Repairing a damaged house by watering foundations: the MACH project

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ABSTRACT

Changes in volume of clayey soils during periods of drought lead to considerable repair costs in France and around the world. Individual dwellings are particularly damaged and, so far, technical repairing solutions used are expensive and can be sometimes traumatic for owners (as they are sometimes undertaken inside the house…).

Cerema proposes an innovative approach, which consists in watering the foundation soil of a house in order to neutralize natural shrinkage during critical droughts. A damaged house was chosen and equipped with a device, that recovers rainwater and injects it under the foundations. A soil moisture monitoring was also set in order to follow evolution of soil suction.

Works took place in Fall 2016 during a severe drought (in France). Early observations suggests encouraging results with, on one hand, suction reduction as the device was used, and on the other hand, closing of existing wall's cracks. The monitoring is planned for 3 years long.

1. INTRODUCTION

In France, natural risks are compensated by a public-private system shared between insurance firms and French state. Floods are the most expensive disasters and swelling and shrinkage of clayey soils phenomenon is the second one. This phenomenon depends on meteorological and geological parameters. Last research project about this topic (ARGIC 1 & 2) aimed that clay minerals have the property to bind water molecules within the cations layers. This mineralogical phenomenon is reversible and induces shrinkage and swelling of clayey soils. Recurrent droughts spell over recent decades have led to a hydric deficit in soil moisture which highlighted vulnerability of typical constructions in France. Thus, clayey soils during severe droughts tend to shrink drastically. Differential settlements affect dwellings and cause several cracks (Mathon and al. 2015).

Most damaged constructions in France are individual dwellings built with building blocks or bricks and founded on a footing (Kreziak and al. 2015). These dwellings have also a slab-on-ground (that is to say the concrete floor is directly laid on a little layer of gravels (10 centimeters thick) and the natural soil. This design is the most common building design in France until the 60's. During severe droughts (as in 2003, 2005 or more recently in 2016), soil settlements occur and induce deformations in the foundation system. Thus bearing walls are cracking. Sometimes, soil settlement is so important, that the slab subsides too. Bearing walls movements cause considerable damages on the interior finishing (partition walls cracked, joineries blocked, damages on inside networks: electricity or water distribution…).

In order to repair these damages, French experts have two main technical solutions:

- underpinning the former foundation system. That is to say, reporting deeper the foundation level to avoid cyclical moistening and drying of shallow soils. Most often used techniques are piles, micro-piles and polymerized products injections (resins);
- soil moisture containment techniques. That is to say, isolating bearing soils of the construction from its environment to avoid hydraulics exchanges. Geomembranes or concrete walls are often used.

Simultaneously, aggravating factors are also fixed:

- cutting (or removing) vegetation growing close to the damaged houses. These plants or trees could dry the soil with their roots;
- checking the sealing of all the pluvial and sewage networks;
- waterproofing perimeter of the construction to avoid water exchange.

When the situation is stabilized (monitoring period that can reach one year or more…), cracks are filled and stapled, interiors finishing is also fixed (partition walls repairing, fine adjustment of the joineries…). Then, new outside coatings are realized.

This classical repairing works are expensive, long and sometimes traumatic for the owners (as they are obviously realized inside the dwelling). The MACH project (Mathon and Godefroy, 2017) is a field experimentation in order to fix cracked houses with a new technical approach.

MACH means "MAison Conforté par Humidification" that could be translate as "HOuse repaired by Watering or moistening". It consists in:

- removing moistening or drying soil factors like vegetation or leaky pipes…
- watering soil located under the footing to neutralize natural shrinkage during critical droughts.

The MACH project is a partnership between Cerema (project leader), ELEX Orleans (a private expert claim firm) and Agence Qualité Construction (French professional agency for construction's quality). The project is 100% funded by the ministry in charge of the sustainable development and involved several local companies.

2. BACKGROUND SURVEY OF THE MACH

The MACH (figure 1) is located in Mer (Loir-et-Cher, France). The house (figure 2) was built in 1968. It is a one storey house with an extension which has been built in 1995 on the East side of the former house. The foundation system is a footing and the floor is a slab-on-ground one. The house is located in a residential area where vegetation is rather small and cared (owner's gardens and some trees in the streets). The MACH is an inhabited house. It was excluded from the French compensating system for the drought of 2015. Thus, the owners are really involved in the experiment in order to repair their dwelling.

Figure 1: Site location

Figure 2: View of the house

Damages

After Summer 2015, the damages were noted only on the extension part of the house. Major cracks were drawn on figure 3. It was found out that the extension is tilting to the East.

Figure 3: Noticed damage survey in 2015 and 2016

Inside the house, the floor did not settle at all. However, the tilled floor is broken at the junction of the former construction and the extension. The tilting phenomenon induced damages on the interior finishing (cracks on partition and doubling walls, offset of windows panels, doors which doesn't close or open…). These damages reduced during Winter 2015/2016 and increased during Summer and Fall 2016.

Climate and vegetation

Mer climate is a mixed oceanic/continental types: average annual cumulative rainfall is about 600 millimeters and average temperature 11°C (about 52°F). Meteorological station of Blois (which is only 25 km far away from Mer) gives following datas:

- 2014 is "a normal year" with 694 mm cumulative rainfall (uniformly spread out across the year) and average temperature equal to 12.5°C. Swelling and shrinkage phenomenon is not a problem in 2014;
- 2015 is dryer than 2014 with only 594 mm annual rainfall and a short drought period during Spring, June and July. Important rainfalls during August and September avoided a major drought;
- Annual cumulative rainfall in 2016 is over 720 mm but with an exceptional rainy Spring (over 210 mm rainfall during May!). Despite this rainy Spring, 2016 is considered as a dry year, especially after June (figure 4).

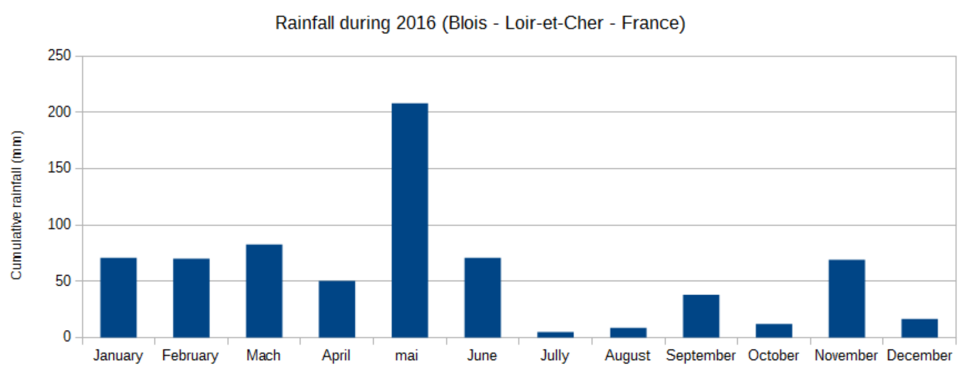

Figure 4: Annual rainfall in Blois (2016)

Vegetation

Every shrubs or trees are transcribed on a plan (figure 5). A cotoneaster hedge is located just in front of the damaged gable of the MACH. A wisteria is also noted on the south facade.

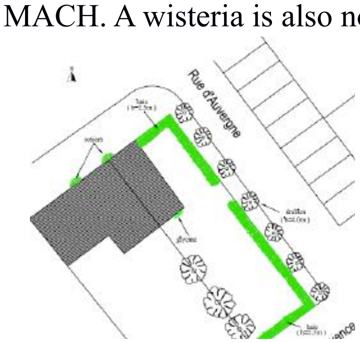

Figure 5: vegetation survey

Geology

Cerema provided a geotechnical survey in order to characterize foundation soil of the house and to determine how it could be fixed.

Thus, Cerema realized two drillings including in situ pressumeters tests close to the house. These investigations allowed to set a geotechnical model which can be resumed as follows:

- a dark brown, strong and plastic clay. This layer is about 2.50 meters thick. It is a decalcification clay;
- the Beauce limestone is found deeper.

Mechanical properties of these geological layers are presented in Table 1:

	Number of values	Limit Pressure pl* (MPa)	Pressumeter modulus E_M (MPa)	Observations
Decalcification clay	4	0.22 < pl* < 0.55 pl* geom. mean = 0.38	$3 < E_M < 6.9$ E_M geom. Mean. = 4.6	Soft clays
Beauce Limestone	5	1.97 < pl* < 2.82	$20.8 < E_M < 131.9$	Altered rock

Table 1: in situ presiometers tests results

An excavator drilling was realized in front of the most damaged edge of the house. It shows that the foundation system, which is an 85 cm deep footing, is set on the soft and plastic clay. The footing is 35 cm thick. Numerous roots are observed in the excavation (see figure 6).

Figure 6: excavator drilling (with numerous roots)

Some soil samples were brought to the laboratory. Table 2 shows main results of the characterization tests.

	localization	Particle size distribution				Plasticity	
		Sieve passing (%)			Dmax (mm)	VBS (g/100 g of dry soil)	Plasticity Index PI (%)
		2 µm	80 µm	2 mm			
Decalcification clay	Excavator drilling	57	97	99	10	/	37
	SP1 (1.5 m)	/	98	99	5	5.5	39
	SP2 (1 m)	/	98	100	5	6.4	/
	SP2 (2 m)	/	89	98	10	6.0	/
Beauce limestone	SP1 (5 m)	/	58	84	20	1.4	/

Table 2: soils parameters

The foundation soil is a soft and plastic clay (PI ≈ 37 to 39), sensitive to swelling and shrinkage phenomenon. Beauce limestone lying under the clay layer is not sensitive.
The conclusion of the geotechnical survey is that early 2015 hydric deficit induced a severe drying of the clays located under the footing of the house. The hedge of cotoneaster was an aggravating factor for the shrinkage phenomenon. This heavy drying caused settlement of the footing and lead to cracking the east gable of the house.

3. MACH'S WORKS DESCRIPTION

Principles
The MACH project consists in watering foundation soil of the damaged house as soon as it is drying. With this purpose, the clayey soils located under the footing are:

- **protected** by removing the cotoneaster hedge close to the East gable of the house;
- **monitored** by tensiometric probes, which measure 4 times a day the moisture content.
- **watered** by a device with 10 water injection points located 15 cm under the footing.

Removing vegetation
Early November 2016, the cotoneaster hedge and the wisteria were removed (see figures 7 and 8). The hedge was substituted by a metallic fence with a green screen.

Figure 7 and 8: MACH's views before removing the hedge and after

Rainwater collecting device

Obviously, the water provenance is a sustainable one: it comes from a device that recovers rainwater. The gutter located on the north facade of the house was modified in order to collect rainwater falling on the North-East part of the extension (about 12 m² roof). A new rainwater down-pipe was set and 3 tanks were installed (see figure 9). The tanks are hidden behind the green screen.

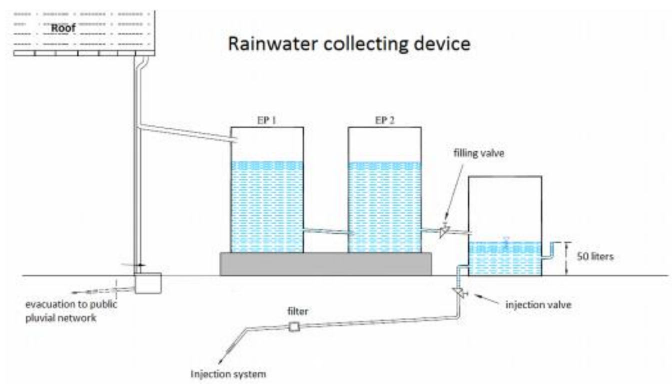

Figure 9: Rainwater collecting device

According to the roof surface and estimate losses of the device, it has been estimated that a cumulative rainwater of 80 mm is required to fill up the three reservoirs.

Water injection device

The principle was to set a manual and robust device that injects water under the foundation level. The MACH owner opens the valve, which releases water from the third rainwater reservoir. The third reservoir is calibrated to contain about 50 liters, which is the estimate water volume to moisten sufficiently clayey foundation soils. Injections points are spread out along the gable of the house. They are located 20 centimeters far from the wall and about 1 meter deep. In fact, an injection point is a PVC pipe (diameter 5 centimeters) which has been driven in a manual auger drill. A capillary tube coming from the rainfall reservoir is put in the PVC pipe (see figure 10) and releases the water in the pipe.

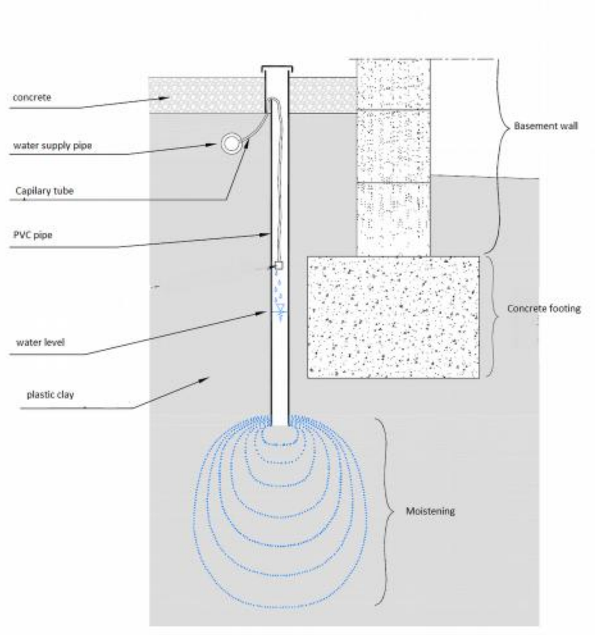

Figure 10: Water injection device

Opening the valve releases the water in each PVC pipe. Thus, water infiltrates the soil only at the bottom end of the pipe.

Tensiometric monitoring

Tension is a concept used in the agronomy field. It gives information about direction of hydraulic flows in the soil and on the available water for cultivating. Tension measurement allows to quantify, on a given point, the attraction force applied by solid particles on water. It is given in kilo Pascal (kPa) and is called, in the soil mechanics field, “soil suction”. Suction and moisture content are linked. Previous research works (Mathon and al. 2015) aimed to correlate them based on an experimental approach of drying. Under a given moisture content (which corresponds to the air inlet), the more tension is increasing, the more moisture content is decreasing. The tensiometric probes (see figure 11) are recording an electric resistivity of a gypsum piece, which is water balanced with natural soil. In the MACH project, 20 probes were driven into the soil at the same depth than the water injection points (about 1 meter depth).

Each probe is linked to a data-logger unit which is located on the south facade of the house (see figure 12). This data-logger send 4 times a day tensiometric information to the Cerema. Thus, soil drying is monitored and water injection can be decided as soon as the engineer analyzes the tensiometric graphs.

 

Figure 11: Tensiometric probe Figure 12: Outside data-logger

Cracks monitoring
Existing damages on the MACH have been noted in October 2015. Every month, Cerema's engineers observe carefully the house in order to drawn every new crack that could be occur. Furthermore, the biggest crack located on the north facade was equipped with a displacement sensor (see figure 13) to record opening and closing of the crack according to the water injections and meteorology. This displacement sensor is a fissurometer and it has been set in November 2016.

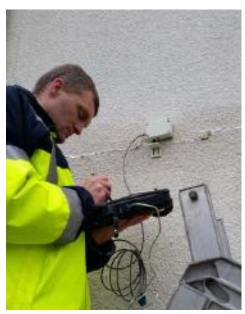

Figure 13: Cerema's agent downloading movement sensor datas

4. MONITORING FIRST FINDINGS

Annual cumulative rainfall in 2016 was over 720 mm with an exceptional rainy Spring. Despite this rainy Spring, 2016 is considered as a dry year especially after June and until December. This exceptional contrast induced a maximal moistening of shallow and expansive soils during Spring and a gradual and durable drying after Summer until the end of the year.

During Fall, the MACH's owner declared that interior doors and windows were really hard to close and open. In October 2016, a new vertical crack was observed on the North facade of the MACH, illustrating the east tilting movement of the extension.
Thus, Cerema decided to open the valve in order to release water in the injection points. The tensiometric probes recorded the quickly moistening of the clayey soils. The MACH's owner

noted that doors and windows were easier to use. Furthermore, a clear closing of the monitored crack was recorded in December 2016 (see figure 14).

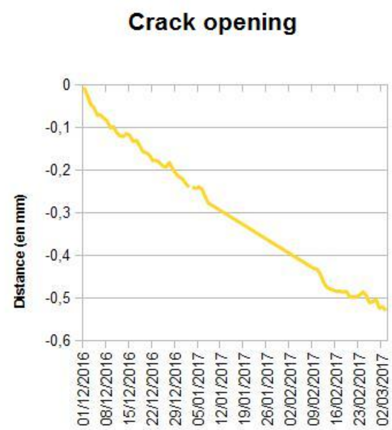

Figure 14: Crack monitoring

5. CONCLUSIONS

The MACH Project is a field experiment of an innovative approach to repair houses that have been damaged by geotechnical drought. The principle of the MACH is to water or moister clayey soil to neutralize natural shrinkage due to its desiccation. A damaged and inhabited house was chosen. Experiment works began in October 2016 during a severe drought period (in France). A relationship between damages, geology and meteorology was highlighted by the geotechnical survey carried out by Cerema.

A watering device has been set under the footing of the MACH. First uses of this device showed encouraging results, as it induced closing of the major crack and decreasing of bad effects felt by the owners. The monitoring of the house is planned until 2019, it will be important to confirm these encouraging first results.

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