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Swelling and Geotechnical Cartography of Saida Soils

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ABSTRACT

The urban expansion and the increase in population led the urbanization to use the spaces called "at risk".The integration and the treatment of ground's movements constitute an important characteristic of the equilibrium established by nature.

In the Saïda town (Algeria), many projects built on grounds with problems showed signs of degradations such as cracks in structures. These degradations led to the total destruction of the buildings. The principal causes of these disasters are: the expansive nature of soils and landslides, and the disaster phenomenon not considered in the first study of these constructions. The damage also touched road embankments, highways and foundations.

In order to solve these problems, it was necessary to propose a geotechnical and risk map for the ZHUN EAST (ESSALAM city, Saïda), a city which includes several yards of the soil with problems, using the Geographical Information Systems (GIS/MapInfo). These tools enable us to express the perception of space and data processing, and consequently the cartography is carried out in an optimal way. These geotechnical and risk maps have a great part of importance in all levels of a study as information, working paper, alert, and especially is a tool for the decision-making aid, by expressing tendencies and orientations.

They enabled us to give a field representing the active and potential movements with a hierarchy of risks to guide the developer and the engineer.

KEYWORDS: Map, Geotechnical engineering, Risks, GIS, Urbanization, Swelling.

INTRODUCTION

In the town of Saïda Wilaya in the south-west part of Algeria, many construction works have been built on argillaceous grounds and showed signs of degradation in form of cracks on the superstructures, and this is because of the dryness of the three last decades (Figure 1). These degradations led to the total collapse of certain construction works. The main cause of these disasters is either the expansive character of clays, the frightening phenomenon not taken into account when designing these construction works, or other geotechnical risks (landslide, settlement…). The damage also touched road embankments, roadways and foundations (Bekkouche et al., 2002).

The awakening of these problems is new and the technical solutions are not always effective, even less easy to implement. If these problems are not taken into account for new constructions, one will have to expect worse.

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This work is devoted to carry out geotechnical maps, at the risks on the level of the east ZHUN of Saïda.

It is a question in particular of analyzing the zones at the risks of the area by using the Geographical Information System "G.I.S." which remains the tool for appreciation of information on cartographic support. Initially, a geological outline of the site is presented. The stepping of this aspect with the available geotechnical data enabled us to carry out a geotechnical map of the zone of study. This map emphasizes great argillaceous horizons which are likely to be expansive and shows the behavior of zones with important slopes, on a chart at the risks.

In order to appreciate the aspect of the behavior of clays, a qualitative and quantitative study was undertaken. This study consisted initially of an identification of the parameters of swelling of these formations while being helped of classifications available in the literature (Djedid et al., 2001) and on the basis of a statistical model of these two parameters of swelling (Bekkouche et al., 2002).

Figure (1): Pathological case in the city of Saida.

PRESENTATION OF THE ZONE OF STUDY

The ground to be studied is of a surface area of about 200 hectares.

A road crosses the ground longitudinally and divides it into two quite distinct parts:

- A part in the East, delimited by the Torba wadi.
- The other part in the West, delimited by a thalweg and a dense forest.

The ZHUN is limited by the following coordinates (LAMBERT):

X1=269.30 à X2=267.75km.

Y1=173.60 à Y2=174.55km.

According to the topographic map the Saida zone sheet is N°304, scale 1/50000.

Concerning the geomorphology of the site, it is presented in the form of basins with some monticules of altitudes which are at least important.

It can be subdivided in two micro-basin slopes. One is located at the East and drained by the Torba River, the other in the West drained by a river which has as a discharge system the river of Saïda.

With regard to the topography of the site, it is located between 822 and 908 of altitude, with broken slopes.

Figure (2): Satellite picture of the town of Saida and the zone of study (Google Earth, V. 4.3).

GEOLOGICAL ASPECT

Natural and Geological Framework

Algeria is generally divided into three structural fields which are from north to south:

- Tellien field.
- Atlassic field.
- Field of the saharan platform.

The area of Saida belongs to the Tlemcénien field, which represents a sub-assembly of the Atlassic field. The Tlemcénien field is before the country of the tel. Of fairly raised altitude, it starts with the solid mass of Ghar Rouben. In the east of this latter, one distinguishes the mounts from Tlemcen, Daia, Saida, and Tiaret with Boughedou, the mounts of Frenda and Djebel Nador. This system is lost under the plate of Sersou and is found in the East in the solid mass of Hodna.

The natural space of the town of Saida belongs to the downstream of the large catchment area of the valley of Saida Wadi. The commune includes three homogeneous physical units:

- Unit I: the plain of the valley of Saida Wadi

It corresponds to the terraces with deep ground, skirting the North of the Saida Wadi. It is a stable unit. It extends on a surface area of 472ha and accounts for 6.23% of the territory of the commune.

- Unit II: karstic plates

This unit presents the plates at low altitude, in the Western center and the South. Components slope of the mountainous areas. It extends on a surface area of 1171ha and accounts for 15.45% of the territory of the commune.

- Unit III: rock hills and the mountainous area

It is the dominant unit which is practically located in the West, the South and the South East and which girdles the city. It is made up of the Karstique landscape in the mountainous area. It corresponds to a surface area of 5937ha and accounts for 78.32% of the territory of the commune.

Part of this unit is covered by the drill and the maquis in the West at the top of the Abdelkrim Mountain and in the South at the top of Djebel Irlem, on a total surface area of 1651ha which is 21.78% of the territory of the commune.

Aquiferous Characteristic

The Wilaya of Saïda is characterized by the diversity of the aquiferous potentialities. In this respect, it is necessary to quote three principal sheets: sheet of Chott Chergui, sheet of mineral water of Saïda and sheet of warm water of Hammam Rabi.

The principal geological stages represented on the level of the area are:

- The paleozoic: the rocks are metamorphic, not very faded and form an impermeable unit.
- the Jurassic inferior and means: formed by a lower extremity consisting of dolomitic rocks known as dolomites with a permeability lower than the permeability of fissures, an intermediate member represented by the marls of Essafeh forming an impermeable level and a dolomite upper member made up of dolomites known as dolomites with a permeability higher than the permeability of fissures.
- The callovo-oxfordien: formed mainly of clays with intercalations of benches of likings, it is a not very permeable unit.
- The Lusitanian: represented by the more or less permeable likings of Franchetti.
- The plio-quaternary: comprises levels of permeable conglomerates.

The principal aquiferous horizons are:

- The likings of the Lusitanian.
- The lower and higher dolomites of the Jurassic inferior and means.

The impermeable levels of important thickness are:

- The clays of Saida (callovo- oxfordien).
- The marls of Essafeh (toarcian).

The sandy trainings of the Lusitanian positioned in altitude constitute isolated reliefs and do not give perennial sources. They do not seem to constitute a potentially mobilizable tank.

The conglomeratic grounds of the quaternary plio-extend on banks from the Saida wadi and offer only low flows when they are exploited in the form of well low depth.

The formations of sandy argilo- of the callovo - oxfordien constitute a practically impermeable level. The dolomitic formations of the very fissured inferior Jurassic and middle Jurassic represent the most important reserve of the area. The lithological distribution makes it possible to divide it into two aquiferous horizons, that of higher dolomites and that of lower dolomites.

The two levels are separated by the impermeable trainings (marls) of the toarcian, affected locally by secondary faults, the layers marly- limestones leave the possibility of communication between the aquifers.

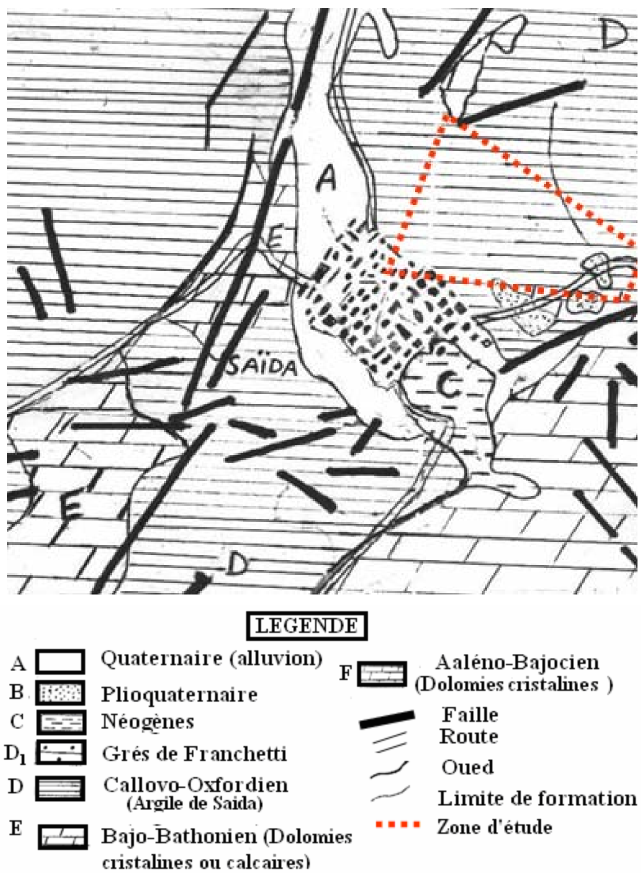

Figure (3): Geological map of the area of SAIDA Scale: 1/50 000.

Boundary Conditions

The substratum consists of not very faded schists and quarzites of the primary level in Tiffrit. One can admit that they constitute a tight vertical limit. Beside a practically impermeable wall, the roof is formed by clays of Saida (callovo-oxfordien) which constitute a tight vertical limit. Laterally, the aquifer has a limit tight in the West and the North-West. The structure shows in these directions that dolomites are partially brought in contact with clays of Saida to the level of the western edge of the trough fault of the valley of the Saida wadi.

In the north, the aquifer is not very thick; one observes a side variation of facies characterized by a dolomite passage lower than the marls of Modsbad. In the North-East, the aquifer stops in bevel on the outcrops of the formations of the mole of Tiffrit (primary).

This situation generated a hydraulic hinge zone between Oum Djrane and Tiffrit, characterizing a central articulation of the various basins and their tectonic zone.

ELABORATION OF THE GEOTECHNICAL MAP

Collecting Geotechnical Information

Information used for the realization of this piecework comes from various sources:

- Analytical folder containing the whole information used for the elaboration of the maps, laid out at NLHC (National Laboratory of Habitat and Construction, Unity of Sidi Bel Abbès) (LNHC, 2002).

There exist 51 points of information (19 test surveys and 32 tests of dynamic penetration) in which we find physicochemical and mechanical tests (LNHC, 2002).

Geotechnical Map

The geotechnical map of the study zone (Figure 4) was carried out starting from the superposition of the maps of the soil layers. These maps of the layers were the result of the projection of the geotechnical cuts in space (three dimensions) (Figure 4).

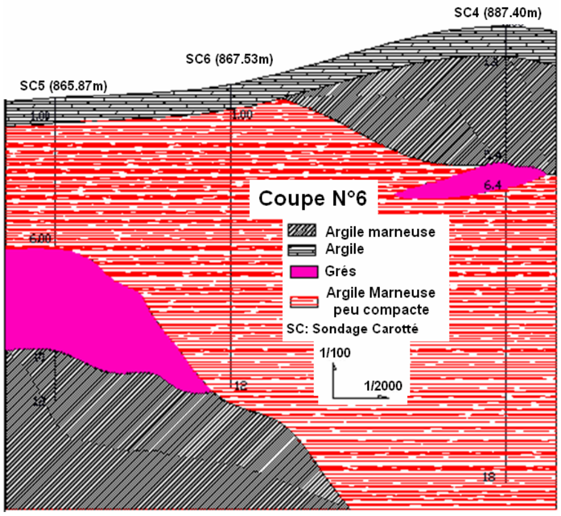

Figure (4): Exemple d'une coupe géotechnique N°6.

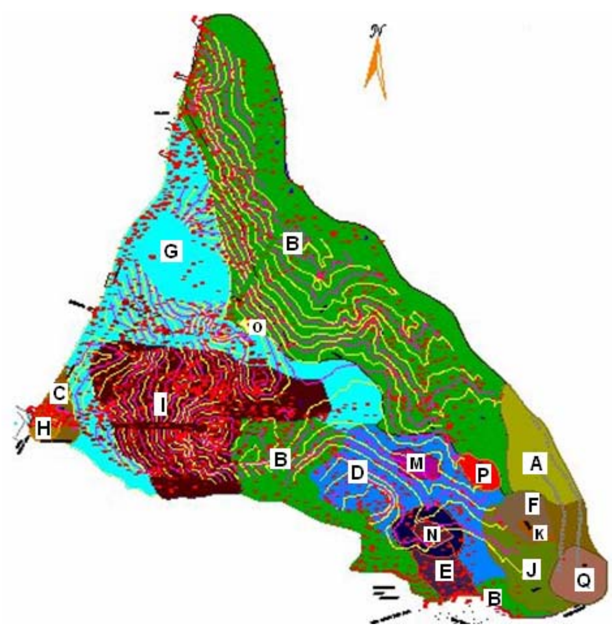

Figure (5): Carte géotechnique de la ZHUN Est de Saida.

Legend of the geotechnical map of the ZHUN East of Saïda

A: compact marly clay.

B: clay, compact marly clay.

C: marly clay, compact marly clay.

D: embankment , clay, compact marly clay.

E: clay, compact marly clay, likings.

F: embankment , marly clay, compact marly clay.

G: marly clay, compact marly clay, sand.

H: embankment, marly clay, compact marly clay.

I: clay, marly clay, compact marly clay, likings.

J: embankment, clay, marly clay, compact marly clay.

K: embankment, marly clay, compact marly clay, likings.

M : fill, clay, compact marly clay, alluvia.

NR: embankment, clay, compact marly clay, likings, limestone.

O: embankment, clay, compact, calcareous marly clay.

P: embankment, clay, compact marly clay, sand, limestone.

Q: marly clay, compact marly clay, sand.

Table (1): Characteristics of the layer of clay and marly clay.

Property		Unit	Min.	Mean	Max.
Depth (m)		m	0.60	6.30	12.00
Natural voluminal weight		T/m³	2.01	2.110	2.22
Dry voluminal weight γ_d		T/m³	1.76	2.030	2.30
Liquid limit L_L		%	42.90	48.450	54.00
Index of plasticity I_p			17.70	26.30	34.90
Degree of saturation S_r		%	15.00	57.00	99.00
Free swelling σ_g		kPa	/	/	/
Carbonates $CaCO_3$		%	16.80	17.90	19.00
Oedometric characteristic	σ_c	kPa	171.0	257.0	343.0
	Cc		0.066	0.094	0.122
	Cg		0.027	0.042	0.057
Shear strength *CD*	C	kPa	25.0	32.0	40.0
	φ	(°)	16.0	17.5	19.0

For the management of this ground, the choice of the initial part must take into account a very great quantity of parameters, a number of which are those arising from geotechnics and are among the most important ones.

A complete geotechnical study ensures safety, economics and facility in execution.

The geotechnical map is a necessary element and is important for the establishment of the plans of occupation of the ground, but insufficient for quantitatively drawing up a project of foundation.

Table (2): Characteristics of the compact marly layer of clay.

Property		Unit	Min.	Mean	Max.
Depth (m)		m	0.80	10.40	20.00
Natural voluminal weight		T/m³	1.73	1.975	2.220
Dry voluminal weight γ_d		T/m³	1.53	1.86	2.190
Liquid limit L_L		%	42.90	55.40	67.90
Index of plasticity I_p			17.70	29.95	42.20
Degree of saturation S_r		%	11.00	55.00	99.00
Free swelling σ_g		kPa	460.0	570.0	680.0
Oedometric characteristic	σ_c	kPa	50.0	290.0	531.0
	Cc		0.038	0.105	0.171
	Cg		0.021	0.059	0.097
Shear strength *CD*	C	kPa	10.0	62.5	115.0
	φ	(°)	5.00	15.0	25.00

It would be however excessive and dangerous to conclude that the absence of past or present problems of ground is a guarantee for stability in the future. They will be able to occur according to the evolution of the natural conditions.

On the level of the specific execution, the specific study remains irreplaceable.

ELABORATION OF MAPS AT RISK

For the elaboration of maps at risk (Figure 4), one takes into account the density of the risks and the multirisk character, the specificity of the types of movements which can occur in a more specific way (NLHC, 2002; Houmadi et al., 2008).

It is no way to be delayed on the analytical phase, for that are necessary:

- A historical investigation into the past movements.
- A research on the ground of the active indices of movement with the support of air topographies.
- From these data, the map at risk is built. It provides the following information:
- In the form of colors (red, orange and green): A zoning of the zones exposed to the risks of ground movement. Various colors express a graduation of the zones according to their degree of exposure at these risks. It is the interpretative part of the map.
- The diversity of the studied phenomena complicates much the definition of the zoning of the multirisk maps when it is necessary to take into account in the same zone the types of movement of different natures; each one having its own scale of graduation in a hierarchisation of the risks.

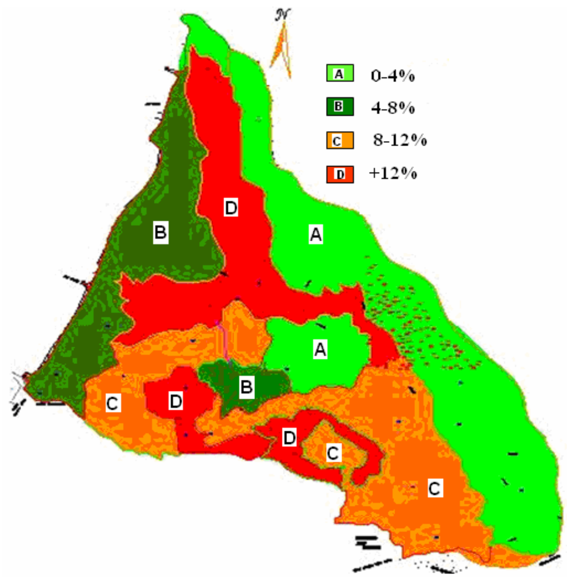

Figure (6): Chart of the slopes of the ZHUN East of Saïda.

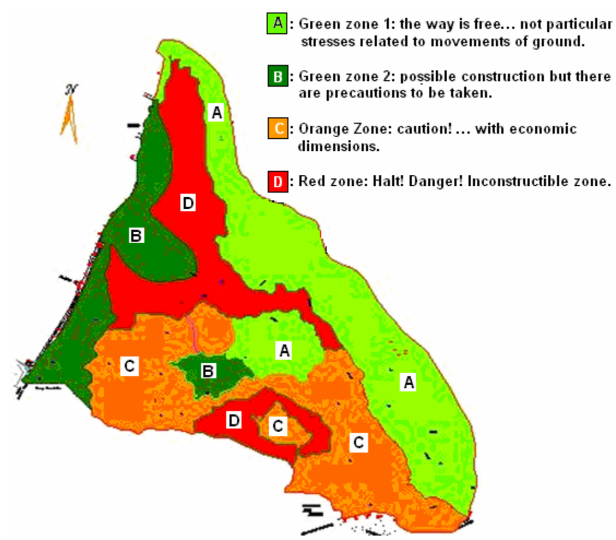

Figure (7): The risk map of the ZHUN East of Saïda.

The chart at risk was carried out starting from the following points:

- The map of the slopes.
- Localization of the various active argillaceous layers.
- Dividing the map into four zones, in the form of colors (green 1, green 2, orange and red).
- Various colors express a graduation of the zones according to their degree of exposure to the risks:
- Green zone 1: the way is free… no particular stresses related to movements of ground.
- Green zone 2: possible construction, but there are precautions to be taken.
- Orange zone: caution!… with economic dimensions.
- Red zone: Halt! Danger! Inconstructible zone.

STUDY OF THE INFLATING CHARACTER OF CLAYS

Starting from a statistical study on 200 samples, David and Komornik (Quoted by Kabbaj, 1989) deduced a relation which makes it possible to estimate the pressure of swelling.

Adjusted with clays of the area of Tlemcen by (Bekkouche et al., 2002), this relation is:

$$\log P_S = 2.08\,W_L + 0.06688\,\gamma_{\mathrm{d}} - 2.69W_n - 1.868 \qquad (1)$$

The pressure of swelling P_S is given in kg/cm², the liquid limit W_L and the natural water content W_n are in decimal digit while the density γ_d is in g/cm^3.

Williams and Donaldson (Quoted by Mouroux, 1989) propose a model which gives the amplitude of swelling according to the load which reigns in the ground. This model is:

$$S_p = \left(\frac{5.3 - 147e}{I_p} - \log P_s\right)(0.525I_p + 4.1 - 0.85W_n) \qquad (2)$$

Also, for a null amplitude *(Sp=0)*, the free pressure of swelling will be given by:

$$\log P_s = (5.3 - 147e)/I_p \qquad (3)$$

In the two preceding relations, e represents the base of the Napierian logarithm (e=2.718), I_p, the index of plasticity and W_n, the natural water content are in % whereas the pressure of swelling P_S is given in 0.1 MPa.

Being based on the results of 270 tests of swelling carried out on various grounds, Vijayvergiya and Ghazzaly propose two models which make it possible to obtain the pressure of swelling. These models-adjusted with clays of Tlemcen-are written respectively:

$$\log P_s = \frac{1}{12}(0.4\,W_L - W_n - 0.4) \qquad (4)$$

$$\log P_s = \frac{1}{19.5}(\gamma_d + 0.65W_L - 139.5) \qquad (5)$$

In these models, the pressure of swelling P_S is given in tsf, the density γ_d in pcf, and the limit liquid W_L and the natural water content W_n are in decimal.

For the amplitude of swelling, the models generally give free swelling. The model suggested by O'Neil and Ghazzaly is:

$$S_p = 2.77 + 0.131W_L - 0.27W_n \qquad (6)$$

While the model suggested by Jonhson and Snethen is:

$$\log S_p = 0.036W_L - 0.0833W_n + 0.458 \qquad (7)$$

In the two preceding relations, S_p is free swelling in %; W_L and W_n are expressed in decimal.

Always on the basis of the results of the 270 tests of swelling quoted before, Vijayvergiya and Ghazzaly propose the following correlations (Chen, 1988):

$$\log S_p = \frac{1}{12}(0.096\,W_L - 0.12\,W_n + 2.10) \qquad (8)$$

$$\log S_p = \frac{1}{19.5}(0.877\,\gamma_d + 0.117\,W_L - 0.253) \qquad (9)$$

where γ_d is in pcf, W_L and W_n are in decimal and S_p in %.

The free swelling obtained starting from the models above, can be reduced if the ground would be subjected to a confining pressure σ_v using the following formula suggested by Gogoll:

$$S_p^{'} = S_p(1-0.0735\sqrt{\sigma_v}) \quad (10)$$

where σ_v is the stress of containment in kPa.

Taking into account the variation noted between the values of the parameters of swelling directly measured and those provided by the models above, a first idea consisted of the adaptation of the models proposed on the ground studied by an adjustment (Bekkouche et al., 2002).

Table (3): Characteristic of the compact marly layer of clay (swelling pressure).

Mathematical expression (statistical model)	
Log $\boldsymbol{\sigma_g}$ = 0.01.$\boldsymbol{I_p}$+1.26.$\boldsymbol{\gamma_d}$-0.008.$\boldsymbol{W_n}$-0.1.$\boldsymbol{M}$-2.179 avec (M=3)	
Statistical characteristics of the pressure of swelling $\boldsymbol{\sigma_g}$ in (bars=10²kPa)	
Average	1.663
Error-type	0.172
Standard deviation	0.8932
Minimum	0.344
Maximum	3.581

Table (4): Characteristic of the compact marly layer of clay (swelling amplitude).

Mathematical expression (statistical model)	
$\boldsymbol{\varepsilon_g}$ =34.388-17.82.$\boldsymbol{\gamma_d}$+0.07687.$\boldsymbol{M}$+0.07687.$\boldsymbol{Z}$ (avec M=3)	
Statistical characteristic of the amplitude of swelling $\boldsymbol{\varepsilon_g}$ (%)	
Average	2.547
Error-type	0.361
Standard deviation	1.655
Minimum	0.349
Maximum	7.562

The examination of the results of this adjustment emphasizes the following remarks: (Bekkouche et al., 2002).

- Models of Seed et al. do not hold account for the natural water content which in our opinion remains a determining parameter in the process of swelling. These models use only interdependent parameters (content of clay, the activity and the index of plasticity).
- The model of Nayak and Christensen and the model of Vijayvergiya and Ghazzaly cannot be used for high values of the content of clay, natural water content and liquid limit. The first model is based on interdependent parameters, as for the second, it does not take account of the natural water content.
- The model of Johnson predicted overall percentages of swelling within limits usually observed in practice.

Based on these results and remarks quoted above, a statistical study on the available data of clays of the zone of study was carried out to seek specific models to these grounds. The models considered seem to be satisfactory.

CONCLUSIONS

This work on the geotechnical cartography and the risks of movement of ground shows the interest caused by these methods, which sounds of multiple forms. It opened the way to a very sensitive improvement of the prevention of risks.

It is advisable, in addition, to stress that parallel to the actions, many pieces of research came to enrich and prolong the purely cartographic results: monitoring of the movements, calculation of stability, seeking techniques of protection… etc.

Also, knowing that the dimensional checks of the parameters of swelling are long and expensive, it would be very interesting to be able to quickly obtain a first estimate of these parameters. The use of the mathematical models offers this possibility. Only, and as specified in this work, the models of the literature are not usable for any family of clay. The solution would be to seek specific models to each family of clay, of course by means of having sufficient information.

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Software: Google Earth, Version 4.3.