

**EVALUATION OF STATIC AND DYNAMIC PROPERTIES
OF SAND REINFORCED WITH HUMAN HAIR FIBERS**

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**EVALUATION OF STATIC AND DYNAMIC PROPERTIES
OF SAND REINFORCED WITH HUMAN HAIR FIBERS**

by

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Submitted

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*Dedicated to My Beloved Parents
Shri Ramesh Chandra Sahu and
Shrimati Laxmi Devi Sahu*

CERTIFICATE

This is to certify that the thesis entitled "**EVALUATION OF STATIC AND DYNAMIC PROPERTIES OF SAND REINFORCED WITH HUMAN HAIR FIBERS**" submitted by **Mr. Raghvendra Sahu** to the Indian Institute of Technology Delhi, is a record of the bonafide research work carried out by him under our supervision and guidance. This thesis work, in our opinion, has reached the standard, fulfilling the requirements for **Doctor of Philosophy** degree. The research report and the results presented in this 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

Machine foundations are designed such that the dynamic forces generated due to the operation of machines does not produce any type of adverse effects on the machine, foundation, operators and structures in close vicinity. When the block type machine foundation does not fulfil the design requirements, either piled foundation is usually provided or ground improvement techniques such as soil reinforcement can be adopted. The use of natural fibers as reinforcement is an economical alternative in place of commercial fibers. The present study investigates the effect of hair fiber (natural fiber) reinforcement on static and dynamic properties of sand.

Laboratory direct shear tests were conducted on unreinforced and hair fiber-reinforced sand under dry condition using unsorted hair fibers; under saturated condition, using both sorted (uniform length) and unsorted hair fibers. Results obtained for sand reinforced with sorted hair fibers were also compared with the results of sand reinforced with polypropylene fibers. The shear stress and volume change behavior measured during direct shear testing were quantified to assess the influence of (i) amount of fiber content and (ii) fiber length. Results indicated that (i) strength parameters increased substantially under dry condition, (ii) increase in strength parameters under saturated condition are observed to be insignificant and (iii) unsorted hair fibers as collected from barber shops can be effectively used as reinforcing elements.

Drained cyclic triaxial tests were conducted on sand reinforced with unsorted hair fibers. Measured shear modulus and damping characteristics were compared with unreinforced sand. Variation of shear modulus and damping ratio with shear strain were developed for sand reinforced with hair fibers up to 1% by dry weight. Shear modulus of sand reinforced with hair fibers exhibited an increase in modulus up to medium strains and damping characteristics marginally reduced compared to unreinforced sand.

Free vibration tests were carried out on model foundation resting on unreinforced and reinforced sand using three different reinforcing materials i.e. human hair fiber (HHF), PET geogrid and HDPE geogrid. The effect of lateral and vertical extent of reinforcement was also investigated using different reinforcement configurations. The data was interpreted to quantify the optimum reinforcement parameters for improving the dynamic properties of sand-foundation system. The results on different reinforcement configuration indicated that the zone of reinforcement equal to the plan dimensions of footing is adequate to shift the natural frequency of sand-foundation system. Damping measured from the model tests was found to be less for reinforced ground as observed from cyclic triaxial test results.

In-situ block vibration tests were conducted to determine the dynamic characteristics of soil-foundation system. Additionally, influence of geocell reinforcement below the foundation was also investigated. The results were interpreted to quantify the effect of reinforcement on shifting the natural frequency and change in amplitude of soil-foundation system. As observed in the model tests, results of field tests confirmed a shift in natural frequency and a reduction in damping characteristics.

Application and economic benefits of hair fiber reinforcement in select geotechnical problems (Retaining wall and machine foundations) were demonstrated.

सार

मशीन नींव इस तरह तैयार किए जाते हैं कि मशीनों के संचालन के कारण उत्पन्न गतिशील बल मशीनों, फाउंडेशन, ऑपरेटर और करीबी नजदीकी संरचनाओं पर किसी प्रकार के प्रतिकूल प्रभाव उत्पन्न नहीं करते हैं। जब ब्लॉक टाइप मशीन नींव डिजाइन आवश्यकताओं को पूरा नहीं करता है, तो या तो पाइल नींव आमतौर पर प्रदान की जाती है या जमीन सुधार तकनीकों जैसे कि मिट्टी सुदृढीकरण को अपनाया जा सकता है। सुदृढीकरण के रूप में प्राकृतिक फाइबर का उपयोग व्यावसायिक फाइबर के स्थान पर एक आर्थिक विकल्प है। वर्तमान अध्ययन रेत के स्थिर और गतिशील गुणों पर बाल फाइबर (प्राकृतिक फाइबर) सुदृढीकरण के प्रभाव की जांच करता है।

बिना प्रयोग किए गए बाल तंतुओं का उपयोग करके सूखी हालत के तहत गैर-प्रबलित और बाल फाइबर प्रबलित रेत पर संतृप्त स्थिति के तहत, सॉर्ट किए गए दोनों, वर्दी लंबाई और रिक्त बाल तंतुओं का उपयोग कर प्रयोगशाला प्रत्यक्ष कतरनी परीक्षण किया गया। छांटे हुए बालों के फाइबर के साथ प्रबलित रेत के लिए प्राप्त परिणामों को भी पॉलीप्रोपीलीन फाइबर के साथ प्रबलित रेत के परिणाम के साथ तुलना किया गया। (i) फाइबर सामग्री की मात्रा और (ii) फाइबर लम्बाई के प्रभाव का आकलन करने के लिए, प्रत्यक्ष कतरनी परीक्षण के दौरान मापा गया कतरनी तनाव और आयतन परिवर्तन के व्यवहार की मात्रा निर्धारित की गयी। परिणाम से संकेत मिलता है कि (i) सूखी हालत के तहत ताकत मापदंडों में काफी वृद्धि हुई है, (ii) संतृप्त अवस्था के तहत ताकत मापदंडों में वृद्धि को तुच्छ माना जाता है और (iii) नाई की दुकानों से एकत्र किए गए बिना व्यवस्थित बाल तंतुओं को प्रभावी ढंग से प्रबल करने वाले तत्वों के रूप में इस्तेमाल किया जा सकता है।

अनियंत्रित बाल तंतुओं के साथ सुदृढ रेत पर रेखीय चक्रीय त्रिकोणीय परीक्षण किया गया। बालों के फाइबर प्रबलित रेत के कतरनी मापांक और अवमन्दक विशेषताओं की गैर-प्रबलित

रेत के साथ तुलना की गई थी। कतरनी मापांक और अवमन्दक अनुपात में भिन्नता, कतरनी तनाव के साथ, 1% बाल फाइबर (सूखी वजन) प्रबलित रेत के लिए विकसित किया गया। बालों के फाइबर के साथ प्रबलित रेत के कतरन मापांक ने मापांक में मध्यम उपभेदों में वृद्धि की है और अवमन्दक विशेषताओं को गैर-प्रबलित रेत की तुलना में कम कर दिया।

गैर-प्रबलित और प्रबलित रेत पर तीन अलग-अलग रीनिफोर्सिंग सामग्रियों का प्रयोग करते हुए मॉडल फाउंडेशन पर स्वतंत्र कंपन परीक्षण किये गये, अर्थात् मानव बाल फाइबर (एचएचएफ), पीईटी जियोग्रिड और एचडीपीई जीओजीड सुदृढीकरण की पार्श्व और ऊर्ध्वाधर सीमा का प्रभाव भी विभिन्न सुदृढीकरण विन्यासों का उपयोग करके जांच की गई। रेत-नींव प्रणाली के गतिशील गुणों में सुधार के लिए इष्टतम सुदृढीकरण मापदंडों को मापने के लिए डेटा की व्याख्या की गई थी। विभिन्न सुदृढीकरण विन्यास के परिणामों ने संकेत दिया कि रेत-नींव प्रणाली की प्राकृतिक आवृत्ति को स्थानांतरित करने के लिए फुटिंग के प्लान आयाम के बराबर सुदृढीकरण का क्षेत्र पर्याप्त है। चक्रीय त्रिकोणीय परीक्षण के परिणाम से मनाया गया कि मॉडल टेस्ट से मापा अवमन्दक, प्रबलित जमीन के लिए कम पाया गया था।

मृदा-नींव प्रणाली की गतिशील विशेषताओं को निर्धारित करने के लिए इन-सितु ब्लॉक कंपन परीक्षण आयोजित किए गए थे। इसके अतिरिक्त, नींव के नीचे जियोसेल सुदृढीकरण के प्रभाव की जांच भी की गई। परिणामों को प्राकृतिक आवृत्ति और मिट्टी-नींव प्रणाली के आयाम में परिवर्तन को बदलने पर सुदृढीकरण के प्रभाव का अनुमान लगाने के लिए व्याख्या की गई। जैसा कि मॉडल परीक्षणों में देखा गया है, क्षेत्र परीक्षणों के परिणाम ने प्राकृतिक आवृत्ति में बदलाव और अवमन्दक विशेषताओं में कमी की पुष्टि की है

चयनित भू-तकनीकी समस्याओं (बनाए रखने की दीवार और मशीन नींव) में बाल फाइबर सुदृढीकरण के अनुप्रयोग और आर्थिक लाभ का प्रदर्शन किया गया।

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