



HAL
open science

Monitoring evidence of slab creep under the effect of daily temperature cycles -The case study of Socoa coast (Bay of Biscay, France)

Clara Lévy, Thomas Dewez, Christophe Garnier, Lucie Guillen, Yannick Thiery

► To cite this version:

Clara Lévy, Thomas Dewez, Christophe Garnier, Lucie Guillen, Yannick Thiery. Monitoring evidence of slab creep under the effect of daily temperature cycles -The case study of Socoa coast (Bay of Biscay, France). 14th International Symposium on Landslides, Jul 2024, Chambéry, France. hal-04541743

HAL Id: hal-04541743

<https://brgm.hal.science/hal-04541743v1>

Submitted on 11 Apr 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Monitoring evidence of slab creep under the effect of daily temperature cycles – The case study of Socoa coast (Bay of Biscay, France)

C. Lévy¹, T. Dewez¹, C. Garnier², L. Guillen¹, Y. Thiery²

¹ BRGM, Orléans, France

² BRGM, Pessac, France

SUMMARY: A supposedly active rock instability was instrumented at Socoa (municipality of Ciboure, France). The objective was on the one hand to diagnose the activity of the instability, and on the other hand, to understand the meteorological-marine phenomena and associated processes which could play a role in its destabilization. Analysis of in situ data (extensometers, temperature probes, weather data) shows that the instrumented slab moved by about 1.6 mm during the first year of measurement. The phenomenon which contributed the most to this small accumulation of deformation is the slab creep under the effect of daily temperature cycles. The amplitude of this yet undocumented phenomenon depends on the temperature conditions: the greater the amplitude of daily temperature, the greater the induced movements. The occurrence of rain reduces the amplitude of this phenomenon. The intensity of this phenomenon is highly likely to increase in connection with climate change, as this coastal zone is supposed to endure an increase of droughts and heat records.

Keywords: rockfall, extensometer, creep, temperature, Socoa

Introduction

Meteorological phenomena and associated processes known to contribute to the weathering and destabilization of cliffs are extremely varied and numerous: freezing of water in cracks and pores, increase in pore pressure, flexural movement of the cliff under the repeated action of waves inducing rupture by fatigue, temperature variations inducing stresses at the crack tips allowing crack expansions, haloclasty, etc. (among others authors, D'amato et al., 2016; Delonca et al., 2014; Collins et al., 2016; Brains et al., 2014). Depending on the geographical areas, the most contributing processes to cliffs destabilization and weathering can be different (Delonca et al., 2014). The identification of contributing processes remains complex because some processes induce phenomena of low intensity and/or are very rare to observe.

This study highlights a still undocumented process (the creep of a slab under the effect of daily temperature cycles) thanks to the implementation of instrumentation for a long observation period (1 year). We show that this phenomenon contributed the most to the accumulation of deformation during the observation period.

The study site at Socoa coast (France) and the monitoring set up

The study area is a coastal cliff composed of flysch, a stack of very different layers: massive limestone strata, marl strata and sometimes thin layers of clay. The instrumented volume is a thin limestone slab (<1 m), located in the upper third of the cliff which is nearly 40 m high at



this location (Figure 1). The supposed mechanism of this instability is a lateral rotation of the slab (Figure 1). The slab is pre-cut laterally by open vertical and horizontal joints connected in a continuous network. It is hypothesized that this rock instability accommodates deformation along its basal surface, this basal surface most certainly being a clay layer. As a result, the expected movement is a widening of the joints, as well as a downward movement of the rock mass. Located at the head of the cliff, this unstable volume is impacted by waves only during sea storms.



Figure 1: Experimental set up with extensometers (E), Pyranometer (P) and Temperature probes (T). The instable slab (white) is supposed to have a rotational movement. Inside the blue circle: photo of one extensometer across the joint (dashed line)

With the aim of following the expected rotation of the slab, 2 extensometers were installed across the joint network, **E₁** and **E₂**, in December 2021 (Figure 1). In order to record the largest possible movements, the extensometers were oriented perpendicular to the joints. They measure the deformation with an accuracy of ± 0.10 mm according to manufacturer data. In order to understand the link between movements and environmental conditions, additional sensors were set up (Figure 1): a pyranometer **P** which allows quantifying direct sunlight; temperature probes at 5 and 60 cm depth, **T₀₅** and **T₆₀**. These measurements are supplemented by rainfall data **P_r** and air temperature data **T_{air}** from the Fort de Socoa weather station located less than 100 m from the site.

Displacements analysis

Data between 16/12/2021 and 06/12/2022 show that the joint opened irreversibly by approximately 1.6 mm at **E₁** and 1.2 mm at **E₂** and that it opens and closes daily (daily cycles). These small variations (around 0.1 mm on average) are mostly reversible. They are due to the contraction and expansion of the rock with daily temperature cycles (Figure 2).

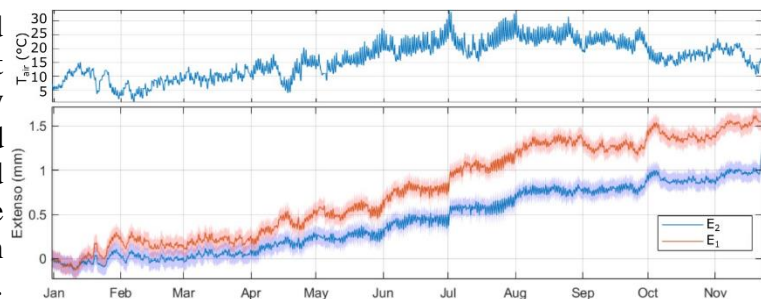


Figure 2: Air temperature and extensometer records during 1st year of experiment (16/12/2021-06/12/2022)

The opening at **E₁** is almost perfectly proportional to **E₂** with $E_1 = a \times E_2 + b$ ($R^2 = 0.99$, Figure 3), and $a = 1.45$ with a 95% Confidence Interval (CI) of [1.448 1.454] and $b = 0.13$ with a 95% CI of [0.127 0.130]. This faster opening at the top of the joint compared to its bottom is consistent with the hypothesis of a rotation mechanism. At the time of installation, the joint was already open by about 5 cm at **E₁** and 2 cm at **E₂**. Thus, assuming a regular evolution of the joint opening, it began around 60 years ago. These observations confirm that the instability is active, with the recording of significant irreversible deformations long time before collapse.

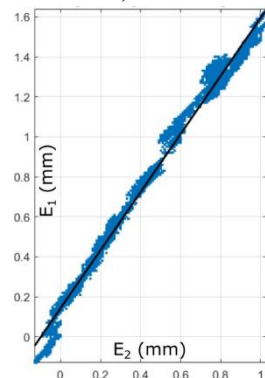


Figure 3: **E₁** as a function of **E₂** with linear fit (black line)



The ratio a between the movements at E_1 and E_2 imposes an assumed pivot point of the rotation about 18 m from E_2 (Figure 4). This position is lower than the exit point of the joint around 12 m from E_2 , visible on topographical data. Despite the uncertainty of this estimate, it is very likely that the pivot point does not correspond to the exit point of the joint. It is therefore assumed that the physical phenomenon(s) at the origin of the observed activity is(are) the cause of the rotation movement.

Temperature measurements at 5 and 60 cm depth allowed resolving temperature variations at several depths using 1D simulation. Comparisons with the data at E_1 show an optimal anti-correlation $C=-0.916$ with the temperatures at 20 cm depth. The photogrammetry data show that there is indeed an interface at this depth, delimiting a volume of 27m³ to 39m³, estimated using the cloudcompare (Figure 4).

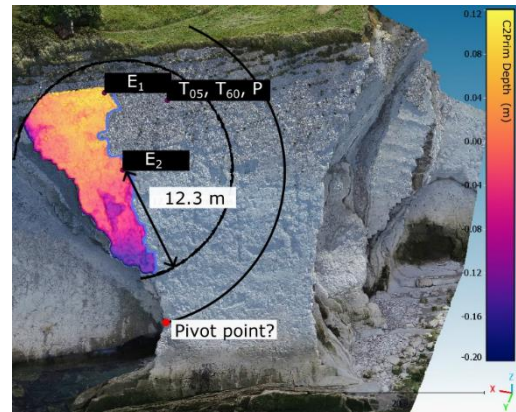


Figure 4: Circles of radius 12.3 and 18 m around E_2 (black). The colour scale indicates the estimated slab thickness for a basal surface assumed at 20 cm depth

For the period 07/08/2022 to 07/14/2022, Figure 5 illustrates the joint opening when the temperature at 20 cm depth decreases (blue periods) and the rock contracts. Conversely, the joint closes when the temperature increases (red periods) and the rock expands. The movement does not appear entirely symmetrical between periods of contraction and expansion. Thus, expansion is systematically lower than contraction and each cycle contributes to the accumulation of irreversible deformation (Figure 5). A ΔT of approximately 2° at 20 cm depth over 24 hours (i.e. a ΔT of 8° at the surface) generates an irreversible accumulation of deformation ΔL of about 0.08 mm. This difference in behavior between the contraction and expansion phase seems less marked when it rains (Figure 5). Thus, as soon as it rains, the accumulation of irreversible deformation becomes negligible. On the scale of one year of measurement, it appears that temperature cycles are responsible for the majority of the observed irreversible deformation.

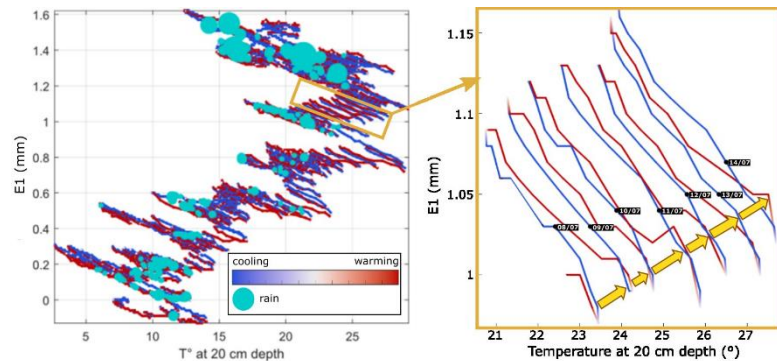


Figure 5: Left: E_1 as a function of the temperature estimated at 20 cm depth (01/2022 to 11/2022). Warming and cooling periods are indicated with alternating red and blue. Blue dots indicate hourly rain with size depending on rain intensity. Right: zoom on the period 07/08/2022 - 07/14/2022. Each daily cycle leads to the accumulation of a small irreversible deformation, shown by yellow arrows.

Conceptual model to explain the observed deformations

The deformation ΔL of a bar of isotropic material, placed horizontally, is proportional to the temperature variation ΔT with $\Delta L = -\alpha L_0 \Delta T$ and L_0 the initial length of the bar and α the coefficient of linear expansion of the material. This deformation is symmetrical with respect to a central axis. The forces acting on the basal surface during contraction are (Figure 6): the weight P , the reaction to the ground R_N , the traction force exerted by the contraction of the material F_{cont} , and the friction force between the bar and floor F_{fric} . During expansion, the force F_{cont} is replaced by the traction force exerted by the expansion of the material F_{dil} , whose orientation is opposite to F_{cont} . F_{fric} force also changes orientation between contraction and expansion.



For a bar placed on an inclined surface of slope β (Figure 7), the involved forces are the same, but the inclination has an impact on which forces facilitate or not the contraction or the expansion of the material. During contraction, the component of the weight tangent to the slope \mathbf{P}_T helps contraction movements in the upper part of the bar. Conversely, during expansion phase, \mathbf{P}_T opposes expansion movements in the upper part of the bar. As a consequence, the position of the fixed zone shifts downwards compared to the case of a horizontal bar. In the contraction phase, the length L_1 above this fixed zone is such that $L_1 > L_0$. Thus, for the same temperature variation ΔT , the deformation in the upper part of the bar is ΔL_1 with $\Delta L_1 > \Delta L_0$. Similarly, during expansion the length L_3 above the fixed zone is such that $L_1 > L_3 > L_0$. Thus, for the same absolute temperature variation ΔT , the deformation in the upper part of the bar is greater during the contraction phase than during the expansion phase: $\Delta L_1 > \Delta L_3$.

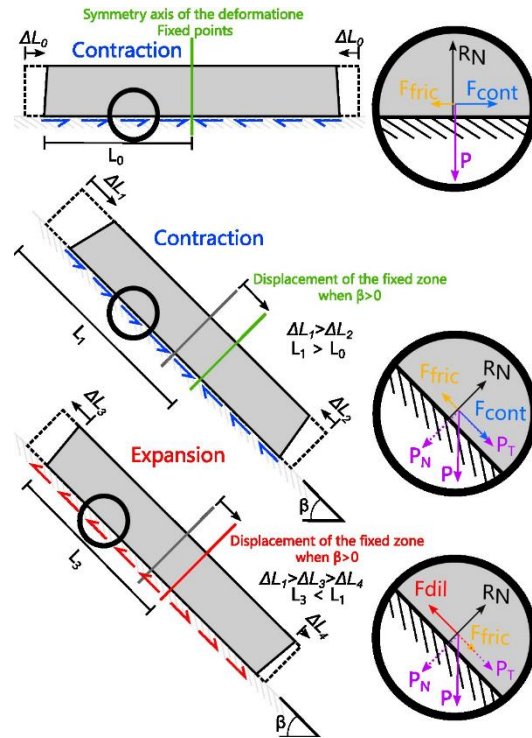


Figure 6: Conceptual model to explain the observed deformations. Forces applying locally on the basal surface are presented on the right

An accumulation of deformation is therefore possible step by step with the succession of thermal cycles leading to the contraction and expansion of the material. In particular, this conceptual model makes it possible to explain our observations of the slab creep during dry periods at Socoa site. We hypothesize that the force \mathbf{F}_{fric} decreases with the lubrication of the basal surface when it rains, which would explain why the accumulation of deformation $\Delta L_1 - \Delta L_3$ during rainy periods is negligible. This creep phenomenon can occur at our site thanks to its geometry: a slab placed on a very smooth and inclined surface, with free edges at its bottom and one side.

Conclusion

Analysis of in situ data shows that a small slab (27m³ to 39m³) accumulated irreversible deformation of about 1.6 during the first year of measurement. The phenomenon which contributed the most to this accumulation of deformation is the creep of the slab under the effect of daily temperature cycles. The amplitude of this yet undocumented phenomenon depends on the temperature conditions: the greater the amplitude of the daily temperature, the greater the induced movements. The occurrence of rain reduces the amplitude of this phenomenon. The intensity of this phenomenon is highly likely to increase in connection with climate change, as this coastal zone is supposed to endure an increase of droughts and heat records.

Acknowledgements

The EZPONDA project was granted by FEDER EU funds (grant FEDER FSE 2014-2020).

References

- Delonca, A., Gunzburger, Y., & Verdel, T. (2014). *Statistical correlation between meteorological and rockfall databases*. Natural Hazards and Earth System Sciences, 14(8), 1953-1964.
- D'Amato, J., Hantz, D., Guerin, A., Jaboyedoff, M., Baillet, L., & Mariscal, A. (2016). *Influence of meteorological factors on rockfall occurrence in a middle mountain limestone cliff*. NHESS, 16(3), 719-735.
- Collins, B. D., & Stock, G. M. (2016). *Rockfall triggering by cyclic thermal stressing of exfoliation fractures*. Nature Geoscience, 9(5), 395-400.
- Brain, M. J., Rosser, N. J., Norman, E. C., & Petley, D. N. (2014). *Are microseismic ground displacements a significant geomorphic agent?* Geomorphology, 207, 161-173.