III) REMEDIAL WAREHOUSE PROJECT

This remedial warehouse project differs from the previous two jobs by the fact that the building slab experienced heave due to expansive soils rather than from shrinkage. However, the soil under this building had not reached its ultimate swell potential and was continuously causing distress to the floor slab. As a remediation plan, it was decided that the floor slab needed to be removed (due to excessive distress), and a combination of chemical soil injection and water injection used to limit the future movement of the soils under the floor slab (Figure 18).

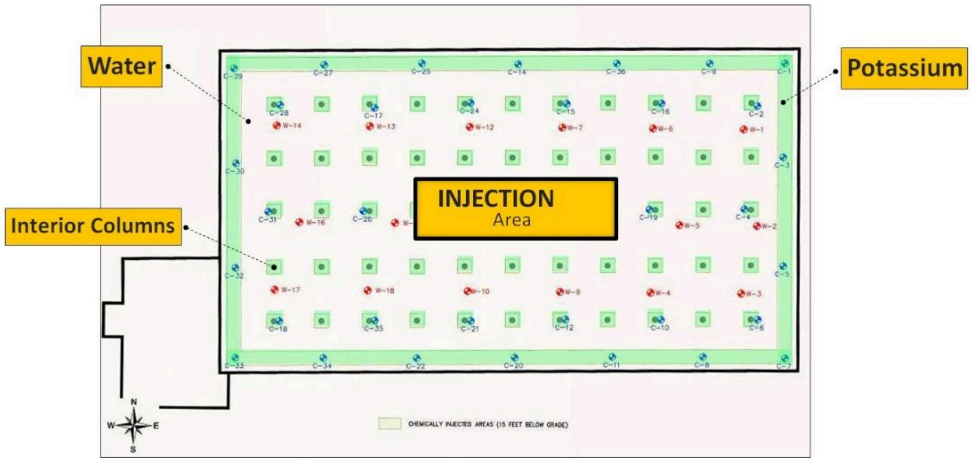

Figure 18. Plan drawing showing where water and potassium injection was performed.

The potassium solution was injected in a five feet wide strip around the perimeter of the inside of the warehouse, and in a ten by ten feet area at each column locations as shown in Figure 17. Injection was performed using a mast mounted on a dozer with four injection rods on two feet centers (Figure 19).

Figure 19. Equipment used to perform chemical and water injection inside the warehouse.

Water was not used around the foundation piers due to the possible damaging of the column and perimeter footings. As mentioned previously, potassium and ammonium satisfy the clay particles' charge without causing the hydration that results in swelling pressure and, thus, surface heave. As a quality control measurement, a daily site progress report was completed which included areas treated each day along with the amount of material injected per area. Post injection swell test results (Fig. 19) showed a good improvement which resulted in the swell being reduced to less than 1% as shown in Figure 20.

BORING NUMBER	DEPTH (ft)	INITIAL MOISTURE CONTENT, %	FINAL MOISTURE CONTENT, %	PERCENT SWELL	AVERAGE PERCENT SWELL	HAND PENETROMETER (tsf)
C-15R2	0-1	37.0			0.71%	X
	1-2	25.0	26.1	0.34		3.25
	2-3	22.6	23.4	0.53		2.25
	3-4	22.9	24.0	0.71		2.50
	4-5	27.0				2.00
	5-6	25.3	26.7	0.40		2.25
	6-7	27.2	28.5	0.84		2.75
	7-8	38.0				0.50
	8-9	-				
	9-10	50.0				X
	10-11	-			1.43%	
	11-12	-				
	12-13	48.0				
	13-14	28.5	32.3	0.38		4.00
	14-15	29.1	33.1	2.48		4.50

Figure 20. Post injection swell test results.

CONCLUSION

The selection of the type of remediation work for buildings affected by the volumetric change of unsaturated clayey soil is always project specific. The type of required injection systems will depend on the in-situ soil properties i.e. soil mineralogy, moisture content and plasticity index. Potassium chemical injection has shown satisfactory results in terms of swell reduction, and is preferably used in-lieu of water injection for remediation jobs in existing structures. Understanding the causes for foundation settlement, building cracks, slab distress or jammed doors and windows, is the first step towards a successful remediation job for situations where expansive clay is the likely source of the problem.

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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. Former research projects and papers about this topic (ARGIC 1 & 2, and many other authors) showed 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).

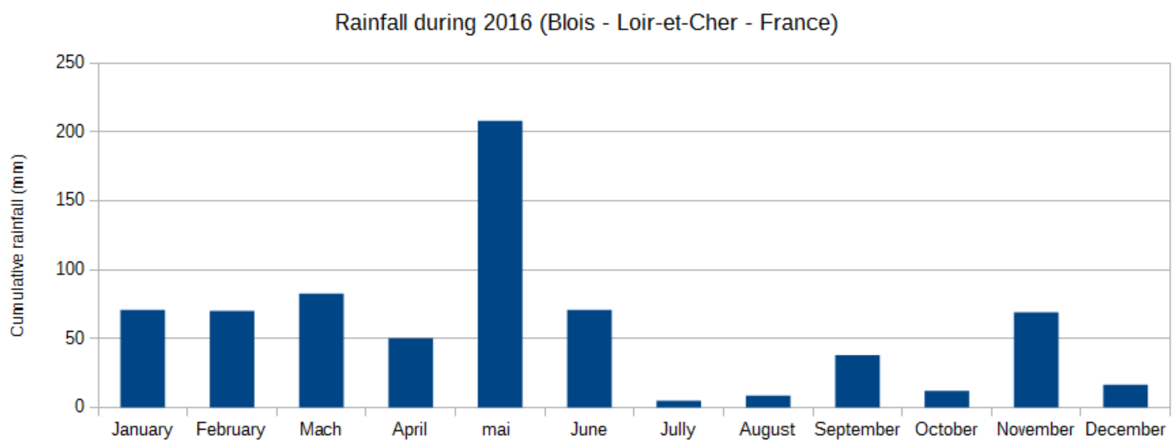

Figure 4: Annual rainfall in Blois (2016)

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.

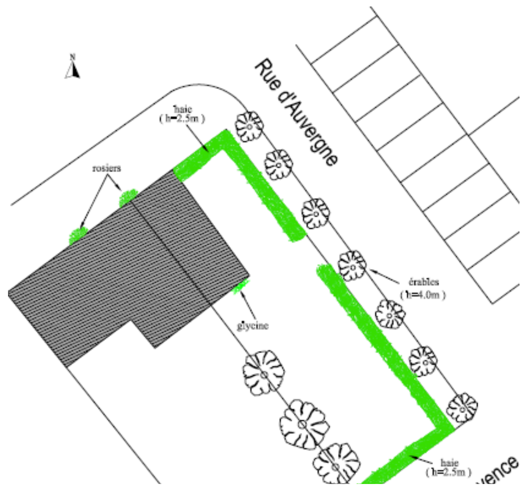

Figure 5: vegetation survey

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 without organic content;
- the Beauce limestone is found deeper.

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

	Limit Pressure pl* (MPa)	Pressumeter modulus E_M (MPa)	Observations
Decalcification clay	$0.22 < pl^* < 0.55$ pl* geom. mean = 0.38	$3 < E_M < 6.9$ E_M geom. Mean. = 4.6	Soft clay
Beauce Limestone	$1.97 < pl^* < 2.82$	$20.8 < E_M < 131.9$	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)	Liquid limit (%)	Plasticity Index PI (%)
		2 µm	80 µm	2 mm				
Decalcification clay	Excavator drilling	57	97	99	10	/	62	37
	SP1 (1.5 m)	/	98	99	5	5.5	58	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 32 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.