10 years of thermo-mechanical monitoring of rock columns - *les chandelles de l'Escalette*, France

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ABSTRACT: Rock instabilities can represent major risks for local populations depending on their geographical location. Even if different factors such as precipitation, seismic activity and freezing, are known to trigger rockfalls it is more and more assumed that thermal cycling have a role in cracking initiation or propagation. Here we use data of the first six years of field monitoring of a 50-meter-high French dolomitic cliff, located above an important highway in the south of France (A75) to support this thinking. Evolution of the aperture of joints and temperature were followed on ten different locations around *les Chandelles de l'Escalette*. Results will be discussed in terms of mechanical response to temperature variations.

Keywords: Thermomechanics, rock columns, monitoring, propagation, failure.

1 GENERAL LAYOUT

The effect of natural thermal cycles on the mechanical behaviour of rocks has been investigated for a decade. Collins & Stock (2016) is often considered as the first important work on this effect, but it is forgetting the work of Gunzburger et al. (2005) and Bakun-Mazor et al. (2013) for instance who worked on the mechanical formulation of thermal effects and, even earlier Hall (1999), Vargas et al. (2009) or Gasc-Barbier et al. (2015) who proposed geomorphological analysis.

Most of the above-mentioned sites were monitored on small, local areas. In les *chandelles de l'Escalette*, eleven crackmeters and temperature sensors were positioned along 50-meter-high dolomitic columns to understand the overall movement of the rock columns and the associated hazard.

1.1 Location of the study site and Instrumentation

Les chandelles de l'Escalette are located in the south of France (see insert in figure 1) just above an important highway. They correspond to the southern part of the Larzac plateau. Eleven pairs of sensors were placed: each red point in figure 1 corresponds to a crackmeter. Temperature of the crackmeters is always recorded, except for B8. Along each important fracture two pairs of sensors were positioned, one at the bottom (B sensors) and one near the top (H sensors). All crackmeters are horizontal, expect V8, which is vertical and located just near B8 (only one red point corresponding to B8 and V8 in figure 1).

It is important to note that, apart from H5 and B6, all the sensors are positioned on the **back side** of the columns, in screw-to-screw of the cliff (see the upper view of the site in figure 2), they are not exposed to direct sunlight. It should also be noted that this monitoring system was not initially installed for research purposes.

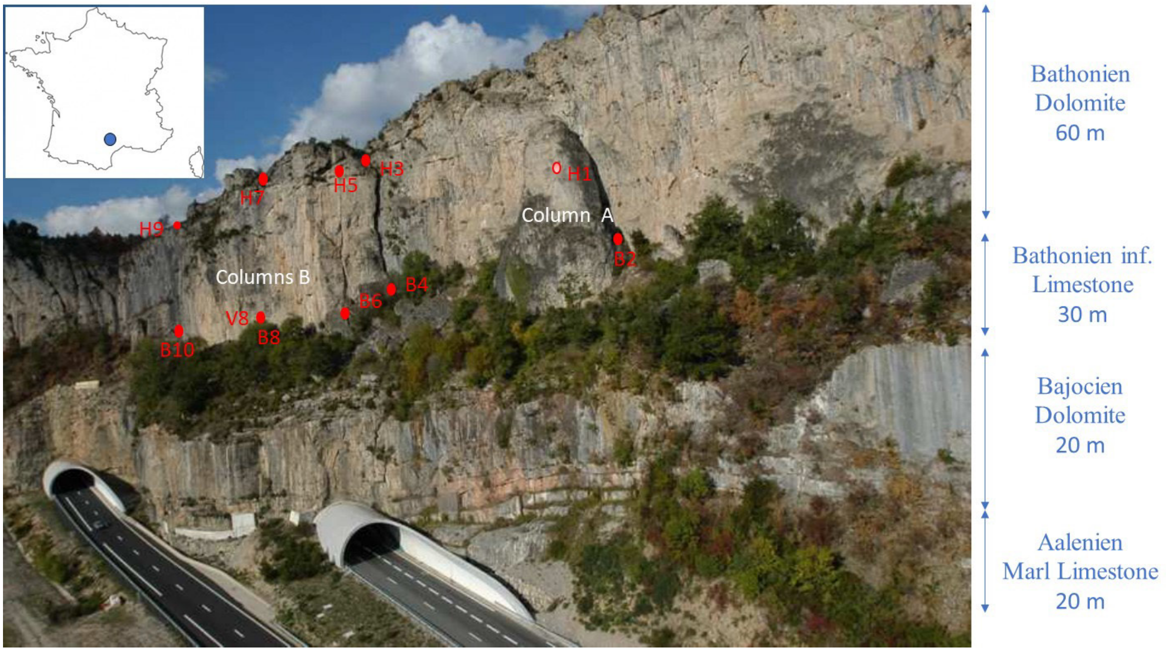

Figure 1. Location of the site, of the sensors and geological clues.

Figure 2. Upper view of the site. Red circles show the large fractures that separate the columns from the cliff.

1.2 Geological and geomorphological clues

A simplified geological log is given on the right part of figure 1. The rock columns are Bathonian dolomitic limestone of approximately 60 m high. They lie on about 30 m of infra-Bathonian interlayer limestone alternated with marl with brown coal debris. The Bajocian is characterized by a rather massive saccharoidal dolomite, and at the bottom, marl -interlace limestone outcrop just before the (south) head of the tunnel. Dolomite from Bathonian and Bajocian give steep cliffs whereas infra-Bathonian and Aalanian limestone leads to gentler slopes.

2 RECORDING

Temperature and displacement recording began in November 2012 (7th). A measure is taken every hour, except for a few periods depending on the sensors. The sensors are still recording even if, after seven years of records, we observe more and more noise and some unexplained steps. To make the curves more readable daily means, and weekly means were computed, and the data after 2019 are not displayed as the recordings have too much noise.

Below, temperature and displacement recording and the displacement curves = f(temperature) are presented. As all curves cannot be displayed, we only focus on H3 and B4 sensors which are located between column B and the cliff, almost at the same position, but not at the same height. The distance between the cliff and the column is about 80 cm at the bottom and about 1.5m at the top.

2.1 Temperature

The H3 and B4 temperatures recorded between 2012 and 2018 are shown in Figure 3. The dots give the week mean (H3 in green, B4 in red), and the errors bars display maximum and minimum week value (H3 in yellow and B4 in blue). Overall, the temperatures are the same with both sensors. Nevertheless, looking deeper, we observe that H3 temperature amplitude is higher than B4 (+/- 3°C). Moreover, we note that the temperature evolves on H3 before on B4 (1 to 3 hours). Those observations are consistent with the position of the sensor: at the back of the column and H3 on the top, B4 on the bottom. Due to the orientation of the cliff, the upper part of the column gets sunlight before the lower part.

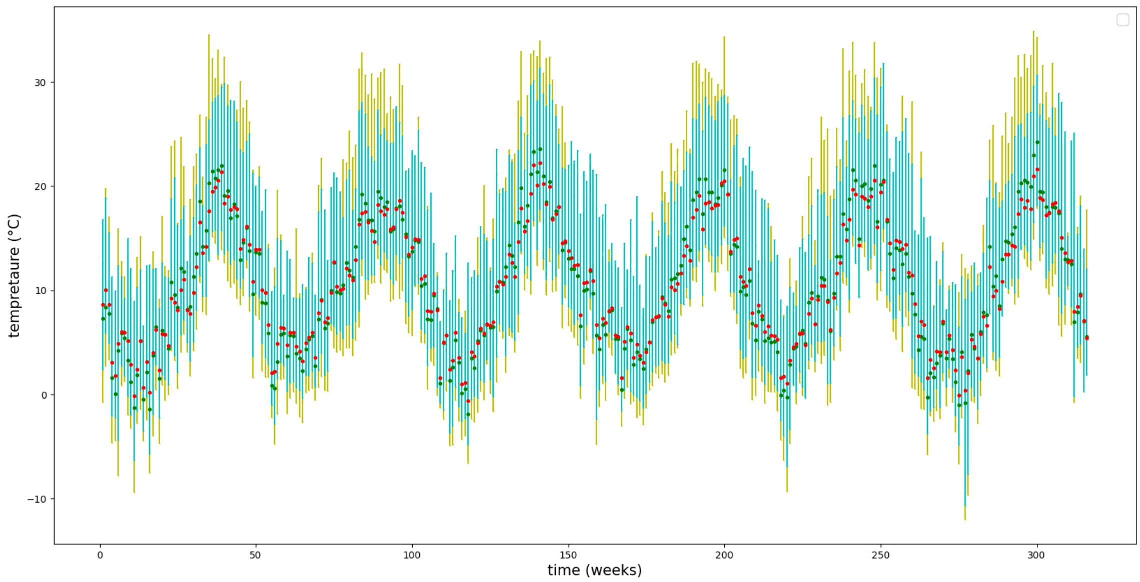

Figure 3. Temperature recording on H3 and B4. Weeks' mean (dots: H3: green, B4: red), maximum and minimum (error bar: H3: yellow, B4: blue).

2.2 Displacements

H3 and B4 displacements between the rock column and the cliff, recorded between 2012 and 2018, are presented on Figure 4. Again, dots give the week mean (H3 in green, B4 in red), and the error bar displays maximum and minimum week value (H3 in yellow and B4 in blue).

Based on those curves, different observations can be made:

- Daily and weekly displacement amplitude is larger on B4 than on H3.
- Annual displacement amplitude is almost the same for both locations.
- A larger drift is observed on H3 displacement than on B4.
- The drift is negative which means that the column tends to get closer to the cliff, which is quite surprising and will be discussed below.

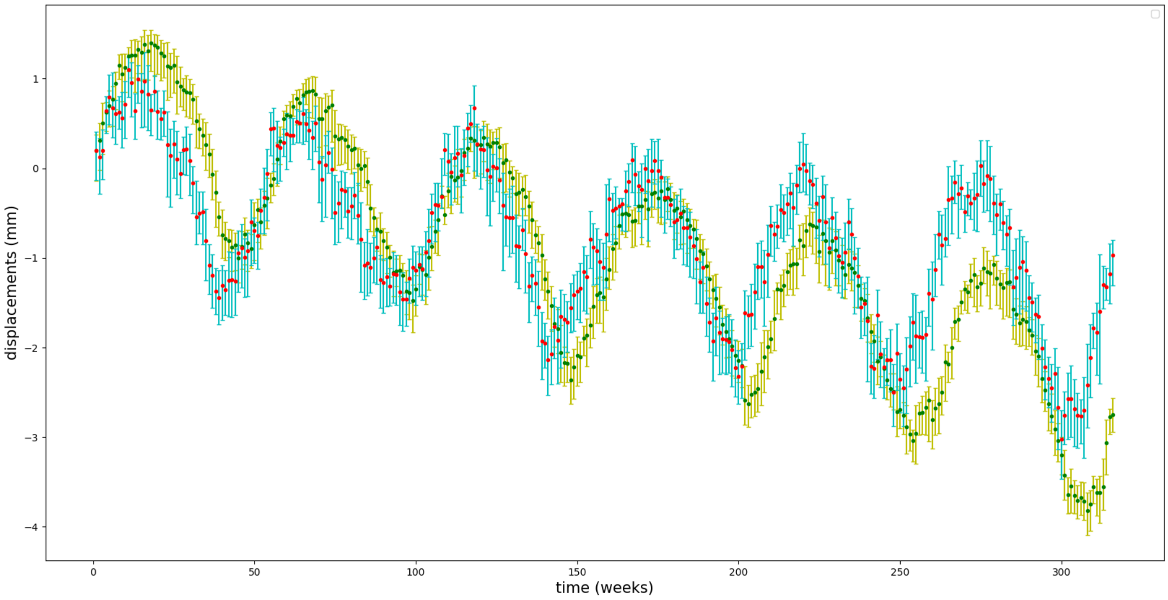

Figure 4. Displacements recording on H3 and B4. Weeks' mean (dots: H3: green, B4: red), maximum and minimum (error bar: H3: yellow, B4: blue).

2.3 Displacement versus Temperature

Figure 5 presents recorded displacements versus recorded temperature in sensor H3 and B4.

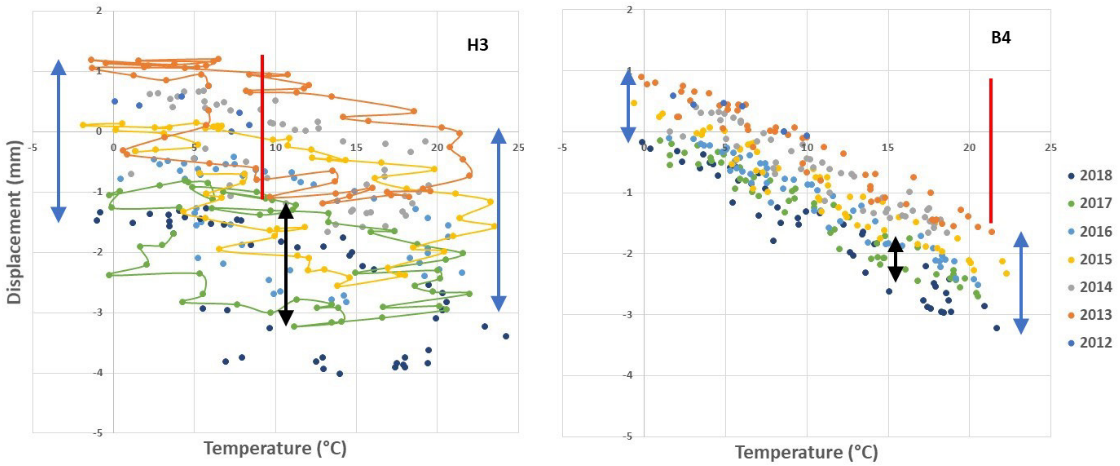

Figure 5. Displacement versus temperature on H3 (left) and B4 (right). Each dot corresponds to a week mean value. Scales and colours are identical. Blue arrows correspond to a 6-years drift, black arrows correspond to an annual hysteresis. Red line is the annual displacement range between min and max temperature.

To smooth the data and make the figure more understandable, we averaged the data per week rather than using a moving average. Here, each colour corresponds to a year and colours are the same for H3 and B4. We choose to link only a few dots (for the years 2013, 2015 and 2017 on H3 and none on B4) to help to be more readable.

As already mentioned, the annual range of temperatures are almost the same on both sensors and does not seem to evolve from year to year (we have “only” a vertical translation of the curves displacement vs temperature), which means that displacements evolve even if the annual temperature range does not. This is a strong indication of the cumulative effect of the temperatures on displacements. After 6 years of recording, the total effect is a decrease in displacement of 1.1 to 1.5 mm on B4 and of about 2.5 to 3 mm on H3, as illustrated with the blue arrows on figure 5 (the amplitude depends on the date considered in the year). This decrease in displacement correspond to the drift observed on figure 4.

In addition, there is a difference between the measured hysteresis of each annual *Dp vs T* curves. On the one hand, on both sensors the hysteresis is almost constant from year to year, but, on the other hand, the hysteresis is nearly 4 times smaller on B4 (about 0.5 mm) than on H3 (about 2 mm), see black arrows on figure 5. Another interesting aspect is pointed out by both red lines: it seems that the amplitude of displacements between max and min temperatures is the same on both sensors.

3 DISCUSSION

3.1 Mechanical interpretation

Considering the general evolution of displacements with temperature, in 6 years, between 2013 and 2018, we can measure a mean displacement drift twice smaller on B4 than on H3 (see blue arrows on figure 5). Considering the general movement of a column, it is not surprising to observe that the movement of the top of the column is greater than the movement of the base. What is more surprising is the global relative movement of the column: a negative drift in displacement means that the column tends to move closer to the rock wall, which is not what would be expected, in fact, as mentioned earlier, the top of the column is farer the cliff than the bottom. Some assumption can be proposed:

- joint opening: if joints opened in the column itself or in the rock mass, it could lead to bring opposite walls closer, a fracture exist on site (see B6 sensor) but is analysis need to be investigated deeper to validate this assumption.
- if the gravity centre of the column is towards the rear, this could probably explain the movement. Unfortunately, there is no precise data on the geometry of the column (laser scan for instance), and therefore, we cannot be precise about the position of its gravity centre. The column can also punch the infra-bathonian interlayer limestone.
- lateral interaction between the column and other rock masses that could limit and constrain the movement of the column can also be evoked.

3.2 Comparison of observations with other sites

Observations realized on *les chandelles de l'Escalette*, are consistent with those obtained on other sites. Merrien-Soukatchoff & Gasc-Barbier (2023) proposed a synthesis on the effects of natural thermal cycles on rock outcrops and pointed out different studies by Bakun-Mazor et al. (2020, 2013), Cloutier et al. (2015), Gischig et al. (2010), Grøneng et al., (2011), Marmoni et al. (2020). Most of the displacement's measurements realized along fractures show the same type of drift, but the range of the evolution depends on the properties of the rocks under study. When comparing data obtained under only positive temperature by Bakun-Mazor et al. (2013) measured in Massada (Israel) about 0.35 mm of displacement amplitude (measurements last 25 months under 20 to 50°C) whereas Guerin et al. (2021) measured on granite exfoliation sheets, a 6 mm displacement amplitude (measurements last 24 hours under 16 to 37°C) and Gasc-Barbier et al. (2021) measured on a limestone cliff a 1 mm displacement variation (measurements lasts 4 years under 5 to 35°C).

4 CONCLUSION

The measurements presented here are one more contribution to the studies carried out over the last 20 years on the role of weak temperature cycles on the overall behaviour of rock masses. The displacements observed and the orders of magnitude measured are consistent with former studies. Questions remain to improve the mechanical understanding of the site: analyses of other sensors and a precise geometry are needed.

An interesting observation is linked to the range of displacements. On both sensors, the greater the hysteresis, the greater the drift, but, in the meantime, the maximum amplitude of temperature lead to the same displacement amplitude on both sensors. These observations should be corroborated on other sites and need further investigations.

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