

Evaluating the Extent and Impact of Saltwater Intrusion on Polyacrylamide-Treated Coastal Earth Embankment Soil

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ABSTRACT

Prolonged inundation is a common issue in coastal Bangladesh, leading to significant erosion and failure of earthen levees during major cyclonic events. To enhance the stability of earthen levees, non-traditional stabilizers, particularly polymers, are replacing conventional stabilizers due to their lower environmental impact, such as reduced CO₂ emissions. While many studies have focused on soil strength improvement with polymer stabilizers, limited research addresses the interaction between saltwater and chemically stabilized earth embankments. This study investigates the effects and degree of saline water intrusion on polymer-stabilized soil, specifically using Polyacrylamide (PAM) as the stabilizing agent. Soil samples collected from the coastal region of Bangladesh were treated with PAM at dosages of 0.0 g/L (control), 0.2 g/L, 0.4 g/L, and 0.6 g/L. The treated soil samples were compacted, cured for 28 days, and then submerged in saltwater tanks with 25, 30, and 35 PPT concentrations. Moisture content, pH, and electrical conductivity (EC) were monitored using reliable sensors over a 72-hour period. Preliminary results indicate that PAM treatment significantly affects the interaction between soil and saline water, with varying PAM concentrations influencing the outcomes. This research provides insights into the sustainable application of polymer-based soil stabilization in marine coastal environments and suggests potential directions for future studies.

Keywords: Polyacrylamide (PAM), Saltwater Intrusion, Earth Embankments, Soil Erosion Control

1 INTRODUCTION

Floodplain regions like Bangladesh are particularly vulnerable to coastal erosion and embankment failures due to frequent flooding and cyclonic events. Traditional earthen embankments often lack the resilience needed to withstand these extreme conditions. In response, chemical stabilizers such as cement, lime, and fly ash have become essential for strengthening these structures. While numerous studies have highlighted the strength-enhancing properties of polyacrylamide (PAM) (Shahriar et al. 2024; Mase et al. 2023; Georgees et al. 2020; Kou et al. 2021), as well as the water retention capacity of PAM-treated soils (Wang et al. 2024), the research on the interaction of chemical stabilizers with saltwater remains limited.

PAM is increasingly used in nature-based solutions, notably for reducing runoff and mitigating soil erosion in slope stabilization projects (Flanagan et al. 2002). Saltwater intrusion, however, can significantly alter soil behavior, impacting both the stability of embankments and the effectiveness of nature-based solutions such as non-saline vegetation. This preliminary study investigates saltwater intrusion patterns in both treated and untreated soils by monitoring parameters such as moisture content and electrical conductivity, aiming to provide insights into the sustainable application of PAM in marine coastal environments.

2 MATERIALS AND METHODS

2.1 Materials

The soil samples for this study were collected from a coastal embankment in Banshkhali, Chattogram, Bangladesh, after removing the topsoil up to a depth of 0.5 meters. The collected soil was air-dried and mechanically crushed to prepare it for testing. Based on the Unified Soil Classification System (USCS), the soil is classified as Fat Clay with Sand (CH) with a composition of 49% silt and 23% clay. The soil's Liquid Limit (LL) is 56%, Plastic Limit (PL) is 22.4%, and Plasticity Index (PI) is 33.6%.

For pH and electrical conductivity (EC) measurements, the RS485 5-pin sensor was used due to its reliability in agricultural applications. Soil moisture was monitored using the MS10 Soil Moisture Sensor.

2.2 Soil Sample preparation

To systematically assess the impact of different PAM concentrations on soil behavior under saline conditions, the experimental design was organized into four main groups, each subjected to varying levels of saline water concentration.

Table 1 outlines the specific groups, their sample designations, the concentrations of PAM used, and the salinity levels tested.

Table 1. Salinity intrusion test groups, PAM concentrations, and tested salinity levels.

Case	Sample Designation	PAM Concentration (g/L)	Salinity (PPT)
PS	PS_25PPT, PS_30PPT, PS_35PPT	0	25, 30, 35
PTS2	PTS2_25PPT, PTS2_30PPT, PTS2_35PPT	0.2	25, 30, 35
PTS4	PTS4_25PPT, PTS4_30PPT, PTS4_35PPT	0.4	25, 30, 35
PTS6	PTS6_25PPT, PTS6_30PPT, PTS6_35PPT	0.6	25, 30, 35

Each sample was compacted in PVC tubes, measuring 10.61 cm in diameter and 12.00 cm in height, targeting a density range between 1.5 and 1.66 g/cm³. This compaction method was carried out in three distinct layers to ensure even distribution. To facilitate the study of saline water intrusion, an additional tube segment of 12 cm was clamped to the top of each filled tube. This setup allowed the intrusion of saline water at concentrations of 25, 30, and 35 PPT through free gravitational flow into the soil samples. Sensors to monitor moisture content, electrical conductivity (EC), and nutrient content (NPK) were installed at one-third the height from the bottom of each tube to effectively capture changes within the soil.

Fig. 1 illustrates the experimental setup, showing the arrangement of the PVC tubes and sensor placements, providing a visual explanation of the methodology described.

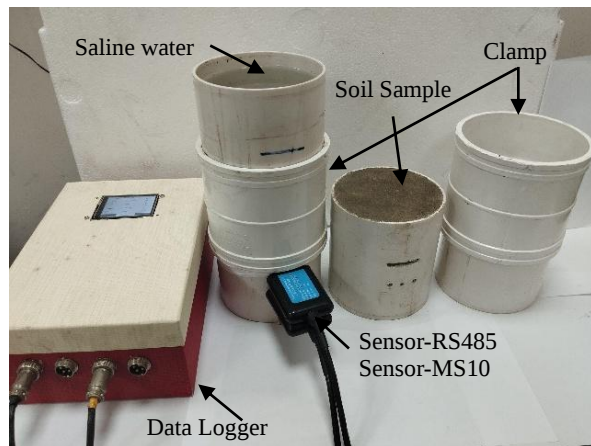


Fig 1. Experimental setup.

3 RESULTS AND DISCUSSION

The pH measurements across different samples did not show significant variations, indicating that the PAM treatment and salinity levels had a minimal impact on the soil's pH. Table 2 summarizes the pH ranges observed in the different test cases.

Table 2. pH ranges of samples.

Case	pH Range		
	25 PPT	30 PPT	35 PPT
PS	5.7 - 7.6	5.8 - 7.5	5.6 - 7.6
PTS2	5.8 - 7.5	5.6 - 7.5	5.7 - 7.7
PTS4	5.6 - 7.6	5.7 - 7.5	5.6 - 7.6
PTS6	5.7 - 7.7	5.7 - 7.6	5.5 - 7.5

Figure 2 illustrates the moisture content trends for soils at 35 PPT salinity, showing varied responses to different Polyacrylamide (PAM) concentrations. Due to the representative nature of the moisture content results across varying conditions, this abstract focuses on the 35 PPT salinity level as it exemplifies the general trends observed at lower salinities as well. Untreated soil (PS_35PPT) maintains high moisture, peaking at 45%. Soils treated with PAM, particularly PTS1_35PPT, demonstrate a moderately high increase in moisture, with a peak above 55%. In contrast, higher PAM concentrations (PTS2_25PPT and PTS3_25PPT, green and orange lines) show lower moisture content, stabilizing below 40%. This pattern suggests that PAM's effectiveness in reducing water intrusion enhances as its concentration increases, attributable to its impact on soil structure. PAM promotes flocculation and soil aggregation, leading to improved soil drainage and reduced waterlogging, despite the osmotic pull of saline water.

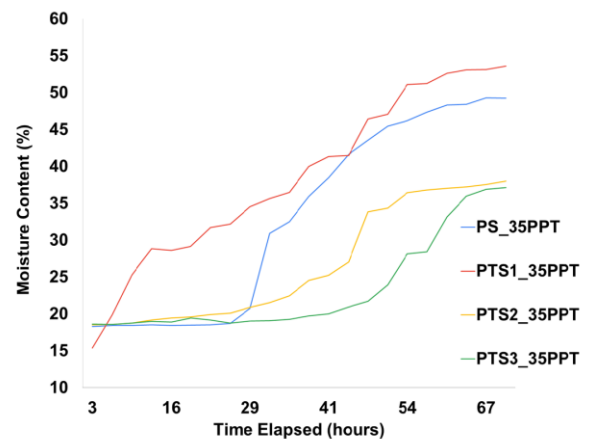


Fig 2. Variation of moisture content over time during saltwater intrusion testing.

Fig. 3 shows the electrical conductivity (EC) trends for soils treated with different concentrations of Polyacrylamide (PAM) across 25, 30, and 35 PPT salinity levels. It is evident from Fig. 3 that electrical conductivity (EC) increases over time for all treatments. Notably, EC rises more significantly with higher concentrations of Polyacrylamide (PAM), particularly in the 30 and 35 PPT experiments. This suggests that PAM interacts with the saline solution, potentially facilitating greater ionic mobility and conductivity in the soil.

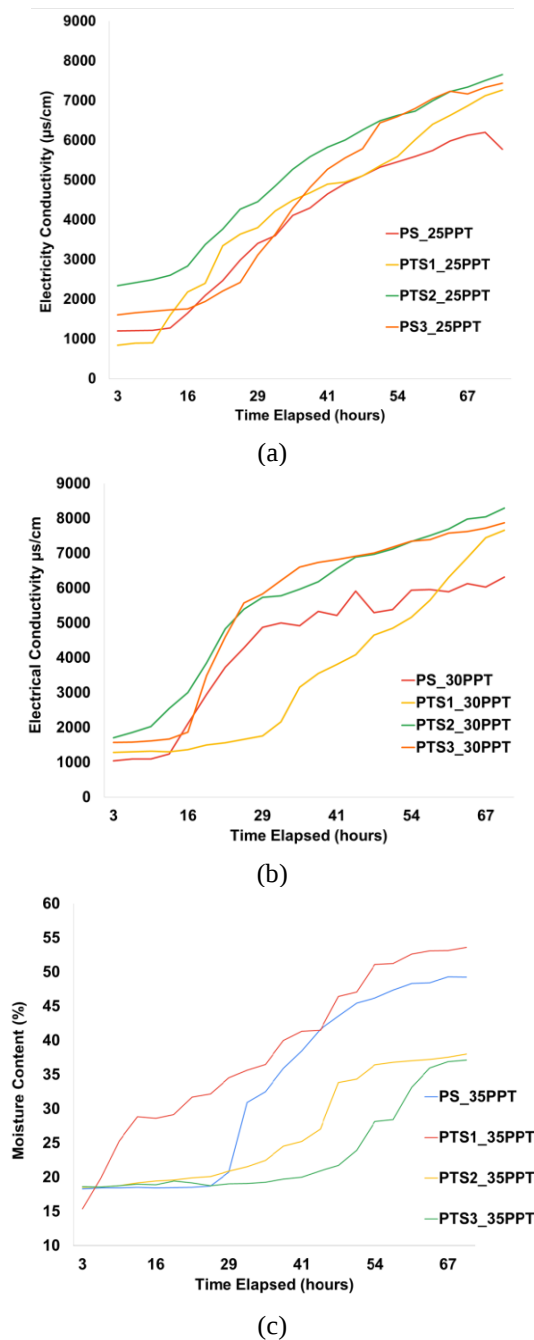


Fig 3: EC variation over time for a) 25 PPT b) 30 PPT and c) 35 PPT

The trends observed indicate that while PAM influences soil properties, its presence notably increases the soil's electrical conductivity, especially at higher salinity levels. These findings demonstrate PAM's

significant impact on soil's electrical properties, which could have implications for soil health and plant growth in saline-affected areas. The enhanced electrical conductivity suggests increased ionic activity, which may affect nutrient availability and osmotic pressure in the soil environment.

4 CONCLUSIONS

This study assessed the effects of Polyacrylamide (PAM) on the electrical conductivity (EC) and pH of coastal embankment soil under varying salinity conditions, finding that PAM significantly increases EC, especially at higher concentrations and salinity levels, while pH levels remain stable. The increase in EC suggests that PAM enhances ionic mobility within the soil, which could affect soil-water interactions and potentially lead to salinity stress that impacts agricultural viability. These results underscore the importance of carefully managing PAM applications to balance its beneficial effects on soil properties with the potential risks associated with increased soil conductivity in saline environments.

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