Piping Phenomena & Erosion Control in Fragile Terrains Soil Piping Mechanism in Flow Slide Prone Areas

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Abstract

Flow slides, prevalent in areas with steep slopes and loose soil or rock, pose significant environmental and social challenges. Soil piping, also termed internal erosion, is both a geomorphological and a land degradation process with severe implications for the environment. This research aims to elucidate the mechanisms of soil piping across diverse soil types and develop mitigation strategies through synthetic and biological methods. Soil samples, including sand, peat, and Kuthiran soil, were analyzed using a constant head hole erosion test to study erosion behaviors. The results indicate that using synthetic abatement (modified polysaccharides) and bio-abatement (vesicular arbuscular mycorrhizae) enhances soil stability and reduces piping. This study highlights eco-friendly and sustainable approaches to combat soil erosion.

Keywords: Soil Piping, Modified Polysaccharides, Versicular Arbuscular Mycorrhizae

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1. Introduction

Soil piping, also known as tunnel erosion, refers to the subsurface erosion of soil by percolating water, leading to the formation of underground conduits. These conduits, commonly a few millimeters to several centimeters in diameter, expand over time due to continuous erosion. As they grow, they compromise land stability, potentially causing surface subsidence and making land unsuitable for agriculture or construction. This process is often hidden and may go unnoticed until substantial damage occurs. Piping is particularly prevalent in fine-grained materials like claystone, mudstone, and siltstone, where weak layers allow water flow to erode the soil.

Figure 1: Soil Piping

During periods of rainfall, infiltrating water carries finer silt and clay particles, creating subsurface passageways. These "pipes" initially measure only a few millimeters to centimeters in diameter but can expand to a meter or more over time.

They may develop near the ground surface or extend several meters below. Once formed, they progressively enlarge due to ongoing erosion, which can result in roof collapses and surface subsidence. Because these processes occur underground, they often go unnoticed until significant damage has occurred. The cavities, or pipes, increase in size over time, leading to extensive land subsidence, rendering the affected areas unsuitable for agricultural use. In some cases, subsurface water flow may generate conduits within relatively insoluble deposits. This phenomenon causes the caving and collapse of surface structures and contributes to the headward extension of gullies, particularly in arid and semi-arid regions. Fine-grained materials such as alluvium, colluvium, and specific rock types like claystone, mudstone, and siltstone are particularly susceptible to piping. The process typically involves a weak, incoherent soil layer that becomes saturated, facilitating water flow toward a free face. This free face might be the wall or head of a gully, the head cut of a landslide, or a human-made excavation. Although pipes are small initially, they form conduits that are far more permeable than the surrounding soil or rock.

1.1. Objectives of the Study

- This study focuses on the following objectives:
- To understand the mechanisms underlying soil piping.
- To evaluate the efficacy of bio-abatement techniques in reducing soil piping.
- To study piping behavior across various soil types.
- To compare the effectiveness of synthetic and bio-abatement methods.

1.2. Scope of the Study

The research investigates soil piping erosion mechanisms and proposes mitigation strategies, emphasizing eco-friendly and economical solutions. The hypothesis is that organic components within soil reduce erosion progression. Laboratory tests simulate piping conditions, aiming to:

- Improve soil stability.
- Enhance vegetation.
- Mitigate landslides and environmental destruction.
- Foster sustainable land use practices.

2. Materials and Methods

2.1. Materials Used

The various materials used in the experimental program are described below.

Sand

Sand samples were coolected from IES College of Engineering air-dried, and analyzed for grain size distribution using IS: 2720-part 4.

Figure 2: Sand

Kuthiran Soil

Landslides continued for the second consecutive day on the face of the Kuthiran. Kuthiran Soil Samples from Kuthiran, Thrissur, known for frequent landslides, were air-dried and subjected to erosion testing.

Figure 3: Kuthiran Soil

Peat Soil

Peat Soil Organic-rich peat soil from Kallur, Thrissur, was tested for its natural resistance to erosion.. The organic soil was collected from Kallur, Thrissur (Fig.4).

Figure 4: Peat Soil

Versicular Arbuscular Mycorrhizae

VAMF is (Fig.5) symbiotic fungus, known for enhancing soil quality by improving aggregate stability and reducing erosion, was utilized.

Figure 5: Versicular Arbiscular Mycorrizha

Modified Starch

Plant-derived modified starch (Fig.6) was employed for its enhanced stability properties under various environmental conditions.

Figure 6: Modified Starch

2.2. Experimental Setup

First, find out the basic properties of the soil samples. Fig.7 shows the experimental setup. The experimental setup was based on the constant-head hole erosion test, which simulates soil piping by creating preformed holes in soil specimens. The test apparatus included clear acrylic molds, allowing visual observation of erosion progression. Soil samples were treated with varying percentages of VAMF and MS to assess their erosion resistance.

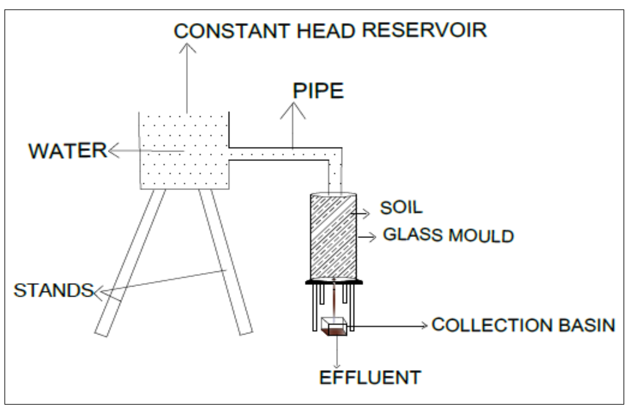

Figure 7: Erosion Test Setup

3. Results and Discussion

Soil Properties

The basic properties of sand, Kuthiran soil, and peat soil were determined using standard laboratory methods (Tables 1–3). The basic properties of the sand were determined as per IS specifications and the resultsare given in the table.1.The table provides essential soil properties, which help in understanding the characteristics and behavior of sand under different conditions:

Uniformity Coefficient (Cu): A value of 3.29 indicates the range of particle sizes in the sand. A higher Cu suggests a wider distribution of particle sizes, which can enhance soil stability. Coefficient of Curvature (Cc): The Cc value of 1.70 reflects the gradation of particles. This value confirms that the sand is well-graded, supporting its classification. Gradation of Sand: Classified as SW (Well-Graded Sand), the sand exhibits a good range of particle sizes, which improves its compaction and load-bearing capacity. Specific Gravity: With a value of 2.65, the specific gravity is typical for quartz-based sands, indicating the material's density relative to water. Maximum and Minimum Dry Densities: The maximum dry density of 1.775 g/cc and minimum dry density of 1.747 g/cc define the range of densities achievable under different compaction conditions. Relative Density (Dr): The given densities for 30%, 50%, and 70% relative density (1.755, 1.760, and 1.766 g/cc respectively) demonstrate the variation in density with compaction effort, providing insights into the sand's structural properties. Permeability: The permeability value of 7.30×10−47.30 \times 10^{-4}7.30×10−4 cm/sec indicates the sand's ability to allow water flow. This moderately high permeability is typical for well-graded sands and implies good drainage properties.

Properties	**Value**
Uniformity coefficient, C_u	3.29
Coefficient of curvature, C_c	1.70
Gradation of sand	SW
Specific gravity	2.65
Max. dry density (g/cc)	1.775
Min. dry density (g/cc)	1.747
Sand density (Dr -30%)	1.755
(Dr -50%)	1.760
(Dr -70%)	1.766
Permeability(cm/sec)	7.30×10^{-4}

Table 1: Basic Properties of Sand

Table 2 shows the properties of Kuthiran soil from various laboratory tests. ·

Specific Gravity: The value of 2.28 indicates the density of soil particles compared to water. This relatively lower specific gravity suggests the presence of lightweight soil particles or organic content. Sieve Analysis (Cu): A uniformity coefficient of 11.05 shows a wide range of particle sizes, suggesting that the soil is well-graded. This distribution improves its compaction and engineering properties. Liquid Limit (LL): At 45%, the liquid limit defines the water content at which the soil transitions from a plastic to a liquid state. This value indicates moderately plastic soil. Flow Index (FI): A flow index of 9% reflects the rate of decrease in shear strength as water content increases, signifying moderate sensitivity to moisture variations. Plastic Limit (PL): The plastic limit of 15% marks the water content below which the soil remains in a semi-solid state. Plasticity Index (PI): The PI of 17% (calculated as the difference between LL and PL) indicates the range of water content over which the soil exhibits plastic behavior. This value suggests moderately plastic soil. Maximum Dry Density (MDD): The MDD of 1.615 g/cc represents the maximum achievable dry density of the soil under standard compaction, reflecting its compaction potential. Optimum Moisture Content (OMC): At 25%, the OMC is the water content at which the soil achieves its maximum dry density. This indicates the soil requires a relatively high moisture content for effective compaction. Permeability: With a value of 7.45×10−47.45 \times 10^{-4}7.45×10−4 cm/s, the soil has moderate permeability, allowing water to flow through at a reasonable rate. Undrained Shear Strength: The shear strength of 55.4 kN/m² signifies the soil's resistance to deformation under undrained conditions, providing an indicator of stability under short-term loading conditions.

PROPERTIES	**VALUES**
Specific gravity	2.28
Sieve analysis, Cu	11.05
Liquid limit	45%
Flow index	9%
Plastic Limit	15%
Plasticity index	17%
Maximum dry density (g/cc)	1.615
Optimum moisture content	25%
Permeability (cm/s)	7.45×10^{-4}
Undrained shear strength	55.4 kN/m^2

Table 2: Basic Properties of Kuthiran Soil

Table 3 shows the properties of Peat soil from various laboratory tests.

Specific Gravity: A value of 1.895 indicates a relatively low particle density compared to water. This suggests the presence of lightweight soil particles, possibly due to organic matter or highly porous materials.Sieve Analysis (Cu): The uniformity coefficient of 9.75 represents the particle size distribution. This indicates the soil has a fairly wide range of particle sizes, making it well-graded and potentially improving its compaction characteristics.Liquid Limit (LL): At 59%, the soil has a high water content threshold before transitioning to a liquid state. This indicates high plasticity and significant sensitivity to moisture.Flow Index (FI): A flow index of 22% reflects a considerable reduction in shear strength as water content increases. This shows the soil is highly sensitive to changes in moisture.Plastic Limit (PL): The plastic limit of 49% represents the minimum water content where the soil remains plastic. This high value aligns with the soil’s high water retention capacity.Plasticity Index (PI): The PI of 10% (difference between LL and PL) indicates the soil has low plasticity. Despite the high liquid and plastic limits, the small PI suggests a narrow range of plastic behavior. Maximum Dry Density (MDD): The maximum dry density of 1.38 g/cc reflects the soil's compaction potential. The relatively low value indicates the soil is lightweight and not particularly dense. Optimum Moisture Content (OMC): The OMC of 29% shows that the soil requires a high moisture level to achieve maximum compaction, characteristic of fine-grained or organic soils. Permeability: With a value of 2.26×10−42.26 \times 10^{-4}2.26×10−4 cm/s, the soil has moderate to low permeability, suggesting water movement through the soil is limited but not negligible. Undrained Shear Strength: A shear strength of 25.2 kN/m² indicates the soil's resistance to deformation under undrained conditions is relatively low, making it less stable under short-term loading.

PROPERTIES	VALUES
Specific gravity	1.895
Sieve analysis, Cu	9.75
Liquid limit	59%
Flow index	22%
Plastic Limit	49%
Plasticity index	10%
Maximum dry density (g/cc)	1.38
Optimum moisture content	29%
Permeability (cm/s)	2.26×10^{-4}
Undrained shear strength	$25.2 kN/m^2$

Table 3: Basic Properties of Peat Soil

3.1 Erosion Rate

By conducting constant head hole erosion tests in each type of soil sample by adding modified starch and versicular arbuscular mycorrhizae.

Sand

The erosion rate of sand is represented graphically in Fig. 9. By adding various percentages of modified starch in sand, the erosion rate is varied. The minimum erosion rate is obtained at 16% corresponding to 24% of modified starch. In case of versicular arbuscular mycorrhizae, the erosion rate is reduced to 13% corresponding to 12% versicular arbuscular mycorrhizae.

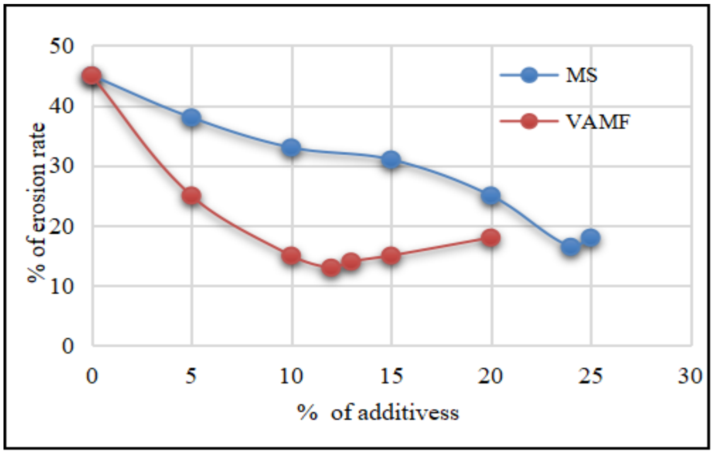

Figure 9: Erosion Rate of Sand

Kuthiran Soil

The erosion rate of kuthiran soil is represented graphically in Fig. 10. By adding various percentages of modified starch in the soil, the erosion rate varies. The minimum erosion rate is obtained at 9% corresponding to 10% of modified starch. In the case of versicular arbuscular mycorrhizae, the erosion rate is reduced to 5% corresponding to 3% versicular arbuscular mycorrhizae

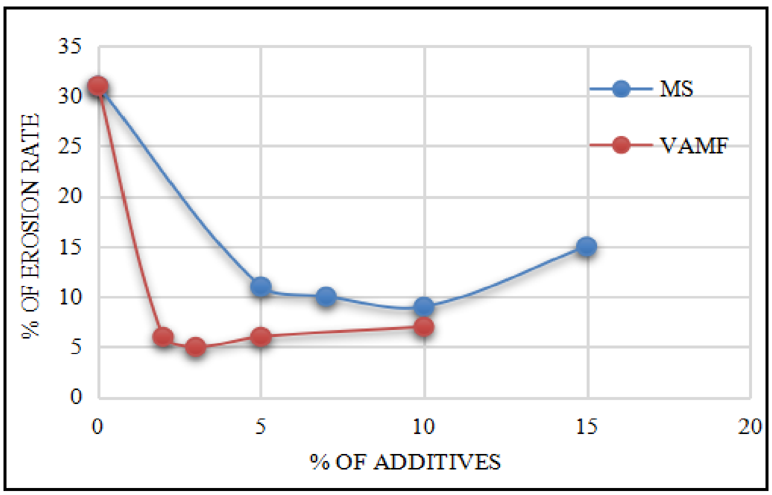

Figure 10: Erosion Rate of Sand

Peat Soil

The erosion rate of peat soil is represented graphically in Fig. 11. By adding various percentages of modified starch in soil, the erosion rate is varied. The minimum erosion rate is obtained at 5.3% corresponding to 2% of modified starch. In case of versicular arbuscular mycorrhizae, the erosion rate is reduced to 3% corresponding to 2% versicular arbuscular mycorrhizae.

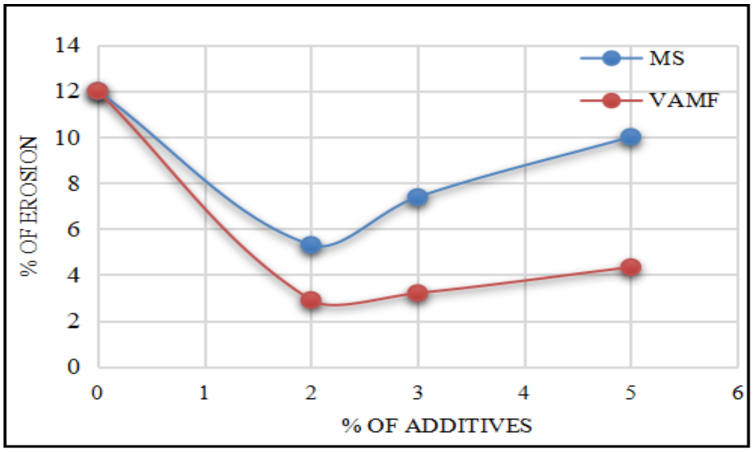

Figure 11: Erosion Rate of Peat Soil

By comparing the erosion results, the versicular arbuscular mycorrhizae have a better effect compared to modified starch. That means soil piping can be mainly reduced by adding VAMF. From the 3 soil specimens, peat soil has less erosion rate. Because they contain organic matter more.

The erosion index in each soil corresponds to the percentage of additives shown in the table.4

SAMPLES	0% Additives	M S (%)	VAMF (%)
Sand	45	16	13
Kuthiran Soil	31	9	5
Peat Soil	12	5.3	3

Table 4. Erosion Index

Figure. 12 shows the graphical representation of the erosion index in each soil corresponding to the percentage of additives. The graph illustrates the erosion rate (%) for three types of soil—sand, Kuthiran soil, and peat soil—under different conditions: without additives (0% Additives), with MS additives, and with VAMF additives. The results highlight the effect of additives in reducing the erosion rate for each soil type. Sand: The erosion rate for sand is highest without additives at 45%. When MS additives are used, the erosion rate significantly decreases to 16%. With VAMF additives, it further reduces to 13%, demonstrating the effectiveness of these additives in minimizing erosion in sandy soil. Kuthiran Soil: Without additives, Kuthiran soil shows an erosion rate of 31%. The application of MS reduces this to 9%, while VAMF additives lower it slightly further to 5%. This indicates that both additives are effective, with VAMF showing marginally better performance. Peat Soil: Peat soil has an erosion rate of 12% without additives. The use of MS reduces this to 5%, and VAMF further reduces it to 3%. Similar to the other soils, additives significantly enhance the soil's resistance to erosion.

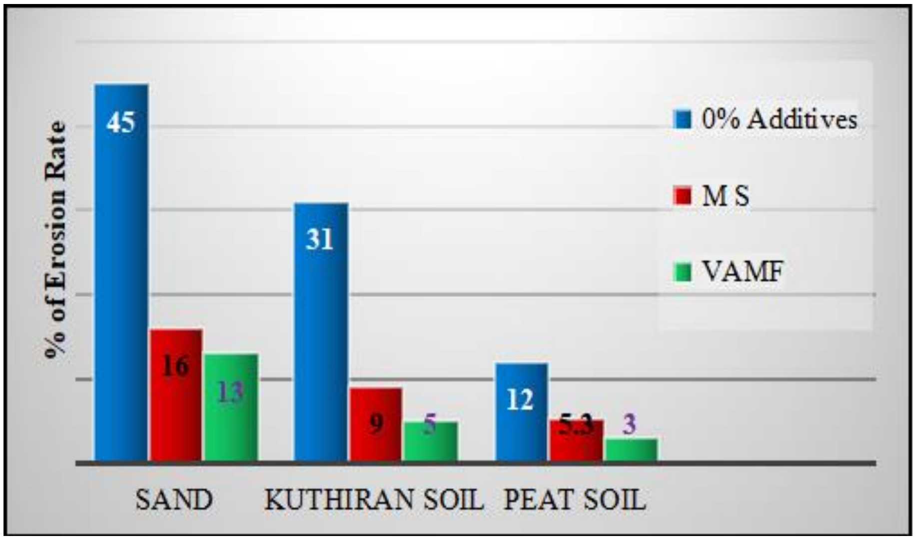

Figure 3: Erosion Index

4. Conclusion

This study confirms that additives such as modified polysaccharides and vesicular arbuscular mycorrhizae significantly improve soil resistance to piping. Key findings include:

- ✓ VAMF outperforms MS in enhancing erosion resistance.
- ✓ Soil piping can be mitigated through improved particle interaction.
- ✓ These eco-friendly solutions enhance slope stability and reduce environmental hazards.
- ✓ Future research should explore large-scale applications of these methods and their long-term effects on diverse terrains.

5. References

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