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Electrokinetic Stabilisation (EKS) Applications in South-West England, UK: A Lime Electrolyte Case Study

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ABSTRACT: Fine-grained soils are widely present in the UK and form the foundations of many residential properties. However, this type of soil is highly sensitive to fluctuations in water content and can result in issues such as shrink-swell and potential compressibility, thus causing excessive differential settlements under residential properties. This is a significant problem for property-owners across the UK. With future climate change expected to bring greater weather extremes of wet-dry cycles, the impact of shrink-swell and compressibility on properties and infrastructure will worsen. Beside seasonality and shrink-swell behaviour of clay soils, the presence of trees which demand water for their growth can also impact differential settlement of property foundations. The damage to properties will be exacerbated adding further to the costs and disruptions to property-owners. Unfortunately, current methods for managing damage to properties are often disruptive and expensive. Therefore, there is a need for methods that can contribute to managing these risks adequately and electrokinetic stabilisation (EKS) is an innovative method that meets these requirements. Despite having been in use in the UK for about two decades, there is a perception that the construction industry continues to have reservations in adopting the EKS method. This paper will use a case study of direct applications in South-West England to give insights about the effectiveness of the EKS method. The case study will focus on the practicability of applying EKS method to existing residential property under subsidence damage and will demonstrate the method's effectiveness while appraising its minimal disruptive nature.

KEYWORDS: Electrokinetic stabilisation, fine-grained soils, property damage, subsidence, electro-kinesis solution, lime electrolyte.

1 INTRODUCTION

The use of fine-grained soils in construction represents a significant problem in geotechnical engineering. These soils have a specific behaviour in the presence of water. They shrink during dry periods, exasperated by the presence of vegetation, and swell during wetter periods. This means that fine-grained soils are sensitive to the variability of water content particularly when associated with seasonality, which will only get worse with the impact of climate change.

In addition to seasonality, another cause of variation in the ground water content is the presence of trees and vegetation, which demand water for their growth (Roberts, 1976). The presence of trees and vegetation roots in proximity to properties is known to affect fine-grained soils (Biddle 2001; Jones et al., 2009). It has long been established that trees can cause shrinkage in clay soils, leading to subsidence in buildings and structures. For example, Skempton et al. (1954) documented a foundation failure due to clay shrinkage caused by poplar trees.

Where trees effects are thought to be the main causes of seasonal subsidence, common mitigation practices involved either removing the offending tree or preventing root interaction with foundations through underpinning or the installation of root barriers. However, with increasing awareness of climate change and the legislative impact of the Environment Act 2021, tree removal is becoming more difficult and publicly opposed in the UK. Meanwhile, traditional alternatives, particularly underpinning, are often expensive, environmentally intrusive, and highly disruptive to homeowners. Electrokinetic Stabilisation (EKS) offers an innovative solution. By permanently reducing the shrink-swell potential of clay soils, EKS minimizes the influence of tree roots and reduces ground movement to non-damaging levels. This technique presents a sustainable and less disruptive alternative to tree removal or conventional underpinning, aligning with both environmental goals and practical needs in managing subsidence risk.

Generally, expansion rates of about 10% are commonly observed in most expansive clays, and the process is not fully reversible (Holtz and Kovacs, 1981). Moreover, Rayner (2023) reported that properties with tree roots in their vicinity and a geology with more shrinkable soils do have a higher score for subsidence damage hazard and that this is potentially worse when there are no appropriate drainage systems, as shown in Figure 1. Also, Clayton et al. (2010) noted the adverse effects on underground features caused by trees and vegetation. Shrink-swell behavior is one of the main causes of differential settlement, foundation failure and subsidence and these issues have cost the economy approximately £3 billion over the last 25 years, thus making it one of the costliest geohazards in the UK today (Jones and Jefferson, 2024). Furthermore, the Association of British Insurers (ABI) indicates that these claims added up to over £400 million annually (Driscoll and Crilly, 2000).

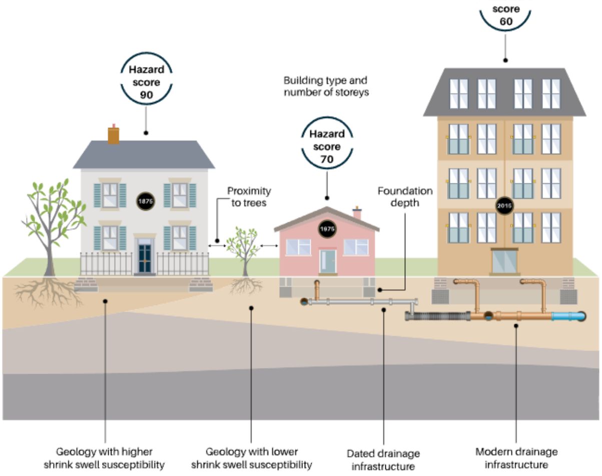

Figure 1. Property subsidence assessment (Rayner, 2023)

1.1 *Expansive soils*

The UK is underlain by significant deposits of fine-grained soils that are subject to problematic expansive behaviour. This type of soil is associated with geological processes developed in the quaternary and associated with glacial mechanisms. Moreover, these soils are characterized by being young geologically and placed in earlier stages of compressibility curves. This also means that they have a greater ability to absorb and lose moisture (Jones and Jefferson, 2024).

The geotechnical challenges posed by these soils have pushed for remediation and stabilization methods to be adopted by industry. However, negative after-effects to fauna and flora are known to be caused by the measures developed and result in nuisance to residents (Lamont-Black et al, 2016). Furthermore, these methods are known to have a high carbon footprint and are also disruptive, expensive and temporary. With the increased impact of the negative effects of climate changes, there is a heightened need for fully sustainable and permanent stabilisation methods to be developed and adopted (Jefferson et al. 2025). This paper will describe the Electrokinetic Stabilisation (EKS) method with a lime additive to the process to treat subsidence on a residential property and demonstrate its potential as a stabilisation method for expansive soils.

2 ELECTRO-KINESIS SOLUTION

Electro-kinesis and electro-osmosis are both electrokinetic phenomena and differ in what moves. Electro-osmosis involves the movement of a liquid due to an electric field acting on a charged surface. On the other hand, electro-kinesis refers to the movement of charged particles within a fluid under the influence of an electric field. Thus, electro-osmosis is a fluid flow, while electro-kinesis is the movement of particles.

Electro-osmosis is a proven method in geotechnics and includes an additive into the soil in the form of direct electrolyte replacement. It improves the soil properties and potentiates mechanisms such as cation exchange in clay minerals and deposition of cementitious materials in pore spaces. This adaptation of electro-osmosis is defined as Electrokinetic Stabilisation.

The application of EKS in geotechnical engineering began with Casagrande in the 1940's (Casagrande, 1949; Casagrande, 1952) while studying electro-osmosis phenomenon and investigating potentials for electroosmotic stabilisation of fine soils. Further research later agreed with Casagrande and demonstrated that electro-osmosis reduces water content and increases shear strength in fine-grained soils, hence benefiting various geotechnical applications such as improvement on pile friction capacity and minimizing expansive clay behaviour (Mitchell and Soga, 2005).

Recently, research carried out at the University of Birmingham successfully proved the feasibility of improving traditional chemical stabilization methods (see Jefferson et al., 2025 for more details). This research also addressed issues around electrode degradation by using carefully selected additives which are transported through clay soils using electrodes. Figure 2 shows the electrokinetics mechanism between anode and cathode electrodes.

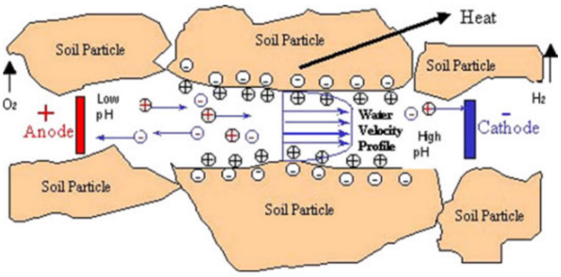

Figure 2. Electrokinetic mechanism

Essentially, EKS is composed of three processes: (1) the electro-osmosis which induces the hydraulic flow by moving pore water through low-permeability soils, (2) the electromigration which describes the movement of ions under an applied electric field, and (3) the electrophoresis which refers to the movement of charged colloidal particles, such as clay minerals.

The rate of ion movement in electro-osmosis depends on factors such as ionic charge, voltage gradient, ion mobility and fluid viscosity. To this end, the main objectives of EKS are the following:

- Reduce plasticity index of soils
- Reducing the potential for shrink-swell ability of expansive clay soils
- Improve performance of fine-grained soils without the need for excavations
- Increase soil's pH values at cathode front to prevent and retard root growth.

2.1 *Effect on clay structure*

The effect of EKS potentiates flocculation of the soil structure which enhances fluid discharge. Flocculation is achieved by disruption of the diffuse double layer (Figure 3), which is caused by pore water movement and cation exchange driven by electro-osmosis.

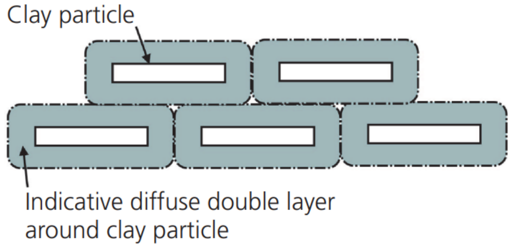

Figure 3. The Diffuse Double Layer is initially deep, causing clay particles to align in a disperse display (Beetham et al., 2015).

However, studies concluded that a thicker diffuse double layer reduces the tendency of particles to flocculate in clay soils (Hiemenz, 1977; Mitchell & Soga, 2005). Therefore, as the electrolyte concentrations increase, it lowers the surface potential (when under constant charge), leading to a faster decay of potential with distance and thinning of diffuse double layer. This promotes particle flocculation and reduces shrink-swell capacity. Therefore, the swelling behavior of clay is strongly influenced by electrolyte concentration.

Clay particles have a negative surface charge which is balanced by hydrated cations within the diffuse double layer.

Divalent cations – such as calcium and magnesium - reduce the thickness of this layer, promoting flocculation as particles reorient into edge-to-face arrangements. This new setting lowers the effective surface area that is in contact with pore water, leading to rapid changes in soil behaviour, as shown in Figure 4.

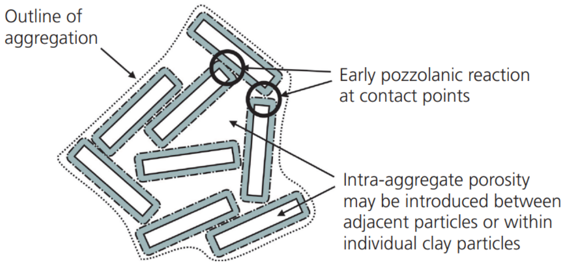

Figure 4. Aggregation of clay particles as diffuse double layer 'buffer' reduction results in repulsion of like charges on clay particles (Beetham et., 2015).

Moreover, it was observed that the Plasticity Index (PI) of natural clay soils originally recorded at 40%, could be reduced due to EKS to just about 8% after treatment, which reflects significant improvement in soil behaviour. This finding agreed with McCarter (1984) who also demonstrated that resistivity increases with increasing liquid limit, reducing moisture content, reducing volumetric water content, and reducing degree of saturation. In clay minerals, isomorphous substitution generates a net negative charge, attracting cations to the particle surfaces and interlayers to maintain electrical neutrality. Many of these cations are exchangeable, and their total is measured as the cation exchange capacity (CEC). Water flows play a critical role in clay behaviour, influencing deformation, volume change, and stability by controlling the rate of these processes.

At the soil-water interface, unbalanced force fields cause interactions among clay particles, dissolved ions, and water. Due to their small size and large surface area, clay particles are highly sensitive to these forces. The balance of interparticle attraction and repulsion governs flocculation, volume change, and strength. Thus, applying principles from surface, colloidal, and soil chemistry is key to understanding and controlling behaviour in clay-water-electrolyte systems. Mitchell & Soga (2005) described the four types of flows that take place during EKS, as shown in Figure 5.

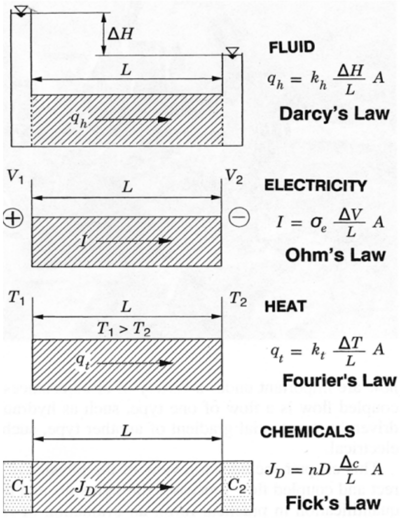

Figure 5. Four types of direct flow (Mitchell & Soga, 2005).

3 CASE-STUDY: BRISTOL, UK

3.1 *Site setting*

A case-study is presented to characterize the effects of EKS. A 4-bedroom detached property constructed in the 1980's, suffered damage in three separate areas at the back and an area of damage at the front. Walls are of cavity brick and block construction under a tile covered timber trussed roof. The ground floor is built from precast concrete beams whilst the first is traditional timber joists and boarding.

The property, shown in Figure 6 is a two-story property founded on 1.4m deep, trench-fill concrete strip foundation. A group of trees is located at the front of the property, and an area of densely broadleaf trees (circa 18m high) is located 20m away from the property. A mature oak tree was present at the rear of the property at 25m distance.

Figure 6. Case study site (A: property receiving EKS treatment)

The site is located within a residential area on the outskirts of the City of Bristol, UK. The ground underlying the property is noted, according to British Geological Survey, as man-made ground overlying bedrock geology of Triassic mudstone (formerly known as Keuper Marl).

However, the ground under the property was found to be underlain by soft clay and, locally firm to stiff with increasing depth. Other claims, equally relating to subsidence, have been noted within the surrounding area. Moreover, laboratory analysis of 12 samples collected within 0.5m of the property and to maximum depth of 2.30m below ground level reported Plasticity Indexes of up to 51%, as shown in Table 1.

Table 1. Soil characterization tests results.

Samples	Depth (m)	WC (%)	LL (%)	PL (%)	Modified PI (%)
1	0.25	30.0	64.0	26.0	39.2
2	1.30	27.0	67.0	26.0	38.3
3	1.80	28.0	68.0	27.0	39.5
4	0.30	22.0	69.0	27.0	34.9
5	1.20	19.0	67.0	26.0	31.3
6	1.00	25.6	72.0	26.0	44.0
7	1.50	21.9	66.0	24.0	34.0
8	2.00	20.7	72.0	26.0	31.0
9	0.30	36.4	80.0	28.0	51.0
10	0.80	29.9	80.0	28.0	51.0
11	1.30	34.3	80.0	28.0	51.0
12	1.80	29.6	73.0	28.0	45.0
13	2.30	32.9	73.0	28.0	45.0

An initial subsidence claim was submitted in November 2017, however, there were descriptions of damage dating earlier than this. Insurers have interpreted the damage as relating to thermal shrinkage and the claims were declined, which eventually led the property-owners to seek alternative methods of stabilization.

3.2 *EKS Installation*

An EKS installation was introduced into the property in 2018, and monitoring is still ongoing at time of writing, with results showing no more level changes (settlement) of the property after treatment (7 years later). The electrodes were installed in a stair array setting around the soil treatment zone (below the property), forming a cats-cradle configuration as illustrated in Figure 7. The EKS installation consisted of:

- Two alternating parallel rows of anodes and cathodes to extend the length of the gable structure
- Electrolyte solutions to be delivered at rates set out in accordance with standard specification
- Electrolyte concentrations in accordance with standard specification: Lime Water 4%, with molecular formula $C_a(OH)_2$ and molecular weight of 74.09. Also available as saturated solution of 25 litres containing less than 3% of calcium hydroxide.
- Rate of delivery of electrolytes monitored daily
- Power supply via solar panels and charge monitored daily
- Ventilated weather protecting canopy installed across full area of electrode array
- Perimeter pet-proof demountable fencing surrounding the treatment area.

The use of lime in the process has been cumulatively reported over the period of 73 days, as shown in Figure 8. However, the figure does not report data from cathode 6 (C6). This was due to the presence of a Cornbrash subsoil or in other words the presence of limestone bands or intrusions within an otherwise shrinkable clay soil. Therefore, C6 was a 70mm auger hole which could not penetrate beyond 1.4m below the ground level. This was both an isolated and localized feature. Fortunately, the cats-cradle configuration of the EKS as shown in Figure 7 can confirm that the remaining electrode pairings were effective and C6's performance in isolation did not significantly affect the treatment of the shrinkable clay soil below the house.

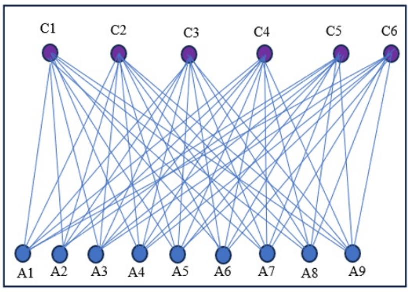

Figure 7 Illustration of the effective treatment zone (where each cathode is paired with each anode)

According to Jones (2009), effectiveness of EKS treatment can be assessed (indirectly) by resistivity measurements. Improvement of resistivity of the soil can be an indication of reduced moisture which, in its turn, is an indication of increased strength (McCarter, 1984). In this case, the outcomes of the EKS treatment are presented through resistivity heat maps (Table 2 and Table 3) to highlight the resistivity to electrical current between each cathode and each anode, henceforth throughout the treatment zone below the foundation of the property.

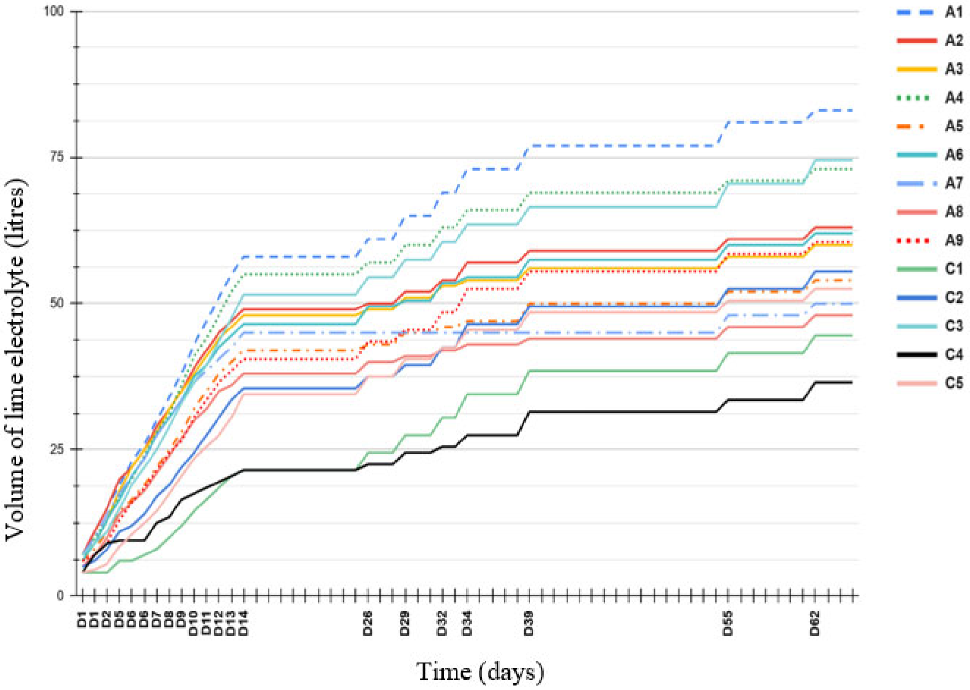

Figure 8 Cumulative lime usage over time (A: anode, C: cathode)

Therefore, each cathode forms a radial network with each anode. This array attempts at optimizing distance between electrodes ensuring the zone of EKS influence is applied equally to the treatment area.

4 RESULTS

According to Jones (2009), effectiveness of EKS treatment can be assessed (indirectly) by resistivity measurements. Improvement of resistivity of the soil can be an indication of reduced moisture which, in its turn, is an indication of increased strength (McCarter, 1984). In this case, the outcomes of the EKS treatment are presented through resistivity heat maps (Table 2 and Table 3) to highlight the resistivity to electrical current between each cathode and each anode, henceforth throughout the treatment zone below the foundations of the property.

To facilitate the visibility of the changes in resistivity that the ground was experiencing following progressive chemical reactions between electrolyte and clay soils, and the effect of the passing electrical current, a color code was designed. Since the resistivity of clay soils is usually around 35 Ohm-meters (Ω.m), and expecting that the first day treatment was not going to change this hugely, it was decided to use light green for values of resistivity less than 50 Ω.m, dark green for resistivity ranging from 50 – 70 Ω.m, amber to resistivity ranging from 71 – 90 Ω.m, pink to resistivity ranging from 91 – 110 Ω.m, and red to values of resistivity above 110 Ω.m. Ranges of resistivity for color codes were deliberately decided based on the minimum and maximum changes in resistivity that could be recorded within one or two days between electrodes, which was found to be up to 20 Ω.m, maximum.

To this end, the resistivity between electrodes was measured daily up to the 73rd day when there were no further changes to the resistivity values, suggesting that the optimum strengthening of the soils had been achieved. Table 2 shows day 1 data and Table 3 shows day 73 data. Overall, soil resistivity is shown to have increased following treatment. Increases in resistivity were also recorded at the cathode 4, which gave erroneous data of resistivity from the beginning due to possible faults of the electrode that led to quick corrosion attack. These results show that the addition of stabilizer enhances the effectiveness of the EKS system, offering clear geotechnical stabilization benefits. The electrolyte used supports the electro-osmosis process, and when used together with EKS technology, the treatment becomes more effective. Moreover, the electrolyte usage during the treatment period was recorded. Cumulatively, higher quantities were consumed at anode 1 with about 86 litres used and this reduced progressively to anode 9 with about 59 litres used during the treatment period.

Table 2. Resistivity results after Day 1 of EKS treatment

Day 1	C1	C2	C3	C4	C5	C6
A1	48	34	42	93	31	33
A2	45	31	36	101	31	30
A3	45	31	36	102	31	30
A4	47	33	38	106	34	32
A5	45	31	36	103	32	31
A6	45	33	36	105	33	31
A7	45	31	36	105	32	31
A8	46	32	36	105	32	31
A9	44	31	35	104	31	29

Colour	Light green	Dark green	Amber	Pink	Red
Resistivity	<50	50-70	71-90	91-110	+ 110

Table 3. Resistivity results after Day 73 of EKS treatment

Day 73	C1	C2	C3	C4	C5	C6
A1	143	122	126	113	110	93
A2	238	193	188	89	40	49
A3	140	110	111	103	94	107
A4	130	110	112	107	92	97
A5	221	198	197	175	150	97
A6	73	63	69	73	98	62
A7	124	116	106	104	68	99
A8	289	275	263	255	215	228
A9	204	184	162	169	142	147

Colour	Light green	Dark green	Amber	Pink	Red
Resistivity	<50	50-70	71-90	91-110	+ 110

Table 4 Rate of improvement % (based on resistivity records)

	C1	C2	C3	C4	C5	C6
A1	299	358	302	122	350	281
A2	528	615	521	88	129	165
A3	312	353	311	101	301	352
A4	278	336	298	101	272	302
A5	489	635	552	170	470	317
A6	162	194	190	70	302	203
A7	276	369	297	99	211	315
A8	630	854	729	243	664	733
A9	460	595	466	163	457	500

5 DISCUSSION

The case-study has demonstrated the successful application of EKS treatment with use of lime as an additive to fine-grained soils. During the treatment time, cumulative electrolyte usage ranged from about 30 liters to 50 liters at each of the anodes.

Based on the improvements in the resistivity records as indicated in Table 2 and Table 3, it was observed that resistivity improvement between six cathodes and nine anodes were significant, as shown in Table 4. The maximum record for resistivity improvement was 854% registered between C2 and A8, followed by 729% between C3 and A8. Similarly, the minimum effective resistivity improvement was 129% between C5 and A2, followed by 162% between C1 and A6. The variation in performance between electrodes could be mainly a result of variations in soil properties. However, the data from electrodes with shortcomings was not used while benchmarking the amount of improvement.

Therefore, the percentage improvement from C4 and from C6 were not deemed to be the best examples of effective improvement due to shortcomings at these cathodes as explained previously. For example, cathode 4 generally shows lower percentages of improvement or resistivity after treatment due to erroneous higher readings of resistivity on day 1, which initially decreased before increasing again throughout the treatment time. Percentages of resistivity improvement at this cathode ranged from 88% between C4 and A2 to 243% between C4 and A8. It should be noted that an investigation indicated that this cathode failed immediately after the installation and was heavily corroded and damaged by the end of the treatment. Therefore, it was reasonable for its data not to be considered as a benchmark for analysis for the effectiveness of the treatment.

On the other hand, cathode 6 was hampered by the presence of limestone and did not reach the full desired depth of treatment below the foundations. This suggests that treatment improvement records from this cathode were above the foundation level and therefore another reason to not consider this as effective treatment. Resistivity improvement between cathode 6 and the nine anodes ranged from 165% between C6 and A2 to 733% between C6 and A8. Significant increases in resistivity registered generally between electrodes were reflected in the reduction of the rate of downward movement of the property after EKS treatment as this was reported in Jefferson et al. (2025).

The case study in this paper shows that a simplified EKS setup results in significant and lasting improvement to ground conditions. These results show that EKS can be applied to foundations and limit the negative impact of vegetation and trees. The method strengthens the soils and modifies their structure, hence significantly reducing soil's potential to shrink-swell behavior and the ability of tree roots to penetrate soils. Moreover, the following can be said as resulting from the EKS treatment of shrinkable soils at this site:

- Effective combination of methods: the integration of EKS with lime (as the chosen electrolyte) proved more effective than either technique used alone in stabilising an expansive clay soil.
- Moisture and plasticity reduction: significant reduction in moisture content was achieved via electro-osmosis, while the PI dropped from 40% to 8% thus improving the soils geotechnical behaviour.
- Preservation of oak tree: the EKS method allowed successful ground treatment without the need to remove large trees.
- Innovative and non-invasive approach: the EKS system, powered by solar panels and utilising controlled electrolyte injection delivered sustainable, low-impact treatment suitable for residential areas.
- Scalable and replicable solution: the success of the Bristol case-study suggests the technique is adaptable for use in other sites with similar expansive soil problems and environmental constraints.

6 CONCLUSIONS

The application of Electrokinetic Stabilisation (EKS), combined with lime additive, at the case study site proved highly effective in addressing the challenges posed by problematic fine-grained soils. The method significantly reduced the moisture content and lowered the Plasticity Index, enhancing the geotechnical properties of the soil. This was achieved without the need for disruptive excavation or removal of mature vegetation, making it an ideal and sustainable solution for sensitive residential environments.

The chemical and physical improvements brought by lime addition, promoted by electro-osmosis and ion migration, resulted in permanent structural changes within the clay matrix. Monitoring through resistivity mapping and level measurements confirmed the success and progression of the treatment. This case supports EKS with lime as a practical, and replicable method for stabilising active clay soils in areas where traditional ground improvement techniques may not be practical.

Finally, it is demonstrated that EKS could be more cost-effective and sustainable as a non-destructive method that requires no extra use of cement or concrete, and destruction of the damaged property to access the ground below the foundations. Furthermore, EKS can be adapted to alternative sources of energy such as solar power to generate electricity to feed the system. This means that the system can be fed internally and help avoid potential interruption of the treatment process due to short-circuiting of the main electricity supply systems to which geotechnical engineers have no control.

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