International Journal of Civil
Engineering (IJCE)
ISSN (P): 2278-9987; ISSN (E): 2278-9995
Vol. 6, Issue 6, Oct – Nov 2017; 37-50

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

THE EFFECTS OF GEOTECHNICAL AND STRUCTURAL PARAMETERS ON THE COLLAPSE OF COLLAPSIBLE SOILS SUBJECTED TO A VERTICAL LOAD

OUAHIBA MANSOURI & SALAH MESSAST

Department of Civil Engineering, Laboratory LMGHU, University of Skikda, Algeria

ABSTRACT

This study consists on the moduating of the behavior of a collapsible soil, under vertica laod. The case considered in this work, is a real project of a foundation placed on a collapsible soil which is presented by Thanh Tra Phung. The study of a reference model was performed by a finit elements method calculation, implemented in the software Plaxis. The reference model adopted presents a good reproduction of reality (settlement soil under a foundation). This work establishes a parametric study in order to put in evidence the effect of several geotechnical parameters (cohesion, friction angle and oedometric modulus) and structural parameters (load applied and width of foundation) on the rate of collapse.

It appears from this study that, the variation of the above parameters in 'reasonable' forks has a considerable effect on the settlement (collapse) under the center of the foundation. This variation of several parameters can give a preliminary idea the method of improvement of this type of soils in the purpose to avoid the problems of collapse in geotechnic.

KEYWORDS: Foundation, Collapsible Soil, Geotechnical Parameters, PLAXIS Code, Collapse, Settlement

1. INTRODUCTION

The collapsible soil is a fine soil, it is in an unsaturated state. It is located in the arid and semi arid zone. it is present in many parts of the world: France, America, China, Africa. etc.

In Geotechnical, the problem of the collapsible soil is when the saturation, the soil undergoes a strong and sudden settlement that may cause a great damage to the foundations batis on this soil.

According to several studies conducted on this type of soil, among the causes of the collapse of the soil which can explained that the macro porous structure of the soil and the saturation of the soil by flood or water leak and with the load (a foundation).

These three factors cause a drop in shear strength and deformation modulus.

Little research has been done on collapsible soil, but the most important are :

Knight (1960) (cited by Barden et al, 1973) defined the potential collapse CP and the conditions of subsidence of the soil.

Smalley (1971) (cited by Liu tumgsheng, 1988), studied the training of collapsible soils (quartz silt and a significant component of calcium carbonate and magnesium).

Abelev et al (1979), studied the origin of collapsible soils (original or pedagogique Wind Generator). Hoang Ngoc Ky (1991) confirmed the origin of the wind generator.

Gallet et al (1998) studied collapsible soils distribution in the world.

Ayadat et al (1999), studied the constitution of collapsible soils and the influence of some geotechnical properties.

Thanh Tra Phuang (2003), modeled collapsible soils and investigated the modeling of two cases of real foundations built on a collapsible soil.

Important settlements resulting from the use of large amounts of water and serious disorders suffered by the works, gave in these three dernieres decennies, an impulse to research on these soils, including methods of their identification and their treatment. In several sites, it is possible to treat the soil to stabilize or to cause its collapse, before you build a structure.

The nature of the treatment to be applied essentially depends on the depth of the collapsible soil and the type of foundation. Line variety of treatment methods has been used or suggested. Among them, include:

- F. Hammoud (2007), studied the influence of Relative Density and Clay Fraction on Soils Collapse.
- M. Laouar (2009), studied the prediction of collapsing soil by the cone penetrometer and ultrasonic tests.
- O. Bahloul (2010), studied the treatment of Collapsible Soils by Salts Using the Double Consolidation Method.
- Lahmadi (2009), studied the treatment of collapsible soil by lime

Boudlal O (2013), studied the experimental study of the mechanical behavior of the fine in the stability of slopes and foundations.In this paper, we have presented a parametric study for the modeling of a real foundation established on a collapsible soil studied by Thanh Tra Phuang (2003). The values of his model are considered as our reference model.

We have used the variation of geotechnical's parameters (friction angle, cohesion and deformation modulus) and structural's parameters (load applied and width of foundation).

This work is considered a guide for choice the technical's methods and the materials of treatment for reduce the rate of collapse with the of results of study of geotechnical's parameters variation and give solutions if the treatment is not possible with the use of results of study of structural parameters variation.

Even the compaction has an influence on soil subsidence, it also depends on the variation of the water content and the void ratio based on the formula 1.

$$\gamma_d = G_s/(1 + (G_s w/S_r) \quad \textbf{(1)}$$

The drop in shear strength and modulus of deformation during the saturation cause sagging (Oloo et al 1996).

The collapse of these soils increase with the decrease of a shear strength and the deformation modulus, and decreases with their increase.

This work is a numerical parametric study. it present the effect of the variation of the strength parameters (the friction angle and the cohesion), the deformation modulus and foundation parameters (load and width of foundation) on the variation of the collapse.

For the numerical simulation, we have used the PLAXIS software. The results of oedometer on collapsible soils, presented by Abelev and al (1979), show that, the behavior of the collapsible soils is elastoplastic, for this way we used the Mohr- Coulomb model to describe their behavior.

2. CHARACTERIZATION OF THE COLLAPSE OF COLLAPSIBLE SOILS (BEHAVIOR OF COLLAPSIBLE SOILS)

The parameter that defines the collapsible soils is the collapse. Knight (1960) (cited by Barden, 1973) proposed a definition of collapse by a Collapse Potential defined by equation 2.

$$CP = \frac{\Delta e}{1+e_0} = \frac{e_1 - e_2}{1+e_0} \quad (2)$$

CP: Degree of the relative collapse (Collapse Potential).

e_0: The initial void ratio.

Δe: The variation of void ratio $(e_1 - e_2)$

e_1: Initial void ratio before collapse.

e_2: Final void ratio after collapse.

The influence of the saturation of soil subsidence dependent on the variation of the water content and the change in the void ratio gived by the relation 3:

$$S_r = G_s w / e \quad (3)$$

The variation of void ratio is obtained from oedometer tests. The oedometric curve (e-σ) can give the behavior of the collapsible soil, given by Abelev and al (1979) from the initial unsaturated state, to the saturated final state.

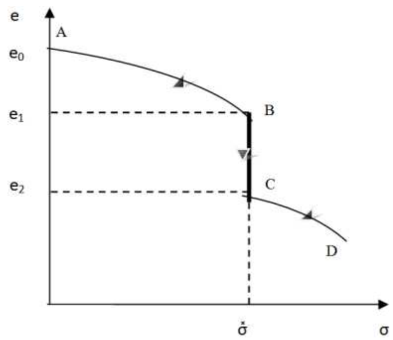

Figure 1: Oedometric Test on Collapsible Soil (Method known as to a Curve)

Figure 1 presents the behavior of collapsible soils from the oedometric curve where:

AB: the oedometric load curve of unsaturated collapsible soil with initial void ratio e_0

B: the soil saturation.

BC: the fall of the void ratio corresponding to the passage from the unsaturated state to the saturated state at constant total axial stress.

CD: oedometric load curve of the saturated soil.

3. CHARACTERIZATION OF SHEAR STRENGTH AND ITS VARIATION WITH THE DEGREE OF SATURATION

The shear strength of saturated soils is given by law of Coulomb:

$$\tau = c' + \sigma' tg\emptyset'' \quad \textbf{(4)}$$

Where:

τ : The shear strength.

C ': the cohesion of the saturated soil.

$\emptyset$ ': the internal friction angle of the saturated soil.

σ': the effective normal stress on the fracture surface.

For unsaturated soils, the Coulomb formula is not applicable because the strength depends on the soil water status. From these findings, Fredlund (1993), conducted studies on unsaturated soils and proposed a new equation:

$$\tau = c' + (\sigma - U_a)tg\emptyset' + (U_a - U_w)tg\emptyset_b \quad \textbf{(5)}$$

Where:

$(\sigma - U_a)$: The pure normal stress of unsaturated soil.

$(U_a - U_w)$**:** The matrix Suction acting on the unsaturated soil.

$\emptyset_b$: The Friction angle attached to the variation of the matricielle suction.

U_a: The atmospheric pressure (air pressure).

U_w**:** The interstitial pressure (water pressure).

The first term is the same value as of shear strength for saturated soils and the second term depends on the degrees of saturation, desideration.

In a fully saturated state, where $U_a = U_w$, the second term vanishes and the equation of Fedlund degenerates into that of Coulomb.

It is found that, the shear strength decreases with the increasing degrees of saturation.

The degree of saturation depends on the variation of the water content and the void ratio, according to the following formula :

$$S_r = \frac{G_s w}{e} \quad \textbf{(6)}$$

Where,

S_r : The degree of saturation of the soil.

G_s: The relative density of grains.

w: The water content of unsaturated soil.

e: The void ratio of unsaturated soil.

The variation of the degree of saturation dS_r , with the two independent variables w and e, is given as follows:

$$\mathrm{dS_r} = \left[\frac{\partial Sr}{\partial w}\right] \mathrm{dw} + \left[\frac{\partial Sr}{\partial e}\right] \mathrm{de} \quad \textbf{(7)}$$

Which yields to:

$$\mathrm{dS_r} = \left[\frac{\mathrm{Gs}}{e}\right] \mathrm{dw} - \left[\frac{\mathrm{Gsw}}{e^2}\right] \mathrm{de} \quad \textbf{(8)}$$

If the humidification dw>0 and de >0 then $\mathrm{dS_r}$ is high and the soil is saturated.

In the case of compaction, dw<0 and de <0 then $\mathrm{dS_r}$ is low and the soil is not saturated.

The shear tests according to the water content and the void ratio showing the relationship between the variation of these two factors and the strength parameters C and $\emptyset$**.**

When Δe <0 and Δw <0 (decreasing) then $\Delta\emptyset > 0$ and ΔC >0 (compaction).

When Δe >0 and $\Delta w > 0$ (increase) then $\Delta\emptyset < 0$ and ΔC<0 (saturation).

4. CHARACTERIZATION OF THE DEFORMATION MODULUS AND ITS VARIATION WITH THE DEGREE OF SATURATION

The deformation modulus is calculated from the oedometer tests according to the formula expressed by Pière Yves Hicher (1996):

$$\frac{E}{\sqrt{P'}} = \frac{450}{e} \quad \textbf{(9)}$$

Where: $P' = P_{0+}\frac{q}{3}$ **(10)**

With: P_0: the preconsolidation stress

q: the applied stress

e: the void ratio

The deformation modulus depends on the applied load, the water content, the void ratio and the Poisson's ratio.

5. SIMULATIONS AND RESULTS

This section presents the numerical simulation of thr response of a collapsible soil subjected to a vertical laod (foundation). To describe the real behavior of the soil, we used the Mohr-Coulomb model.

We used the equation of state proposed by Phuong Thanh Tra (2003). It is defined as:

(SUS) + (w) + consolidation = (SS) + (Collapse) **(11)**

Where:

(SUS): the soil unsaturated in the initial state.

(W): the water rise to saturate the soil.

(SS): the soil in the saturated state.

(Collapse): the collapse due to the soil saturation.

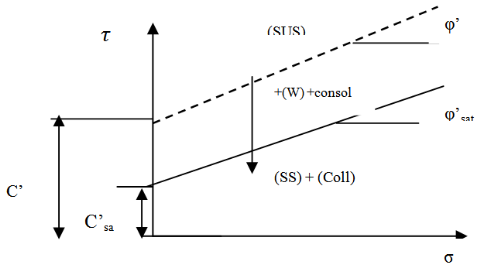

Figure 2: The Method of Modeling a Collapsible Soil

In figure 2, the initial state, an unsaturated soil is designated by the dashed line (SUS). Then the soil (SUS) becomes (SS) + (Coll) after the saturation and consolidation. The saturation causes the fall of shear strength of soil and the deformation modulus witch hence its collapse.

5.1. Description of the Foundation Cases

The two foundation cases calculated by Tra Thanh Phuong (2003) are real cases in south of Vietnam. These foundations undergo a subsidence. The physical and mechanical properties of these two soils are obtained from tests conducted in the laboratory. The properties interpreted according to the Mohr-Coulomb model are shown in table1**,** table 2 and table 3 (Tra Thanh Phuong, 2003)**.**

Table 1: The Soil and Foundation Properties (Tra Thanh Phuong, 2003)

Case of Foundation	B (m)	σ (kPa)	Υ_d (kN/m³)	Initial Unsaturated State (ν=0.3)					Final Saturated State (ν=0.28)				
				w (%)	C' (kN /m³)	Φ' (°)	Υ_{hum} (kN/m³)	E_{oed} (kpa)	w_{sat} (%)	C'_{sat} (kN/m³)	Φ'_{sat} (°)	Υ_{sat} (kN/m³)	E_{sat} (kPa)
Case 1	2	200	16.7	12	40	22	18 .7	14000	22	18	16	20,4	6800
Case 2	2	130	16.5	16	36	20	19.14	11000	20.34	15	14	19 .85	4000

The permeability coefficient are Kx = ky = 5. 10^{-3} m / day

The wetting and compaction have an influence on the soil collapse. Wetting and compaction cause the variation of some physical and mechanical properties. The useful properties for modeling by the Mohr-Coulomb model are: the strength parameters C and ϕ and the deformation modulus E.

5. 2. Numerical Model

To use the Mohr-Coulomb model, we must present our model in a multilayered soil.

The degree of saturation increases from top to downwards and the properties C, ϕ, E decrease from top to down.

The numerical model is shown in figure 3.

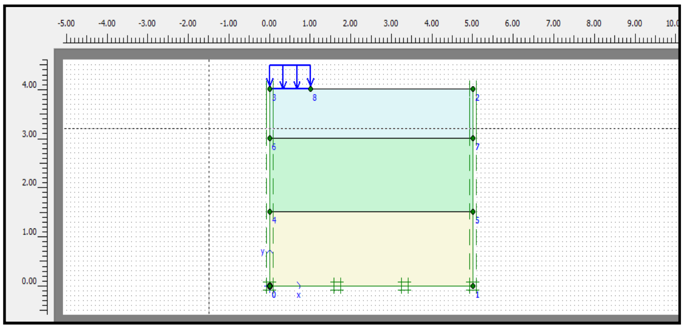

Figure 3: The Numerical Model of the Foundation Case 1 in Multilayer

5.3.The Variation of the Friction Angle

The varation of the friction angle is within a range of ± 2°

The real value of the friction angle of the foundation in case1 is Ø = 22° and for case2 Ø = 20°.

Figure 4 presents the deformation mesh of the soil under the foundation case 1.

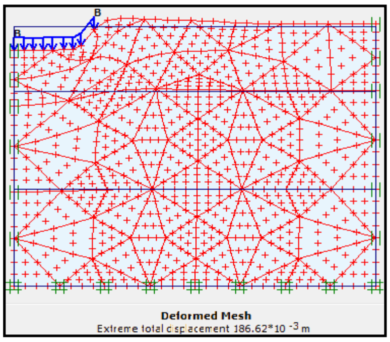

Figure 4: The Deformation Mesh of the Soil with the Foundation Case 1

In the saturation state, the soil changes from the elastic state to the plastic state. Points who undergoes this change of answers are presented by the plastics point on the figure 5

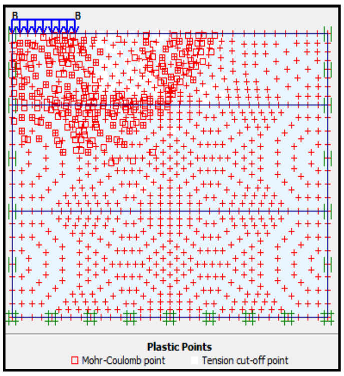

Figure 5: The Concentration of Plastic Points under the Foundation Case 1

The settlement under the center of the foundation case 1 depending on the load applied shows in figure 6.

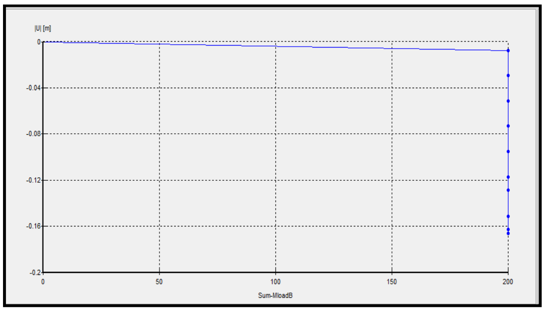

Figure 6: The Vertical Displacement under the Center of the Foundation Case 1

The soil can support in the unsaturated state a importante load but at saturation, the soil undergoes a strong and instantaneous settlement under de vertical load.

The different curves indicating the behavior of the soil under the Foundation 1 and 2 with the variation of the angle of friction are given in figures 7 et 8.

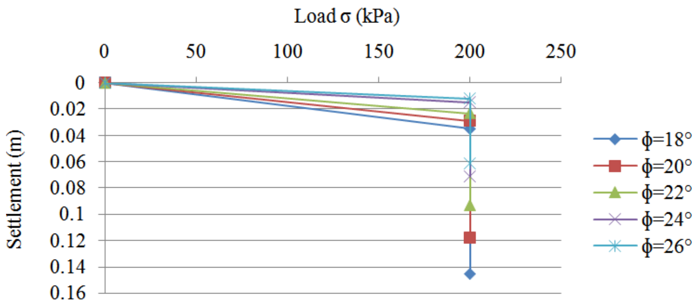

Figure 7: The Variation of Settlement of Foundation Case 1 Function the Load with Variation of Angle of Friction

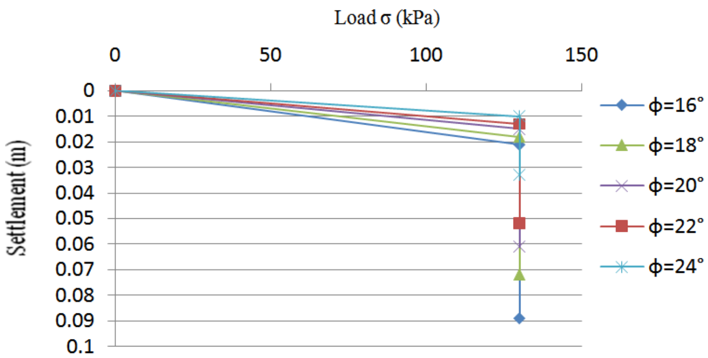

Figure 8: The Variation of Settlement of Foundation Case 2 Function the Load Applied with Variation of Angle of Friction

For both foundations, at saturation state, fore friction angle minimal the settlement is maximal.

The influence of the varation of the friction angle on the collapse of soil is very remarkable when the range is important witch is shown in figure 9.

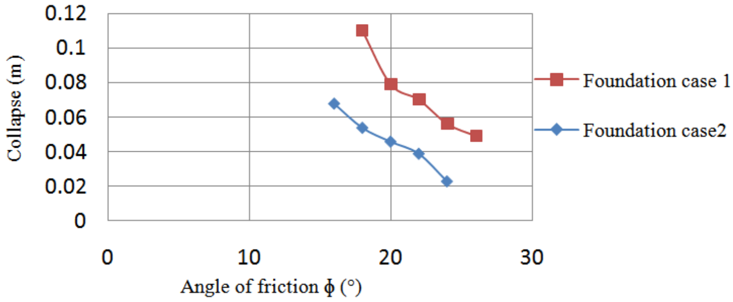

Figure 9: The Varation of the friction Angle Function the Collapse

The little variation of friction angle has not an important effect on the collapse, but a variation of **±** **4** ° causes a variation of ± 30% from the value of collapse of the reference model.

5.5. The Variation of the Cohesion

The variation of the cohesion is in a range of ± 5 kPa**,** the real values of cohesion of both foundations are respectively

C = 40kPa and C = 36kPa.

The variation of cohesion leads to a change of the void ratio .The collapsible soils are characterized by an index of the void ratio higher which the cohesion is less important .In the unsaturated state, soil resists to the applied loading more than the saturation state. Higher settlement corresponds to the low cohesion which is present in figure10 and 11**.**

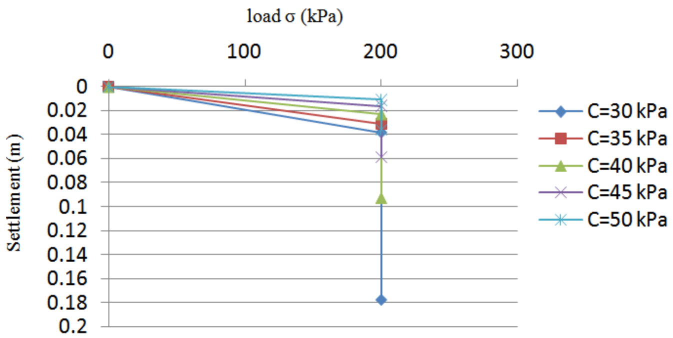

Figure10: The Settlement of Foundation Case 1 with the Cohesion Variation of Soil

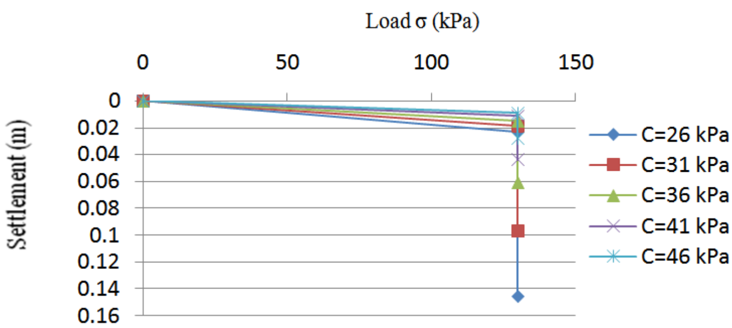

Figure 11: The Settlement of Foundation Case 2 Function the Variation of Cohesion

For both foundations, the soils having the cohésion very highly settle more at saturation. the collapse caused by the variation of the cohesion of both foundations is presented in figure 12.

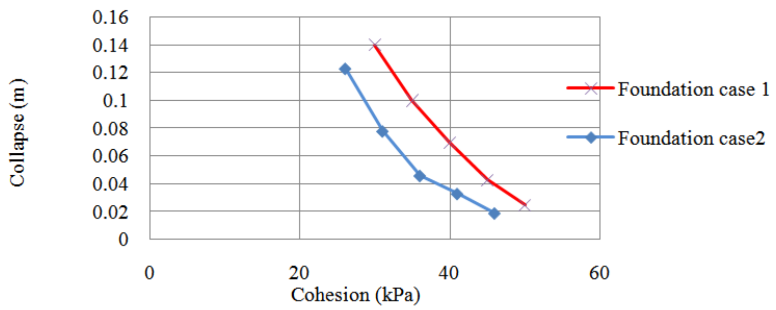

Figure 12: The Varation of Cohesion Function the Collapse

The variation of cohesion causes an important effect on the collapse compared to the real value of the foundation.

The variation of the cohesion from 30 kPa to 50 kPa of foundation 1 give a collapse from 0,14 m to 0,025m.

For foundation 2, the collapse varied from 0,123 m to 0,019 m for the cohesion values from 26 kPa to 46 kPa.

The minimum value of the collapse of both foundations (0,025 m and 0,019 m) is considered negligible.

5.6. Variation of the Deformation Modulus

The variation of the deformation modulus is in a range of ± 1000kPa.

The real value of the deformation modulus of the foundation in case 1 is E = 14000KPa and for the foundation in case 2 is E =11000KPa.

The collapse of the soil to both foundations according to the variation of the deformation modulus is shown in figure 13**.**

The deformation modulus link between load and deformation that is produced in the soil.

The deformation that is produced in the soil is the settlement in the saturation and unsaturation state.

The settlement caused by the loading applied with different values of deformation modulus are shown on figure 13.

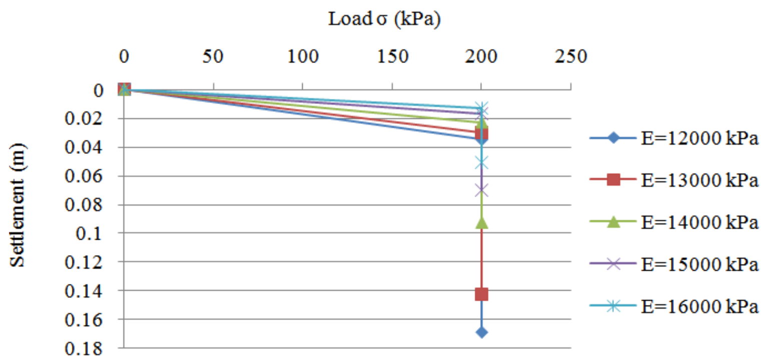

Figure13: The Soil Settlement According to the Variation of the Modulus of Deformation Foundation Case 1

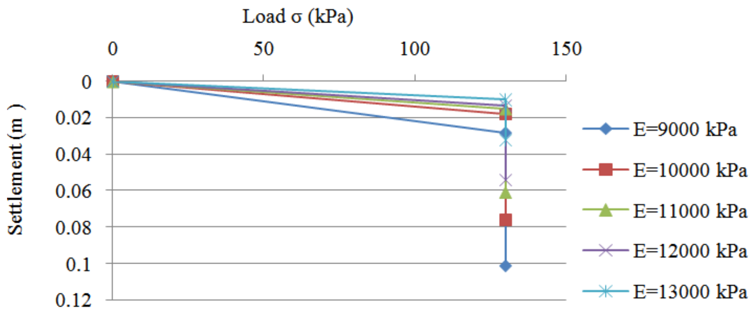

Figure14: The Settlement of Foundation Case 2 with the Variation of Déformation Modulus

The deformation in the ground in the saturation state is abrupt collapse expressed on the figure 15

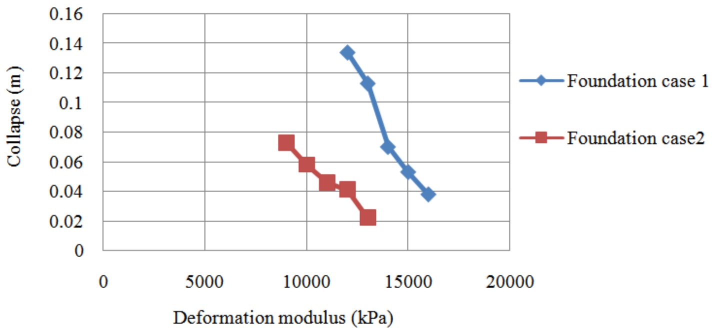

Figure15: Collapse of Soils of the both Foundation Function the Variation of the Deformation Modulus

The influence of the deformation modulus variation is important on the collapse for both foundations.

The rincreaze with high rate of deformation moduls (+2000 kPa) cause 0.038m for collapse for foundation case 1 and for foundation case 2, the collapse is 0.02m.

5.7. Variation of the Applied Load

The change in the load is in a range of ± 20 kPa

The real value of the load applied by the foundation case 1 is σ = 200 kPa and for the case **2,** the load is σ= 130 kPa

The response of both foundations function the variation of the applied load presented by the settlement in saturation state in figure 16 and 17.

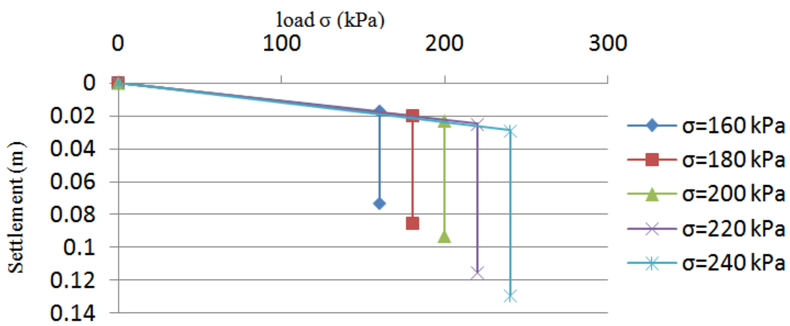

Figure 16: The Settlement of the Soil According to the Variation of a Load Applied by Foundation Case1

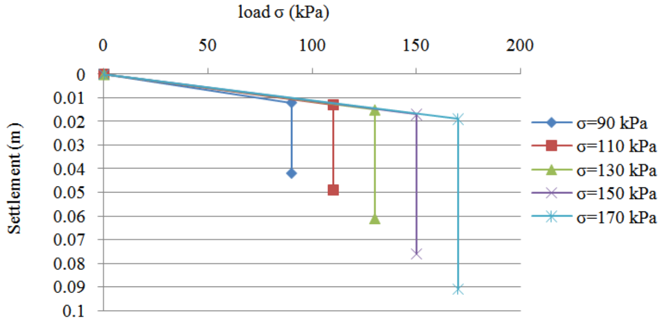

Figure 17: The Settlement of the Soil According to the Variation of a Load Applied by Foundation Case 2

The collapse for both foundations depending on the variation of loading is presented in figure18.

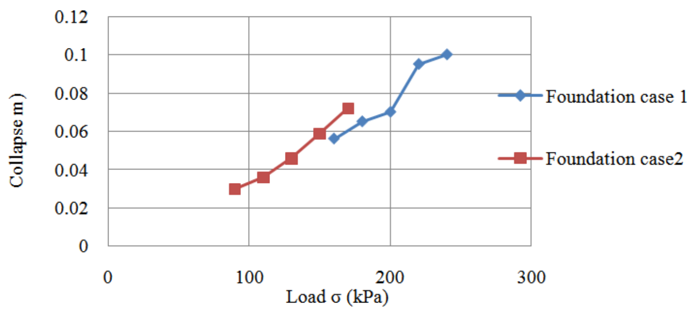

Figure 18: The Collapse of Both Foundation with the Variation of Load

The collapse under the center of foundations varied between 0.056 m and 0.1m for foundation case 1 and from 0.03 m to 0,072m for the foundation case 2.

The reduction of load applied on the foundation can reduce the collapse almost half.

5. 8. Variation of the Width of the Foundation

The change in the width is within a range of ± 20cm.

The real value of the width foundation case 1 is B = 2m and for the foundation case 2 is B = 2m.

The effect of area of the foundation on the collapse is very important as it is shown in figure 19 and 20**.**

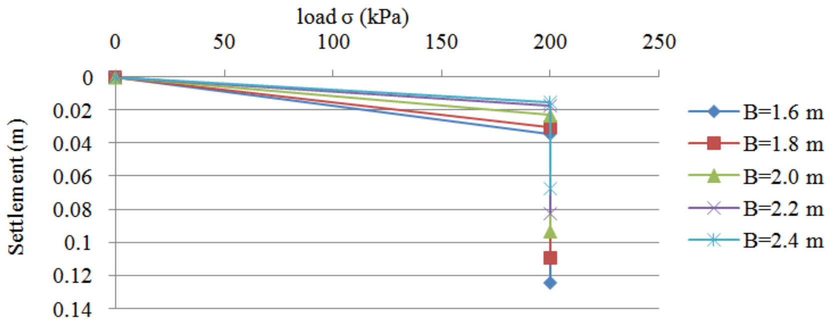

Figure19: The Settlement of the Soil According to the Variation of the Width of the Foundation Case 1

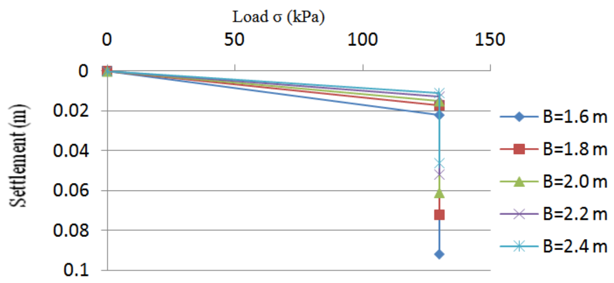

Figure 20: The Settlement of the Soil According to the Variation of the Width of the Foundation Case 2

The distribution of the load over a large area of foundation can avoid the collapse almost half of the value of the reference model.

The collapse for both foundations depending on the variation in the width of the foundation is presented in figure 21.

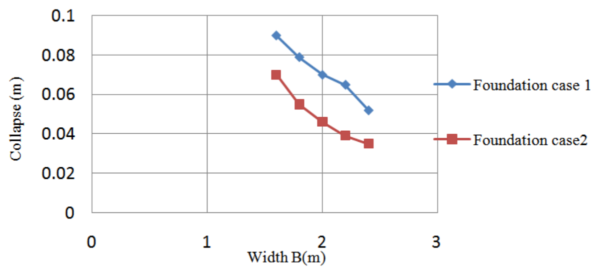

Figure 12: The Collapse for Both Foundations Depending on the Variation in the Width of the Foundation

An increasing in the width of the foundation causes a reduction of the collapse from 0,07m to 0,056m for the foundation 1 and from 0,046m to 0.035m for the foundation 2.

There was a slight variation in the collapse due to the variation of the width and the load applied.

We can reduce the collapse if we change the area of foundation.

6. CONCLUSIONS

The results obtained from numerical calculation of the collapsible soil behavior; during saturation is the same, obtained from the oedometer test. Numerical modeling of the foundation shows that, the two major causes of the instantaneous collapse of collapsible soil are the drop of the strength and the deformation modulus, caused by saturation. The parametric study of the modeling of the foundation gives the variation of the subsidence according to the variation of strength parameters and the deformation modulus. The variation of the friction angle of roughly 18% yields to a variation of the cohesion from -8% to 10% and the variation in the cohesion of more or less than 25% varies the collapse of -15% to 18%.The variation of the deformation modulus of more or less than 28% gives a variation of the collapse from -6% to 9%. We notice that the variation of cohesion has a remarkable influence compared to the variation of other parameters. The effect of the load and the width of the both foundation is not important compared to other parameters variation. But it is solution for reduce the collapse if the treatment of sol is not possible. For the improvement of collapsible soils, this study is considered as a guide for the choice of technical's methods and materials of treatment used to avoid the problems of the collapsed in geotechnical and others solution if the treatment is not possible.

REFERENCES

1. Abelev yu. and M-Abelev Mr. Yu., 1979, 'Basic project development and construction on loess collapsible soils' - J. P. Magnan-translation of the 3rd Edition Russian-Lavoisier 1986, P275.
2. L. Barden McGow A-Collin K., 1973 'The collapse mechanism in party saturated soil.' Eng Geol. 7, 1973, pp44-60,
3. Tra Thanh phuong., 2003 'Study of rheological loess soils of southern Vietnam and the modelisation of the behavior of foundations built on this material.' University of Grenoble, France, pp271-294.
4. Hicher P. Y.,1996 'Elastic properities of soils.' ASCE. ,flight. 122 N 8, aug. 1996, pp. 641-648,
5. D. G. Fredlund -Morgenstern N. R.,1978," 'The shear strength of soils Unsatured'. Can. Geotech. J., 15,1978, pp313-321.
6. D. G. Fredlund -Xing Anquing., 1985," 'The relationship of the Unsaturated soils shear strength to the soil-water characteristic curve.' Can. Geotech. J., 32, 1985, pp440-448.
7. D. G. Fredlund -Rahardjo H.,1993, 'Soil mecanics for Unsatured soils.' John Wiley & Sons – 1993, pp344-349.
8. K. Abbeche, F. Hammoud et T. Ayadat, 2007, "Influence of Relative Density and Clay Fraction on Soils Collapse," Experimental Unsaturated Soil Mechanics, Springer Proceedings in Physics, 112, pp.3–9.
9. K. Abbeche, M. Laouar and F. Messaoud, 2009, "Prediction of collapsing soil by the cone penetrometer and ultrasonic tests," International Symposium UNSAT-WASTE, Shanghai, Chine.
10. K. Abbeche, O. Bahloul, T. Ayadat and A. Bahloul, 2010, "Treatment of Collapsible Soils by Salts Using the Double Consolidation Method," In Experimental and Applied Modeling of Unsaturated Soils, ASCE Geotechnical Special Publication, American Society of Civil Engineering, pp. 69–78.
11. K. Abbeche, T. Ayadat et A. Lahmadi, 2009, « Treatment of collapsible soil by lime » ," International seminar Innovation and development in the Civil Engineering (INVACO1), Hammamet, Tunisie, pp. 161–168.
12. Boudlal O, 2013, « Experimental study of the mechanical behavior of the fine in the stability of slopes and foundations». University of Tizi-ouzou, Algeria. p217.