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EXPANSIVE AND AGGRESSIVE SOIL CHARACTERISTICS AND THEIR IMPACT ON BUILDING CONSTRUCTION: CASE OF EL KOUIF CITY (TEBESSA, ALGERIA)

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ABSTRACT

Prediction of soil swelling characteristics and accurate quality estimation can be of a great consideration and contribution regarding the site stability. Any concerned investigation is correspondingly an advanced priority for the project realization. Related inquiries allow potential reduction concerning financial and technical charges damage prior to any urban development. The determination of soil characteristics lead for a better recognition, and allow to make the best choice of foundation type adopted for each site. Thus, in any urban case study, much gain can be made by team work recording and surveying the related data. In the considered city of El Kouif, located in Tebessa (Algeria), several buildings have been mainly built on expansive soils. Observations indicate different severe damages which were caused mostly in the nearby structures. These damages are characterized by deflection and failure of walls. Lateral and vertical displacements evidences support the presence of shear movements and subsidence. The scale up of these movements occurrence can reach millimetric shifting dimension.

Ground and subsurface risk activity affecting El Kouif city site are also related to the presence of destructive chemical components such as sulfates. The sulfate occurrence is illustrated through generally gypsum minerals concentration present in the concerned soil. During building projects, these soils, in meeting concrete and in presence of water, are source of new mineral generation such as ettringite. It consists on the assemblage of water and sulfate in addition to calcium. Source for these chemical products expansion might be associated to historical event: the city of El Kouif was the field of phosphates mining area in addition to established phosphate extraction plant. Thus, determination of soil characteristics and involvement of chemical components turn out to be the main objectives in this investigation.

Keywords - Expansive soil - Swelling - Sulfates - Soil Contamination - Aggressive Soil - Damage.

CARACTÉRISTIQUES DES SOLS GONFLANTS ET AGRESSIFS ET LEUR IMPACT SUR LES CONSTRUCTIONS : CAS D'ÉTUDE DE LA VILLE D'EL KOUIF (TÉBÉSSA, ALGÉRIE)

RÉSUMÉ

La prévision du caractère gonflant d'un sol et l'estimation rapide des paramètres de gonflement est une considération à grand intérêt économique pour l'étude et la réalisation d'un projet.

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Elle permet de réduire le coût des travaux ainsi que la durée des travaux d'exécution du projet. La détermination du caractère du sol peut orienter sur de meilleures reconnaissances qui permettent le bon choix des types de fondation à adopter pour un site donné. Dans la région d'El Kouif, wilaya de Tébéssa (Nord est de l'Algérie), plusieurs édifices ont été bâtis sur des sols gonflants. Après les sorties sur le terrain et les observations des zones de construction à El Kouif, nous avons constaté que ce phénomène de retrait gonflement des sols a conduit à des dégâts irrémédiables. Ces dégâts se caractérisent par des fissurations au niveau des murs, des affaissements affectant les pavements et les trottoirs et des tassements différentiels traduits par des déplacements très nets au niveau des joints dans les bloc. Les mesures ainsi que les photographies faites sur terrain montrent que ces endommagements sont à différentes échelles.

La dégradation des différentes constructions peut aussi être liée à la présence d'un fort pourcentage de sulfates dans les sols qui à été mis en évidence par les analyses de diffractométrie. Ces sulfates sont à l'origine d'agressivité des sols. Une fois ces sulfates en contact avec le béton et surtout en présence d'eau, ils peuvent donner naissance à un nouveau minéral expansif appelé ettringite ($Ca_6Al_2(SO_4)_3(OH)_{12}$ $26H_2O$). La richesse des sols étudiés, en sulfate peut être liée à l'historique de la région qui abritait l'ancienne mine de phosphate d'El Kouif. À cet effet, la détermination des caractéristiques de gonflement des sols et leur agressivité est l'objectif principal de cette recherche.

Mots-clés - Sol expansif - Gonflement - Sulfates - Sols contaminés - Sols agressifs - Dommage.

1- INTRODUCTION

Soil Expansion is a phenomenon affecting many clayey or silty soils, particularly those containing significant quantities of smectites clay minerals. In many cases, the shrinking and swelling of expansive clays joined to moisture content can be, with time, a serious cause for residential buildings damage. Solution for this worldwide frequent phenomenon is costly. In geotechnical engineering, any action against, can be fairly complex. Investigation for that purpose was from different researches led by (Skempton, 1953; William and Withman, 1979; Donald and *al*., 1983; Mouroux and *al*., 1988; Al-Rawas and Woodrow, 1992; Derriche and Kebaili, 1998; Derriche and *al*., 1999; Hachichi and Fleureau, 1999; Bultel, 2001; Djedid and *al*., 2001; Nowamooz, 2007; Youdjari, 2010, Rocher , 2011; Medjnoun and *al*., 2014a; Medjnoun and *al*., 2014b). A synopsis from these different authors approaches is stated as: encountered soils expansion can be due to their change in behavior when they are mixed to variation in moisture with their ability in adsorption, absorption and desorption changes. Modification in these soil properties leads essentially to difference in compaction and swelling scale up. Investigation for the purpose of expansive soil and type in addition to moisture presence had been made by Gordon (1992). The author developed a laboratory study based on different tests applied to expansive soils. He found that suction change is allocated to the degree of saturation. In his experimental study, based on the outcomes, the investigator concluded that on a swelling soil are depending on stress path even if a wetting process is performed. In an investigation on clayey soils of the Eastern Saudi Arabia Province, Abduljauwad and *al*., 1992 found that soils are highly expansive, this is due to matrix suction being possibly coupled with climate effect. The led investigation was based on geotechnical laboratory tests, X-ray diffraction, scanning electron microscope and different thermal analyses.

Chemical products such as gypsum are also implied within soil when this latter is coupled with concrete. In the presence of sulfate, water will affect the mineral soil, making the material more aggressive. This aggressive action can be through the fluid solution circulation and penetration of elements or ions such as Cl or Mg within the microstructure. They result essentially in the attack of the concrete through fluid circulation and, chemical reaction will lead to the precipitation of some undesired minerals such as ettringite. Stephen and *al.*, (1986) found that the quality of any soil in association with the sulfate presence is characterized by a sulfate concentration and possibly pH acidity especially when the latter is overcoming the threshold. Outcomes from expansive soils combined to sulfate components presence are reported by Ejjaaouan (2008), Richard and *al*. (2012), Al-Amoudi (1992), Pat Harris and *al*., (2004) and Anand and *al.,* (2002). They concluded that interactions occurrence between foundations and expansive soils can react adversely: building material (concrete) and chemicals (sulfate) or other acidic influence might have a considerable impact on the concrete or slab attack. In similar cases, interface elements and type of cement are recommended. Ejjaaouani (2008) treated the effect of the foundation load on the stress and strain state in the soil. Restrictions on that regard might produce either settlement or heave, depending on the relative values of the swelling pressure and vertical stress in the soil. The author found that the uniform swelling doesn't cause real damage for the buildings compared to the non uniform ones.

In the case study, since 1972 and up to now, El Kouif city (Tebessa, North-East of Algeria) (fig.1) underwent a considerable building extension with high rate of urban infrastructure development such as buildings, schools, mosques, and nurseries. Conversely with time, different building zones have been affected at different stages. It appears that, the type and behaviour of soils over which these buildings are set, are among the causes. The identified soils consist commonly on: clay, tuffs, embankment and marl with frequently high percentage of gypsum. As known, those characterized

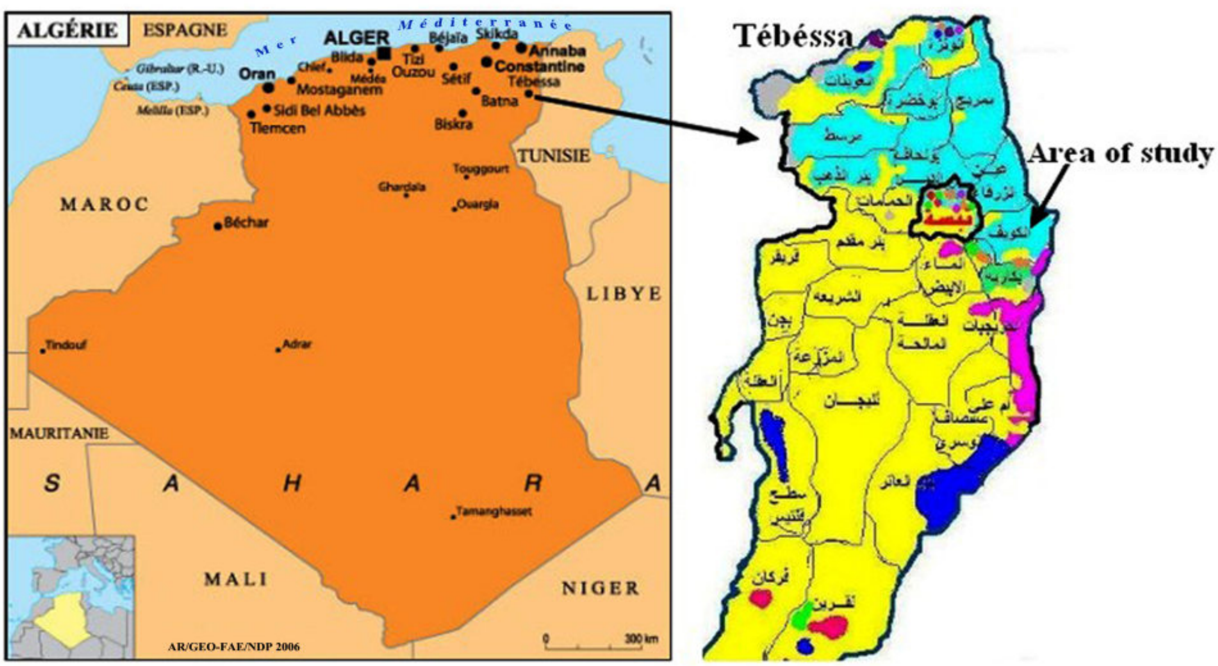

Fig. 1 - Location map of the study area (El Kouif city: North-East of Algeria)

Carte de situation de la région d'étude (Commune d'El Kouif : Nord-est de l'Algérie)

soils might lead to an important impact concerning the stability of any considered site. Thus, leading an investigation for understanding the case study soil type behavior is wisely vital. With reference to soil properties and providing more information on chemical components and their involvement with concrete slabs and foundation, the overall afford appreciative conception for the case study problem. Thus, the investigation will improve advices and solution on the actual state prior to any other project step. Therefore, objectives concerned with this investigation can be established as:

- an approach aimed to introduce, identify and classify the case study soil with regard to swelling impact;

- a determination of clay mineral types and their contribution in soil behavior in regarding the phenomenon of swelling.

2- MATERIAL

The collected material was from coring and test pits (1m to 15 m depth). Lithologically, it consists from the bottom to the top on:

- Scattered and dispersive clay and laminated massive green, beige, brown and grey marl of Paleocene, with the presence of a large quantity of gypsum crystals well identified within the host (fig. 2 a and b). The overall thickness of this facies type is reaching almost 14 to 20 m.

- Limestone and sandy tuff, beige in color, with gravel. This formation type is crumbly and permeable reaching a thickness of around 5 m to 6 m. We note also the presence of beige limestone gra-vel (2 m to 3 m in thickness).

- Bank of the old phosphate pit, composed of limestone fragment, weathered clay and altered marl mixture with presence of sulfate mineral, gypsum (phosphogypsum). The thickness of the concerned facies is about 3 m.

3- EXPERIMENTAL WORK PROCEDURE

To examine the geotechnical properties of soil foundation, site investigation data was collected from 11 building sites located in El Kouif region (North-East of Algeria).

Laboratory testing program was designed to determine the physical, mechanical and chemical properties according to the French standard (AFNOR). The laboratory tests used were:

- a determination of natural water content and dry density (NF P 94-050, NF P 94-053 and NF P 94054, in addition to Atterberg limits (NF P 94-051). Particles size distribution was achieved according to NF P 94-056 and NF P 94-057 norms;

- a swell pressure test (constant-volume) accomplished was based on NF P 94-091;

- a soil aggressiveness was determined subsequent to the standard (NF P 18-011);

- a standard procedures were used to determine soil properties. Thus, obtained results are presented by a descriptive statistical analysis in table I.

To support the experimental work and to determine clay minerals, XRD analysis was realized. This procedure was applied essentially for the soil characterization purpose. This work was carried out at the University of Al Manar Laboratories (Tunis- Tunisia). The X-ray diffraction tests were achieved on the whole rock and also on the thin fraction. Results are presented in table II

4- RESULTS AND DISCUSSION

Determined parameters from swelling soil identification tests have been combined in a number of different classification schemes. Seed and *al*. (1962), in an extensive study on swelling characteristics of compacted clays, have developed a chart based on clay activity and percentage. In the case study, the use of the proposed chart was

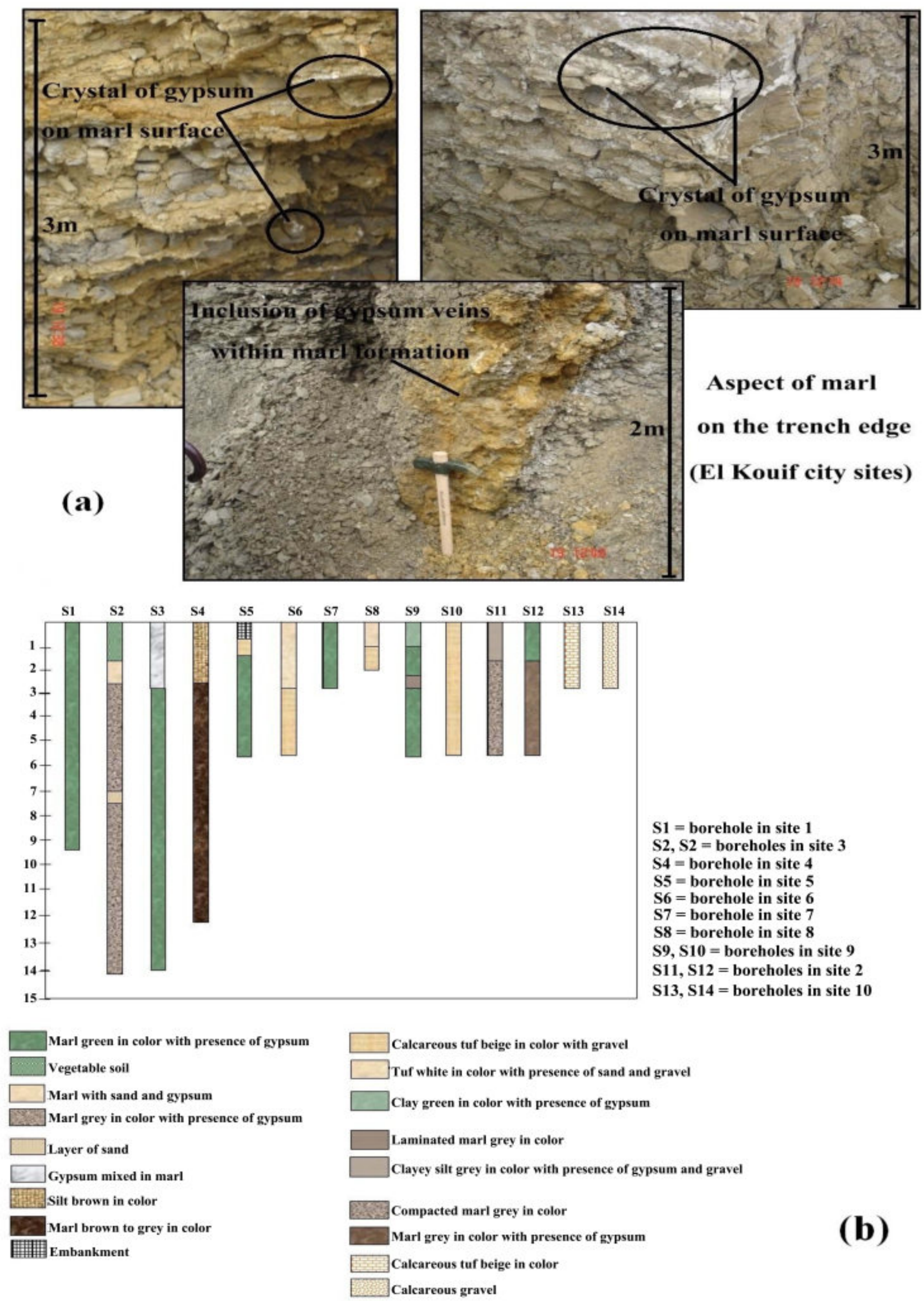

Fig. 2 - (a) Photo of marl outcrop with presence of gypsum collected from the concerned site (El Kouif)

Photo montrant la marne avec présence du gypse dans le site d'étude (El Kouif)

(b) Representative boreholes executed in different sites of the study area

Sondages représentatifs réalisés dans différents sites de la région d'étude

Table I : Results from laboratory experimental work on soil properties

Résultats des essais* de *laboratoire effectués sur les sols étudiés

Variable	Active number	Mean	Minimum	Maximum	Standard deviation
Wn (%)	79	29,53	7,9	61	11,17
Sr (%)	59	85,84	44,14	103,1	12,91
γd (t/m3)	62	1,41	0,98	1,9	0,21
γh (t/m3)	58	1,84	1,53	2,1	0,15
LL (%)	83	77,93	28,25	158	22,85
PI (%)	83	40,02	8	89	16,16
2 mm (%)	72	87,81	9,61	100	19,54
0.08 mm (%)	87	75,54	6,47	99,9	27,46
20 µm (%)	45	38,82	7	92	25,4
2 µm (%)	42	19,56	4	90	19,09
BV (g/100g)	18	6,35	0,65	13,6	4,3
Anhydrite (%)	6	3,6	0,1	7,1	3,13
Gypsum (%)	35	17,25	0,36	60,4	16,95
Sulfate (mg/l)	35	86010,69	2007,648	336838,7	90249,06
$CaCO_3$ (%)	43	43,27	12	85,7	21,53
Pc (bar)	33	2,97	0,58	12,6	2,65
Ct	32	0,23	0,017	0,6	0,19
Cg	32	0,09	0,001	0,3	0,09
Pg (bar)	15	1,5	0,106	5,1	1,23
A	42	3,25	0,42	10,6	2,47

Wn=Natural water content, Sr = Degree of saturation, γd = Dry density, γh = Humid desity, LL = Liquid limit, PI = Plasticity Index, (2 mm, 0.08mm, 20 mm) = Grain size distribution, 0.02µm = Clay fraction, BV = Methylene blue value, Pc = Consolidation Pressure, Ct = Compressibility coefficient, Cg = Swell Index, Pg = Swell Pressure, A = soil Activity

based on the obtained field data (table I), where clay activity parameters, is deduced from plasticity index and clay percentage, according to the following equation (Skempton, 1953):

$$A= \frac{I_p}{J} \quad (1)$$

where,
A : soil activity
Ip :plasticity index in %
J : clay fraction in % (clay fraction is issued from sedimentometry tests (table I))

Results from the activity plat and clay percentage size (fig. 3) indicate that the studied soils are distributed as follow: 21% of the soils have low swelling potential, 40 % have medium swelling poten- tial and about 25% of samples have high swelling potential while 13% of the soil are characterized by a very high swelling potential (fig. 3). Developed method from Van der Merwe (1964) supports also such outcomes. This method consists on plotting the calculated plasticity index versus clay content. Distribution of the samples results, on the author proposed swell potential chart, point out that 29 % of the samples enclose low swell potential, 32 % are characterized by a medium swell potential, 9% have a high swell potential, whereas 30 % of

Table II - Mineralogical results obtained from the clay fractions XRD (<2µm) of some the study area soil samples ***Résultats minéralogiques obtenus par DRX de la fraction argileuse (<2µm) pour quelques échantillons du sol de la région***

Minerals / Sites	Smectite	Kaolinite	Illite	Sepiolite	Gypse	Calcite	Anhydrite	Total
2	38.06	6.77	7.62	6.31	20.42	19.04	1.75	99.99
5	29.86	20.79	5.84	5.14	29.91	6.85	1.59	99.98
6	38.252	8.28	7.75	6.61	22.23	14.66	2.19	99.99
8	32.894	10.758	6.514	5.681	31.62	11.053	1.478	99.99

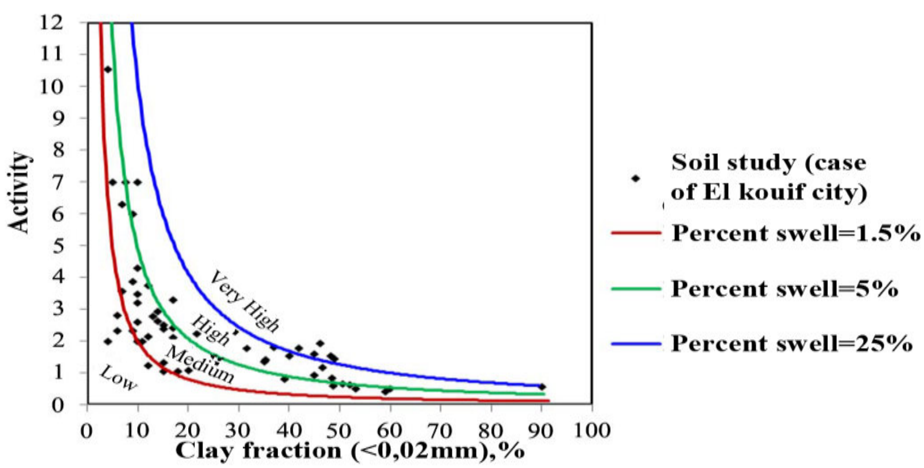

Fig. 3 - Classification diagram indicates swell potential (Seed and *al.*, 1962) applied for the soil of El Kouif city (study case).

Diagramme de classification du potentiel de gonflement (Seed et al., 1962) appliqué pour les sols de la commune d'El Kouif (cas d'étude)

soils have shown very high swell potential (fig. 4). The differences between the charts can be attributed to the different initial soil conditions (chemical and mineralogical composition) and different initial water contents. Support for such results is from different authors where behavior and capacity of exchange can be relatively variable from one sample to another with reference to the listed parameters. This distinction can be sustained by the process of adsorption suction ability related essentially to the collected soil chemical and mineralogical composition (Nelson and *al*., 1993). Therefore, for the same soil sample analysis, both classification methods may give different swell potential values. They result on a defined totally or partially volumetric deformations and also influence differentially the hydromechanical behavior of swelling soil (especially compacted swelling soils). Owing to the diversity of samples distribution (fig. 3 and fig. 4), the concerned soils are mostly considered as heterogeneous types with regard to their swelling behavior. That why, dissimilarity properties might subsist.

Sulfate presence mainly represented by gypsum ($CaSO_4$, $2H_2O$) and Anhydrate ($CaSO_4$) can be another factor in the soil deterioration for the study case (fig. 2). Chemical analysis from table I indicates a variable amount of sulfate presence within the collected soil samples. These chemical products are well known in affecting soils when they are present as reasonably considerable amount (fig. 5). These sulfates effect might reach concrete in the presence of important water solution. The sulfates contents got the ability to penetrate the concrete microstructures causing dama- ges at different degrees. The microstructural alteration often has a harmful influence on the engineering properties of the material and can even markedly reduce the service life of the structure (Skalny and *al*., 2002).

In the conducted investigation, one of the main occurrence sources for sulfate is from the phosphogypsum constituting the bank stockpile in the region (fig. 6). The sulfate presence is proper to the mining history of the area (Sonarem, 1963). As stated previously, the mixture of sulfate with soil is

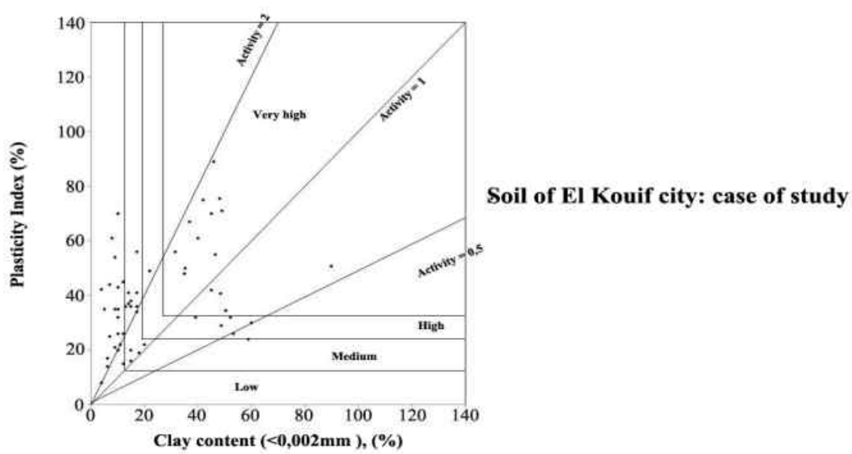

Fig. 4 - Plot and distribution of El Kouif collected samples on activity and swell potential chart proposed by Van der Merve (1964).

Diagramme de classification du potentiel de gonflement (Van der Merve, 1964) : Application aux sols de la région d'El Kouif

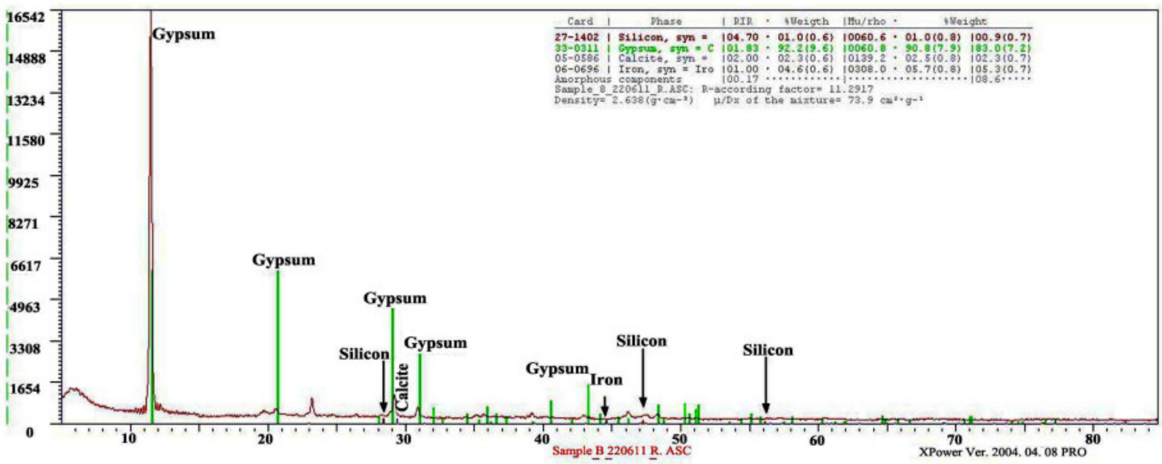

Fig. 5 - Example of an XRD of the whole rock showing the amount of gypsum (92%) in the soil sample in the study area

Exemple sur la DRX de la roche totale montrant le taux de gypse (92%) dans l'échantillon des sols de la région d'étude

Fig. 6 - Sites location map compared to the old phosphate plant in the study area

Carte de localisation des sites par rapport à l'ancienne usine de phosphate dans la région d'étude

rendering the latter more aggressive. This aggressive action is mainly sustained by the sulfates mineral watering and dewatering process in charge of the probable substratum instability. The process is referred to the followings reverse chemical reactions:

$$CaSO_4 2H_2O + H_2O \rightarrow Ca^{+2} + SO_4^{-2} + 3H_2O \quad (2)$$

Anhydrite + Eau → Gypsum

$$CaSO_4 + 2H_2O \rightarrow CaSO_4\ 2H_2O \quad (3)$$
$$(46cm^3)\ (36cm^3)\quad (74cm^3)$$

Equation (2) reveals gypsum dissolution whereas equation (3) is highlighting the transformation of anhydrite to gypsum when water can react with anhydrite. The difference in specific volume between the initial anhydrite and the subsequent gypsum is shown in equation (3) (Wittke, 1990; Rauh and Thuro, 2007). A comparison of the specific volumes indicates that the one of crystallized gypsum is greater than that of anhydrite by equation (4):

$$\Delta V = \left[\left(\frac{74 - 46}{46}\right) x\ 100\right] = 61\% \quad (4)$$

The causes for this latter statement might be due to the soil type being exposed in similar circumstances to shrinkage and desiccation during subsidence whith lead to its dewatering. This latter event is accentuated by the local arid to semi arid climate. During the wetting phase, increase of volume by the process of swelling can be due to the cracks obtained during dewatering phase and then becoming water filled cracks. The process is sustained by the soil material structures and microstructures occurrence where mineral foliations allow the fluid entering the plan spaces in addition to hydrated and dehydrated sulfate. Low and Margheim (1979), Schafer and Singer (1976), Parker and *al*. (1982) in Taboada (2003) found that throughout the process of hydration and dehydration adsorption molecule process in similar soil is a highly dominant event. Therefore, loss in soil volume is associated to the reduction of water molecules and the increase is coupled to the wetting phase.

Consequently, change in soil volume process creates a disturbance responsible not only for the expansive soil properties but also for its mobility especially as substratum (Schafer and Singer, 1976; Parker and *al.,* 1982). Source for this change in volume stated in, is from the periodic infiltration and drying episode in the concerned area (fig. 7) and schematic illustration (fig. 8) from Taboada (2003). Swelling development in the study case can also be from the encountered organic matter (fig. 9). The presence of the organic matter and its contribution towards the swelling soil is mentioned by Parker and *al*. (1982). In the COLE index calculation, the author found that organic matter is also, closely exposed to water retention.

In addition, the sulfate aggressiveness impact towards concrete and slabs can be illustrated through the presence of an expansive mineral (Ettringite) responsible for the fracturing system found on different scales in the investigated district. Sulfate presence can also be associated, for the generation of ettringite, whith the presence of water rendering the material more aggressive as listed previously. This aggressive action can be through solution circulation involving ions such as Cl or Mg penetrating the microstructure and resulting essentially on concrete attack. Thus, the acquired chemical reaction will lead to the precipitation of some undesired minerals such as ettringite. Thus, chemical processes accentuate volume change and contributes to the movability and the fracturing of the whole system.

To support the experimental work, geotechnical classification, chemical analysis and for the purpose of clay fraction determination, XRD analysis was conducted. This procedure was applied essentially for the purpose of soil characterization. This work was carried out at the University of Al Manar Laboratories (Tunis- Tunisia). In this case, detailed requirement for the samples preparation

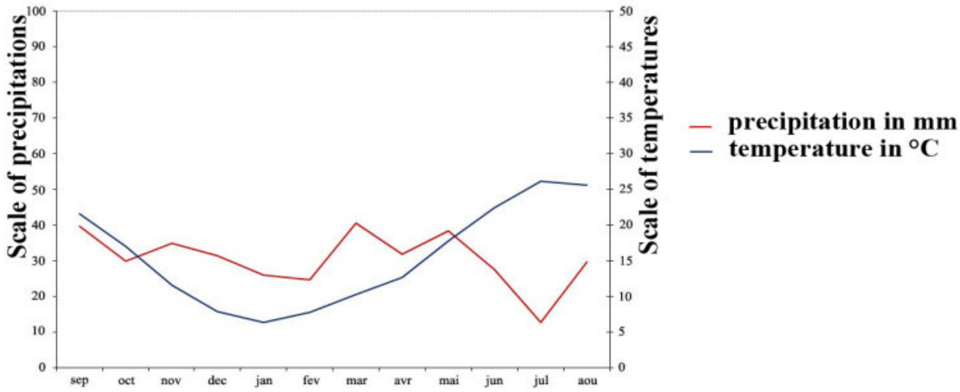

Fig. 7 - Gaussen diagram established for the region weather station (period of 36 years: 1972-2008) After (Weather forecast station of Tebessa city)

Diagramme de Gaussen établi pour la région d'étude sur une période de 36 ans (1972-2008) (Station météorologique de Tébéssa)

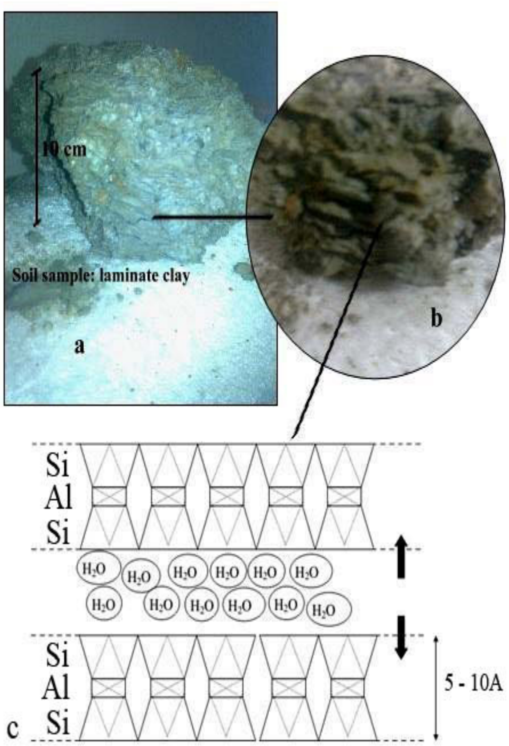

Fig. 8 a and b - photos show the lamination of the studied soils

Photos montrant le feuilletage des sols étudiés

c- A diagram showing the intercalation of water molecules in the inter-plane space of clay smectites (after Low and Margheim, 1979; Schafer and Singer 1976; Parker and *al.*, 1982 *in :* Taboada, 2003)

Diagramme montrant l'intercalation des molécules d'eau dans les feuillet de smectites (d'après Low et Margheim 1979, Schafer et Singer 1976, Parker et al., 1982 in : Taboada, 2003)

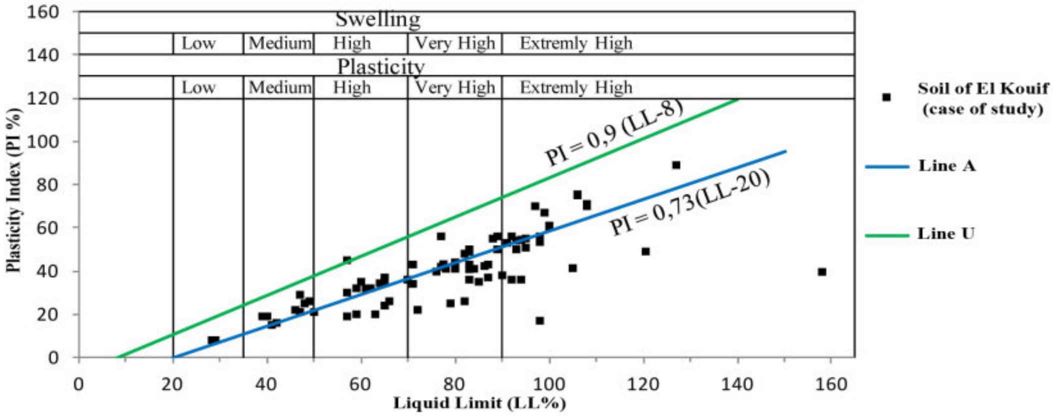

Fig. 9 - Casagrand chart modified by Daksanamurty and Raman (1973) for the evaluation of plasticity and swelling applied for the studied soils according to the Casagrand classification.

Diagramme de Casagrande modifié par Daksanamurty et Raman (1973) pour l'évaluation de la plasticité et du gonflement, appliqué pour les sols étudiés

is the respective oriented plate. Sample preparation consists on its decarbonazation by HCl at 10% followed by distilled water washing process and centrifuging at a rotation, 3000 rotation per minute during 15mn. This practice is scheduled for the split up between the clay fraction and other components. This method is conducted not only for clay determination type but also for establishing clay type percentage. Results of XRD interpretation was obtained according to the method proposed by Holtzapffel (1985) and after examining the ASTM file. Thes results were confirmed by the program (EXCEL MINERA, 1997).

The smectites showing a clear predominance of expansive clay, following the classic test, smectites have a principal reflection between 14 and 17 A°. The assertion that high liquid limits of cohesive soils are typical of smectites is confirmed (fig. 10).

The information obtained on the mineralogical assemblage of the soil samples from X-ray diffraction analysis is in conformity with geotechnical classification and chemical analysis. Major clay mineral that is responsible for swelling and shrinkage of soil in the study area is smectites which is present with a high percentage. Other minerals like kaolinite, illite and sepiolite show variable that is low to appreciable swell-shrink character, those are present with low percentage (table II and fig. 10)

The second mineral which has a considerable role in the construction damages at the study area is the gypsum. Gypsum shows the second major percentage followed by calcite, the two later minerals are abundant in arid regions of Algeria, and those participate in clayey soils structure (Halitim, 1984). In the other hand, source of those minerals can be related to the existence of phosphate and the old plant of phosphate extraction. The calcite is one of the principal components of phosphate, gypsum has its origin in the phosphogypsum. The role of gypsum in the accentuation of the statement in study area was explained above in the text Although, the low percentage of anhydrite (tabl. II and fig. 10) but it can confirm the increasing in volume illustrated above by equation (3). Ettringite was not inspected by the XRD analysis in clayey soils of area study. In our point of view, this mineral can be commonly developed at the concrete level (fig. 11). Consequently, smectites and gypsum have combined to accentuate the actual constructions statement (fig. 12).

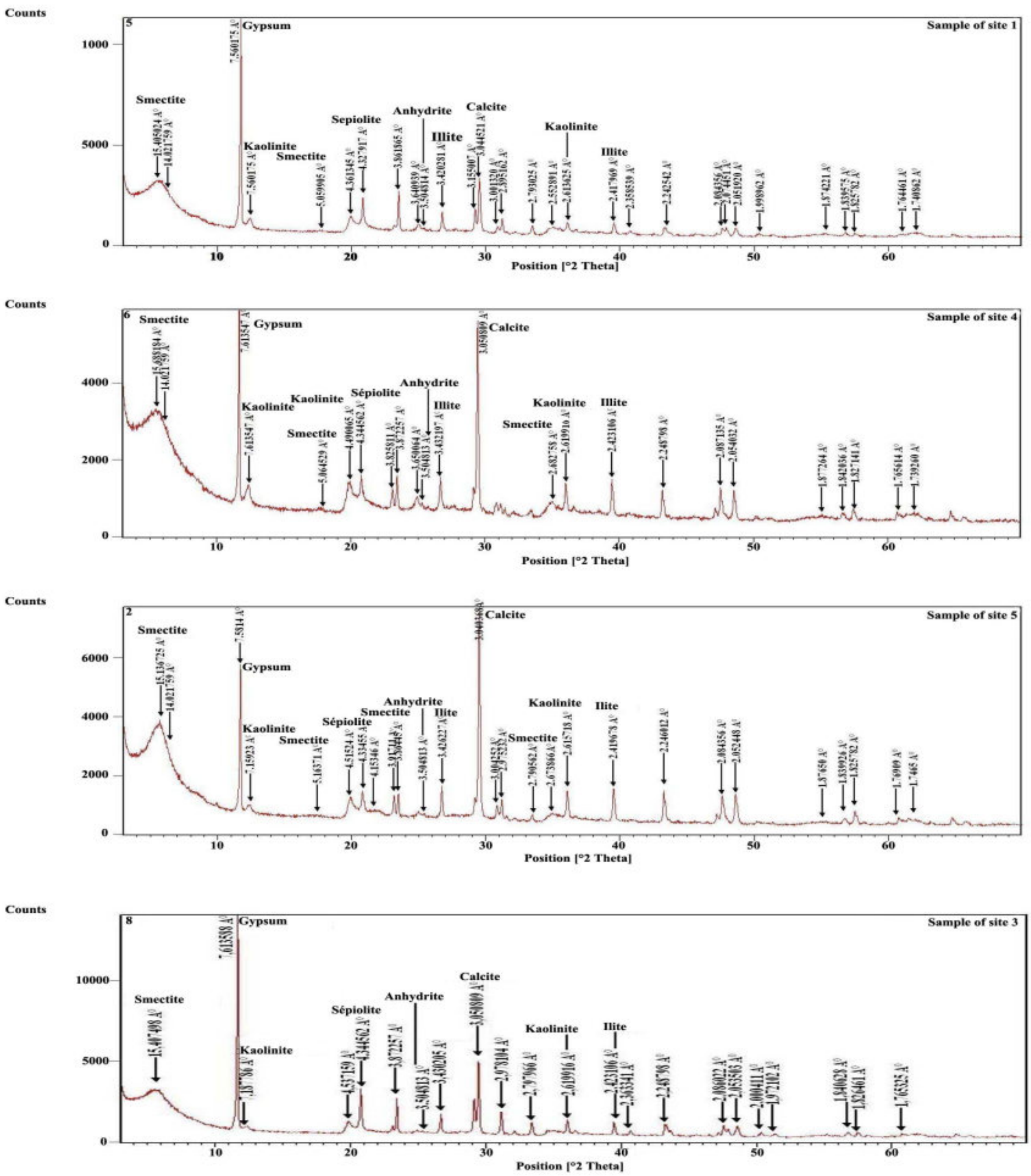

Fig. 10 - XRD patterns of clay fractions (<2µm) of some soil samples
(table II present the mineralogical assemblage of this patterns in descending order)

Exemple sur la DRX de la fraction argileuse (<2µm) pour quelques échantillons du sol
(le tableau II présente l’assemblage minéralogique de ces exemples dans un ordre décroissant)

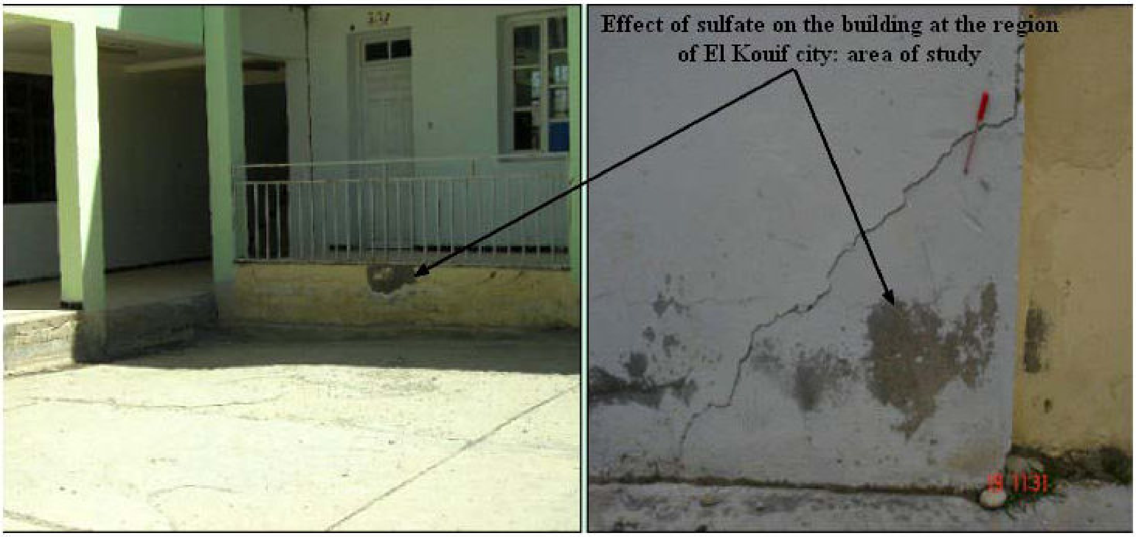

Fig. 11 - Photos showing the sulfate effect on buildings in the study area
(Region of El Kouif city)

***Photos montrant l'effet des sulfates sur les constructions dans la region d'étude
(Région de la commune d'El Kouif)***

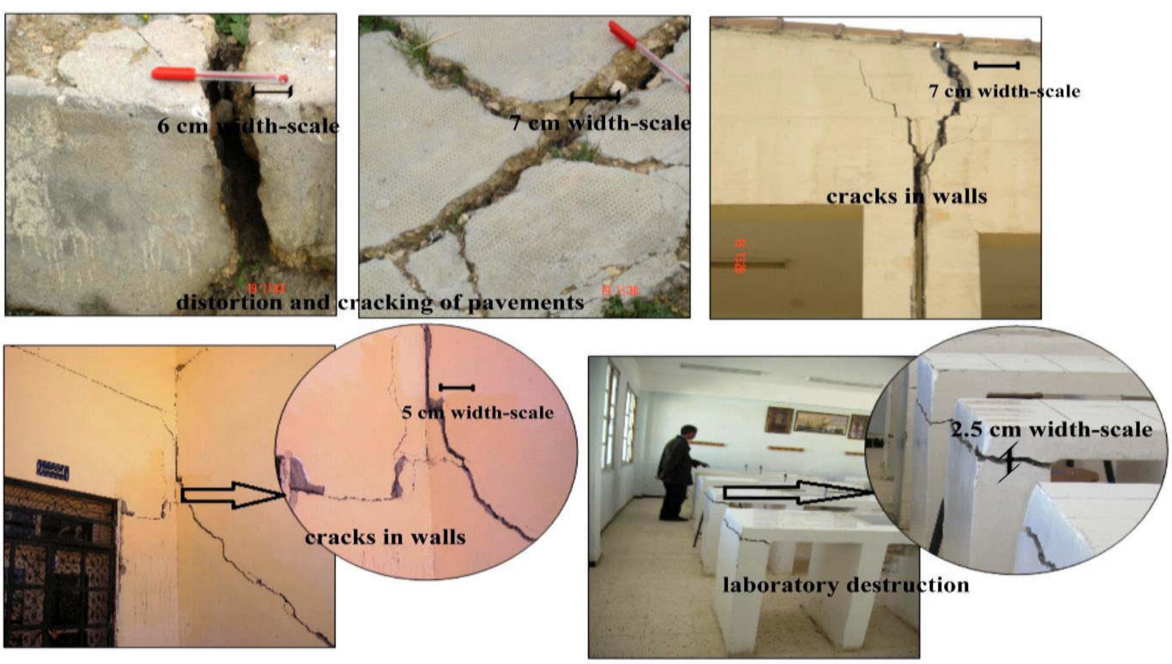

Fig. 12 - Photos showing almost diagonal cracks affecting buildings structure in the investigated site (El Kouif)

Photos montrant les fractures diagonales dans les constructions endommagées de la ville d'El Kouif

5- CONCLUSION

It is important to mention that El Kouif soil district is characterized by an expansive soil where swelling on different scales is encountered. Swelling phenomenon has been affecting different building structure causing different damages. This damage is set through obtained soil classification. Based on experimental work results, soil classification showed that the major party of samples are characterized by high index plasticity and high liquid limit. Those later parameters governed the high swelling soils behavior.

In the other hand, chemical analyses results attest that the soil contains high quantity of sulfate. Sulfate presence has been supporting this event occurrence. Sulfate with water presence has reached the seal of concrete alteration, rendering the overall structures as an unsteady state. Thus, vital solutions become absolute to tackle difficulties affecting the site and reaching likely the concrete prior to any other building project in the near future.

Mineralogical results obtained by XRD analysis are in conformity with geotechnical classification and chemical analysis where smectites and gypsum are the two abundant components. Smectites is responsible of the swelling behavior, gypsum contributes in the aggressive character of soil in one hand, in the other hand, transformation of anhydrite to gypsum lead to increase in volume.

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