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Research paper

Application of geochemical, mineralogical and geotechnical methods to site characterization for road construction purposes at a1 highway northeastern Algeria

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Abstract

This research study focused on the role of the lithological, physical–mechanical and structural factors in the slope movements' genesis using a combination of methods. The geochemical, mineralogical and geotechnical characteristics of the study area soils were identified by various tests and analyzes such as X-ray diffractometry, X-ray fluoricence, infrared spectroscopy, particle size distribution and Atterberg Limit. This study was carried out through the comprehensive compilation of the analyzes results to qualitatively assess the tendency of the study area geological formations to sliding wich are commonly composed of fine-grained soils. Quantitative and qualitative clay contain of the soils were examined in relation on 12 historical landslides. It was found that laboratory determined instabilities of the basement materials from the slip zones was closely related to clay content, liquid limit and plasticity index. This study has allowed to improve the understanding of the genesis of mass wastiong under the study site.

Keywords: *Clays; X-Ray Diffractometric; X-Ray Fluorescence; Infrared Spectroscopy; Particle Size Distribution.*

1. Introduction

The population mobility sustainability is crucial for the economic and social development of any country [1, 2]. Assuring the stability of the transport infrastructures subgrade foundation and controlling the mechanisms of their disorder, are of paramount importance [3, 4]. Like all the Mediterranean countries, Algeria is affected by land movements phenomenon. In recent years this phenomenon has shown an increasing trend with the global climate change. That changes affect the stability of natural and engineered slopes and have consequences on landslides [5-12]; causing disastrous damages, particularly to the transport network. Several township of the West of Borj-Bou Arirедj and the Eastern of Bouira region, have been seriously affected by the phenomenon in their roads and dwellings [13]. Mudflows, landslides, rock falls, etc. are very common in some valleys, and they generally vary in size and nature. In addition, most of these instabilities affect not only the superficial formations covering the valleys edges but also the deeper clayey and marly substrate (Fig. 1). They often occur after heavy and acute thunderstorm [14]. This problem has urged us to consider the controlling factors of the instabilities taking place in the study area, such as the steep slopes, clay-marly lithology and infiltrating water. The review of the literature on mineralogy related landslides shows a lack, in large parts of Algeria [15-16]. We recommend to fill the gap with new study. We examine advantages and limits of the approaches adopted to evaluate the effects of clays variations on landslides, including prospective modelling and retrospective methods that use landslide and mineralogy records.

The A1 Highway, is greatest motorway construction in Algeria, and one of the largest public works projects in Africa. Costing $12bn, it is considered as Algeria's most expensive project wich have generated over 100,000 jobs. The project will stimulating economic and social development and cut travel times and provide better and safer access from the northeast to the Northwest of the country. The project is a six-lane toll highway, developed along Algeria's borders with Morocco and Tunisia. From the east to the west, it will connect the main megalopolises of the country such as Annaba, Constantine, Setif, Algiers, Blida, Tlemcen and Oran. The development will have 12 tunnels, 70 viaducts and 60 interchanges, 42 service stations and several maintenance facilities. The project is part of the 4350mi-long Hwy Trans-maghrébine project, which is being developed in two phases. In first, the A1 Highway, involves the construction of a 756 mi section linking Om Teboul in the east to Zouj Beghal border post in the west, passing through 24 Algerian provinces. Then it will connect Tunisia, and Morocco. The construction have used a base course of cement-treated gravelly sand, laid 8" thick. Following a 6" bituminous bound base, the road is coated with 3" of asphaltic concrete [17]. The aim of this study was to establish a methodology for the study area and for sites with similar lithology, a same predisposing factors, and a close geomorphological and geological context.

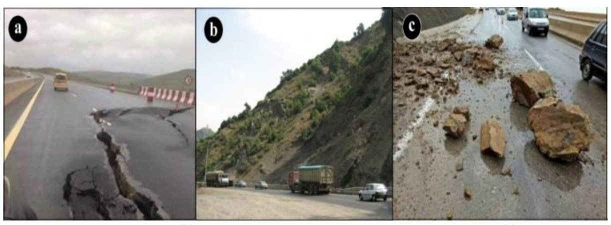

Fig. 1: A) Lanslides Affecting A1 Highway; B) Lanslides Affecting (RN5) National Road; C) Rockfall on Chiffa-Médéa National Road (RN1).

2. Study area general context

The study area is located in the North of Algeria, about 138km east of Algiers, 40km East of Bouira and 60km Northwest of Bordj Bou Arréridj city. Administratively, the study site is part of Hanif township. The study area is predominantly mountainous, of Alpine character, with an east-west alignment and a natural slope varying from 20° to 35°. The topography is irregular, characterized by hills frequently interrupted by gullies and interfluves in the North. The altitudes are relatively high and the main Jebels are Lala Khedidja (2308m), Chouk Chot (1852m), and Moutene (1705m). With 4°16'39"E and 36°14'12"N UTM coordinates, the study site is located on the A1 highway (PK 240+847); (Fig. 2) 8Km South of RN5 national road. A rather dense road communication network (CW, CC, secondary roads, and tracks) is distinguished in its vicinity [18] The hydrographic network is very developed. The main streams crossing the highway within or close to the study site are Sidi Aissa wadi and Sebkha wadi tributaries of Sahel wadi. These wadis are dry in summer and flooded in winter.

The climate of the region is semi-arid, characterized by a dry and warm summer and a cold and humid winter with snowfall in the mountains. The recorded rainfalls are about (≈800 mm/year). The heavy rains gully the soil and limit the vegetation mat. The wooded area is rather abundant illustrated by the Bibans forest. Agriculture is dominated by cereal crops, olive and vegetable crops. Industry is timidly developed. It is represented by the exploitation of the vraconian limestones, triassic gypsum, river sands, in addition to some oil mills.

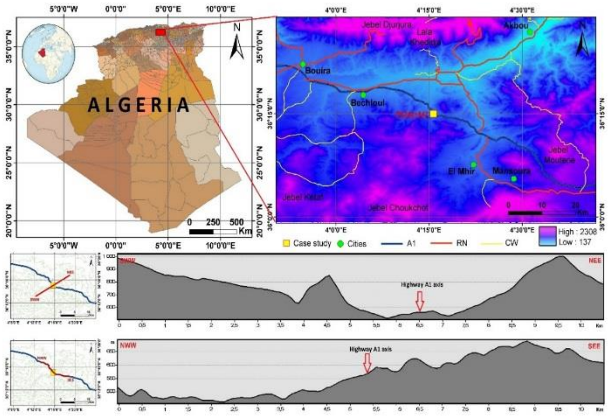

Fig. 2: (Top, Left) Geographic Location of the Study Site; (Top Reight) DEM of the Study Site; (Bottom) Cross-Sections of the A1 Highway Axis.

The different studies introduce the study area as a basin in the marls and black clays covered by lacustrine limestone bars, under which lie several interposed clay and gypsum levels [19]. The lithostrtigraphy of the study area is composed of Cretaceous and Neogene sedimentary deposits predominantly carbonated [20], (Fig. 3). The Quaternary deposits are mainly found in the Sahel valley. They are represented by silts, gravel, sand, conglomerate, calcareous crusts, clay and sandy loams. Based on the beforehand knowledge of the sites, on the one hand, and the achieved laboratory analyses, on the other, we can affirm the predominant marly character with clays and gypsum clays of the study site. These formations have a confined permeability, a high alterability, and lose easily their mechanical strength in the presence of water. The soil is often moist, and the water content often exceeds the liquidity limit, resulting in an insufficient cohesion. Silty soils, particularly the poorest in clay and organic matter, are very sensitive to heavy rainfalls.

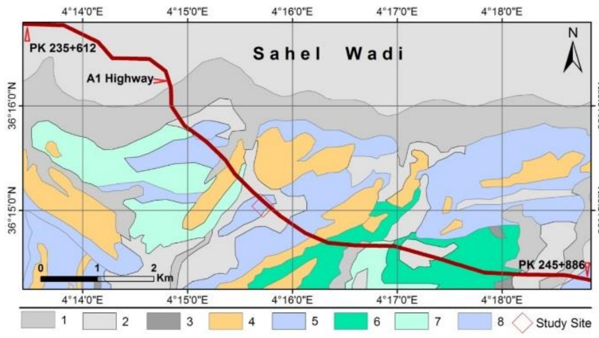

Fig. 3: Lithological Map of the Study Area.

(Legend: 1= Solatanian-Rharbian (q^{5-6}): Silt, gravel and alluvial sand. 2=Amirian-Tansiftian (q^{3-4}): Silt, gravel and torrential sands. 3=Saletian (q^{2}): Conglomerate and torrential sandstones, Calcareous crusts. 4=Pliocene ($p\text{-}q^{1}$): Brown conglomerate with pebbles; Limestones and calcareous crusts. 5=Upper Albian (n^{7}_{1}): Marls with limestone past marly. 6=Middle-Upper Albia n (n^{6b-7}): aleurolites clays, level of marl spent gong. 7=Middle- Albian (n^{6b}): Alternating clays, Sandstone and marl past. 8= Lower-Albian (n^{6a}): Alternating clays with sandstone beds with quartizoids, marl and limestone).

3. Material and method

The collection and treatment of a valuable data allows us to understand the slope movements mechanics that occur in the study area and to highlight the soil behavior. These tasks require in a first an overall analysis of the predisposition factors, in second the modeling of the phenomenon using appropriate methodologies. Finally, the mineralogical, lithological and morpho-structural indicators should make it possible to specify the most likely formations that control instabilities. And to develop a useful approach for the land users and the consulting firms. The study adopts a methodology that combined laboratory and field investigations. Thus, the nature, structure and characteristics of soils and rocks are approached by different tests. The geotechnical, geochemical and mineralogical characterization performed on the various samples makes it possible to better understand and predict the behavior of the soil. Holes were drilled to reveal the different substratum layers (Fig. 4). The analyses were carried out on the clay layer constituting a favorable interface for the development of a sliding surface. The different samples were collected from the drill site.

Fig. 4: Drill Core Boxes of PK240+847.

Our study provides an ideal method to approach the various dataset, of the study area. It permits the analysis of data related to lithology, mineralogy, geotechnic, and environment. They are used to define a synthetic model, which leads to make a decision according to specific criteria. The collection of datasets from the previous studies, internal reports, sinister survey folders, in situ and laboratory tests and measurements, DEM, geologic maps, pluviometric data, etc. allows the editing of the study project database. The adopted method permits the valorization of a large amount of data collected along four years of fieldwork. The flowchart of the adopted methodology is shown in figure 5.

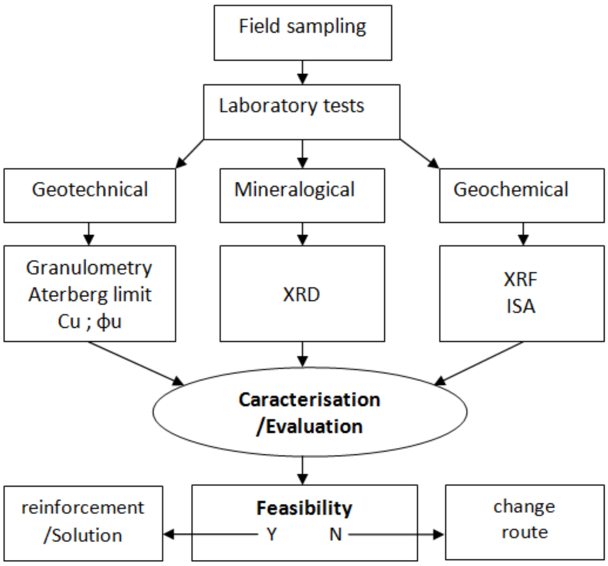

Fig. 5: Methodological Flow Chart of the Adopted Approach.

3.1. Particle size analysis and aterberg limit

To makes it possible to determine the weight percentages of the different grain diameters constituting the samples; the particle size analysis (NF P94-056) was performed on samples taken on a horizontal cross-section to the road from top to bottom on the profile through Pk 240+847, (A1) with a 20m spacing [21]. The Atterberg limits are also applied. This basic measure of the critical water contents of the fine-grained soil: (shrinkage limit, plastic limit, and liquid limit) can evaluate the plastic behavior of clay formation.

3.2. X-ray diffraction analysis

The X-ray diffraction (XRD) analysis allows determining the mineralogical composition of the sample. This technique is based on the scattering of the monochromatic X-ray beams by the reticular planes of the crystals contained in the sample, according to the BRAGG law ($N\lambda = 2d \sin\theta$). The sample was prepared beforehand according to Moore and Reynolds' (1989) method [22].
The diffraction spectrum is recorded for angles of 2° to 30°, 2θ in diffractogram form for each treated sample. The different inter-reticular distances of each peak for the various mineral species, reveals the name of the mineral and its percentage by applying a multiplicative corrective factor to the measured intensity determined by Cook et al. (1975), [23] and modified by Boski et al. (1998) [24]. The corrected intensities are summed and the relative percentage of each mineral is calculated in relation to a sum reduced to 100%. A D8-Advance Bruker type device equipped with an X-ray tube with anticathode of copper was used (Emerging Materials Research Unit, Setif 1 university, Algeria).

3.3. Infrared spectroscopy analysis

Infrared spectroscopy (ISA) is a trustworthy analytical technique complementary to X-ray diffraction, used to investigate clays [25]. The infrared spectrum can serve as a fingerprint for mineral identification, but it can also give unique information about the mineral structure, the family of minerals to which the specimen belongs and the degree of regularity within the structure [26]. In this study the middle infrared (MIR) range (4000–400cm^{-1}) enables us to characterize the functional groups frequencies. It is of considerable interest for the analysis of the study site clay soils structure.

3.4. X-ray fluorescence analysis

The X-ray fluosrescence spectrometry (XRF) is a non-destructive multi-element analysis method. The used X-rays are of wavelengths ranging between a few tenths and a few tens of Angstrom. This technique is based on the X-radiation interaction with the electrons of the atoms deep layers, [27]. These interactions lead to the electrons internal reorganization, responsible for a characteristic radiation emission, which will make it possible to qualitatively identify the studied atoms. The intensity measurement of the characteristic lines will make it possible to determine quantitatively the centesimal composition of the analyzed sample.

4. Resultants and discussion

The lithological formations observed during the recognition campaign are (from top to bottom): Gravelly silt with variable thickness between 0.2 and 2.0 m located in the ravines. Silty stones varying in thickness from 0.2 to 3m, on the slope or at the foot of the slope. Clay with a thickness varying between 10 and 30 m can be found in the section at PK240 +847. The totally altered marl was at a thickness varying from 0.2 to 2.0m whereas the very altered marl was at a thickness ranging from 2.0 to 6.0m.

4.1. Particle size analysis and atterberg limits

It is found that the clay fraction, characterized by a diameter of less than 63 µm, makes up mostly 70% of the clay sample mass. The remainder of the sample consists of silt and fine sand. The ASTM classification makes it clear that it is fine clay [28]. The Atterberg limits allows to classify this slice of soil among the plastic soils. These soils yielded wet densities and mean water levels. Undrained straight unbound shear tests yielded the following values: Cu = 0.31 bar; φu13.47 °.

4.2. X-ray diffraction analysis resultants

The XRD results are represented as two-axis spectra (counts/s and °2Theta). Analysis shows that the total clay consists of Quartz, Calcite, Feldspar, Kaolinite and Illite. The proportions are estimated from the peaks area (Fig. 6a).
Having removed the calcium carbonates and sulphates, the clay fraction analysis shows Kaolinite illite and interstratified peaks. These are clear enough in the first part of the diffractogram of the glycol test (Fig. 6b). The proportions vary between 55.00% for the kaolinite, 25.00% for the Montmorillonite and 20.00% for the interstratified Chlorite-Vermiculite. The comparison of the three analyzed samples shows a mineralogy dominated by the clay minerals of the Kaolinite group.

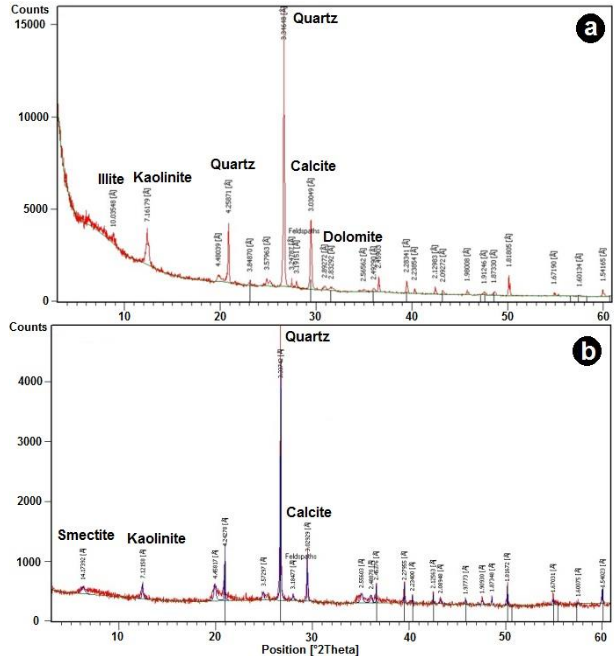

Fig. 6: XRD Analysis: A) Total Sample, B) Clays Sample.

4.3. Infrared Spectroscopy analysis resultants

This analysis was achieved on the same samples, studied through the particle size analysis and XRD. All the adsorption bands, relating to the clay phase and the impurities of the studied samples, were examined and the corresponding infrared spectra are displayed in figure 7. The low intensity bands, located at 798cm^{-1} and close to 750cm^{-1} indicate the presence of Kaolinite. The carbonates are detected in almost all the samples, their characteristic band is at 1400cm^{-1}. The capacity of the clays to swell because of the penetration polar molecules between the planes is demonstrated in the range 1400-1600cm^{-1} and the water adsorption capacity between 3600-3700 cm^{-1}. It worth noting that such strong absorbance bands, 3600-3800cm^{-1}, are characteristic of Kaolinite. Among these bands we can cite mainly those which correspond to the vibrations of the Si-O, Si-O-Al, Si-O-Mg, Al-Al-OH and Al-Mg-OH bonds. These results confirm the X-ray diffraction results, confirming that these clays belong to the Kaolinite Montmorillonite group.

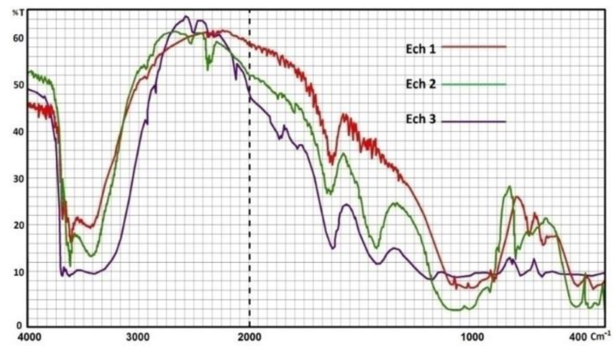

Fig. 7: Infrared Spectrum of the Three Samples.

4.4. X-ray fluorescence analysis resultants

The XRF analysis results are obtained as the percentages of the major elements. They shows that the samples consist on inorganic oxides, soluble salts and organic materials (table 1). This geochemical analysis allowed us the following results:

The two most characteristic elements are: SiO_2 with an average grade of 39.47%d ; and Al_2O_3 with an average content of 25.17%. The attendance of Fe_2O_3 in a large proportion (09.29%); is probably due to the alteration of the schist. The increase in SO3 (0.08%) and FeS2 (0.12%) indicates the presence of gypsum and pyrite.

Table 1: Geochemical Analysis Results for the Three Samples

N°	SiO_2	Al2O3	Fe_2O_3	CaO	MgO	SO_3	FeS_2
1	39.342	26.880	08.922	2.212	3.010	0.100	0.120
2	40.440	25.342	09.012	2.010	2.920	0.086	0.050
3	38.426	23.284	09.940	1.962	2.442	0.062	0.180
Average	39.470	25.169	09.291	2.061	2.791	0.083	0.117

5. Conclusion

From the obtained results in this work, the primary conclusion that can be drawn is that on the surface, the terrain is covered by the slope formatios, constituted by clayey marls. This cover is followed by a clayey substratum materials at about 6 m depth with Kaolinite-Montmorillonite type. They exhibit very favorable characteristics to sliding genesis if associated with water and steep slopes.

The lithological, mineralogical and geochemical characteristics of the study area have been approached with universally reliable qualitative and quantitative tests. The geotechnical and geophysical data have been integrated to fulfill the analysis and open its scope to other disciplines. Clays an clayey silts taken from a landslide in the A1 highway have been analysed in order to study the role of sediment composition in the slope stability and the development of a slip zone. A Drill holes were used to collect samples. A slip zone at a depth of about 17 m was identified. Compositional and physical–mechanical characterisation of samples was carried out. Some compositional characters, such as a ≤63 μm grain-size fraction, clay mineral content, increase the sliping. Some correlations have been found between geotechnical properties and the same compositional characters, which can therefore be considered possible factors influencing slope stability. Combining the lithological, geotechnical, mineralogical, and geochemical identification, this approach is feasible in a relatively acceptable time lapse, cheap, concrete and resulting in valid information on the geological origin elements and their behavior. The findings result in an accessible, simple and practical tool for decision-taking whether for decision makers or infrastructure and urban project managers.

As a future perspective we will be able to detail the complexity of the geological structuring of the slopes and thus the layout of the different discontinuity planes. We also think that the results of the geological data have interesting consequences for a better understanding of the structural evolution of large-scale deformations in the study area.

Finally, it is strongly recommended to reinforce the Pk235 to Pk245 road section by geosynthetic to remedy the detrimental effects of the clay-like soil support and the geomorphology of the site. A technico-economic study is necessary to prove the feasibility and the rationality of this technique.

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