticity Index PI) (ASTM D4318-05,2005) were used to classify the soil based on USCS classification.

3.6 Compaction tests

Compaction tests were performed to assess the OWC and MDD of a soil subjected to a specific mechanical effort. The Standard Proctor and Modified Proctor compaction tests (ASTM D698-07, 2007) were used to calculate the compaction ratio.

4. Results and Discussions

4.1 Soil chracterisation and classification

The results of laboratory tests are summarized in Table (2). The range of natural water content of Kh, Q, M, and B sites were (11.5%-13.5%), (12.5%-18.5%), (17%-19.3%),(18.8%-24%), respectively. The difference in soil type, texture causes these variations (Chen and Hu, 2004). Specific gravity of Kh, Q, M, B were ranged (2.63-2.66) ,(2.65-2.67), (2.64-2.68), (2.67-2.75), respectively. The narrow range of specific gravity values reflects the similarity in mineral content (Das, 2002). The Atterberg Limits of Q, Kh ,B ,M site showed that (LL) ranged between 24% for B8 sample and 41.2% for M3 sample. The soil can be considered of low plasticity where $LL < 50\%$ Budhu (2015).

Figure (2) shows grain size distribution and plasticity chart used for USCS Classification of Q site samples. According to sieve analysis Fig (2a), sand, silt and clay ratio were (44.9%-63.2%), (34.1%-46.2%), (0.7%-2.58%),sequentially. Plasticity chart Fig (2b) was used to determine the fine grained type. All site samples are classified as silty sand (SM).

Figure (3) shows grain size distribution and plasticity chart used for USCS classification of B site samples. Grain size analysis (Fig.3a) showed that sand, silt and clay portions were ranged (7.18%-30.3%), (53%80.2%), and (10.3%-30.8%), respectively. The soil is classified in this site as (CL) to (CL-ML). (Fig.3b).

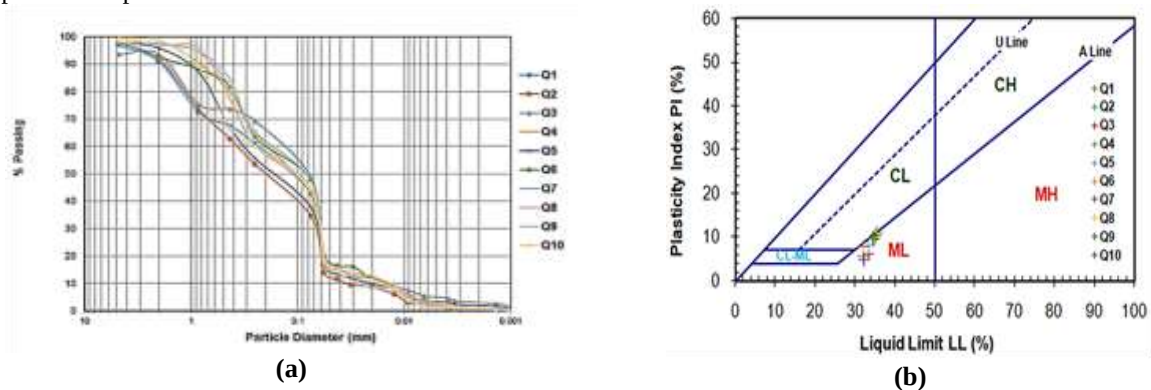


Fig. 2: (a) Grain size curves (b) Plasticity chart of Q site

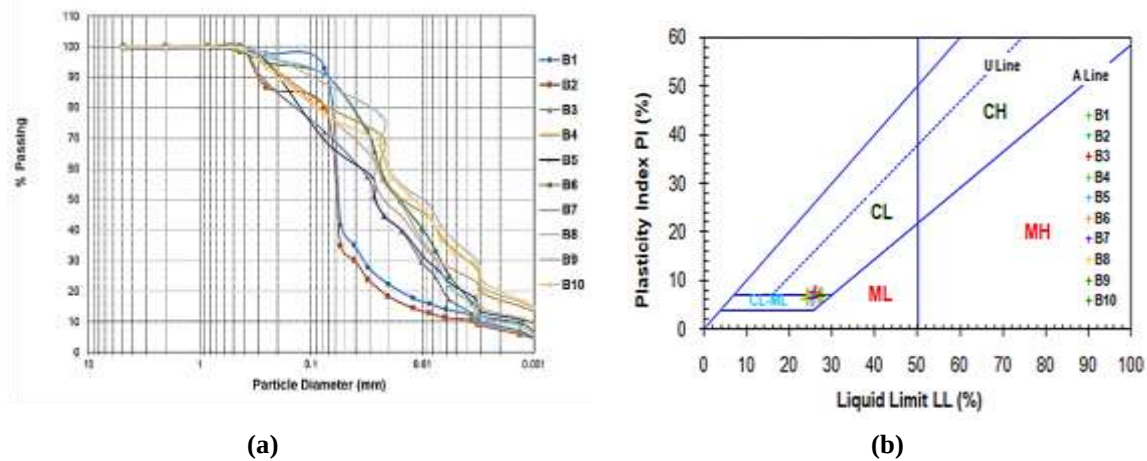


Fig. 3: (a) Grain size curves (b) Plasticity chart of B site

Figure (4) depicts grain size distribution and plasticity chart used for USCS Classification of Kh site samples. Sieve analysis Fig. (4.a) showed that sand, silt and clay, were ranged (11%-50%), (38.3%-82.3%), (5.05%-26.7%), respectively. Based on the plasticity chart (Fig.4b), the soil was classified as (CL) except Kh4 was SC.

Figure (5) shows grain size distribution and plasticity chart used for USCS Classification of M site samples. Sieve analysis Fig. (5b) showed that sand, silt and clay were ranged (11.1%-36.54%), (45.9%-75.526%), and (11%-33.3%) respectively. Based on plasticity chart Fig (5b) M1,M2,M5, and M7 are ML, while M3,M4,M6 are CL.

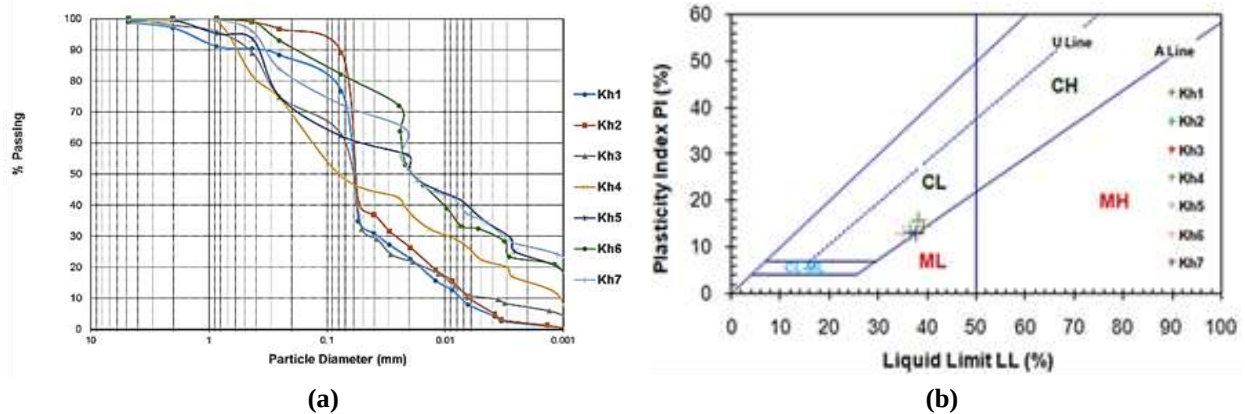


Fig. 4: (a) Grain size curves (b) Plasticity chart of Kh site

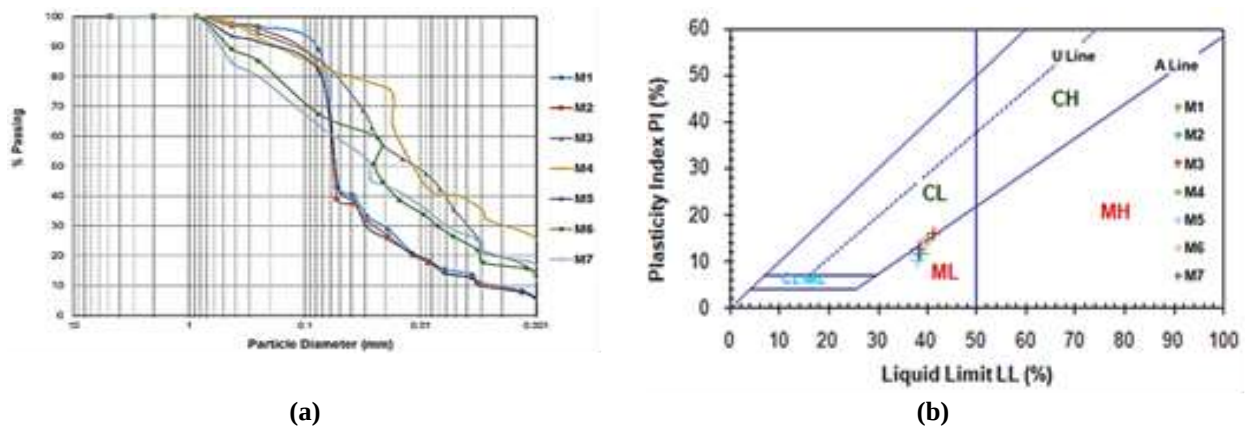


Fig. 5: (a) Grain size curves (b) Plasticity chart of M site

All soil samples have a plasticity index of less than 15%, which indicates mildly to moderately plastic soils.

4.2. Plasticity and liquidity of soils

Fundamental geotechnical characteristics of cohesive soils are the liquidity (LI) and consistency (CI) indices, Table(1). These parameters indicate consistency and physical state of the soil (Krawczyk & Flieger 2018). The Liquidity Index (LI) can be expressed as:

$$LI = \frac{Wt - PL}{PI} \quad \dots(2)$$

The consistency Index (CI) is expressed as:

$$CI = \frac{LL - Wt}{PI} \quad \dots(3)$$

For Q samples, the values of LI were ranged between (-2.262) to (-0.744), while CI values were ranged between (1.744) to (3.262) indicating semi solid to solid consistency (Krawczyk & Flieger 2018). Similarly, for B samples, the values of LI were varied between (0.058) to (0.701), while CI values were ranged between (0.299) to (0.942) indicating plastic consistency. In addition, for Kh samples, the values of LI were varied between (-0.977) to (-0.673), while CI values were ranged between (1.673) to (1.977) indicating semi solid to solid consistency.

Table 2: Index properties test results and soil classification of the studied sites

No.	Sample Symbol	Grain-size distribution					Atterberg limits			Gs	LI	CI	Soil type
		W %	Gravel %	Sand%	Silt%	Clay%	LL%	PL%	PI%				
1	Q1	17.30	3.08	54.30	42.00	0.70	32.00	26.40	5.60	2.67	-1.625	2.625	SM
2	Q2	17.00	2.19	63.20	34.10	0.73	34.30	24.70	9.60	2.67	-0.802	1.802	SM
3	Q3	13.40	6.36	44.90	46.20	2.58	33.30	27.20	6.10	2.67	-2.262	3.262	SM
4	Q4	12.50	0	57.60	41.30	1.10	35.50	24.60	10.90	2.66	-1.110	2.110	SM
5	Q5	14.00	1.85	60.40	36.40	1.32	33.50	25.40	8.10	2.67	-1.407	2.407	SM
6	Q6	18.50	1.67	50.60	46.00	1.77	32.10	24.30	7.80	2.65	-0.744	1.744	SM
7	Q7	18.30	2.26	50.20	46.20	1.38	32.30	27.50	4.80	2.66	-1.917	2.917	SM
8	Q8	17.00	0	55.80	42.70	1.50	35.40	25.60	9.80	2.67	-0.878	1.878	SM
9	Q9	15.50	1.88	53.50	43.80	0.80	35.00	24.50	10.50	2.65	-0.857	1.857	SM
10	Q10	15.50	1.23	54.40	43.60	0.75	34.70	25.10	9.60	2.66	-1.000	2.000	SM
11	B1	22.20	0	7.18	80.20	12.60	24.20	17.50	6.70	2.74	0.701	0.299	CL-ML
12	B2	19.30	0	20.13	71.00	8.87	24.30	18.00	6.30	2.74	0.206	0.794	CL-ML
13	B3	23.00	0	27.94	61.30	10.80	25.80	18.00	7.80	2.69	0.641	0.359	CL
14	B4	18.80	0.16	19.06	54.10	26.70	24.30	18.00	6.30	2.69	0.127	0.873	CL-ML
15	B5	20.50	0.46	30.29	54.70	14.50	26.00	19.00	7.00	2.68	0.214	0.786	CL-ML
16	B6	20.50	0	9.25	70.80	20.00	26.50	19.00	7.50	2.68	0.200	0.800	CL
17	B7	21.0	0	9.40	73.40	17.20	25.20	18.80	6.40	2.73	0.344	0.656	CL-ML
18	B8	20.00	0	21.81	67.90	10.30	24.00	17.20	6.80	2.75	0.412	0.588	CL-ML
19	B9	23.00	0	12.13	57.10	30.80	27.60	20.40	7.20	2.67	0.361	0.639	CL
20	B10	20.60	0.26	21.83	53.00	24.90	27.10	20.20	6.90	2.68	0.058	0.942	CL-ML
21	Kh1	12.00	1.19	22.20	71.50	5.05	38.10	22.50	15.60	2.65	-0.673	1.673	CL
22	Kh2	11.60	0	11.00	82.30	6.67	36.40	23.30	13.10	2.65	-0.893	1.893	CL
23	Kh3	12.40	0	37.50	56.10	6.38	38.30	25.20	13.10	2.63	-0.977	1.977	CL
24	Kh4	13.50	0.95	50.00	38.30	10.80	39.30	24.80	14.50	2.63	-0.779	1.779	SC
25	Kh5	13.50	0.48	37.40	39.80	22.40	38.10	24.70	13.40	2.66	-0.836	1.836	CL
26	Kh6	11.50	0	18.00	55.40	26.70	35.20	22.40	12.80	2.64	-0.852	1.852	CL
27	Kh7	13.20	0.30	27.40	46.90	25.50	37.60	24.60	13.00	2.65	-0.877	1.877	CL
28	M1	17.50	0	11.10	75.50	13.30	38.60	27.00	11.60	2.65	-0.819	1.819	ML
29	M2	17.00	0	17.30	71.60	11.20	38.20	26.60	11.60	2.68	-0.828	1.828	ML
30	M3	19.30	0	14.40	55.70	30.00	41.20	25.20	16.00	2.66	-0.369	1.369	CL
31	M4	18.30	0	16.60	50.00	33.30	40.00	25.30	14.70	2.66	-0.476	1.476	CL
32	M5	18.00	0	18.70	70.40	11.00	38.00	27.70	10.30	2.65	-0.942	1.942	ML
33	M6	17.70	0	32.70	49.80	17.50	39.40	25.00	13.80	2.67	-0.529	1.572	CL
34	M7	16.30	0	36.50	45.90	17.60	38.20	25.60	12.60	2.64	-0.738	1.738	ML

4.3. Soil compaction characteristics

Figure (6) shows compaction curves of Standard and Modified Proctore compaction tests of all soil samples collected in the area with Zero Air Voids ZAV line. Table (2) lists the compaction characteristics, MDD and OMC derived from compaction curves in addition to the calculated compaction ratio.

For Q samples, MDD and OMC values of Standard Proctor compaction tests were ranged (1.51- 1.62) gm/cm³ and (14.9%-17.2 %), respectively. MDD and OMC values of Modified Proctor compaction tests were ranged (1.64 -1.74) gm/cm³ and (11.30% -13.70 %), respectively.

For B samples, MDD and OMC values of Standard Proctor compaction tests were ranged (1.65 -1.73) gm/cm³ and (5.8% 18.4%), respectively. MDD and

OMC values of Modified Proctor compaction tests were ranged (1.775-1.825) gm/cm^3 and (13.3 % -14 %), respectively.

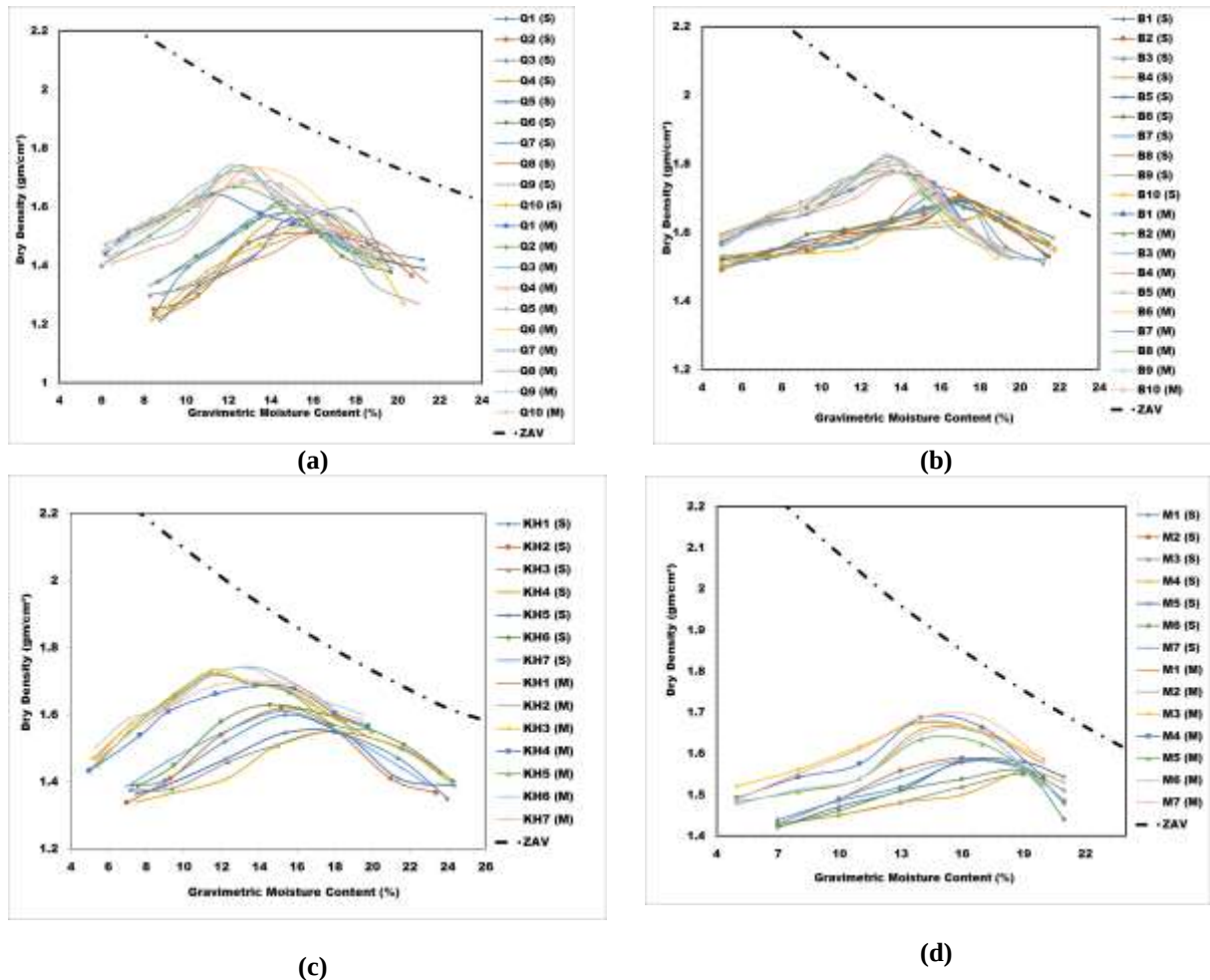


Fig. 6: Compaction curves of (a) Q samples (b) B samples, (c) Kh samples (d) M samples

For Kh samples, MDD and OMC values of Standard Proctor compaction tests were ranged (1.55-1.63) gm/cm^3 and (14.8%-17.8 %), respectively. MDD and OMC values of Modified Proctor compaction tests were ranged (1.677-1.74) gm/cm^3 and (11.7% -14.1 %), respectively.

Finally, for M samples, MDD and OMC values of Standard Proctor compaction tests were ranged (1.55-1.59) gm/cm^3 and (16.1 % - 19.24 %), respectively. MDD and OMC values of Modified Proctor compaction tests were ranged (1.64 -1.678) gm/cm^3 and (14.5% - 15.6%), respectively.

Calculated R values in the studied sites from site to site. A 95% are recommended to be considered.

Figure (7) illustrates the relationship between MDD and OMC of soil samples. Increases compaction effort from Standard to Modified compaction increases MDD and reduces OMC required to reach MDD.

MDD-OMC relationships were compared with those similar relationships from previous studies as shown in Fig (8).

Table 3: compaction characteristics of samples under investigation.

No.	Soil Symbol	Standard Proctor		Modifid Proctor		Standard (R)	Modified (R)
		MDD	OMC	MDD	OMC%		
1	Q1	1.58	15.2	1.64	11.30	76.96	74.15
2	Q2	1.51	16.00	1.67	12.50	77.95	70.48
3	Q3	1.59	17.20	1.74	12.10	82.96	75.80
4	Q4	1.58	15.00	1.73	13.20	75.00	68.50
5	Q5	1.56	14.90	1.677	13.70	82.95	77.16
6	Q6	1.62	14.90	1.735	13.40	85.99	80.29
7	Q7	1.61	15.00	1.74	12.60	73.98	68.45
8	Q8	1.52	17.00	1.725	12.80	87.96	77.51
9	Q9	1.53	16.40	1.73	12.40	87.97	77.80
10	Q10	1.54	16.10	1.678	12.70	90.00	82.60
11	B1	1.715	16.70	1.776	13.60	94.93	91.67
12	B2	1.704	17.00	1.825	13.50	87.97	82.14
13	B3	1.695	16.85	1.775	13.40	90.97	86.87
14	B4	1.7	17.00	1.775	14.00	87.00	83.32
15	B5	1.692	17.10	1.80	14.00	88.95	83.61
16	B6	1.685	16.40	1.776	13.50	89.97	85.36
17	B7	1.7	16.90	1.82	13.50	94.00	87.80
18	B8	1.73	15.80	1.815	13.30	84.97	80.99
19	B9	1.65	18.00	1.825	13.40	78.00	70.52
20	B1	1.66	18.40	1.81	14.00	92.95	85.25
21	Kh1	1.6	15.80	1.72	11.70	81.00	75.35
22	Kh2	1.62	15.50	1.74	13.50	80.99	75.40
23	Kh3	1.55	17.80	1.715	11.80	78.00	70.50
24	Kh4	1.55	17.60	1.677	14.10	76.97	71.14
25	Kh5	1.56	17.10	1.725	11.90	81.99	74.14
26	Kh6	1.63	14.80	1.74	13.00	84.97	79.60
27	Kh7	1.61	15.20	1.70	13.90	80.99	76.71
28	M1	1.584	17.20	1.674	15.00	89.96	85.13
29	M2	1.59	16.10	1.675	14.90	90.00	85.43
30	M3	1.55	19.10	1.675	14.50	90.97	84.18
31	M4	1.56	19.24	1.678	15.00	90.00	83.67
32	M5	1.59	17.20	1.64	15.00	88.99	86.28
33	M6	1.56	18.50	1.67	15.50	90.96	84.97
34	M7	1.585	16.50	1.7	15.60	89.97	83.88

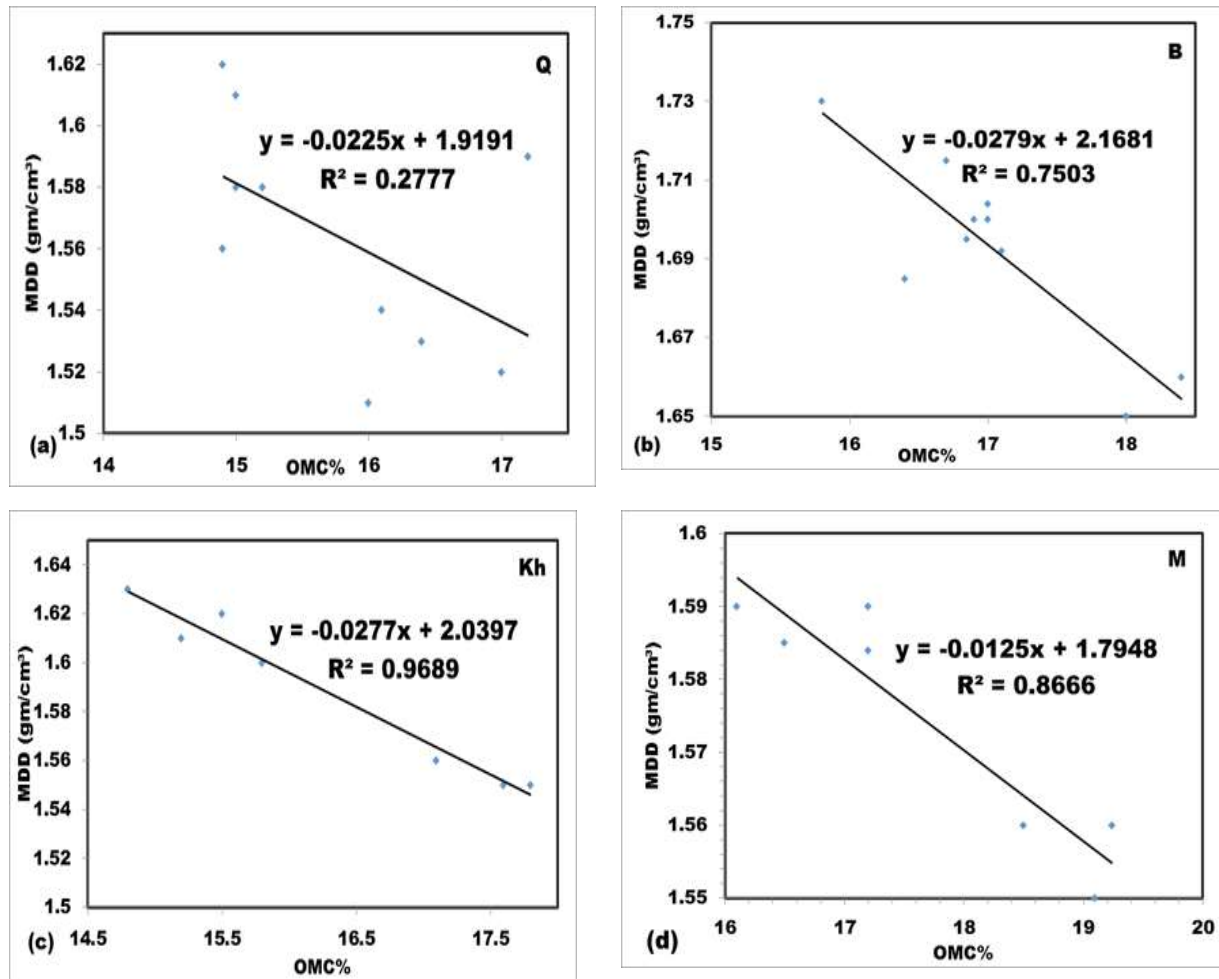


Fig.7: MDD-OMC relationships (a) Q samples (b) B samples (c) Kh samples, and (d) M samples

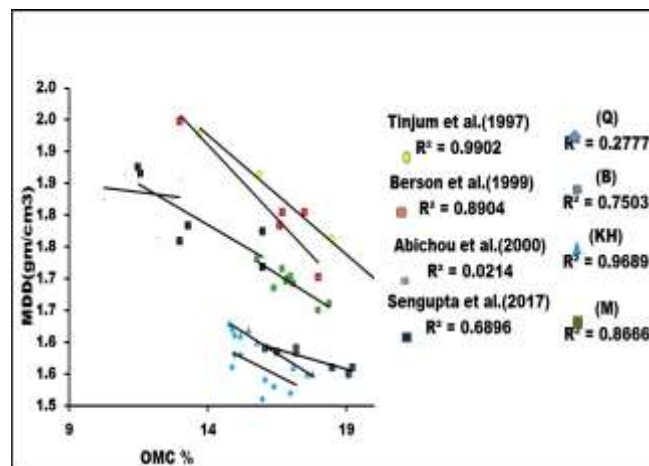


Fig. 8: MDD and OMC relationship compared with data from the literature.

5. Conclusions

Basic geotechnical index properties were performed to characterise and classify thirty four soil samples collected from selected site in Diyala Governorate. Standard and Modified Compaction tests were carried out to determine OMC and MDD and compaction ratio of these soils. All tests were carried out per

ASTM standards: The main conclusion can be listed as follows;

1. Based on USCS, the soil type was; SM at Qarattapa (Q) site, CL, SC at Khanaqin (Kh) site, CL, CL-ML at Baqubah (B) site, and ML, CL at Muqdadiya (M) site.
2. OMC and MDD for Standard Proctor compaction tests were, respectively, 16.05%, 1.56 gm/cm³ for Q

site samples, 17.10%, 1.69 gm/cm³ for B site samples, 16.30 %, 1.59 gm/cm³ for Kh site samples, and 16.30%, 1.59 gm/cm³ for M site samples.

3. OMC and MDD for Modified Proctor compaction tests, were, respectively, 12.50%, 1.69 gm/cm³ for Q site samples, 13.65%, 1.80 gm/cm³ for B site samples, 12.90%, 1.71 gm/cm³ for Kh site samples, and 15.05%, 1.66 gm for M site samples.

4. All soil samples have a plasticity index of less than 15%, which indicate mildly to moderately plastic soil.

5. For Q samples, the values of LI were ranged between (-2.262) to (-0.744), while CI values were

ranged between (1.744) to (3.262) indicating semi solid to solid consistency. For B samples, the values of LI were varied between (0.058) to (0.701), while CI values were ranged between (0.299) to (0.942) indicating plastic consistency. In addition, for Kh samples, the values of LI were varied between (-0.977) to (-0.673), while CI values were ranged between (1.673) to (1.977) indicating semi solid to solid consistency.

6. The calculated compaction ratio Q varies in the studied sites. Q of 95% is recommended for future field compaction work.

6. References

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