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Contribution to the geotechnical study and estimation for differential settlements of Mila region soils (North-East Algeria)

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Abstract. This work presents the geotechnical study to part of Mila region (Algeria); case of Marechou site which forms the southern extension of Mila city. It's characterized by steep slope terrains and clayey nature belonging to Mio-Plio-Quaternary age. These trainings constitute seat of lot geotechnical problems such as differential settlements, who's engenders damages in the constructions. This study has done to contribute and to solve this problems. Therefore, we have preceded chemical analysis, petrographic analysis according to the model of Czerminski and geotechnical study by analysis of various parameters. The results of chemical and petrographic analysis shows marl, clay and sometimes sandy soils predominantly low aggressiveness. The geotechnical analyzes have shown that these soils are medium clays with very saturated steep, slightly moist to moist, more or less compact and belong to three main families of clay minerals (montmorillonite, kaolinite and illite). The lithological nature (clays and marls) and morphology of land as well the presence of groundwater are the main factors in triggering ground movements, including differential settlements which present major risks. The combination of geological, morphological and geotechnical data allowed emphasizing the favorable and unfavorable areas to construction. The introduction of protection techniques against these risks is highly recommended.

Keywords: *Geotechnical analysis, Petrographic analysis, Differential settlements, Mila, Algeria*

1. Introduction

In the world, the soil is exposed to various natural hazards or risks such as erosion [1], contamination [2], salinity [3], slips [4], settlements [5], swelling [6]…etc.

Algeria has been the subject of a lot research's, we quote the effort of Azzouz 2015 on Tlemcen region [7], Benaissa 2003 on Constantine [8], Bellatrache 2013 on Ain Aminas region [9]and Athmania 2010, 2011, Afes 1996, Afès & Didier 2000 and Khellaf & al. 2015 on Mila region [10, 11, 12, 13, 14]…etc.

Mila region is part of Constantinois basin. It's characterized for the most part by gray, brown and black clays overlying gray marl of Mio-Plio-Quaternary age [15]. These soils have very large volume variations (differential settlements) [13, 7,16] when their water content varies on response to climatic conditions, the existence of aquifer and it's depth, the lithological nature, the mineralogical composition and the anthropogenic actions [16, 7]. These variations on volume affect the foundations working and constructions [5] in contact with these soils cause particularly intense damages on periods of drought [17, 18].

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This work focuses on chemical analysis and analysis of geotechnical parameters for soils on Marechou region (Mila) mentioned above, in order to establish differential settlements map for this area and find adequate solutions for resulting technical problems encountered during the infrastructures implantations.

2. Material and Method

2.1.Study Riding

The Marechou region (Mila) is located at about 5 km of southern Mila city and geologically belongs to Neogene Mila-Constantine basin [15]. This zone is mainly formed by black marl or marly clays of Mio-Pliocene age [19]. The site is limited on the South by mountainous of Marechau ridge, on the East road to Marechou village, on the North Sennawa city and DNC and on the west road towards Oued el Atmania (Fig. 1).

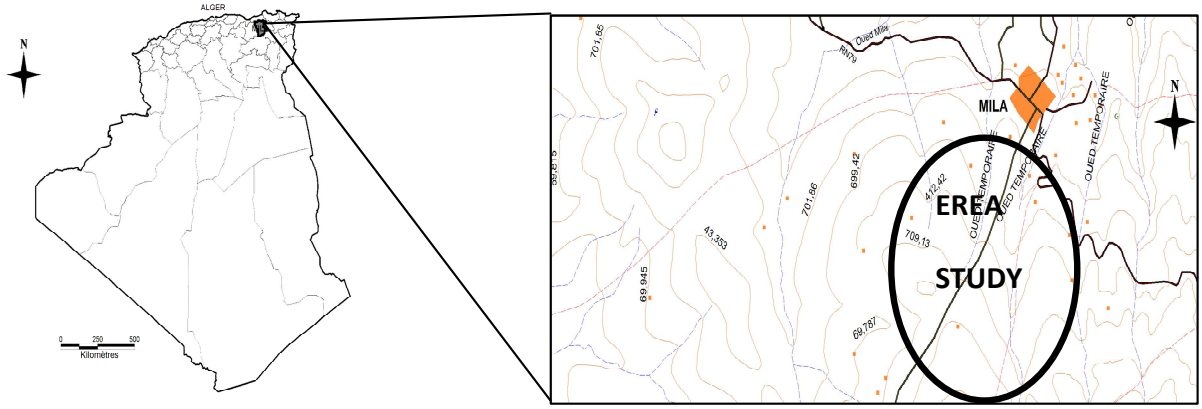


Fig. 1: Geographical location of Marechou region (Mila).

2.2. Litho-stratigraphic characteristics of studied region

2.2.1.Neogene deposits

Marechou region is mainly characterized by detrital deposits (gravels, sands, conglomerates and clays), evaporitic deposits (gypsum and rock salts) and lake limestones [19]. On Mila Basin, these deposits are largely dominated by lagoon-marine (clays, marls and evaporites). It's dated from superior Miocene (Seravalian) to Paleocene [15].

2.2.2.Quaternary deposits

They cover previous formations and represented by shingles and blocks of several cubic meters on a mass of red clay. These deposits correspond to mass displacements on form of muddy flows [15]. According to this author, the most important part of Mila city is built on these flows.

2.3.Sampling

Clays examined have been taken from different depths. These clays have been chosen according to the problems encountered in this region specially the instability of the area.

2.3.1.Samples Analysis

The analysis of samples has been performed as follows:

- Petrographic or chemical-weight analysis, which determines the percentages of carbonates, clays and sands, for specific weight of fine soil with a diameter less than 0.063 mm [20].
- Geotechnical analysis: This analysis is performed by determining various geotechnical parameters to soil of the two studied sites [21].

The interpretation of the results obtained is from the international bibliography.

3. Results and Discussion

3.1.Chemical analyzes

The results of these analyzes are grouped in the following table (Table 1).

Table 1 : Chemical analysis results of samples examined [22].

SC	Depth (m)	Sulphates (g/kg)	SC	Depth (m)	Sulphates (g/kg)
SC 1	2.70-3.00	Traces	SC 8	2.40-2.80	22.48
SC 2	2.70-3.00	8.85	SC 10	2.30-2.60	Traces
	4.70-5.00	Traces		4.70-5.00	Traces
SC 5	2.90-2.90	Traces	SC 12	2.00-2.40	16.28
SC 6	3.00-3.40	Traces			

The samples examined show a low sulphate rates (trace) for the majority results; except for the three samples (SC2, SC8 and SC12) which has a higher content. So, this soil presented a low aggressiveness for the majority of ground [23]. The presence of these sulphates may have several origins, for example gypsum formation dissolution [24, 25, 26, 27].

3.2.Petrographic analysis (chemical-weight) and rocks classification

The results obtained are grouped and represented on the following ternary graphs (Fig. 2).

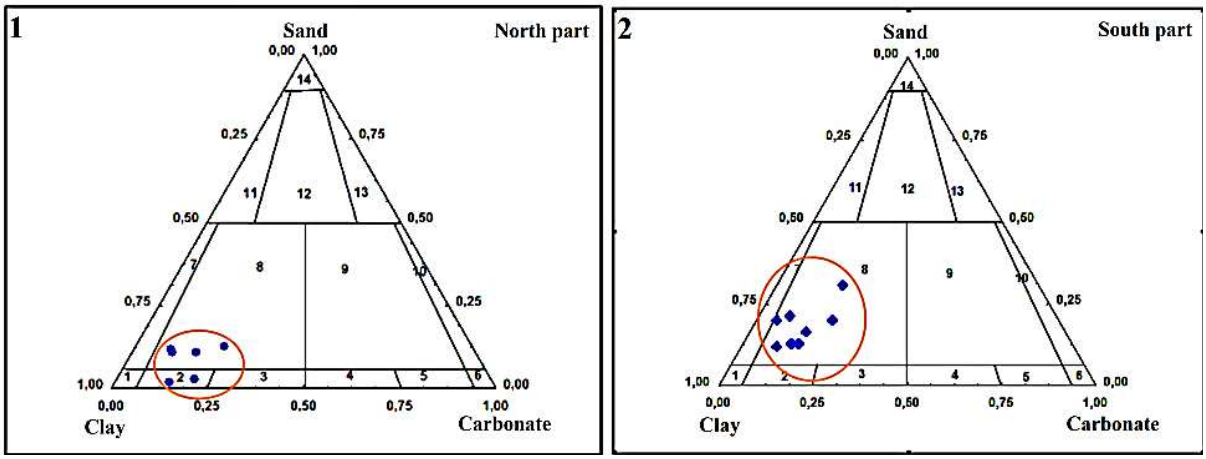


Fig. 2 : Ternary presentation of chemical-weight results analysis and sedimentary rocks classifications according to Czerminski method. 1 . Profile 1 (South part of site), 2 . Profile 2 (north part of site), 1.Clay, 2.Marly Clay, 3. Clayey marl, 4. Marl, 5. Marly limestone, 6. Limestone, 7. Sandy clay, 8. Marly sandy clay, 9. Sandy marly limestone, 10. Sandy limestone, 11. Clayey sandstone, 12. Marly sandstone, 13. Limestoneous Sandstone. 14. Sandstone.

The petrographic analysis of the samples taken (Fig. 2) gave, in general, marly clays, marl-sandy clays and sandy clays. The levels of fine sediment components are 44.85 to 83.17% for clays, 2.34 to 30.33% for carbonates and 0.12 to 40.73% for sands. These analyzes show higher clay contents (>

75%) which makes it's possible to classify the Marechou site soils as clays, marl and sometimes sandy clays [28, 29], contents of silica (SiO_2) is less than 80%; this percentage is the boundary between swelling and non-swelling soils [30, 31, 10, 11] and low to medium calcium carbonate contents (0 to 30%); which is a good index of soil mechanical resistance [32].

3.3.Analysis of geotechnical parameters to the studied site

The following Fig.s and tables summarize the results obtained from these tests and their presentation, classification and interpretation based on the conceptions shown on the international bibliography.

Table 2 : Physical characteristics to soils of Marechau site [33].

SC	Depth (m)	w (%)	Sr (%)	γ_d (t/m^3)	γ_h (t/m^3)	WL (%)	Ip (%)	σ_c (bar)	Cc (%)	Cg (%)	C (bar)	φ (°)
1	2.7-3.00	19.18	94.72	1.73	2.06	56.28	35.19	1.43	0.23	0.06	0.76	4
	5.00-5.50	18.93	99.93	1.77	2.01	51.12	27.61	1.32	0.19	0.05	0.52	4
2	2.7-3.00	19.64	95.91	1.72	2.06	65.32	41.63	2.43	0.23	0.09	0.28	2
	4.70-5.00	20.55	92.74	1.67	2.10	64.57	39.05	2.28	0.19	0.07	0.53	2
	6.00-6.60	17.94	89.70	1.73	2.04	-	-	1.50	0.18	0.07	-	-
3	2.20-2.50	17.65	93.47	1.77	2.08	60.95	36.31	1.93	0.20	0.05	0.43	4
	4.40-4.70	15.20	92.24	1.85	2.13	48.58	26.09	2.00	0.15	0.07	0.33	4
4	2.20-2.70	21.37	95.66	1.67	2.02	43.93	23.83	1.52	0.17	0.03	0.33	4
	4.50-5.00	19.33	96.18	1.73	2.06	63.37	37.63	2.06	0.22	0.04	0.11	2
	6.60-7.00	19.33	96.18	1.73	2.06	-	-	1.03	0.20	0.06	-	-
5	2.60-2.90	16.58	96.59	1.82	2.12	42.34	24.26	1.40	0.23	0.06	0.40	7
	5.60-5.90	13.63	94.21	1.92	2.18	44.20-	24.15	1.07	0.20	0.05	0.11	4.2
6	3.00-3.40	19.10	89.89	1.70	2.02	-	-	2.43	0.23	0.09	0.4	4
	5.70-6.00	19.05	85.99	1.67	1.99	52.43	27.30	1.54	0.14	0.05	0.10	4
8	2.40-2.80	22.80	93.62	1.61	1.98	50.95	26.33	150	0.16	0.04	0.15	4
	6.10-6.50	16.79	96.19	1.81	2.12	54.36	32.66	1.35	0.11	0.04	0.11	5
9	2.00-2.40	20.66	96.61	1.69	2.04	59.19	32.90	1.35	0.19	0.05	0.28	6
	5.00-5.40	19.27	96.64	1.73	2.07	49.77	26.16	1.50	0.20	0.06	0.10	8.2
10	2.30-2.60	21.98	94.52	1.64	2.00	64.68	38.55	1.21	0.16	0.05	0.08	10
	4.70-5.00	16.24	96.50	1.83	2.13	43.59	24.71	1.29	0.14	0.06	0.34	10
	6.80-7.00	19.17	92.69	1.71	2.04	-	-	1.21	0.16	0.05	-	-
11	3.60-4.00	17.75	94.46	1.77	2.09	57.31	33.89	1.30	0.18	0.03	0.43	3.7
	5.50-5.90	19.07	90.84	1.70	2.03	39.54	20.98	0.76	0.22	0.06	0.17	2
12	2.00-2.40	23.81	96.18	1.60	1.98	-	-	1.35	0.20	0.07	0.08	5
	5.00-5.40	18.90	93.48	1.73	2.05	61.71	36.90	2.28	0.18	0.08	0.15	4

The Marechou site soils have water contents (w) from 13.63 to 29.85%, saturation degree (Sr) from 85.99 to 99.97%, wet densities (γh) from 1.88 to 2.18 t/m3, dry densities (γd) from 1.48 to 1.92 t/m3, Atterberg limits gave WL values of 39.54 to 79.46% and Ip from 20.98 to 49.44% [35, 33], their representation on the Casagrande diagram and abacus shows that these clays are, on the one hand, positioned above the line A (Fig. 3), on the other hand, are between the line A and the line U (Fig. 4). These results make it's possible to classify the soils analyzed as medium to steep clay very saturated by water and slightly wet to wet, calyey nature [32, 36, 37, 38], exhibit a more compact and sometimes more or less loose behavior [38], are on the whole little plastic (AP) to very plastics (AT) and belongs to three main families of clay minerals (montmorillonite, kaolinite and illite) (Fig. 4).

From this results obtained it's noted that the values of limits are largest enough that the norms and clays studied are swelling [39].

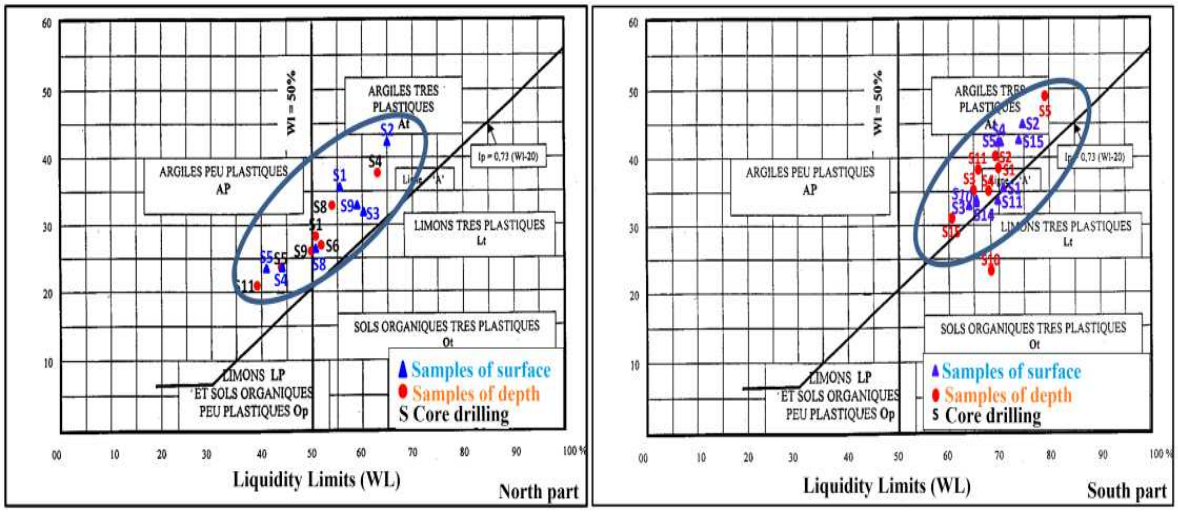


Fig. 3 : Position of Marechou clay on the Casagrande plasticity diagram.

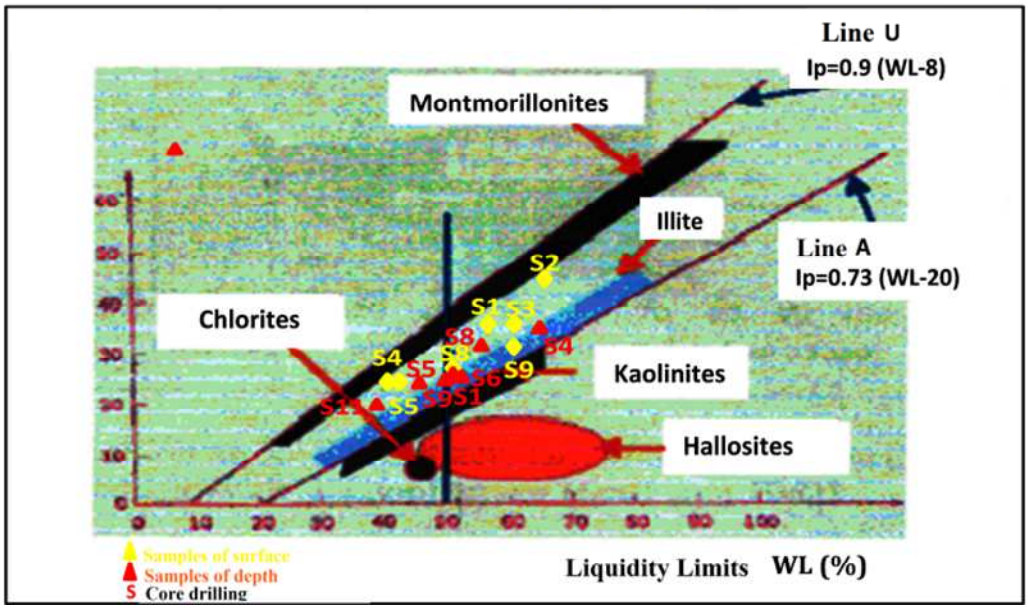


Fig. 4 : Position of Marechou clay on the Casagrande plasticity abacus.

Sieving granulometric analysis (Table 3) shows that: the soil samples analyzed gave a higher percentage of fines (80µ) from 57 to 87% greater than 50% (LCPC) and low to very low level of coarse elements (sand and gravel) from 0 to 17%. According classifications given; these soils are clays and loamy clays [14, 13, 37, 36, 38].

Table 3 : Granulometric analysis results from some core holes on Marechou site [33].

Parametres	SC3		SC4	SC10
Depth (m)	1.20-1.80	1.80-3.00	3.0-3.40	1.0-1.40
% Gravels	3	17	0	1
% Coarse sand	8	11	0	3
% Fine sand	12	10	13	14
% clay and limon	73	54	87	82

The triaxial test of UU and CD type had a cohesion (C) less than 1 bar (0.08 to 0.76 bar), an internal friction angle (φ) of 2° to 10° (UU) and average of 13.86 to 40.54° for (CU). The oedometric test gave an underconsolidation stress (σc) from 1.03 to 3.22 bar, the compressibility coefficient (Cc) from 0.11 to 0.32 and swelling index (Cg) from 0.05 to 0.092. The low cohesion and internal friction angle (UU) due to the small percentage of fine elements and the high percentage of sands, the low cohesion and the average internal friction angle are due to the high proportion of fine sands in clays [40, 34]. This shows that all facies analyzed are medium to steep clays and coherents [38, 26]; the results of oedometric test show stiff clay [38] medium overconsolidated, medium to highly compressible and medium to high swelling potential [41, 39]. The parameters variations seem to confirm heterogeneity of the terrain [27].

3.3.4. Calculation of foundation settlements from laboratory tests

Penetrometrical soundings that have been carried out gave us peak resistance minimum values from 16 to 70 bars. According to this result we recommend the superficial foundations (strip or square footing). Calculation of settlement for these foundations is done according to conceptions shown on the international bibliography.

• For strip footing

If we have strip footing there is no influence of foundation shape and in the worst case the groundwater in the studied site is at 2m deep (Z) so, we show it's influence by checking the following condition : 0 <D <1,5B (D is the anchoring foundations equal 2m). For a foundation of width B = 2m so, the condition is verified and there is influence of groundwater. In this case the general formula of limit stress and admissible stress are: Second point.

$$q_L=((\gamma'+D/1,5B)(\gamma_2-\gamma')).(0.5BN_\gamma)+N_q(\gamma_1D_1+\gamma_2D_2) \quad (1)$$

$$q_{ad}=(\gamma_1H_1+\gamma_2H_2)+(q_L-(\gamma_1H_1+\gamma_2H_2))/3 \quad (2)$$

• For square footing

For the square footing there is an influence of foundation shape and the groundwater (which is at 2m depth). In this case the general formula of limit stress and admissible stress becomes. And so on.

$$q_L=0,5BN_{\gamma 2}(\gamma'+(D/1,5B)(\gamma_2-\gamma')(1-(0,2B/D))+(\gamma_1H_1)+\gamma_2H_2)N_{q2}+(10,2B/D)N_{c1} \quad (3)$$

$$q_{ad}=(\gamma_1H_1+\gamma_2 H_2)+(q_L-(\gamma_1H_1+\gamma_2H_2))/3 \quad (4)$$

For that the calculation of settlements formula (ΔH_i) for the overconsolidated soils is the following.

$$\Delta H_i=H_i(Cc/(1+e_o))\log((\sigma_o+\Delta\sigma_z)/(\sigma_c') \quad (5)$$

and for underconsolidated soils is:

$$\Delta H_i=H_i(C_g/(1+e_0))\log(\Delta\sigma_z/\sigma v_o) \quad (6)$$

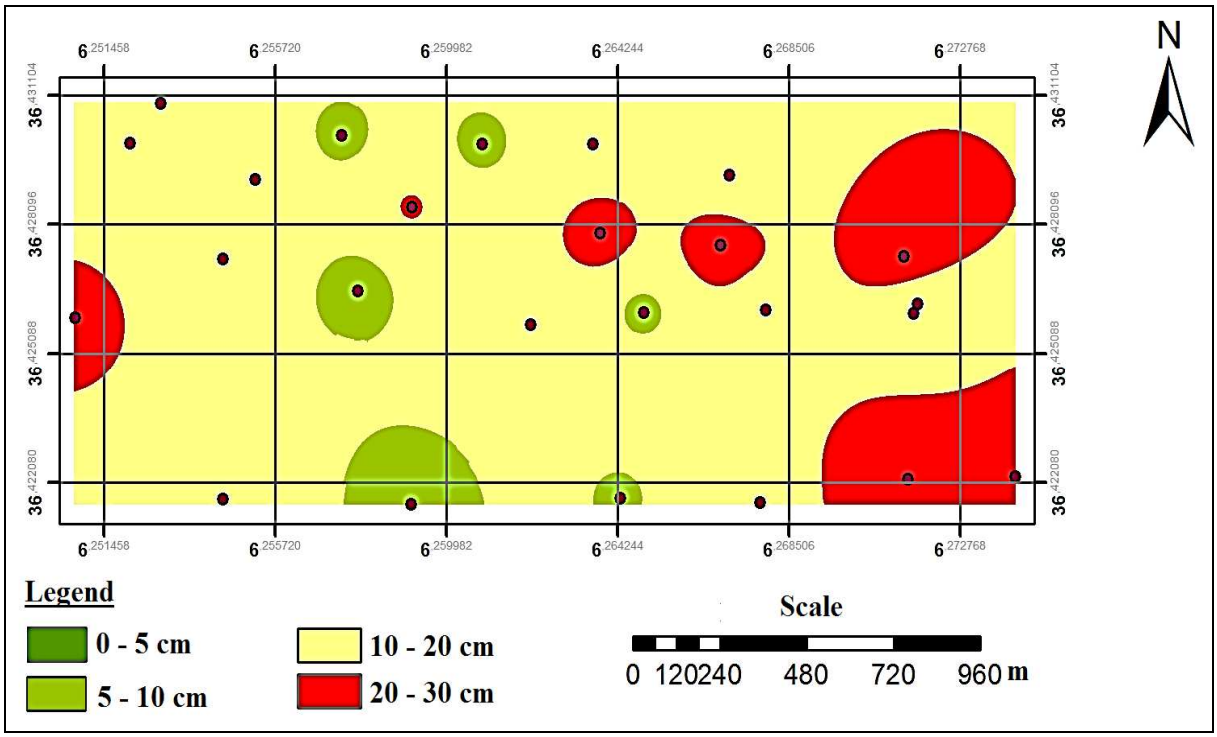
The results obtained are regrouped in the tables and the Fig.s below.

Table 4 : Calculation Results of qL, qad and ΔHi (Strip footing).

South Part				North Part			
Paramètres	q_L (KN/m^2)	q_{ad} (KN/m^2)	ΔH (cm)	Parametres	q_L (KN/m^2)	q_{ad} (KN/m^2)	ΔH_i (cm)
C1	855,9	381,33	16.29	SC1	683,86	304,15	10.6
SC2	604,94	268,95	19.654	SC2	611,9	272	15.44
SC3	686,5	305,34	6.82	SC3	656,21	291,74	8.14
SC4	875,55	390,16	11.20	SC4	610,97	271,3	8.24
SC5	603,5	268,3	24.38	SC5	755	336,3	13.45
SC6	1229,47	505,2	19.11	SC6	1059,5	435,02	14.65
SC8	704,41	313,47	4.98	SC7	834,18	350,86	16.96
SC9	612,74	272,46	9.15	SC8	802,21	357,22	20.6
SC10	718,64	302,05	17.92	SC9	665,83	295,98	24.41
SC11	554,25	246,25	27.75	SC10	355,54	187,26	26.2
SC12	595,48	264,57	22.88	SC11	740,91	329,77	27.66
SC13	487,11	216,17	16.86	SC12	653,49	290,56	8.13
SC14	720,28	320,44	14.35				

Table 5 : Calculation Results of qL, qad and ΔHi (square footing).

South Part				North Part			
Parametres	q_L (KN/m^2)	q_{ad} (KN/m^2)	ΔHi (cm)	Parametres	q_L (KN/m^2)	q_{ad} (KN/m^2)	ΔH_i (cm)
SC1	45,3	141,33	15.95	SC1	83,24	159,44	11.69
SC2	20,59	87,89	13.78	SC2	50,41	118,4	10.99
SC3	63,88	140,394	7.54	SC3	139,02	212,02	15.84
SC4	124,48	222,79	4.45	SC4	38,84	106,48	6.80
SC5	63,84	131	17.42	SC5	27,63	112,2	9.30
SC6	98,41	193,8	20.30	SC6	85,67	167,55	10.38
SC8	89,1	167,78	24.82	SC7	43,23	116,04	10.9
SC9	51,85	120,06	25.90	SC8	27,08	116,9	14.27
SC10	13,47	75,98	12.28	SC9	52,74	126,79	17.32
SC11	76,37	137,87	19.78	SC10	108,88	177,63	18
SC12	30,513	96,59	15.82	SC11	43,63	126,44	18.14
SC13	34,63	88,43	11.52	SC12	14,89	87,62	15,1
SC14	40,061	120,41	9.12				



.**Fig. 5** : Spatial variability map of differentials settlements under strip footing.

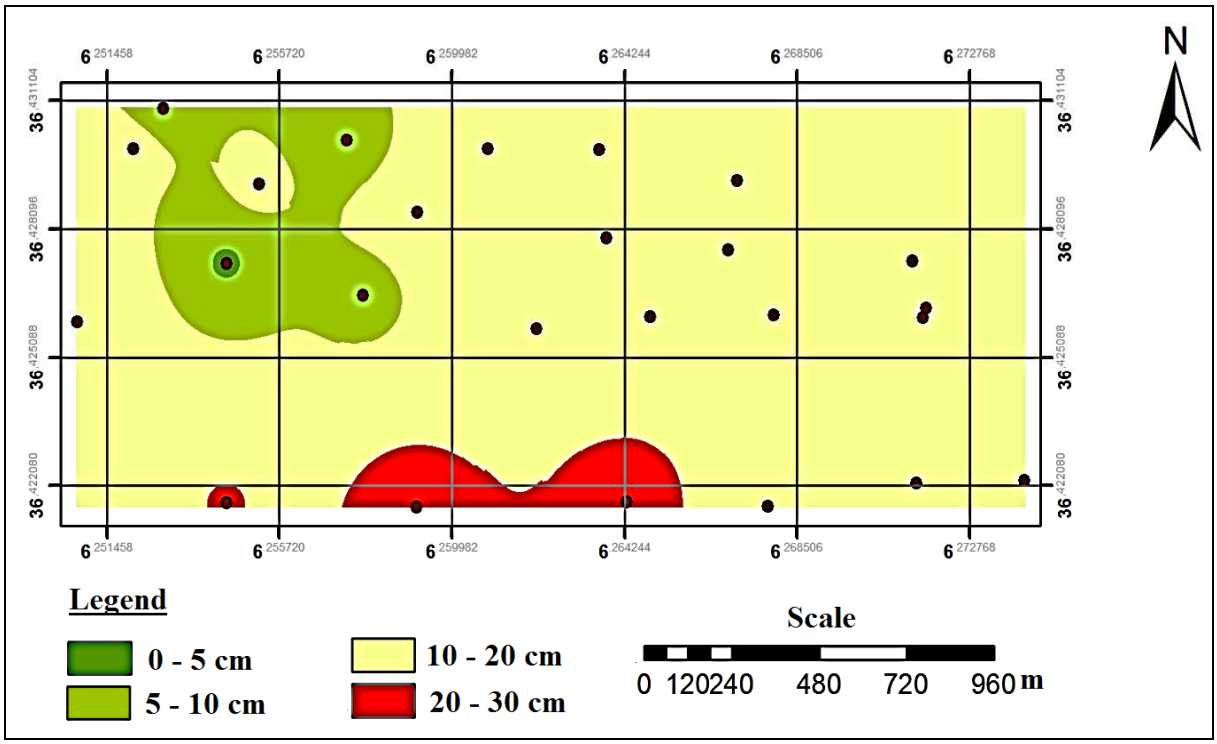


Fig. 6 : Spatial variability map of differentials settlements under square footing.

The values of differentials settlements (ΔHi) recorded at Marechou site are very high, ranged between 6.82 to 27.75 cm for strip footing and from 4.45 to 25.90 cm for square footing (Table 4 and 5). The Interpolation and representation of these values on spatial variability maps (Fig. 5 and 6) shows that the majority soils of this region are presented very large volume variations and have tendency to settle.

These differentials settlements are greater than 5 cm either under strip or square footing and occupy the whole of studied region. The zones where these settlements ($\Delta Hi < 5cm$) are minimal and occupy reduced area on maps (Fig. 5 and 6). The values recorded under strip or square footings in our site studied, appeared to be identical and are mostly greater than 5 cm. Therefore, they are not admissible so, buildings and individual houses are in danger [18, 38, 5]. This phenomenon is generated in this region when their water content varies in response to climatic conditions, hydrostatic effect of groundwater [7], the difficulty of draining water from these soils, draining the groundwater [16] and the presence or abundance of fine clay minerals on soils; such as the smectite which is very sensitive to the phenomenon of shrinkage- swelling, especially in semi-arid zone, which can manifest itself as differential settlements of foundations [10].

3. Conclusion

The Marechou region (Mila), which includes the studied site, belongs to Neogene basin of Mila-Constantine; characterized by tellian formations mostly formed by marl and clay of Mio-Pliocene age. The chemical analysis of site soils shows low to very low levels of sulphates with low aggressiveness. The petrographic analysis of these soils yielded marly clays, marl-sandy clays and sandy clays.
Laboratory tests make it possible to classify the Marechou soils as medium to steep clay that are very saturated by water, slightly moist to wet, not very plastic (PA) to very plastic (AT), exhibit a more compact behavior, sometimes more or less loose, uniformly sized and spread. These clays are consistent, overconsolidated, medium to highly compressible and medium to high swelling potential.
As a result, these clays also have large volume variations and show very high differentials settlements values (greater than 5 cm).These settlements affect working foundations and constructions in contact with these soils so, they are the cause of particularly intense damage in periods of drought.

4. Recommandations

Once the problem occurred on study area, we concluded that the dwellings installed in this site will be uninhabitable because settlements will increase under permanent loads and operating expenses which threatens life human, for that we recommend:

- A drainage system to accelerate consolidation.
- Continuous monitoring of settlements until stabilization.
- If the settlement is excessive, this problem must be solved either by strengthening the soil or by modifying the anchoring of foundations (changing the type of foundation) or modifying the stress imposed by the structure to increase the carrying capacity of foundation
- Drainage upstream of site with rainwater collection
- Maintain the level of groundwater below the anchorage of foundations by performing a peripheral drainage.
- To prohibit the implantation of trees near to device constructions

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