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Research Article

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Atterberg Limits and Ground Engineering Classification of Soils Containing High Amounts of Smectite

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Abstract Ground engineering properties of the epipedons and subhorizons of 16 model soil profiles with high clay content, and belonging to Haploxerert and Calcixerert Great Groups of Vertisol Order, have been studied. As a result of the investigation it was determined, that the liquid limit (LL) plastic limit (PL), and plasticity indexes (PI) values of the studied Vertisol soils, varied in the ranges of 25-88%; 14-38% and 14-58%, respectively. Most of the investigated soils own poor and unsuitable ground engineering properties, and main part of them are classified in "A-7-6 "class and identified as “bad clays”, according to AASHTO (Public Roads System) classification. Extremely heavy textured Turkgeldi soils, owing plasticity indices values up to 40-50, are classified in "A -7-5" AASTO group. Relatively light textured Osmanlı, Eskikadın, Beyazkoy and Yeni Mahalle soils with lower plasticity indices, and 5-14 group indices are included in "A-6" AASTO group. According to the Unified Soil Classification System (USCS), the properties of the investigated soils varied from "inorganic clays of low and medium plasticity- CL" to "inorganic clays of high plasticity or fat clays- CH", even to "organic clays of medium to heavy plasticity- OH".

Keywords vertisols, clay, liquit limit (LL), plastic limit (PL), AASTO, USCS

1. Introduction

The Vertisol soils are widespread in some regions of Turkey as Thrace, Çukurova, Southeast Anatolia and etc. As a whole the chemical and water holding properties of Vertisol soils are favourable, and the percentage of base saturation is almost 100%; and cation exchange capacity (CEC) reaches to very high values of 25-66 me / 100 gr [1-3]. However, there are significant problems arising from the physical properties of these soils.

The soil engineering properties of the soils belonging to Vertisol Soil Order, are not favourable due to their high content of 2: 1 smectite clay mineral, owing high swelling and shrinkage properties. The internal pressure formed at the depth of the profile causes cracking of the walls of the buildings; bending of poles, fences and trees; and damaging of roads, irrigation and drainage channels, as well as drinking and sewage water networks. These soils are extremely hard when dry, and very sticky and plastic when wet. Due to the mentioned properties they can maintain the annealing state only for a short time, which leads to difficulties in the agricultural management of these soils. In addition; when processed at wet status they adhere to tools and machines, slime and form large mud abrasions, while their resistance to the tools and traction requirements are very large when processed at dry consistency status. That’s why, the evaluation and studies on ground engineering characteristics of these soils, widespread in Thrace region of Turkey is of primarily importance.

Cangir [4-5] pointed out that, the soils of Vertisol Order own unfavourable properties in terms of soil engineering, due to higher (33% and more) content of 2:1 type clays in the texture, and are difficult for the management practices as tillage, irrigation and etc. In a study carried out in Tekirdag province of Turkey, Cangir and Ekinci [6] evaluated the soil engineering properties of Vertisol soils, belonging to the Pelloxerert

Great Group, and determined that the upper horizons of the mentioned soils consist of moderately plastic inorganic clays, while the lower horizons up to a depth of 150 cm are formed of excess plastic inorganic clays, and the evaluated soils are classified in the A-7-6 group of AASTO classification system, with group index values in the ranges of 17-20. In the research carried out in the same region by Ekinci et al. [7], were studied the Udic Haploxerert and Chromic Haploxerert Vertisol Order soils, and was determined that exists very high coefficient of linear expansion. The studied soils were classified in A-7-6 group, which may undergo large volume changes, according to the AASHTO classification system. Evaluations performed using Casagrande plastic card showed; that the soil of Udic Haploxerert was in "extremely high plastic inorganic clay" class, while the Chromic Vertisol soil was classified as "intermediate moderately plastic inorganic clay".

The engineering properties and liquit limit (LL), plastic limit (PL) and plasticity index (PI) values of the soils have been searched in different countries of the world, and various values have been reported for soils of different clay content [8-12]. In Bangkok, Islam et al [13], determined that the liquid and plastic limit moisture values of soil containing 61.5% clay, reached up to 51 and 26.2%, respectively. Taha et al [14] have reported that the liquid limit and plastic limit of residual soil decrease with depth due to reduced content clay with increasing depth. Zolfaghari et al [15] concluded that the Atterberg consistency limits and indices of West Iranian soils, were significantly different among the land uses and slope positions. They also reported that the liquit limit (LL), plastic index (PI), friability index (FI) , and soil activity (A= PI/clay%), showed significant variations depending on land uses, and the highest values of the mentioned parameters were observed in the toeslope position, probably due to higher OM and CEC/clay (i.e., greater content of expandable phyllosilicate clays). Sunil et al [16], determined that LL and PL of the Indian soils with lover clay content in their texture varied in the ranges of 41-50 and 25-28 %, respectively. Though Shridharan et al [17] reported much higher values of 60-120 % and 30-60%, for liquit and plastic limit of Montmorillonite soils in the same country.

Zaffar et al [18] studied the physico- mechanical properties of Vertisols in Pakistan and concluded that both fly ash and biochar applications, significantly improved the mentioned characteristics of the searched soils. The authors stated that the amendments like biochar (SB, WCB and WSB) and fly ash (FA) improved the consistency limits of the physical properties like plastic limit (PL), liquid limit (LL) and plasticity index (PI).

More recently Tamfuh et al [19] evaluated the soils of Vertisol Order in North Cameroon, and noticed that they contain at least 30% clay fraction, and smectite, cation exchange capacity (CEC) and base saturation values of the evaluated soils are very high. The authors mentioned also that Lithomorphic Vertisols are developed on various parent rocks and topographic positions, where weathering generates base-rich environments that promote smectite synthesis. The most of the evaluated vertisol soils were classified under the A-7-5 and A-7-6 classes, typical of inorganic clays of medium to very high plasticity designated as "bad clays" according to AASHTO.

The aim of this study was to determine the ground engineering properties of the soils containing high amounts of 2:1 type minerals in their texture, and to classify the studied soils according to AASHTO (American Association of State Highway and Transportation Officials) and USCS (Unified soil classification system)

2. Material and Methods

The lands covered with Vertisol soils, exhibiting peculiar views as Gilgai micro-relief and self-mulching (Fig 1), and wide cracks and clod structure in the soil profile (Fig 2), located in the borders of provinces of Thrace region of Turkey were studied in the investigation. The surveyed soils were examined following procedures described in Soil Survey Staff [20]. The depth and boundaries of the soil horizons and sub-horizons, as well as the properties as soil colour, structure, consistency, pores, presence of roots and other special views of the profile were studied on locations summarised in Table 1.

Field observation and laboratory analysis were conducted on the soil profiles of Eski kadın (D1), Osmanli (D2 and D3), and Akardere (D4) in Edirne province; Ulukonak (D5), Yeni Mahalle (D6), Karahalil (D7), Kadikoy (D8), Babaeski (D9), Buyuk Mandira (D10), and Turkgeldi TIM (D11 and D12) in Kirklareli province; and Beyazkoy (D13), Vakiflar (D14), Seymen (D15) and Karacakilavuz (D16) of Tekirdag province [3]. The description of the soil profiles were accomplished according to the criteria specified in Soil Survey Staff [20].

Approximately 2 kg of soil samples were collected from each genetic horizon and/or sun-horizons of the researched profiles in the field, and delivered to the laboratory for laboratory analyses and further evaluations.

Figure 1: Gilgai microrelief and self mulching view typical for Vertisols

Figure 2: Cracks and clod structure in the soil profile of Vertisol

After drying the soil samples obtained from each horizon of the study profiles, the experimental soils were sieved and further prepared for consistency tests. The liquid limit (LL) was determined in accordance with the Standard Method of Determining the Liquid Limit of Soils (AASHO) Designation: T89-60), and the plastic limit (PL) in accordance with the Standard Method of Determining the Plastic Limit of Soils (AASHO Designation: T90-56). The plasticity index (PI) was calculated according to the Standard Method of Calculating the Plasticity Index of Soils (AASHO Designation: T91-54).

Table 1: Geographical position, elevation and classification of the evaluated soil profiles

Profile	Location (Settlement) and Elevation	Geographical Position	Classification
D1	Eski kadın- Edirne 106 m	41°42'56N; 26°27'24E	Chromic Calcixerert (Soil Taxonomy) Calcic Vertisol (FAO/UNESCO)
D2	Osmanli-Havsa 115 m	41°35'07N; 26°51'33E	Udic Haploxeret (Soil Taxonomy) EutricVertisol (FAO/UNESCO)
D3	Osmanli-Havsa 90 m	41°34'30N; 26°51'00E	Udic Haploxerert ((Soil Taxonomy) Eutric Vertisol (FAO/UNESCO
D4	Akardere- Suloglu 140 m	41°40'13N; 26°57'02E	Udic Haploxerert (Soil Taxonomy) Eutric Vertisol (FAO/UNESCO
D5	Ulukonak – Kirklareli 143 m	41°39'37N; 27°00'50E	Typic Calcixerert ((Soil Taxonomy) Calcic Vertisol (FAO/UNESCO)
D6	Yeni Mahalle-Babaeski 156 m	41°34'19N; 27°08'00E	Chromic Haploxerert (S. Taxonomy) Eutric Vertisol (FAO/UNESCO)
D7	Karahalil-Babaeski 148 m	41°35'59N; 27°03'50E	Udic Haploxerert (Soil Taxonomy) Eutric Vertisol (FAO/UNESCO)
D8	Kadıköy-Babaeski 89 m	41°28'50N; 27°03'55E	Udic Haploxerert (Soil Taxonomy) Eutric Vertisol (FAO/UNESCO)
D9	Babaeski-Kirklareli 89 m	41°25'08N; 27°07'20E	Typic Calcixerert (Soil Taxonomy) Calcic Vertisol (FAO/UNESCO)
D10	Buyuk Mandıra – Babaeski - 30 m	41° 35' 58N; 27° 04' 53E	Sodic Haploxerert (Soil Taxonomy) Eutric Vertisol (FAO/UNESCO)
D11	Lüleburgaz Turkgeldi-Kirklareli-79 m	41°22'55N; 27°19'13E	Udic Haploxerert (Soil Taxonomy) Eutric Vertisol (FAO/UNESCO)
D12	Lüleburgaz Turkgeldi-Kirklareli- 74 m	41°22'50N; 27°19'07E	Sodic Haploxerert (Soil Taxonomy) Eutric Vertisol (FAO/UNESCO
D13	Beyazkoy- Saray 101 m	41°21'25N; 27°40'24E	Lithic Calcixerert (Soil Taxonomy) Calcic Vertisol (FAO/UNESCO
D14	Vakiflar-Çorlu 118 m	41°15'56N; 27°39'27E	Udic Haploxerert (Soil Taxonomy) Eutric Vertisol (FAO/UNESCO
D15	Seymen-Çorlu 114 m	41°05'58N; 27°56'41E	Sodic Haploxerert (Soil Taxonomy) Gypsic Vertisol (FAO/UNESCO)
D16	Karacakılavuz- Tekirdag 184 m	41°09'40N; 27°20'04E	Udic Haploxerert (Soil Taxonomy) Eutric Vertisol (FAO/UNESCO)

3. Results and Discussion

3.1 Liquit limit (LL), Plastic limit (PL) and Plasticity Index (PI) of studied soils

Laboratory results obtained for consistency features, as liquit limit (LL), plastic limit (PL) and plasticity index (PI) of the studied soils are presented in Tables 2, 3, 4 and 5. Evaluation of the data in the mentioned tables shows, that close relationship exists between soil texture (clay amount) and the Atterberg limit values of the soil. The liquid limit humidity values determined in different horizons of the scrutinized profiles, generally varied between 28% and 88%, and exhibited significant differences from profile to profile, and from soil horizon to soil horizon. Lower values, in the rangers of 27.7-37.0%; 29.6-44.4 %; 35.8-43.7%; 31.50-45.5% and 39.18-42.91 % respectively, were recorded in soils samples collected from the horizons of Osmanli (D3) and D(2), Eski kadin (D1), Yeni mahalle (D6) and Beyazkoy (D13) soil profiles, containing less clay amounts in their textures. On the other hand, very high LL values in the ranges of 69.84 - 88.0%; 65.6-79.3% ; 58.75-78.0% ; 59.9-66.8% and 47.6-83.9 % were recorded in the soils of heavy textured Turkgeldi (D11 and D12), Buyuk

Mandira (D10), Babaeski (D9) and Seymen (D15) soil profiles, containing up to 63.01-77.05 %, 62.46-75.15%, 62.11-72.76%, 63.94-73.12% and 51.52-76.12% clay in the texture.

Table 2: Atterberg limits (%) and ground engineering classifications of soils of D1, D2, D3 and D4 soil profiles

Profile	Horizons	Texture		Liquid Limit, LL	Plastic Limit, PL and Plastic Index		AASHTO[a]	USCS[b]
		Clay, %	Texture Class*		Plastic Limit, PL	Plastic Index, (PI)		
	Ap	38.78	CL	39.10	19.00	20.10	A-6 (10)	CL
	A	38.81	CL	40.50	19.84	20.66	A-7-6 (9)	CL
	2A	43.05	C	43.70	19.09	24.61	A-7-6 (12)	CL
D1	3AC	38.34	CL	39.10	20.07	19.03	A-6 (9)	CL
	3Ck1	35.96	CL	36.40	20.72	15.68	A-6 (7)	CL
	4Ck2	35.51	CL	35.80	19.40	16.40	A-6 (10)	CL
	4Ck3	40.02	C	38.25	17.84	20.41	A-6 (11)	CL
	Ap	34.83	CL	31.07	14.45	16.62	A-6(8)	CL
	A	34.63	CL	29.60	13.87	15.73	A-6(7)	CL
	2Ass1	43.96	C	42.60	17.83	24.77	A-7-6(10)	CL
D2	2Ass2	44.12	C	44.40	17.22	27.18	A-7-6(14)	CL
	2AC	41.56	C	39.90	15.03	24.87	A-6(13)	CL
	2C	34.74	CL	33.20	16.51	16.69	A-6(10)	CL
	2Ck	26.15	SCL	30.65	12.89	17.76	A-6(5)	CL
	A1	31.78	SCL	32.50	16.62	15.88	A-6(6)	CL
	A2	29.73	SCL	30.50	15.07	15.43	A-6(5)	CL
	A3	33.13	CL	28.70	14.67	14.03	A-6(6)	CL
D3	A4	30.44	SCL	31.80	14.21	17.59	A-6(6)	CL
	Ass	39.19	CL	37.00	14.01	22.99	A-6(10)	CL
	2C	23.94	SCL	27.70	14.58	13.12	A-6(2)	CL
	Ap	47.00	C	46.10	21.88	24.22	A-7-6(14)	CL
	A	46.93	C	49.10	22.03	27.07	A-7-6(16)	CL
	Ad	49.18	C	51.60	23.99	27.61	A-7-6(16)	CH
D4	Ass1	49.37	C	52.25	21.85	30.40	A-7-6(17)	CH
	Ass2	51.30	C	52.70	18.99	33.71	A-7-6(17)	CH
	2A	51.40	C	55.20	20.22	34.98	A-7-6(18)	CH
	2CA	53.48	C	56.80	22.91	33.89	A-7-6(19)	CH
	3C	63.75	C	49.10	19.64	29.46	A-7-6(18)	CH

* C. clay; CL. clay loam; SCL. sandy clay loam

[a] American Association of State Highway and Transportation Officials

[b] Unified soil classification system

CL- Inorganic clays with low to medium plasticity

CH- High plastic inorganic clays

Similar results were obtained in terms of the plastic limit (PL) values of the examined soils. In general, the plastic limit moisture values of the studied soils started from 12-16% under conditions of moderate textured soils as D2, D3 and D6, and reached up to 37-38% in the samples collected from the heavier textured soil profiles. Though, the highest values of PL, in the ranges of 30-40%; 26-36% and 21- 30 % were found in the soils taken from different horizons of D11 and D12 soil profiles (Turkgeldi), containing very high clay amounts in their texture.

Relatively lower plastic limit moisture percentages were recorded for the soils of Buyuk Mandira (D10) soil profile, containing 62-72% clay in its texture and is located close to Turkgeldi (D11 and 12) soils. The plastic limit moisture content of different layers of this profile, characterised with high exchangeable sodium ratios

(ESP) values, was determined as 25.05%; 25.09%; 25.74%; 25.58% and 26.30%, for Ap, A, Ass, Ak, ACk and C horizons respectively. As can be concluded from the numerical values listed, different clay contents of horizons of the latest soil profile, did not affect the plastic limit value of the soil. Namely, the PL values (25.05%) of Ap horizon containing 62.1% clay, and that of (26.3%) for Assn3 horizon with 72.8% clay content in the texture were almost at the same level. The peculiarity of the discussed profile probably appeared due to high exchangeable sodium percentages (ESP) measured in each horizon of the mentioned profile [3].

Table 3: Atterberg limits and ground engineering classifications of soils of D5, D6, D7 and D8 soil profiles

Profile	Horizons	Texture		Liquid Limit. LL	Plastic Limit. PL and Plastic Index		AASHTO[a]	USCS[b]
		Clay. %	Texture Class*		Plastic Limit. PL	Plastic Index. (PI)		
	Ap	45.76	C	41.10	18.93	22.17	A-7-6(11)	CL
	A	45.85	C	47.55	20.22	27.33	A-7-6(14)	CL
	Ass1	48.41	C	50.10	20.24	29.86	A-7-6(16)	CH
D5	Ass2	49.09	C	50.50	20.28	30.22	A-7-6(16)	CH
	Ass3	51.26	C	50.10	18.81	31.29	A-7-6(17)	CH
	Ck	55.23	C	49.70	19.14	30.56	A-7-6(17)	CL
	C	58.50	C	43.75	20.21	23.54	A-7-6(13)	CL
	Ap	32.57	SCL	31.50	16.62	14.88	A-6(5)	CL
	Ad	34.70	SCL	32.84	16.06	16.78	A-6(6)	CL
	Ass1	39.08	SC	40.00	14.38	25.62	A-6(9)	CL
D6	Ass2	34.95	SCL	37.80	16.37	21.43	A-6(7)	CL
	A1	36.79	SC	38.90	15.26	23.64	A-6(8)	CL
	A2	38.32	SC	40.00	14.66	25.34	A-6(9)	CL
	Cn	45.09	C	45.50	13.39	32.11	A-6(14)	CL
	Ap	43.34	C	43.40	20.73	22.67	A-7-6(12)	CL
	A	45.59	C	44.70	19.61	25.09	A-7-6(13)	CL
	Ass1	41.42	C	47.70	21.47	26.23	A-7-6(14)	CL
D7	Ass2	45.85	C	48.00	20.00	28.00	A-7-6(15)	CL
	Ass3	52.43	C	54.50	15.56	38.94	A-7-6(18)	CH
	C	52.08	C	58.00	16.11	41.89	A-7-6(18)	CH
	Ap	50.77	C	46.30	23.35	22.95	A-7-6(13)	CL
	A	50.88	C	50.55	18.47	32.08	A-7-6(17)	CH
	Ass1	55.77	C	48.40	17.50	30.90	A-7-6(17)	CH
D8	Ass2	53.47	C	50.40	17.56	32.84	A-7-6(17)	CH
	CA	55.11	C	50.10	16.80	33.30	A-7-6(17)	CH
	2C	30.13	CL	30.80	18.60	12.20	A-6(8)	CL

* C. clay ; CL. clay loam; SCL. sandy clay loam

[a] American Association of State Highway and Transportation Officials

[b] Unified soil classification system

CL- Inorganic clays with low to medium plasticity

CH- High plastic inorganic clays

The difference between liquid limit (LL) and plastic limit (PL) humidity values is defined as plasticity index (PI) or plasticity number, which is a very important criterion for soil tillage and other agricultural management practices, since the plasticity index has a high correlation with the internal friction angle, affecting the splitting resistance of the soil. In general, the annealing status of the soil worsens with the increase in plasticity index.

As a result of the study it was determined, that the plasticity index values in our investigation varied in large ranges from profile to profile, and/or even from horizon to horizon of the same soil profile. The lowest plasticity numbers were found in the soils of D3, D2, D1, D13 and D6 profiles, containing significant sand fraction along

with clay in their textures. The values of the discussed parameter in the soil of different horizons of the listed profiles, were defined as 13.12-22.9; 15.73-27.18; 15.68-24.61; 16.6-23.6 and 14.88-25.62, respectively. However, very high plastic indices were recorded for soils of different depths of the evaluated heavy textured vertisols in Turkgeldi, Buyuk Mandira and Seymen locations, with variations between the ranges of 32.6-58.0 (D11); 29.25-48.43 (D12); 33.7-51.7 (D10) and 26.4-26.7 (D15).

On the other hand, the high exchangeable sodium concentrations determined in the lower horizons of the Buyuk Mandira (D10) and Seymen (D15) soils (data not included), lead to an increase in the plasticity numbers of these horizons. This phenomenon appears more clearly in Seymen soil, where the plasticity indices varied from 26.4 for the surface Ap horizon with 1.32 ESP value, to 35.5; 49.5 and 56.7 versus 5.19, 12.3 and 15.46 exchangeable sodium percentage (ESP) values, respectively determined in the soils of the deeper located horizons.

The plasticity index value of surface horizons is of primary importance in terms of soil annealing status and soil tillage. According to Bawer [21], the best criterion for soil annealing is the Atterberg limits and especially the plasticity index. According to the researcher, the smaller the plasticity index, the better is the annealing condition. As a general it could be concluded, that the plasticity indices of the surface horizons are lower than those of the deeper lying horizons, except for C horizons involving the parent material of the soil. However, there are some exceptions to this generalization. For instance, the plasticity index of the upper (A1 and A2) horizons of the Osmanli-Havsa (D3) profile is approximately 16 and 15.5, then decreases to 14 in the following A3; and increases again to 17.3, in the layers below 50 cm depth.

Very high plasticity indices were determined in most of the researched soils. In particular, the plasticity numbers of around 30, were calculated for the soils of the heaviest textured D9, D10, D11, D12 and D15 profiles, corresponding to poor annealing conditions in terms of the soil management. In contrast, the profiles D1, D2, D3, D4, D5, D6, D7, D8, D13 and D16 with relatively lighter soil texture provide better annealing conditions than the above mentioned profiles. The view that the annealing properties of Vertisol Order soil are worse than that of the other Orders is frequently stated in the scientific literature. Ekinci et al. [7], investigated the soils of the mentioned Order located on Karacakilavuz lands in Tekirdag province, and found out that liquid limit (LL), plastic limit (PL) and plasticity index (PI) values of the Karacakilavuz series, containing 53% clay, reached up to 54.0%; 22.0% and 32.0%; while the values of he listed parameters in the case of Kayi series with 45.5 % clay in the texture, were 49.0%; 17.0% and 32.0%, respectively. The LL and PL values of the soils comprising 32% silt and 6.5% sand in Bangkok were reported as 51% and 26.2%, respectively [13]. The results obtained in our study support also data published previously in the international scientific literature [8, 9, 14]. Though our results concerning the increasing effect of the clays on liquit limit values of the soil, did not support the view of Shridharan et al [17], that the clay size fraction and surface area values did not relate the LL values of montmorillonite soils. The contradiction probably appeared due to the differences in the clay mineralogy of the studied soils.

Table 4: Atterberg limits and ground engineering classifications of soils of D9, D10, D11 and D12 soil profiles

Profile	Horizons	Texture		Liquid Limit. LL	Plastic Limit. PL and Plastic Index		AASHTO[a]	USCS[b]
		Clay. %	Texture Class*		Plastic Limit. PL	Plastic Index. (PI)		
D9	Ap	63.94	C	59.90	29.04	30.86	A-7-6(20)	CH
	A	65.17	C	66.80	29.07	37.73	A-7-6(20)	CH
	Ass	67.22	C	64.86	26.35	38.51	A-7-6(20)	CH
	Ak	69.47	C	57.60	23.96	33.64	A-7-6(20)	CH
	ACk	67.23	C	45.50	20.88	24.62	A-7-6(15)	CL
	C	73.12	C	60.00	23.97	36.03	A-7-6(20)	CH
	Ap	62.11	C	58.75	25.05	33.70	A-7-6(20)	CH
	Ad	64.10	C	60.60	25.09	35.51	A-7-6(20)	CH
	Assn1	69.15	C	66.80	25.74	41.06	A-7-6(20)	CH

D10	Assn2	71.12	C	73.80	25.58	48.22	A-7-6(20)	CH
	Assn3	72.76	C	78.00	26.30	51.70	A-7-6(20)	CH
	Ap	63.01	C	69.84	37.20	32.64	A-7-5(20)	CH
	A	70.23	C	74.70	35.19	39.51	A-7-5(20)	CH
	Ass1	72.66	C	81.20	39.91	41.29	A-7-5(20)	CH
D11	Ass2	72.22	C	86.00	37.75	48.25	A-7-5(20)	CH
	Ass3	72.56	C	88.00	30.00	58.00	A-7-5(20)	CH
	AC	77.05	C	80.25	35.96	44.29	A-7-5(20)	CH
	C	74.54	C	85.14	29.60	55.54	A-7-5(20)	CH
	Ap	62.46	C	65.60	36.35	29.25	A-7-5(20)	OH
	A	66.23	C	72.90	35.31	37.59	A-7-5(20)	CH-OH
	2Ass	66.70	C	77.50	34.31	43.19	A-7-5(20)	CH-OH
D12	2AC	68.41	C	72.95	34.66	38.29	A-7-5(20)	CH
	3Ass	75.17	C	79.30	30.87	48.43	A-7-5(20)	CH
	3Cn	71.54	C	73.65	26.10	47.55	A-7-5(20)	CH

* C- clay

[a] American Association of State Highway and Transportation Officials

[b] Unified soil classification system

CL- Inorganic clays with low to medium plasticity

CH- High plastic inorganic clays

OH- Organic clays, organic silts

3.2. Ground engineering classification of investigated soils

Evaluation of the results related to liquid limit, plastic limit and plasticity index of the studied soils, using standards of American Association of State Highway and Transportation Officials system (AASTHO) classification system showed, that most of the examined soils are in group "A-7-6" " bad clays", which can undergo large volume changes and own high plastic index values. However, there are significant differences in terms of group indices between profiles and horizons belonging to the same group. The group index values of the different horizons of the soil of Vakiflar (D14) profile are estimated as (8), (11), (11), (12), (13) and (13), respectively for Ap; A1; A2; Ass; CA and Ckg horizons. However; the soils of all horizons of the Buyuk Mandira (D10) profile, and all of the horizons of Babaeski (D9) profile, except the ACk horizon, correspond to a very poor road subgrade materials (base) with (20) group index. Similar results were obtained for the deeper five soil horizons of the Seymen profile (D15). However, the soils of different horizons of the Osmanli profile (D3), involving lower clay material than the other Vertisol soils, and indicated as sandy clay textured (SC), were determined to have low plasticity "A-6", with (5) and (6) group index values. The soils of other Osmanli profile (D2), were classified in the same group "A-6", with group indices values between 10-14 , except for the soils of 2Ass1 and 2Ass2 horizons evaluated in "A-7-6" group. In similar way, the lighter soil profiles (D6) and D (13), containing clay fraction in the limits of 32-39 % (except C) and 37-43 % respectively, were involved also in group "A-6" with index values between (5) and (10), except for C horizon (14) of the Yenikoy (D 6) soil profile. The soil profiles of Turkgeldi State Agricultural Farm (D11 and D12) involving the highest clay fraction (up to 77 and 75) in their textures, can be characterized as profiles having the most unsuitable soil engineering properties. The mentioned profiles, having very high (40-50) plasticity index values, are defined as "bad clays" in the AASTHO group "A-7-5". Soils of the all depths of these two profiles, correspond to a "very poor road subgrade material", with (20) group index. The situation was almost the same in the case of Babaeski and Buyuk mandira (D9 and D10) soils, located close to those of D11 and D12 on the Agricultural State Farm.

The soils of 16 model profiles were interpreted also using criteria of the Unified Soil Classification System (USCS). Assessments performed on the base of the results obtained for soil texture, plasticity properties and suitability as construction material, showed that significant diversity exist in terms of the soil profiles and/or different horizons of one and the same profile. In other words, the soils of all horizons of the profiles with lighter texture and less amount of clay as D1, D2, D3, D6, D13 and D16; the upper four horizons of Karahalil

(D7); the upper two horizons of Akardere (D4); the upper two and deeper two horizons of Ulukonak (D5); and the surface (Ap) horizon of Kadikoy (D8) profiles, were defined as "low to medium plastic inorganic clays" (CL). However; the soils of all the horizons of very heavy textured D9, D10 and D11 profiles; almost all of the D15 (except Ap); almost all of Kadikoy profile (except of surface and the deep parent material); Assn3 and C horizons of Karahalil (D7) soil; the majority of Ulukonak (D5) and Akardere (D4) profiles, were classified as CH or "high plastic inorganic clays".

Quite different situation was observed in the Turkgeldi (D12) profile. While the soil of the surface (Ap) and subsurface A and 2Ass horizons were classified as; "organic clays" (OH), or "organic clays" and "high plastic inorganic clays" (OH-CH), the soils of the deeper 2AC, 3Ass, 3 Cn horizons were delivered to "high plastic inorganic clays" (CH) class of the USCS evaluation system.

In earlier studies, Cangir and Ekinci [6] investigated the ground engineering properties of the agricultural soils scoped by different Great Soil Groups, widespread in Tekirdag province, and determined that the evaluated soils were generally classified in "A-4"; "A-6" and "A-7" classes of AASHTO, and ML, CL and CH unified groups of the USCS classification system. In another research carried out in the region, Ekinci et al. [7] observed the soils of Karacakilavuz and Kayi Vertisol series and concluded that the studied soils belonged to "A-7-6" group, which can undergo large volume changes and have high plastic index values, and identified as "bad clays" (18 and 19) in AASHTO system. The authors classified the soils of Kayi series as highly plastic inorganic clay (CH) according to USCS system. Tamful et al. [19] reported that most of the evaluated Vertisol soils in North Cameroon, were evaluated under the A-7-5 and A-7-6 classes, with group index values varying from 13 to 20, typical inorganic clays of medium to very high plasticity designated as bad clays according to AASHTO system.

Table 5: Atterberg limits and ground engineering classifications of soils of D13, D14, D15 and D16 soil profiles

Profile	Horizons	Texture		Liquid Limit. LL	Plastic Limit. PL and Plastic Index		AASHTO[a]	USCS[b]
		Clay. %	Texture Class*		Plastic Limit. PL	Plastic Index. (PI)		
	Ap	39.18	SC	33.20	16.64	16.56	A-6(7)	CL
	Ad	39.48	SC	41.00	18.23	22.77	A-7-6(10)	CL
	Ag	41.90	SC	39.15	23.77	15.38	A-6(7)	CL
D13	ACmg	39.61	SC	37.40	18.00	19.40	A-6(8)	CL
	CAmk	42.91	C	33.90	16.77	17.13	A -6(7)	CL
	Cmk	36.80	SC	32.10	14.39	17.71	A-6(6)	CL
	Ap	42.15	SC	40.40	21.65	18.75	A-6(8)	CL
	A1	42.60	SC	46.30	20.16	26.14	A-7-6(11)	CL
	A2	45.80	SC	47.00	19.91	27.09	A-7-6(11)	CL
D14	Ass	45.00	C	49.50	21.50	28.00	A-7-6(12)	CL
	CA	47.24	C	51.50	18.21	33.29	A-7-6(13)	CH
	Ckg	46.95	C	50.50	19.40	31.10	A-7-6(13)	CH
	Ap	51.52	C	47.60	21.16	26.44	A-7-6(15)	CL
	Ad	54.24	C	56.50	21.03	35.47	A-7-6(18)	CH
	Ass	65.76	C	73.00	23.49	49.51	A-7-6(20)	CH
D15	Assny1	76.17	C	83.90	27.17	56.73	A-7-6(20)	CH
	Assny2	52.20	C	74.50	28.40	46.10	A-7-6(20)	CH
	2CAny	48.33	SiC	65.80	25.71	40.09	A-7-6(20)	CH
	3Cnyg	59.63	C	76.50	30.19	46.31	A -6(20)	CH
	Ap	39.27	CL	35.95	15.76	20.19	A-6(10)	CL
	A	41.28	C	38.50	15.03	23.47	A-6(12)	CL
	Ad	41.46	C	38.70	15.38	23.32	A-6(12)	CL
D16	AC	41.56	C	39.60	15.90	23.70	A -6(12)	CL

CA	45.89	C	41.45	14.50	26.95	A-7-6(14)	CL
CAss	45.85	C	44.60	15.20	29.40	A-7-6(16)	CL
CA'	45.82	C	44.00	17.03	26.97	A-7-6(14)	CL
Ck	43.65	C	42.10	16.85	25.25	A-7-6(13)	CL

* SC. sandy clay: C. clay; CL. clay loam; SiC. silty clay

[a] American Association of State Highway and Transportation Officials

[b] Unified soil classification system

CL- Inorganic clays with low to medium plasticity

CH- High plastic inorganic clays

4. Conclusions

Liquid limit (LL) plastic limit (PL), and plasticity indexes (PI) moisture values of the studied Vertisols soils, varied in the ranges of 25-88%; 14-38 and 14-58%, respectively. The values of the listed properties, in the soils of relatively lighter textured Osmanli (D2 and D3); Eskikadın and Yeni Mahalle soils, can reach the limits of 27.7-45.5%; 12-20% and 13.12-27.18. However, much higher values of LL, PL and PI, in the ranges of 58.75-88.0%; 26.1-37.8% and 26.4-51.7%, could be detected in clayey soils, with very high clay amounts in the texture as Turkgeldi (D11 and D12); Buyuk Mandira and Babaeski soil profiles.

According to AASTO classification; most of the investigated soils are in "A-7-6" group, which can undergo large volume changes and have high plastic index values. All horizons of the Buyuk Mandira and Babaeski profiles, and most of soil horizons of Seymen soil, have been identified as "bad clays" and very poor base material, with group indexes of 18-20. The soil engineering properties of the two Turkgeldi profiles, which have high content (up to 75-77 %) of clay in their structure, are even worse. The mentioned soils are classified in "A-7-5 " group, with very high (40-50) plasticity index values, with a group index of 20, corresponding to a very "bad base soil" of AASTHO.

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