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GEOTECHNICAL FEATURES AND PROBABILISTIC CORRELATIONS IN THI QAR GOVERNORATE, IRAQ

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ABSTRACT: Thi Qar is the civilized capital of Iraq. In recent times, the governorate has witnessed a noticeable increase in tourists and arrivals due to the ancient monument, thus increasing the construction of hotels, commercial and investment markets, and construction flourished in them. The foundations of structures are built on the soil, so the soil is one of the most critical materials used in construction, and the geotechnical engineer has to study its properties. In light of the high cost of soil investigations and compressive properties tests, in particular, this paper has been prepared to explore the geotechnical properties of Thi Qar. The data of 85 reports for several projects distributed over the governorates to examine soil investigations were collected, obtained, and statistically analyzed using excel for this purpose. The study area was divided into four regions to represent the data more accurately. First, the geotechnical properties of all regions were studied, including soil properties, standard penetration test results (SPT-N), Atterberg boundaries and sieve analysis results, standardization results, and other physical aspects. In addition, the chemical analysis of the soil of Thi Qar was studied. Then the average geotechnical design characteristics with depth were calculated, and many correlations were obtained from the field and laboratory characteristics of the soil. Then the probabilistic and cumulative analysis was performed, and graphs representing the measured data were drawn using excel and mat lab.

1. INTRODUCTION

Thi Qar is located in the southeast of Mesopotamia, 360 km from the capital, Baghdad (figure1). The province's importance stems from the distinctive geographical location. One of the most critical problems facing a geotechnical engineer is soil layers' spatial variation and characteristics [1]. Therefore, site investigations cannot be considered a valuable tool for a geotechnical engineer unless thoroughly studied. For the initial design of the projects and due to the lack of site data, data was collected for the projects constructed near the reviewed sites. Correlations are a key parameter used in the reliability analysis. As it is known, there is a relationship between cohesion and the angle of soil friction, and this correlation directly affects the reliability of geotechnical structures. The correlation between the cohesion and the friction angle of the soil must be determined. The data are obtained from laboratory and field tests of the site; these tests are usually insufficient to provide important information, so a probability distribution is used. Determining the value of the geotechnical param of a site is essential in the geotechnical analysis and design of a particular site [2][3]. The calculation assumes that the soil is statistically homogeneous with normally distributed shear strength and has an expected strength linearly depends on the adequate normal pressure [4]. Probabilistic modeling provides more reliable geology in engineering systems [5]. Caution considers the uncertainty in the computation represented by the variance inherent in the calculation, conversion uncertainty, measurement error, and statistical erro r[6]. Determining the distinctive value of any soil characteristic plays an essential role in geotechnical design [7].

In some areas of the soil layer, the average spatial characteristics of the soil represent the relevant soil param in geotechnical judgment. It is estimated that the spatial mean of soil properties includes statistical uncertainty, inherent spatial uncertainty, and regular uncertainty. The resulting variance can be evaluated using a random field[8][9]. During geological processes, soil/rocks change spatially due to natural conditions such as erosion and weathering, resulting in unique soil properties at particular locations. The researcher referred to modeling the variance of the data using a random field[10]. Experimental and theoretical correlations between different soil properties through which the design characteristics of the site can be directly estimated[11]. In past centuries, engineering judgment based on prior experience and knowledge has dominated reliability-based geotechnical design[12].

Geotechnical engineers usually seek to describe the engineering properties of the area's soils to be analyzed and designed[13]. Param were developed to determine uncertainties with local correlations of field tests and soil and compressibility tests [14]. It is not just about shear strength param. Still, there are many probabilities based design codes developed and implemented worldwide (e.g., load factor, resistance, European Standard 7). The characteristic value of soil or what is known (nominally) soil/rock is use properties in design codes and are predetermined as mean or below average by 5% of the statistical distributions of soil properties[15][16]. Experienced engineers lie much less than the mean, perhaps less than one standard deviation[17]. Accurate knowledge of soil physical properties is essential for safe design[18]. The amount of data does not generate meaningful statistics, making choosing the correct property value a challenge in design codes because a small amount of data does not generate meaningful statistics, making choosing the correct property value difficult. This investigation includes conducting field tests such as the Standard Penetration Test (SPT) in wells, collecting disturbed and non-disturbed soil samples, and performing laboratory tests on the collected soil samples.

In addition, soil samples are tested in the laboratory to determine soil samples' physical and mechanical engineering properties at various specific depths. Matlab and excel tools were used to perform probability distributions and establish empirical relationships for soil properties using SPT results, where several param experimentally related to SPT were produced. (Saad Eddin and Abdul Rasoul, 2017) studied the geotechnical and geophysical characteristics of different soil types to build a database in different regions of Iraq (North, northeast, northwest, southeast, southwest, south, east and west) [19]. The researcher used SPT results and sediment analysis in seven selected areas of the soil of Maysan Governorate using 19 test holes extending at a depth of 20 m to study the geotechnical characteristics [20]. Geological modelling is essential to reservoir studies as the petrophysical characteristics of southern Iraq have been described [21]. In his study, the researcher (Jassim, 2020) pointed out that some southern regions of Thi Qar Governorate suffer from desertification and sand dunes [22]. (Al-Jaberi et al., 2020) Studied four areas in Thi Qar Governorate and one site in Basra to reveal the environmental characteristics in these areas [23].

The results showed that the heavy metals were distributed through the surface sediments and the predominance of sandy soils, silt, and sand. In northern Iraq, the compressive properties of Sulaimani soils were studied where beneficial bonding relationships were developed, and compression properties were expected [24]. In Hamadan, western Iran, a study was conducted on eight rocks to evaluate their physical and mechanical properties [25]. The engineering properties of the Bukit Timah granite and the remaining soil in Singapore were evaluated based on data from site survey wells and laboratory tests by [26]. In addition, test correlations have been made, and valuable statistics have been provided to simulate the projects [27]. (Greco, 2016) A theoretical approach has been made to evaluate the relationship between the shear strength coefficients (cohesion and angle friction) resulting from the direct shear test and the uncertainty. The majority of studies focused on the attributes of Basra's soil[28] [29]. The researcher (Al-abboodi, Z. Hamoodi and M. Salih, 2020) studied the geotechnical characteristics and soil behavior and determined the geotechnical information to check the soil layers in Basra and Ammarah [30][31].

Experimental and theoretical correlations between different soil properties through which the design characteristics of the site can be directly estimated despite the geographical location and the economic and cultural importance of Thi Qar Governorate, located in the southeastern part of Mesopotamia, it lacks the study of geotechnical characteristics of this type. There have been few studies available by some researchers on the geotechnical characteristics of some of the southern provinces of Mesopotamia. In southern Iraq, the geotechnical properties of the Karmat Ali clay were studied, from which many fields and laboratory correlations of soils were obtained [32]. It is essential to consider correlations when examining the reliability of an analysis that considers geotechnical, structural failures[33]. This study focused on the results of standard penetration testing. Standard penetration testing is one of the most common, cost-effective and informative field techniques and is widely used in the subsurface analysis[34]. The primary purpose of this paper is to study the geotechnical characteristics of Thi Qar soil by collecting data from several sites representing the study area and then analyzing it statistically. This study aims to obtain a comprehensive assessment of the soil on which the foundation will be built and provide the basic requirements for the design.

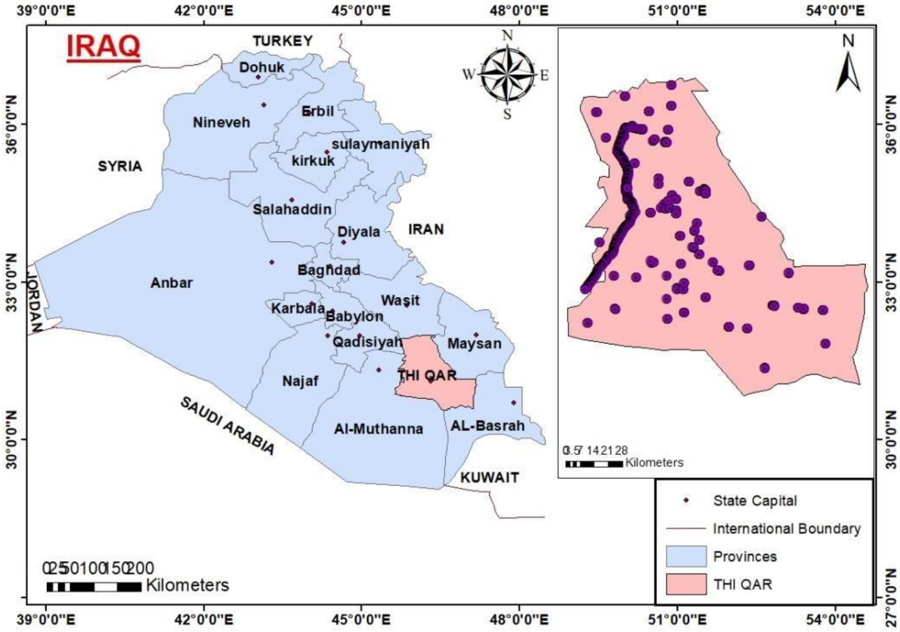


Figure 1. Location of the study area and borehole.

2. Database used

The geotechnical data obtained in this study from the laboratory soil survey reports were excavated by the laboratories of Thi Qar University and other laboratories, the engineers syndicate laboratory, and the laboratories of Al-Mustansiriya University. Exploration of the subsoil conditions of the proposed sites is essential to support the geotechnical design and construction program availability following the needs of the structural engineer. Eighty-five soil test reports were collected distributed over large governorate areas, as shown in fig. 2. Each piece contains 3 to 4 test wells except for one piece due to the area's importance as an oil investment area containing 200 test wells. Some of the wells were geolocated using the Global Positioning System (GPS). The study area was divided into four sections; the first and second sections are the center, where the first zone includes Al-Shatrah, Al-Gharraf, and Al- Dawayah, where the soil of each zone may differ from the other according to the site. The second zone comprises Nasiriyah, Al -Islah, Sayed Kheel, Al -Bathaa, the third zone, Suq Al-Shuyukh, Al-Chibayish, and the fourth zone, the northern regions. It includes Al-Rifai, Qalat Sukar, Al Neser, and Al-Fajr.

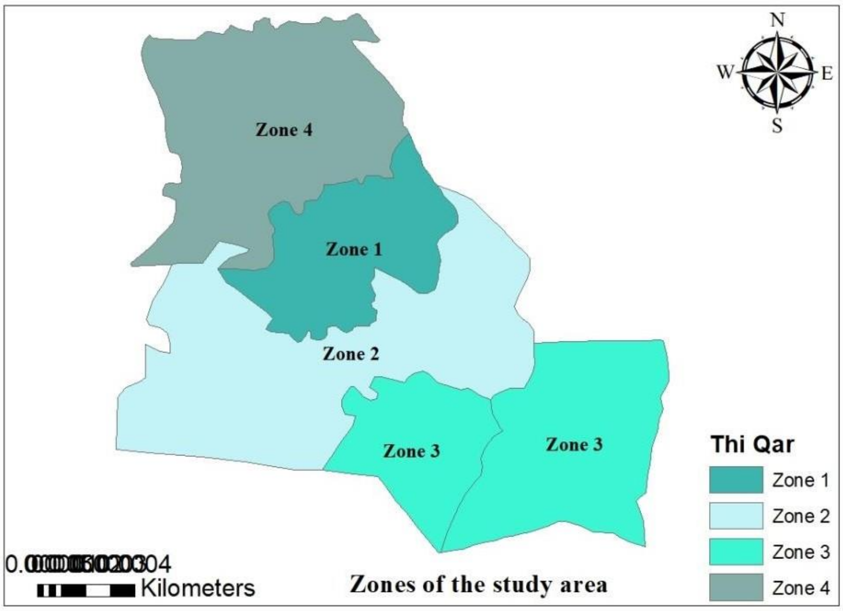


Fig 2. Zones of the Thi Qar.

3. Geology of soil in Thi Qar

The study relates to the Thi Qar governorate, located in southern Iraq. It is situated on the Mesopotamian plain and near the Euphrates river [35]. The floodplain of Mesopotamia contains a tetrahedral river. Reactive deposits of the Tigris and Euphrates rivers merge into the northern Basra swamp and the Shatt Al-Arab delta plain between Basra and the Araba / Persian Gulf [23]. Flood plain, the Tigris and Euphrates region is a relatively flat region with a low-level topographical relief that occupies part of the anterior pelvis Zagros folding and propulsion belt (31, 32). The rivers flowing from northwest to southeastern Turkey through this basin dry up annually (12,000 years) one million tons of sediments by reviewing the floodplain area that contains silt, mud, and sand, where silt forms about (60%) of the deposits [36][37]. Where silt and sand settle in the swamps and the mud runs below the Shatt Al-Arab. A dry continental desert characterizes the climate of the study area with hot summers and cold, rainy winters [38].

4. Geotechnical Characteristics of Soil in Thi Qar

As indicated in the previous section, the governorate was divided into four sections. Zone1 represented Al-Shatrah, Al-Gharaf, and Al-Dawayah. In contrast, Al-Nasiriyah, Al-Batha, and Al-Islah represented zone2. The southern part represented zone 3 and included Al-Chibayish and Al-Fuhud. In addition to Suq Al-Shuyukh, the northern part represented zone 4 and had Al-Rifai, Al-Fajer, Al-Neser, and Qalat Sukar. Soil samples used in the study the soil condition of the study was obtained from 250 wells to a depth of 20 m from all parts of the governorate. Field tests indicated the table of groundwater in the study area is exchanged between 2 to 13.5 m. As it was observed, the highest level of groundwater was recorded in zone 3, the southern part of the governorate, which is 2 m away from the ground level, and then zone 2, the groundwater level is within a range of (3-6) m from the surface. The ground, while zone 3, the groundwater distances approximately (6-8) m, while the northern regions move away from the groundwater from the surface to a depth of 13.5 m. The information obtained from 85 soil investigation reports distributed throughout the governorate was used.

5. Results and discussion

5.1. Subsoil Material Description

For zone 1, zone 3, and zone 4, it is found that the soil layers generally consist of four layers except for zone 2, which is made up of 5 layers, as shown in fig. 3 and as follows:

1. Black sandy clay, green-brown, inferior plastic, wet, fine consistency, with a trace of black colour (organic problems). (ML) extend from the earth's surface to a depth of 4 m in zone 1, while zone 4 extends from the surface to a depth of 8 m.
2. A thin layer is formed from 4 m to 8 m deep. The soil layer is greenish-brown, sandy loam with

low plasticity and moist, medium consistency (CL) in zone 1, while the zone 4 layer extends from 8 to 12 m deep.

3. In zone 3, the colour of the soil is dark green-brown, sandy loam with high elasticity moist, medium consistency, with light traces of black (organic Issues). (C.H.) extend to a depth of 4 m. The layer is from 4 to 10 m deep in brown clay, sandy with poor plasticity, moist, medium Texture (ML), then 10 to 14 green sandy clayey loams with low plasticity, wet, medium consistency (CL). Then from 14 to 20 m depth, the soil layer is brown clay, sandy with poor plasticity, moist, medium consistency (ML).
4. Zone 2 shows a thin layer extending from the surface of the earth to a depth of 2 m brown, slightly sandy clay of high plasticity, moist, medium consistency (M.H) then from depth 2 to depth 4 is also a dark green thin layer, high plastic sandy clay moist, medium texture, with slight traces of black (organic Problems) (C.H). Then from 4 to 20 m, the soil layer is brown clay, sandy with poor plasticity, moist, medium, consistency (ML). Finally, there is sandy green clay of low plasticity, moist and medium consistency (CL) in the center.
5.

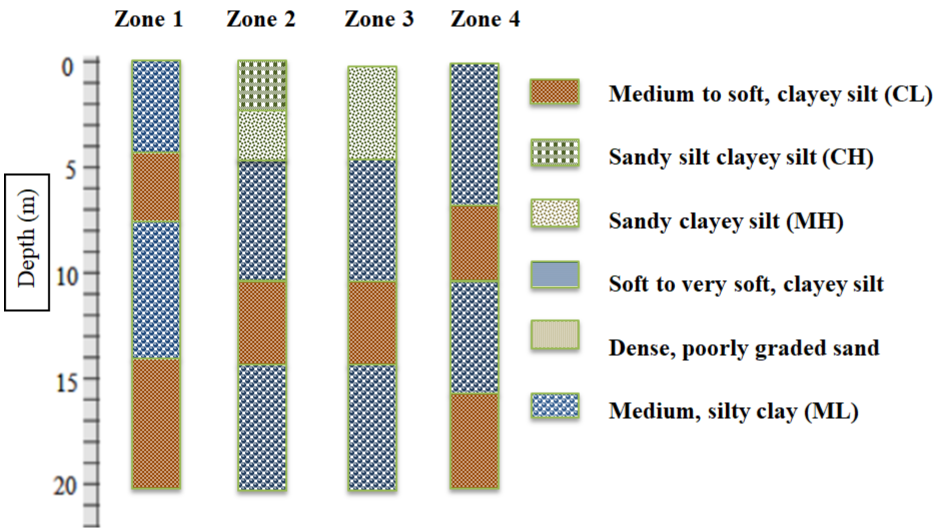


Figure 3. Typical geotechnical features of zone 1, zone 2, zone 3, and zone 4.

5.2. specific gravity, moisture content, and unit weight

Table 2 shows the range of average values for water content, specific weight, and dry density for the Thi Qar governorate. The results showed that the water content is uniformly distributed with depth, and it also showed that the specific weight increases with increasing depth.

Table. 1 Physical characteristic of Thi Qar soils

Characteristic	zone 1			zone 2			zone 3			zone 4		
	max	min	Avg	max	min	Avg	max	min	Avg	max	min	Avg
G_S	2.78	2.65	2.7	2.74	2.65	2.7	2.78	2.65	2.7	2.78	2.67	2.7
Wc %	38	11	25.6	56.5	18	30	30.8	11	24.7	36.35	18.2	27
γ_d (KN/m^2)	18.9	13.7	15.2	17.8	13.8	14.8	17.8	13.7	14.6	17.80	13.61	14.9

5.3. consolidation test results

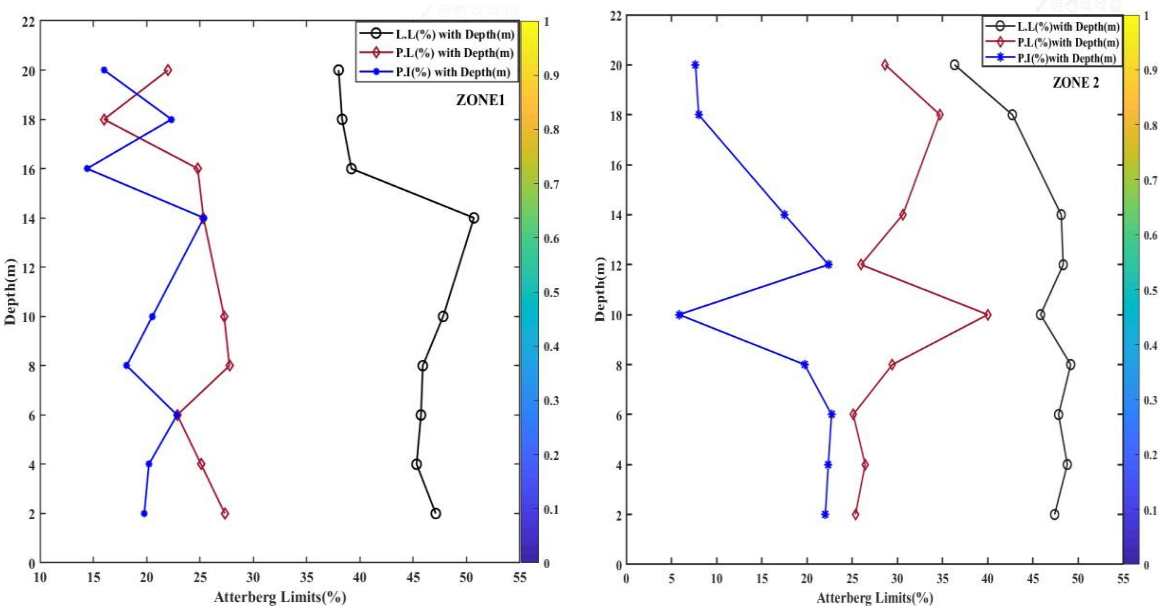
Consolidation tests were performed for non-disturbed soil samples. The mean values of the maximum and minimum values of the initial voids ratio, compression index, and recompression index, respectively, for each zone, are shown in table 2.

Table. 2 Consolidation test results for Thi Qar.

characteristic	zone 1		zone 2		zone 3		zone 4	
	max	min	max	min	max	min	max	min
initial voids ratio(e°)	0.98	0.5	0.95	0.38	0.97	0.76	0.93	0.38
compression index(Cc)	0.9	0.11	0.65	0.027	0.49	0.18	0.48	0.155
recompression index(Cr)	0.24	0.018	0.12	0.014	0.24	0.014	0.29	0.02

5.4. Atterberg limits of Thi Qar soils

Figure 3 shows the average values of the liquid limit (L.L), plastic limit (P.L), plasticity limit (P.I), and depth for four zones. Plasticity characteristics of the governorate of Thi Qar from north to south Fig.4 show the extent of the difference in the boundaries of the consistency of the governorate's soil in any of the studied parts. The results showed that the average fluid limit and the plasticity limit for zone 1 fall in the range (38-51) % and (14-25) %, respectively. Zone 2 shows consistency of values with a range of (36, 49) (6, 23) %, while zone 3 offers the range of values as (47.59) % and (18.26) %. Zone 4 is finally revealed with a (39, 49) % and (16, 26) % range. The results show that the soil is cohesive to a depth of 20 m of low plasticity (L.L <50) in zone 1 and zone 2, and zone 4. At the same time, zone 3 cohesive soils have low elasticity to a depth of 4; then cohesive soil also has a high degree of plasticity (L> 50).



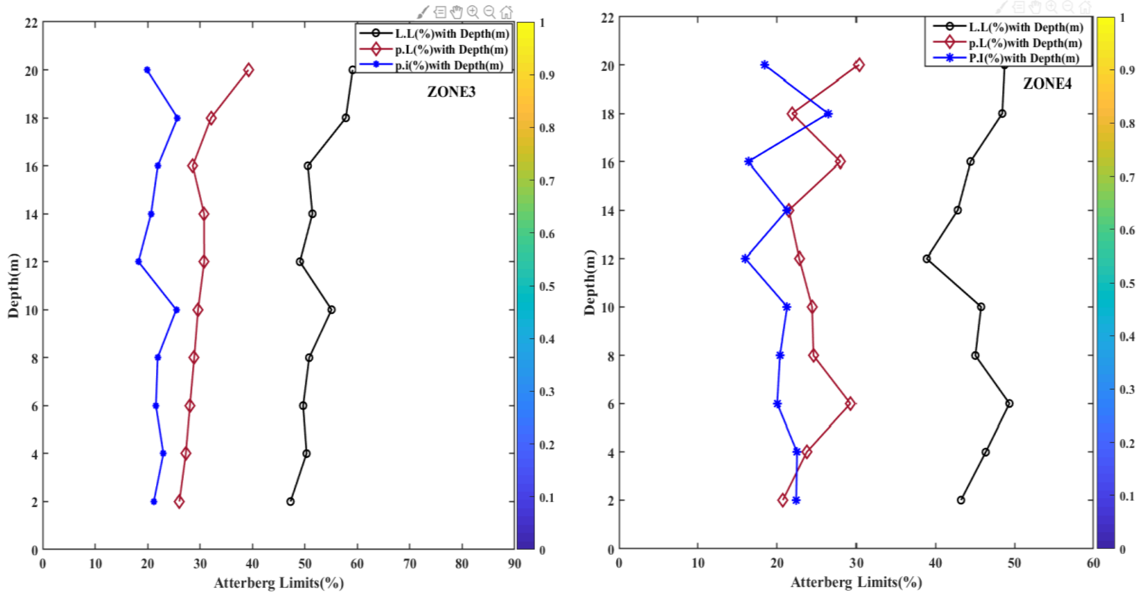


Figure 3. Average values of L.L, P.L, and P.I for soils of zone 1, zone 2, zone 3, and zone 4.

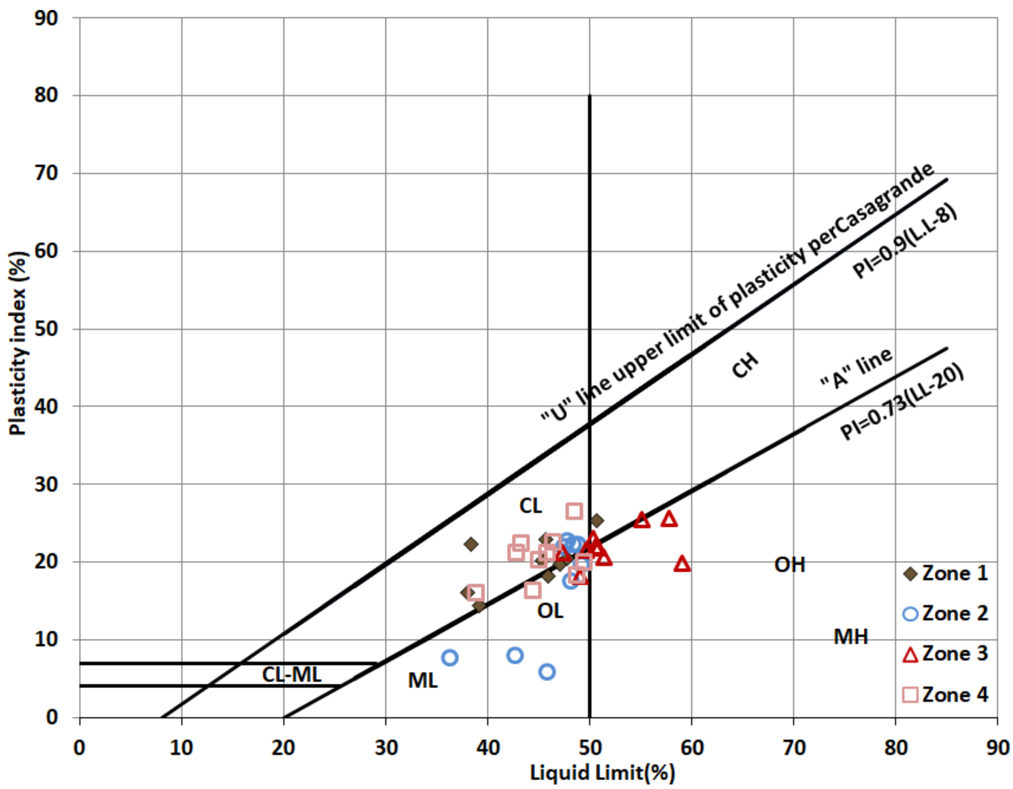


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Figure 4. plasticity chart for Thi Qar soils.

5.5. Soil Strength Parameter (cohesion, Angle friction, SPT-N)

A series of tests were relied on to evaluate the consistency of disturbed samples taken from a distance of up to 20 m from the drilled wells in Thi Qar governorate. Figure. 5 shows the mean cohesion values and their relationship to a depth from the soil surface to 20 m. The results show a weak direct relationship between cohesion and depth, as cohesion increases with depth. Each zone shares the same difference in cohesion with depth. See again figure 5. zone 2, zone 3, and zone 4 gradually increase the cohesion value with depth. Soil strength measurements at shallow depths indicate soft to medium symmetry. Figure.6(a) shows the relationship between the average angle of soil friction with a depth ranging from (0-8)° 1.5 m above the soil; then, the values tend to rise at deeper depths in some areas reaches 25°. In general, the friction angle of Thi Qar governorate soil is close to zero. While figure.6 (b) shows the interrelation between cohesion and the rise of soil friction. There is an average direct relationship where the angle of friction increases with the increase in soil cohesion. figure 7 shows average standardized penetration corrected values varying within zone 1, zone 2, zone 3, and zone 4, where penetration results were measured from a depth of 2 m to 20 m. The value of zone 3 (SPT-N) can be observed at depths of 2-4 m, not exceeding 10 borehole / 300 mm, and at depths of 4-8 m, not exceeding 20 borehole / mm. The soil at these depths can be classified into zone 3, medium to soft the sand content increases at deeper depths, reflecting the highest SPT-N value recorded at a depth of 12-20 m. See fig.7 again the average SPT-N corrected value exceeds 50 borehole / mm, soil symmetry tends to be very hard from 14-20 m depth except for zone 1 that the bulk is soft to medium soil.

5.6. Probability Distributions (PDF) and cumulative distribution (CDF)

Reliability provides a means of assessing the impact of uncertainty and characterizing conditions in which uncertainty is high or low. Still, this theory requires much data, and the latter requires sufficient time and effort. It is possible to apply the concept of reliability with the data available to us without further effort and cost through mat lab since it is possible to make functional assessments of reliability (the probability of safety is more significant than 1) is 99.5%. Figure.8 (a) shows the distribution curve for (PDF) and (b) the cumulative distribution (CDF) of the distribution of cohesion values in eight probabilistic ways for the county soils. The normal distribution curve takes the form of a bell, and the head of this bell represents the average distribution probability values. The average coherence odds range from (0 to 160) kN/m^2 with an average of 60 kN/m^2. For the data and coincides with the histogram estimated at 30 kN/m^2 as if looking at the inverse Gaussian shows the same value from here, it can be said that 95% of the distribution curve for coherence ranges between (20-60) kN/m^2. The deviation of the figure to the left indicates that a normal distribution cannot represent the data (c). The stable, gamma, Gaussian, and Weibull distributions represent the data for (c). The format of the histogram file is J, which makes it difficult for normal distributions to represent the data successfully. The inverse Gaussian distribution represents the best data distribution among the other distributions. Then follows the inverse Gaussian distribution, the Lognormal distribution with the Gamma distributions, respectively. They are the best in representing soil cohesion data for Thi Qar Governorate.

Figure.9(a) also shows the friction angle values on a proportional plot in the form of bars representing the measured data. Offers the range of measured values where each of the relative columns in the graph denotes the number of values in each basket divided by the total number. The PDF value indicates the probability of any value of the variable occurring where the value of the friction angle is limited between (0-30)° and may intersect with 30 ° with an average estimate of 20° as a standard distribution curve. At the same time, it is equal to 25° for the most appropriate distribution of values and with the least standard deviation. Figure.9 (b) shows the data's fit to the standard distribution curve (CDF). Figure.11(a) and (b) shows the ability of the normal, inverse Gaussian, and logarithmic distribution and other possibilities to represent the bulk density data. The average γd values are estimated at around 1950 kg/m3. The curve fits the data more closely to average values of 2000 kg/m3, with peak bells being 95% as reliable probability values from 1900 kg/m3 to 2100 kg/m3. The probability distribution of the data shows that the Rayleigh distribution is unable to represent the data, while the Weibull distribution curve curves slightly to the right to give the optimal distribution of the data following logistic and other possibilities. Figure.10(a) shows the inability of a normal distribution to represent the SPT-N data. Gamma, Weibull, and Stable represent the data successfully. Figure.10(b) Displays the optimal cumulative distribution curve for the data distribution where the gamma curve and the stable distribution fit the data curve . The distribution shape of the SPT-N param is classified as J and U because they fall within the region of the U and J shapes. The distribution represents the inverse of Gaussian and stable SPT-N data distribution. The curve starts from zero to exceed 60 boreholes with a mean of 25 boreholes for the curve of the distribution curve most suitable for data distribution when outliers are removed. The cumulative curve also shows the probability of the most favorable data distribution, with the Gaussian inverse curve showing a mean of 15 boreholes from here. It turns out that the probability distribution with 90% reliability is (10-23) borehole.

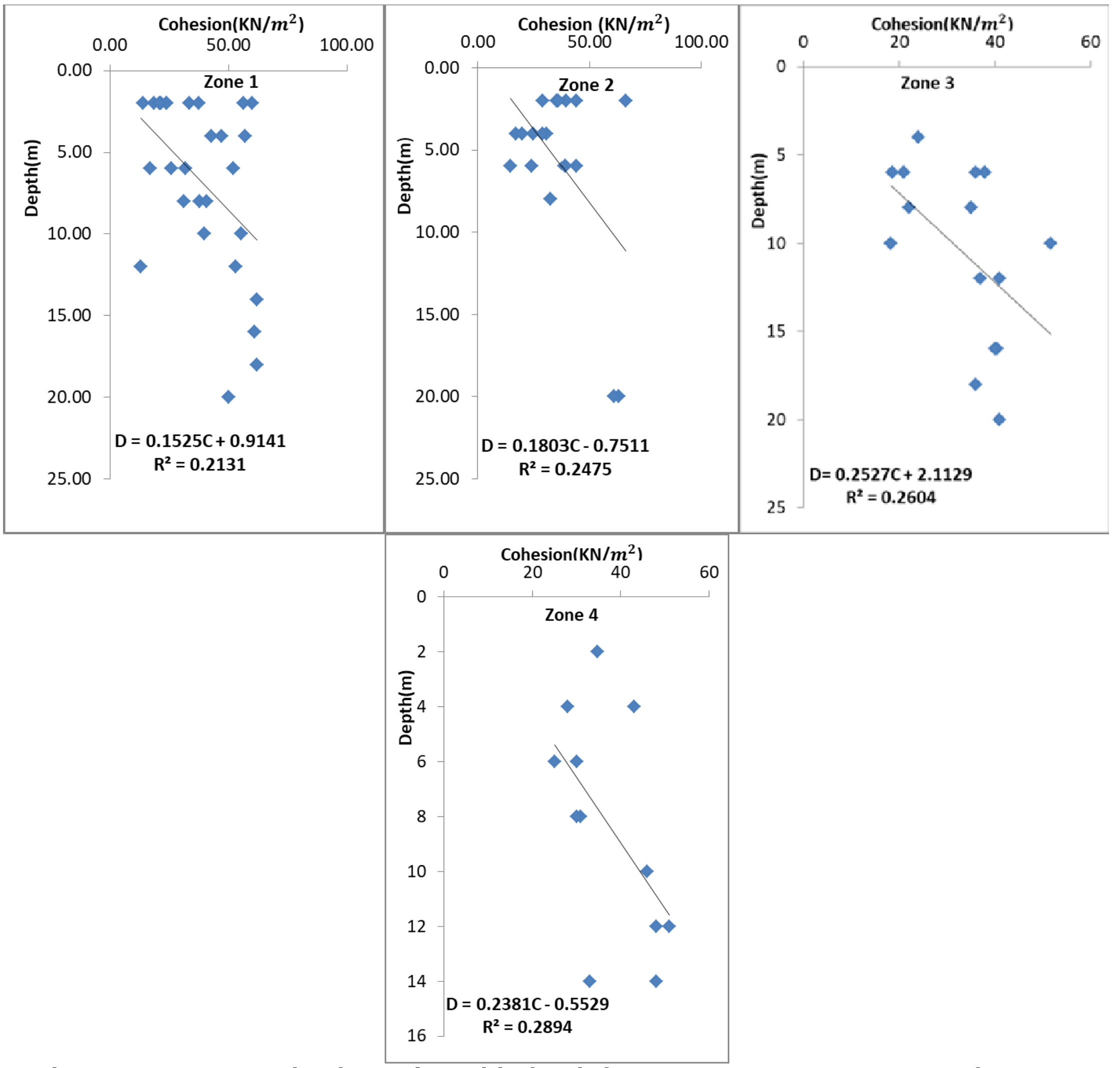
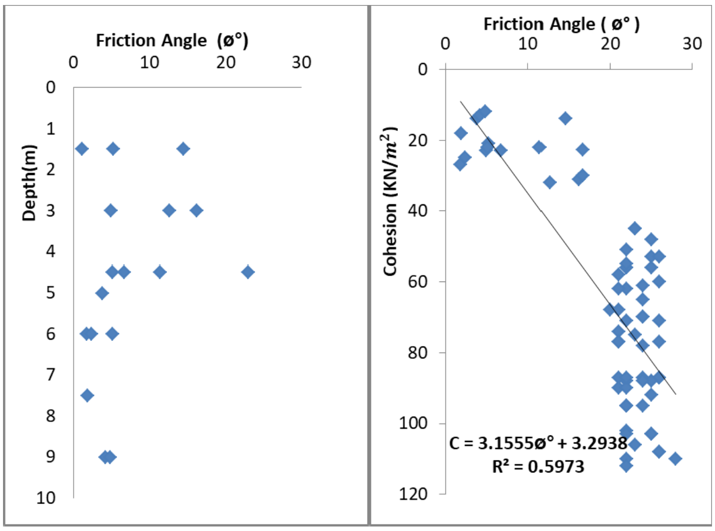


Figure 5. average cohesion value with depth for zone 1, zone 2, zone 3, and zone 4.



(a) (b)

Figure 6. (a.(a) average angle of friction with depth; (b) The relationship between average soil cohesion and average friction angle.

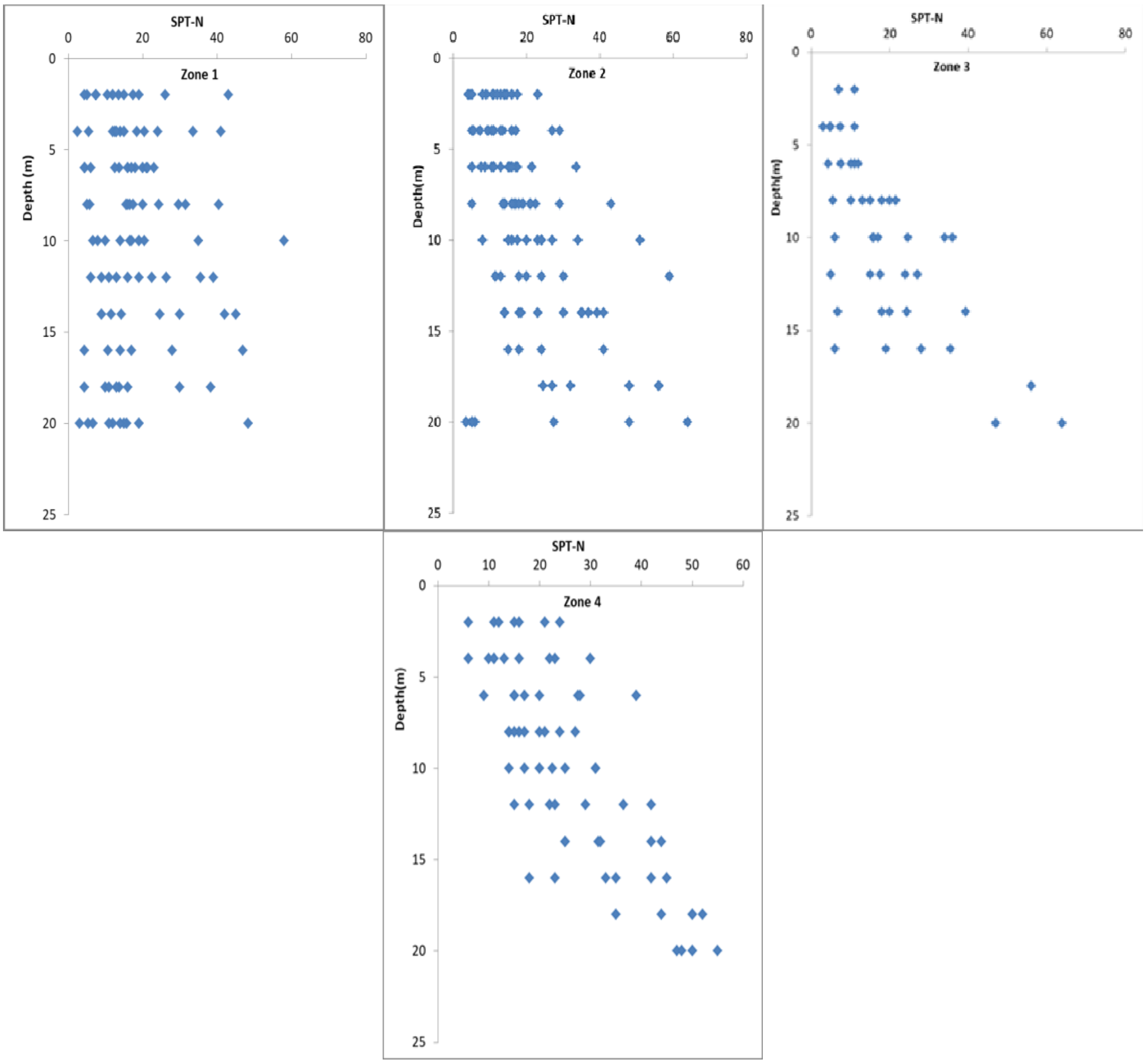
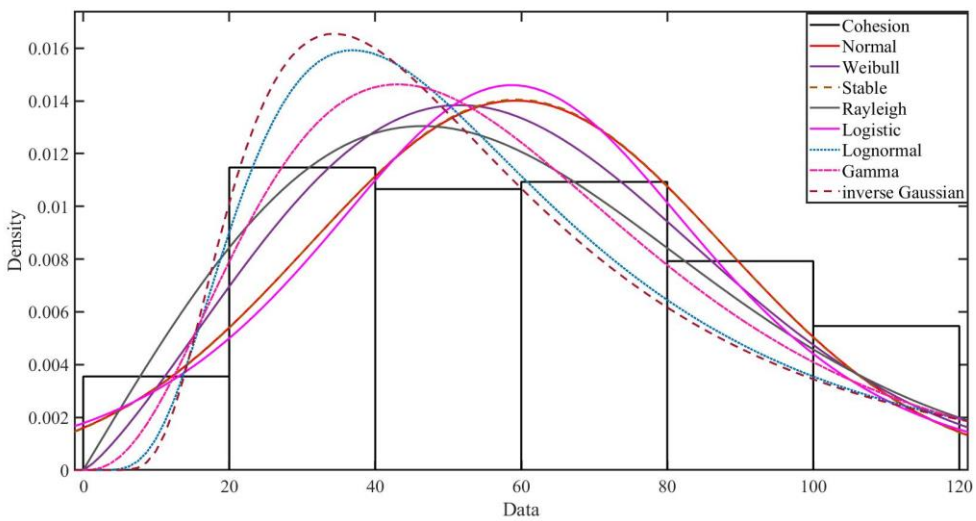


Figure 7. mean SPT-N value with depth (m) for zone 1, zone 2, zone 3, and zone 4.

(a)



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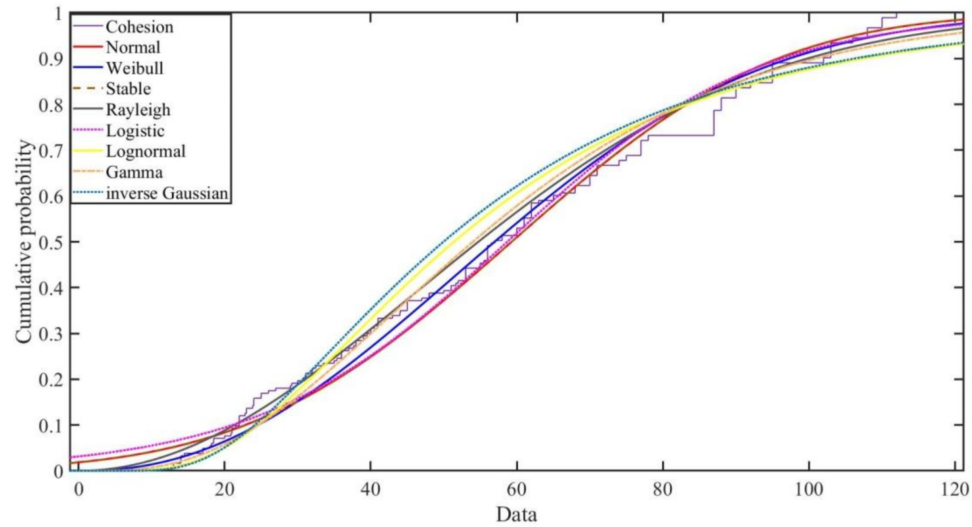
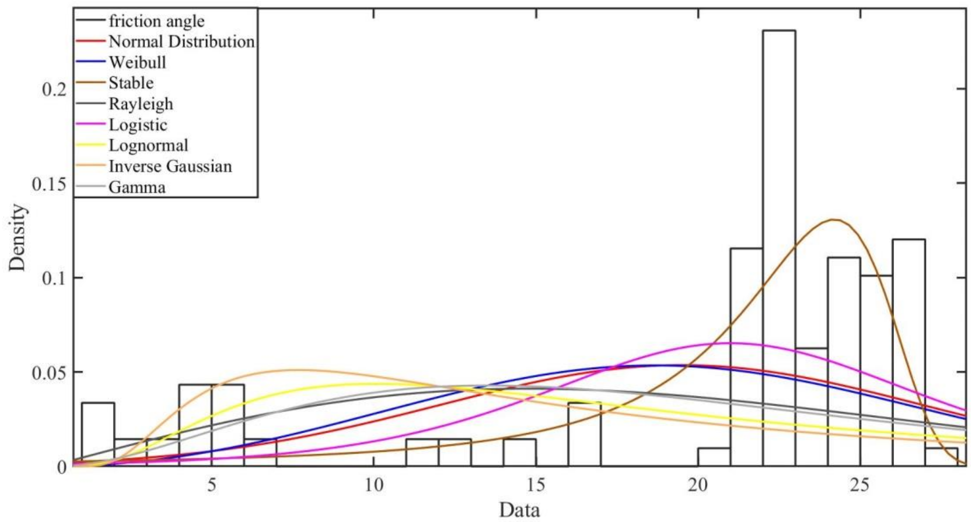


Figure 8. (a) probability distribution function (PDF) of eight proposed distributions of coherence (c); Cumulative probability (CDF) of eight proposed distributions of cohesion (c).

(a)



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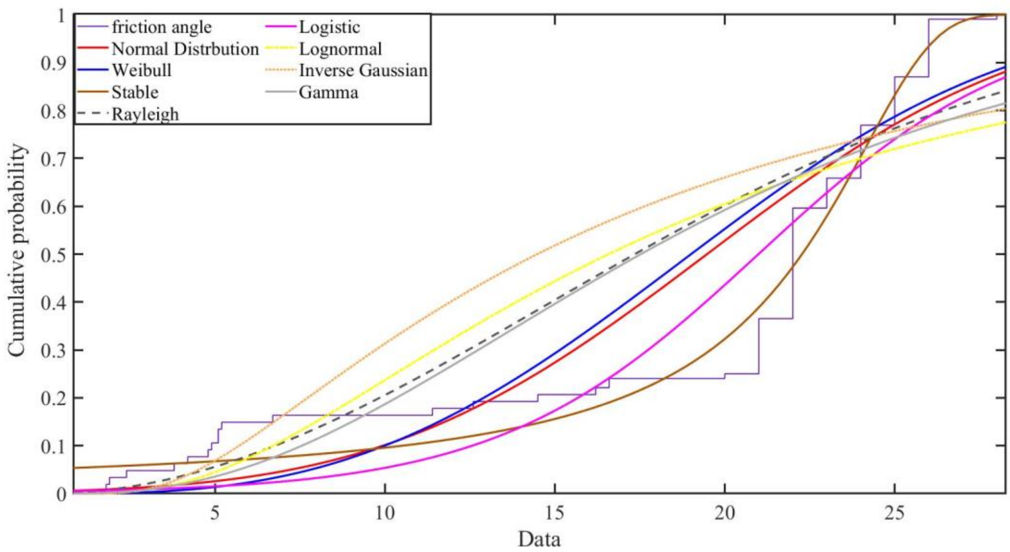
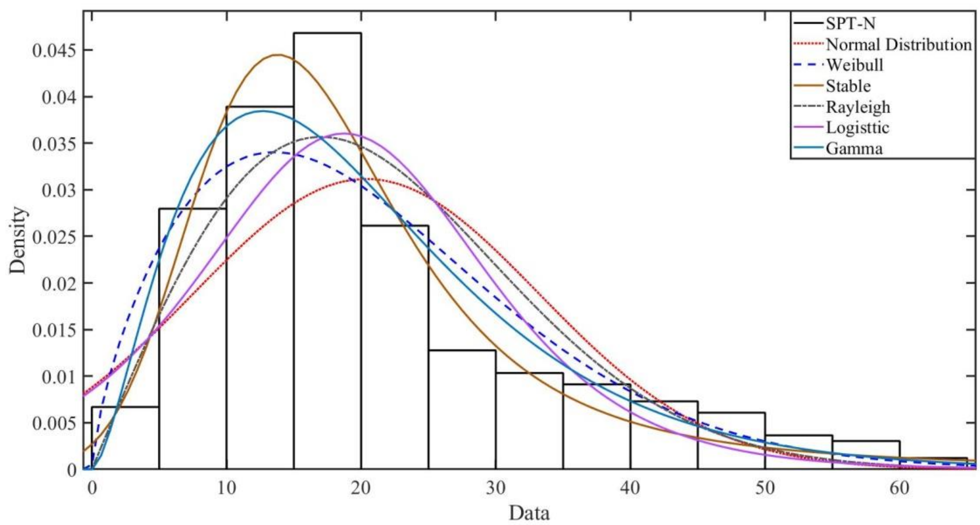


Figure 9. (a) probability distribution function (PDF) of eight proposed distributions of soil friction angle (ø°); (b) cumulative probability (CDF) of eight proposed distributions of soil friction Angle (ø°).

(a)



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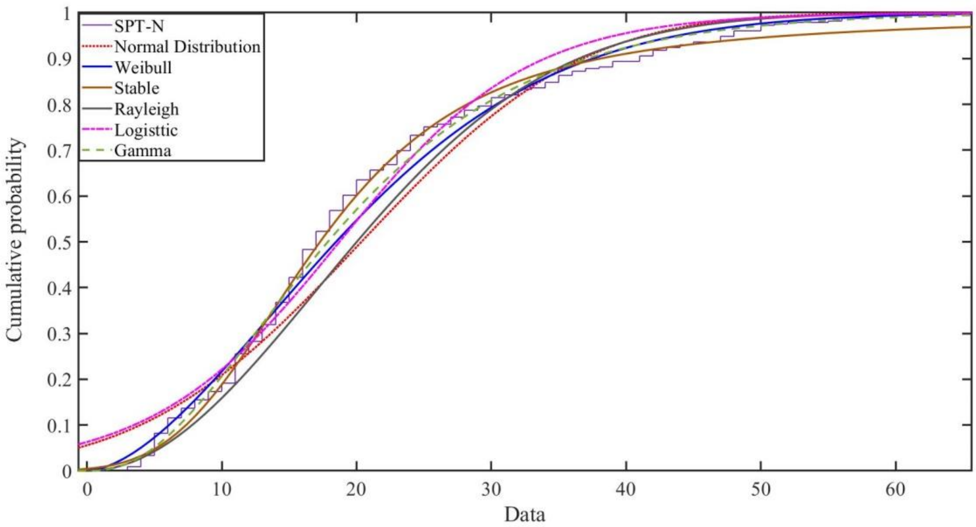
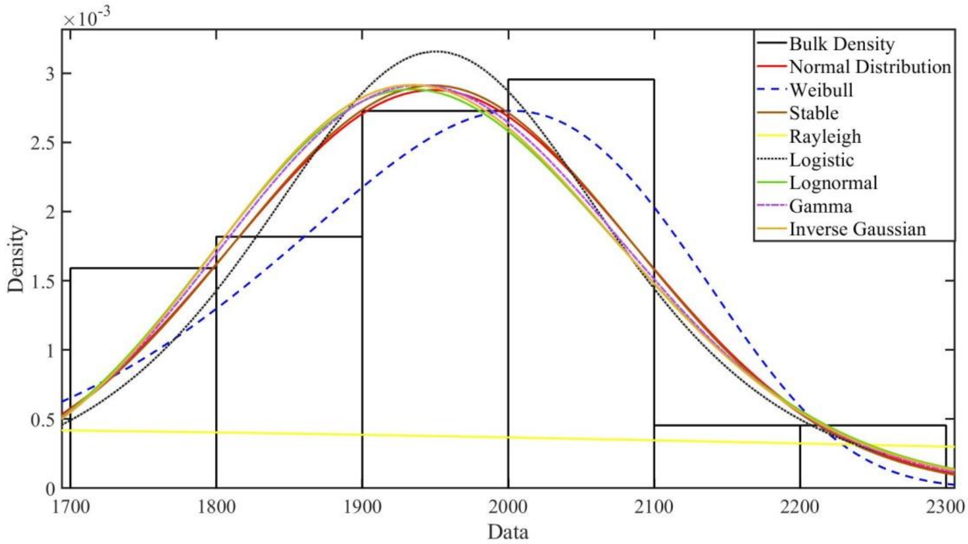


Figure 10 . (a) probability distribution function (PDF) of six proposed distributions of (SPT-N); (b) cumulative probability (CDF) of six proposed distributions of (SPT-N).

(a)



(b)

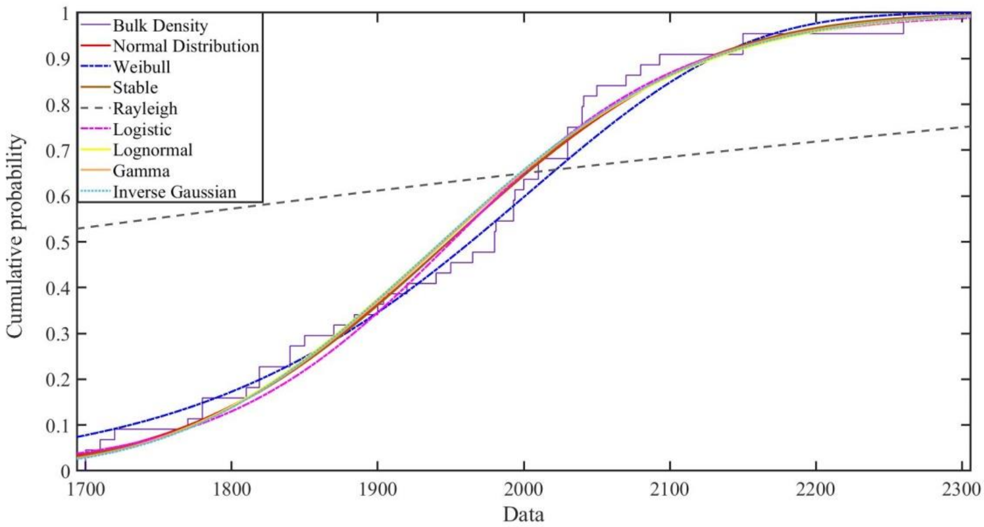


Figure 11 . (a) probability distribution function (PDF) of eight proposed distributions of bulk density; (b) cumulative probability (CDF) of eight proposed distributions of bulk density.

5.7. grain size distribution

The grain size distribution at different depths, shown in figure 12, shows the acceptable grain content ranging from 89% at a depth of 2 m and 11% and 0% for gravel and sand. Then the percentage of fine particle size increases to 96% at a depth of 10 m. Then the proportion of fine particles is reduced to 95% at a depth of 14 m until sand grains appear in the soil. Finally, the ratio of sand gradually increases to a depth of 20 m until it constitutes 17% of the soil, as shown in table No. 3. These proportions represent the majority of the regions of Thi Qar governorate. In addition, the study showed that the samples are sandy silt clay that constitutes about 95% of the samples, while 85% of the samples are clay clayey sandy samples and about 20% are sandy clay silt.

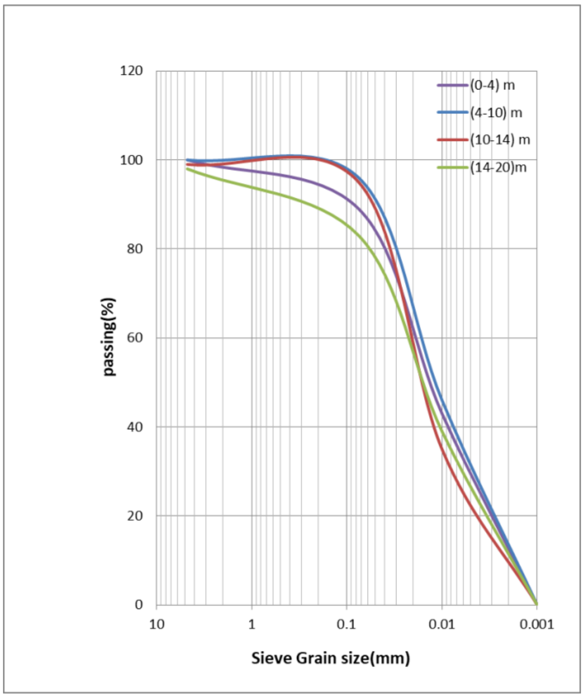


Figure 12 Average grain size distribution with depth

Table 3. The ratio of the grain size distribution of soil samples in Thi Qar.

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Depth(m)	Clay%	Silt%	Sand%	Gravel%	Fine friction %
0-4	43	46	11	0	89
4-10	46	50	4	0	96
10-14	35	60	5	0	95
14-20	39	44	17	0	83

5.8. chemical test results

Soil chemical tests include the determination of sulfate content, soil pH, gypsum content, chloride contents, and soluble salts. Table 4 shows the analysis of available data for chemical tests of soil samples, sulfate content, chloride contents, organic matter contents, calcium carbonate and gypsum content. It was found that the value of sulfates such as SO3%, organic matter of soil samples, dissolved solids content, and gypsum content were continuously varying with depth.

Table. 4 soil chemical test properties.

Chemical properties	Min	max	Avg
Gyp (%)	4.8	6	5.18
SO3 (%)	1.2	3	2.14
TSS (%)	5.9	7	6.28
ORG (%)	0.2	0.4	0.28
CL%	0.19	0.4	0.30
0.M%	1.8	3.7	2.74

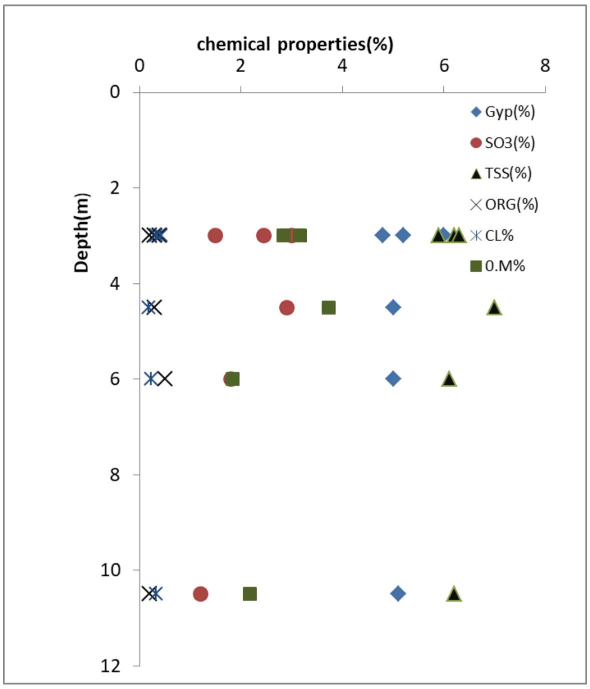


Figure 13. Avg value of chemical properties of soil with depth.

5.9. compressibility properties

Soil compaction properties are among the most important in geotechnical engineering. Compression index are used to calculate subsidence and because of the need for the safe and economical design of structures. The compression and recompression index is expensive and cumbersome, and based on previous studies; correlations were made between the Atterberg limits and the compression index. The results of the simple linear regression analysis showed the stress index versus consistency. Figure.14 shows the expected relationship between the variables with the coefficient of determination (R2). There is no correlation between compression indices and Atterberg limits, as we observe shallow (R) values and others close to zero. It is also possible to know the index of compression and recompression utilizing probability and index of normal distribution based on the site and previously measured data. The data was organized in excel and called in the mat lab program to make this distribution reliable and less costly. Figure.15 and Figure.16 show the probability curve for the normal distribution and the cumulative distribution of compressive properties. The results of the probability distribution show that the average most suitable value for Cc and Cr is 0.2, 0.03, respectively. These values indicate that the Thi-Qar soils are of low compressibility. The top of the distribution curve represents the 95% reliable values. Thus, the compressibility coefficients of the studied area range from (0.02 -0.04) for Cr, and Cc range from 0.15 to 0.25, where the figure shows the distribution of the measured values as a normal distribution on the distribution curve. Figure.15 (b) shows a stable probability distribution that best represents the data, where the distribution curve matches the data curve, and the variance is very little. Figure.6 (b) shows that the lognormal distribution is best suited to represent the Cr data than the stable and inverse Gaussian distribution.

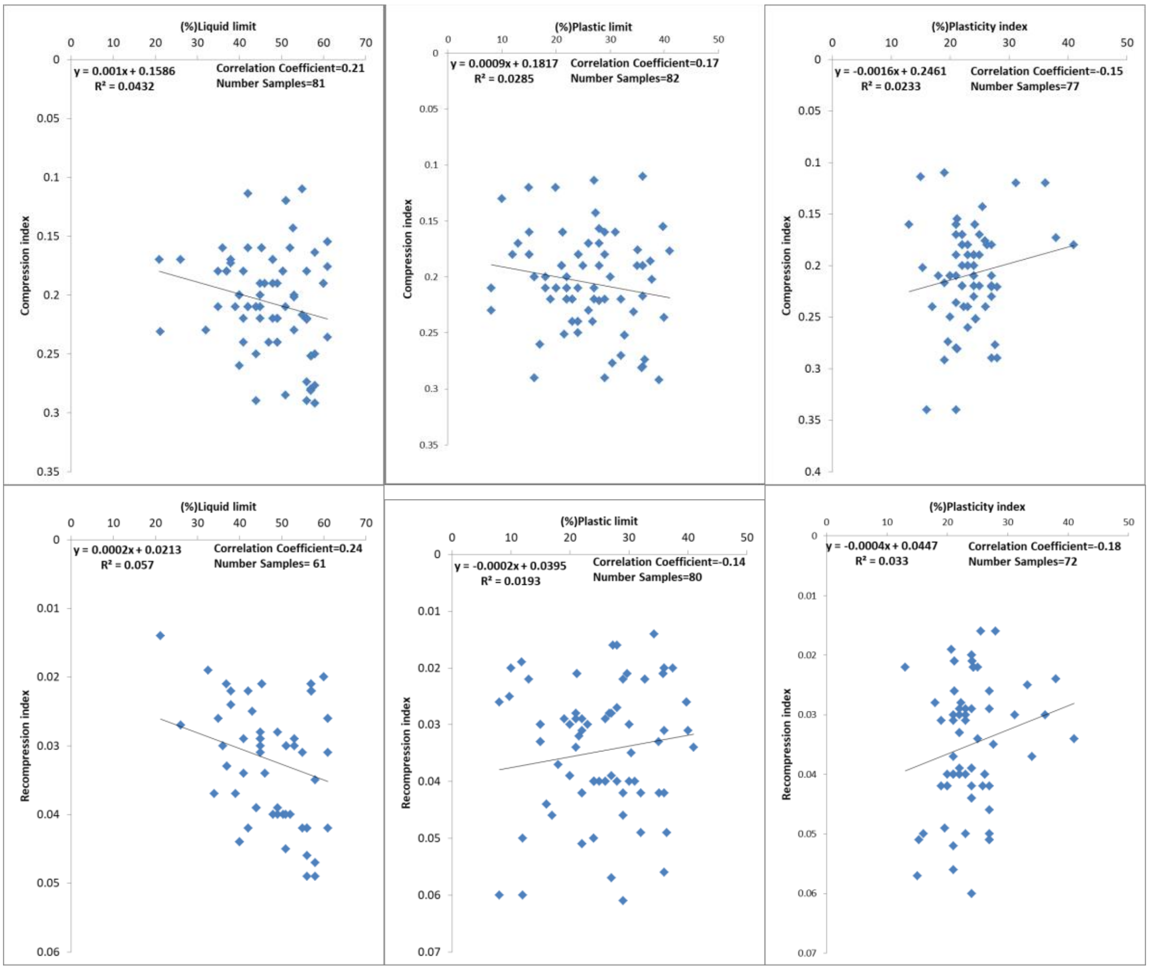
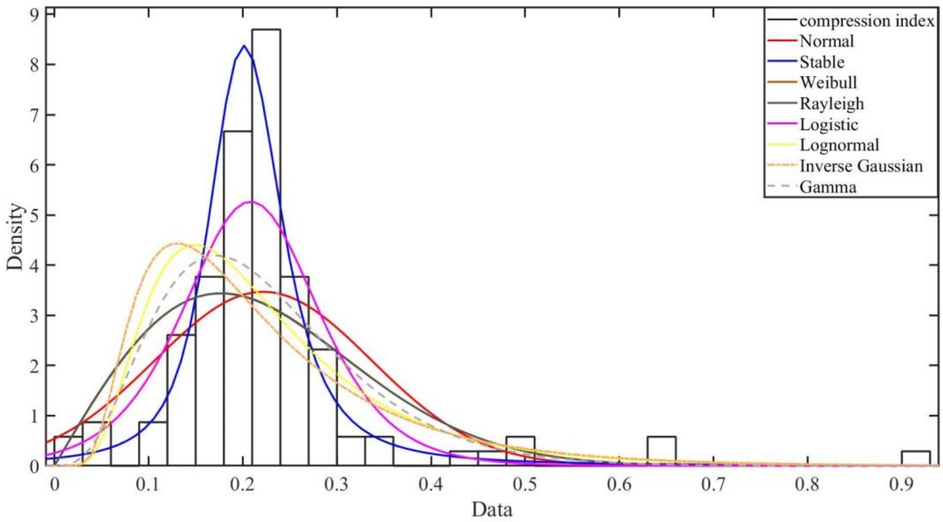


Figure 14. Correlation between consistency and compressibility properties.

(a)



(b)

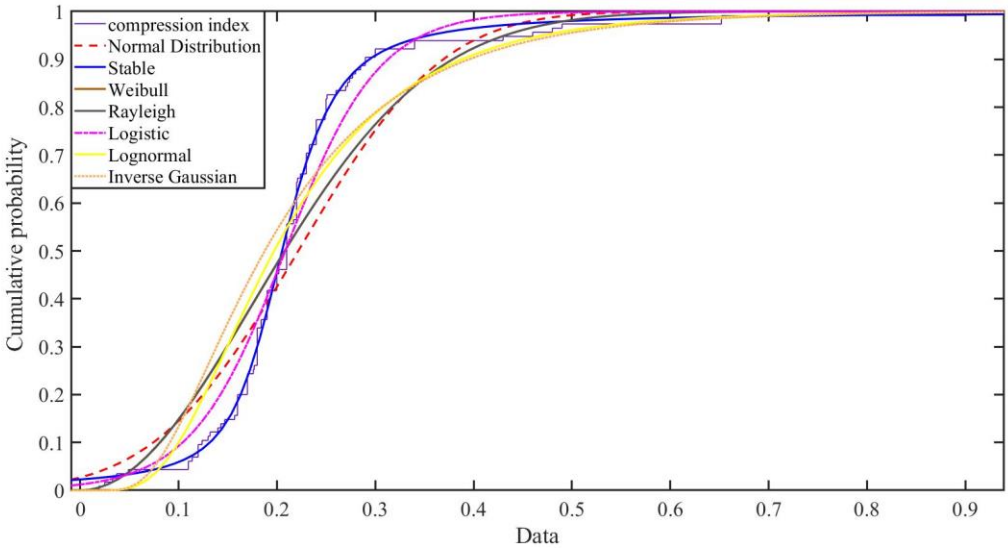
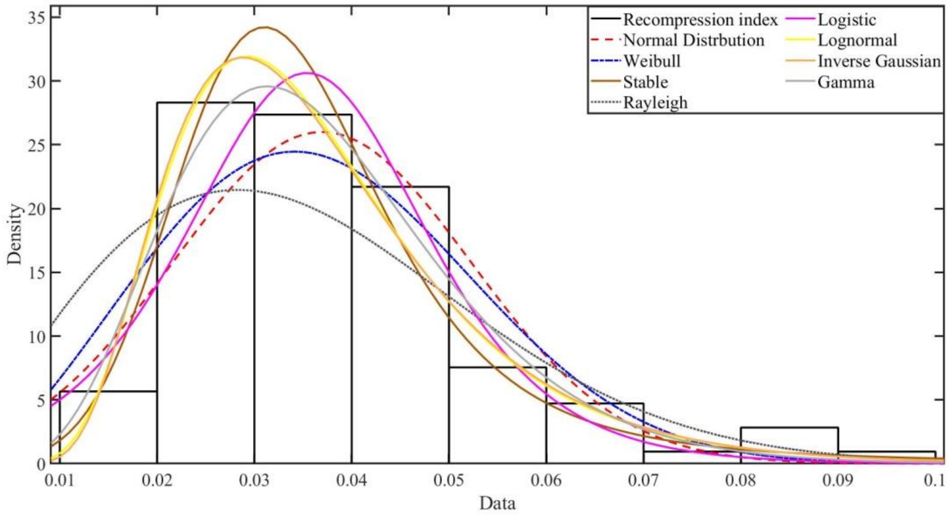


Figure15. probability distribution function (PDF) of eight proposed distributions of compression index (Cc); (b) cumulative probability (CDF) of eight proposed distributions of compression index (Cc).

(a)



(b)

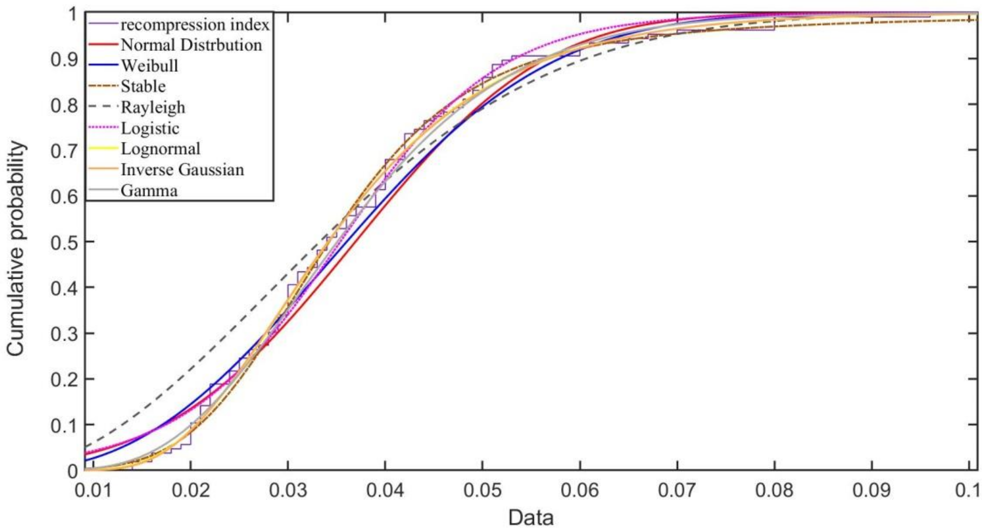


Figure 16. Probability distribution function (PDF) of eight proposed distributions of recompression index (C_r); (b) cumulative probability (CDF) of eight proposed distributions of recompression index (C_r).

6. Conclusions

The objective of the geotechnical survey of Thi Qar governorate is to explore the properties of the underlying soil, as several critical geotechnical properties were mentioned in the initial design of the foundation. Among the most important of these characteristics:

1. The northern zone of zone 1, zone 4 mainly represents very stiff clay soils of low plasticity. Cohesion extends from the surface of the earth to a depth of 20 m. In contrast, the cohesion of zone 2 and zone 3 decreases at specific depths, while the plasticity increases and the soil becomes organic with high plasticity in the middle of Thi Qar (zone 2). As a result, silt increases in zone 3, represented in the southern part.
2. Geotechnical properties have some common characteristics between the four regions, for example, the rate of distribution of soil particles and the ratio of chemical properties. But, at the same time, they differ in the properties of resistance and cohesion.
3. Depending on the limits of Atterberg and the plasticity diagram, fine-grained Thi-Qar soils can be determined. Low plastic clays/clay mixtures with plasticity except for zone 3 high plastic organic clays.
4. According to the unified soil classification, the soil of Thi Qar governorate was classified as clay soil with low to high plasticity.
5. There is no correlation between the compression index and Atterberg limits.

Symbology

CL: organic clay of low plasticity; CH: organic clays of high plasticity; ML: organic silts of low plasticity; $W_{C.}$: water content; L.L: liquid limit; P.L: plastic limit; P.I: plasticity index; SPT-N: stander penetration test; C_c: compression index; C_r: recompression index; C: cohesion; ø:angle friction soils.

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