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# Alteration of the Hydromechanical Performances of a Stabilized Compacted Soil Exposed to Successive Wetting–Drying Cycles — Source link

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

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# ABSTRACT

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

**Keywords:**

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

## 1. Introduction

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

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

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

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

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

## 2. Materials and experimental setup

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

### 2.1. Materials

The soil selected to perform this study was sampled in Northern France. The main characteristics are provided in Table 1. The mineralogical composition of the untreated soil was evaluated using X-ray diffraction. The results showed that the soil is mainly composed of quartz and feldspars, its clay fraction being composed of illite and kaolinite with a significant amount of interstratified illite and smectite minerals (Mehenni, 2015). The soil can be classified as CL according ASTM standard D2487, or A2 according the French classification system (LCPC–SETRA, 2000).

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

**2.2. Samples preparation**

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

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

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

The soil samples employed for strength and permeability determination, untreated and treated, were statically compacted by static axial compression in a cylindrical mold to the target dry density (Table 2) (European standard, 2005). The initial height of the samples was 70 mm with a diameter of 35 mm. After treatment and compaction, the soil specimens were sealed in airtight bags and cured at 20°C during a period of 90 days prior to use.

### 2.3. Wetting and drying protocols

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

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

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

### 2.4. Determination of mechanical and hydraulic characteristics

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

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

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

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

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

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

### 3.1. Untreated soil

The first test series was performed on the untreated soil samples, as a reference (Figure 2). In the case of the AG cycles, the samples were destroyed during the first cycle without the possibility to perform the mechanical tests. A slight reduction of the UCS of the untreated silt can be evidenced after the imposition of the cycles with the method HR. After 12 cycles the UCS was 121 kPa, the mean water content of the samples at the time of testing being equal to 17.5 ± 1 %, comparable to the initial moisture content of the samples (Table 2). Thus, the strength of the untreated soil after the cycles is of the same order of magnitude as the strength of the samples not submitted to wetting and drying cycles. Therefore, the impact of the wetting and drying cycles imposed with the HR method is limited.

### 3.2. Lime-treated samples

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

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

### 3.3. Cement-treated samples

The impact of the accumulation of wetting and drying cycles on the samples treated with 3 % of cement is plotted in Figure 5. The AG cycles induced a progressive continuous decrease of the strength. It was not possible to test the samples after 7 cycles since they were extensively degraded. The HR cycles led to a progressive decrease of the strength of the samples, with a stabilisation of the performance after 3 cycles of wetting and drying. Compared to the sample stored 300 days without cycles, 12 HR cycles induced a loss of performance of the cement-treated soil of about 50 %. Similar trends were obtained with the samples treated with 6 % of cement (Figure 6). However, in the case of the AG cycles, the strength of the samples reached a stable value after 12 cycles. The cycles induced a reduction by a factor of 2 of the performance of the soil compared to the reference. HR cycles lead to a progressive decrease of the strength down to 750 kPa after 12 cycles, corresponding to a reduction of about 50 % of the strength of the cement-treated soil.

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

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

### 4.1. Untreated soil

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 the imposition of 6 HR cycles, corresponding to about one order of magnitude (Figure 7). The hydraulic conductivity remained stable between 6 and 12 cycles. It was not possible to determine the hydraulic conductivity after the AG cycles, the sample being too much damaged even after one cycle of wetting and drying.

### 4.2. Lime-treated samples

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

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

**4.3. Cement-treated samples**

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

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

## 5. Discussion

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

The results also allowed to discuss the impact of the wetting and drying protocols as a function of the treatment product and the dosage. The UCS test results were also plotted as a function of the number of wetting and drying cycles (Figure 12). The results showed that the AG-cycles tend to induce a significantly higher degradation of the samples with both lime contents, and with 3% of cement. The difference between the results obtained with the two types of wetting drying cycles increased progressively with the number of cycles. Moreover, with the HR method, the results tend to indicate a stabilisation of the performance after a certain number of wetting and drying cycles. Some authors showed that imposing the first wetting and drying cycles could induce a significant modification of the microstructure of the soil, the microstructure remaining constant after subsequent cycles. The extent of the reorganisation, and thus the modification of the hydromechanical behaviour of the material being a function of the moisture content (i.e. suction) amplitude (Chen et al., 2018; He et al., 2017). Moreover, the fact that with 6% of cement, the results obtained with two protocols are equivalent should be noted. Optimisation of the treatment product dosage implies the limitation of the amount of treatment product.. Employing the AG-method may lead to an underestimation of the long term performance of a treated soil, especially when an optimisation of the dosage is needed..

## 6. Conclusions

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

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

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# Tables

**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 μm (%) | 99.2 |
| Clay size content (<2 μm) (%) | 6.0 |
| Specific gravity Gs (−) | 2.64 |

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

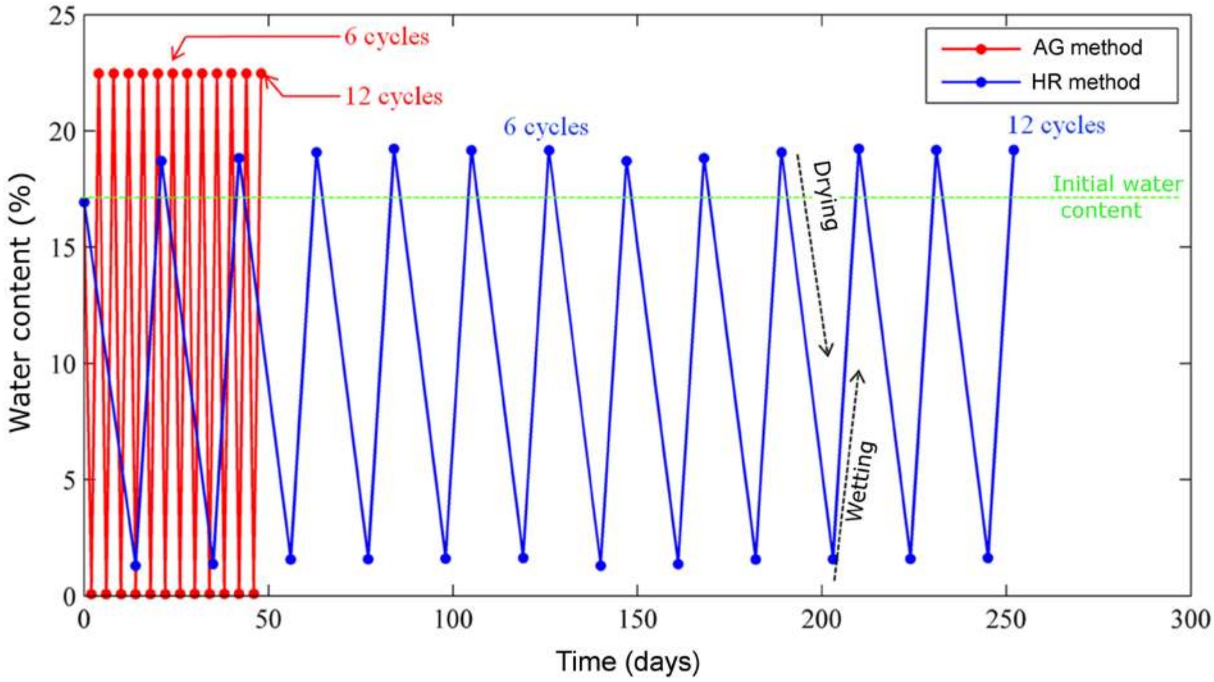
| Type of treatment | Notation | Optimum Proctor compaction characteristics | | Compaction characteristics for the tested samples | |
|---|---|---|---|---|---|
| | | $\rho_{dmax}$ (Mg/m$^3$) | $w_{OMC}$ (%) | $\rho_d$ (Mg/m$^3$) | $w$ (%) |
| Silt | S | 1.82 | 15.0 | 1.73 | 17.5 |
| + 1% lime | SL 1% | 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

**Table 3. Saturation protocol for testing the saturated hydraulic conductivity in flexible wall 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 |

475 # FIGURES




476

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

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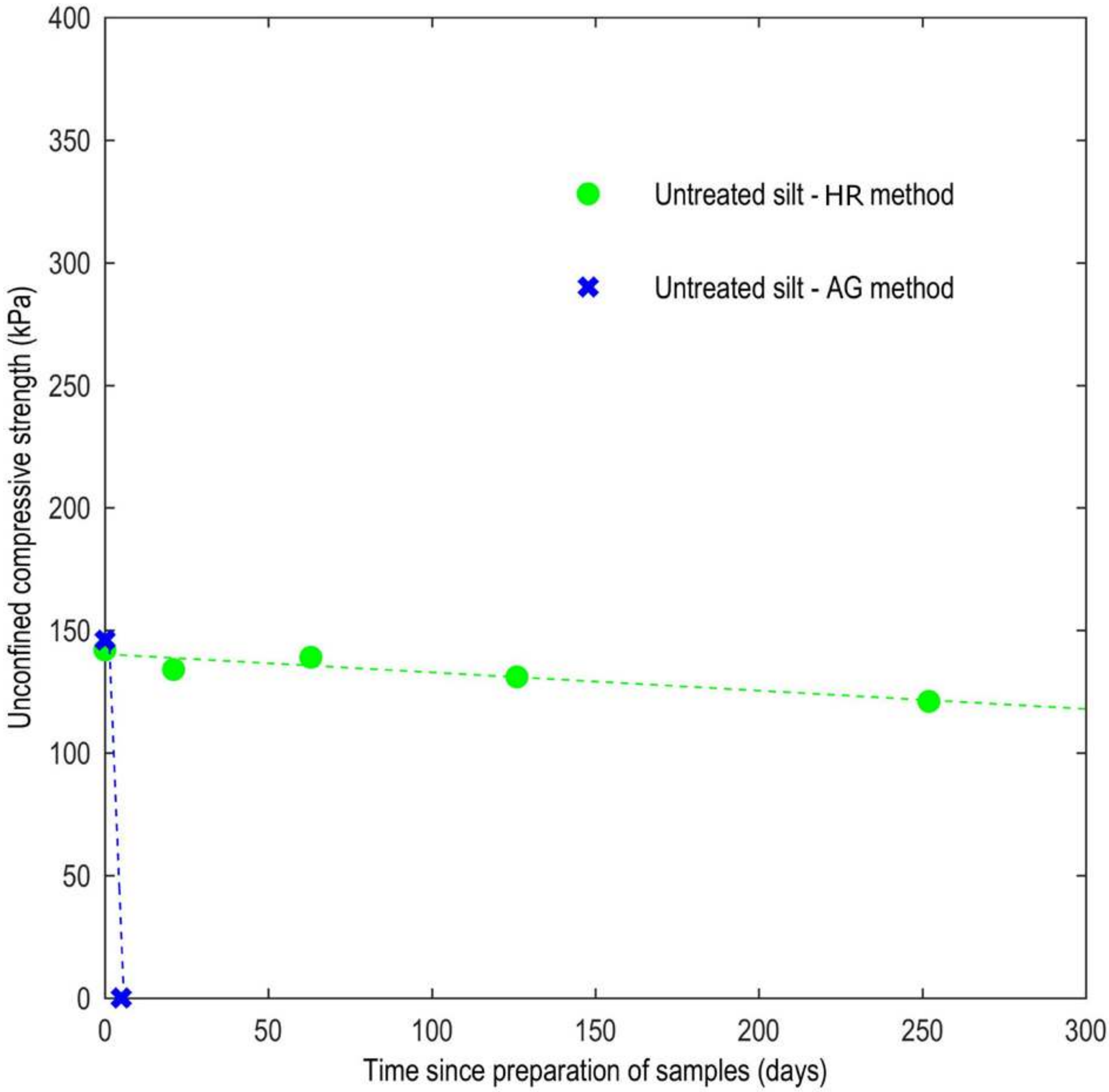


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480 Figure 2. Impact of the wetting and drying cycles on the strength of the untreated soil.

481

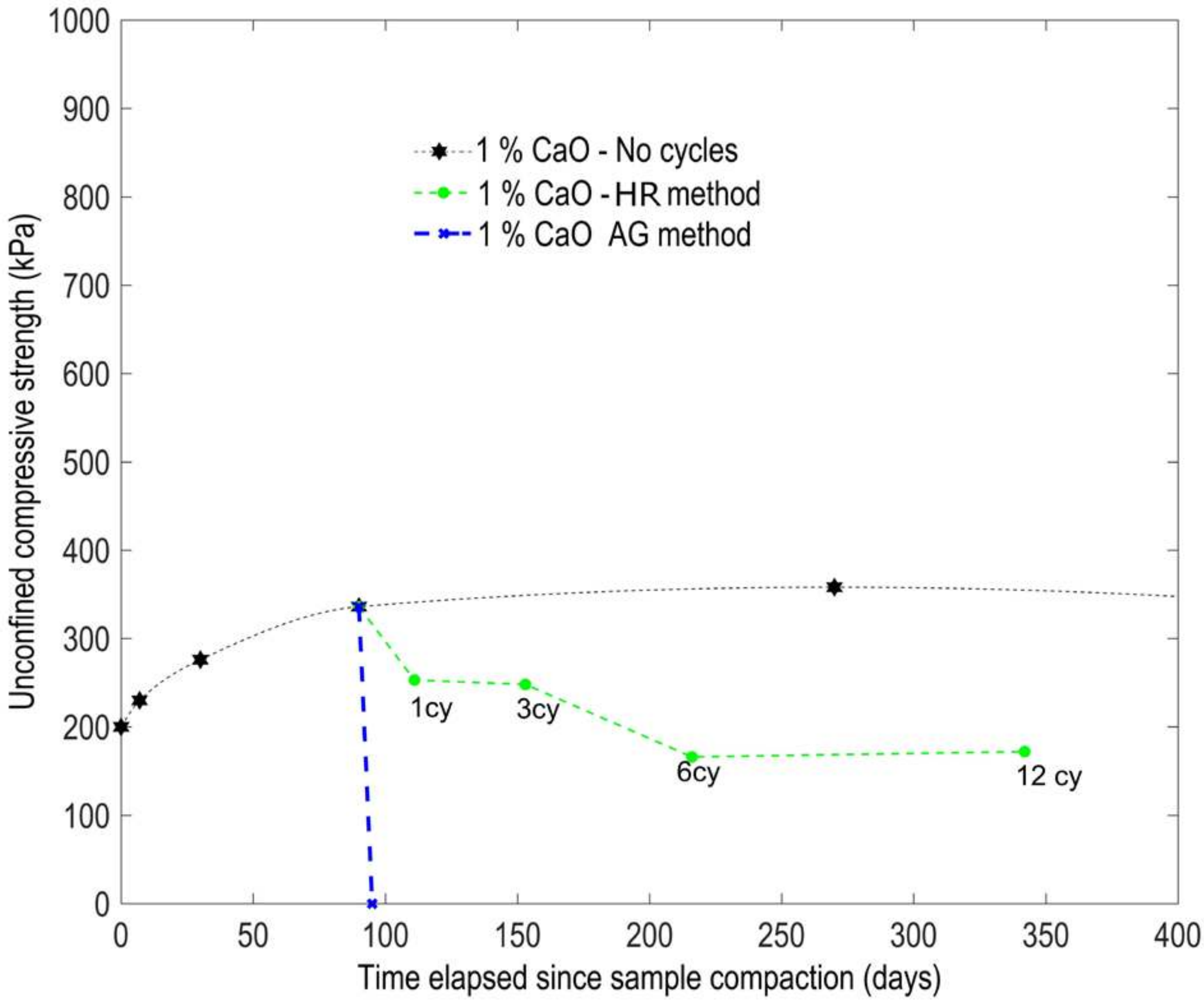



Figure 3. Impact of the wetting/drying cycles on the UCS of samples treated with 1 % of quicklime.

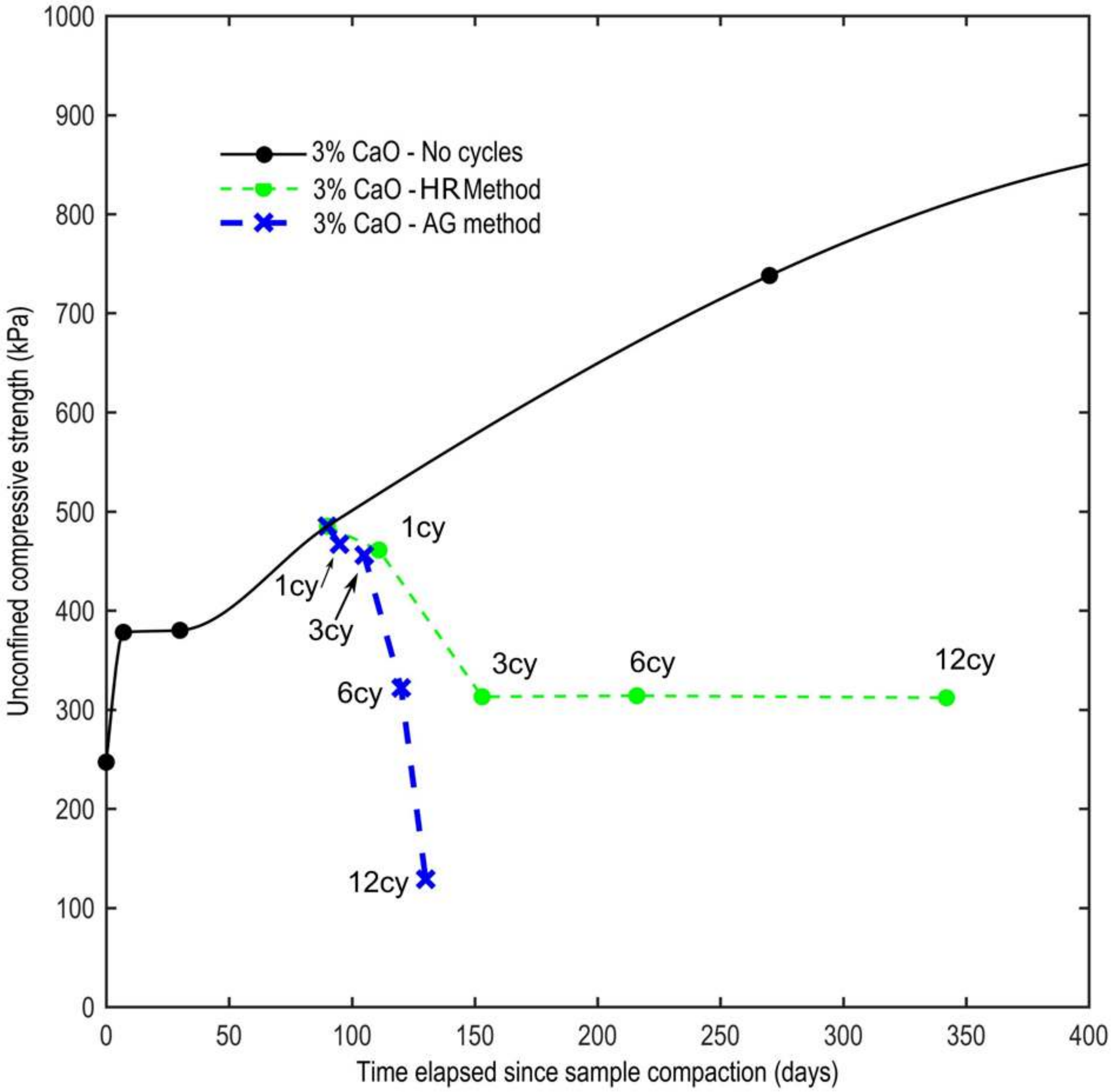
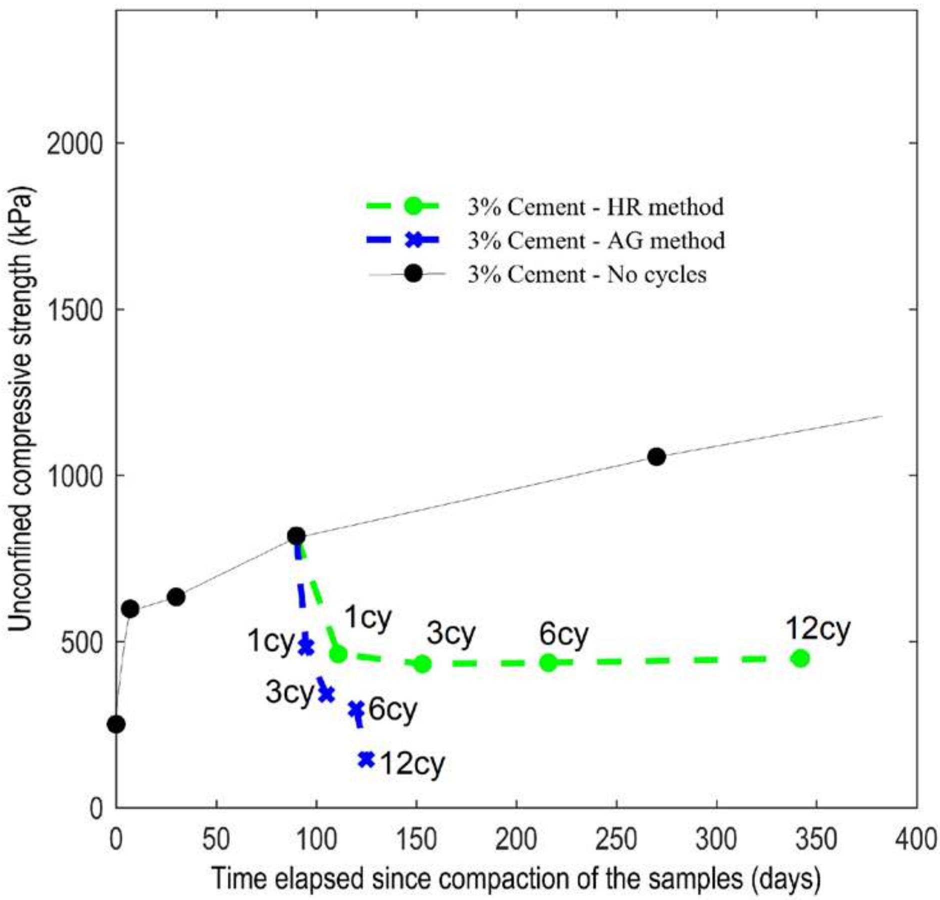



Figure 4. Impact of the wetting/drying cycles on the UCS of samples treated with 3 % of quicklime.

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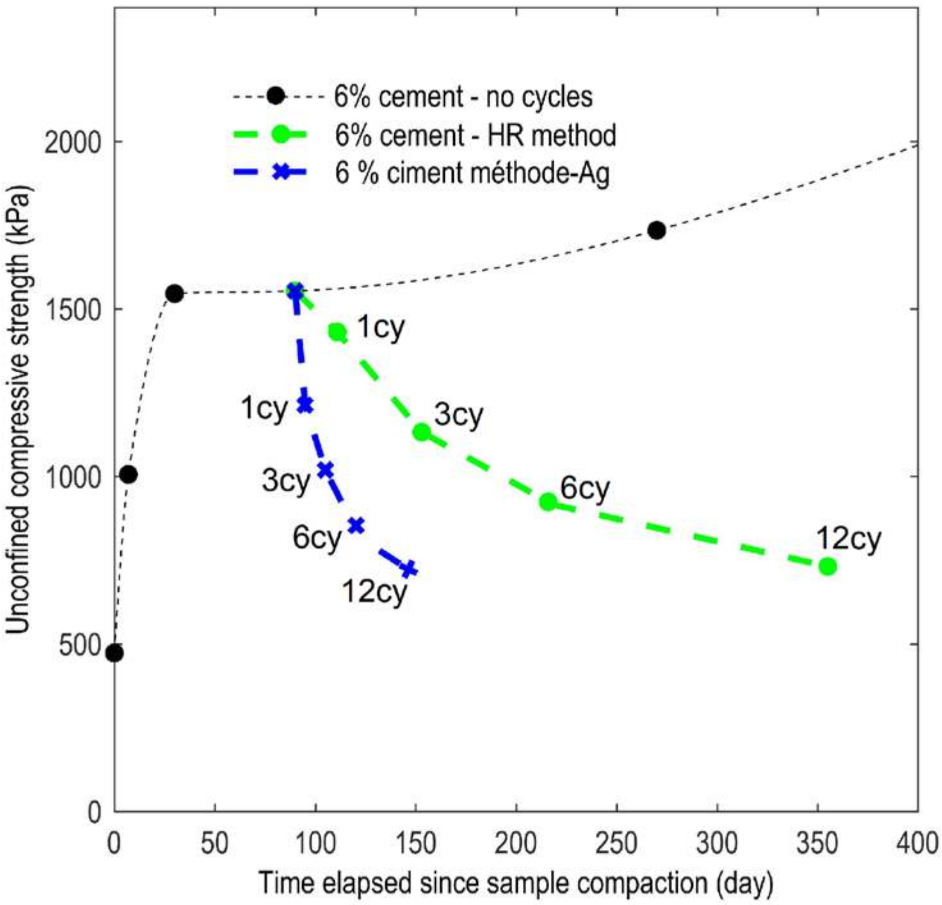
489 Figure 5. Impact of the wetting/drying cycles on the UCS of samples treated with 3 % of cement.

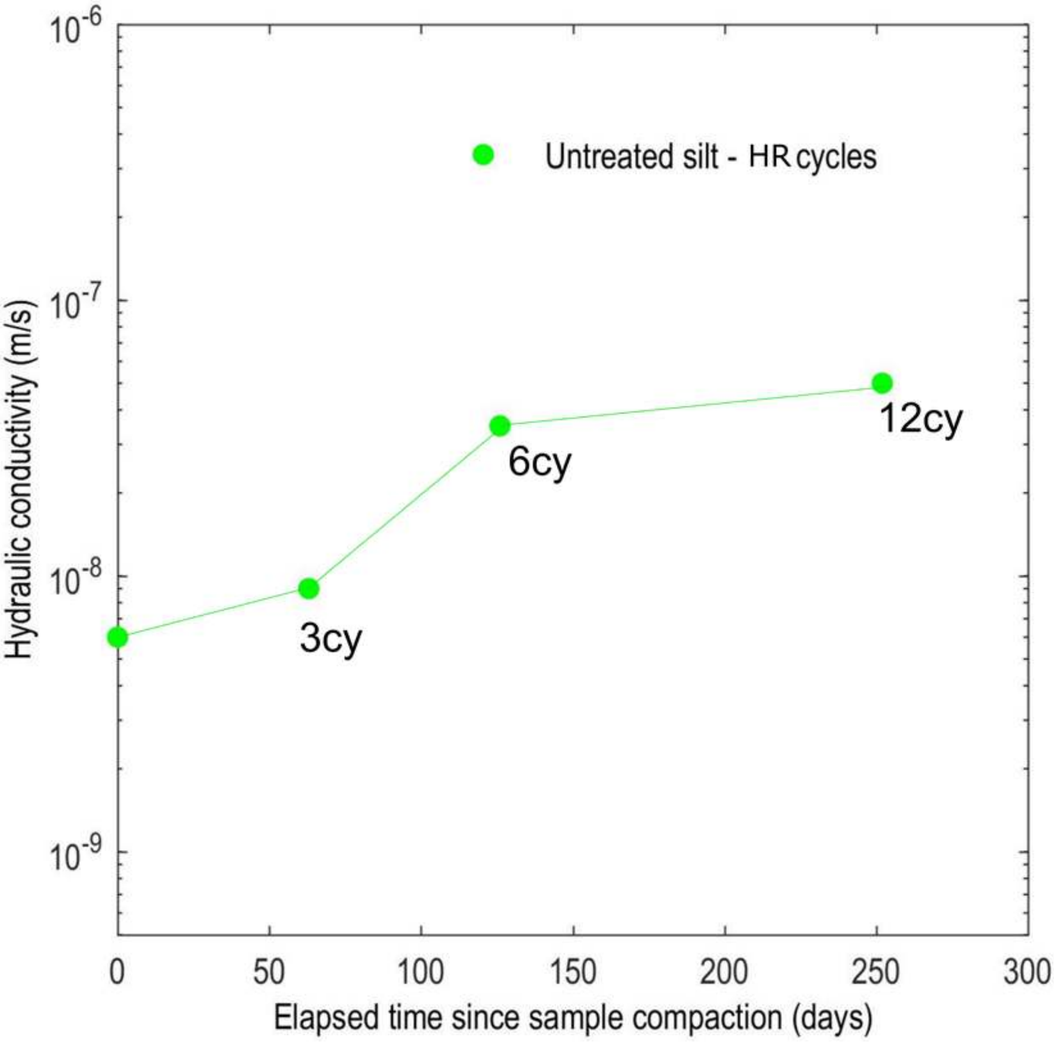
490




491

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

493




494

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

496

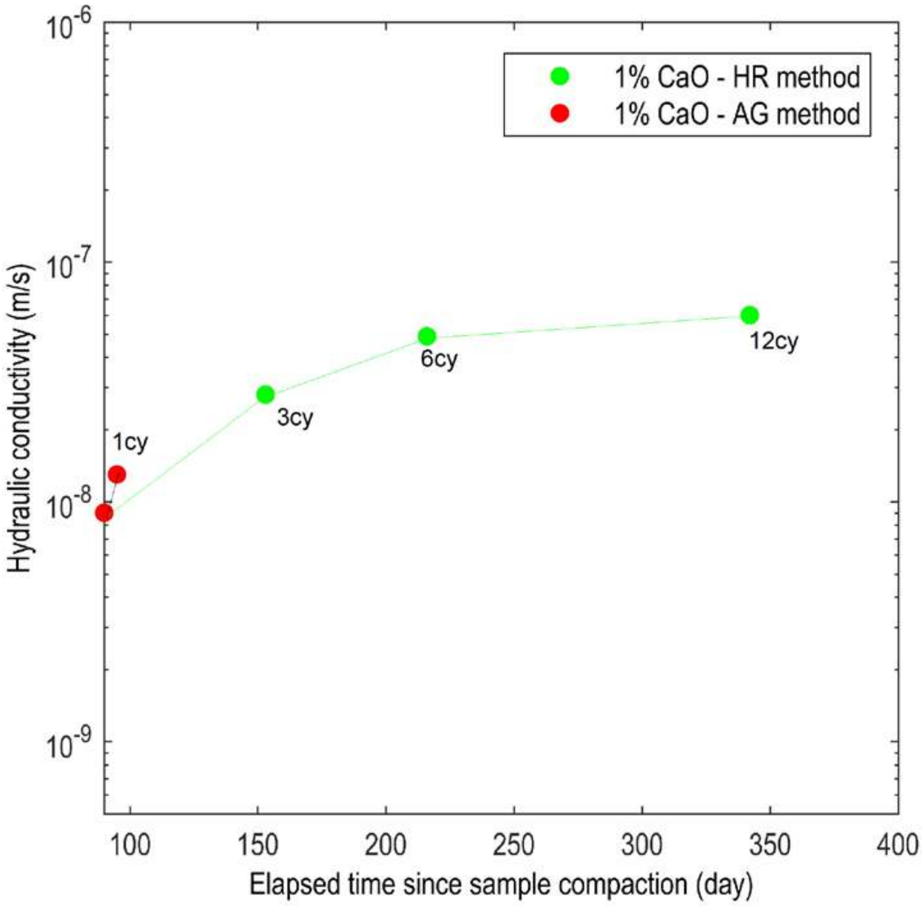



Figure 8. Impact of wetting and drying cycles on saturated hydraulic conductivity of the silt treated with 1% of quicklime.

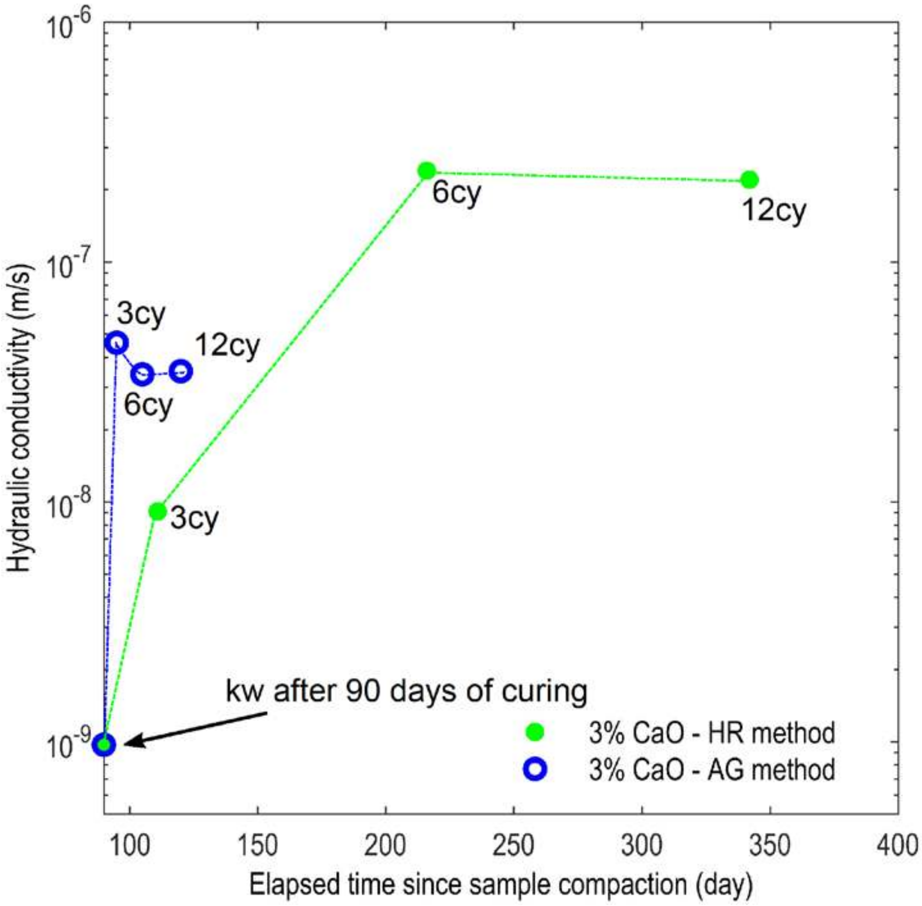



Figure 9. Impact of wetting and drying cycles on saturated hydraulic conductivity of the silt treated with 3% of quicklime.

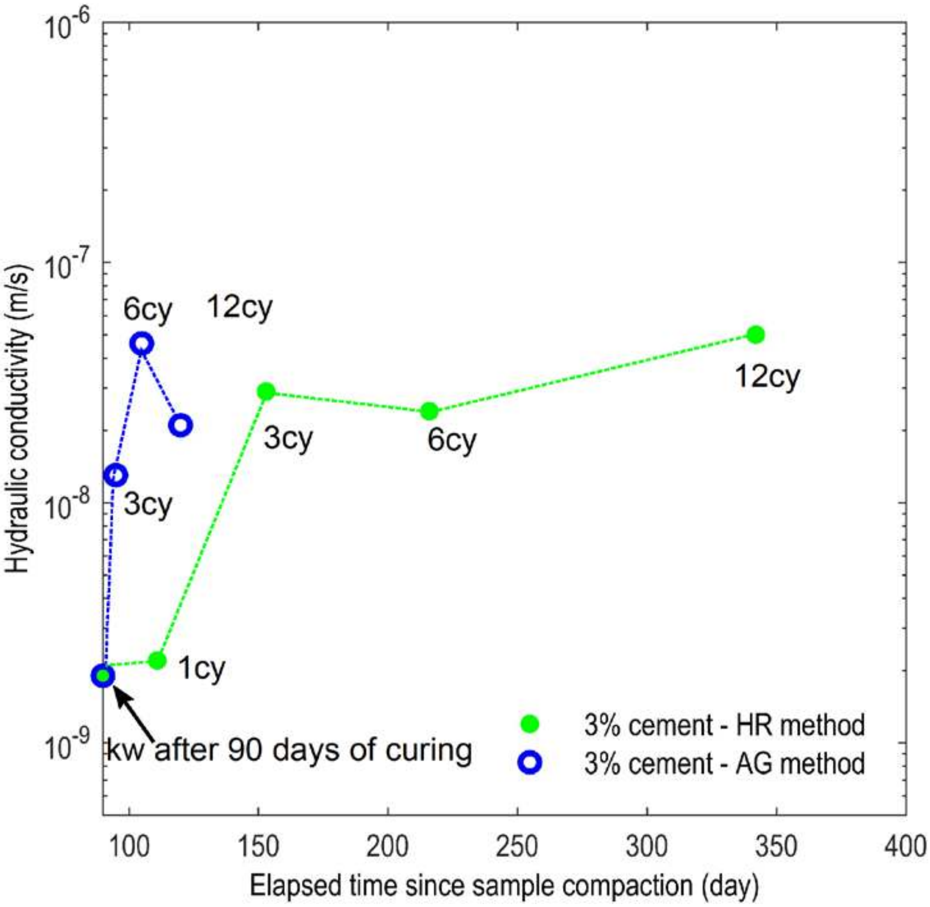



Figure 10. Impact of wetting and drying cycles on saturated hydraulic conductivity of the silt treated with 3% of cement.

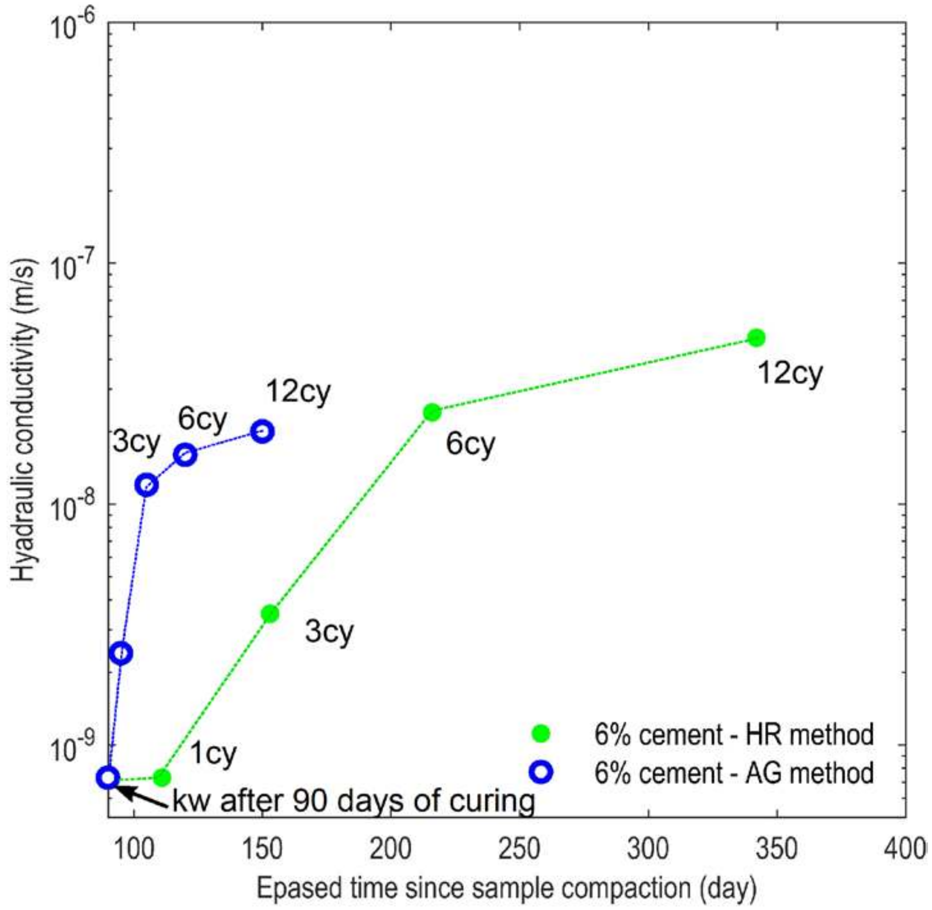



Figure 11. Impact of wetting and drying cycles on saturated hydraulic conductivity of the silt treated with 6% of cement.

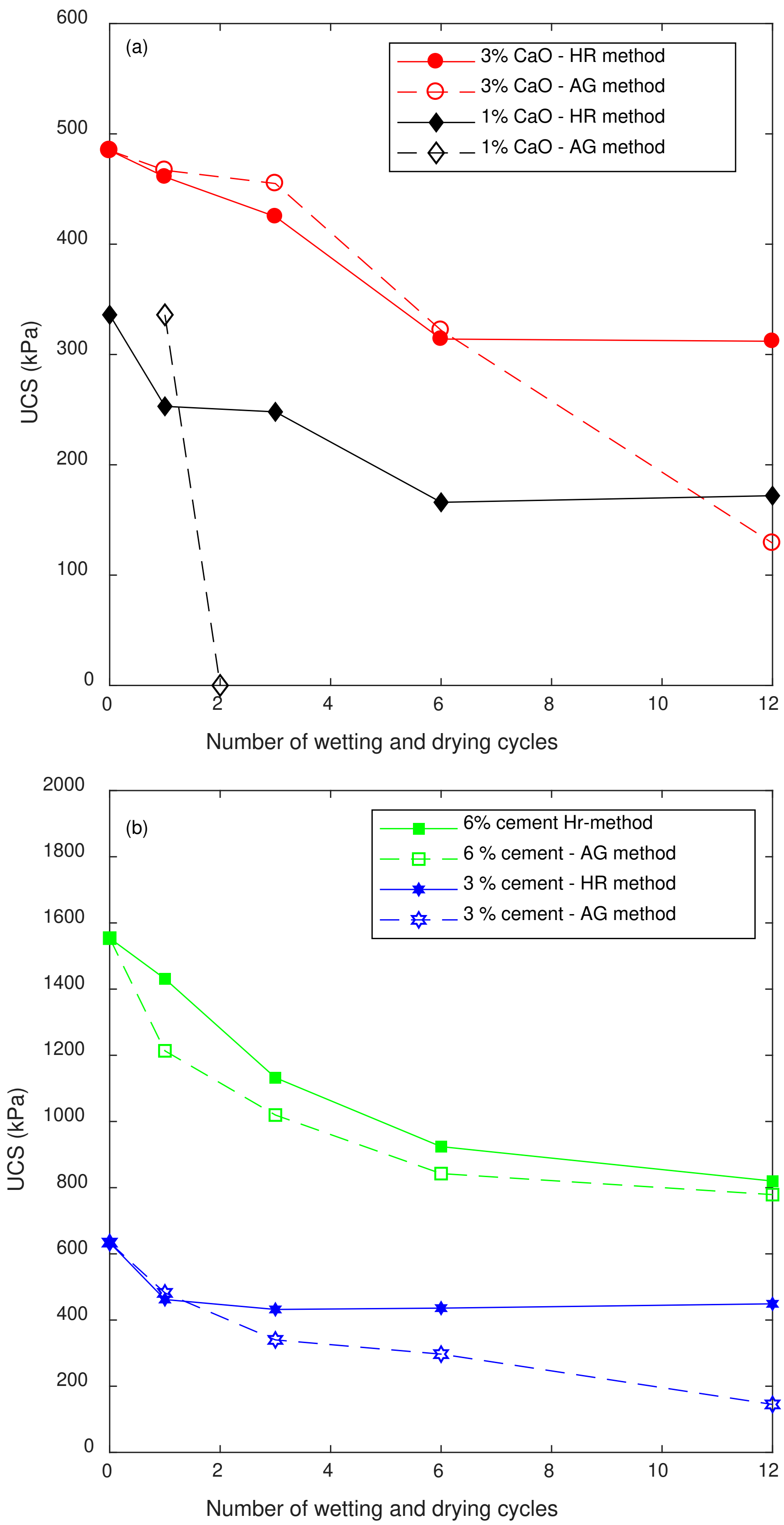



Figure 12. Degradation of strength as a function of the number of wetting and drying cycles for (a) lime-treated samples and (b) cement treated samples.