Geotechnical Characterization and Behaviour of Tunis Soft Clay

Nadia Mezni[1] and Mounir Bouassida[2]
[1,2]*Université de Tunis El Manar – Ecole Nationale d'Ingénieurs de Tunis. LR14ES03-Ingénierie Géotechnique, BP 37 Le Belvédère, 1002, Tunis, Tunisia*
E-mail: Mounir.bouassida@fulbrightmail.org

ABSTRACT: Tunis soft clay being known as one of the most problematic soils has poor mechanical characteristics, high compressibility and exhibits fragile shear strength. This paper considers the geotechnical characterization of Tunis soft clay by compiling results from in situ and laboratory tests. Accordingly, some correlations are suggested. The assessment of observed behaviour of Tunis soft clays in the zone of interchange ramps was investigated. The follow up of ramps behaviour was performed for a period of three months. The evolution of settlement was monitored by rod settlement, hydraulic settlement and multi-points settlement. A plane strain model was built for numerical investigation conducted by Plaxis software to simulate the behaviour of the ramp's embankment. Hardening Soft Soil Model (HSM) and Soft Soil Model (SSM) were adopted for the soft clay layer. The results showed an agreement between the predictions of the two models of the behaviour of the soft clay. Using measured settlement, the adopted behaviour for Tunis soft clay is justified.

KEYWORDS: Geotechnical investigation, Data, Characterization, Simulation, Soft clay, Behaviour

1. INTRODUCTION

The characterization of soft soils still remains a challenging task as reported throughout several studies carried out in all regions of the globe. For this reason, numerous research projects were carried out to recommend the suitable investigation tools for in-situ and laboratory testing and to propose useful correlations ensuring the best geotechnical characterization of soft clays. In this view different methods were suggested for the estimation of soft soils properties, in particular the determination of undrained cohesion, a key parameter for the design.

Further, solutions of foundations often require the practice of ground improvement techniques; therefore the design of improved soft soils by vertical drains (Bergado et al, 1996), vacuum consolidation, (Indraratna and Rujikiatkamjorn, 2006) stone columns (Bouassida, 2016), deep soil mixing techniques (Chai et al, 2012) , etc.. involve other investigations for example linked to the acceleration of consolidation, e.g. permeability, and the improvement of soft soil characteristics owed to specific installation procedure for each improvement technique (Guetif et al 2007). All these facts show that research investigations on soft soils should be treated carefully.

The ground of Tunis is mainly constituted by clay layers often very soft over the first 20m depth. This soft soil causes significant problems especially in terms of geotechnical identification because of the extraction of undisturbed samples which is too difficult and also when performing the in situ tests. From several oedometer tests conducted on intact specimens extracted at various depths less than 20 m the over-consolidation ratio of Tunis soft clay was found in the range of 0.8 to 1.1 (Bouassida, 2006). Although those results indicate that Tunis soft soil is classified as slightly under consolidated it is almost assumed normally consolidated soil.

Besides, the design of foundations on such soil requires some precautions. Among the well known cases history in Tunis, the construction of the 20 floors Africa hotel located at Bourguiba Avenue. The problem lied in the inadequate choice of the execution technique of piled foundation. In addition, several pathological case histories have been reported for existing buildings founded on Tunis soft clay.

Certainly, the soft soil cannot be extracted without being disturbed. The soft aspect of clay significantly affects the results of laboratory tests mainly because of its sensitivity to transportation. These factors well mark the big difference between results obtained from laboratory tests.

The reconstitution of soft soil represents a suitable solution in using homogeneous samples with controlled water content and well known history of consolidation. The first, or initial, consolidation allows to avoid the correction of the consolidation curve of reconstituted sample. But in reality, the results obtained from mechanical tests conducted on reconstituted samples are not comparable to results determined from tests performed on intact ground (Bouassida, 2006; Klai and Bouassida, 2015).

This paper aims to the characterization of Tunis soft clay by compiling collected data from geotechnical surveys conducted for buildings and infrastructures constructed during the last three decades along the Republic avenue of Tunis City. Then correlations are suggested for Tunis soft clay. Using the correlated geotechnical parameters an embankment case study built on Tunis soft clay (TSC) improved by geodrains is investigated numerically. The validation of predicted embankment behavior is discussed.

2. SITE AND DATABASE DESCRIPTION

The studied area is the Republic Avenue which runs along 2 kM. This avenue connects with the highway A1 from the north to the south side. Guilloux and Nakouri (1976) developed geotechnical maps classifying this site as compressible ground. Later, data collected by Kaâniche (1989) classified this site to be with poor characteristics formed by a muddy complex up to 60m depth. Ammar (1989) developed an electronic geotechnical data describing the lithology as: embankment, soft clay and rigid stratum at 67m of depth.

Since a decade the study of behavior of Tunis soft clay started at the geotechnical laboratory of National Engineering School of Tunis (Bouassida 1996, Tounekti et al 2008 and Touiti et al 2009). Those investigations only focused on laboratory tests and the simulation of numerical behavior of Tunis soft clay. Recently, more attention has been given to the characterization of Tunis soft clay for much suitable design of structures built in Tunis City where this problematic soil is frequently encountered. Accordingly, it was thought that the creation of an updated geotechnical database from existing projects at the Republic avenue site will be an efficient tool to the characterization of Tunis soft clay. The geotechnical investigations carried out for seven projects are given in Figure 1.

Data was collected from sixty (60) Pressuremeter borings (PB), thirty six (36) Cored borings (CB), seven (7) piezocone and cone penetration tests (PCPT/CPT), six (6) Vane shear tests (VST) and one hundred and fifty seven (157) Undisturbed Samples (US).

Table 1 summarizes the type, the number of borings and reached depth for each geotechnical survey mainly performed for buildings and infrastructure projects along the Republic Avenue (Tunis City)..

Statistically, the consistency of site investigation program confirms that the pressuremeter apparatus is the most used testing tool in geotechnical investigation with 55% like proved by Haffoudhi et al (2005).

Figure 1 Map location of the studied area

The results of laboratory tests were selected over one hundred fifty seven (157) grain size distributions, twenty nine (29) oedometer tests, seven (7) direct shear tests, thirteen (13) triaxial CU+ u tests and twenty two (22) triaxial UU tests.

The selected results are compiled to suggest an updated Tunis soft clay characterization with related correlations. Using these results the simulation of behavior of embankment ramps is investigated.

Table 1 Consistency of in situ geotechnical investigations

Project	Survey		
	Type	Depth (m)	Number
Culture City	PB	61 to 69	21
	CB	60 to 70	11
Interchange "Cyrus Le Grand"	PB	65 to 70	11
	CB	65	9
	PCPT	28	2
Interchange Z4	PB	68 to 70	15
	CB	70	6
	CPT	40	2
	PCPT	40	3
	VST	15	4
National Transportation Society	PB	70	3
	CB	70	2
	VST	51 to 55	2
UBCI bank	PB	60	2
	CB	60	2
Twenty store building	PB	70	6
	CB	25 to 70	4
Mokhtar ATTIA Parking	PB	60	2
	CB	60	2

3. RESULTS AND CORRELATIONS

3.1 Results

The averaged soil profile along the Republic avenue shows an upper fill layer of thickness of 2 to 4 m, followed by a soft grayish clay layer of variable thickness from 15 to 20m having quite low pressuremeter modulus (E_M) between 0.2 and 17 MPa and limit net pressure (Pl^*) between 0.08 and 0.8 MPa, a compressible clay layer with sandy clay to sand in some places having a pressuremeter modulus between 0.5 and 30 MPa and net limit pressure between 0.08 and 1.4 MPa. The rigid stratum is located at 50m depth toward the North direction while the level stratum is 60 m to 70m in the South direction. The ratio E_M/Pl^* related to the soft clay in the first 20 m depth is generally between 6 and 10. Thus, this soil after Menard's correlation is classified under consolidated. CPT and CPTu data reveal that the soft soil layer is characterized by a tip resistance (q_c) lower than 1MPa and the friction ratio is between 1 and 3. According to Van Wambeke et al. (1982), the ratio q_c/p_l is 3 in clays that was confirmed by Frikha et al (2013).

Referring to the compiled data, the calculated values for the water content are high on the surface with 94%, these values decrease with depth because of the consolidating effect. The liquid limit is usually between 45 and 60%. The plasticity index ranges between 20 and 40%. The specific weight of the solid grains varies from 26 to 27 kN/m^3. These values are closely similar to those initially measured by Bouassida (1996) and, later on, confirmed by Klai (2014) for intact Tunis soft clay specimens.

3.2 Correlations

Geotechnical parameters correlations from the database are useful for several objectives; Robertson and Mayne (1998). Firstly, correlations are important for an initial estimate of soil parameters to suggest a preliminary design. Second, they are helpful for evaluating parameters obtained from laboratory test. Moreover, they are helpful for the evaluation of the empirical correlations from in situ tests results.

Pearson's correlation is one of the practical tools for the geotechnical parameters to correlated. Pearson's correlation coefficients of some geotechnical parameters of Tunis soft soil are summarized in Table 2.

This reveals algebraic values which lead to a proportional or inversely proportional agreement between geotechnical parameters. It is obvious that the liquid limit, the water content, the compression index and the void ratio are positively correlated. The water content can also be correlated with the undrained cohesion, while the friction angle is positively correlated to the void ratio. The undrained cohesion is significantly negatively correlated with the void ratio and the dry unit weight. Also, the water content, the vane test cohesion and the void ratio are negatively correlated with the depth, reflecting that these parameters decrease proportionally with depth.

Table 3 displays the most important correlations between some geotechnical parameters. In Figure 2 the compression index decreases with the dry unit weight. In Figure 3, the compressibility index of Tunis soft soil increases proportionally to the void ratio. These results are in agreement with other correlations which were proposed for clayey soils by a number of researches mentioned in Table 4.

In Figure 4, the compression index increases with the water content. Whilst, from Figure 5 the friction angle decreases when the plasticity index increases. It is concluded that the parameters of the soft soil compressibility are satisfactorily obtained from the void ratio and the water content which are easily determined parameters. Accordingly, the shear strength, which is used for the study of stability of earth structures, is closely linked to the pre-consolidation pressure.

Table 2 Pearson's correlation matrix of geotechnical parameters of Tunis soft clay

	Depth (m)	w	W_l	Ip	γ_s	c_c	C_u vane (kPa)	e_0	C' (kPa)	φ' (°)
Depth (m)										
w	-0,57									
W_l	0,02	0,38								
Ip	0,18	0,08	0,79							
γ_s	-0,13	0,12	0,09	-0,29						
c_c	-0,52	0,78	0,35	0,11	0,38					
C_u vane (kPa)	0,63	-0,32	0,29	0,03	-0,60	-0,31				
e_0	-0,69	0,90	0,19	0,02	-0,15	0,89	-0,38			
C' (kPa)	0,55	-0,77	-0,19	0,24	-0,91	-0,55	1,00	-0,89		
φ' (°)	-0,03	-0,15	-0,02	0,54	0,62	0,30	-1,00	0,67	-0,34	

w: water content ; W_l: liquid limit; Ip: plasticity index; γ_s: unit weight of solid particles; c_c: compression index; C_u: undrained cohesion; e_0: void ratio; C': undrained cohesion; φ': drained friction angle.

Table 3 New correlations between geotechnical parameters of Tunis soft clay

Parameters	Correlation	R^2
c_c, e_0	c_c=-0.293 e_0	0.801
c_c, γ_d	c_c=-0.5333 γ_d+1.009	0.831
c_c, w	c_c= 0.008w-0.038	0.817
φ', I_p	φ'= -0.031I_p^2+0.372I_p+18.97	0.755
C', w	C'= -28.7 Ln(w)+122.2	0.601
C', e_0	C'=204.8e_0^2-453.4 e_0+256.1	0.932
C', c_c	C'=731.9c_c^2-675c_c+157.4	0.595

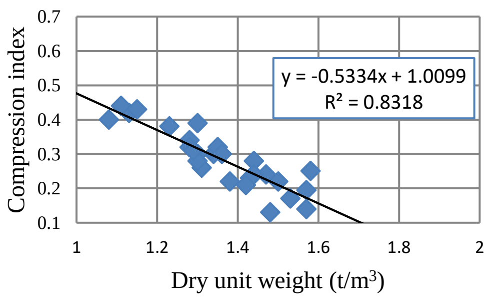

Figure 2 Correlation between the compression index c_c and the dry unit weight γ_d

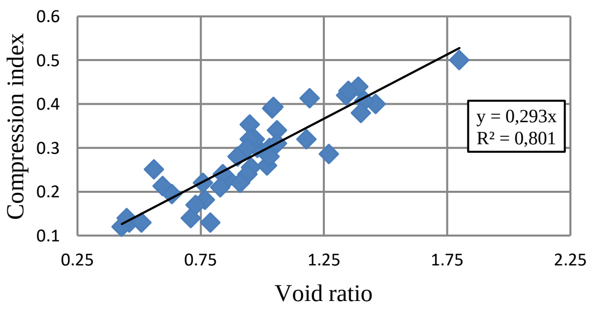

Figure 3 Correlation between the compression index $\mathbf{c_c}$ and the void ratio e_0

Table 4 Correlation between the void ratio and the compression index

Correlation	Author (s)	year
c_c=0.3 (e_0-0.27)	Terzaghi and Peck	1948
c_c=0.54 (e_0-0.35)	Nishida	1956
c_c= 0.208 e_0+0.0083	Azzouz et al	1976
c_c=0.5269 (e_0-0.2117)	Nath and DeDalal S.S	2004

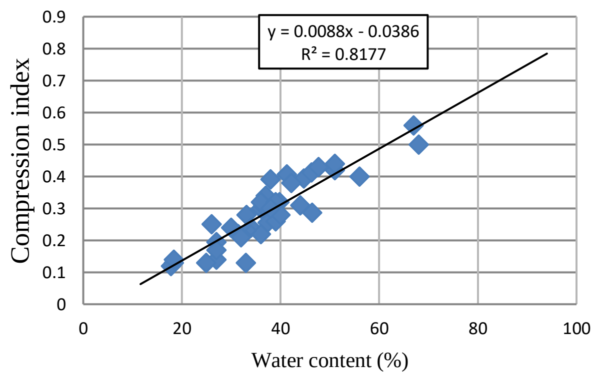

Figure 4 Correlation between the compression index $\mathbf{c_c}$ and the water content w

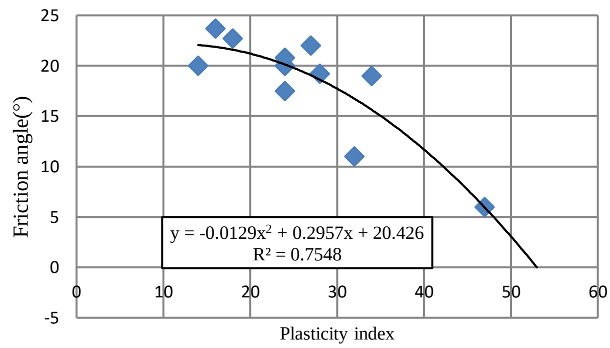

Figure 5 Correlation between friction angle (triaxial CU+U) and the plasticity index Ip

4. STUDY OF THE SETTLEMENT OF THE RAMP ACCESS OF "CYRUS LE GRAND" INTERCHANGE

The interchange of "Cyrus Le Grand" was built from 2006 to 2008 (Figure 6). This novel two ways interchange aimed to the increase and the improvement of the fluidity of traffic across Tunis City that was estimated by 120 000 vehicles per day. The full length of the interchange is 475meters, it is composed of two spans of 13 m width each founded on bored piles embedded at 60m depth.

Figure 6 The interchange of "Cyrus Le Grand" in 2007

A monitoring system was implemented to follow-up the evolution of consolidation settlement. Twelve (12) piezometers, 40 rods' settlement, 12 hydraulic settlement and 5 multipoints settlement recorders were installed over the whole area of studied interchange.

In this paper, the main interest is to investigate the evolution of settlement of the ramp access, namely C1, from the North direction to Bizerte City. The soil profile and installed settlement recorders are shown in Figures 7 and 8.

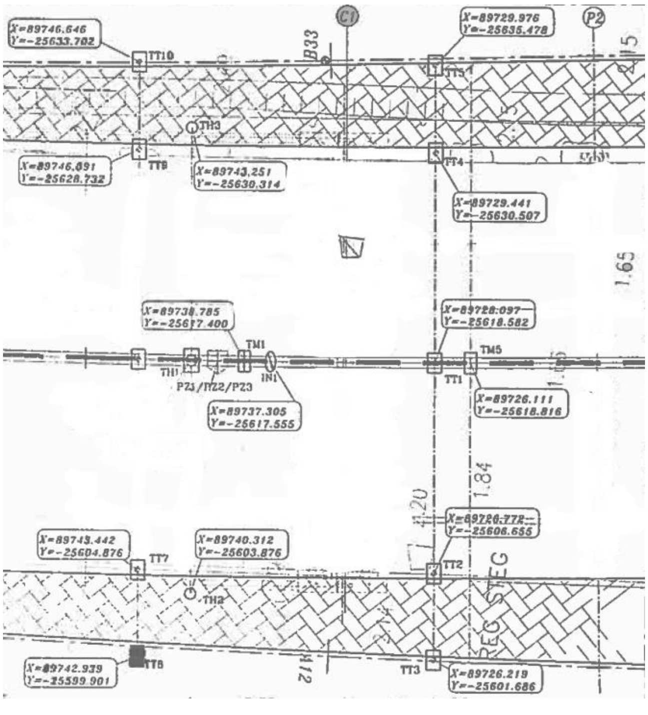

Figure 7 Location of settlement recorders as follow up instruments

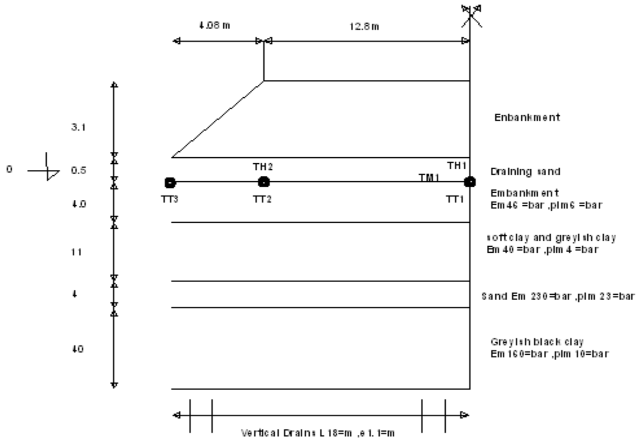

Figure 8 Geotechnical profile of embankment foundation

4.1 Geotechnical profile

The geotechnical profile under the access ramp shows a first fill layer of 4m thickness followed by soft grayish clay layer of 11m thickness. Then, a thin sand layer of 4m thickness followed by a grayish black clay and sandy clay layers of 40m thickness are crossed up to the top level of rigid stratum layer located at 60m depth.

Geodrains of 18 m in length were installed in square pattern with axis to axis spacing of 1.1m to accelerate the consolidation of high compressible soft soil upper layers with compression index of 0.42.

A preloading embankment of 3m total height was built in two construction stages:

- The first phase refers to the preloading started on May 25th, 2007 and runs for 24 days to reach a height of 2m.
- The second phase refers to the preloading started on June 29th, 2007 and runs to achieve 95 days to reach a height of 3.1m.

A drainage sand mattress of 0.5m thickness preceded the embankment construction at the surface of improved soil to facilitate the water evacuation from the geodrains. This sand layer can also contribute of a better load transfer avoiding significant differential settlement.

4.2 Evolution of settlement

The settlement recorders were installed at 5m in front of the abutment C1 and at 10m behind it. Rod settlement TT1 was installed at the embankment axis; TT2 and TT3 rods settlement were installed on the right side, whilst TT4 and TT5 were installed on the left side. Behind the abutment C1, rod settlement TT6 was installed at embankment axis, TT7 and TT8 on the right side, TT9 and TT10 on its left side. Hydraulic settlement TH1 and multipoint settlement TM1 were installed at embankment axis, TH2 and TH3 multipoint settlement were installed on the right and on the left side, respectively.

The follow-up of settlement was maintained for a period of 3 months. Unfortunately, after this short period of time there were no recorded settlements to date. Figures 9, 10, 11 and 12, show the evolution of recorded settlements in the axis and two extremities of instrumented embankment. It can be noted that that the recorded settlement at the axis of embankment were significantly higher than those measured at the embankment extremities. This observation also remains valid for recorded values by the rod settlement and hydraulic settlement tools as illustrated by Figure 9 and Figure 10, respectively. Due to the symmetrical ramp geometry, the recorded settlements by TT2 and TT4 as well as TT3 and TT5 were almost similar. The significant difference between those recorded settlements can be attributed, first, to the difference of soil profile and, second, for a different spacing of vertical drains that was 1.3m.

Along the embankment axis, it is also noted from Figure 12 that the multipoint settlement recorded a value of 37.6 cm after 95 days. However, by the hydraulic settlement the recorded value was limited to 24 cm after 94 days. It was reported by the follow-up team that recorded values provided by the multipoint settlement tool should be handled with caution. Indeed it was observed that the probe of the multipoint settlement tool could not be lowered due to the lateral deformation of the tube (MEHAT, 2007).

From recorded values by the rod settlement were comprised between 26.7cm and 35 cm after 90 days over a distance 15m between TT1 and TT6 devices. It is concluded that the rod settlement recorded values were in between the hydraulic settlement and the multipoint-settlement measurements.

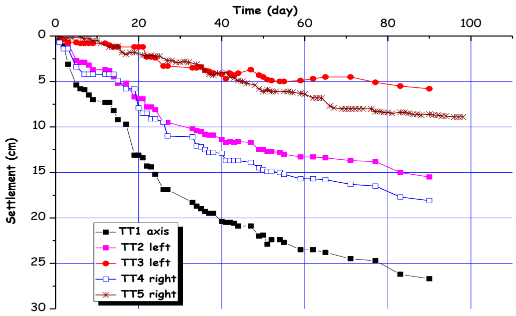

Figure 9 Recorded settlement under the access embankment

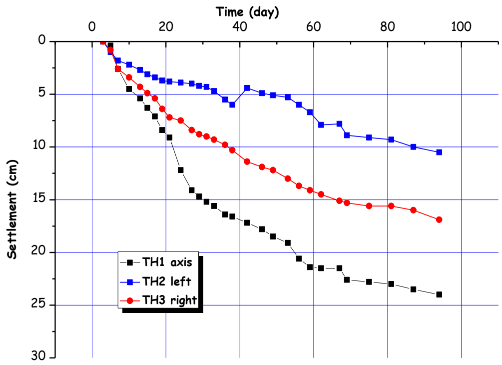

Figure 10 In situ settlement measurement by hydraulic settlement

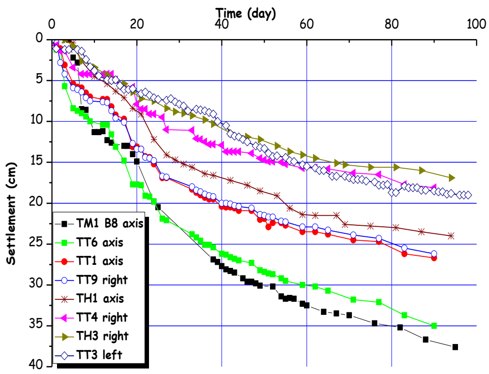

Figure 11 Observed settlement at the axis, left and right sides of embankment

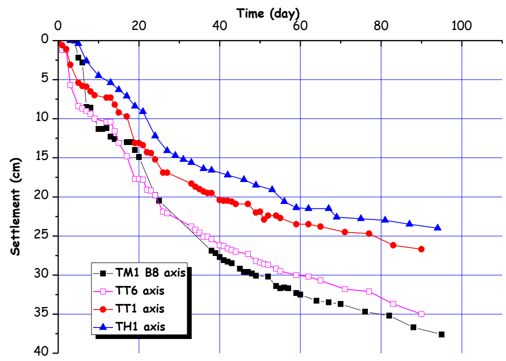

Figure 12 Settlement in the axis of the ramp obtained by rod settlement, hydraulic settlement and multipoint settlement

4.3 Numerical simulation of the behaviour of the ramp access

The study of the behavior ramp access embankment was investigated numerically to compare between the recorded vertical displacements and numerical predictions by using the suggested correlation for geotechnical parameters above detailed for Tunis soft clay.

The numerical simulation was run by PLAXIS 2D code (version 2015). A plane strain numerical modeling was adopted. It is composed by 15 nodes triangular finite elements with medium precision mesh to minimize the computation time.

All material characteristics of soil layers and embankment material are given in Table 5. The Mohr Coulomb constitutive law was selected to describe the behavior of embankment material, preload embankment, drained sand and sand layer by adopting a drained behavior. In turn, for the soft soil and grayish-black clay layers, the hardening soil model (HSM) and the soft soil model (SSM) were adopted in undrained behavior.

Related to the boundary conditions of the numerical model, vertical and horizontal displacements are zero at the rigid stratum level; the horizontal displacement along vertical borders is also assumed zero. The water table is located at 2m depth. The settlement was monitored in accordance with the time given to the actual settlement. The follow up of settlement was investigated in the alignment of three points which are A at the embankment axis, B at the crest of embankment and C at the toe of embankment.

From in-situ observed settlements and predicted ones, it is agreed that the consolidation settlement was increasing versus time, unfortunately only over a period of three months. The in situ settlement as recorded by all measurement tools fairly show acceptable agreement both in terms of the evolution and magnitude of settlement (Figure 12).

The behavior of unimproved soil (without geodrains) was also analyzed by the same numerical model to highlight the benefits of geodrains technique. Figure 13 summarizes the numerical predictions, when the SSM is adopted for soft soil layers, of settlements evolution under the ramp access of embankment.

The evolution of settlement at embankment axis (point A) predicts 9cm after 13 days for improved soil by geodrains. But, the same settlement is expected after 24 days for the unimproved soil. The final predicted settlement after 95 days by the SSM is 31.9 cm for the improved soil whilst it is 17.7 cm for the unimproved case. After 95 days, the settlement of unimproved soil is by 55% of that predicted for improved soil by geodrains installed in square pattern with spacing of 1.1m. Hence, this study confirmed the beneficial role of geodrains in accelerating the consolidation of Tunis soft clay settlement as reported recently from experimental work by (Jebali et al, 2017).

Table 5 Adopted parameters of soft soil model and hardening soil model

Parameters	HSM model		SSM model	
	Soft Clay	Grayish Clay	Soft Clay	Grayish Clay
γ_h (kN/m^3)	17	18	17	18
γ_{sat} (kN/m^3)	19	20	19	20
$k_x = k_y$ (m/day)	1.52 10^{-4}	1.02 10^{-4}	1.52 10^{-4}	1.02 10^{-4}
E_{50}^{ref} (kN/m^2)	1505.952	1543.421	-	-
E_{oed}^{ref} (kN/m^2)	1204.762	1234.737	-	-
E_{ur}^{ref} (kN/m^2)	8132	7408	-	-
ν_{ur}	0.35	0.38	-	-
R_f	0.9	0.9	-	-
P_{ref} (kPa)	100	100	-	-
c_c	0.42	0.38	0.42	0.38
c_s	0.056	0.057	0.056	0.057
e_0	1.2	1.04	1.2	1.04
C'	-	-	6.08	8.46
φ'(°)	-	-	20.41	20.56
ψ(°)	-	-	0	0

c_s: swelling index; ψ(°): angle of dilatancy, $k_{x(y)}$: horizontal (vertical) permeability; Poisson's ratio in unloading reloading path; R_f: failure coefficient.

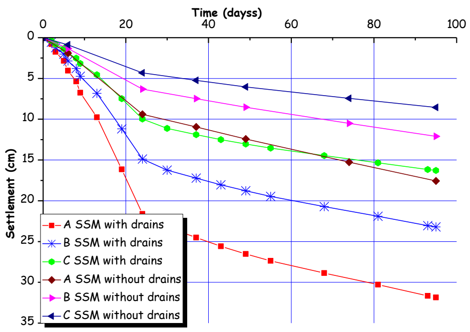

Figure 13 Numerical settlement predicted by the SSM for improved soil by geodrains and unimproved soil

Referring to the observed settlement, the maximum recorded settlement (after 95 days) by the multipoint settlement recorder at the axis of embankment exceeds the predicted SSM settlement by 5,75cm which represents 9 %. Whereas records by the rod settlement TT1 which represents 15.3% (Figure 14). Recorded value by the rod settlement TT6 exceeds the predicted SSM settlement by 3.14 cm and the hydraulic settlement gave lower values than to the predicted SSM settlement by 5.2cm and 7.86cm, respectively. It can be concluded that numerical predictions by the SSM were in a good agreement with the in-situ measurement values which prove the efficiency of correlated parameters.

In regard to settlements at the crest and toe of embankment which correspond to points B and C (Figure 11), predicted settlements overestimate the in-situ measurements by the rod settlement and hydraulic settlement devices. This result can be explained by the reduced effectiveness of the geodrains especially at the toe of embankment.

The difference between predicted settlements by the soft soil and hardening soil models does not exceed 2 cm. Such result indicates that by the two constitutive laws, governed by the HSM and SSM, quasi identical behaviour is expected to occur (Figure 15). Consequently, it can be concluded that modelling the behaviour of Tunis soft clay by the SSM and the HSM are both suitable for predicting the studied behaviour of ramp access embankment.

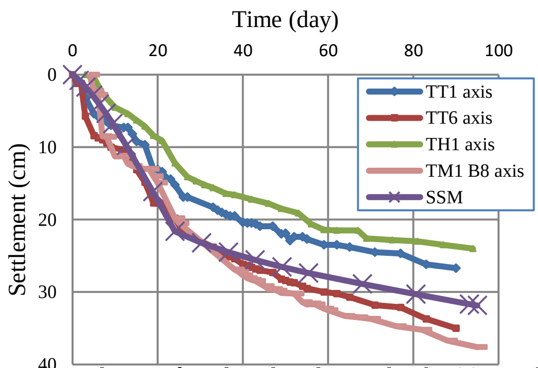

Figure 14 Evolution of predicted settlement by the SSM and recorded data

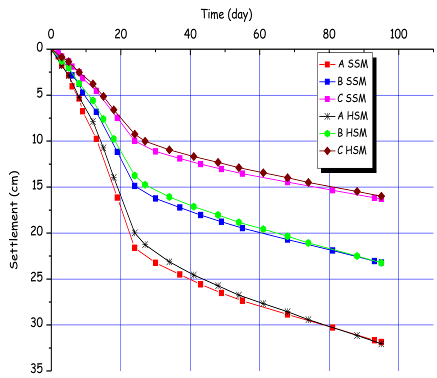

Figure 15 Numerical settlement obtained by SSM and HSM for improved soft soil by geodrains

5. CONCLUSIONS

This paper dealt with the characterization of Tunis soft clay and the study of behavior of improved soft soil by geodrains. After geotechnical investigations conducted for seven projects at the site of Republic Avenue of Tunis City selected results were compiled to characterize the geotechnical parameters of Tunis soft soil. Those data led to the suggestion of some correlations between geotechnical parameters of Tunis soft clay. These correlations remain valid for the studied area, therefore their use must be handled carefully for similar projects even around the investigated.

The settlement of ramp access embankment built on improved soft layers by geodrains of 18 m length was monitored by different types of settlement recorders, e.g. rod settlement, hydraulic settlement and multipoint settlement. It was noted that recorded settlement values by the multipoint device slightly exceeded the settlements recorded the rod and hydraulic settlement devices.

Using a plane strain model a numerical simulation was performed for the validation of observed behavior of ramp access embankment in terms of settlement evolution. The hardening soil and the soft soil modeling were both considered to describe the behavior of Tunis soft clay and compressible layers. Numerical predictions of settlements under the ramp access embankment in different locations revealed quasi similar. It was then concluded, for the studied case history, the HSM and SSM revealed both valid. Indeed, the comparison between predicted settlements by the SSM and the recorded values during the follow-up of embankment were in acceptable agreement especially when recorded settlement values by the multipoint device were considered. It was also checked that the installation of geodrains provide a good acceleration of consolidation settlement in comparison to the simulated settlement of unimproved soil.

So, the correlated geotechnical parameters in the area of Avenue Republic of Tunis City revealed quite helpful to characterize the soft soil layers extending at 40m depth. This finding was evidenced by the validation of numerical predictions of the behavior of access ramp embankment built of improved soft layers by geodrains.

6. REFERENCES

Ammar B. (1989). Etude de l'environnement de Tunis et de sa région en relation avec l'art de l'ingénieur en génie civil. Thèse de doctorat, Université des Sciences et Technologies, Languedoc, France, 296 pages.

Azzouz AS, Krizek RJ and Corotis RB (1976) Regression analysis of soil compressibility. Soils and Foundations 16 (2): 19–29.

Bouassida M. (1996). Etude expérimentale de la vase de Tunis par colonnes de sable- Application pour la validation de la résistance en compression théorique d'une cellule composite confinée. Revue française de géotechnique. N° 75. pp 3-12.

Bouassida M. (2006). Modeling the behavior of soft clays and new contributions for soil improvement solutions , Keynote Lecture." 2nd Int. Conf. on Problematic Soils. Edit Bujang, Pinto and Jefferson. Petaming Jaya, Salengor, Malaysia., pp. 1-12.

Bouassida M. & Klai M. (2012). Challenges and Improvement Solutions of Tunis Soft Clay. Int. Journal of Geomate, Sept. 3 (1), 296-305.

Bouassida M. (2016). Design of Column-Reinforced Foundations. J. Ross Publishing (FL, USA), September. 224 pages. ISBN: 978-1-60427-072-3.

Bryan A. McCabe, Brian B. Sheil, Michael. M. Long, Fintan J. Buggy and Farrell, E.R. (2014). Empirical correlations for the compression index of Irish soft soils. ICE Proceedings Geotechnical Engineering. Vol. 167 No.6. December 2014,pp 510-517.

Bergado, D.T., Anderson, L.R., Miura, N., and Balasubramaniuam, A.S., Soft Ground Improvement in lowland and other Environments. ASCE Press. New York, 1996.

Chai, J. and Carter, J. P. Deformation analysis in soft ground improvement. Springer, 2011, Dordrecht.

Indraratna, B. & Rujikiatkamjorn, C. (2006). Predictions and Performances of Prefabricated Vertical Drain Stabilized Soft Clay Foundations. Proceedings of the Symposium on Rigid Inclusions in Difficult Soft Soil Conditions. International Society for Soil Mechanics and Geotechnical Engineering. (ISSMGE TC36).

Frikha W. Ben Salem Z and Boussida M. (2013). Estimation of Tunis soft soil undrained shear strength from pressumeter data. Proceeding of the 18th International Conference on Soil Mechanics and Geotechnical Engineering. Paris.

Guetif, Z.; Bouassida; M. and Debats, J. M. (2007). Improved Soft Clay Characteristics Due to Stone Column Installation. Computers and Geotechnics. Vol 34 n°2; 104-111.

Guilloux A & Nakouri L. (1976). Contribution à l'étude géotechnique des sous sols de Tunis, Revue Tunisienne de l'Equipement, Tunisie, n°16, 58-68.

Haffoudhi S, Khediri S and Zaghouani K. (2005). Utilisation du pressiomètre en Tunisie. Rapports nationaux. Proc. ISP5-PRESSIO 2005. Int. Symposium 50 years of pressuremeters. (22-24 August). Edit. LCPC-ENPC, Paris Vol. 2 283-292.

Jebali H., Frikha, W., and Bouassida, M. (2017). 3D consolidation of Tunis soft clay improved by geodrains. Geotechnical Testing Journal. Vol 40. N3. 361-370.

Kaâniche A. (1989). Conception et réalisation d'une base de données géologiques (Tunis-Data-Bank) orienté vers la cartographie géotechnique automatique (Tunis, Géo-Map) ; Application à la ville de Tunis, Thèse de doctorat, Institut National des Sciences Appliquées, Lyon, France, 327 p.

Klai, M., Bouassida, M & Tabchouche, S (2015). Numerical modelling of Tunis soft clay. Geotechnical Engineering Journal of the SEAGS & AGSSEA Vol. 46 No. 4 December, 87-95.

Klai, M. and Bouassida, M. (2016). Study of the behavior of Tunis Soft Clay. Innov. Infrastruct. Solutions 1:31.doi: 10.1007/s41062-016-0031-x.http://rdcu.be/ntus.

Lambe, T.W. and Whitman, R.V. (1969). Soil mechanics. SI version. J. Wiley et Sons Edition.

MEHAT (2007). Travaux de l'échangeur Cyrus Le grand-Ghana Liaison Nord-Sud. Rapport de suivi de consolidation des rampes. Direction générale des Ponts et Chaussées. Tunis.

Nath A and DeDalal S.S (2004). The role of Plasticity Index in Predicting Compression Behavior of Clays. Electronic Journal of Geotechnical Engineering. 1-7.

Nishida Y (1956). A brief note on the compression index of soil. Journal of the Soil Mechanics and Foundations Division, ASCE 82(3): 1–14.

Robertson and Mayne (1998). Geotechnical Site Characterization. Proceedngs of the First International Conference on Site Characterization ISC 98. Atlanta , Georgia 19-22.

Terzaghi, K. and Peck, R.B. (1948). Soil Mechanics in Engineering Practice, John Wiley & Sons, New.York.

Tounekti F, Bouassida M and Klai M. (2008). Etude expérimentale en vue d'un modèle de comportement pour la vase de Tunis. Revue Française de Géotechnique. 114(122) 25-36.

Touiti L, Bouassida M and Van Impe W. (2009). Discussion on Tunis soft soil sensitivity. Geotechnical and Geological engineering. 27. Doi: 10.1007/s10706-009-9263-2, 631-643.

Widodo S and Ibrahim A (2012). Estimation of Primary Compression Index (c_c) using Physical Properties Of Pontianak Soft Clay. International Journal of Engineering Research and Application (IJERA) , Vol 2, Issue 5.