

CHAPTER IV
ENGINEERING
GEOLOGICAL
IDENTIFICATION

CHAPTER (IV)

ENGINEERING GEOLOGICAL IDENTIFICATION

4.1 Introduction

The main target of engineering parameters measurements is the identification of the adequateness degree of the soil to be foundation materials. Ingles and Metcalf (1972) stated that the soil at any particular locality may be unsuited, wholly or partially, to the requirements of the construction engineering. A basic decision must therefore be made, whether to:

- Accept the site material as it is, and design to standards sufficient to meet the restrictions imposed by its existing quality.
- Remove the site material and replace it by a superior material.
- Alter the properties of the existing soil so as to create a new material capable of better meeting the requirements of the task in hand.

The later choice, the alteration of soil properties to meet specific engineering requirements is known as soil stabilization. The base materials of the area under study are subjected to instability, for example settlement and slip failure due to the interaction between these materials and water. Wetting cause swelling to soil and the decay rock under foundation and drying out may cause shrinkage, such wetting and drying out may cause foundation damage even shallow foundations in the area under study. Such foundation problems related to geotechnical parameters were investigated by many authors (Holtz and Bara, 1965; Carother, 1965; Al Rawas et al., 1998; Al Mhaidib, 1999; Ismail, 2006 and Ismail, 2007).

4.2 Geotechnical index parameters

Soil properties such as grain size analysis, Atterbeg limits, swelling and shrinkage were determined for three sections west of Fayum depression along Wadi El Nazla-El Roba area (Fig. 2.3). These sections are (A), (B) at Roba area and section (C) at El Nazla area (Figs. 2.4, 2.5 and 2.6).

The properties of clays have been investigated due to their effects on foundations problems and slope failure because clay presents problems to geotechnical engineers due to its complex nature and its swelling-shrinkage behavior when it contact with water. This derives from its plasticity and volume change (Yalcin, 2007). Plasticity characteristics and volume change behavior of soils are theorized to be directly related to the amount of colloidal particles ($< 1\mu\text{m}$) in soils (Anderson et al., 1973). So that representative disturbed and undisturbed soil samples were collected for laboratory investigations. Geotechnical testing in the present study includes grain size analyses, consistency of clay, plasticity index, clay activity, free swell and linear shrinkage. The conditions of clay can be altered by changing the moisture content. Atterberg limits include liquid limit, plastic limit, and plasticity index, the boundaries between the soils states depend on the consistency index values (I_C) (Fig. 4.1).

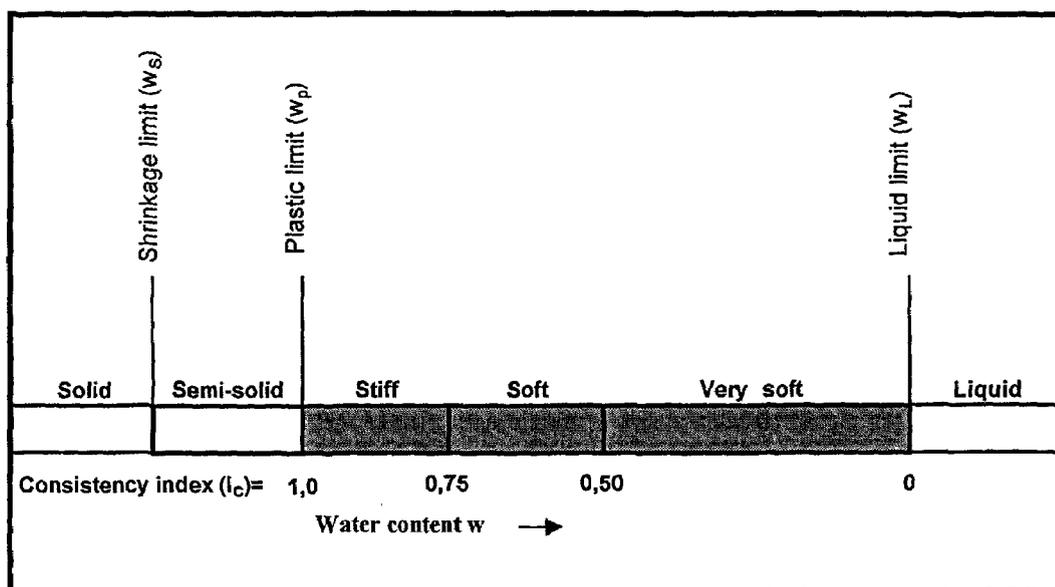


Fig. 4.1: Soil state in relation to consistency limits and consistency index (I_c) (After Fecker and Reik, 1996 from Ismail, 2004).

Liquid limit is the moisture content at which a soil begins to flow or the moisture content at which soil passes from the plastic to liquid state. The plastic limit is the moisture content at which a soil stiffens from a plastic to a semi-rigid and friable state, or the minimum amount of water to attain the soil in plastic state (Hillel, 1980). Plasticity index (PI) is defined as the difference between liquid limit and plastic limit. The plasticity index gives the range in moisture content at which a soil is in a plastic condition (Fig. 4.1). The plasticity index equation is given in British Standards (BS 1377:1975, chapter 2, moisture content and index tests) as $P_I = L_L - P_L$. Where P_I : plasticity index, L_L : liquid limit and P_L : plastic limit.

The relation of moisture content to L_L and P_L can be expressed numerically as soil Consistency or Liquidity Index as follows:

1- Soil Consistency:

It is physical state of fine grained soil at particular moisture content. According to (Terzaghi and Peck, 1948), consistency index is the ratio difference

between liquid limit (LL) and natural moisture (W) content to plasticity index (PI).

$$\text{Consistency index: } I_C = (L_L - W) / P_I$$

2- Liquidity Index:

According to Lambe and Whitman (1969) the ratio difference between moisture content and plastic limit to plasticity index is defined as liquidity index.

$$I_L = (W - P_L) / P_I$$

According to Skempton (1953), plasticity index depends on the clay fraction (the percentage finer than $2\mu\text{m}$). Thus, Atterberg limits and clay content have been combined into a single parameter called the Activity Ratio (A) developed by Skempton (1953). The activity ratio sometimes called the activity index and is calculated as:

$$\text{Activity index (A) = plasticity index / clay fraction \%}$$

Skempton (1953) proposed three classes of clays according to the activity ratio as follows:

- 1) Inactive clay: $A < 0.75$
- 2) Normal: A between 0.75 and 1.25
- 3) Active: $A > 1.25$

The activity index depends mainly on the type of clay minerals; the active clays provide the most potential for expansion. A Ca- saturated montmorillonite has an estimated activity ratio of 1.5 whereas a Na-saturated montmorillonite has an activity ratio greater than 7. Kaolinite has an activity index of about 0.3 and illite has an activity of about 1. Another classification for activity according to

BS (1377:1975, chapter moisture content and index tests), the clay activity is classified into four classes:

- 1) Inactive: $A < 0.75$
- 2) Normal: A between 0.75 and 1.25
- 3) Active: A between 1.25 and 2
- 4) Highly active clays $A > 2$. (eg. Bentonite with $A = 6$ or more).

A practical use of the Atterberg limits are shown on Fig. 4.2, the liquid limit is plotted against the plasticity index on Plasticity chart or Casagrande chart. By plotting the liquid limit and plasticity index values of the soil samples can give an indication about the soil types.

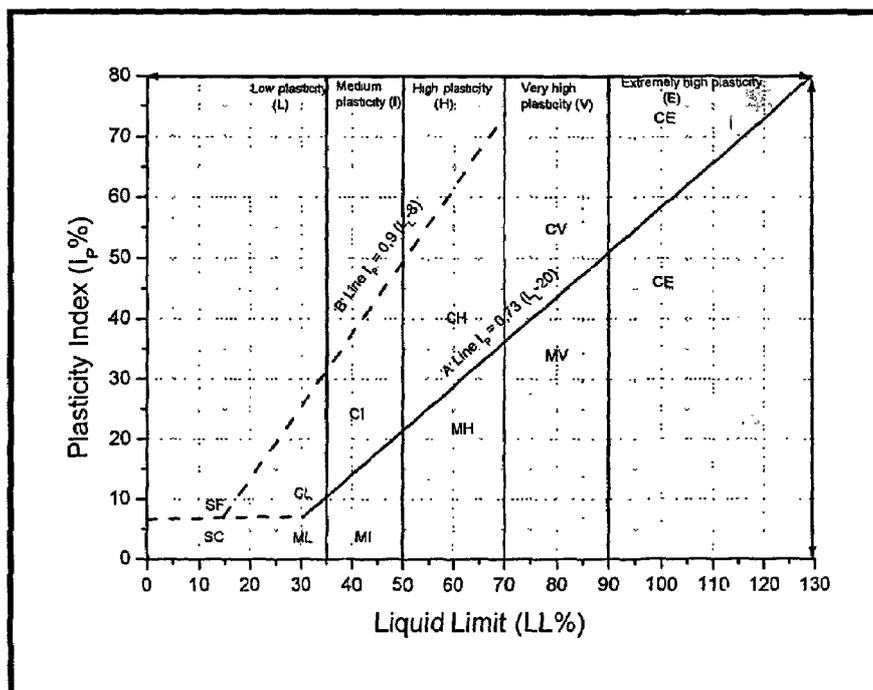


Fig. 4.2: Soil classification diagram (BS 1377:1975, chapter moisture content and index tests).

Casagrande chart is useful in identifying the type of clay mineral present using P_I and L_L . According to BS 1377:1975, chapter moisture content and index tests, A line drawn on the plasticity chart is used to differentiate clay-like materials (above A line) from those which are silt-like (below A line).

A- Line is defined by the relationship $P_I = 0.73 (L_L - 20)$. This chart is divided into five zones, giving the following categories for clay

- 1) Clay of low plasticity (CL) where $<35\% L_L$
- 2) Clay of medium plasticity (CI) where L_L ranges from 35 % and 50 %
- 3) Clays of high plasticity (CH) where L_L ranges from 50 % to 70 %
- 4) Clays of very high plasticity (CV) where L_L ranges from 70 % to 90 %
- 5) Clays of Extremely high plasticity (CE) where $L_L >90\%$

Silt size material lies below A-Line and takes the group symbols ML, MI, MH and MV.

The dashed line labeled B- Line is a tentative upper limit for all soils. It is defined by the relationship $P_I = 0.9 (L_L - 8)$.

The Atterberg limits are widely used procedure for establishing and describing the consistency of soil. They can provide useful information regarding soil strength, behavior, stability, type and state of consolidation, or as classification of an organic or inorganic clay. The small range between plastic and liquid limits, commonly presented by such materials, determines their ability to change rapidly from semi-solid to liquid state, resulting in the significant decrease of cohesion, angle of internal friction, shear strength and bearing capacity after water supply (Lambe and Whitman, 1979).

The values of Atterberg limits are dependent on various soil parameters, e.g., particle size distribution, clay mineral contents and chemical composition (Ismail, 2004). Soils with high liquid limits generally indicate high clay content and minerals of high specific surface area, for instance montmorillonite clay mineral has specific surface area ($800 \text{ m}^2/\text{g}$) and is higher than that of illite and Kaolinite with $100 \text{ m}^2/\text{g}$ and $10 \text{ m}^2/\text{g}$ respectively (Hardt, 1985). So it shows that montmorillonite clay mineral has higher values of engineering parameters eg. plasticity,

swelling and shrinkage more than illite and kaolinite minerals (Table. 3.1 and 3.3).

The sedimentary rocks and their weathering products in the area under investigation comprise late to middle Eocene (Gehannam-Formation) and Quaternary deposits. Index properties have been determined on samples from Gehannam Formation and Quaternary deposits to give an account about the engineering characteristics of the materials derived from such Formations and to classify the materials from geo-engineering point of view. As far as the collected materials were still in a solid state, it has been mechanically comminuted to a soil-like powder before testing according to soil mechanics procedures (BS 1377:1975, chapter 4 particle size and German standards classification, DIN 18123). In the further discussion, the comminuted rock powder may sometimes be referred to as a soil for verbal simplicity.

4.3 Methodology

4.3.1 Particle size distribution and texture

Grain size distribution is a major factor of classification schemes for the differentiation between various soil types. British standards (BS 1377:1975, chapter 4 particle size) and German standards classification (DIN 18123) include both wet sieving and sedimentation analysis and both were used to obtain the particle size distribution over the complete range of particle sizes. Wet sieving analysis is used to determine the weight percentage of the material with a grain size coarser than 63 μm . The clay and silt sized particles are determined by hydrometer test.

4.3.1.1 Wet Sieving fine soil (German standards classification, DIN 18123).

4.3.1.1.1 Procedures

About 100 gm of the specimen to be used for the test is obtained from the original sample by quartering. The specimen is placed on a tray and is allow drying, preferably over night in an oven at 105-110°C. Then cool and weight. Sieves used should cover the range of aperture sizes for each particular soil (sieves 2.5 mm, 1 mm, 0.63 mm, 0.35 mm and 0.063 mm). The soil is placed a little at time on the 2.5 mm sieve and washed over a sink with a jet or spray of clean water, the silt and clay will be waste. The mass retained in each sieve were calculated (all sieves analysis data are obtained in table. 4.1).

4.3.1.2 Hydrometer Analysis

4.3.1.2.1 Test Procedures (German standards classification, DIN 18123).

- 1) Put 25 ml of the prepared calgon solution by centrifuging of 20 gm sodium hexa-meta phosphate within 1000 ml distilled water for 30 min., on 50 g of the soil passing 0.063 mm in beaker for overnight.
- 2) In the next morning complete the beaker content to 200 ml with distilled water and make centrifuge at 2000 mev for 15 min., then transfer the content to 1000 ml cylinder and complete it with distilled water, make hydrometer test. Place a second cylinder containing distilled water for cleaning the hydrometer between the readings. Insert rubber bung into the sedimentation cylinder, the cylinder is then shaken vigorously to obtain a uniform suspension; the cylinder is inverted for a few seconds and then

3) Remove the rubber bung, insert the hydrometer steadily and allow it to float freely. Readings of the hydrometer are taken at the top of meniscus level at the following times from 30 sec., 1, 2, 4 min. etc. The hydrometer is then removed slowly and rinsed in distilled water then place in the separate cylinder of distilled water. Insert the hydrometer for further readings at the following times, remove and place it back in the distilled water cylinder after each reading 8, 15, 30 min., 1, 2, 4, 8 hr., overnight (about 16 hr.) and the last reading at 24 hour. Provided that the actual time of each reading is recorded on the hydrometer test sheet (BS 1377:1975, chapter 4 particle size and DIN 18123). Temperature of the suspension should be checked at intervals.

4.3.1.2.2 Corrections of hydrometer readings and calibration (BS 1377: 1975, chapter 4 particle size).

1- Correction of hydrometer readings

To each reading R^h four corrections must be applied as follow:

a- Meniscus correction

A hydrometer is calibrated to read at the liquid surface in which it is immersed, since soil suspension is not transparent enough to permit a reading to be taken at this level. The meniscus correction (C_m) has to be added to R^h in order to obtain the true reading R_h and the meniscus correction C_m is determined as follows:

The hydrometer is inserted in a 1000 ml cylinder about three quarter full of distilled water, the plane of the liquid surface is seen as an ellipse, from just below the surface, the eye is raised until the surface is seen as a straight line and the scale marking at which this plane intersect the hydrometer stem is noted (Reading A), by looking from just above the plane of the liquid surface, the scale marking at the level of the upper

limit of the meniscus is noted (Reading B). The difference between the two scales readings multiplied by 1000 is the meniscus correction (Table. 4.1). The true hydrometer reading R_h is given by $R_h = R^h + C_m$.

b- Temperature Correction

Hydrometer is usually calibrated at 20°C, if a test is carried at different temperatures, both density of water and the density of hydrometer due to thermal glass expansion will be different, this factors given on the temperatures correction chart (BS 1377, 1975) and are add to the true hydrometer reading R_h (Table. 4.1).

c- Dispersing agent correction

The addition of the dispersing agent results in the density of the liquid in which sedimentation take place being greater than that of the water. To determine the dispersing agent correction (x), a volume of exactly 50 ml of the dispersing agent solution is placed in a weighted evaporating dish. The water is evaporating by drying in the oven at 105°C and the mass of the dispersing agent (md g) remaining in the container is determined. The correction x to applied to R_h is given by $x = 2md$. The x correction value is always subtracted from the R_h value (Table. 4.1).

d- Water density correction

British stander (BS 1377, 1975) specifies that the scale of the hydrometer shall be calibrated in g/ml to read 1000 at 20°C. The density of pure water is exactly 1.000 g/cm³ only at 4°C, at this temperature the density at its maximum. At higher temperature it less than the density value cited above, at 20°C the density is 0.9982 g/cm³ so that the hydrometer readings must be increased by 1.8. The fully corrected hydrometer reading R is given by $R = R^h + C_m + M_t - x + 1.8$.

2- Calibration of hydrometer

The hydrometer must be calibrated in the cylinder in which it is to be used, as the cross-sectional Area (A) of the cylinder comes into the calibration calculation.

1) To determine the cross-sectional area (A), measure the distance L (mm) between two well spaced graduations on the cylinder, the volume included between this two marks is divided by $L \times 1000$

$$A = \text{Volume} / (L \times 1000) \text{ mm}^2.$$

2) Measure the distance from the bulb neck to the lowest calibration mark on the hydrometer (N).

3) Measure the distance H corresponding to each reading R_h mark and the lowest calibration mark L_1, L_2, L_3 .

4) The distance H corresponding to each reading R_h is given by $N + L_1, N + L_2, N + L_3 \dots$ ect.

5) The distance between the neck to the Bulb bottom is measured (mm) and is denoted by h.

6) Volume of the hydrometer bulb V_h can be measured by measuring the rise in level of water in a 1000ml cylinder initially filled to the 800 ml mark.

7) The distance of center of the gravity of the bulb from the bottom is denoted by h_g , and for asymmetrical Bulb ($h_g = \frac{1}{2}h$). The effective depth HR (mm) corresponding to each major calibration mark R_h is calculated from the equation:

$$HR = H + 0.5 (h - h_g) V_h / 2A$$

If the hydrometer Bulb is symmetrical this equation become $HR = H + 0.5 (h - V_h / A)$. Values of HR are plotted against R_h on ordinary graph paper; straight line equation will be produced, that inserted within the computerized program responsible the calculation (Table. 4.1).

4.3.1.2.3 Calculations

The hydrometer calculations curve, were incorporated into computer program, it is then necessary to enter only the hydrometer reading and the time in order to obtain immediately the particle size and percentage. If linked to an X-Y plotter, the particle size curve can be drawn automatically.

4.3.2 Natural Moisture content (BS 1377:1975, test 1a)

The slight changes in soil moisture content can change the strength of a soil. The water content of a soil is defined as the weight of water in a soil divided by the oven-dried weight of the soil. A drying temperature of 105°C is specified as the standard procedure and this should be used as general rule. For peat and soil containing organic matter, a drying temperature of 60°C is to be preferred to prevent oxidation of organic content, for soil containing gypsum the water of crystallization may be lost at temperature above 100°C so temperature not exceeding 80°C should be used.

4.3.2.1 Test procedures

Clean and dry the container then weight (m_1). Select representative soil samples, separate moisture content determination should be done and the average moisture content is calculated. Weight the container with the wet soil (m_2) and then place them in the oven at 70°C. Cool in a desiccator and weight the container with dry soil (m_3). Let m_1 = container mass, m_2 = container and wet soil mass and m_3 = Container and dry soil mass. $w = (m_2 - m_3 / m_3 \cdot m_1) 100\%$. The value of w for each individual moisture content specimen is calculated and the average value is then calculated.

4.3.3 Atterberg limit and soil consistency, methodology and procedures

4.3.3.1- Liquid Limit:

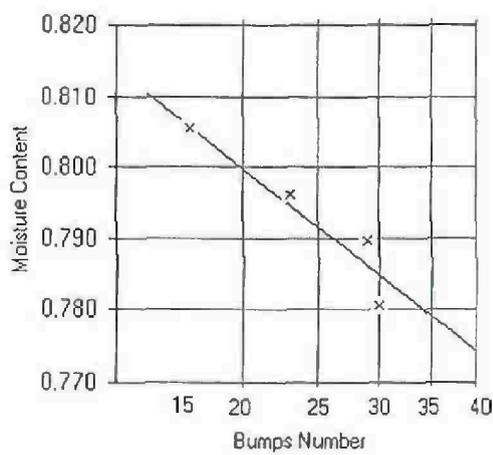
Liquid limit is the moisture content at which the soil passes from the plastic to liquid state. The cohesion of a soil is a general indication of its strength thus; the liquid limit test is a general index of cohesion because cohesion has been largely overcome at the liquid limit (Lambe and Whitman, 1979).

4.3.3.1.1- Procedures

Liquid limit has been determined using British Standards (BS 1377:1975, test 5) by mixing the material passing through a 425 μm sieve with distilled water on glass plate for over night in an air tight container to allow water to permeate through the soil mass. Transfer the soil from the container to the bowl. A groove is cut through the sample from back to front in circular motion dividing it into two equal halves. Turn the crank handle of the machine at steady rate of two revolutions per second so that the bowl is lifted and dropped. Determine the number of blows of a standard cup and moisture content at which two halves of a soil cake will flow together for a distance of about 13 mm. The moisture content is determined for soil part taken from the groove where the two half of soil have flowed together. Add of little more soil from the mixture on the glass plate; about as much as removed in the forming the groove and mix the soil in the cup then repeat the last stages. Soil moisture versus number of blows is then plotted on arithmetic paper and the moisture content at which the plotted line (called a flow curve) crosses the 25- blow line is the liquid limit (Table. 4.2).

Table 4.2: Index parameters determination in sample B₆ cultivated land of Quaternary deposits.

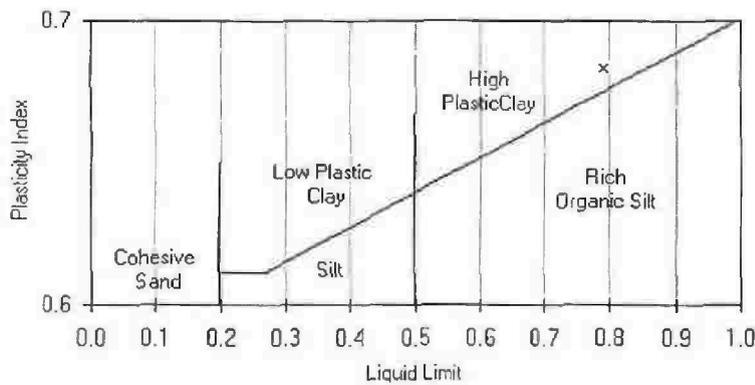
Container No	L _L				P _L		
	A69	A70	A71	A72	A73	A74	A75
Number of Bumps	30	29	23	17			
Wet Soil and Container(g)	60.0792	61.5177	36.9855	36.9955	36.9141	42.6368	42.6477 [g]
Dry Soil and Container(g)	59.1087	60.2021	36.1133	36.1133	36.685	42.495	42.44 [g]
Moisture Loss(g)	0.971	1.316	0.872	0.882	0.229	0.142	0.208 [g]
Dry Soli(g)	1.243	1.666	1.095	1.095	1.560	1.108	1.870 [g]
Moisture Content(g)	0.781	0.790	0.796	0.805	0.147	0.128	0.111



F_S: 77%
 W: 5%
 L_L: 79.2%
 P_L: 12.9%



P_I: 66.3%
 I_C: 1.119 (Semi-solid)



F_S: Free swell W: Natural moisture content L_L: Liquid limit
 P_L: Plastic limit P_I: Plasticity index I_C: Soil Consistency

4.3.3.2- Plastic limit test

This test is to determine the lowest moisture content at which the soil is plastic. The test usually carried out in conjunction with liquid limit test.

4.3.3.2.1- Procedural stages

About 20 gm of soil passing the 425 μm sieve is mixed with distilled water. Shaped the soil into ball, mould this ball between the fingers and rolls between palms of the hand so that the warmth of the hand slowly dries it. When slight cracks begin to appear the surface divide the ball in two portions each of about 10 gm. Further divided each into four equal parts, but keep each set of four parts together. One of the parts is formed into a thread about 6 mm diameter using the first finger and thumb of each hand. The thread must be intact and homogeneous. By using a steady pressure roll the thread between the fingers of one hand and the surface of the glass plate. The pressure should reduce the diameter of thread from 6 mm to about 3 mm after five to ten back and forth movement of the hand. Don't reduce pressure as the thread approach 3 mm diameter. The first crumbling point when the sample has been rolled to 3 mm is the plastic limit. If no crumbling at 3 mm mould soil between fingers again to dry it further. Repeat the procedures until the thread crumbles, when it has been rolled to 3 mm diameter determine the moisture content of this thread. Repeat the above mentioned stages for other sets of soil. Calculate the average of the moisture content of three plates (Table. 4.2).

4.3.3.3- Linear shrinkage (BS 1377:1975, Test 5)

The change in the length of a bar sample of soil when dried from about its liquid limit expressed as percentage of the initial length.

4.3.3.3.1- Procedure:-

About 150 g of air dried soil passing the 425 μm sieve is mixed with distilled water. Then it is placed in mould shrinkage of 14 mm length and 25 mm diameter and level off along the top edge of the mould with palette knife or straight-edge. Leave the mould exposed to the air, so that the soil can dry slowly. When the soil has shrunk away from the walls of the mould, it can be transferred to an oven set at 60-65 °C. When shrinkage has virtually ceased, increase the drying temperature to 105°C to complete the drying. Allow the mould and soil to cool in a dissector. Measure the length of the bar of soil with the vernier calipers. Take the average (L_D) of two or three readings. Calculate the linear shrinkage (L_S) as percentage of the original length of the specimen from the equation:
 $L_S = (1 - L_D/L_0) \times 100\%$, where L_0 = original length (140 mm) and L_D = dry specimen length.

4.3.4- Free swell

Free swell is defined as an increase in volume of soil from a loosely dry powder when it is poured into water, expressed as a percentage of the original volume. The free swell is determined by comparing the initial volume with the final volume.

4.3.4.1- Test Procedures

About 50 g of soil is oven dried and passed through a 425 μm sieve. Place the dried soil loosely in a dry 25 ml cylinder up to the 10 ml mark. The powder should not be compacted or shaken down. Pour the dry soil

powder slowly and steadily into the water. Allow the main part of the solid particles to come to rest; this will take from few minutes to half hour. The finest particles may remain in suspension for much longer but these can be ignored. Read off and record the volume of settled solids (V ml). Calculate the free swelling from the equation:

$$\text{Free swelling} = (V-10/10) \times 100\%.$$

4.4- Report and results

4.4.1- Grain size distribution

Grain size distribution curves are used to display the results of both sieve and hydrometer tests of Gehannam and Quaternary samples. All results obtained from wet sieving and hydrometer analyses are presented in Figs. 4.3, 4.4 and Table. 4.3.

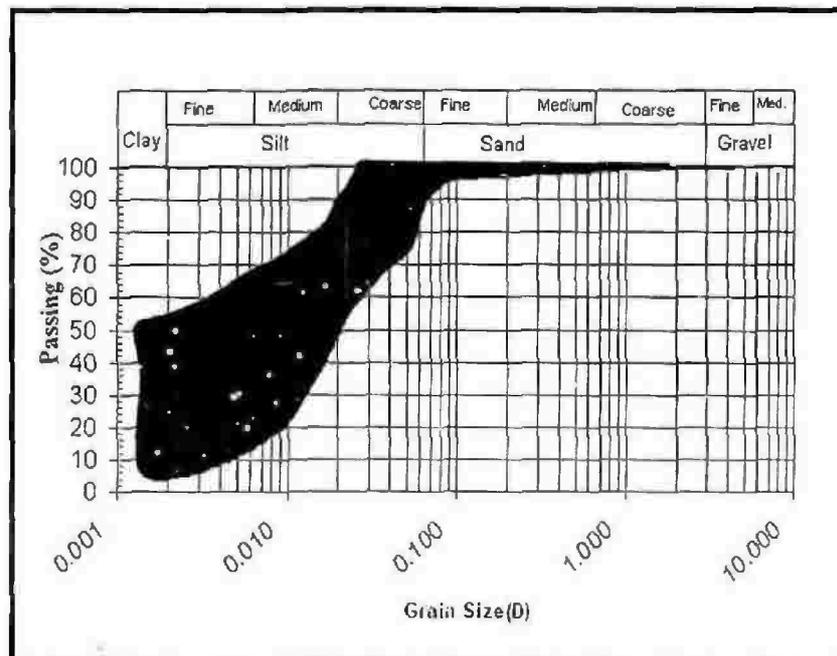


Fig. 4.3: Band of grain size distribution curves of the studied Gehannam samples.

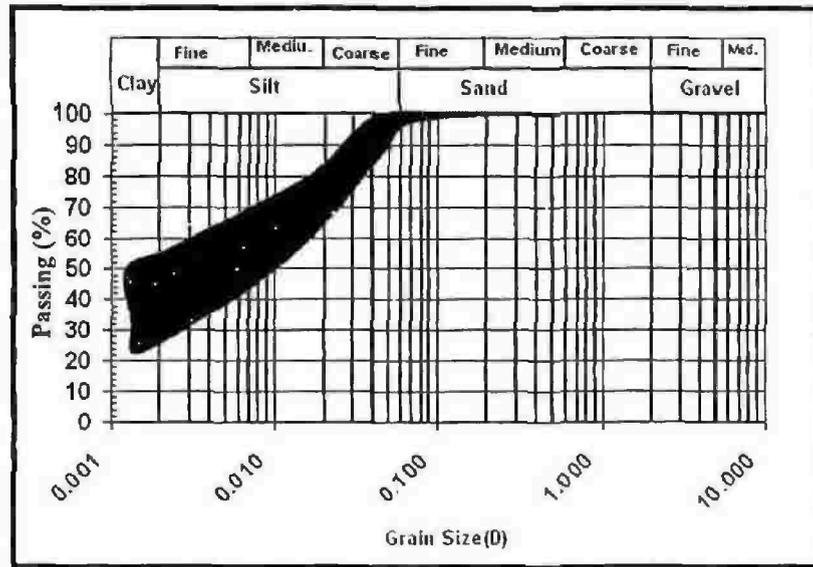


Fig. 4.4: Band of grain size distribution curves of the studied Quaternary samples.

Table 4.3: Grain size distribution of studied Gehannam Formation and Quaternary deposits.

	Sample No.	Gravel %	Sand %	Silt %	Clay %
Gehannam Formation	A ₁	0.00 %	3.00 %	89.00%	8.00 %
	A ₂₋₁	0.00 %	4.90 %	% 65.10	30.00 %
	A ₂₋₂	0.00 %	7.94 %	50.10 %	42.00 %
	A ₃₋₂	0.00 %	2.00 %	46.00 %	52.00 %
	B ₂	0.00 %	0.50 %	81.50 %	18.00 %
	B ₃	0.00 %	2.00 %	94.00 %	4.00 %
	C ₂₋₁	0.00 %	2.00 %	62.00 %	36.00 %
	C ₂₋₃	0.00 %	0.70 %	55.30 %	44.00 %
	C ₂₋₄	0.00 %	1.00 %	75.00 %	24.00 %
Quaternary deposits	B ₅	0.00 %	0.00 %	74.00 %	26.00 %
	B ₆	0.00 %	0.00 %	60.00 %	40.00 %
	C ₃	0.00 %	1.50 %	44.50 %	54.00 %
	C ₄	0.00 %	0.50 %	59.50 %	40.00 %

It shown from the results obtained, that almost all the material passes the 2 mm sieve. The average percentage of the material passing 63 μm sieve is 96.96 % and 99.54 % for Gehannam and Quaternary deposits samples respectively. The unconformity surface between the two Formations is relatively rich in sand fraction (up to about 58.57%).

According to Folk (1954) triangle chart, Gehannam Fromation samples are plotted on the field silt to mud. Quaternary samples are plotted on the field of silt to mud (Fig. 4.5). Using British standard triangle diagram (1377:1975, chapter 4 particle size), Gehannam samples under investigation range from silt to clay fraction. The Quaternary samples are located between silty clay with sand to clay (Fig. 4.6).

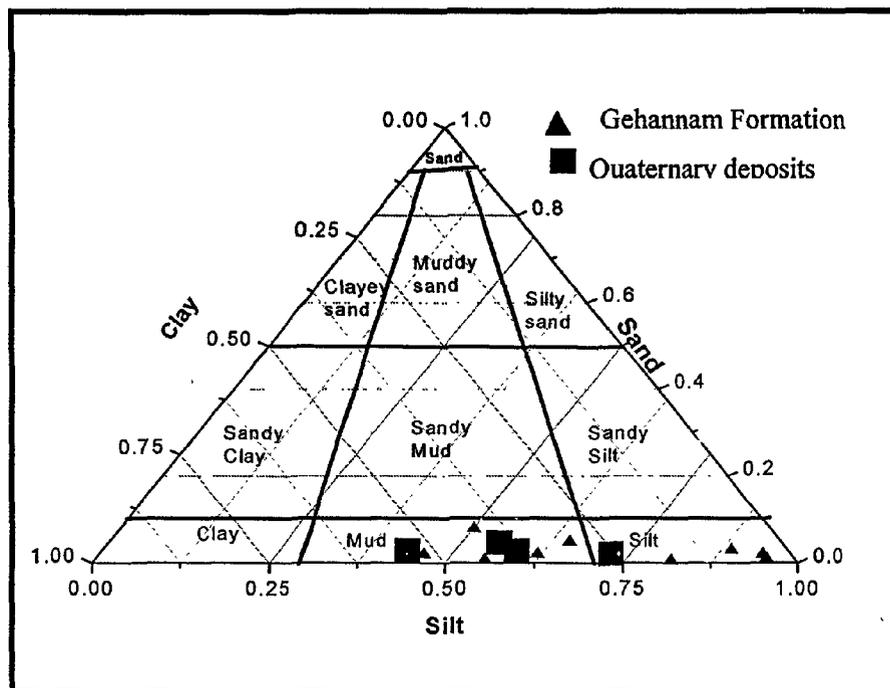


Fig. 4.5: Triangular classification diagram (after Folk, 1954) for the Gehannam Formation samples and Quaternary deposits samples.

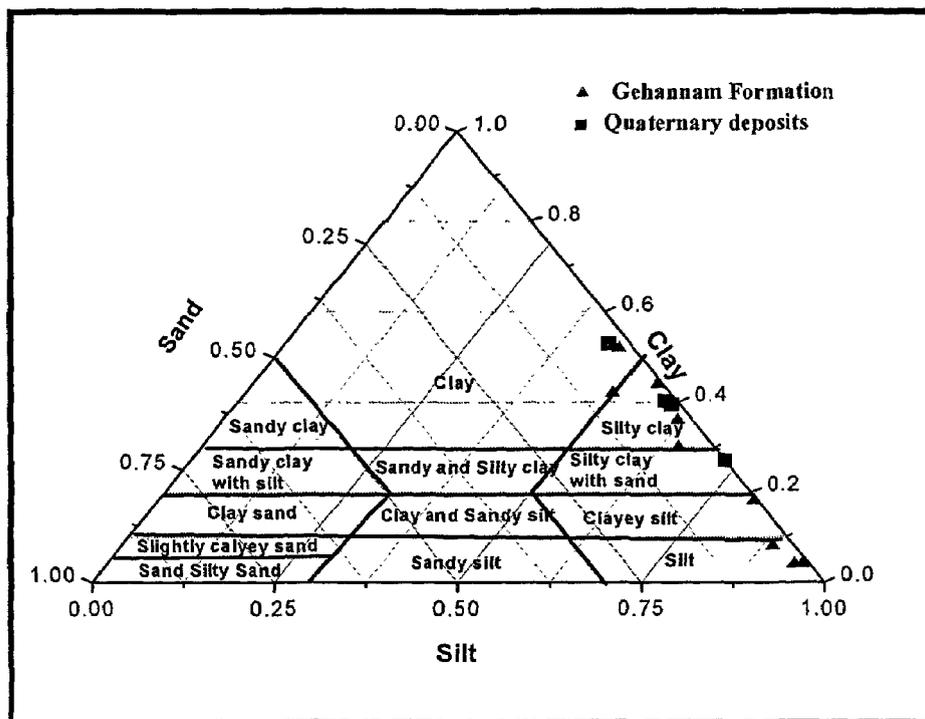


Fig. 4.6: Triangular classification diagram according to BS: 1377:1975, chapter 4 particle size for the Gehannam Formation samples and Quaternary deposits samples.

4.4.2- Natural Moisture content results

It ranges from 2% to 31% with an average of 10.428 for Gehannam Formation while it ranges between 4% and 34% with an average of 18.582% for Quaternary deposits (Table. 4.4 and Fig. 4.7).

Table. 4.4: Engineering parameters of Gehannam Formation samples and Quaternary deposits samples.

	Sample No.	W	L _L	P _L	P _I	I _C	Ac	F _S	L _S	L _I
Gehannam Formation	A ₁	32.000	79.000	17.000	62.000	0.758	7.750	103.000	15.710	0.242
	A ₂₋₁	5.000	39.300	14.100	25.200	1.361	0.840	13.000	12.140	-0.361
	A ₂₋₂	17.000	46.800	14.400	32.400	0.920	0.771	47.000	14.071	0.080
	A ₃₋₁	3.000	47.900	12.100	35.800	1.254	-	30.000	5.980	-0.254
	A ₃₋₂	2.000	46.100	13.000	33.100	1.332	0.637	40.000	12.030	-0.332
	B ₁₋₁	7.000	76.300	17.000	59.300	1.169	-	160.000	8.570	-0.169
	B ₂₋₁	20.000	86.000	16.400	69.600	0.948	-	140.000	10.000	0.052
	B ₂	10.000	77.100	19.500	57.600	1.165	3.200	150.000	10.714	-0.165
	B ₃	3.000	30.500	12.900	17.600	1.563	4.400	3.000	5.290	-0.563
	C ₁	7.000	36.000	16.600	19.400	1.495	-	5.000	5.710	-0.495
	C ₁₋₂	4.000	38.300	14.200	24.100	1.423	0.669	27.000	12.230	-0.423
	C ₂₋₂	22.000	61.500	16.100	45.400	0.870	-	40.000	-	0.130
	C ₂₋₄	7.000	69.700	22.000	47.700	1.314	1.064	80.000	18.071	-0.314
	C ₃₋₂	7.000	71.100	24.300	46.800	1.370	11.925	123.000	7.140	-0.370
Quaternary deposits	B ₅	4.000	63.000	12.900	50.100	1.178	1.927	43.000	17.357	-0.178
	B ₆	5.000	79.200	12.900	66.300	1.119	1.658	77.000	18.140	-0.119
	C ₃	34.000	108.300	16.100	92.200	0.806	1.707	60.000	17.620	0.194
	C ₄	31.300	99.700	16.100	83.600	0.818	2.090	97.000	17.860	0.182

L_L: Liquid limit
P_I: Plasticity index
Ac: Activity
L_S: Linear shrinkage

P_L: Plastic limit
I_C: Soil Consistency
F_S: Free Swell
L_I: Liquidity index

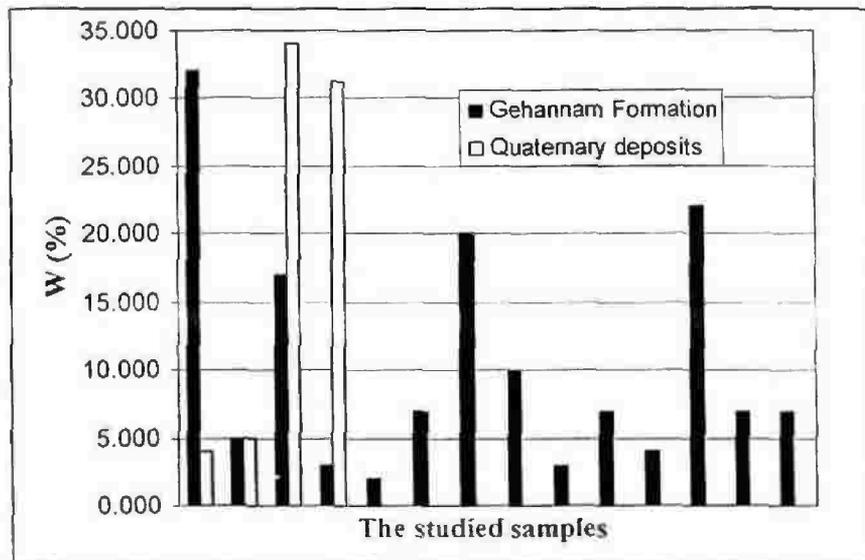


Fig. 4.7: Natural Moisture content distribution (W) of studied samples from Gehannam Formation and Quaternary deposits samples.

4.4.3- Results of Atterberg limit and soil consistency.

The results of Atterberg limits of both Gehannam Formation and Quaternary deposits were summarized in Table 4.4 and Figs (4.8 and 4.9).

4.4.3.1- Liquid limit (L_L):

The liquid limit for Gehannam shale samples range between 30.5 % and 86 % with an average of 57.542 % while it ranges between 63 % and 108.3 % with an average of 87.55 % for Quaternary deposits. The difference between the two soils has been attributed to higher percentage of I/smectite mixed layer and illite in the Quaternary deposits more than Gehannam Formation samples or to the high content of kaolinite in Gehannam Formation samples more than Quaternary samples. Another factor is the gypsum and lime content, where it is more distributed in Gehannam Formation samples more than in the Quaternary samples.

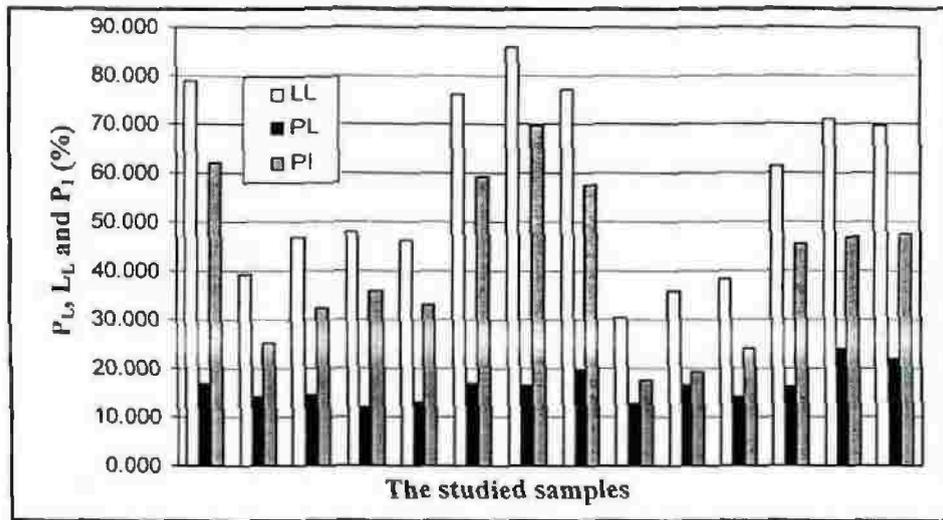


Fig. 4.8: Liquid limit (LL), plastic limit (PL) and plasticity index (PI) for the studied samples from Gehannam Formation.

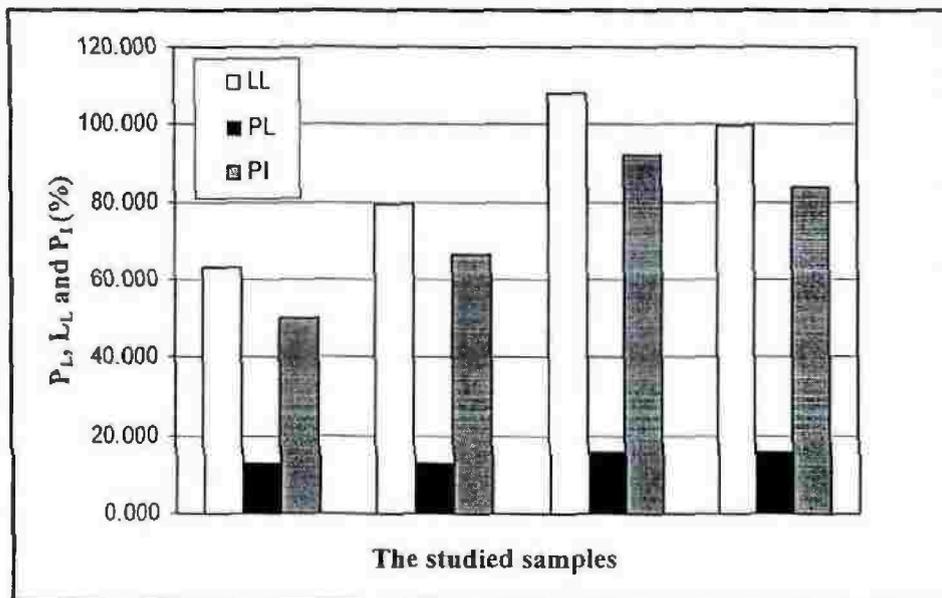


Fig. 4.9: Liquid limit (LL), plastic limit (PL) and plasticity index (PI) for the studied samples from Quaternary deposits.

4.4.3.2- Plastic limit (P_L):

The Plastic limit for Gehannam shale samples ranges from 12.1 % to 24.3 % with an average of 16.480 % while it ranges from 12.9 % to 16.1 % with an average of 14.576 % for Quaternary deposits.

4.4.3.3- Plasticity index (P_I):

It can provide useful information regarding soil strength, behavior, stability, type and state of consolidation, or as classification of an organic or inorganic clay. The small range between plastic and liquid limits, commonly presented by such materials, determines their ability to change rapidly from semi-solid to liquid state, resulting in the significant decrease of cohesion, angle of internal friction and bearing capacity when moisture contents increase (Lambe and Whitman, 1979).

In this study, plasticity index values range from 17.6% to 69.6% with an average of 41.128% for Gehannam Formation while it ranges from 50.1% to 92.2% with an average of 73.075% for Quaternary deposits samples. The great values of plasticity index showing that great change in soil moisture content required converting the soil from a semi-solid to liquid state. The relation of the plasticity index % to the degree of soil expansion (Table. 4.5) was discussed by Williams and Donaldson, 1980. Accordingly the studied samples within Gehannmam Fromation range from moderate expansive to very high expansive soil while all the suited samples within Quaternary deposits represent a very high expansive soil.

Table. 4.5: Degree of expansiveness based on plasticity index % (Williams and Donaldson, 1980).

PI %	Degree of expansion
>35	Very high
24 - 32	High
12 - 24	Medium
<12	Low

According to plasticity chart (Fig. 4.10), Gehannam Formation samples are located between low plasticity and very high plasticity while Quaternary deposits samples range from high plasticity to extremely high plasticity.

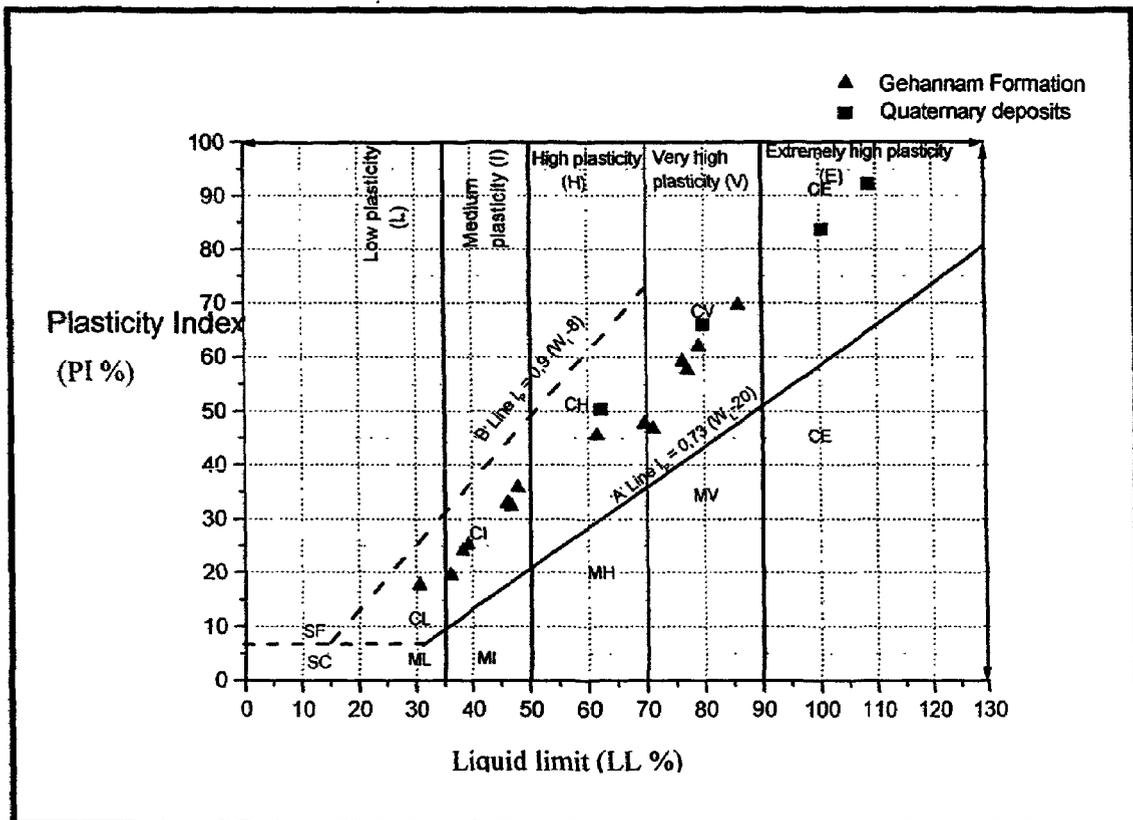


Fig. 4.10: Plasticity chart of Gehannam Formation and Quaternary deposits.

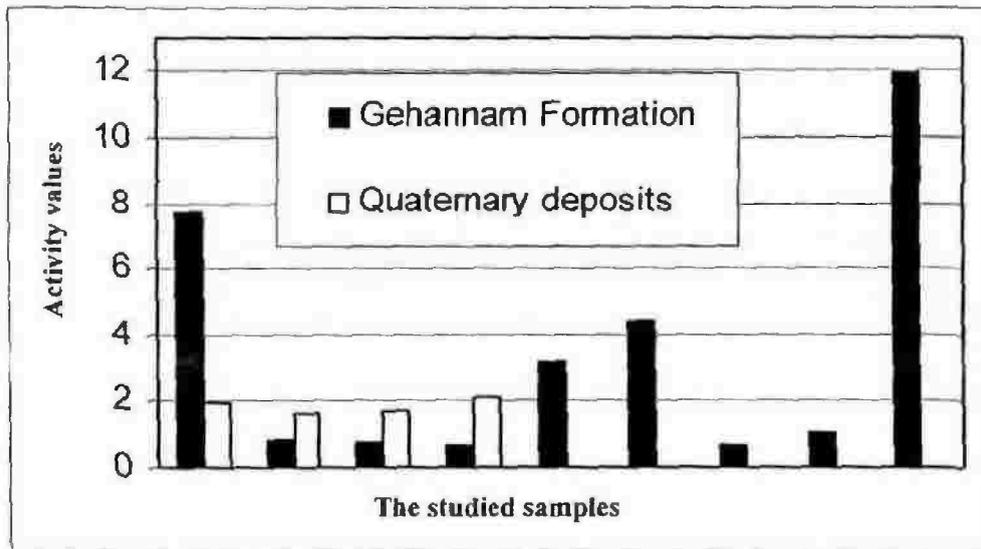


Fig. 4.12: Activity (A) distribution of studied samples from Gehannam Formation and Quaternary deposits.

4.4.3.6- Soil consistency (I_C):

The physical state of a fine-grained soil at particular water content is known as soil consistency and is calculated as:

$(L_L - W) / P_L$ where L_L : liquid limit, W : natural moisture content and P_L : plasticity index (Table. 4.2).

In this study soil consistency ranges from 0.77 to 1.56 for Gehannam Formation samples with an average of 1.21 while it ranges from 0.81 to 1.18 with an average of 0.98 for Quaternary deposits samples (Fig. 4.13). It is indicated that Quaternary and Gehannam samples range from solid to semi-solid state as indicated in Fig. 4.1. Values of relative consistency and liquidity indices throughout the moisture content are summarized in Table. 4.6 (BS 1377, chapter moisture content and index test). As shown in the table, all the studied samples of both Gehannam Formation and Quaternary deposits have natural moisture content below P_L and between P_L and L_L .

Table 4.6: Relative consistency and L_1 (BS 1377).

Moisture content Range(w)	Relative consistency (I_C)	liquidity Index (I_L)
Below P_L	>1	Negative
At P_L	1	0
Between P_L and L_L	1 to 0	0 to 1
At L_L	0	1
Above L_L	Negative	>1

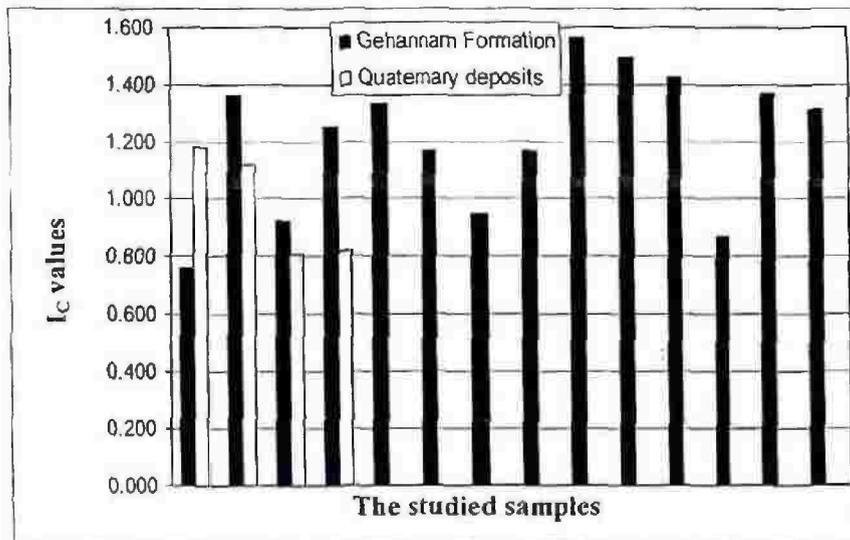


Fig 4.13: Soil Consistency (I_C) distribution of studied samples from Gehannam Formation and Quaternary deposits.

4.4.3.7- Linear shrinkage (LS) results:

The results range from 5.290 % to 18.071 % for Gehannam Formation with an average of 10.588% but for Quaternary deposits samples, it ranges from 17.36 % to 18.140 % with an average of 17.745 % (Fig. 4.14). Linear shrinkage as a guide to the degree of expansion (Table. 4.7) was introduced by Altmeyer (1955), accordingly the studied samples within Gehannam Formation soil range from critical to marginal degree of expansion while all the studied Quaternary deposits samples represent a critical degree of expansion.

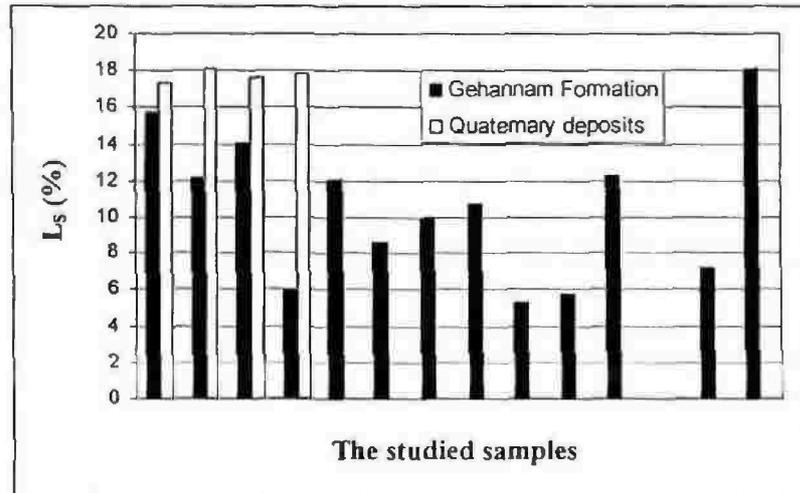


Fig. 4.14: Linear shrinkage (L_s) distribution for the studied sample from Gehannam Formation and Quaternary deposits.

Table. 4.7: Linear shrinkage % as a guide to degree of expansion (Altmeyer, 1955).

Linear shrinkage %	Degree of expansion
> 8 %	Critical
5 -8 %	Marginal
< 5 %	Non critical

It was shown that, Quaternary deposits have higher linear shrinkage more than Gehannam Formation samples due to the mineralogy change, which confirms the effect of mineralogical compositions on engineering parameters specially clay mineral contents variation between the two types of the Formations.

4.4.4- Free swell results

Free swell is defined as an increase in volume of soil from a loosely dry powder when is poured into water, expressed as a percentage of the original volume. The free swell is determined by comparing the initial volume with the final volume. Values of free swelling ranges from

3 % to 160 % for Gehannam Formation (Table 4.4 and Fig 4.15) with an average of 68.642 % but it ranges between 43 % and 97 % with an average of 69.25 % for Quaternary deposits. The lowest values of free swell in Gehannam Formation are due to the occurrences of Gypsum mineral and lime materials (swelling 3 %). A soils having free swell values greater than 100 % are considered potential problems (have strong tendency to swell or shrink considerably under light loading up on changes of moisture content), whereas soils with free swell values below 50 % are not likely to show expansive properties (BS 1377: 1975 and Gibbs and Holtz, 1956). However, Dawson (1953) reported free swell values of about 50 % of several Texas clays showed extensive expansion. Hence such changes in moisture content may lead to heave or differential settlement of foundation and corresponding structural damage of building.

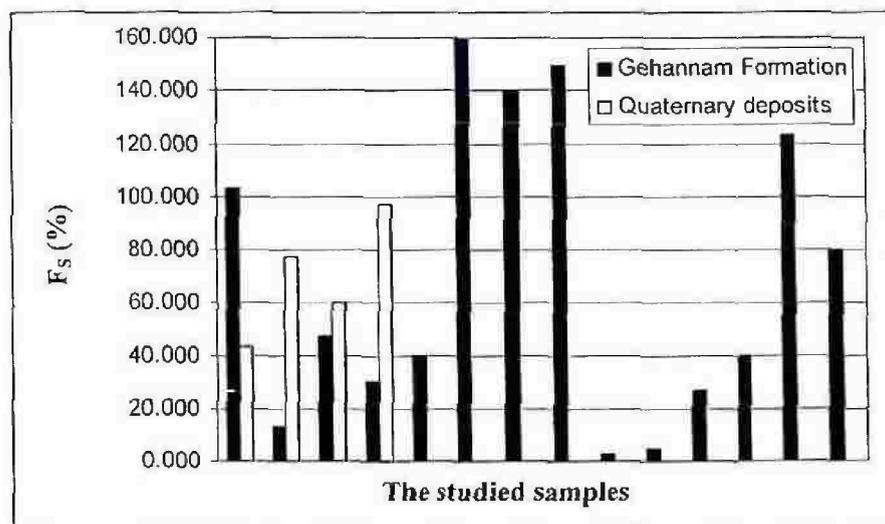


Fig. 4.15: Free swell (FS) distribution for the studied samples from Gehannam Formation and Quaternary deposits.

4.5 - Mutual relations between plasticity index and free swelling

Gehannam Formation can be classified into three groups (A, B and C) and Quaternary deposits as group D according to swelling percentages and plasticity index values (Table. 4.8 and Fig. 4.16).

Table 4.8: Classification of Gehannam Formation samples as groups (A, B and C groups) and Quaternary deposits samples as group (D) according to plasticity index values and swelling (%).

Groups	Sample No	Plasticity index	Swelling (%)
Group A	B ₃	17.600	3.000
	C ₁	19.400	5.000
	C ₁₋₂	24.100	27.000
	A ₁₋₂	25.200	13.000
	A ₂₋₂	32.400	47.000
	A ₂₋₃	33.100	40.000
	A ₁₋₃	35.800	30.000
	C ₂₋₂	45.400	40.000
Group B	C ₃₋₂	46.800	123.000
	C ₂₋₄	47.700	80.000
	A ₁	62.000	103.000
Group C	B ₂₋₁	69.600	140.00
	B ₂	57.600	150.000
	B ₁₋₁	59.300	160.00
Group D	B ₅	50.100	43.000
	C ₄	83.600	97.000
	B ₆	66.300	77.000
	C ₃	92.200	60.000

Mostly of samples are classified into four groups as follows:

- 1) Low swelling group (Group A), the swelling values range from 3 % to 47 % and the plasticity index values range from 17.6 to 45.4.
- 2) Moderate swelling group (Group B), in which the swelling % ranges from 80 % to 123 % plasticity index between 46.8 and 62.
- 3) High swelling group (Group C), where the swelling % ranges from 140 % to 160 % and plasticity from 57.6 to 69.6.

4) Moderate swelling group (Group D), in which the swelling % ranges from 43 % to 97 % and plasticity index from 50.1 to 92.2.

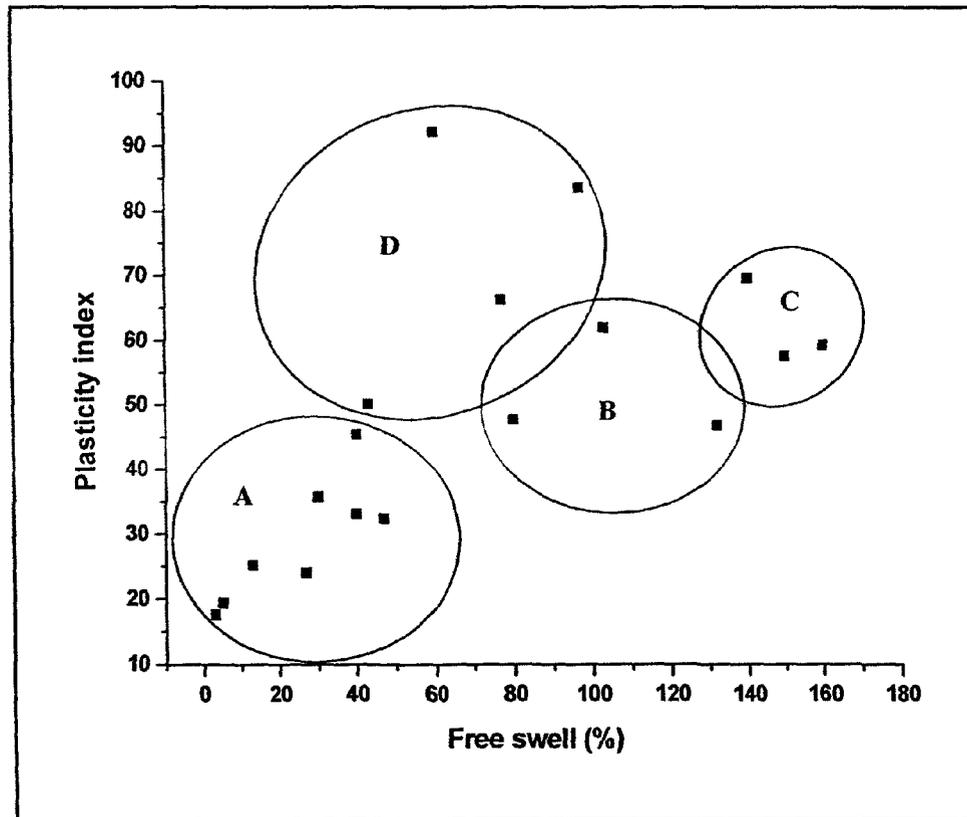


Fig. 4.16: showing the illustration of the four groups A, B, C and D.