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"Research Note"

GEOTECHNICAL PROPERTIES OF BAHMANSHIR SERIES, SOUTHWEST KHUZESTAN, IRAN*

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Abstract – Holocene in Southwest Khuzestan is represented by a fluvio-tidal succession termed the Bahmanshir Series which consists of two clayey layers separated by silty sand to silt beds. This paper describes the geotechnical properties of the clayey layers that have wide exposure in the lowlands of the Persian Gulf coast. Studied layers are generally clay sized and consist of a lesser percentage of clay minerals. Most of the clayey layers have intermediate plasticity, and low potential for expansion. The variation of physical and engineering properties of the layers from base to top and along the Bahmanshir River is investigated in this research. The engineering properties of the beds seem to be affected by tidal and river flow currents and totally by their formation sedimentary environments. Links of the geotechnical data with geological features as formation sources in the upstream of the basin, the cementation due to the capillary feature in the floodplain sub-environment and the flocculated texture of clays in the brackish water, have been discussed in this paper. Overall, it is observed that the geotechnical data could be correlated with the geological features of the Bahmanshir Series.

Keywords – Bahmanshir, series, clay, geotechnical properties, sedimentary environment, Holocene

1. INTRODUCTION

The Holocene deposits of the southwest Khuzestan plain, known as the Bahmanshir Series, are mostly developed by fluvial to shoreline processes on deltaic to meandering fluvial systems. The principal locations of the series are along the Bahmanshir River and the Persian Gulf coast, where the Bahmanshir and Arvandrood Rivers meet the sea (Fig. 1).

The Bahmanshir Series consist, generally, of two gray to black clay-size layers intercalated with silty sand(SM) or silty layers(ML) (Fig. 2). The sandy and silty horizons between upper and lower clayey layers are believed to be developed in tidal channels which were highly affected by the Persian Gulf tidal regime. In terms of composition, using the XRD technique the principal minerals in the Bahmanshir clayey layers are quartz, feldspar and mica, and clay minerals consisting of a lesser percentage of soil.

The present paper aims to provide a comprehensive investigation on the geotechnical properties of the Bahmanshir Series and compare the results with those of similar deposits around the world [1-6]. A survey of the relation between the achieved geotechnical properties of constituent lithologies and their depositional environment is another purpose of this study [7].

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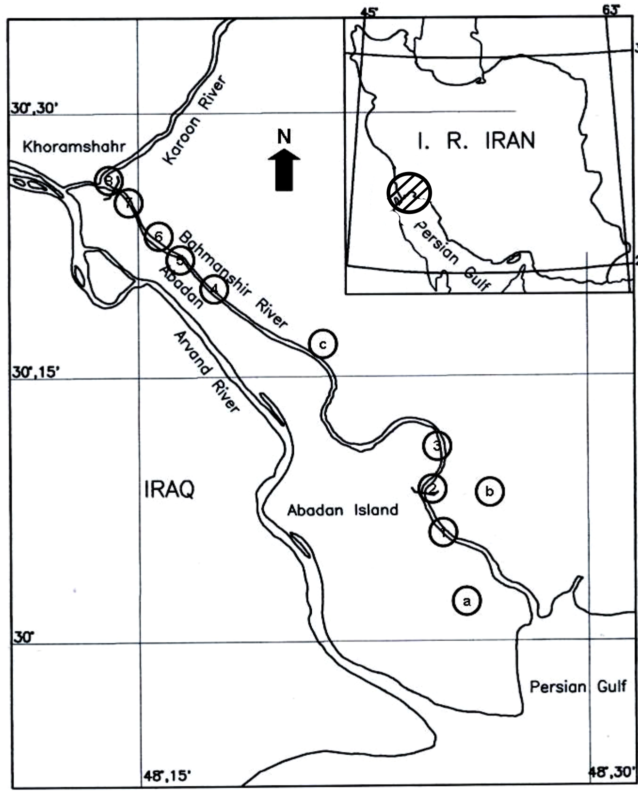

Fig. 1. Location map of the Bahmanshir Series and the boreholes in the study area (Geotechnical data of locations a, b and c have not been used in this research)

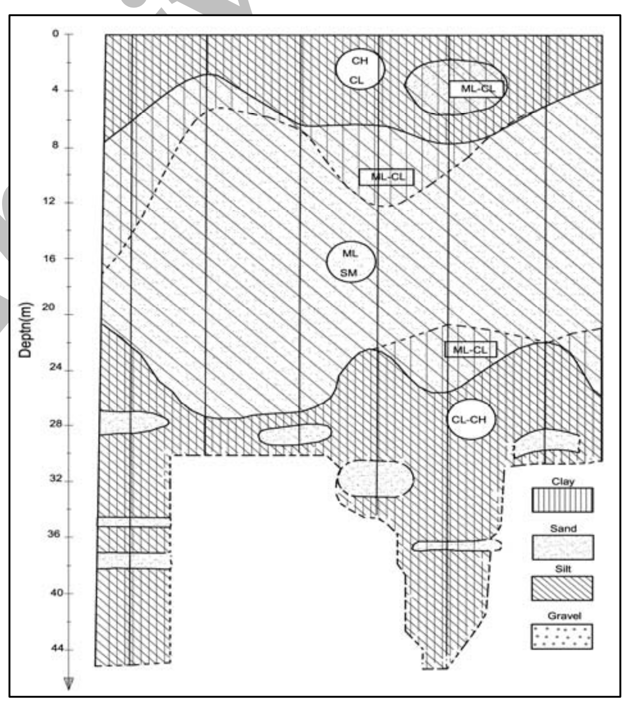

Fig. 2. Representative profile of Bahmanshir Series (Thickness of upper clay bed changes from 3-16m and thickness of lower clay bed changes 3- 20m)

2. GEOLOGICAL SETTING

The studied area is part of the Khuzestan plain/zone which belongs to the northern part of the Arabian platform. This area is mainly covered by Quaternary deposits, the thickness of which exceeds 300m in some areas. Sedimentological measurements in the studied boreholes indicate the thickening of sediments southward. The upper parts of the sediments (average 35m thick) are considered as early Holocene deposits developed by fluvial systems wandering on the Khuzestan plain. They are made up of fine-grained terrigenous sediments similar to the Holocene deposits of the Persian Gulf NW coast [8-10]. The age of the upper fine terrigenous sediments are reported 8630±50 years using AMS 14^C determinations [11]. In terms of depositional environment, it seems that sedimentation dominantly occurred in tidal channels and Persian Gulf inter-tidal zones.

3. BASIC PROPERTIES

Physical properties of the upper and lower clay bed of the Bahmanshir Series are shown in Table 1. The clay fraction (FC%) exceeds 90%, hence the term "clay" is more appropriate. There is not a wide range of bulk density in the Bahmanshir Series. This is to be expected by the associated values of specific gravity. Void ratio and moisture content do not vary significantly.

Table 1. Physical properties of upper and lower clay bed of Bahmanshir Series

Bed	location	D_{50} (mm)	FC%	LL%	PI%	w%	Bulk Density (gr/cm^3)	Dry Density (gr/cm^3)
Upper clay bed	1	0.009	88.0	35.2	13.0	30.0	1.82	1.40
	2	0.010	86.3	41.6	17.3	39.7	2.01	1.44
	3	-	-	-	-	-	-	-
	4	-	-	-	-	-	-	-
	5	0.014	92.6	43.3	19.7	45.5	1.72	1.17
	6	0.007	96.3	34.0	12.9	37.4	1.97	1.44
	7	0.009	93.2	37.0	15.1	30.0	1.89	1.41
	8	0.015	96.4	35.7	13.4	21.2	1.84	1.52
	Average	0.012	90.9	39.0	15.8	34.1	1.85	1.38
Lower clay bed	1	0.011	89.2	40.3	17.6	24.3	1.95	1.56
	2	0.010	94.1	36.1	14.3	24.0	1.96	1.59
	3	0.004	96.4	60.7	32.6	21.6	1.96	1.62
	4	0.004	96.0	42.2	16,9	24.4	1.95	1.56
	5	0.009	94.5	44.3	21.0	24.5	1.82	1.54
	6	0.005	85.8	36.8	14.8	20.3	2.07	1.72
	7	0.015	91.0	40.8	18.8	23.3	2.01	1.65
	8	0.006	94.5	46.1	22.4	19.5	2.10	1.75
	Average	0.008	92.7	43.4	20.2	22.7	1.98	1.63

The average of the void ratio being 1.3 and 0.8 for upper and lower clay layers, respectively. Some of the lowest void ratios are found in the lower bed, indicating a general tendency to reduce with depth. The moisture content, like the void ratio, appears to show a notable difference in variation from the upper to lower bed, but does not appear to change with depth into each layer. The relations between plasticity index, PI, and liquid limit, LL, with a high correlation coefficient of 0.93 and 0.92 in upper and lower clay beds, respectively, are as follows:

PI=0.66 (LL-14)………. (Upper clay bed) PI=0.69 (LL-14)…..…. (Lower clay bed)

In reality, according to the above equations and the percentage of clay fractions (up to 90 percent) in Bahmanshir clay beds, most of the particles are generally clay sized.

Bahmanshir clay is mainly of intermediate plasticity in most of the specimens (Fig. 3). In other words, according to the plasticity chart, these are inorganic clays of intermediate plasticity.

Nonetheless, the Bahmanshir clay is inactive. All the values of activity obtained for both clay beds being less than 0.5. The activity chart (Fig. 4) shows that these clays are low expansive. From the values of SPT, it appears that the upper Bahmanshir clay is a soft to very soft clay and the lower bed is a stiff to very stiff clay. The investigations do not show notable changes of physical properties along the Bahmanshir River into each bed.

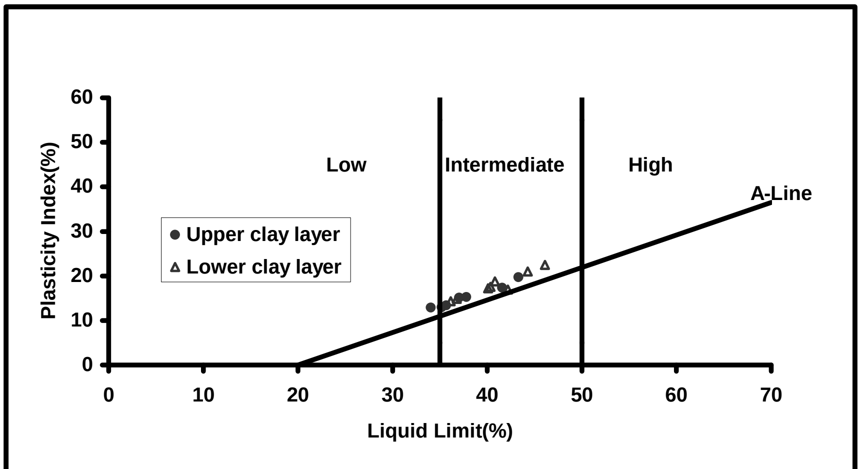

Fig. 3. Plasticity of Bahmanshir clay beds (Average values of consistency limits for locations)

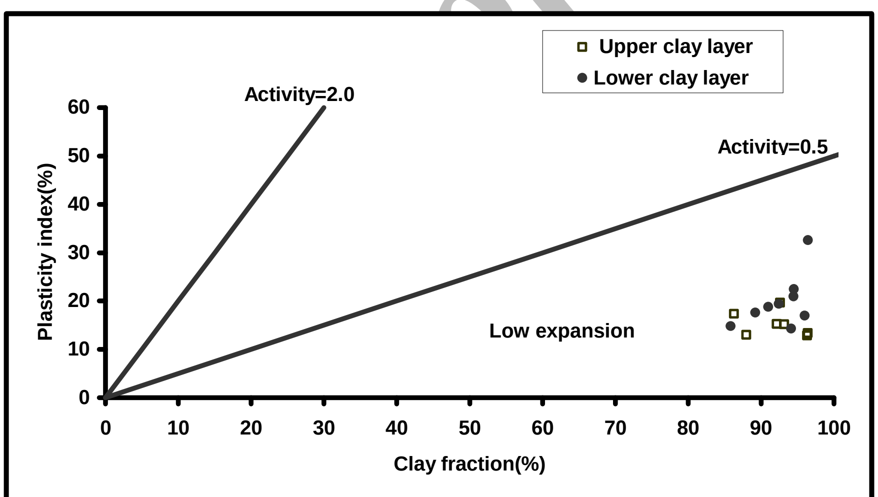

Fig. 4. Activity of Bahmanshir clay beds

In terms of the chemical properties of the Bahmanshir clay layers, average PH is 7.5 to 8.1 and electrical conductivity (E.C.) of this soil differ 2 - 230 mmho/cm in the horizons. The amount of $CaCo_3$ is generally more than 21% in the upper horizons of the Bahmanshir clay. Gypsum varies in amount, it exceeds about 20 meq/100 gr. soil in upper horizons to less than 4 meq/100gr soil in lower horizons and is generally decreased towards the sea. The mean percent of chlorine (CL%) is about 0.15 for the upper clay layer and 1.05 for the lower clay layer and finally, the mean percent of organic is about 0.77 for the upper clay layer which is decreased to about 0.62 for the lower clay layer.

4. ENGINEERING PROPERTIES

The undrained shear strength, as obtained by vane testing in the field, and the standard penetration test

(SPT) indicate that the upper layer of the Bahmanshir Series is a soft to very soft clay and the lower is a stiff to very stiff clay (Table 2). The highest strength is found in the lower bed. This may be the result of overburden pressures. Discounting the two beds, the others range in undrained shear strength, as remarked, is influenced by the moisture content and the clay fraction. Conversely, as the moisture content and the clay fraction increases, both tend to give rise to a decline in the undrained shear strength. Undisturbed and remolded vane shear strengths are obtained to investigate the sensitivity of the clay layers.

Table 2. Strength and consolidation characteristics of upper and lower clay layers of Bahmanshir Series

Bed	Location	SPT	q_u (kg/cm^2)	Φ°	C (kg/cm^2)	Φ′°	C′ (kg/cm^2)	C_c	C_s	e_0	Su_u (kg/cm^2)	Su_r (kg/cm^2)
Upper clay bed	1	2	0.280	-	-	-	-	-	-	-	-	-
	2	2	0.208	-	-	-	-	-	-	-	0.640	0.415
	3	-	-	-	-	-	-	-	-	-	-	-
	4	-	-	-	-	-	-	-	-	-	-	-
	5	1	0.140	-	-	19	0.100	0.34	0.09	1.6	-	-
	6	1	-	28	0.013	32	0.017	-	-	-	0.455	0.440
	7	4	-	16	0.511	25	0.084	0.37	0.02	1.1	0.550	0.460
	8	4	2.705	29	0.830	30	0.077	-	-	-	-	-
	Average	2	0.244	24	0.451	26	0.069	0.36	0.06	1.3	0.640	0.415
Lower clay bed	1	7	7.818	0.4	0.700	-	-	0.15		0.7	0.520	0.170
	2	12	1.463	7	0.750	25	0.000	0.15	0.03	1.4	1.063	0.513
	3	10	0.925	1	1.167	-	-	0.18	-	2.0	-	-
	4	23	1.600	0.3	0.283	-	-	0.19	-	0.7	-	-
	5	13	-	17	0.700	19	1.000	-	-	-	0.630	0.590
	6	22	2.893	-	-	-	-	-	-	-	-	-
	7	19	2.564	2	0.930	18	0.100	0.20	0.03	0.8	-	-
	8	15	9.295	33	0.550	29	0.185	-	-	-	-	-
	Average	15	3.794	9	0.726	23	0.321	0.18	0.03	1.2	0.738	0.424

SPT: Standard penetration test; qu: uniaxial strength; C: cohesion; Φ: angle of friction; C′: effective cohesion; Φ′: effective angle of friction; Cc: compression index; Cs: Sewell index; e_0: Void ratio; Su_u : undisturbed vane shear strength ; Su_r : remolded vane shear strength

In terms of sensitivity, ($S_t = Su_u / Su_r$) the upper clay bed is insensitive. The sensitivity in this layer does not show notable changes along the river. The lower clay bed shows changes of sensitivity along the Bahmanshir River. The predominately relatively sensitive clays near the river mouth give way to insensitive clays toward the upstream (Fig. 5). The insensitivity tends to increase with depth.

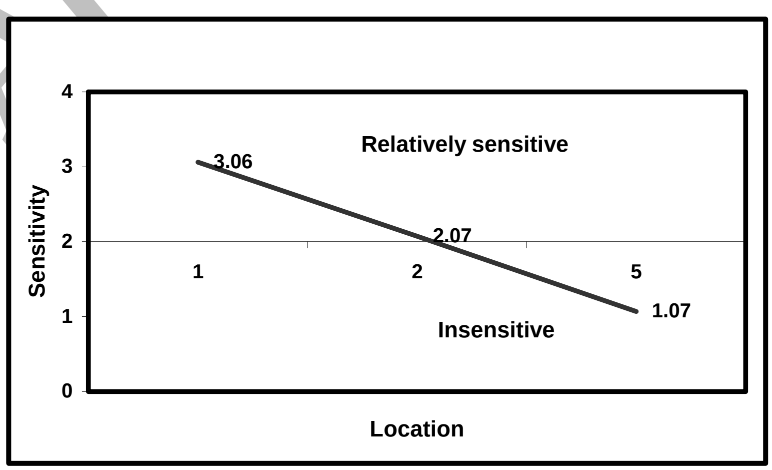

Fig. 5. Change of sensitivity for lower clay bed along Bahmanshir River

The compression and average swelling indexes for the upper and lower clay beds, together with pre-consolidation pressure (Pc´) in consolidation tests, confirm that the Bahmanshir clay is normally consolidated clay. The value of permeability of the Bahmanshir upper and lower clay beds was obtained 4×10^{-5} cm/s. This value indicates that the Bahmanshir clay is impermeable.

5. LINK OF THE GEOTECHNICAL DATA WITH GEOLOGICAL FEATURES

In this section, some links of the geotechnical data with geological features are represented. According to the relations between the plasticity index and the liquid limit, the percent of clay fractions (up to 90 percent) in Bahmanshir clay beds and the XRD technique, most of the particles are generally clay sized and consist of quartz, feldspar and mica and clay minerals consisting of a lesser percentage of the soil. This refers to their formation sources in the upstream of the basin (northern part of the Khuzestan Plain).

Because of the capillary feature in the Bahmanshir floodplain, the amount of gypsum and $CaCo_3$ exceed in the upper horizons. This event has had an influence on some properties of the soil. For example as mentioned above, the Bahmanshir clay is normally consolidated clay, so it is expected that the cohesion values from the CU tests to be close to zero, but these values are reported as larger values (Table 2). This disagreement is explained by the cementation due to the capillary feature in the floodplain sub-environment and increasing in the amount of gypsum and $CaCo_3$ in soil.

The sensitivity in the upper clay layer does not show any notable changes along the river which could explain why the bed has not been consolidated enough to show more than a 50% difference between undisturbed and remolded shear strengths. Due to the formation of the flocculated texture of clays in the brackish water of the sea the predominately relatively sensitive clays of the lower bed near the river mouth gives away to insensitive clays toward upstream. The effect of brackish water is decreased towards the upstream and river flow effects are gradually overcome. The insensitivity tends to increase with depth which could possibly reflect the change in mineral content with depth and be influenced by increasing overburden pressure.

Generally compressive strengths must be about twice those of the undrained shear strengths ($q_u=2S_u$). In Table 2, there is disagreement between these two parameters. It seems that, this deviation is due to the inaccuracy of laboratory tests. As explained above, in Bahmanshir clay beds, most of the particles are generally clay sized and consist of quartz, feldspar and mica, and clay particles consisting of a lesser percentage of the soil, so sampling this soil does not give a complete undisturbed sample and the samples for compressive strengths (qu) laboratory tests have some defects which cause decreasing values. Insitu tests like vane shear give logical and more reliable results in this soil.

Overall, it is observed that the geotechnical data could be correlated with the geological features of the Bahmanshir Series.

6. CONCLUSIONS

The Bahmanshir Series of South Khuzestan, which represent a succession of Holocene strata in Iran, generally consist of two clay layers which are separated by silty sand or a silt layer. These deposits were formed in a recent fluvio- tidal sedimentary environment.

Bahmanshir Clays can be classified as inorganic silty clays of intermediate plasticity. These clays are inactive and low expansive. The upper Bahmanshir clay can be regarded as soft to very soft clay and the lower bed is a stiff to very stiff clay. The upper clay bed is insensitive. For the lower bed, the predominately relatively sensitive clays near the river mouth give way to insensitive clays in the upstream. The Bahmanshir clay is normally consolidated.

It is observed that the geological features as Formation sources in the upstream of the basin, the cementation due to the capillary feature in the floodplain sub-environment and the flocculated texture of clays in the brackish water mainly affect the geotechnical properties of the soil. In other words, the conditions of sedimentary environments affect the geotechnical characteristics of the soil.

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