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1 **Alteration of the hydro-mechanical performances of a stabilised**  
2 **compacted soil exposed to successive wetting-drying cycles**

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**ABSTRACT**

25 This study intends to examine the impact of successive wetting and drying cycles on the strength and the  
26 hydraulic conductivity of lime and cement treated soil, with a special emphasis on the protocol that is  
27 employed to impose the cycles. Compacted specimens were cured for 90 days before being exposed to  
28 different numbers of wetting and drying cycles. These cycles were imposed to treated samples with two  
29 protocols. The first one is based on oven drying and full saturation, while the second one is based on the  
30 control of the relative humidity of the samples at room temperature, to thus obtain more realistic conditions  
31 for the wetting and drying cycles. The unconfined compressive strength and saturated hydraulic  
32 conductivity were monitored as a function of the number of cycles. The results highlight the role of the  
33 imposed wetting and drying cycles technique for a better assessment of the long term performances of  
34 treated soils. A special attention was also taken to evaluate the relationship between the alteration of  
35 hydraulic conductivity and mechanical strength as a function of the number of applied wetting and drying  
36 cycles. The results showed that the degradation of the strength of the treated samples is associated to a  
37 significant increase of their hydraulic conductivity as a function of the number of cycles.

38 **Keywords:**

39 Soil stabilisation; lime; cement; long term; wetting and drying cycles; strength; hydraulic conductivity

## 40 1. Introduction

41 Soil stabilisation with lime and/or cement is commonly employed in geotechnical engineering to enhance  
42 soil characteristics like strength, bearing capacity, elastic modulus, among other features. The main  
43 effects of these treatments are relatively well characterised. Several authors (Bell, 1996; Brandl, 1981;  
44 Kafodya and Okonta, 2018; Little, 1995) showed that lime treatment improves the soil workability as well  
45 as the soil strength and elastic modulus. Lime can also have an impact on the hydraulic conductivity of  
46 soils depending on the compaction conditions (Le Runigo et al., 2009; McCallister and Petry, 1991), limit  
47 the swelling potential of expansive soils (Nalbantoglu and Tuncer, 2001; Stoltz et al., 2012), or improve  
48 soil resistance to erosion (Chevalier et al., 2012; Mehenni et al., 2016). In the case of cement addition,  
49 several studies showed the enhancement of mechanical characteristics of soils after cement treatment  
50 (Al-Amoudi, 2002; Sariosseiri and Muhunthan, 2009), a modification of the hydraulic conductivity  
51 (Bellezza and Fratolocchi, 2006), and a positive impact on swelling capacity in the case of expansive soils  
52 (Al-Rawas et al., 2005).

53 Beyond the performance obtained with a given treatment, an important concern is the evaluation of the  
54 alteration of the performances of the treated soil over the service life of the structure to be built. Some in  
55 situ investigations of lime stabilised roads showed qualitatively that exposure to climatic conditions can  
56 have a negative impact on the behaviour of stabilised soils in the long term (Cuisinier and Deneele, 2008;  
57 Gutschick, 1978; Kelley, 1988). This was also evidenced through laboratory studies that showed that  
58 successive wetting/drying periods (Alavez-Ramirez et al., 2012; Chittoori et al., 2018; Guney et al., 2007;  
59 Khattab et al., 2007; Neramitkornburi et al., 2015; Rao et al., 2001) or repeated freezing/thawing (Bin-  
60 Shafique et al., 2010; Consoli et al., 2017; Dempsey and Thompson, 1968), etc.) may lead to a significant  
61 decrease of the treated soil hydromechanical characteristics. Other processes like leaching (Le Runigo  
62 et al., 2011; McCallister and Petry, 1991; Moghal et al., 2015), permanent contact with water (Kenai et  
63 al., 2006; Mehenni et al., 2015) can also induce a negative modification of the performances over time.

64 Thus, several concerns exist regarding the long term characteristics of the stabilised soil over time when  
65 exposed to climatic conditions.

66 In the context of this study, a particular attention was paid to the impact of successive wetting and drying  
67 on the performances of lime and cement stabilised soils. In most of the existing studies, the wetting and  
68 drying cycles experimental protocol is derived from the ASTM D559 standard (ASTM-D559, 2015) where  
69 the soil samples are alternatively immersed in water, and then placed in an oven for complete drying  
70 (Consoli et al., 2018; Guney et al., 2007; Horpibulsuk et al., 2016; Khoury and Zaman, 2007; Pedarla,  
71 2009). The alteration degree can be evaluated by measuring the loss in mass of the samples after each  
72 cycle, or by the determination of mechanical characteristics as a function of the number of cycles  
73 (strength, resilient modulus, etc.). The beneficial effects of lime/cement stabilisation are partly lost once  
74 the mixture has been subjected to several wetting-drying cycles. However, this protocol could be  
75 considered relatively severe compared to the conditions a treated soil could be exposed to in situ. Indeed,  
76 during such cycles, the water content of the sample fluctuates between full saturation and totally dry state.  
77 Immersion in water may result in the progressive leaching of the treatment product out of the tested  
78 sample with a detrimental impact of long-term performance (Khattab et al., 2007; Le Runigo et al., 2011).  
79 Moreover, the high temperature the soil is exposed to in an oven could impede the results. First, the  
80 setting reactions are influenced by the temperature (Al-Mukhtar et al., 2010a, 2010b; Eades and Grim,  
81 1960) and, secondly, it is also known that significant alteration of soil microstructure is associated to oven  
82 drying, especially compared to other methods of drying (Cuisinier and Laloui, 2004; Delage and Pellerin,  
83 1984; Penumadu and Dean, 2000). Tang et al. (2011) showed that the bonding induced by lime-treatment  
84 are altered by successive wetting and drying. Therefore, a significant additional degradation of soil  
85 performance may result from a drying phase applied in an oven. Moreover, some authors suggested a  
86 positive relationship between the amplitude of the wetting and drying cycles and the degree of alteration  
87 of the performance (Cuisinier and Deneele, 2008; Stoltz et al., 2014). Therefore, employing an aggressive

88 method may lead to over-conservative conclusions about the long term performance of a given stabilised  
89 soil exposed to wetting and drying cycles.

90 In this context, the objective of this study was to evaluate impact of the wetting and drying protocol on the  
91 hydro mechanical behaviour of a lime or cement stabilised silty soil. Successive wetting and drying were  
92 imposed to treat samples with two different protocols. The first one was derived from the ASTM D559  
93 standard (ASTM-D559, 2015). The second one was based on the control of the relative humidity of the  
94 samples at room temperature, to thus obtain more realistic conditions for the wetting and drying cycles.  
95 Such protocol would permit to evaluate the alteration of the performance over time with the accumulation  
96 of wetting and drying cycles. Both the unconfined compressive strength (UCS) and saturated hydraulic  
97 conductivity were monitored as a function of the number of cycles.

## 98 **2. Materials and experimental setup**

99 In this section, details regarding the tested materials, the experimental protocols and setups are  
100 successively provided.

### 101 **2.1. Materials**

102 The soil selected to perform this study was sampled in Northern France. The main characteristics are  
103 provided in Table 1. The mineralogical composition of the untreated soil was evaluated using X-ray diffraction.

104 The results showed that the soil is mainly composed of quartz and feldspars, its clay fraction being composed of  
105 illite and kaolinite with a significant amount of interstratified illite and smectite minerals (Mehenni, 2015). The soil  
106 can be classified as CL according ASTM standard D2487, or A2 according the French classification system (LCPC-  
107 SETRA, 2000).

108 Quicklime (1 and 3%) and cement (3 and 6%) were selected as the treatment products. The product  
109 dosages were calculated on a dry soil weight basis. These quantities of treatment product were defined  
110 based on common practices relative to the use of these products in France (LCPC-SETRA, 2000). The  
111 quicklime contained more than 94% of quicklime (CaO). The category of the cement was CEM II with a  
112 proportion of 65% of clinker, 35% of limestone and fly ash.

## 113 2.2. Samples preparation

114 First, the optimum water content and the maximum dry density for each soil for each treatment dosage  
115 were determined. The compaction characteristics of the soils, treated and untreated are provided in Table  
116 2.

117 The main concern of this study was focused on the hydromechanical performance of stabilised soils  
118 (strength and hydraulic conductivity). It has been shown that the hydraulic conductivity is minimum on  
119 the wet side of optimum (Benson and Daniel, 1990; Mitchell et al., 1965; Watabe et al., 2000). The  
120 investigations were focused on one specific compaction state for each treatment and each corresponding  
121 percentage, on the wet side of the optimum. This state was defined by  $w = w_{OMC+3\%}$  and  $\rho_d = 0.96 \rho_{dmax}$ ,  
122 depending on the nature and percentage of each treatment, where  $w$  is the compaction moisture content  
123 (%),  $w_{OMC}$  is the optimum moisture content (%),  $\rho_d$  is the dry density ( $Mg/m^3$ ) and  $\rho_{dmax}$  is the maximum  
124 dry density ( $Mg/m^3$ ) (Table 2).

125 In a first stage, the moisture content was set to the target value for compaction. A storage period of 24h  
126 permitted the homogenisation of the moisture content of the soil. Then, the soil and the treatment product  
127 were mixed in a mechanical mixer during a few minutes. The compaction curves were determined for  
128 each type and percentage of treatment according to the standard ASTM-D 698. Lime/soil mixtures were  
129 left for 1 hour in an airtight container before compaction to allow for the immediate reactions to take place.  
130 In the case of cement, compaction was carried out within a few minutes (maximum of 30 min) after the  
131 mixing process, to limit the impact of the setting reactions. The compacted samples were wrapped in  
132 plastic sheets and kept at  $20.0 \pm 1.5^\circ C$  during the curing period, avoiding thus water exchange. This  
133 protocol has been employed in several studies (John et al., 2011; Lemaire et al., 2013; Okyay and Dias,  
134 2010; Tang et al., 2011).

135 The soil samples employed for strength and permeability determination, untreated and treated, were  
136 statically compacted by static axial compression in a cylindrical mold to the target dry density (Table 2)  
137 (European standard, 2005). The initial height of the samples was 70 mm with a diameter of 35 mm. After

138 treatment and compaction, the soil specimens were sealed in airtight bags and cured at 20°C during a  
139 period of 90 days prior to use.

### 140 **2.3. Wetting and drying protocols**

141 Two experimental protocols were employed to impose the wetting and drying cycles. The first one is  
142 derived from the ASTM 559 standard. Samples, after the selected curing period, were successively  
143 immersed in demineralised water for two days, and then oven dried at 60°C for another two days in an  
144 oven. This method is denoted AG in the remaining of the paper.

145 The second method employed a climatic chamber (SECASI technologies SH-600 ©) to impose the drying  
146 phase to the sample under a relative humidity of 54 % and a temperature of 20°C. This humidity was  
147 selected as it corresponds to the mean relative humidity than can be reached in summer in the Northern  
148 part of France. The wetting phase was applied by capillary rise: the samples were placed over a porous  
149 stone in contact with demineralised water. The samples were placed in a closed chamber, the temperature  
150 being maintained at 20°C and the relative humidity of the chamber close to saturation. To ensure  
151 homogeneity of the samples, they were periodically turned back during the wetting phase. One wetting  
152 and drying cycle lasted approximately 25 days. This method is denoted HR in the remaining of the paper.  
153 The temperature was kept at 20°C for the different phases to avoid any impact of temperature modification  
154 on the long term behaviour of the samples with that protocol.

155 In both cases, the mass of the samples was checked at the end of each phase and their dimensions  
156 measured. The moisture content of the samples at the end of each wetting and each drying phases was  
157 estimated. Only samples without a dry mass loss lower than 5% compared to the initial state were  
158 employed for strength and permeability analysis. The performances were determined up to 12 wetting  
159 and drying cycles.

## 160 2.4. Determination of mechanical and hydraulic characteristics

161 Unconfined compressive strength UCS was determined with a displacement rate of  $1.04 \text{ mm}\cdot\text{min}^{-1}$ . For  
162 each combination of parameters, three samples were tested. The results provided are the mean of these  
163 three values.

164 Saturated hydraulic conductivity was determined in flexible wall permeameters connected to three  
165 pressure volume controllers installed in a temperature-controlled room. This technique was used to limit  
166 preferential flow paths along the sample, especially after the wetting and drying cycles. The protocol  
167 developed to ensure full saturation of the samples is described in Table 3. The inflow and outflow were  
168 also carefully monitored. The final degree of saturation, after the test, was determined and was always  
169 higher than 98.5 %. More details about the protocol can be found in (Mehenni, 2015). One complete  
170 hydraulic conductivity determination test lasted about a month.

171 The impact of the wetting and drying cycles was quantified relatively to the performances of the treated  
172 soil cured at constant water content, without being exposed to wetting and drying cycles and kept up to  
173 300 days at constant temperature, wrapped in plastic to avoid any loss or gain of water exchange with  
174 the atmosphere.

175 This comparison must take into account the time required to impose the different cycles since 4 days are  
176 required for the method AG while 25 days are necessary for HR method (Figure 1). Therefore, the results  
177 will be plotted as a function of the time elapsed since the compaction of the samples.

## 178 3. Impact of the wetting and drying cycles on the sample strength

179 This section is dedicated to the presentation of the impact of the wetting and drying cycles on the strength  
180 of the samples.

### 181 3.1. Untreated soil

182 The first test series was performed on the untreated soil samples, as a reference (Figure 2). In the case  
183 of the AG cycles, the samples were destroyed during the first cycle without the possibility to perform the  
184 mechanical tests. A slight reduction of the UCS of the untreated silt can be evidenced after the imposition

185 of the cycles with the method HR. After 12 cycles the UCS was 121 kPa, the mean water content of the  
186 samples at the time of testing being equal to  $17.5 \pm 1$  %, comparable to the initial moisture content of the  
187 samples (Table 2). Thus, the strength of the untreated soil after the cycles is of the same order of  
188 magnitude as the strength of the samples not submitted to wetting and drying cycles. Therefore, the  
189 impact of the wetting and drying cycles imposed with the HR method is limited.

### 190 3.2. Lime-treated samples

191 Samples treated with 1 % of quicklime were submitted to the wetting and drying cycles after 90 days of  
192 curing at 20°C in hermetically sealed bags. During this curing period, strength increased from 200 kPa,  
193 one day after compaction up to 340 kPa after 90 days (Figure 3). The imposition of wetting and drying  
194 cycles with the AG method resulted in the destruction of the samples after the first cycle. The first cycles  
195 with the HR method induced a progressive decrease of the performance of the-treated soil. It remained  
196 stable between 6 and 12 cycles. The final strength was of the same order of magnitude as the UCS after  
197 1 day of curing. The strength after 12 cycles can be compared to the strength of the sample cured for 300  
198 days. The HR cycles reduced by a factor of 50% the strength of the treated soil. It should be noted that  
199 the samples evidenced no external signs of degradation after the cycles under these conditions.

200 In the case of the samples treated with 3 % of quicklime, the strength increased from about 250 kPa one  
201 day after compaction up to about 700 kPa after 300 days without cycles (Figure 4). The AG cycles led to  
202 an important decrease of the strength after 1 cycles. The HR method is associated to a significant  
203 decrease of the strength up to 3 cycles, subsequent cycles did not impact significantly the strength of the  
204 stabilised silt. The loss of strength after 12 cycles is about 60 % compared to the sample not submitted to  
205 wetting and drying and stored for 300 days at constant temperature.

### 206 3.3. Cement-treated samples

207 The impact of the accumulation of wetting and drying cycles on the samples treated with 3 % of cement  
208 is plotted in Figure 5. The AG cycles induced a progressive continuous decrease of the strength. It was  
209 not possible to test the samples after 7 cycles since they were extensively degraded. The HR cycles led

210 to a progressive decrease of the strength of the samples, with a stabilisation of the performance after 3  
211 cycles of wetting and drying. Compared to the sample stored 300 days without cycles, 12 HR cycles  
212 induced a loss of performance of the cement-treated soil of about 50 %. Similar trends were obtained with  
213 the samples treated with 6 % of cement (Figure 6). However, in the case of the AG cycles, the strength  
214 of the samples reached a stable value after 12 cycles. The cycles induced a reduction by a factor of 2 of  
215 the performance of the soil compared to the reference. HR cycles lead to a progressive decrease of the  
216 strength down to 750 kPa after 12 cycles, corresponding to a reduction of about 50 % of the strength of  
217 the cement-treated soil.

#### 218 **4. Impact of the wetting drying cycles on the hydraulic conductivity**

219 This section is dedicated to the presentation of the hydraulic conductivity results.

##### 220 **4.1. Untreated soil**

221 The hydraulic conductivity of the untreated soil increased from  $6.0 \times 10^{-09}$  m/s up to  $5.0 \times 10^{-08}$  m/s after  
222 the imposition of 6 HR cycles, corresponding to about one order of magnitude (Figure 7). The hydraulic  
223 conductivity remained stable between 6 and 12 cycles. It was not possible to determine the hydraulic  
224 conductivity after the AG cycles, the sample being too much damaged even after one cycle of wetting and  
225 drying.

##### 226 **4.2. Lime-treated samples**

227 The hydraulic conductivity of the samples treated with 1% of quicklime was equal to  $9.0 \times 10^{-09}$  m/s, after  
228 90 days of curing, slightly higher than the hydraulic conductivity of the untreated soil (Figure 8). After 300  
229 days of curing, no significant modification of the hydraulic conductivity was observed. The imposition of  
230 the cycles with the HR method led to a progressive increase of the permeability up to  $6.0 \times 10^{-08}$  m/s after  
231 6 cycles, the permeability remained stable between 6 and 12 cycles. After the first cycle with the AG-  
232 method, the results showed an increase of the permeability after the first wetting and drying cycle.  
233 Additional cycles led to a dramatic degradation of the sample, proper measurement of the permeability  
234 being no longer possible.

235 The variation of the hydraulic conductivity of samples treated with 3 % of quicklime as a function of the  
236 number of wetting and drying cycles is plotted in Figure 9. Before the imposition of wetting and drying  
237 cycles, the hydraulic conductivity was equal to  $1.0 \times 10^{-09}$  m/s after 90 days of curing. A dramatic increase  
238 of the hydraulic conductivity up to  $2.0 \times 10^{-07}$  m/s was observed after 6 cycles of wetting and drying  
239 performed with HR method. No loss of mass or modification of dimensions was evidenced during the  
240 cycles. The samples did not exhibit any external sign of damage. With the AG wetting and drying protocol,  
241 an increase of hydraulic conductivity was observed even after the first cycle up to  $4.80 \times 10^{-08}$  m/s, and  
242 remained almost constant after 6 cycles.

#### 243 4.3. Cement-treated samples

244 The hydraulic conductivity of the samples treated with 3 % of cement was equal to  $2,0 \times 10^{-09}$  m/s (Figure  
245 10). The hydraulic conductivity increased progressively by more than one order of magnitude after the  
246 imposition of 12 cycles with the HR method, without any sign of external degradation of the samples. The  
247 wetting and drying cycles with the AG method induced similar increase of the hydraulic conductivity after  
248 6 cycles, up to  $2.1 \times 10^{-08}$  m/s. It was not possible to determine the hydraulic conductivity for a larger  
249 number of cycles because of the degradation of the sample. This degradation might explain the dispersion  
250 in the results that was observed after 3 and 6 cycles.

251 The results obtained with 6% of cement are plotted in Figure 11. After 90 days of curing the hydraulic  
252 conductivity of the treated soil was lower than  $10^{-9}$  m/s. The imposition of the cycles with the HR method  
253 is associated to a progressive increase of the hydraulic conductivity of the treated soil up to  
254  $4.9 \times 10^{-08}$  m/s, after 12 wetting and drying cycles. Similar trend was observed consequently to the  
255 imposition of the cycles with the AG, the hydraulic conductivity was equal to  $2.0 \times 10^{-08}$  m/s after 12  
256 wetting and drying cycles. In both cases, the cycles induced an increase of the permeability without any  
257 significant external degradation of the samples or loss of mass over the cycles.

258 **5. Discussion**

259 The results evidenced a positive relationship between the strength degradation and the relative increase  
260 of hydraulic conductivity, after the wetting and drying cycles, for both AG and HR protocols. On one hand,  
261 it is known that the silty soil micro-structure is dramatically altered by cyclic moisture content modification  
262 (Cuisinier and Laloui, 2004; Koliji et al., 2006; Stoltz et al., 2012), the soil hydraulic conductivity being  
263 directly impacted by these modifications of the micro-structure (Albrecht and Benson, 2001; Romero,  
264 2013; Romero and Simms, 2008). On the other hand, some authors explained the impact of wetting and  
265 drying cycles on the performance of lime-treated samples by a progressive alteration of the soil micro-  
266 structure (Aldood et al., 2014; Consoli et al., 2018; Tang et al., 2011), i.e. the cementation between the  
267 particles. This impact of the cycles on the micro-structure of the soil, might also be connected to the fact  
268 that the samples were initially prepared at a moisture content on the wet side of the optimum moisture  
269 content, to minimise the hydraulic conductivity. Indeed, some authors showed that, for untreated  
270 compacted soils, the higher the water content, the more important the micro-structural modifications  
271 induced by drying (Birle et al., 2008; Chen et al., 2017).

272 The results also allowed to discuss the impact of the wetting and drying protocols as a function of the  
273 treatment product and the dosage. The UCS test results were also plotted as a function of the number of  
274 wetting and drying cycles (Figure 12). The results showed that the AG-cycles tend to induce a significantly  
275 higher degradation of the samples with both lime contents, and with 3% of cement. The difference  
276 between the results obtained with the two types of wetting drying cycles increased progressively with the  
277 number of cycles. Moreover, with the HR method, the results tend to indicate a stabilisation of the  
278 performance after a certain number of wetting and drying cycles. Some authors showed that imposing the  
279 first wetting and drying cycles could induce a significant modification of the microstructure of the soil, the  
280 microstructure remaining constant after subsequent cycles. The extent of the reorganisation, and thus the  
281 modification of the hydromechanical behaviour of the material being a function of the moisture content  
282 (i.e. suction) amplitude (Chen et al., 2018; He et al., 2017). Moreover, the fact that with 6% of cement,

283 the results obtained with two protocols are equivalent should be noted. Optimisation of the treatment  
284 product dosage implies the limitation of the amount of treatment product.. Employing the AG-method may  
285 lead to an underestimation of the long term performance of a treated soil, especially when an optimisation  
286 of the dosage is needed..

## 287 **6. Conclusions**

288 The long term performance of a stabilised compacted soil was studied by its exposition to repeated wetting  
289 and drying cycles employing different protocols. The results showed that the exposure to wetting and  
290 drying cycles with both experimental protocols AG and HR has a negative impact on the strength of a  
291 treated soil as well as on its hydraulic conductivity. Both methods employed for wetting and drying are  
292 able to provide an evaluation of the performance alteration as a function of the number of cycles. However,  
293 the method based on oven drying and full immersion (AG) appeared to be conservative, since it conducted  
294 to the destruction of the samples treated with a smaller amount of treatment product while using the HR  
295 wetting and drying method. The results also showed that the degradation of the strength of the treated  
296 samples due to wetting and drying cycles is associated to an increase of up to two orders of magnitude  
297 of the hydraulic conductivity.

298 This study shows that assessing the impact of wetting and drying cycles on mechanical and hydraulic  
299 behaviour of a stabilised soil is of primary importance since they can induce a dramatic alteration of the  
300 behaviour. The relevance of the experimental protocol employed to reproduce the cycles in the laboratory  
301 must be carefully evaluated since it could lead to over-conservative conclusions, or to the selection of a  
302 higher dosage of treatment products. Additional experiments and analysis are required to better identify  
303 the mechanisms at the origin of the degradation of the performances. These potential weathering  
304 processes should be taken into account in the design of engineering structures including soil treatment.  
305 The impact of the amplitude of the moisture content variation during the wetting and drying cycles should  
306 be investigated to better understand the degradation process.

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466

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## Tables

468 Table 1. Identification characteristics of the soil employed in this study.

Characteristics	Value
Liquid limit (%)	28.5
Plastic limit (%)	20.5
Plasticity index (%)	8.0
Passing sieve 80 $\mu\text{m}$ (%)	99.2
Clay size content (<2 $\mu\text{m}$ ) (%)	6.0
Specific gravity $G_s$ (-)	2.64

469

470 Table 2. Impact of the different treatments on the compaction characteristics of the selected soil.

Type of treatment	Notation	Optimum Proctor compaction characteristics		Compaction characteristics for the tested samples	
		$\rho_{dmax}$	$W_{OMC}$	$\rho_d$	$W$
		(Mg/m <sup>3</sup> )	(%)	(Mg/m <sup>3</sup> )	(%)
Silt	S	1.82	15.0	1.73	17.5
+ 1% lime	SL 1%	1.75	17.5	1.70	20.0
+ 3% lime	SL 3%	1.71	17.5	1.66	20.0
+ 3% cement	SC 3%	1.81	15.0	1.75	17.5
+ 6% cement	SC 6%	1.82	15.0	1.75	17.5

471

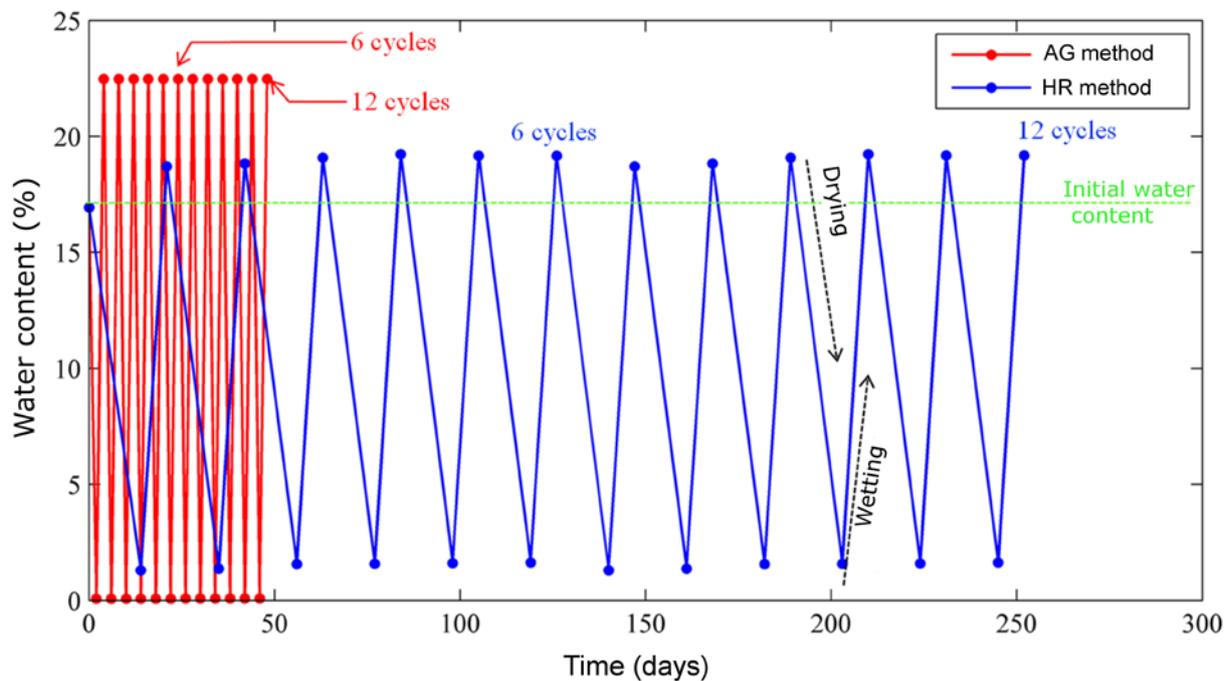
472 Table 3. Saturation protocol for testing the saturated hydraulic conductivity in flexible wall  
 473 permeameter.

Phase	Time	Hydraulic gradient (-)	Base pressure (kPa)	Top pressure (kPa)	Mean confining total stress $\sigma_3$ (kPa)	Mean confining effective stress $\sigma'_3$ (kPa)
1	1 to 3 days	42	30	0	50	35
2	1 week	21	30	20	50	25
3	1 week	21	80	70	100	25
4	1 week	21	180	170	200	25

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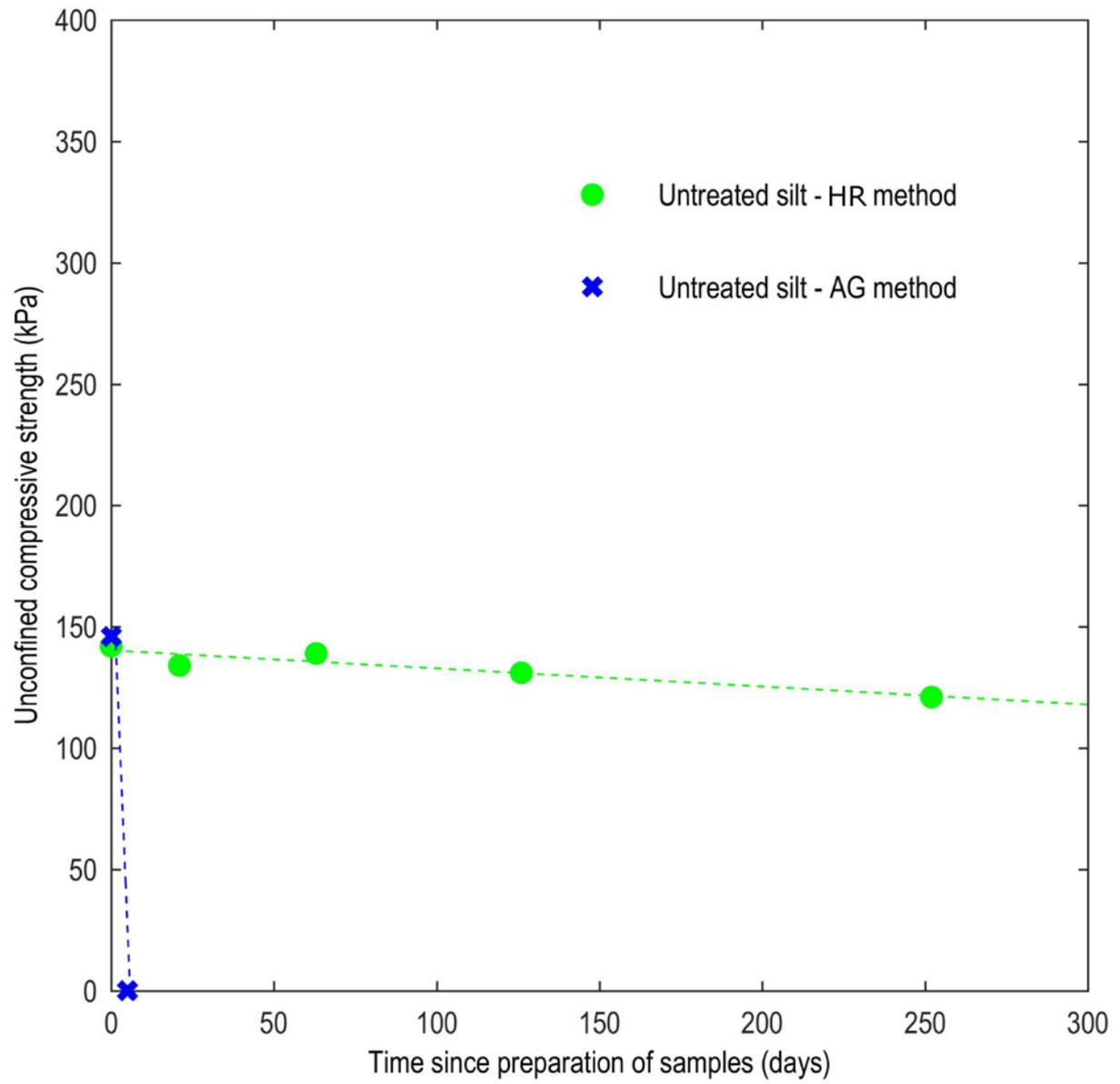
### FIGURES



476

477 Figure 1. Time duration of the different experiments as a function of the wetting and drying protocol.

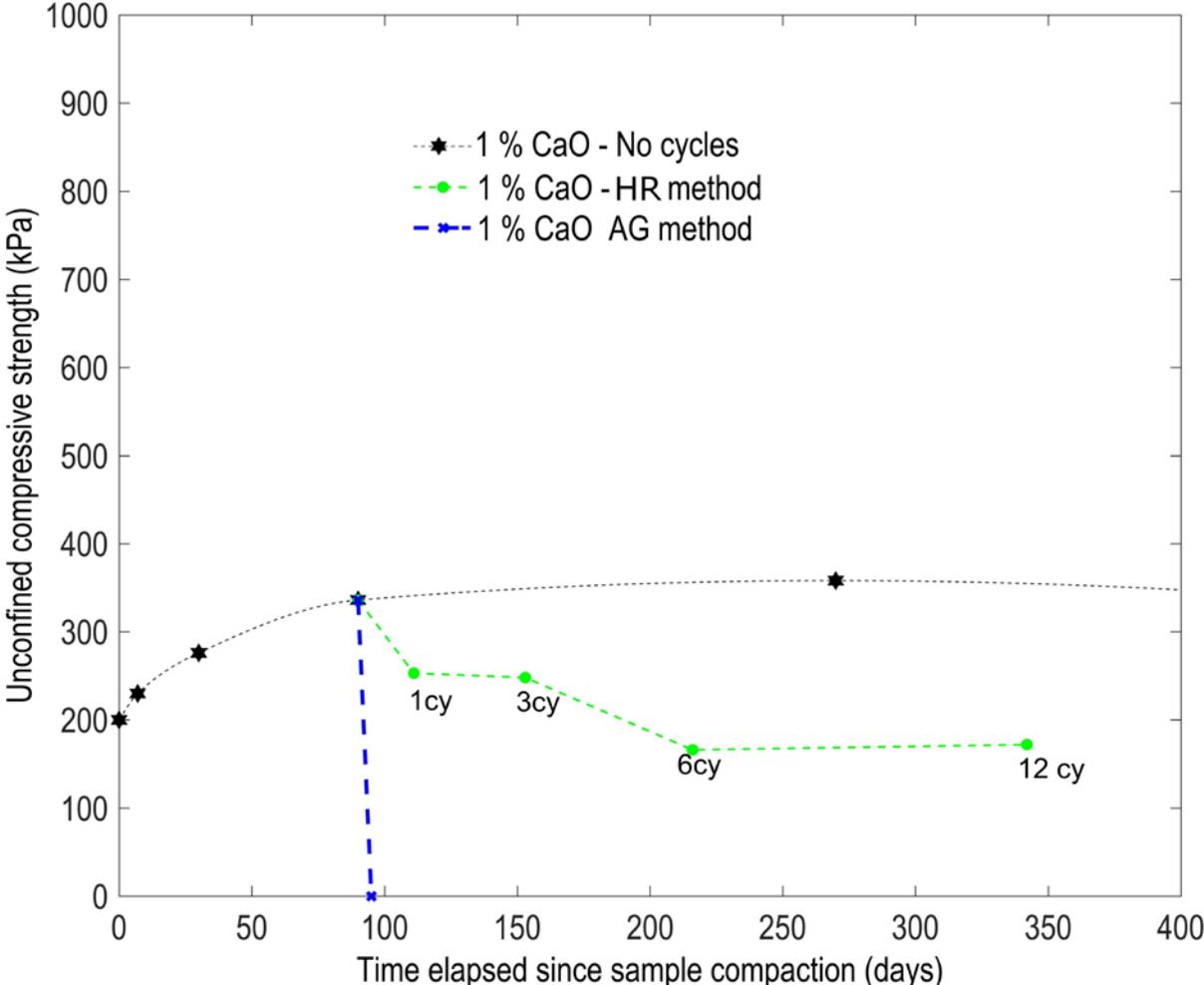
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480 Figure 2. Impact of the wetting and drying cycles on the strength of the untreated soil.

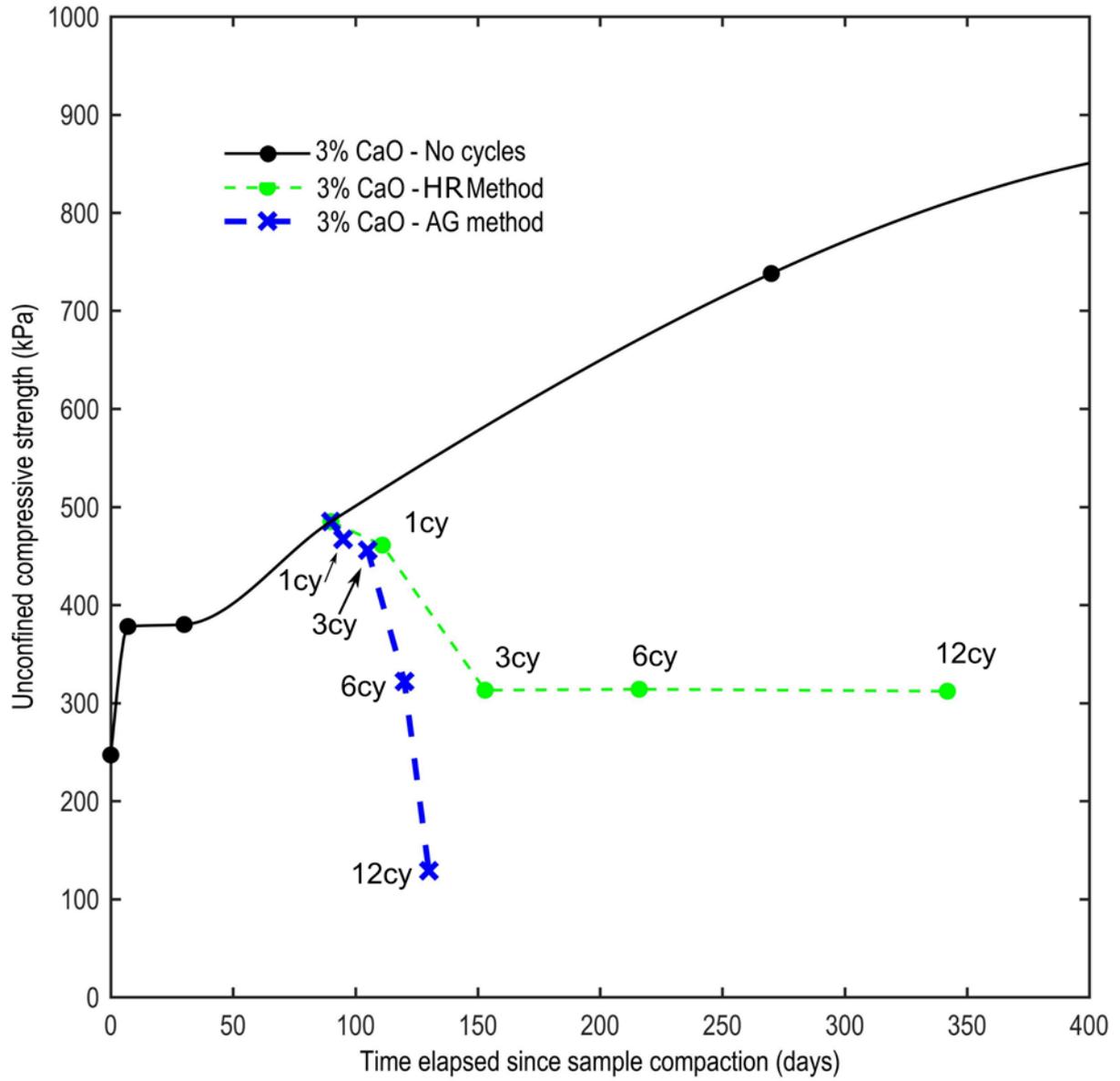
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482

483 Figure 3. Impact of the wetting/drying cycles on the UCS of samples treated with 1 % of quicklime.

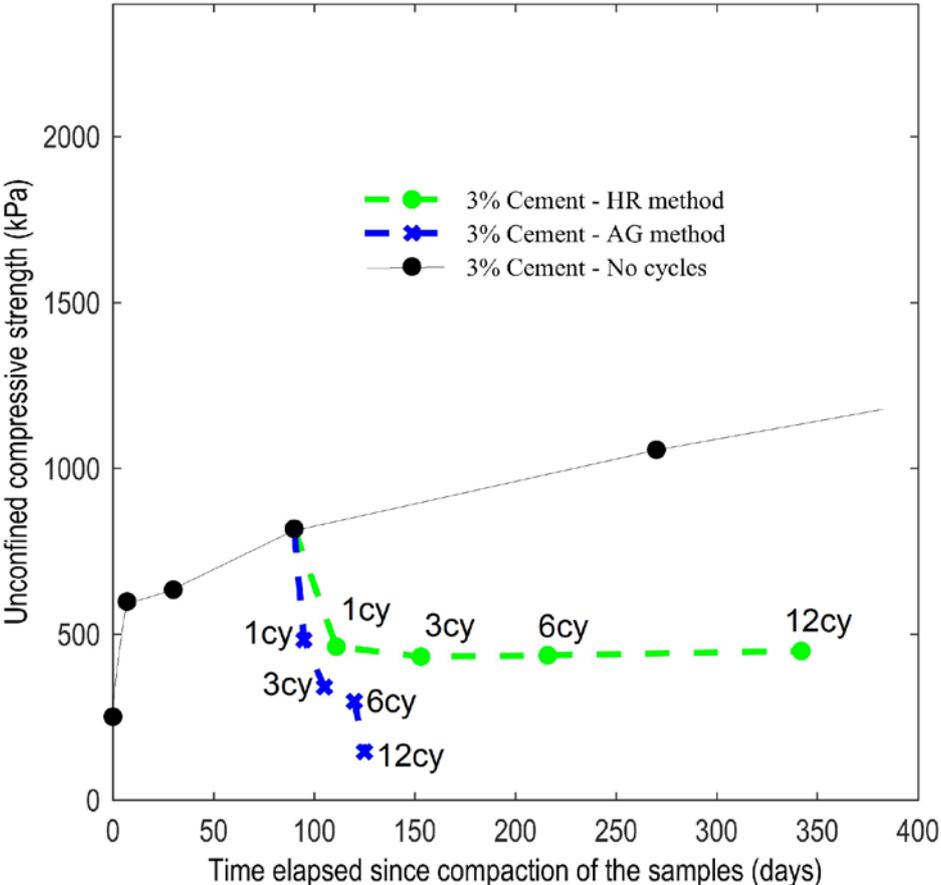
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485

486 Figure 4. Impact of the wetting/drying cycles on the UCS of samples treated with 3 % of quicklime.

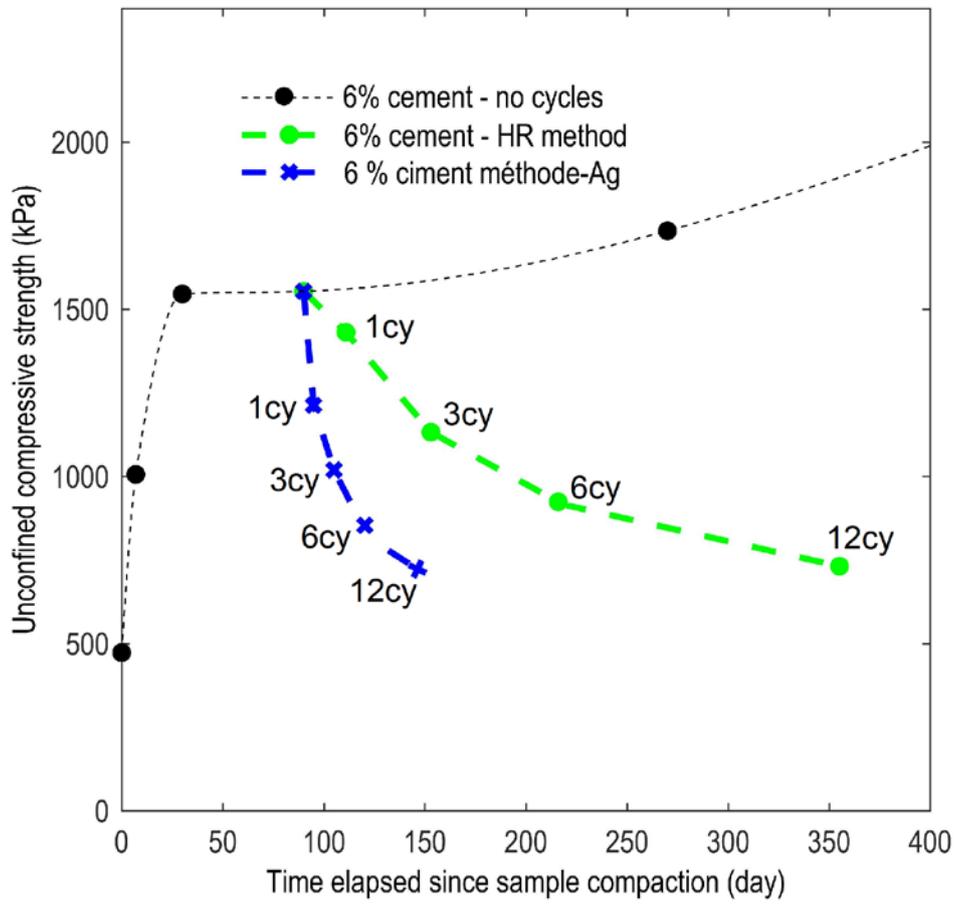
487



488

489 Figure 5. Impact of the wetting/drying cycles on the UCS of samples treated with 3 % of cement.

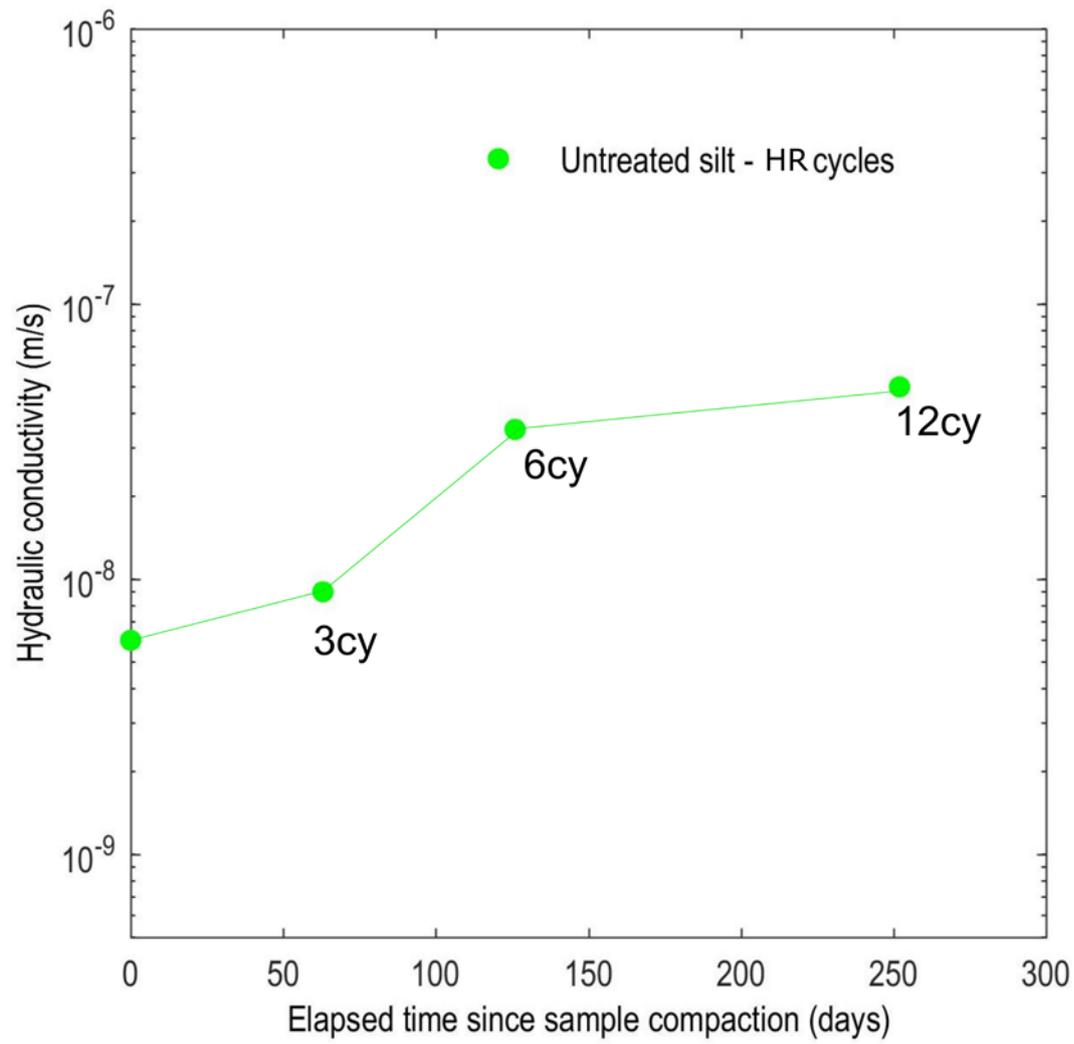
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491

492 Figure 6. Impact of the wetting/drying cycles on the UCS of samples treated with 6 % of cement.

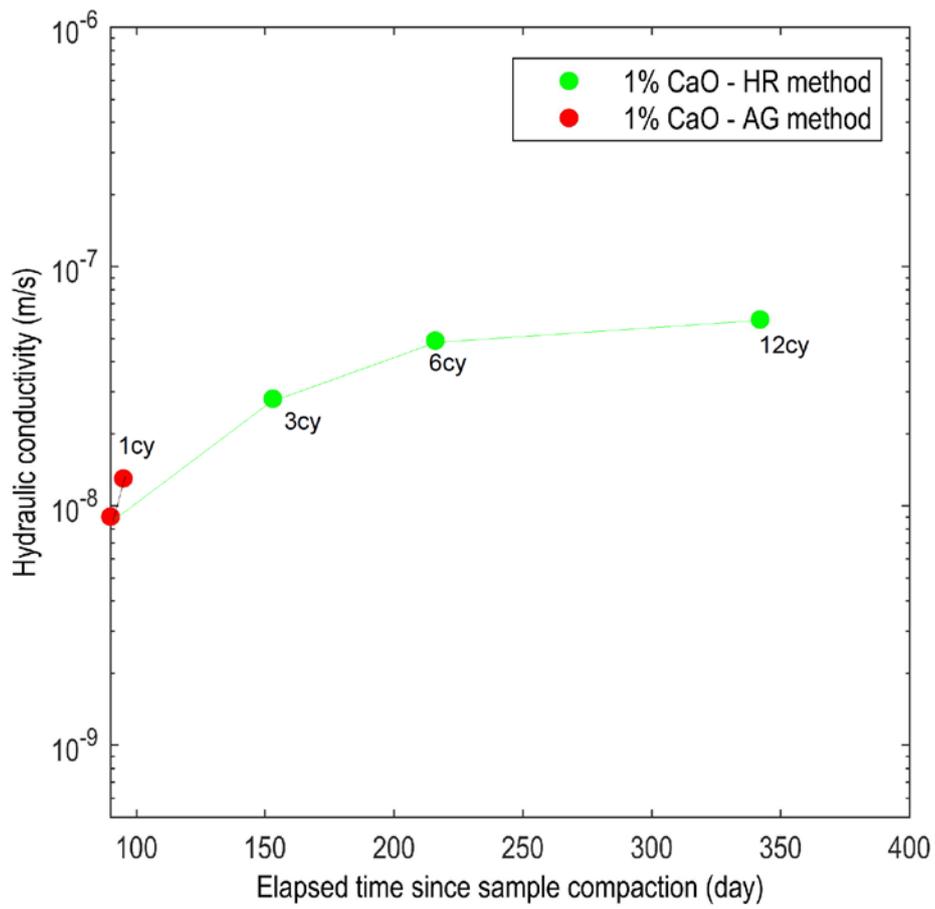
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495 Figure 7. Impact of wetting and drying cycles on saturated hydraulic conductivity of the untreated silt.

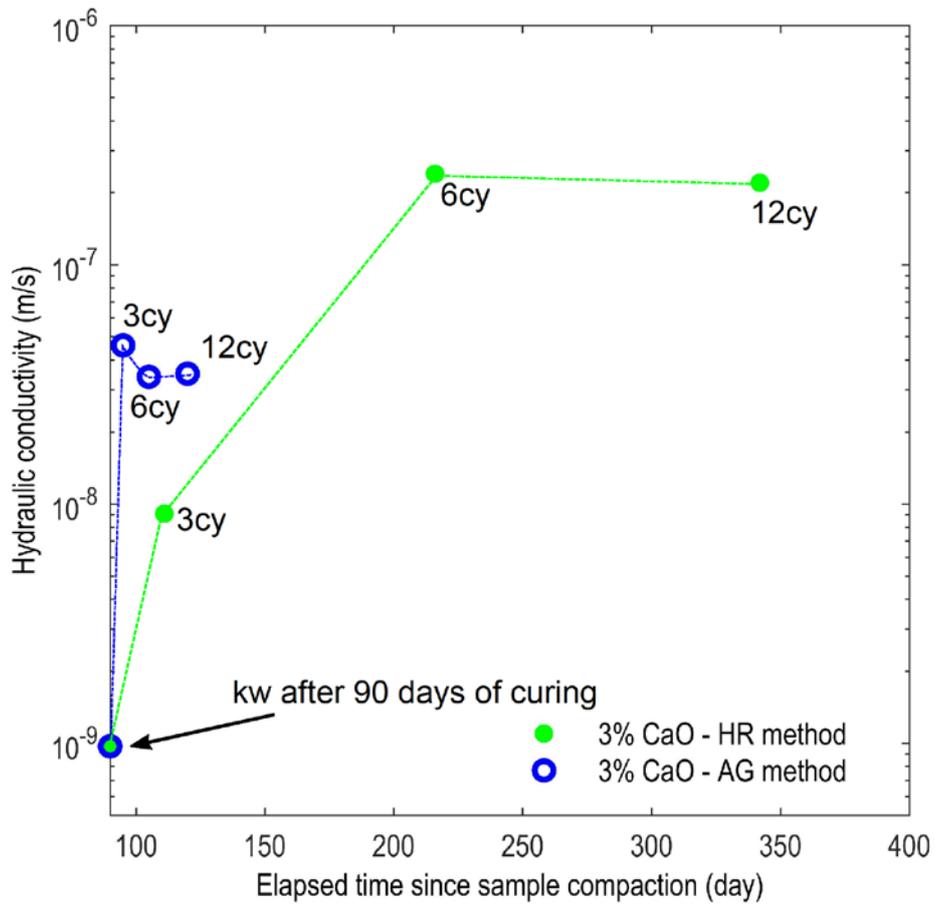
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498 Figure 8. Impact of wetting and drying cycles on saturated hydraulic conductivity of the silt treated with  
499 1% of quicklime.

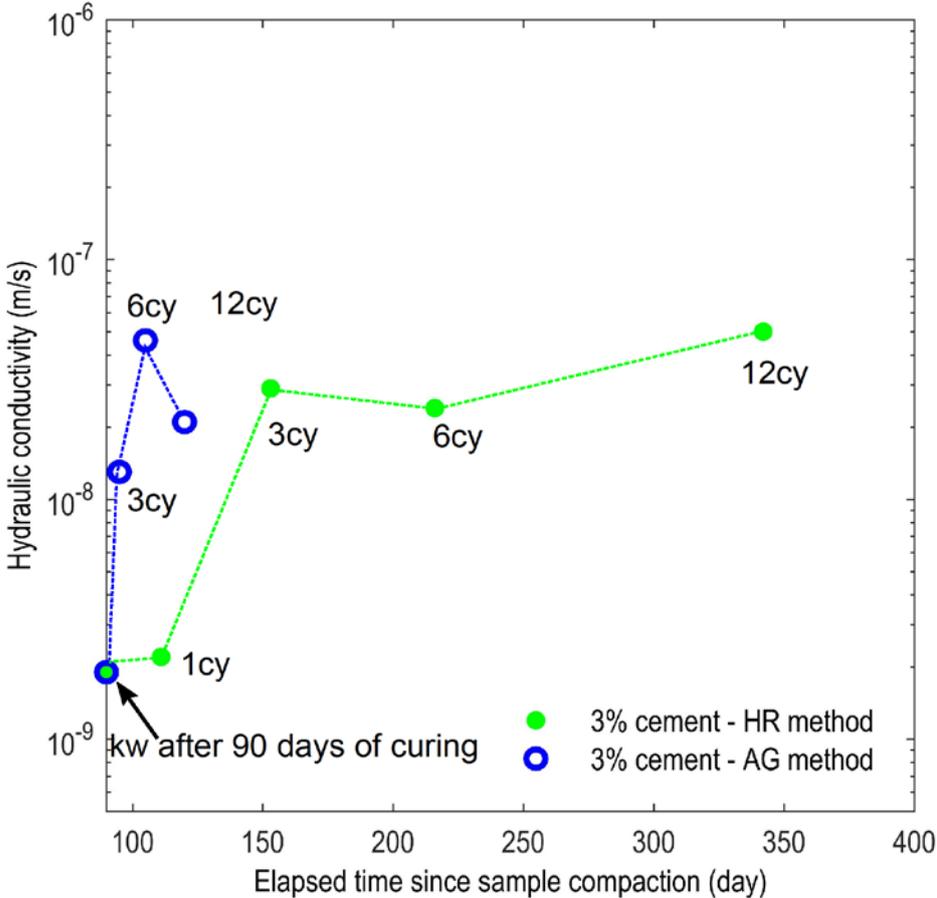
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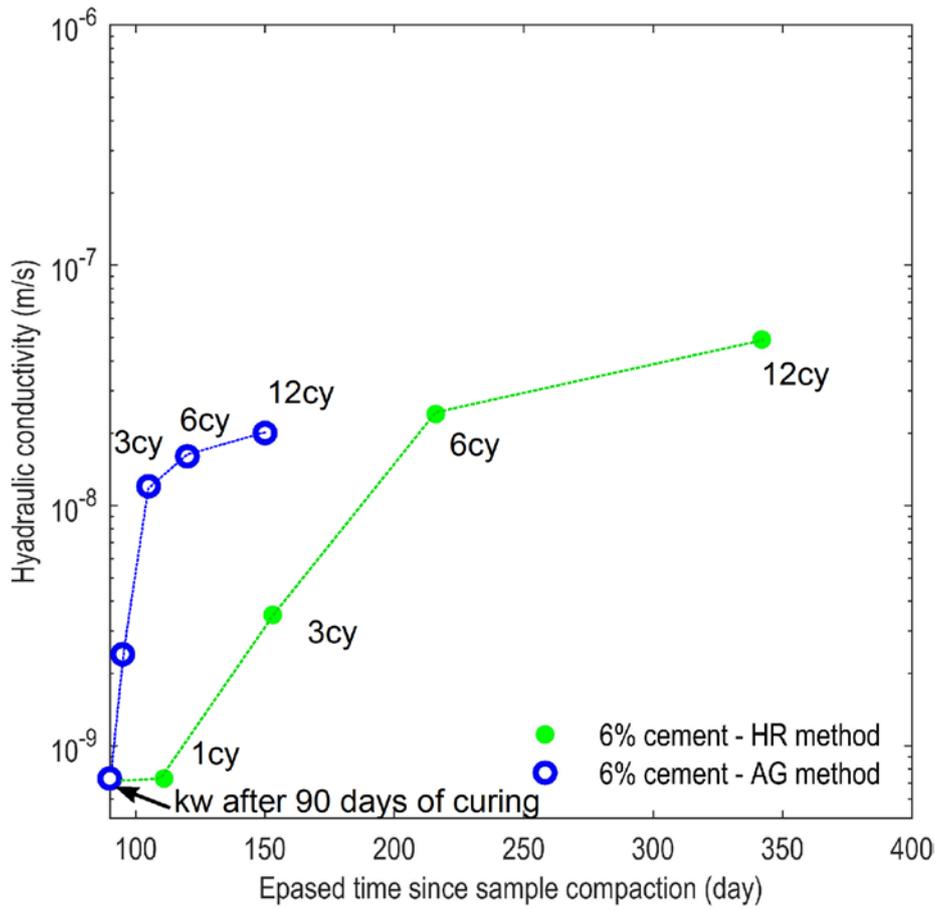
501

502 Figure 9. Impact of wetting and drying cycles on saturated hydraulic conductivity of the silt treated with  
 503 3% of quicklime.

504



505  
506 Figure 10. Impact of wetting and drying cycles on saturated hydraulic conductivity of the silt treated with  
507 3% of cement.  
508

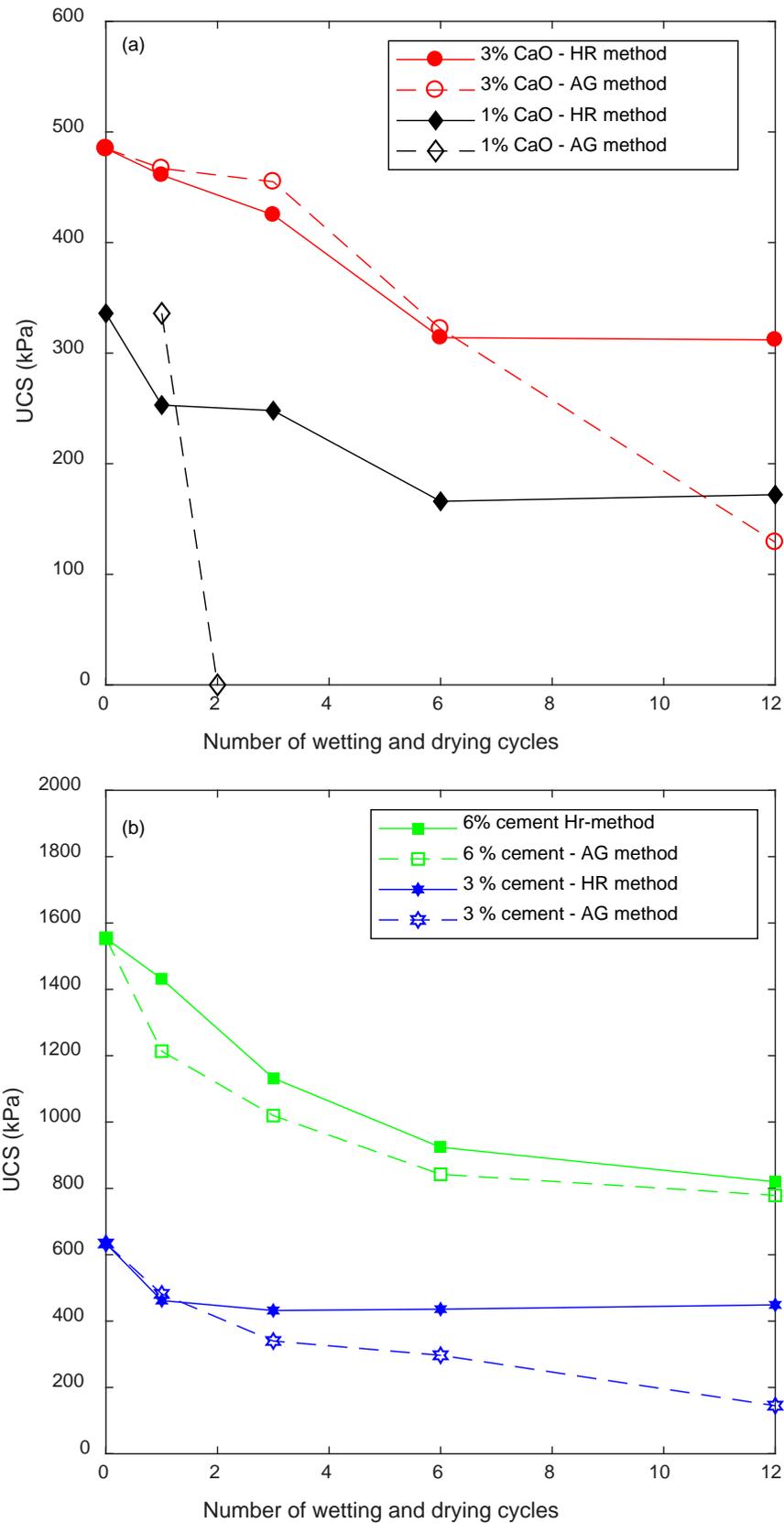


509

510 Figure 11. Impact of wetting and drying cycles on saturated hydraulic conductivity of the silt treated with

511

6% of cement.



512

513 Figure 12. Degradation of strength as a function of the number of wetting and drying cycles for (a) lime-

514 treated samples and (b) cement treated samples.