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DETERMINATION OF SOIL STRENGTH PARAMETERS OF QUATERNARY DEPOSITS BASED ON PHYSICAL PROPERTIES (SOUTH OF ESFAHAN, IRAN)

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Abstract

In this paper the effects of physical properties of Quaternary deposits on the strength parameters of soil are studied in north of Esfahan. The soil samples are classified as GM according to the Unified Soil Classification System. The samples were well graded with dry density ranges between 1.77 and 1.95 g/cm^3 and moisture content ranges between 5.2% and 10.9%. The scope of the experimental program reported in this paper was to perform plate load test on alluvial fan deposits with different density and moisture content. Variations in modulus of a soil (modulus of subgrade reaction, Ks and modulus of elasticity, Es) and strength parameters (friction angle and cohesion) were determined at different experimental levels of physical parameters (dry density and moisture content). Results showed that all parameters of soil strength and modulus increased with increased dry density. In contrast these parameters decrease with increased moisture content.

Key words: plate load test, modulus of subgrade reaction, modulus of elasticity, dry density and moisture content, Quaternary deposits

Introduction. The testing of soils by applying a load has resulted in a worldwide revival of interest over the last few decades. In geotechnical engineering, the engineering properties of soil layers must be known to the required depths [1,2]. Engineering properties can be determined by means of tests carried out in the field and laboratory. The modulus of subgrade reaction (K_s) and modulus of elasticity (E_s) of a soil are an elastic soil parameter most commonly used in the estimation of settlement from static loads elastic deformation analysis. The shear strength, two parameters, Young's modulus of elasticity and Poisson's ratio, were also found to increase with bulk density [3]. The test results of Clay Sand presented by [4], showed that the friction angle and cohesion show an increase with increasing density. Estimation of mechanical parameters of soils was considered by many researchers [5,6]. Mechanical properties are not just a soil parameter; they are also affected by structural stiffness.

The city of Isfahan is located at the central part of Islamic Republic of Iran (Fig. 1). The soil samples used in this study were taken from a site to the south of the Isfahan city. Quaternary deposits of the city Isfahan are divided into two groups. The first group consists of fluvial deposits and the second one is alluvial fan. In the paper, we study on the alluvial fan deposit. Isfahan city is located in the area that Jurassic, Cretaceous, and Quaternary formations have been observed [7].

This paper presents the effects of physical properties on the strength parameters for the alluvial fan. Laboratory and in situ tests were carried out on soil to assess the effect of soil dry density and moisture content on soil mechanical properties, namely C, φ, E_s, K_s, etc.

Results and discussion. ***Soil physical properties.*** The characteristics of the soil at the site have been determined through an extensive testing program that consisted of a combination of laboratory and in situ tests. Tests were conducted on 12 naturally occurring soils having almost the same geologic origins. The soils were obtained from borrow pits in natural ground. The soils used in this investigation were characterized using grain-size, density, moisture content, liquid limit (LL), plastic limit (PL), and plasticity index (PI) according to ASTM Standard test methods. These soils could be classified as GM according to the Unified Soil Classification System. The grain size distribution, as well as the Atterberg limits and dry density of the soil, are presented in Table 1.

Soil mechanical properties. Soils, like most solid materials, fail either in tension or in shear. Shear failure starts at a point in a mass of soil when, on some surface passing through the point, a critical combination of shearing and a normal stress is reached. The soil shear strength is a function of the two components, soil cohesion and internal friction angle [8]

$$\tau = C + \sigma_n \tan\varphi.$$

In this equation the symbol τ is the shearing resistance or shearing strength, C is the cohesion, σ_n is the normal stress to the failure plane and φ is the internal friction angle.

Soil strength is the resistance to mass deformation developed from a combination of particle rolling, sliding and crushing. It is reduced by any pore pressure that exists or develops during particle movement. This resistance to deformation is the shear strength of the soil as opposed to the compressive or tensile strength

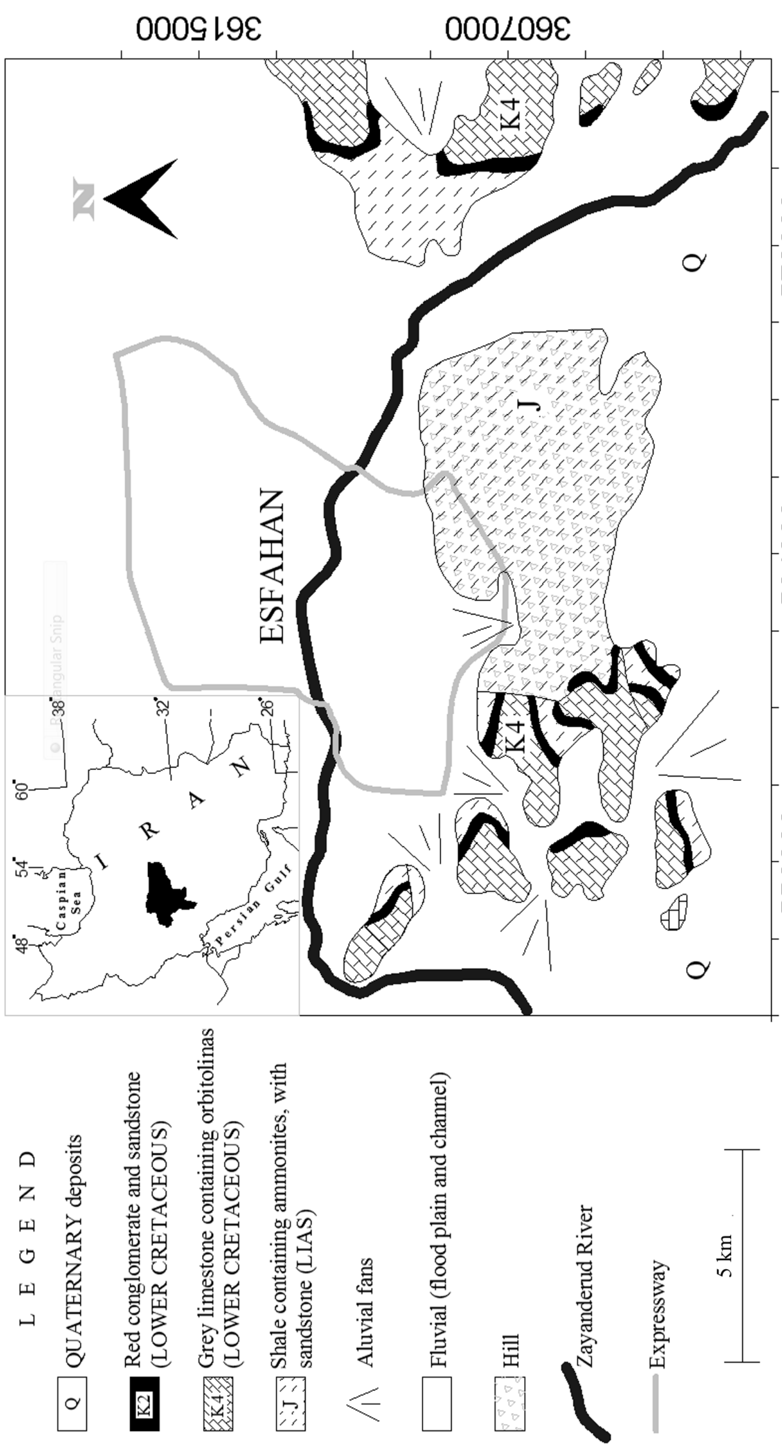

Fig. 1. Geological map of the study area

Table 1

Physical and mechanical properties of tested samples

	Grain-size distribution		Physical							Mechanical	
Sample number	Percent fine	Percent gravel	Bulk density	Dry density	Porosity	Moisture content	Liquid limit	Plasticity index	Friction angle	Cohesion
	(< 75 µm) (%)	(< 4.75 mm) (%)	γ_b (g/cm^3)	γ_d (g/cm^3)	n %	W %	LL %	PI %	φ (deg)	C (kg/cm^2)
S1	20	53	1.96	1.77	34	10.9	33.1	8.2	29.1	0.12
S2	20	64	1.97	1.78	33	10.7	29.7	8.8	29.8	0.11
S3	19	60	1.97	1.79	33	9.8	30.1	7.4	31.1	0.12
S4	18	59	1.98	1.81	32	9.6	32.4	7.6	30.8	0.14
S5	19	57	2.01	1.85	31	8.9	30.8	6.9	32.8	0.13
S6	18	57	2.02	1.87	30	8.3	32.1	8.6	31.8	0.14
S7	24	65	2.01	1.87	30	7.6	31.6	7.3	33.2	0.16
S8	19	46	2.02	1.89	29	7.1	34.9	10.7	32.7	0.14
S9	20	62	2.03	1.91	29	6.4	33.5	8.7	33.4	0.15
S10	25	63	2.04	1.92	28	6.2	30.6	9.4	32.9	0.16
S11	22	64	2.05	1.95	27	5.2	34.4	9.1	34.6	0.17
S12	22	54	2.04	1.93	28	5.7	33.4	10.4	33.9	0.15

of other engineering materials [9]. The oldest method for investigating the shearing resistance (e.g. cohesion and internal friction angle) of soils is the direct-shear test. The apparatus consists of an upper box that is stationary and a lower one that can be moved in a horizontal direction. The specimen is located between two porous stones that serve as drains during the first and second steps of the test [8]. The direct shear test is used to estimate the shear strength of a laterally confined sample when breaking along a prefixed horizontal plane [10]. According to ASTM D 3080-04, the direct shear box test has several particle-size to box-size requirements when preparing specimens for testing [11]. It is recommended that the minimum specimen width should not be less than ten times the maximum particle-size diameter and the minimum initial specimen thickness should not be less than six times the maximum particle diameter. It should be mentioned that, the ASTM D 3080-04 standard test method for direct shear tests of soils stipulates the apparatus size to be at least ten times the size of the largest particle size, and the horizontal dimension of the apparatus to be at least twice the vertical dimension.

In this study, specimens for the direct shear test were conducted on 12 naturally occurring soils from alluvial fan deposit having the same geological origins. The soils were obtained from borrow pit, remolded with natural density and Moisture content. Shear strength parameters for the alluvium fan deposit used in this testing program were determined using a square shear box with a width of 300 mm and a depth of 100 mm ($H/L = 0.34$). The test results are presented in Table 1.

Plate Load Test (PLT). As with many geomaterials, the soil showed nonlinear behaviour from the very beginning of loading history during the triaxial test. Therefore, special attention should be paid to the calculation of Young's modulus of elasticity. Soil elastic modulus can be estimated from laboratory or in-situ tests, or based on correlation with other soil properties. Plate loading tests provide a direct measure of compressibility and occasionally of the bearing capacity of soils which are not easily sampled. The standard method for field load tests is given by the American Society for Testing and Materials under designation ASTM D1194-94 (Standard 1998b). Circular steel bearing plates of 152.4 mm to 762 mm in diameter and (304.8×304.8 mm) square plates are available for this type of test. Based on the plate load tests conducted in the field, an estimation of the bearing capacity and associated elastic settlement of full-scale foundations can be made [12]. The plate load test (PLT) has been examined by researchers in [13,14].

The pit for plate load tests was excavated to a depth between 1–4 m, into the layer of deposits. The area at the bottom of the excavations was about 8 m^2. It allows the determination of the relationship between the applied pressure and the displacements (pressure-displacement curve). The tests were conducted using 300 mm in diameter and 25 mm thick, rigid circular steel plates. The load was applied through a system comprising a hydraulic jack and a reaction beam and measured using a calibrated load cell. Four dial gauges with divisions of 0.01 and 50 mm travel were used for settlement measurement. The gauges were fixed to a reference beam and supported on rods installed outside the test pits. The first step in the test was to estimate the ultimate bearing capacity of the soil. The load was applied in cumulative equal increments of not more than one-tenth of the estimated ultimate bearing capacity. For each load increment, measurement of settlements was made at the following fixed times: 0, 30 s, 1, 2, 4, 8, 15, 30, 60, and 120 min. Each increment was maintained until the following criterion was achieved:

$$L_n - L_{n-1} \leq 0.05(L_n - L_1),$$

where L_n is the average dial gauge reading at a specified time, L_{n-1} is the immediately previous average dial gauge reading to L_n, and L_1 is the first reading of the stage of loading, taken just after stage loading application. In accordance with Brazilian Standard NBR-12131 and ASTM D1194 (ASTM 1998b) [11,15], each increment was maintained for a minimum of 30 min. In this study a total of 12 plate load tests were performed using a 305 mm in diameter and 25 mm thick plate.

The applied pressure versus the resulting settlement data were plotted for each of the tests performed. Load-settlement curve obtained from these tests is shown in Fig. 2. In the study the modulus of subgrade reaction was determined as:

$$K_s = q_{\text{all}}/\delta_{\text{all}},$$

where K_s is subgrade modulus for 305 mm diameter plate, q_{all} is the allowable bearing capacity, and δ_{all} is the settlement. According to Fig. 2 and equation above the modulus K_s for alluvium fan deposits north of Isfahan city was defined.

For plate tests intended to give modulus E_s values for soils or rocks BS 5930:1981 recommends the use of the equation for a uniformly loaded rigid plate on a semi-infinite elastic isotropic solid, i.e.

$$E_s = \frac{\pi q B(1-\nu^2)}{4\delta},$$

where E_s is the elastic modulus, q is the applied pressure between plate and soil, B is the plate width, δ is the settlement under applied pressure q, and ν is the Poisson's ratio. For granular soils and soft rocks Poisson's ratio will normally be between 0.1 and 0.3, and so the term $(1 - -\nu^2)$ has a relatively small effect. Where plate tests are carried out in the stressed zone of a proposed foundation the value of q can be taken as the vertical foundation stress to be applied at the level of the plate test, or alternatively, a safety margin can be incorporated by taking q to be 50% (for example) higher than the estimated applied stress [16].

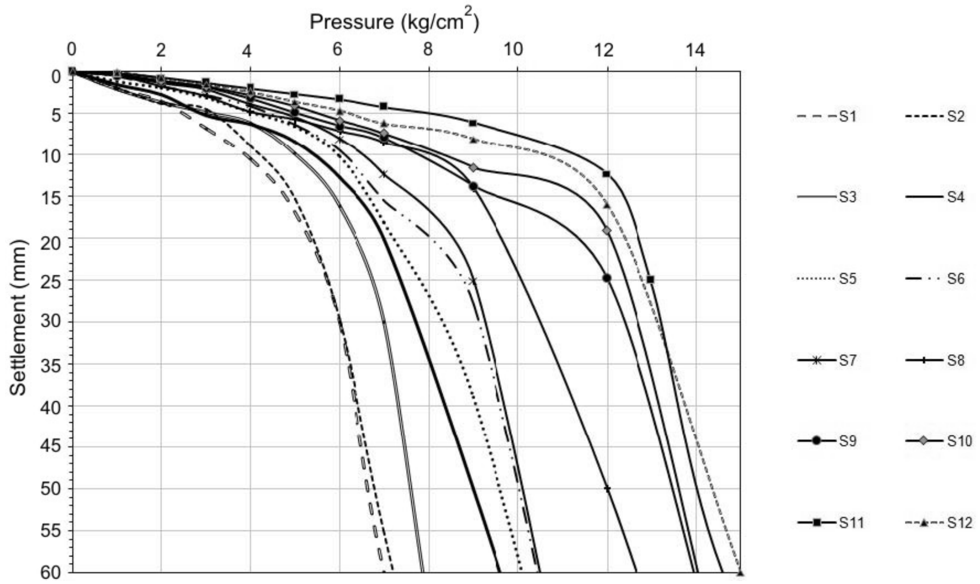

Fig. 2. Pressure-settlement curves

Table 2

Summary of Plate Load Tests

Test number	Ultimate bearing capacity	Allowable bearing capacity (S.F. = 2.5)	Settlement at allowable bearing capacity	Modulus of subgrade reaction	Modulus of elasticity
	q_{ult} (kg/cm^2)	q_{all} (kg/cm^2)	δ_{all} (mm)	K_s (kg/cm^3)	E_s (kg/cm^2)
S1	5.8	1.64	2.4	5.47	120
S2	6.2	1.84	2.7	5.58	122
S3	6.9	2.28	3.1	5.43	119
S4	7.3	2.52	3.1	5.60	123
S5	7.5	2.6	3.0	10.83	237
S6	7.9	2.76	3.2	11.50	252
S7	8.3	2.92	2.8	13.27	291
S8	9.6	3.44	4.5	9.05	198
S9	10.8	4.12	4.8	11.14	244
S10	11.3	4.48	4.1	13.58	297
S11	12.8	5.12	2.8	17.57	385
S12	11.7	4.6	3.2	15.60	342

Modulus of subgrade reaction (K_s), modulus of elasticity (E_s) and ultimate and allowable bearing capacity (q_{ult}, q_{all}) are presented in Table 2.

Relation between physical and mechanical parameters. As is well known, the deformability of soil subjected to loading depends on soil's shear strength parameters. One of the main objectives of this research is to assess the possibility of using simple in-situ test for Determined E_s and K_s in the site. Information about physical properties of soil is a support for simulation by computation techniques to predict E_s and K_s and finally bearing capacity of soil. The variation in the mechanical properties as affected by dry density and moisture content are discussed in the following section. In order to establish relationships for estimating the variation in the mechanical properties of the soil, regression analyses were performed on data obtained from the direct shear and plate load test compression apparatus.

Cohesion and internal friction angle. Strength parameters (friction angle φ and cohesion C), obtained by direct shear test as function of dry density γ and moisture content (W) exhibit a strong dependence with both factors.

The friction angle and cohesion for each sample soil as physical properties are also presented in this section. The results show that as the dry density increased, the friction angle increased and cohesion decreased in most cases, and so with the moisture content increasing, the friction angle decreased and cohesion increased in most cases. The statistical equations result from multiple regression analysis to predict internal friction angle are written as:

$$\varphi = 61.5 - 3.9W - 1.4\gamma^2 + 0.13W^2, \quad C = -0.41 + -1.7\gamma^2 + \gamma + 0.3W.$$

Modulus of a soil. As with many geomaterials, soils do not exhibit a linear stress strain curve. Therefore, special attention should be paid to the calculation of modulus of a soil. Soil elasticity has substantial changes on different physical conditions. The results show that as physical properties increased, the modulus of a soil (modulus of subgrade reaction K_s and modulus of elasticity E_s) increased. In contrast, moduli of a soil (K_s, E_s) increased with the decreasing of moisture content. The statistical equations result from multiple regression analysis to predict K_s, E_s are written as:

$$E_s = -447.1 - 60.4W + 207.4\gamma^2 + 4.3W^2, \quad K_s = -21.K - 2.5W + 9.4\gamma^2 + 0.18W^2.$$

Conclusions. The following conclusions are applicable to the results of this program of field and laboratory tests on an alluvium fan deposits of Esfahan city.

- Regression equations developed to relate the modulus of a soil (modulus of subgrade reaction K_s and modulus of elasticity E_s) and strength parameters (friction angle and cohesion) with physical parameters (dry density and moisture content) were quite simple, and had high determination coefficients ranging from 92% to 96%.

- Using the equations of this research, the modulus of a soil (K_s, E_s) and strength parameters (φ, C) can be determined based on physical parameters (γ_d, W). Therefore, these equations can be used for the prediction of the variation in these mechanical properties of alluvial fan deposit for any combination of dry density and moisture content. Establishing these empirical equations can be considered an advantage from an economical point of view because of avoiding the need for carrying out the costly field tests.

- All parameters of soil strength and modulus increased with decreasing moisture content. In contrast, these parameters decreased with increasing moisture content.

- All parameters of soil strength and modulus increased with increasing dry density. In contrast, these parameters decrease with decreasing dry density.

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