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1 **Physicochemical and microstructure evaluation in lime-treated silty soil exposed to**  
2 **successive wetting-drying cycles submitted to different testing conditions.**

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14

15 **Abstract**

16 Physicochemical-and microstructural-evolution in lime-treated soil subjected to successive wetting and  
17 drying (W-D) cycles were investigated, and the relevancy of the laboratory-implemented testing condition  
18 with in-situ conditions was discussed. Lime-treated soils were exposed to 17 W-D cycles using different  
19 testing conditions. Two laboratory testing conditions were operated at laboratory temperature, consisting of  
20 W-D duration representing the saturation level close to the one experienced in in-situ soil during rainy-and  
21 drought-periods. The results obtained were interpreted with those obtained using the reference ASTM  
22 procedure, which involves oven-drying of specimens at 71°C. Drying of lime-treated soil at 71°C reduced  
23 the water content from about 20% to 0.85%. This has led to greater contact between soil particles, thus,  
24 increasing the suction from about 143.5 MPa to 270 MPa. Such a phenomenon increased the Unconfined  
25 Compressive Strength (UCS) of the oven-dried soil up to about 3 times compared to the air-dried specimen,  
26 though the available cementitious bonding reflected by the presence of pores smaller than 3000 Å was  
27 comparatively low in the former than the latter. Percentage leaching of calcium components with respect to  
28 the initial calcium content of the soil was significantly low during W-D cycles due to greater exposure of  
29 only the outer part of the compacted soil structure during wetting. However, the leaching was comparatively  
30 higher in the oven-dried soil. The implemented wetting duration and drying temperature influence the

31 wetting front velocity of water, which significantly affects the duration taken by infiltrated water to invade  
32 the core of an earthen structure, and hence its durability.

33 Keywords: Wetting and drying cycles; Unconfined compressive strength; physicochemical; microstructure;  
34 Lime-treated soil.

35

## 36 **Introduction**

37 The sustainability of earth structures by lime treatment was shown to improve through several laboratories  
38 (Cuisinier et al. 2011; Runigo et al. 2009; 2011; Shen et al. 2021) and a few field investigations. Some  
39 recent in-situ evidence was provided in the study reported by Akula et al. (2020) and Das et al. (2020).  
40 Akula et al. (2020) reported the behavior of the Friant-Kern Canal in California, United States, a hydraulic  
41 earthen structure built with heavy plastic clay soil. The Friant-Kern Canal suffered severe erosion and slope  
42 sliding in the early stages after construction due to the low engineering properties of the plastic soil. Several  
43 sections of the Canal were renovated with 4% quicklime during the '70s. Study of up to more than 40 years  
44 was conducted to inspect the long-term performance of the lime-treated material used for the repair and  
45 reinforcement of the bottom and blankets of the canal. The study evidenced the increased long-term strength,  
46 reduction in swelling and shrinkage potential, as well as significant resistance to erosion, thus showing the  
47 improved geo-mechanical stability of the structure. Another study, reported by Das et al. (2020), was related  
48 to the mechanical and physicochemical performance of a 2.5% quicklime-treated embankment built with  
49 silty soil after 7 years of atmospheric exposure. The embankment was exposed to the climate of Rouen,  
50 France, which experiences a mostly damp climate throughout the year due to heavy rainfall and frost.  
51 However, despite this exposure, an average UCS of  $3.29 \pm (0.45)$  MPa was reported in the core of the lime-  
52 treated embankment. Additionally, the physicochemical and microstructural investigation evidences the  
53 long-term impact of lime treatment towards such significant evolution in compressive strength.

54 Lime, when added to soil in the presence of water, brings physical improvement in the short-term  
55 and chemical modifications in the long-term. The short-term improvement includes decreasing the plasticity  
56 of the soil, thus resulting in increased workability of the soil (Diamond and Kinter 1965; Little 1995). In the

57 long-term, lime undergoes pozzolanic reactions, which form cementitious compounds such as Calcium  
58 Silicate Hydrate (CSH), Calcium Aluminate Hydrate (CAH) (Ali and Mohamed 2019a; Mehenni et al.  
59 2016). These compounds play a central role in improving the long-term hydromechanical performance of  
60 lime-treated soil.

61 Although several studies report the improvement brought by lime treatment; however, the  
62 performance of lime-treated soil upon its exposure to successive alterations of seasonal temperatures as well  
63 as fluctuations in water level is still a concern. Such concern varies with the climate of the specific regions  
64 in which the structure is located or constructed. Some field investigations conducted with lime-stabilized  
65 roads evidenced that a significant alteration in climatic conditions can negatively impact the performance  
66 of lime-treated soil (Cuisinier and Deneele 2008; Kelley 1977). Additionally, several laboratory studies are  
67 available that delineated the severity of wetting and drying (W-D) cycles, as well as freeze/thaw cycles on  
68 degrading the improved hydromechanical behavior of lime-treated soil (Chittoori et al. 2018; Cuisinier et  
69 al. 2020; Nabil et al. 2020). For instant, Chittoori et al. (2018) reported that lime-treated expansive soil  
70 containing higher montmorillonite content suffers premature failure during W-D cycles than the one  
71 dominant in other clay minerals. Another study reported by Nabil et al. (2020) stated that the severity of W-  
72 D cycles impact on lime-treated soil is resistible only for soil treated with greater lime content. The effect  
73 of W-D cycles in the field is explained below.

74 In the field, the slope of the lime-treated hydraulic earthen structure built near water bodies often  
75 suffers W-D cycles due to several fluctuations in water level (Chen et al. 2018; Jia et al. 2009; Johansson  
76 and Edeskär 2014; Xiong et al. 2019). During heavy rainy periods, due to the rise in water level in water  
77 bodies, the slope towards the base of the hydraulic structure may remain underwater for several weeks to  
78 months. Such a situation can increase the available saturation level of the soil. On the other hand, during  
79 severe drought periods, a drastic decrease in the water level might occur, thus exposing the same base level  
80 to severe drying for several months to years, which in turn can decrease the saturation level. Such a  
81 fluctuation in the saturation level can modify the mechanical resistivity of the lime-treated soil and might  
82 impact the service life of the structure. Though assessment of the durability of lime-treated soil subjected to

83 W-D cycles was extensively studied, of which most of the studies were made following the testing condition  
84 provided in ASTM D559 standard (ASTM 2015). According to the ASTM standard, the soil sample is  
85 alternatively immersed in water for 5 hours at laboratory temperature and then placed in the oven for 42  
86 hours of drying at 71°C. The benefit brought by lime treatment was then shown to be partially lost under  
87 the impact of alterations of W-D Cycles either by showing the loss in mass or decrease in strength as a  
88 function of the number of cycles. However, how well this technique represents the above in-situ W-D  
89 situation is less investigated.

90 Recently, Cuisinier et al. (2020) demonstrated the importance of establishing a field-representative  
91 laboratory testing protocol to evaluate the W-D cycles impact on stabilized soil. The study compared results  
92 obtained from specimens subjected to W-D cycles as per ASTM standard and by drying at laboratory  
93 temperature. It showed that oven-drying and full immersion of specimens during W-D cycles conducted as  
94 per ASTM standard led to comparatively greater UCS degradation and increased the hydraulic conductivity  
95 values up to two orders in magnitude. This demonstrates the essentiality of investigating the mechanism,  
96 which has led to such differences in UCS, and hydraulic conductivity based on the implemented testing  
97 conditions.

98 In this context, this study focuses on analyzing the physicochemical and microstructure mechanism  
99 contributing to the evolution of UCS in compacted lime-treated cured specimens subjected to different  
100 testing conditions. It is worth noting that the previous study by Das et al. (2020) demonstrates the long-term  
101 effect of lime treatment on the physicochemical and microstructural properties of silty soil after 7 years of  
102 atmospheric exposure. This study is aimed to highlight the importance of reproduction of laboratory testing  
103 conditions close to the field's weather and soil condition, while evaluating the W-D effect on the long-term  
104 performances of lime-treated soil by comparing the UCS, physicochemical and microstructural evolution.  
105 Two laboratory testing conditions were proposed to represent the W-D cycles lime-treated soil may  
106 experience in the field. The results obtained were compared with the respective results obtained using the  
107 reference ASTM standard. The first part of the study focuses on comparing the UCS evolution and volume  
108 variation of the specimens. Later, the physicochemical and microstructure characteristics are presented. In

109 the end, the mechanism correlating the physicochemical and microstructure properties with the UCS  
110 evolution is explained.

111

## 112 **Properties of Soil and Lime**

113 The soil used was silty soil imported from Marche-Les-Dames (Belgium). The geotechnical properties of  
114 the soil, which is obtained from the study reported by Nguyen et al. (2019) are presented in Table 1. The  
115 mineralogy of the soil was obtained by X-ray diffraction, which showed the presence of Illite, Kaolinite,  
116 and Chlorite as clay minerals, along with Quartz and Feldspars (Nguyen et al. 2019).

117 Quicklime (CaO) was used for the treatment. The lime consists of 90.9% of available CaO and a  
118 reactivity ( $t_{60}$ ) of 3.3 min. The Lime Modification Optimum (LMO) of the silt was determined by Eades and  
119 Grim test as per ASTM standard D 6276-99a (ASTM 2006) and was found to be 1% by weight of lime. The  
120 Lime Modification Optimum is defined as the minimum amount of lime that is essential to initiate the  
121 hydration reaction between lime and soil (Cherian and Arnepalli, 2015; Little, 1987). However, in field  
122 practice, to ensure a long-term pozzolanic reaction between lime and soil as well as the enhancement of its  
123 hydromechanical performances, the quantity of lime to be added is recommended to be higher than LMO  
124 (Runigo et a., 20011; Das et al., 2022). Thus, lime content, 1.5% higher than LMO, *i.e.*, equal to 2.5%, was  
125 used herein. Also, this 2.5% of quicklime was shown to be sufficient to bring significant long-term  
126 improvement in a full-scale experimental embankment built using the studied soil by Das et al. (2020).  
127 Besides, this embankment was previously studied by Makki-Szymkiewicz et al. (2015), where the  
128 permeability performance of the lime-treated soil is reported. Hence, 2.5% quicklime content is chosen in  
129 the present study to keep the continuation of any necessary comparison required to be made with previous  
130 studies.

131

## 132 **Sample preparations**

133 The maximum dry density,  $\rho_{d(max)}$ , and Optimum Moisture Content (OMC) of the untreated and the lime-  
134 treated silty soil were obtained as per ASTM D698-12e2 (ASTM 2012) (Table. 2).

135  
136 The silt was mixed with distilled water at a water content of  $1.1 \times \text{OMC}$ , *i.e.*, specimens were  
137 prepared at the wet of optimum (WMC). This is because a compaction moisture content similar to the one  
138 reported by Das et al. (2020) was maintained, which involved a study regarding the performance of an in-  
139 situ embankment built with the present soil configuration. The soil mixture was then stored in sealed plastic  
140 bags to allow moisture content homogenization for about 24 hours. The soil mixture was then mixed with  
141 lime and rested for 1 hour before compaction. This process of soil preparation was as per the French GTS  
142 Technical Guide for soil treatment (GTS - LCPC-Setra Technical Guide 2000).

143 Cylindrical specimens of dimensions 0.10 m in height and 0.05 m in diameter were prepared by the  
144 static compaction method at WMC. The process of static compaction involves compression of the  
145 specimens from top and bottom, as demonstrated by Holtz et al. (1981). A total of 2 untreated and 14 lime-  
146 treated specimens were prepared, of which 4 lime-treated specimens were presented in Fig.1. After  
147 compaction, specimens were wrapped in plastic film and then subjected to curing at a laboratory temperature  
148 of  $20 \pm 1$  °C. A 10 month curing time was implemented herein, considering it the longest laboratory  
149 implemented curing time to have the most suitable results in a one-year time frame.

150

## 151 **Laboratory Experiments**

152 This section explains the testing conditions developed, followed by tests performed successively in the  
153 study.

154

155 *Testing conditions for Wetting and drying cycles*

156 The W-D cycles were imposed as per the ASTM standard and using two laboratory-developed testing  
157 conditions. The testing condition implemented as per the procedure demonstrated in ASTM D559, which  
158 involves 5 hours of wetting at laboratory temperature followed by 42 hours of oven-drying at 71°C is  
159 denoted as AP. Fig. 2 shows the wetting and drying of the AP subjected specimens. The second and third  
160 testing conditions were proposed to represent the situation a soil might experience in the field during rainy  
161 and drought seasons, respectively.

162 Alteration of W-D cycles brings an increase and then decrease of the soil-saturation level,  
163 respectively. During rainy periods, when the slope towards the base of the hydraulic earthen structure  
164 remains under water for a long time, the soil can be assumed to have attained a maximum saturation level  
165 of 85-90%. Again, due to the greater frequency of precipitation during the rainy season, the soil can be  
166 assumed to have reach a saturation level not less than 65-70% during the drying period, when the water  
167 level in the water bodies decreases for a certain period. Similarly, the soil was assumed to dry up to a  
168 saturation level of 25-30% during the drought season, and considering the slightest rainfall that can probably  
169 happen during the drought period; the soil was supposed to reach a maximum saturation level of only 65-  
170 70%. For the present lime-treated soil, the duration required to attain the above assumed saturation level  
171 during rainy and drought periods was measured in the laboratory, during which the temperature and relative  
172 humidity varied from 22.1-25.2°C and Relative Humidity (RH) of 34.3-52.8%, respectively. The present  
173 study considers the laboratory temperature and RH as the reference condition to highlight the essentiality of  
174 considering the field conditions. The obtained wetting and drying duration were then used to undergo  
175 successive W-D and drying-wetting cycles to represent the rainy and drought situations, respectively. The  
176 testing conditions and the duration required to attain the assumed levels of saturation are provided in Table  
177 3. The second and the third testing conditions, which represent the rainy periods and drought periods,  
178 respectively, are regarded as RP and DP, respectively, in the following study. It is worth noting that  
179 specimens subjected to AP and RP experience alternate W-D cycles, whereas specimens subjected to DP  
180 experience alternate drying and wetting (D-W) cycles.



181           The RP and DPs were conducted by a laboratory proposed device, which involves successive  
182 wetting of the specimens by soaking in water for the proposed time and then drying the same by allowing  
183 the water to move out after completion of the wetting duration. A part of the water after each wetting, *i.e.*,  
184 the effluent, was stored for chemical analysis. A total of 17 wetting-drying and drying wetting (W-D/D-W)  
185 cycles were operated using the three testing conditions. This is because, within the time frame of one year,  
186 10 months were used for curing, and in the remaining 2 months, 17 was found to be the maximum number  
187 of cycles that can be achieved for all the testing conditions. The mass and volume of the specimens subjected  
188 to all three conditions were recorded at the end of each cycle. During these measurements, samples were  
189 carefully handled, and the excess water around the specimens was wiped off to avoid any error in the  
190 measurements. To establish the homogeneity of the specimens, they were periodically turned during the  
191 alternate cycles.

192           Of the 14 lime-treated specimens prepared and cured, three sets of 4 specimens were subjected to  
193 the three testing conditions, and the remaining 2 were used to evaluate the initial state of the specimen after  
194 10 months of curing.

195

#### 196 ***Unconfined Compressive Strength measurement***

197 10 months cured specimen, *i.e.*, the initial specimen, and the specimens subjected to 5<sup>th</sup>, 9<sup>th</sup>, 13<sup>th</sup>, and 17<sup>th</sup>  
198 alternate W-D/D-W cycles in each of the three testing conditions were subjected to UCS test using a  
199 mechanical press with a load sensor of 10 KN. The load was applied to the specimens at a constant axial  
200 displacement rate of 1 mm/min.

201

#### 202 ***Measurement of Physicochemical properties***

203 The water content of each UCS-subjected specimen was measured by oven drying at 105°C (ASTM D2216-  
204 10) and was used to estimate the water content corresponding to the remaining cycles. The suction of the  
205 UCS subjected specimen was determined using the WP4C Dewpoint Potentiometer. The pH of the UCS  
206 subjected specimens was also measured. Specimens collected at the end of the UCS test were crushed and

207 then mixed with demineralized water in a 5:1 liquid: solid ratio for 1 hour, and then the pH of the solution  
208 was recorded (ASTM D4972-19). To have more reliable results, at least an average of the three values of  
209 preceding properties was reported.

210 The Electric Conductivity (EC) of the effluents collected after each wetting was determined by a  
211 Water Quality Meter. A part of the collected effluent corresponding to a certain number of wetting cycles  
212 was filtered using a 0.45  $\mu\text{m}$  syringe and then subjected to Inductively Coupled Plasma Optical Emission  
213 Spectrometry (ICP OES) analysis. This was done to determine the elementary concentrations of Calcium  
214 ( $\text{Ca}$ ) that have been leached from the lime-treated soil subjected to W-D/D-W cycles.

215  
216 ***Pore structure determination***

217 Pore Size Distribution (PSD) was analyzed by Mercury Intrusion Porosimetry (MIP) test and Barrett-Joiner-  
218 Halenda pore (BJH) method (Barrett et al. 1951). Since MIP was known to investigate macropores and BJH,  
219 the mesopores more elaboratively, as shown by Das et al. (2020); hence both the methods are used herein.  
220 The analysis was made on the freeze-dried samples gathered from the core of the 10 months cured specimen  
221 and the specimens subjected to the UCS test.

222 During the MIP test, mercury ( $\text{Hg}$ ) was progressively intruded into freeze-dried specimens  
223 contained inside a sealed penetrometer after the evacuation of the specimen via heating. The intruded  $\text{Hg}$   
224 volume and the corresponding applied pressure,  $p$  (MPa), were registered, using which pore sizes were  
225 obtained from the Washburn equation (Romero and Simms 2008). Similar, to the MIP test, freeze-dried  
226 samples were degassed at 50°C, and then nitrogen gas was injected during the Brunauer-Emmett-Teller  
227 (BET) test (Brunauer et al. 1938). From the isotherms obtained in the freeze-dried specimens, the BJH  
228 method analyzes the PSD using the Kelvin equation. The discussion of pore structure is presented as per the  
229 International Union of Pure and Applied Chemistry (IUPAC) (Rouquerol et al. 1994), which classifies pores  
230 based on their pore-width as macropores ( $> 500 \text{ \AA}$ ), mesopores (20-500  $\text{ \AA}$ ), and micropores ( $< 20 \text{ \AA}$ ).

231

232 **Results**

233 This section is focused on presenting the observation made with the results, and then the mechanism behind  
234 such observations is followed up in the discussion section.

235

### 236 *W-D/D-W cycle influence on UCS evolution*

237 The untreated compacted silty soil was destroyed when submitted to the first wetting cycle, as shown in Fig.  
238 3; hence, no UCS test and any further tests could be conducted with the untreated specimens.

239 The UCS evolution of the lime-treated soil subjected to 17 W-D/D-W cycles as per the 3 testing  
240 conditions is presented in Fig. 4. The UCS of the initial specimen after 10 months of curing was measured  
241 to be 1.26 MPa. This UCS increased to 3.40 MPa after the lime-treated soil underwent 5 cycles of W-D  
242 cycles as per the AP (Fig. 4). Further increase in the W-D cycles brought a slight decrease in the UCS to  
243 about 3.26 MPa after the 9<sup>th</sup> W-D cycle compared to the UCS attained after the 5<sup>th</sup> cycle. This UCS decreased  
244 significantly to 2.28 MPa, and 1.57 MPa after the 13<sup>th</sup>, and 17<sup>th</sup> W-D cycles, respectively. Thus, the UCS of  
245 the AP-subjected soil increased significantly after the 5<sup>th</sup> and 9<sup>th</sup> W-D cycles and then decreased. However,  
246 the overall evolution of UCS throughout the 17 W-D cycles remained higher than the UCS obtained with  
247 the initial specimen.

248 For the RP-subjected soil, the UCS decreased slightly to 1.04 MPa after the 5<sup>th</sup> W-D cycle and then  
249 reached a value that was about 0.40 MPa higher than the initial UCS after the 9<sup>th</sup> W-D cycle. After 13<sup>th</sup> W-  
250 D cycle, the UCS again decreased to a level similar to the one attained after the 5<sup>th</sup> W-D cycle and then  
251 remained the same as the initial UCS after the 17<sup>th</sup> W-D cycle. However, compared to the initial UCS, the  
252 overall fluctuations observed in the evolution of UCS with the RP-subjected specimens were significantly  
253 less than the one attained with the corresponding AP-subjected specimens throughout the 17 W-D cycles.

254 The UCS of the DP-subjected soil showed a gradual decrease up to the 13<sup>th</sup> D-W cycle, and then  
255 after the 13<sup>th</sup> and 17<sup>th</sup> D-W cycles, the obtained UCS was almost similar.

256

### 257 *W-D/D-W cycle influence on volume variations*

258 The change in volume of the specimens during W-D/D-W cycles is presented as a percentage increase or  
259 decrease in the volume of respective specimens compared to the volume of the initial specimen in Fig. 5 (a-  
260 c). The presented percentage change in volume is the average of the volume change obtained during the 17  
261 W-D cycles of the 4 specimens subjected to each RP, AP, and DP.

262 The amplitude of average volume changes between the wetting and drying phase and between 2  
263 successive cycles during the W-D cycles remained less significant in the specimens submitted to the RP  
264 testing condition (Fig. 5a). A maximum increase and decrease of about 0.8% in the average volume occurred  
265 compared to the initial volume.

266 Compared to the initial volume of the specimen, the AP submitted specimens showed a slight  
267 increase in average volume during the 1<sup>st</sup> wetting, and then the volume decreased by about 2% after the 1<sup>st</sup>  
268 oven-drying (Fig. 5b). In the successive W-D cycles from 1<sup>st</sup> to about 8<sup>th</sup> cycles, the amplitude in average  
269 volume variations between the wetting and drying phase remained almost similar, where the increase and  
270 decrease in the average volume was less than 1% and 2%, respectively than the initial volume. The  
271 fluctuation in the average volume variation was then lowered in the following W-D cycles. However, the  
272 maximum increase in average volume during wetting remained lower by about 0.4% compared to the initial  
273 volume throughout the 17 W-D cycles.

274 DP-subjected soil underwent a maximum decrease in average volume during drying of about 1.5%,  
275 and the maximum increase in average volume corresponds to the initial volume from the 1<sup>st</sup> to about 7<sup>th</sup> D-  
276 W cycles. For the remaining cycles, the loss in the average volume was almost insignificant (Fig. 5c). The  
277 overall trend observed in the average volume variation between the AP, and the DP submitted specimens  
278 were almost the same. However, the percentage of average volume loss after each drying was comparatively  
279 higher in the AP compared to the DP-subjected soil. On the other hand, the percentage increase in average  
280 volume after each wetting was relatively higher in the DP than the AP-subjected soil.

281

282 *W-D/D-W cycle influence on water content variations in the specimens*

283 The water content was measured for the 10 months cured soil and for the specimen subjected to UCS test  
284 after 5<sup>th</sup>, 9<sup>th</sup>, 13<sup>th</sup>, and 17<sup>th</sup> cycles. The water content corresponding to the remaining cycles was then  
285 estimated by using the bulk mass of the soil measured after each cycle and the dry mass of the soil measured  
286 at the end of the 17<sup>th</sup> cycle. This method of back estimation was approved in ASTM D559. The evolution  
287 of average water contents is presented in Fig. 5 (d-f).

288 According to Fig. 5d, a maximum of 2% increase and decrease in the average water content occurred  
289 during the wetting and drying phases, respectively, at laboratory temperature in the RP-subjected soil  
290 throughout the 17 W-D cycles. This increase and decrease in the average water content were found to almost  
291 correspond with the average maximum and minimum saturation level set earlier for the RP testing condition.  
292 The global trend of average water content evolution between 2 successive wetting and drying cycles  
293 remained almost constant.

294 Similar to the RP-subjected soil, the overall trend in the variation of the average water content  
295 between the wetting and drying phases and between 2 successive cycles remained almost constant in the  
296 AP-subjected soil (Fig. 5e). About 1% increase in the average water content compared to the initial water  
297 content occurred during every 5 hours of wetting at laboratory temperature; however, almost a complete  
298 loss in water content occurred during each 71°C oven-drying of the AP submitted soil.

299 In the DP submitted soil, the increase in average water content level during each wetting remained  
300 almost at a similar level, which was equivalent to the initial water content (Fig. 5f). However, a mean loss  
301 in average water content of about 13% occurred during the D-W cycle compared to the initial water content.  
302 The increase in average water content attained during almost each wetting, though corresponds with the  
303 average saturation level set for the DP testing condition, the average saturation level has fluctuated during  
304 the drying in certain number of cycles.

305

### 306 ***W-D/D-W cycle influence on soil suction and soil pH evolution***

307 At the end of the UCS test, the soil suction and pH of the soil were measured and presented in Fig. 6 for  
308 each testing condition, with the soil suction and soil pH recorded from the initial soil.

309 As expected, the soil suction of the AP submitted soil increased significantly in comparison to the  
310 initial suction of the soil due to almost total loss in water content (as seen in Fig. 5). The soil suction  
311 increased to 143.5 MPa after 5<sup>th</sup> cycle, then it increased to 270.0 MPa after 9<sup>th</sup> cycle and then remained  
312 approximately unchanged for the 13<sup>th</sup> and 17<sup>th</sup> cycles. The difference in the soil suction measured for the  
313 corresponding RP submitted soils remained less significant compared to the initial soil suction (Fig. 6a).  
314 The soil suction decreased for the DP-subjected soil up to 9<sup>th</sup> cycle, and then this decrease was slightly  
315 lowered after the 13<sup>th</sup> and 17<sup>th</sup> D-W cycles.

316 The pH measured for the initial specimen was 11.86. For the RP-subjected soil, this pH remained  
317 approximately unchanged up to 17<sup>th</sup> cycle (Fig. 6b). The pH of the AP-subjected soil decreased to 10 from  
318 the initial soil pH after the 5<sup>th</sup> cycle. The pH then further decreased; however, the decrease was relatively  
319 lower and remained above 9.3. Similar to the AP submitted soil, the pH of the DP submitted soil also  
320 decreased compared to the initial pH of the soil (Fig. 6b).

321

### 322 *W-D/D-W cycle influence on Ca concentration and EC evolution in the effluents*

323 Fig. 7 presents the concentration of *Ca* and EC measured in the effluents collected during the W-D/D-W  
324 cycles conducted as per the testing conditions. The initial CaO in the untreated silty soil was estimated as  
325 0.5%, and 2.5% of CaO was added during specimen preparation. Thus, the lime-treated soil consists of 3%  
326 CaO before curing. The *Ca* content in the 3% of the CaO, *i.e.*,  $Ca_{initial}$  was estimated, and the release of *Ca*  
327 measured in the effluent, *i.e.*,  $Ca_{leached}$  was then expressed as a percentage of the former in Fig. 7a.

328 The percentage of *Ca* leached from the lime treated soil was observed to be extremely low in all the  
329 specimens, regardless of the testing conditions (Fig. 7a). However, the loss of *Ca* and the magnitude of EC  
330 obtained were relatively higher in AP-subjected soil compared to the corresponding RP-subjected soil  
331 throughout the W-D cycles. The trend of the loss in *Ca* concentration and the measured EC decreased during  
332 the W-D cycles for the AP-subjected soil. On the other hand, this trend remained almost constant for the  
333 corresponding RP-subjected soil.

334 For the specimens subjected to DP testing conditions, the leaching of  $Ca$  and EC measured remained  
335 relatively lower than both RP and AP-subjected specimens, and the overall evolution was almost similar  
336 throughout the D-W cycles (Fig. 7b).

337  
338 ***W-D/D-W cycle influence on pore structure modifications***  
339 The PSD and cumulative pore volume evolution in the lime-treated W-D/D-W cycles subjected specimens  
340 were compared with the one obtained from the untreated and the 10 months cured soil by MIP and BJH,  
341 respectively, in Fig. 8.

342  
343 ***Determination of PSD by MIP***  
344 Fig. 8 showed that the untreated soil exhibits greater intensities of macropores of diameter in the range of  
345  $10^4$  and  $10^5$  Å. After lime treatment and 10 months of curing, macropores of diameter  $10^5$  Å evolved, a  
346 significant decrease of macropores of diameter  $10^4$  and  $10^5$  Å and an increase in pores smaller than 3000 Å  
347 occurred (Fig. 8(a-c)). Pores of diameter  $10^5$  Å were due to agglomeration of lime-treated soil, while pores  
348 smaller than 3000 Å evolved because of cementitious bonding as reported in previous studies (Das et al.  
349 2021; 2022; Cuisinier et al. 2011).

350 On subjecting the 10 months cured lime-treated soil to the W-D cycles as per the AP testing  
351 condition, macropores of diameter  $10^4$  Å increased, and the broad pore peak developed in the 10 months  
352 cured soil over pores smaller than 3000 Å was narrowed down during the W-D cycles (Fig. 8a). These  
353 features remained almost similar irrespective of the number of W-D cycles the specimens were subjected.  
354 On the other hand, 10 months cured lime-treated soil, despite being subjected to over 17 cycles of W-D as  
355 per the RP, showed no significant change in the broad pore peak developed over a pore range smaller than  
356 3000 Å (Fig. 8b). A slight insignificant rise in intensities of pores of diameter  $10^4$  Å occurred during the  
357 W-D cycles.

358 For specimens subjected to DP, pores smaller than 3000 Å were gradually decreased, and pores of  
359 diameter  $10^4$  Å increased with an increased number of D-W cycles (Fig. 8c).

360

361 ***Determination of cumulative pore volume evolution by BJH***

362 Using the BJH method, the evolution of cumulative pore volume in the pore range 24-250 Å, which comes  
363 under the mesopores range, was analyzed and presented in Fig. 8(d-f).

364 According to Fig. 8(d-f), lime-treated 10 months cured soil showed a significant development of  
365 pore volume in the mesopore range 24-250 Å compared to the untreated soil.

366 For the AP-subjected specimens, after the 5<sup>th</sup> W-D cycles, the cumulative pore volume in the  
367 mesopore range 24-250 Å remained at a similar level to the initial 10 month cured specimen (Fig. 8d).  
368 However, after the 9<sup>th</sup> W-D, these cumulative pore volumes increased by about 1.3 times compared to the  
369 initial specimen. Further increase in W-D cycles, *i.e.*, after the 13<sup>th</sup> and 17<sup>th</sup> W-D cycles, has resulted in a  
370 decrease in the cumulative pore volume by about 1.5 to 1.6 times compared to the initial specimen.

371 Specimens that underwent W-D cycles as per the RP testing condition showed a minimal difference  
372 in the cumulative pore volume in the mesopore range 24-250 Å over the entire 17 W-D cycles compared to  
373 the initial specimen (Fig. 8e).

374 For the DP-subjected soil, the cumulative pore volume in the mesopore range 24-250 Å after the 5<sup>th</sup>  
375 D-W cycles remained at a similar level to the initial specimen (Fig. 8f). This feature then gradually decreased  
376 by about 1.1 times in the specimen that has suffered the 9<sup>th</sup> D-W cycles and by about 2 times in the specimen  
377 subjected to the 13<sup>th</sup> D-W cycles. The cumulative pore volume then remained almost similar for the 17<sup>th</sup> D-  
378 W subjected specimen with the 13<sup>th</sup> D-W subjected soil.

379

380 **Discussions**

381 The UCS of a lime-treated soil is the resistance to deformation of the compacted soil structure under  
382 unconfined compression. This resistance is a resultant of the inter-and intra-aggregates modifications, which  
383 are influenced by the water content (Yin et al. 2018) and cementitious compounds (Little 1995). Thus,  
384 during these W-D/D-W cycles, a significant loss or gain in water can modify the inter-aggregate structure  
385 of the compacted soil. In the present study, subjecting the lime-treated soil to high drying temperature (71°C



386 in oven) as per AP testing condition resulted in accelerated pozzolanic reactions between soil minerals and  
387 lime (Little 1995; Wang et al. 2017). Concurrently, a total loss of moisture content occurred as measured at  
388 the end of each AP's W-D cycle (Fig. 5e). Again, the development of pozzolanic reactions is dependent on  
389 water availability (Diamond and Kinter 1965; Little 1995). Hence, the loss in water content and the necessity  
390 of water for pozzolanic reactions possibly have created a competition between the pozzolanic reaction and  
391 soil suction evolution during the cycles. However, Fig. 6(a) presents a significant increase in total suction  
392 of the AP-subjected soil compared to the initial soil suction, and the AP-subjected soil did not show  
393 significant evolution of cementitious compounds during the W-D cycle as reflected by the difference in the  
394 generation of pores smaller than 3000 Å in Fig. 8a & d. Thus, it can be derived that the high UCS developed  
395 in the AP-subjected soil was mostly contributed by the high soil suction generated due to induced contact  
396 between soil particles because of water loss. The preceding statement is supported by the less significant  
397 evolution of soil suction (Fig. 6a) and UCS (Fig. 4) in the specimens with similar configurations but was  
398 subjected to air-drying as per RP and DP testing conditions. Thus, the soil suction developed in the lime-  
399 treated soil during successive W-D/D-W cycles possibly contributes to the evolution of UCS.

400 The insignificant soil suction generated in the RP-subjected soil (Fig. 6a) during the W-D cycle  
401 compared to the initial suction is attributed to only 2% average water content loss during every 17 hours of  
402 air-drying at 22.1-25.2°C (Fig. 5d). However, though the average water content loss after each air-drying  
403 was higher in the DP-subjected soil compared to the RP-subjected soil, due to the longer air-drying of the  
404 DP-subjected soil (Figs. 5d & f), the suction evolution was comparatively lower in the former than the latter  
405 (Fig. 6a). This was due to the presence of higher water content in the DP-subjected soil, as the soil suction  
406 was measured after the wetting phase of the D-W cycles, while suction measurement was conducted after  
407 the drying phase of the W-D cycles in the AP-and RP-subjected soil.

408 The amplitude of the average volume variations between wetting and drying phases and the overall  
409 trend of average volume changes in the specimens over the 17 W-D cycles evolved based on the  
410 temperatures and durations of wetting and drying applied as per the three different testing conditions (Fig.  
411 5 (a-c)). However, the overall trend of average volume variations was insignificant. Such an observation

412 can be due to the absence of smectite as a clay mineral in the present silty soil, which is mainly responsible  
413 for the volume change behavior of soil (Das and Bharat 2016; Gapak et al. 2017). Also 2.5% quicklime  
414 treatment might have subsided the possible ability of the soil to show considerable volume change (Chittoori  
415 et al. 2013, 2018). For the RP-subjected soil, owing to the air-drying at 22.1-25.2°C, which caused a  
416 minimum loss in average water content, the amplitude of average volume change in each cycle remained  
417 almost insignificant compared to the initial volume of the specimen (Fig. 5a). Though DP-subjected soil  
418 was also air-dried at 22.1-25.2°C, however, due to 70 hours of drying, which was 53 hours higher than the  
419 RP-subjected soil, the amplitude of average volume change was comparatively higher (Fig. 5c). However,  
420 the complete evaporation of water in the AP-subjected soil caused the maximum average volume loss of the  
421 specimen during each oven-drying (Fig. 5b).

422 Durability of a hydraulic earth structure is interlinked with the ability of water to flow into the  
423 structure. Water flow level can be quantified by the rate at which the wetting front developed during the  
424 infiltration of water into the soil (Johnson 1963; Kirkham 2014). This velocity of the wetting front can be  
425 said to vary based on W-D cycles created by the in-situ water fluctuations. Thus, a greater wetting front  
426 velocity can increase the dampness of the structure and causes the structure to collapse due to loss in  
427 mechanical strength (Jia et al. 2009; Johansson and Edeskär 2014). Besides, lime-treated soil is prone to  
428 leach more lime if subjected to a greater wetting front velocity (Chittoori et al. 2013; Hara et al. 2008).  
429 Thus, considering the wetting front velocity of water as an important parameter, the same was estimated  
430 herein for the specimens subjected to W-D/D-W cycles as per the different testing conditions. Using the  
431 average increase in the volume of the specimens during each wetting of the W-D/D-W cycles, the average  
432 volume flow rate of water ( $Q$ ) was calculated. From the  $Q$ , the average velocity of wetting front ( $W_f$ ) into  
433 the specimens was estimated as per Eq. 1.

434

435 
$$W_f = Q/A = V_i/A \times t \quad (\text{Eq. 1})$$

436 where  $Q$  is the average volume flow rate of water into the specimens in  $\text{m}^3/\text{s}$ ;  $V_i$  is the increase in the average  
437 volume of the specimens during each wetting in  $\text{m}^3$ ;  $t$  is the duration of wetting during each cycle in  $\text{s}$ ;  $W_f$   
438 is the average wetting front velocity of water in  $\text{m}/\text{s}$ ;  $A$  is the total surface area of cylindrical specimen in  
439  $\text{m}^2$ . Since the flow of water into the specimen occurred from all directions during wetting hence, the total  
440 surface area of the cylindrical specimen was considered.

441 Table 4 presents the average of the estimated average  $W_f$  of water into the specimens subjected to  
442 W-D/D-W cycles as per the different testing conditions. Using the estimated average velocity of  $W_f$  the  
443 duration required by the infiltrated water to flow to the center of an in-situ structure of reference thickness  
444 1m was obtained (see Table 4).

445 The average  $W_f$  caused during wetting of the W-D/D-W cycles was maximum for the DP- followed  
446 by AP-, and then RP-subjected soil. Correspondingly, the duration estimated for the water to invade the  
447 center of an in-situ structure was maximum for RP- followed by AP-, and then DP-subjected soil. Thus,  
448 Table 4 evidence that lime-treated soil exhibiting similar configuration on being subjected to W-D/D-W  
449 cycles conducted as per different testing conditions can show different  $W_f$  which can lead to a difference in  
450 the durability of the structures. However, interestingly, the  $W_f$  was higher in the DP-subjected soil compared  
451 to the AP-subjected soil, though the AP-subjected soil underwent complete evaporation of water during  
452 each drying (Fig. 5e). Such an evolution was noticed due to greater amplitude of average volume increase,  
453 *i.e.*, swelling during wetting in the DP-compared to the AP-subjected soil (Fig. 5b & c). Studies have  
454 reported that oven-drying of soil cause soil aggregation and loss in plasticity, thus, resulting in a reduction  
455 of the swelling potential of soil (Basma et al. 1994; Sunil and Deepa 2016). Thus, in the present case, it  
456 might be probably due to the preceding statement the swelling was relatively lowered in the AP-subjected  
457 soil due to oven-drying. Since the  $W_f$  was estimated based on the increase in volume during each wetting  
458 thus, it occurred to be lower in the AP- than the DP-subjected soil. Thus, oven-drying of soil may cause an  
459 underestimation of the  $W_f$

460 Specimens subjected to W-D/D-W cycles showed  $Ca$  leaching, which was significantly lower than  
461 the  $Ca$  content estimated to be present in the soil during sample preparation (Fig. 7a). This is attributed to

462 the consumption of *Ca* by the pozzolanic reactions during the 10 months curing, thus, probably leaving a  
463 limited soluble *Ca* in the soil. Also, the limited contact of the soil structure with water during wetting, which  
464 mostly exposes the outer layer of the compacted soil to leach a comparatively higher amount of minerals  
465 than the internal soil structure, has led to the presence of such lower *Ca* concentration in the effluent.  
466 However, despite the fact that the RP-subjected soil was exposed to longer wetting hours than the  
467 corresponding AP-subjected soil, the leaching of *Ca* and EC measured was comparatively higher in the  
468 latter than the former (Figs. 7a & b). Such an evolution was due to the complete drying of the AP-subjected  
469 soil because of oven-drying, thus, making the soil more vulnerable to loss of minerals during wetting.  
470 However, due to only 2 hours of contact of the specimens with water during each wetting as per the DP  
471 testing condition, the loss in *Ca* and the measured EC remained relatively lower (Figs. 7a & b).

472 Additionally, according to Figs. 7a & b, the trend observed in the evolution of *Ca* and EC was  
473 almost equivalent. Fig. 9 presents the obtained linear trend for the *Ca* and EC evolution in the W-D/D-W  
474 subjected specimens. Such an observation demonstrates the important role of *Ca* component on controlling  
475 the EC evolution of the lime-treated soil. Thus, EC can be used as an important parameter to assess the  
476 leaching process of *Ca* occurring during the W-D/D-W cycles.

477 The above discussion shows that specimens subjected to RP testing condition exhibited an  
478 insignificant change in soil suction (Fig. 6a), minimum volume and water content variations (Figs. 5a & d),  
479 minimum *Ca* loss, and EC evolution (Fig. 7). Thus, the soil pH remained almost unchanged compared to  
480 the initial soil pH (Fig. 6b), despite being subjected to 17 W-D cycles. The preceding  
481 feature favored the conservation of cementitious bonding formed in the 10 months cured soil as evidenced  
482 by the almost similar presence of smaller pores lower than 3000 Å (Fig. 8b) and mesopores volume (Fig.  
483 8e) in the RP-subjected soil. On the other hand, a gradual loss in soil pH up to less than 10 from the initial  
484 soil pH 11.86 (Fig. 6b) occurred in the AP-and DP-subjected specimens. Fig. 8a & c showed that the  
485 significant evolution of pores smaller than 3000 Å in the initial specimen decreased, and macropores at 10<sup>4</sup>  
486 Å increased. The former feature evidenced the possible loss in cementitious bonding, which contributed to  
487 the decrease in soil pH, and the latter was probably due to soil shrinkage, thus, inducing crack and increasing

488 the macropores. In addition to the loss in cementitious bonding, the observed loss in soil pH in the AP and  
489 DP submitted soil could also be a consequence of possible carbonation, as reported in previous studies  
490 (Deneele et al. 2021; Xu et al. 2020).

491 However, the observed decrease in pores smaller than 3000 Å compared to the one available in the  
492 10 months cured soil was more significant in the DP-compared to the AP-subjected soil during the D-W  
493 and W-D cycles, respectively. Owing to the subjection of specimens to high temperature during each drying,  
494 accelerated-pozzolanic reactions were induced (Little 1995; Wang et al. 2017), which probably have  
495 resulted in the presence of more pores smaller than 3000 Å in the AP-subjected soils. The preceding  
496 statement was evidenced by the pore structure analyzed by both MIP and BJH in Fig. 8a & d, where the  
497 pores smaller than 3000 Å increased after the 9<sup>th</sup> cycle in the AP-subjected soil. Such a feature was missing  
498 in the specimens subjected to other testing conditions. Thus, such a phenomenon explains that 5 hours of  
499 wetting duration followed by oven-drying at 71 °C provides sufficient water to reactivate the generation of  
500 cementitious compounds in the AP-subjected soil. Thus, such evolution can overestimate the actual  
501 cementitious compounds that can be expected from an in-situ lime-treated soil subjected to W-D cycle.

502 Additionally, the gradual decrease in pores smaller than 3000 Å with increased D-W cycles in the  
503 DP-subjected soil can be attributed to only 2 hours of contact of the lime-treated soil with water during each  
504 wetting (Fig. 8c & f). This is evident from the maintenance of cementitious compounds in the RP-subjected  
505 soil (Fig. 8b & e), which was subjected to 5 hours of wetting under the same testing environment  
506 (temperature and RH), as the DP-subjected soil. Thus, the duration of wetting hours implemented during  
507 the W-D/D-W cycles significantly influence the maintenance of cementitious compounds.

508

## 509 **Conclusions**

510 The physicochemical properties and microstructure modification that underlines the mechanism governing  
511 the UCS evolution in lime-treated soil subjected to W-D/D-W cycles as per different testing conditions were  
512 evaluated. Following conclusions were derived based on the evaluations:

513 1) The soil suction generated in the lime-treated soil during successive W-D/D-W cycles contributes towards  
514 the UCS evolution. Lime-treated soil subjected to W-D/D-W cycles did not show any significant generation  
515 of cementitious compounds compared to the one that evolved during curing time. However, the total loss in  
516 water content during the oven-drying of the AP-subjected soil induced a greater soil-particles contact, which  
517 increased the soil suction and resulted in up to about 3 times greater UCS in the AP-subjected soil. At the  
518 same time, the corresponding UCS and suction evolution remained insignificant in the soil subjected to  
519 testing conditions that represent a situation close to the field condition.

520 2) Wetting front velocity of water in specimens during W-D/D-W cycles is an important index to estimate  
521 the duration taken by infiltrated water to invade an in-situ hydraulic structure, which is interlinked with the  
522 durability of such structure. Soil subjected to W-D/D-W cycles as per different testing conditions exhibited  
523 different wetting front velocities. DP-subjected soil showed 3 times greater wetting front velocity than the  
524 AP-subjected soil. At the same time, RP-subjected soil showed 3 times lower wetting front velocity than  
525 the AP-subjected soil.

526 3) The leaching of calcium from specimens exposed to W-D/D-W cycles is mainly regulated by the exposure  
527 of the soil structure to the water during wetting. Since such exposure was mainly limited to the external  
528 surface of the specimens thus, the overall leaching of calcium remained significantly low, regardless of the  
529 testing conditions they are subjected to.

530 4) Oven-drying of AP-subjected soil at 71 °C makes the soil comparatively more prone to leach minerals  
531 during the wetting phase. Thus, the leaching of calcium and the electric conductivity measured in the  
532 effluent obtained from the AP-subjected specimens was comparatively higher than the specimens subjected  
533 to the RP testing condition.

534 5) A similar trend of *Ca* and EC evolution occurred in the lime-treated soil submitted to the W-D/D-W  
535 cycles, thus, demonstrating *Ca* as a controlling component on the EC evolution of the lime-treated soil.  
536 Thus, EC can be used as an important parameter to assess the leaching process of *Ca* occurring during the  
537 W-D/D-W cycles.

538 6) Re-wetting of lime-treated soil followed by oven-drying at 71°C during each cycle of the W-D cycles  
539 induced pozzolanic reactions, which potentially overestimates the actual cementitious compounds that can  
540 be expected from an in-situ lime-treated soil subjected to W-D cycle. As a result, though the loss of calcium  
541 and soil pH in the AP-subjected soil was comparatively higher, pores smaller than 3000 Å, which evolved  
542 due to lime treatment, seems to be less affected.

543 7) The maintenance of cementitious compounds in lime-treated soil subjected to W-D/D-W cycles is  
544 significantly influenced by the wetting hours implemented under the same testing environment (temperature  
545 and RH). RP-subjected soil being in contact with water for 7 hours, maintained the cementitious bonding  
546 formed during the 10 months curing, while the same was gradually lost in the DP-subjected soil during the  
547 successive D-W cycles, which remained only for 2 hours in contact with water.

548 The results emphasized the fact that based on the type of testing conditions implemented at a  
549 laboratory for conducting W-D/D-W cycles, the physicochemical and microstructural modifications occur,  
550 which brings a considerable change in the UCS evolution of lime-treated soils. Thus, consideration of the  
551 temperature, RH, and wetting and drying durations based on soil saturation level is essential while  
552 evaluating the impact of W-D/D-W cycles on the long-term performances of soil.

553 The present study is conducted under laboratory temperature, RH, and using an assumed saturation  
554 level; however, in the field, based on the weather conditions of the in-situ project locations, these parameters  
555 will vary. Also, the curing time implemented is 10 months, the difference in which can bring a variation in  
556 the presently reported properties of the lime-treated soil. The selection of the convenient curing time is  
557 fundamental as it ensures continuous contact between the soil, water, and the binder. Hence, further studies  
558 should focus on reproducing a laboratory environment that resembles the actual temperature, RH, soil  
559 saturation level of the targeted project sites, and intended curing time of the land infrastructure. This would  
560 provide a more accurate representation of the expected long-term hydromechanical performance of the soil  
561 structure under consideration.

562 Besides, additional studies should also be made (i) to evaluate the influence of the W-D/D-W cycle  
563 on lime-treated soil that represents a situation similar to the one produced by wave effects on harbors, levees,

564 *etc.* during boat movements (ii) to investigate how such a difference in testing condition can affect the  
565 carbonation of the lime-treated soil. However, based on the present results, it can be said that lime-treated  
566 structures can maintain a longer durability in regions exhibiting longer rainy periods compared to the ones  
567 with longer dry periods.

568

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## 574 **Data Availability Statement**

575 Data generated or analyzed during the study is included in the submitted manuscript.

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710

711 **Table 1.** Geotechnical properties of soil studied (Nguyen et al. 2019)

Clay fraction (< 0.002mm) (%)	Fraction (< 0.08 μm) (%)	Methylene Blue Value (g/100g)	Atterberg’s limit			USCS Classification
			PL (%)	LL (%)	PI (%)	
24	99	2.4	23.2	30.1	7	ML

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714 **Table 2.** Maximum dry density and OMC of untreated and lime-treated silty soil

Soil	$\rho_{d(max)}$ (kN/m <sup>3</sup> )	OMC (%)
Untreated silty soil	18.4	14.3
Silty soil treated with 2.5% lime	17.1	18.5

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**Table 3.** Presentation of testing conditions

Designation	Testing conditions			Sequence of cycles	Number of specimens
	Wetting hours	Drying hours	Temperature (°C)		
AP (ASTM standard)	5	43	22.1-25.2 (wetting) 71 (drying)	Wetting then drying (W-D)	4
RP (to represent in-situ rainy situation)	7	17	22.1-25.2	Wetting then drying (W-D)	4
DP (to represent in-situ drought situation)	2	70	22.1-25.2	Drying then wetting (D-W)	4

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727 **Table 4.** Estimated average velocity of wetting front and duration required by infiltrated water to flow to the center of a reference  
728 in-situ structure

Testing conditions	Average $W_f$ (m/s)	Duration to reach the center of a 1m reference thickness in-situ structure (years)
AP	$3 \times 10^{-09}$	05
RP	$1 \times 10^{-09}$	13
DP	$9 \times 10^{-09}$	02

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736 **Figure Captions List**

737 **Fig.1.** Statically compacted lime-treated specimens.

738 **Fig. 2.** Immersion of specimens during wetting (a) and oven-drying of specimens at 71 °C (b) as per ASTM  
739 procedure.

740 **Fig. 3.** Appearance of compacted untreated silty soil after the 1<sup>st</sup> wetting cycle

741 **Fig. 4.** UCS evolution in the lime-treated specimens subjected to W-D/D-W cycles as per AP, RP, and DP  
742 testing conditions

743 **Fig. 5.** Average volume variations (a-c), and water content variations (d-f) measured in the specimens  
744 subjected to W-D/D-W cycles as per AP, RP, and DP testing conditions

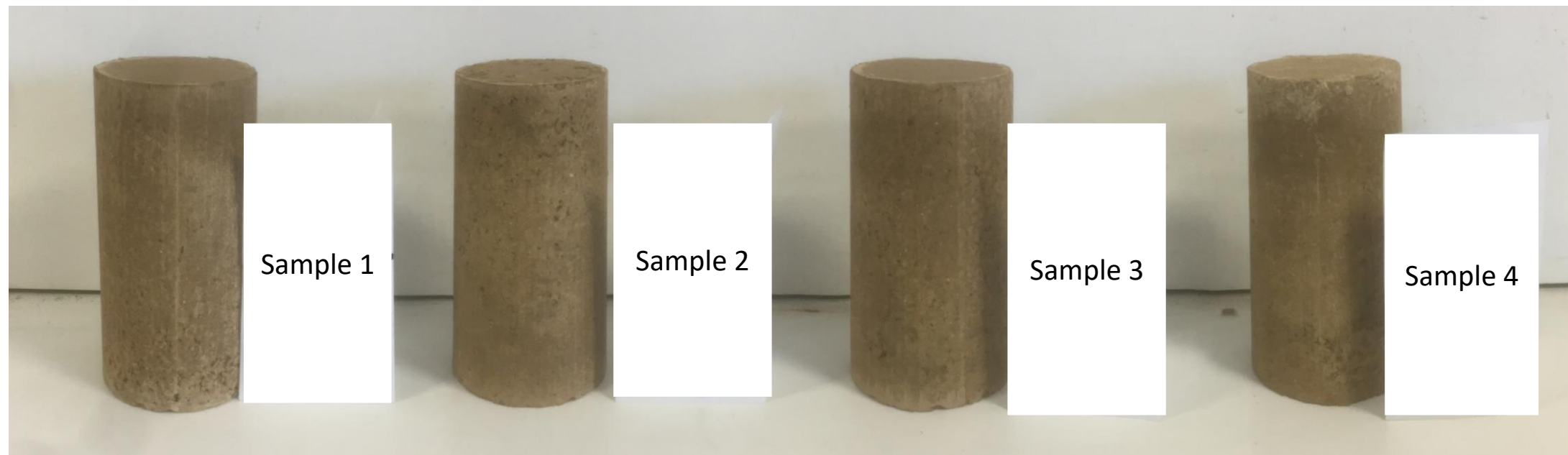
745 **Fig. 6** Suction (a) and pH (b) measured in the initial and UCS subjected specimens during W-D/D-W cycles  
746 as per AP, RP, and DP testing conditions.

747 **Fig. 7.** Calcium concentration (a) and Electric Conductivity (b) measured in the effluents collected from the  
748 specimens subjected to W-D/D-W cycles as per AP, RP, and DP testing conditions

749 **Fig. 8.** Comparative PSD by MIP (a-c), and Cum. (cumulative) pore volume evolution by BJH (d-f) between  
750 untreated and 10 months cured lime-treated specimen with the lime-treated specimens subjected to W-D/D-  
751 W cycles as per AP, RP, and DP testing conditions



752 **Fig. 9.** Comparative evolution of calcium concentration and electric conductivity in the specimens subjected  
753 to W-D/D-W cycles



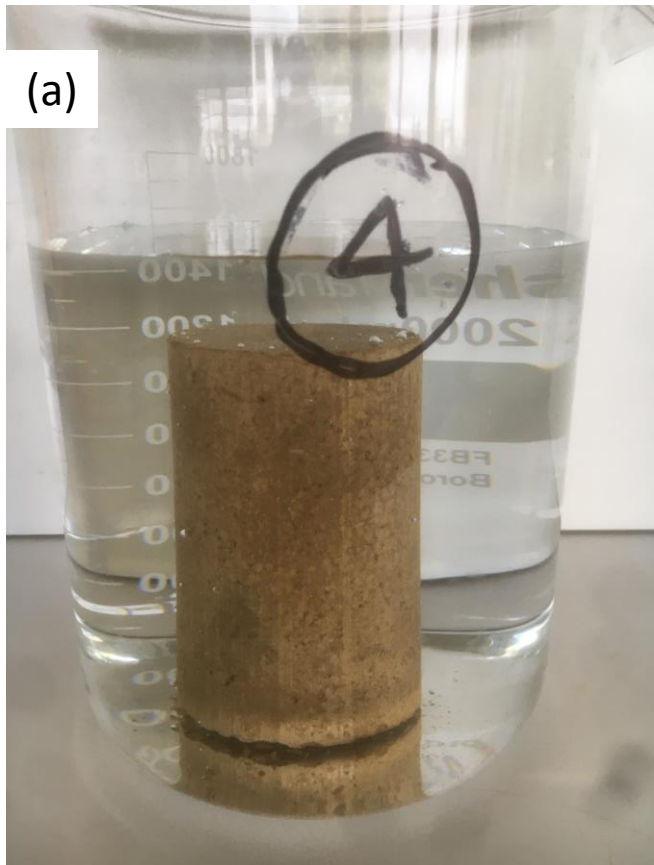




Fig. 4

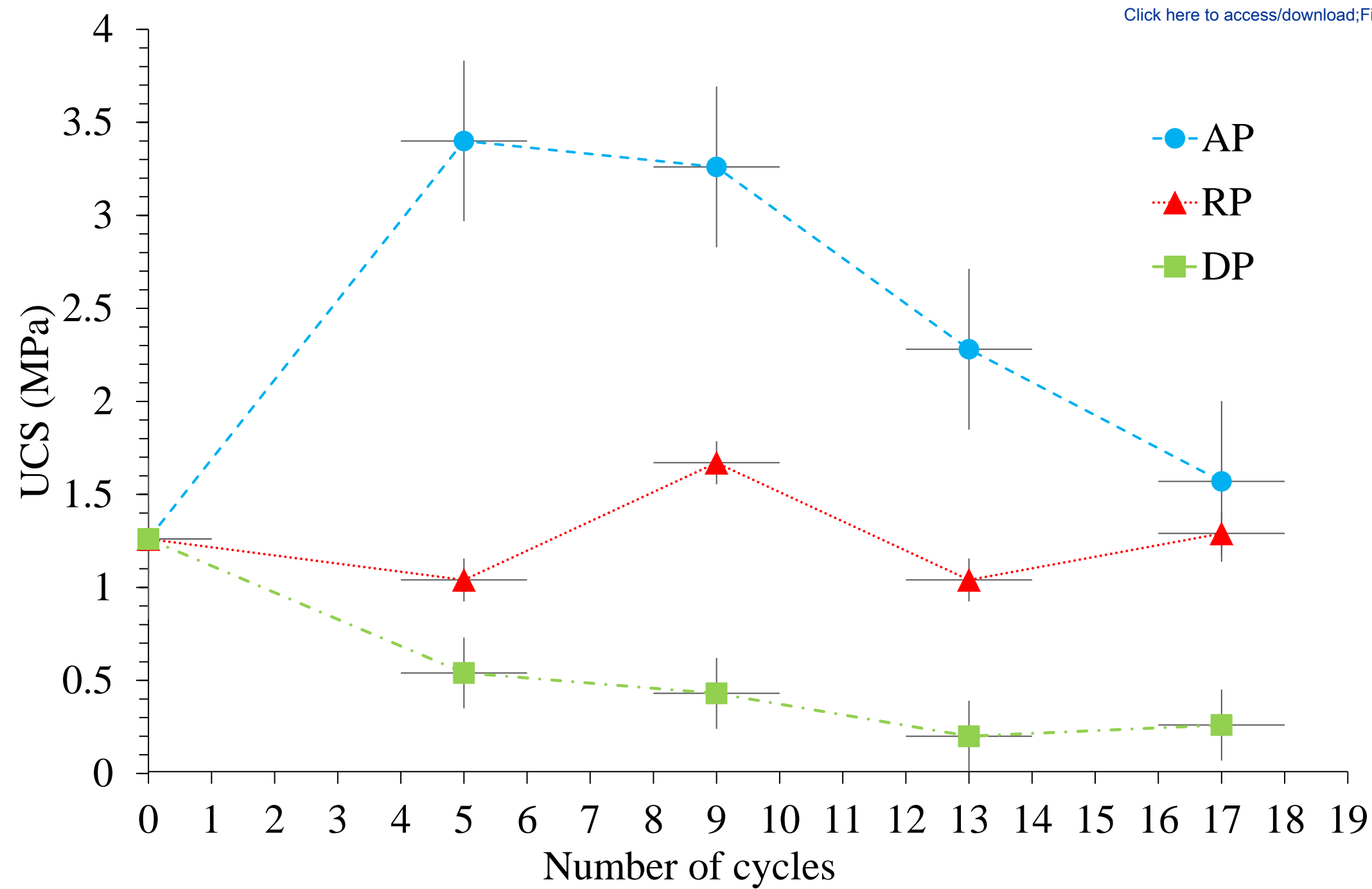
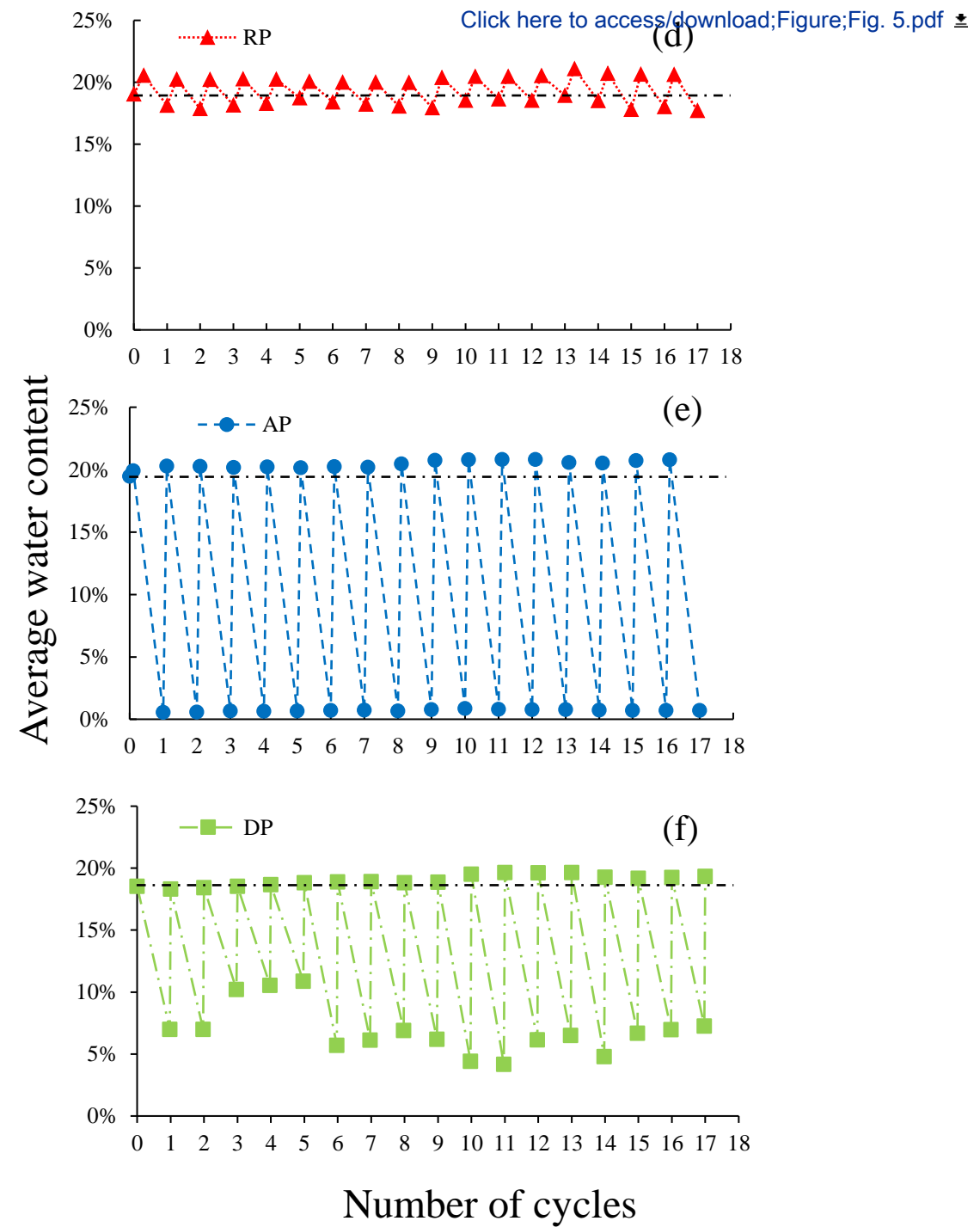
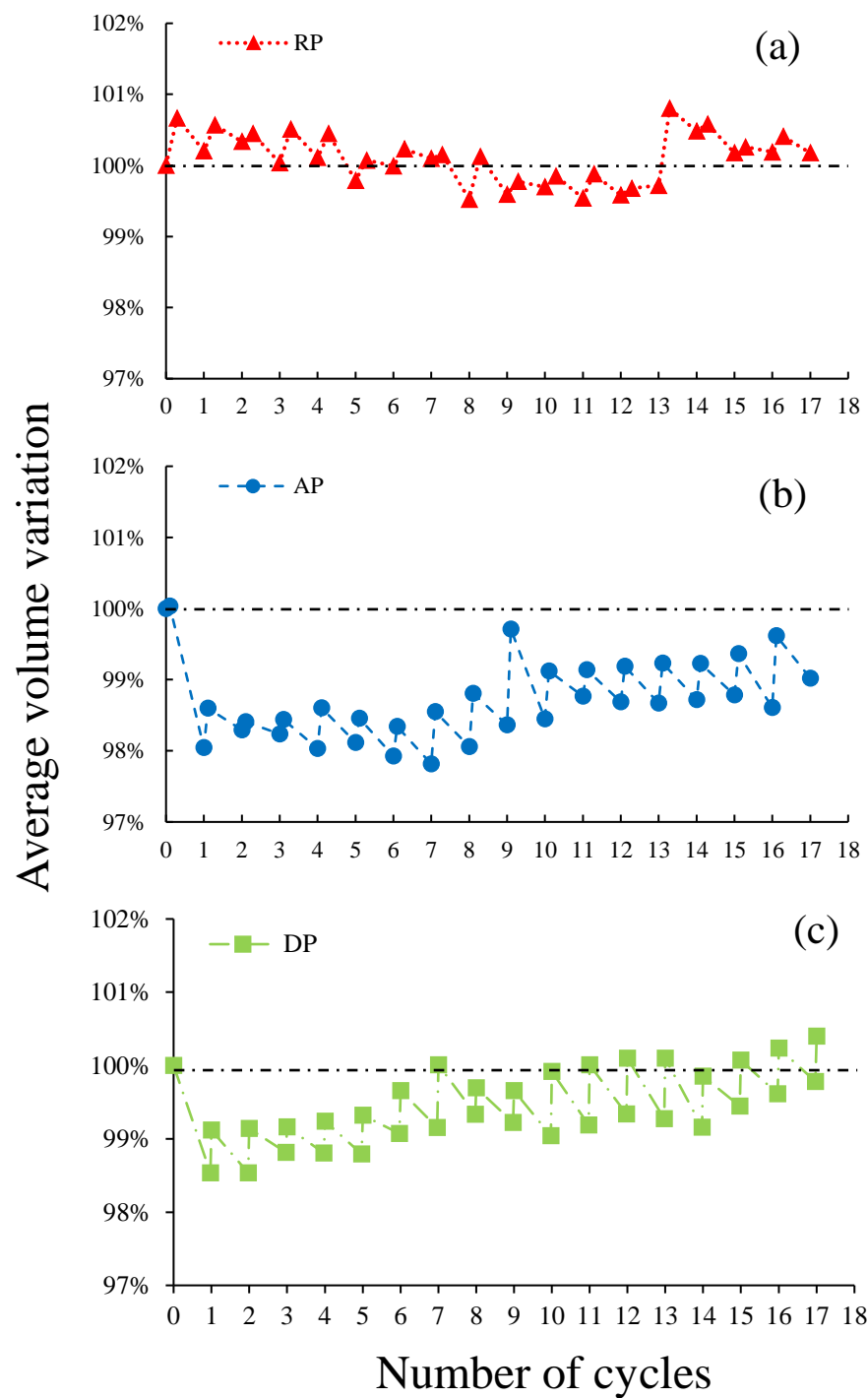
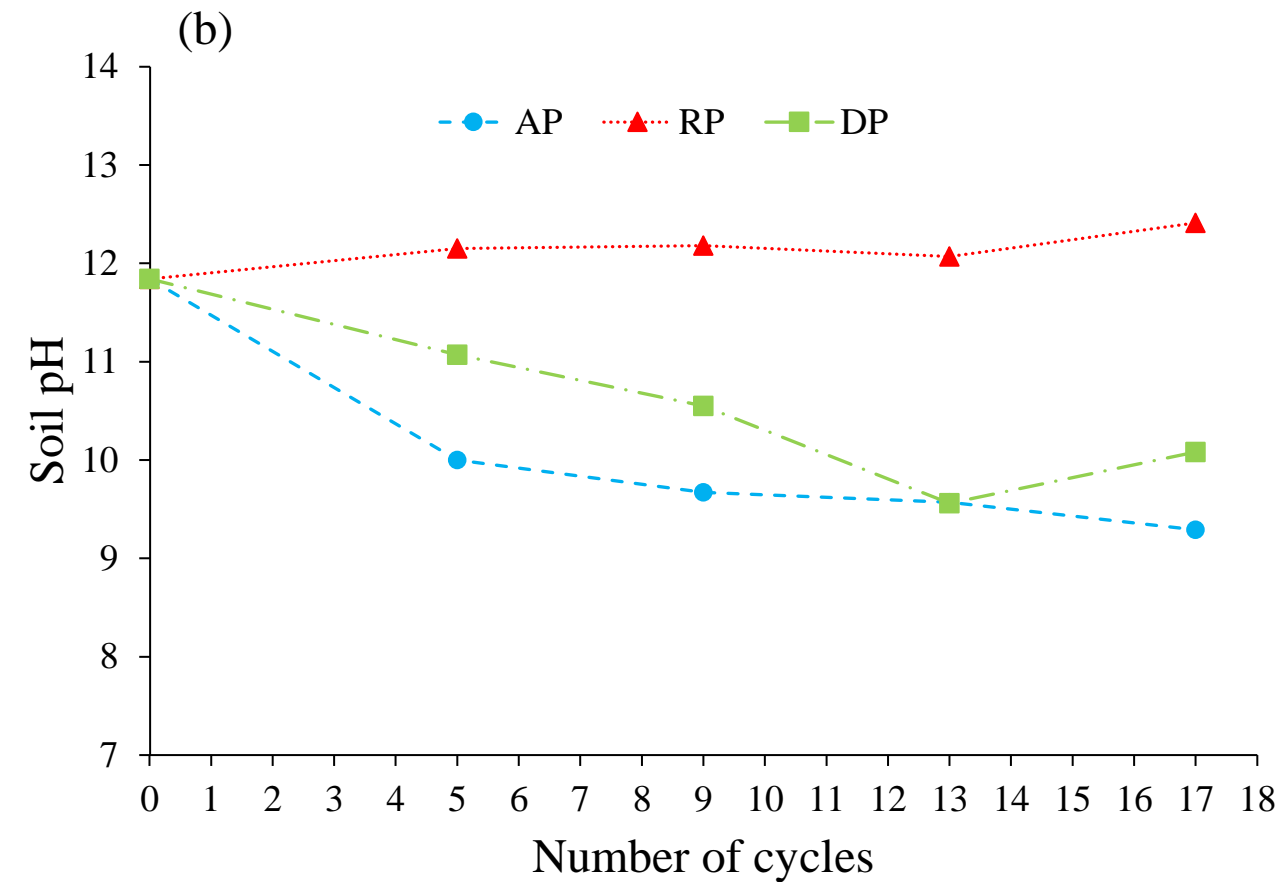
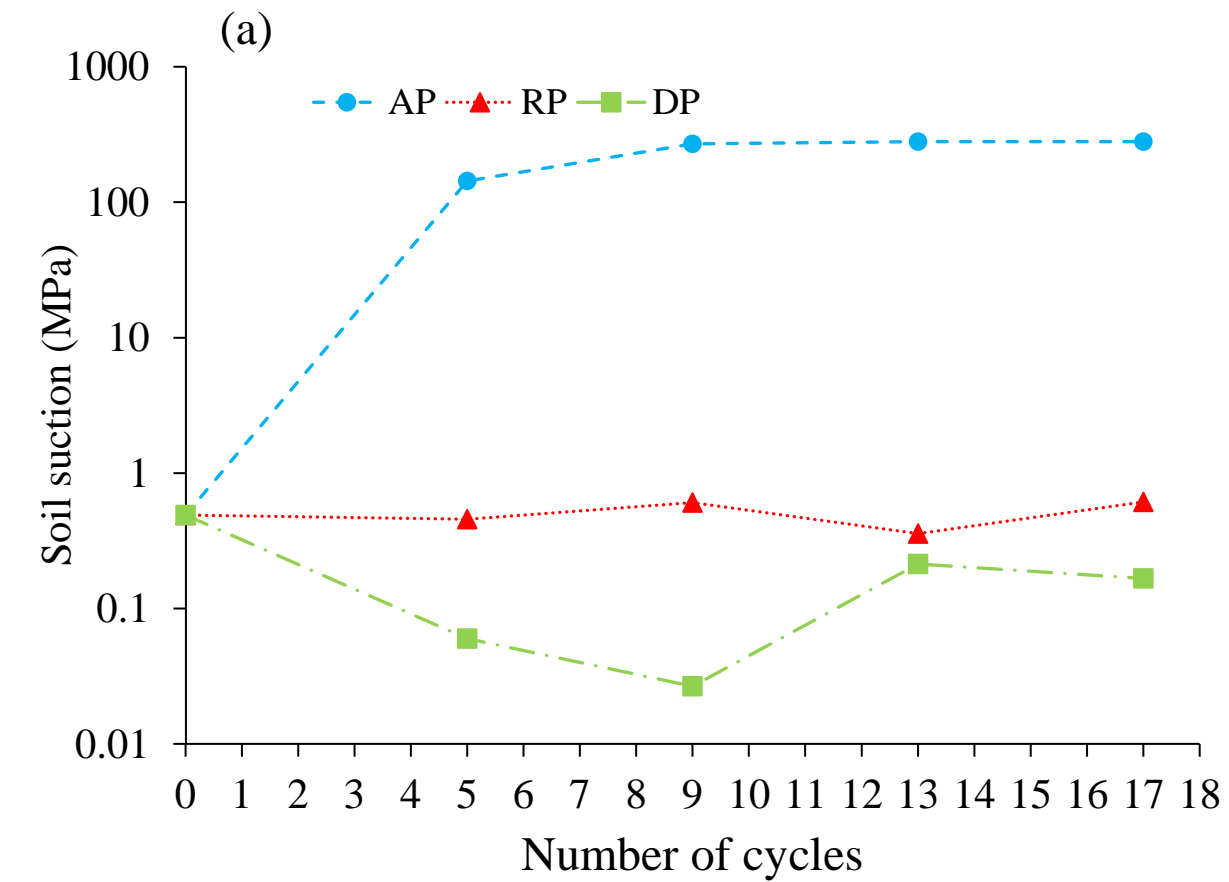


Fig. 5





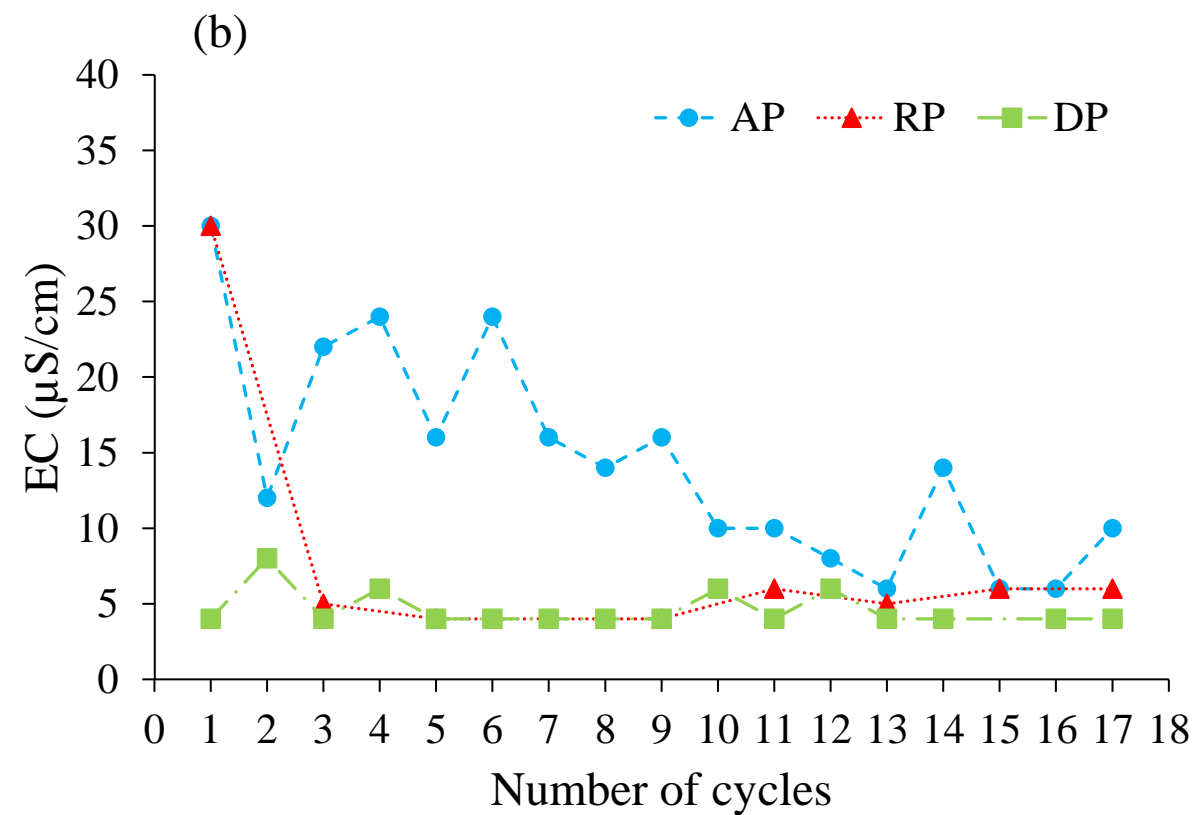
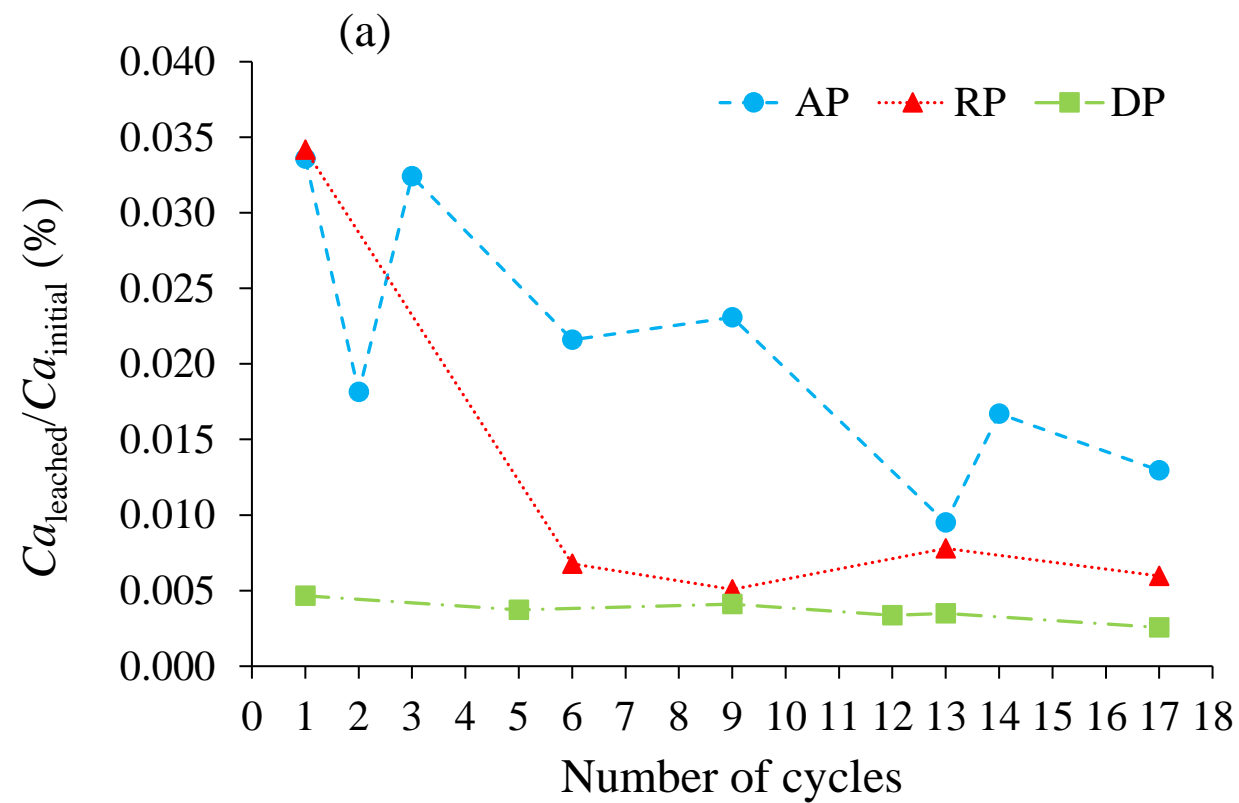
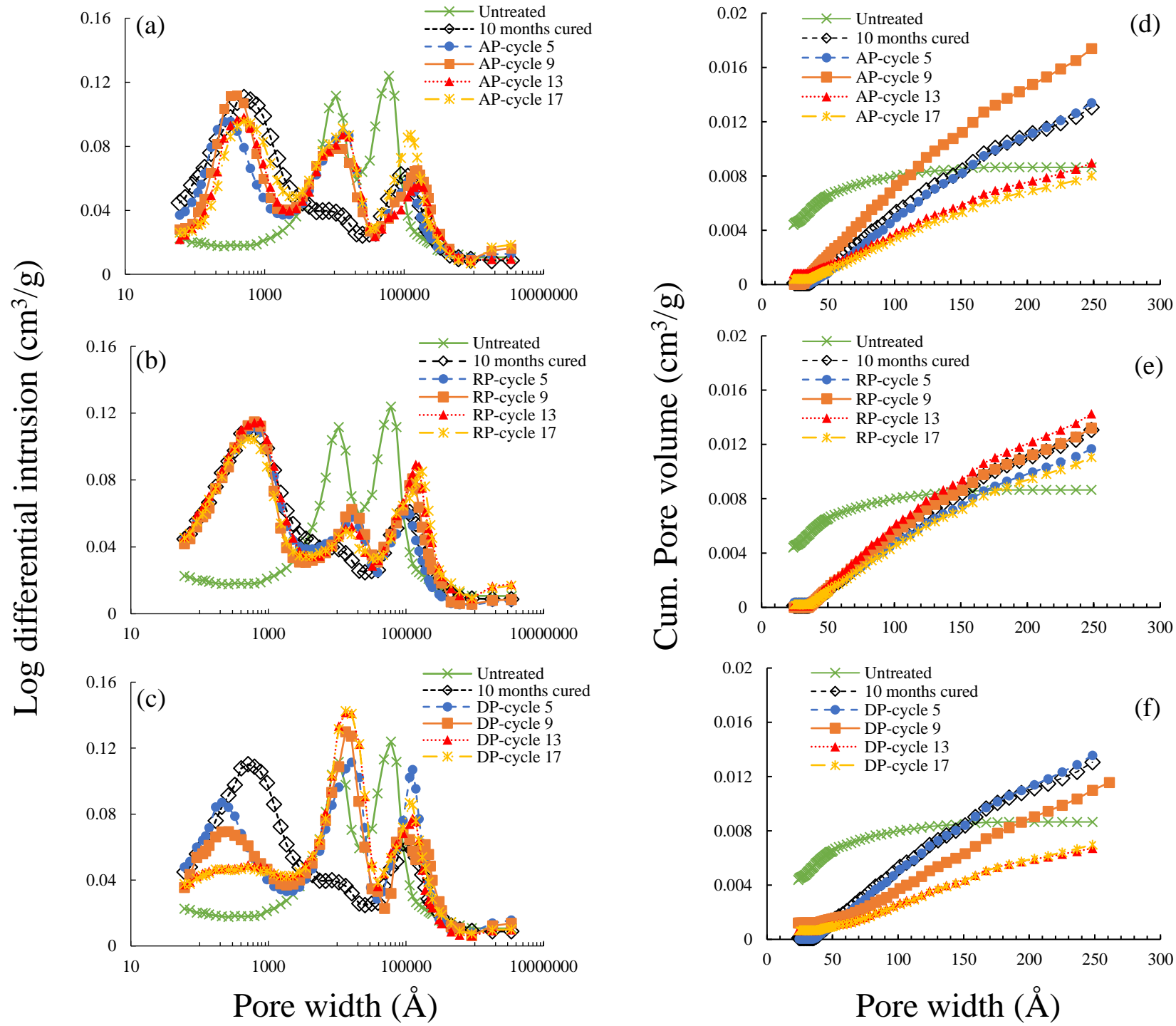




Fig. 8



[Click here to access/download;Figure;Fig. 8.pdf](#)

