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Hamam Meskoutine hydro-thermal cascade subsidence (North-East Algeria): Causes and effects on the landscape

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Informations	Abstract
Keywords : Subsidence, Cohesion, Friction angle, Cascade, Hamam Maskoutaine *Correspondance : benamara.abdelwaheb@yahoo.fr	The outlets of thermo-mineral water spread large quantities of minerals. Their deposits may form attractive natural cascades however, some events (natural or anthropogenic), degrade the appearance of these wonders, and contribute to the destruction of parts of these natural landscapes. Within this context, the focus of this paper is in the Hamam Meskoutine cascade, whose temperature and water mineralization are high, reaching 90° and 1400 mg/l respectively. The north-eastern part of the cascade has crumbled and collapsed which directed our research towards soil studies. Thus, the hydration-dehydration phenomena of the outcropping clay formations cause differential movements manifested by disintegration of infrastructures. For this reason, tests on samples taken from stable rock and degraded rock show that changes in the physical properties of the soil can lead to partial movement of earth, causing damage to buildings. This aspect is linked to climate change and influenced by external phenomena such as sunlight, humidity, and human activity.

1. Introduction

In Algeria the richness in hot springs is known for a long time and their use for curative action is a tradition know for more than Millennium (Samia Amarouche.Yala, Ali Benouadah, Abd el Ouahab Bentabet, Adnane Soufi Moulla, Sid Ali Ouarezki, Ahmed Azbouche 2014). Thermo-mineral water after cooling deposits significant amounts of minerals especially calcium carbonates and magnesium. Then suddenly, the water drops fall down and reaching it is spreading by forming basins where the temperature varies between 45 ° near to the shorn and not exceeding 30 ° at the edges (Helene Mugard 1965), which produce spectacular cascade formations. These deposits can be of ordinary or extraordinary shapes that represent monumental images that adapt in colors and shapes.

For humans, these formations (cascades) reflect beautiful landscapes, sometimes becoming must-see travel destinations. Local natural changes caused by erosion or sedimentation can make these natural wonders disappear completely. Human activities affect such natural phenomena by accelerating the speed of erosion. Digging cavities, extracting or

diverting fluids flowing over the cascade lead to subsidence whether continuous or discontinuous in time and space. Subsidence refers to "collapse" and the collapsed areas present breaks in the formations (Raymond Morose. 2013) and degradation of geological clay made from a form of limestone in origin (T. House, F. Laouafa, JM Fleureau, P. Delalain, 2009). In the case of the Hamam Meskoutine cascade, it has been physically damaged causing a loss of part of its deposits.

This study focuses on assessing the causes and impacts of the deterioration of these cascades and the socio-economic impact on societies. The partial inactivity of the cascade incited a deeper look into the cause by studying the mechanics of the rocks. Analysis of the rocks (KAZAN Youssa. 2002) and soils (shear resistance characteristics) on both stable and affected rocks have traced the evolution of the parameters depending on the discontinuity of tangential movement (Ismaila Gueye. 1993).

2. GENERAL FRAME OF THE STUDY:

2.1 Geographical Situation of the Study Site:

The Hamam Meskoutine cascade is located in Guelma (north-eastern Algeria). The zone is limited

in the north by the city of Annaba and in the south by Skikda, Oum El Bouaghi, and Constantine.



Fig.1: Geographical situation of the study zone

The study area has a Mediterranean climate with two seasons characterized by a soft, humid winter and a hot, dry summer with oscillating precipitations between 500 and 600 mm per year. The temperature range is from 10° C in winter to 30 ° C in summer and an average annual evapotranspiration of 511.22mm per year.

2.2 Geological Site

The geological site being studied is complex, and the formations are sedimentary dating back from the Quaternary to the Jurassic period. This geological section presents a variety of forms of limestone containing rich pelagic micro-fauna dating back to the Aptian age, outcropping at the Mount of Jebel Debagh (Vila 1972).

From the tectonic point of view, the Alpine area, localized in the mountains of Guelma, is the source of the tectonic activity in the hot springs of Hammam Meskoutine. The north-eastern part of Algeria, the Alpine areas (Raoult (1974), Vila (1980) are subdivided into several structural and paleogeographic domains.

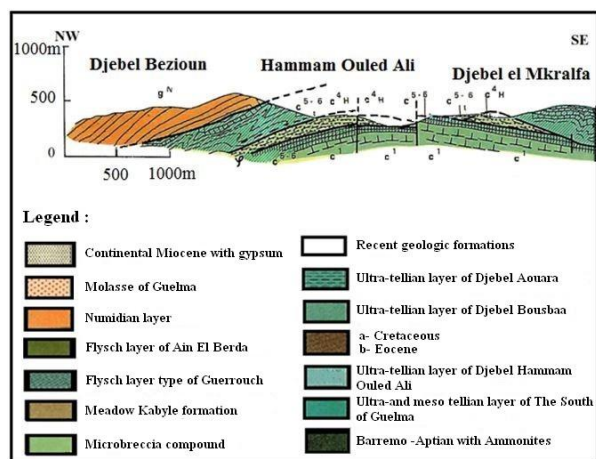


Fig .2: Geological section of the study area

3. MEANS AND METHODS

3.1 Material and Manipulation

To study the physical characteristics of the rock, samples were taken in May 2014 from three observation sites (**Fig. 3**), from the rocks forming the cascade. To prevent the removal of weathered rock surface, a depth of 15 to 30 cm was reached to obtain the samples. The samples, cut off from their natural environment, were directly placed in a clean plastic bucket and delivered the same day to the LTP laboratory in eastern Annaba for analysis.



Fig .3: Localization of the sampling points

Sampling was performed by cutting into the limestone forming the Hammam Meskoutine cascade. A knife was used made of stainless steel. Rectilinear shear tests were carried out from pieces of rock collected using a shear tester called "Wyken Farrance". The test was performed without consolidation, undrained, under a fast shearing rate of 0.4 mm per minute. The results corresponded to the short-term behavior of thin soil as a saturated specimen.

4. RESULTS AND DISCUSSION:

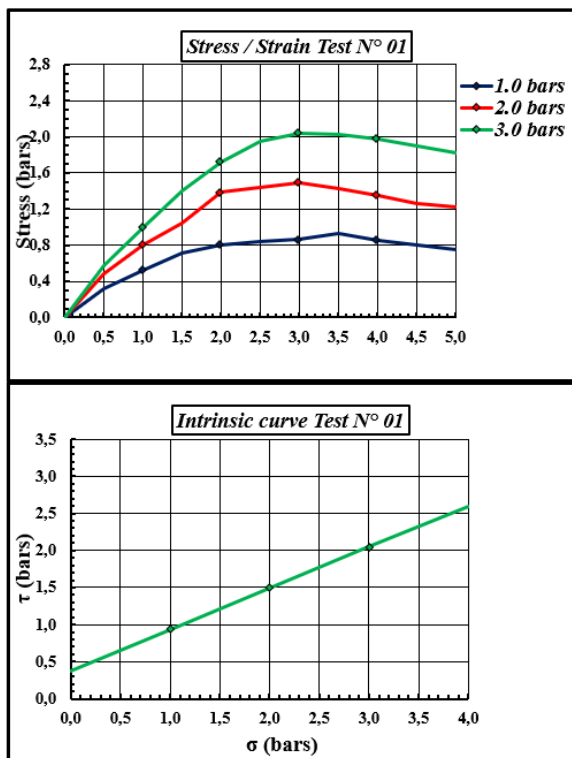
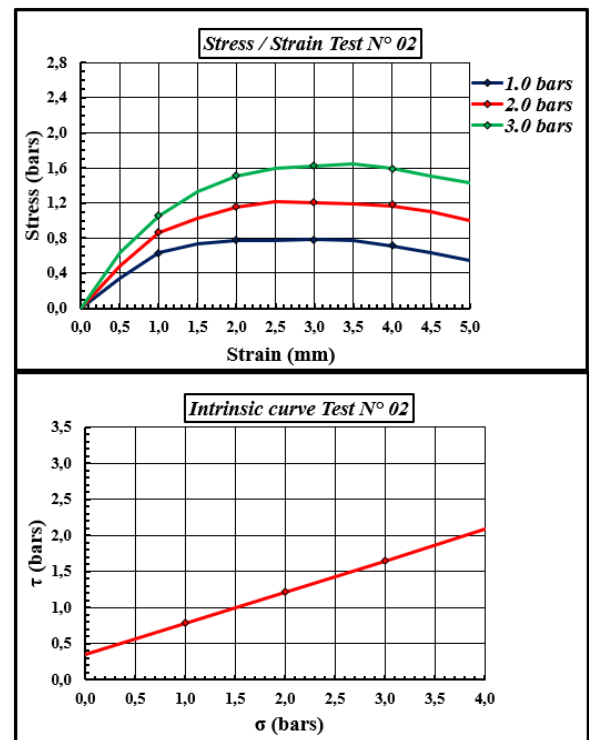
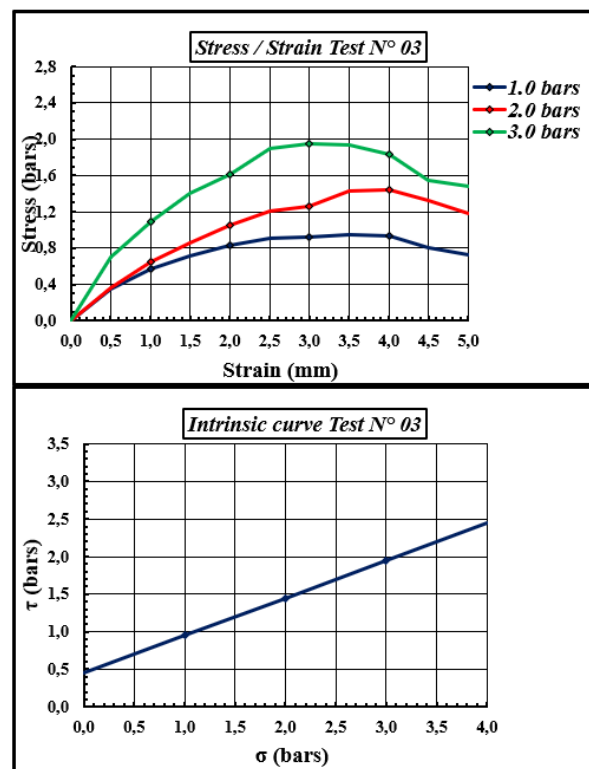
4.1 Results:

The purpose of the test was to determine the intrinsic curve of the studied soil in order to calculate the rocks shear strength under normal stress and infer its' mechanical properties; internal friction angle, and cohesion. Once the sample was treated, the results were reported in (**Table 1**):

Table 1: Table summarizing test results

Unit of Annaba		Shear testing the box Norm : NFP.94-071-1		
Provenance : Hammam Meskoutine cascade, GUELMA		Test type: CU		
Drilling-Well : surface		Ring coefficient <k>:0.35		
Operator : LTP-EST ANNABA		Shear Velocity: 0.4 mm/mn		
Depth : surface		Soil Nature: limestone.		
N° of the test		I	II	III
Dry density	$\gamma_d(t/m^3)$	1.25	1.83	1.56
Water content	W(%)	34.4	14.6	23.4
Saturation degree	Sr(%)	87	83	91
Humid density	$\gamma_h(t/m^3)$	1.69	2.09	1.93
Rectilinear shear	Test type	CU	CU	CU
	σ (bars)	1.0 2.0 3.0	1.0 2.0 3.0	1.0 2.0 3.0
	τ (bars)	0.9 35 1.4 49	0.7 83 1.2 16 1.6 49	0.9 48 1.4 46 1.9 44
	C (bars)	0.38	0.35	0.45
	ϕ (°)	29.03	23.42	26.47

The treatment of the data allowed us to draw curves and graphs (**Figures 3, 4, and 5**), depicting the constraints based on deformations:

**Fig. 4:** Shear test n°1**Fig. 5:** Shear test n°2**Fig. 6:** Shear test n°3

4.2 DISCUSSION

4.2.1 Strain-Stress Curves:

Curves from **Figures 3, 4, and 5** show the stress according to the strain in the studied cascade rock. In abscissas, the stress-strain were proportional to the displacement of the lower half box, and thus, to the deformation of the sample. For the ordinates,

indications of the ring comparator were approximately proportional to various shear forces from the ring calibration curve, showing the force according to the indication of the comparator, was approximately linear.

Indeed, the almost systematic absence of a peak on the stress-strain curves required an arbitrary determination of the stress-strain. A hypothesis was retained for the experimental results with reference to the parameters determined from the intrinsic curve.

4.2.2 Intrinsic curves:

The processing of data from (Table 1), allowed the calculation of the physical parameters of the rock that composes the cascade of Hammam Meskoutine. The obtained curve is a linear model representing the variation of the tangential stress applied on the limestone soil during its rupture according to applied normal stress. This line is called the "intrinsic curve"; it is an increasing function determining what is called the "friction angle".

The cohesion constant (C) and the friction angle (ϕ) are mentioned in the curve (Fig.3, 4 and 5). The constant corresponds to the shear stress which is supported by the material under average stress while the angle (ϕ) refers to the internal friction of the material. If C is null/zero and (ϕ) is not, the material is called "powdery". If (ϕ) is null/zero and C is not, the material is purely coherent.

The mechanical parameter pair C and ϕ (cohesion and friction angle), vary respectively between 0, 38 ° 29, 03-bars, 0, 35 bars - 23 °, and 42 0, 45 bars; 26.47 °. The presented values of cohesion C and the internal friction angle depend on the strain/deformation rate retained at the stress-strain curves to determine the couples σ and τ represented in the diagram of Mohr-Coulomb (Fig.1,2, and 3) or the intrinsic curve.

The values used in this case correspond to a maximum value of the tangential stress τ , the cohesion average, and a friction angle giving a pair of 0.393 bars; 26, 30 °. It is noticeable that the internal friction angle is high and the cohesion is low however, they are different from zero. We can say that the soil is not cohesive, classified as a low shear strength soil that is not compacted according to shear strength standard shown below (Table 2):

Table 2: Soil classification according to the Cohesion standard.

C_u (kpa)	Shear resistance
<10	extremely weak/low
10-20	very weak/low
20-40	weak/low
40-75	average
75-150	high
150-300	very high
>300	extremely high

2. CONCLUSION:

In this work a study was conducted on the collapse of the hydro-thermal cascade of the Hammam Meskoutine. For this purpose, the literature was focused on rectilinear shear tests and the choice was based upon the popular use of such in the field of geo-technical engineering. This cascade is a regular tourist attraction that must be maintained from external threats. Its' hardness and cohesion lies within the saturation phenomenon with water pouring from the hot springs (hydration), which reaches a temperature of 94 °. The decrease of temperature removes significant amounts of mineral.

When diverting this water in a specific area, the water is deviated to another destination. The dehydrated part becomes fragile and vulnerable, then collapses. This has happened before when the water's course was changed, and as a result, pieces began to dry slowly and collapse, as confirmed by witnesses. This led to further study of samples taken by cutting through the rectilinear shear at different sampling points for laboratory testing.

The rectilinear shear tests conducted, contributed greatly in determining the intrinsic characteristics of a soil sample (using undrained, cohesion C {in bars}, and friction angle ϕ {degree°} shearing apparatus (Wyken Farrance). These two parameters (C , ϕ), are necessary knowledge prior to any work execution. The knowledge of the intrinsic characteristics of a soil allows us to determine its' shearing resistance. It was then shown that the tests gave almost identical results; low cohesion and high friction angle. In this case, it can be concluded that the hydration phenomena gives greater hardness to the cascade. On the contrary, dehydration gives low resistance and based on the data presented; this is what this paper has shown.

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5. ANNEX:



Fig .7: The hot springs of water flowing over the waterfall.



Fig .8: Development of the cascade.



Fig .9: The collapsed



Fig .10: Prediction of recovery.