Influence of MSW leachate contamination degree on soil shear behavior

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Abstract:

This investigation assesses the influence of leachate contamination on the shear strength of soil and its microstructural implications over a six-month period. Employing a combination of macroscopic shear tests and microscopic SEM analyses, the study interprets the dynamic interactions between soil stability and varying leachate concentrations. Shear strength parameters, including peak and residual friction angles, alongside cohesion, were measured at leachate concentrations of 5%, 10%, 15%, 20%, and 25% relative to the soil's dry weight. The results indicate a decrement in both friction angles with increased contamination, while cohesion initially rises at lower contamination levels, peaking at 15%, before deteriorating. SEM imaging reveals significant microstructural transformations, highlighting the chemical and physical alterations in the soil matrix. These microstructural changes correspond to the observed macroscopic mechanical behavior, with increased contamination compromising the mechanical interlocking critical for soil shear strength.

Keywords: Leachate, Soil contamination, Shear parameters, SEM

1. Introduction

In the contemporary era marked by exponential urban growth and industrial proliferation, society faces serious environmental challenges when it comes to waste management. The most common waste management strategy adopted worldwide is landfilling. Consequently, environmental regulations have evolved to require landfill designs to incorporate inclusive isolation barriers aimed at reducing leachate penetration to the subsurface and reducing the contamination risk. Despite these measures, the threat of environmental accidents that can develop is still reported in the literature.

Understanding the interaction between soil mechanics and environmental contaminants in leachate is essential for the safety and stability of structures in contaminated areas, especially with the reintegration of former landfills for community use as parks and green places. The infiltration of leachate into the subsurface can significantly affect the shear strength of soils, a fundamental parameter that dictates the soil's ability to resist shear stress and, consequently, its structural integrity(Mosavat and Nalbantoglu, 2013; Moody and Townsend, 2017). This modification also raises significant environmental concerns due to the potential for hazardous substances to migrate and impact the surrounding environment. Therefore, a comprehensive investigation into the shear strength parameters of leachate-contaminated soil is essential for assessing the risks associated with land development and formulating effective soil remediation strategies(Shariatmadari *et al.*, 2018; Khodary *et al.*, 2021).

This paper is part of extensive research on the influence of municipal solid waste (MSW) leachate contamination on soil behavior. It focuses on the leachate influence on soil shear parameters. This investigation offers a cautionary framework for both environmental and geotechnical engineering methodologies in addressing the complexities of waste management and soil contamination.

1. Method:

1.1. Leachate characteristics:

This study focuses on soil shear strength alterations due to leachate contamination, and for that, the leachate used for the testing was directly taken from the leachate collecting system of the Pusztazámor landfill in Hungary in order to preserve its initial characteristics. The chemical properties of the used leachate are given in Table 1.

Table 1 : Leachate characteristics (CODcr= Dichromate oxygen consumption; BOI5= Biological Oxygen Demand; TIN =Total inorganic N; ASS= All suspended solids; P= Total phosphorus; TDS= Total dissolved salts ; Fe= Iron; F = Fluoride; S =Sulfides)

Tested parameter	**pH**	**Conductivity**	**CODcr**	**BOI5**	**TIN**	**ASS**	**P**	**TDS**	**Fe**	**F**	**S**
Unit	-	µS/cm	O_2 mg/L	mg/L	N mg/L	mg/L	mg P/L	mg/L	mg/L	mg/L	mg/L
	8,9	25900	7110	1280	2070	753	8,9	12300	5,6	<5	47.8

1.2. Soil characteristics

The soil used in this experiment was collected from the same landfill, typical of that region and very abundant, used as leveling soil and daily cover. The samples were subject to rigorous geotechnical testing to determine their properties, essential for the study of leachate impact on shear strength. Table 2 summarizes their characteristics.

Table 2: Soil characteristics

Property	**Sand**	**Silt**	**Clay**	**K**	**C**	**fi**
Value	30.14%	55.59%	10.73%	6.428×10^{-7}	10.3 (kPa)	36.5°

1.3. Test program

This study presents a comprehensive evaluation of how various leachate concentrations affect the shear strength of soil in a 6-month time frame. this experimental setup offers a thorough analysis of leachate's impact on soil, combining both macroscopic mechanical tests and microscopic structural examinations.

Soil samples were mixed with leachate in concentrations of 5%, 10%, 15%, 20%, and 25% relative to the soil's dry weight. This range was chosen to cover an extensive array of contamination scenarios. Rigorous mixing ensured an even distribution of leachate within the soil.

Post-preparation, the samples were stored at a steady laboratory temperature of 25°C in airtight containers. This was crucial to isolate them from external variables such as atmospheric composition, oxygen, and light, which could potentially modify their characteristics. The samples were conditioned over six months to maintain a consistent interaction between the soil and leachate.

After the conditioning period, the soil samples were subjected to shear strength tests using a 60mm x 60mm direct shear apparatus, in line with the ISO 17892-10:2018 standards. The samples underwent a series of loads under normal stresses of 50, 100, 200, 300, 400, and 500 kPa to assess the impact of leachate concentration on the soil's shear resistance.

To further understand the changes in shear strength, Scanning Electron Microscopy (SEM) was employed on selected samples. This analysis aimed to reveal the microstructural changes due to leachate interaction, linking these changes to the overall mechanical behavior of the soil. This multi-scale analysis approach provides a more in-depth understanding of the soil's response to contamination.

2. Results

2.1. Shear parameters

The influence of leachate concentration on the shear strength parameters of the soil was examined over a six-month conditioning period. Incremental additions of leachate to soil samples showed a discernible impact on both the friction angle and cohesion of the soil, as illustrated in Figure 1.

For clean soil, the friction angle (Fi) was observed at its maximum. However, with the introduction of leachate at concentrations ranging from 5% to 25%, a marginal decrement in the friction angle was noted. The trend was not strictly linear but indicated a general inclination towards reduced friction angles as the concentration of leachate increased, suggesting a diminution in the soil's intrinsic resistance to shear deformation.

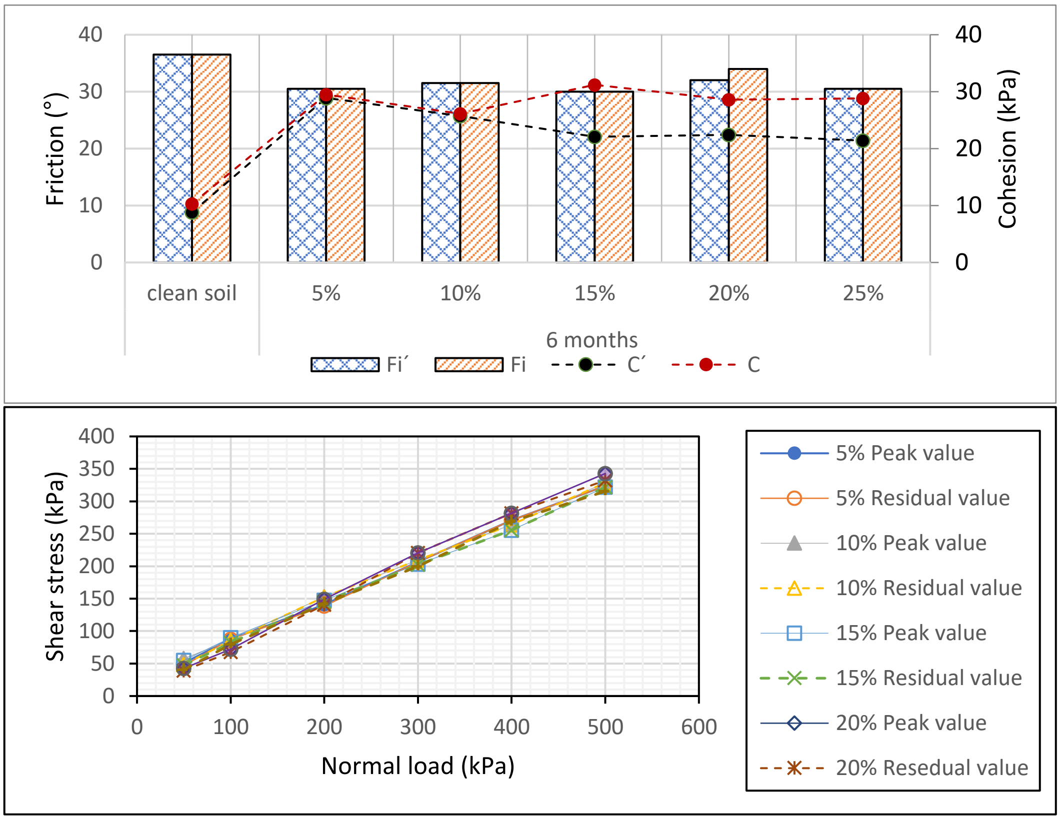

Figure 1: Shear parameters of contaminated soil (A: Cohesion and friction angle of clean and contaminated soil; B: Shear envelope)

Conversely, peak cohesion (C) values exhibited an initial increase, peaking noticeably at a 15% leachate concentration, which suggests a threshold level at which the leachate-induced interparticle forces contribute positively to the soil's cohesive strength. Nonetheless, a subsequent decline in cohesion was recorded at concentrations beyond 15%, alluding to a potential oversaturation effect that undermines the aggregative forces within the soil matrix. On the other hand, residual cohesion values, despite the increase compared to the initial clean soil cohesion, displayed a different liner trend of reduction after a remarkable peak at 5% of the contamination rate.The disparity observed between the peak and residual cohesion values is attributable to the interaction between the soil and the leachate, which facilitated the formation of new soil bonds. However, these newly established bonds were insufficiently robust to withstand the applied shearing forces. These founding are in accordance with several results reported in the literature(Shrihari and Nayak, 2009; George and Beena, 2011; Sujatha *et al.*, 2013).

2.2. SEM:

The Scanning Electron Microscopy (SEM) analysis provided a stark portrayal of the microstructural evolution in soil samples subjected to varying degrees of leachate contamination. The SEM images, presented in Figure 2, effectively illustrate the progression from pristine to contaminated soil conditions and the ensuing microstructural transformations.

Panel A captures the baseline condition of the clean soil, characterized by a relatively uniform and undisturbed matrix of soil particles. The granular integrity and lack of agglomeration serve as a control against which the effects of contamination are measured.

Panels B and C reveal the onset of particle agglomeration in soils with increasing leachate contamination. This agglutination is a direct reflection of the cohesive forces at play, induced by the leachate, which is also suggested by the enhanced cohesion values observed in the shear strength tests. The extent of this agglomeration is more pronounced as we progress from Panel B to C, indicating a higher degree of contamination and suggesting a correlation with the observed increase in cohesive strength noted in our mechanical tests.

Panels D and E depict a noticeable shift in the soil structure with clear signs of surface alteration and corrosion. The integrity of individual soil particles appears compromised, with the particle surfaces exhibiting signs of disintegration. This degradation is symptomatic of the chemical interactions between the leachate and the soil constituents, potentially contributing to the observed decrease in the soil's friction angle.

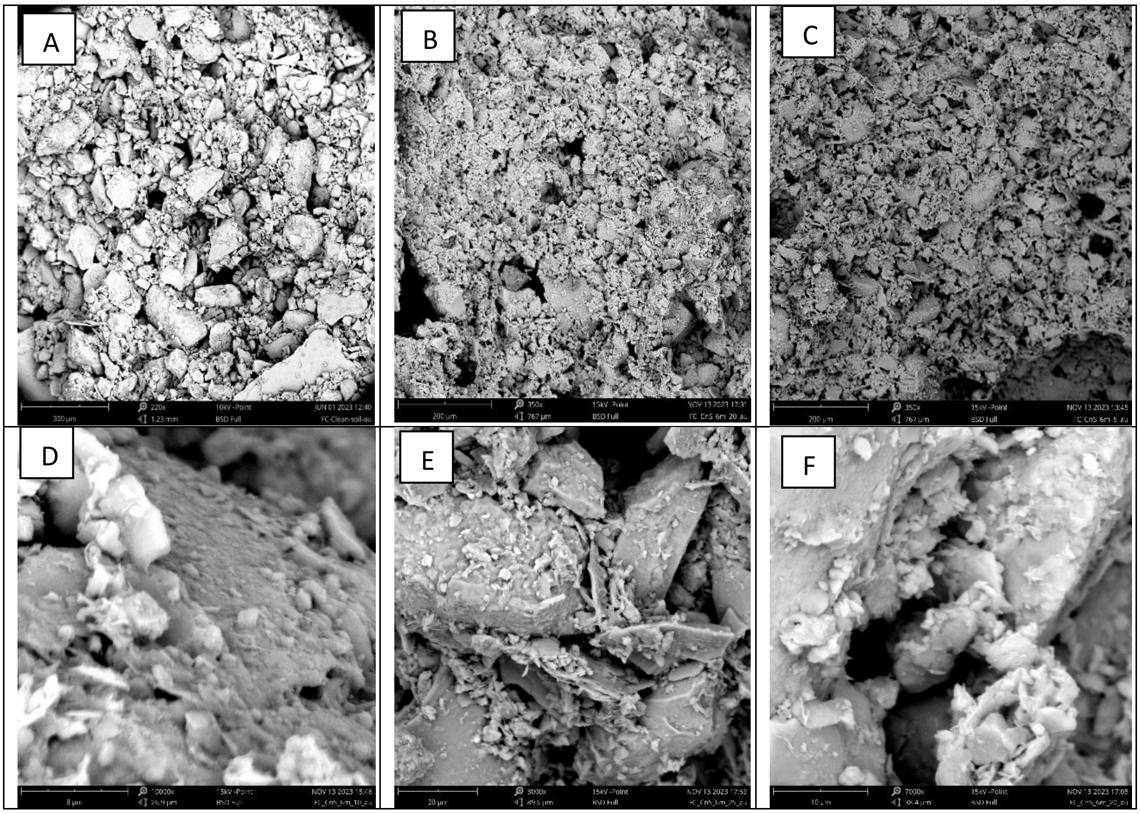

Figure 2: SEM results (A: Clean soil, B and C: agglomeration of contaminated soil; D and E: Soil particles alteration and corrosion; F: new mineral crystals formation)

Panel F illustrated an advancing formation of new mineral crystals throughout the specimens. The emergence of these crystals was significantly more evident in samples subjected to higher levels of contamination. Specifically, at a contamination intensity of 25%, these crystalline structures seemed to enhance the soil matrix's robustness. Similar results were reported by Sitaram et al., and Oztoprak and Pisirici (Shrihari and Nayak, 2009; Oztoprak and Pisirici, 2011).

3. Conclusion:

The experimental investigation has yielded pivotal insights into the interaction between leachate contamination and soil stability, with direct implications for environmental safety and landfill management. The study presents a multifaceted picture of how varying degrees of contamination modulate soil behavior:

A complex pattern of cohesion is observed. Regardless of the degree of contamination, the cohesion registered was much higher than the clean soil. Nevertheless, an initial increase at lower contamination levels suggests enhanced particle bonding, followed by a decrease at higher levels of contamination. An optimal contamination threshold, identified at a 15% leachate concentration, enhances soil cohesion, likely due to chemical interactions among soil particles. Beyond this concentration, the beneficial effects are surpassed by detrimental impacts on new soil integrity.

SEM analyses have uncovered alterations within the soil, including the formation of novel mineral crystals at elevated levels of contamination. Leachate-induced microstructural changes in soil, particularly at higher contamination levels, including the formation of novel mineral crystals at elevated levels of contamination. These changes manifest as a reduction in interparticle friction, undermining the soil's inherent shear strength and an increase of cohesion. The findings indicate a critical contamination threshold (15%), exceeding which may lead to a deterioration of the soil's structural and mechanical characteristics.

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