

**NATURAL FIBRE-BASED PREFABRICATED
VERTICAL DRAINS: A SUSTAINABLE
ALTERNATIVE FOR SOFT SOIL
CONSOLIDATION**

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Indian Institute of Technology Delhi**

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by

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Department of Textile and Fibre Engineering

Submitted

in fulfillment of the requirements of the degree of

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CERTIFICATE

This is to certify that the dissertation entitled “**Natural Fibre-Based Prefabricated Vertical Drains: A Sustainable Alternative for Soft Soil Consolidation**”, being submitted by **Mr. Temesgen Regassa Woyessa**, Entry No.2019TTZ8452, to the **Department of Textile and Fibre Engineering**, Indian Institute of Technology Delhi, New Delhi, India, in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy**, is a bonafide record of research work carried out by him. He has worked under our guidance and fulfilled the requirements for the submission of the thesis, which has attained the standard required for a Ph.D. degree of this institute.

The results contained in the thesis have not been submitted, in part or full, to any other University or Institute for the award of any degree or diploma.

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Abstract

Prefabricated vertical drains (PVDs) are widely employed in ground improvement to accelerate soil consolidation by facilitating pore water dissipation. With increasing emphasis on sustainable engineering, natural fiber-based PVDs (NPVDs) are gaining attention due to their biodegradability, cost-effectiveness, and widespread availability. This study presents a comprehensive evaluation of the hydraulic properties of natural fibre coir, jute, and kenaf compared to conventional polypropylene (PP) fibers commonly used in synthetic PVDs.

Hydraulic conductivity tests were conducted in accordance with ASTM D4716 under varying porosity levels (0.80, 0.90, and 0.95) and hydraulic gradients (0.5, 1.0, and 2.5). Among the tested fibers, coir exhibited the highest hydraulic conductivity, followed by jute and kenaf. The porosity of the fibrous media significantly influenced the water discharge rates. Over time, natural fibers demonstrated a decline in performance, whereas polypropylene maintained relatively stable conductivity.

The drainage behavior of NPVDs was further assessed through the wicking and siphon performance of their constituent yarns under both dry and wet conditions. Coir yarns exhibited rapid initial wicking, while jute yarns achieved higher wicking heights and greater overall distances. Wet yarns displayed superior wicking performance, indicating enhanced capillary transport due to increased saturation. Capillary siphon tests revealed that coir yarns discharged a greater volume of water, while jute yarns exhibited higher permeability. Parallel configurations of coir and jute yarns yielded improved water discharge compared to wrapped configurations.

Soil clogging, a critical factor limiting long-term performance of PVDs in field conditions, was evaluated using Delhi silt and kaolinite clay slurries. Results indicated a reduction in wicking and discharge capabilities due to clogging, with Delhi silt exerting a more pronounced adverse effect than kaolinite. Despite clogging, coir yarns retained siphon discharge for longer durations due to their larger capillary channels. Higher slurry concentrations further decreased the wicking height and rate in both yarn types.

Based on the complementary hydraulic properties of coir and jute yarns, a novel natural-fiber-based Green Prefabricated Vertical Drain (GPVD) was developed. Three GPVD prototypes were fabricated using various combinations of coir and jute yarns with a woven jute sheath. Among these, GPVD-B comprising coir and jute yarns in parallel within a woven jute sheath exhibited the highest water discharge capacity. Performance evaluations under different confining pressures (10, 50, 100, and 200 kPa) and hydraulic gradients (0.1, 0.5, and 1.0) demonstrated that GPVD-B outperformed conventional NPVDs up to 100 kPa, with a slight decline in performance beyond this pressure. Kaolinite clay caused a greater reduction in discharge capacity than Delhi silt, although the performance of GPVDs stabilized over time under both conditions.

The biodegradability of GPVDs was assessed over a six-month period in three environments: Delhi silt, kaolinite clay, and tap water. Results indicated faster degradation in tap water and kaolinite environments, while decomposition proceeded more slowly in Delhi silt. Synthetic PVDs retained higher residual tensile strength than GPVDs. However, the decomposition of GPVDs had minimal impact on soil and water pH, slightly lowering it toward neutral. Soil fertility index (SFI) marginally declined after GPVD degradation but remained within acceptable limits.

Overall, this study provides critical insights into the hydraulic behavior, clogging resistance, and biodegradability of natural-fiber-based PVDs, demonstrating the technical viability of GPVDs as sustainable alternatives to synthetic PVDs in geotechnical engineering applications.

सारांश

प्रीफैब्रिकेटेड वर्टिकल ड्रेन (PVDs) का व्यापक उपयोग भूमि सुधार में मिट्टी के समेकन को तेज करने के लिए किया जाता है, जिससे छिद्र जल का निस्सारण आसान हो सके। सतत इंजीनियरिंग पर बढ़ते जोर के साथ, प्राकृतिक फाइबर आधारित PVDs (NPVDs) अपनी जैव-अवक्रमणीयता, किफायतीपन और व्यापक उपलब्धता के कारण ध्यान आकर्षित कर रहे हैं। यह अध्ययन नारियल रेशा, जूट और केनाफ जैसे प्राकृतिक फाइबरों की हाइड्रोलिक विशेषताओं का व्यापक मूल्यांकन प्रस्तुत करता है और इनकी तुलना सिंथेटिक PVDs में सामान्यतः प्रयुक्त पॉलीप्रोपाइलीन (PP) फाइबर से करता है।

हाइड्रोलिक चालकता परीक्षण ASTM D4716 के अनुसार विभिन्न रंधता स्तरों (0.80, 0.90 और 0.95) और हाइड्रोलिक ग्रेडिंट्स (0.5, 1.0 और 2.5) पर किए गए। परीक्षण किए गए फाइबरों में नारियल रेशे ने सबसे अधिक हाइड्रोलिक चालकता दिखाई, इसके बाद जूट और केनाफ का स्थान रहा। रंधता का जल प्रवाह दरों पर महत्वपूर्ण प्रभाव पड़ा। समय के साथ, प्राकृतिक फाइबरों के प्रदर्शन में गिरावट आई, जबकि पॉलीप्रोपाइलीन ने अपेक्षाकृत स्थिर चालकता बनाए रखी।

NPVDs के निस्सारण व्यवहार का आगे मूल्यांकन उनके घटक यार्न की विकिंग और सिफन क्षमता के माध्यम से सूखी और गीली दोनों स्थितियों में किया गया। नारियल यार्न ने तेज प्रारंभिक विकिंग प्रदर्शित की, जबकि जूट यार्न ने अधिक विकिंग ऊंचाई और अधिक दूरी हासिल की। गीले यार्न ने बेहतर विकिंग प्रदर्शन प्रदर्शित किया, जो बढ़ी हुई संतृप्ति के कारण बेहतर केशिकीय परिवहन का संकेत देता है। केशिकीय सिफन परीक्षणों से पता चला कि नारियल यार्न ने अधिक मात्रा में पानी निकाला, जबकि

जूट यार्न ने अधिक पारगम्यता प्रदर्शित की। नारियल और जूट यार्न के समानांतर विन्यास ने लिपटे हुए विन्यास की तुलना में बेहतर जल प्रवाह प्रदान किया।

मैदान की परिस्थितियों में PVDs के दीर्घकालिक प्रदर्शन को सीमित करने वाले एक महत्वपूर्ण कारक के रूप में मिट्टी का क्लॉगिंग दिल्ली सिल्ट और कैओलिनाइट क्ले स्लरी का उपयोग करके मूल्यांकित किया गया। परिणामों से पता चला कि क्लॉगिंग के कारण विकिंग और प्रवाह क्षमता में कमी आई, जिसमें दिल्ली सिल्ट का प्रतिकूल प्रभाव कैओलिनाइट की तुलना में अधिक था। क्लॉगिंग के बावजूद, नारियल यार्न ने बड़े केशिकीय चैनलों के कारण लंबे समय तक सिफन प्रवाह बनाए रखा। उच्च स्लरी सांद्रता ने दोनों यार्न प्रकारों में विकिंग ऊंचाई और दर को और कम कर दिया।

नारियल और जूट यार्न के पूरक हाइड्रोलिक गुणों के आधार पर, एक नया प्राकृतिक-फाइबर-आधारित ग्रीन प्रीफैब्रिकेटेड वर्टिकल ड्रेन (GPVD) विकसित किया गया। तीन GPVD प्रोटोटाइप विभिन्न नारियल और जूट यार्न संयोजनों के साथ बुने हुए जूट शीथ का उपयोग करके तैयार किए गए। इनमें से, GPVD-B, जिसमें नारियल और जूट यार्न को बुने हुए जूट शीथ के भीतर समानांतर रखा गया, ने सबसे अधिक जल प्रवाह क्षमता प्रदर्शित की। विभिन्न संपीड़न दबावों (10, 50, 100 और 200 kPa) और हाइड्रोलिक ग्रेडिएंट्स (0.1, 0.5 और 1.0) के तहत प्रदर्शन मूल्यांकन से पता चला कि GPVD-B ने 100 kPa तक पारंपरिक NPVDs से बेहतर प्रदर्शन किया, हालांकि इस दबाव से आगे प्रदर्शन में हल्की गिरावट आई। कैओलिनाइट क्ले ने दिल्ली सिल्ट की तुलना में प्रवाह क्षमता में अधिक कमी की, हालांकि दोनों स्थितियों में समय के साथ GPVDs का प्रदर्शन स्थिर हो गया।

GPVDs की जैव-अवक्रमणीयता का छह महीने की अवधि में तीन वातावरणों – दिल्ली सिल्ट, कैओलिनाइट क्ले और नल के पानी – में मूल्यांकन किया गया। परिणामों से पता चला कि नल के पानी और कैओलिनाइट वातावरण में अपघटन तेजी से हुआ, जबकि दिल्ली सिल्ट में विघटन धीमी गति से हुआ। सिंथेटिक PVDs ने GPVDs की तुलना में उच्च अवशिष्ट तन्यता शक्ति बनाए रखी। हालांकि, GPVDs के विघटन का मिट्टी और पानी के pH पर न्यूनतम प्रभाव पड़ा, जिससे यह तटस्थ की ओर थोड़ा कम हुआ। मिट्टी की उर्वरता सूचकांक (SFI) GPVD के विघटन के बाद थोड़ा घटा लेकिन स्वीकार्य सीमा के भीतर रहा।

कुल मिलाकर, यह अध्ययन प्राकृतिक-फाइबर-आधारित PVDs के हाइड्रोलिक व्यवहार, क्लॉगिंग प्रतिरोध और जैव-अवक्रमणीयता पर महत्वपूर्ण अंतर्दृष्टि प्रदान करता है, जिससे यह स्पष्ट होता है कि GPVDs भू-तकनीकी इंजीनियरिंग अनुप्रयोगों में सिंथेटिक PVDs के सतत विकल्प के रूप में तकनीकी रूप से व्यवहार्य हैं।

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