

**PERFORMANCE ASSESSMENT OF GEOCELL
REINFORCED ROAD PAVEMENT**

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PERFORMANCE ASSESSMENT OF GEOCELL REINFORCED ROAD PAVEMENT

by

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Department of Civil Engineering

submitted

in fulfilment of the requirements for the degree of

Doctor of Philosophy

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

APRIL 2025

*Dedicated to
Baba*

DECLARATION

I hereby certify that, unless explicitly cited and acknowledged, all the content presented in this thesis is my original work. This thesis has not been submitted, in full or in part, for the award of any degree or diploma at this or any other institution. It is solely the result of my independent efforts and includes no collaborative contributions. The preparation of this thesis has adhered to the guidelines prescribed by the institute. The thesis comprises less than 64,000 words and less than 120 figures.

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CERTIFICATE

This is to certify that the thesis titled “**Performance assessment of geocell reinforced road pavement**”, submitted by **Ms. Sayanti Banerjee** to the Indian Institute of Technology Delhi is a record of bonafide research work carried out by him under our supervision and guidance. This thesis work, in our opinion, has reached the standard of fulfilling the requirements for a **Doctor of Philosophy** degree. The research report and results presented in this thesis have not been submitted, in part or full, to any University or Institute for the award of the degree or diploma.

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ABSTRACT

Due to rapid population growth and industrial expansion, pavements are increasingly being constructed on weak subgrades that are prone to uneven settlement, low shear strength, and high compressibility, leading to premature pavement failures. In response to these challenges, geocells have become a widely adopted method for soil stabilization.

This study aims to thoroughly examine the performance of geocell-reinforced pavement and discern the key factors affecting its performance through a combined approach of experimental and numerical analyses. It begins with large-scale model testing of reinforced and unreinforced sections, followed by numerical analysis conducted using the three-dimensional finite element program PLAXIS 3D. This study involved systematic, large-scale instrumented model tests on both geocell-reinforced and unreinforced pavements under various loading conditions. The tests were conducted on pavements built over clayey and sandy subgrade soils, with variations in weld spacing ($SW = 330$ mm, 356 mm, and 445 mm) and geocell height ($H = 75$ mm, 100 mm, 150 mm, and 200 mm). Additionally, a finite element model delves into the effects of various parameters on the performance of reinforced pavement, including base material and diameter of wheel contact area. The responses studied were stress distribution in different pavement layers, induced strains in geocell walls, and settlement characteristics. Based on the outcomes obtained from experimental and numerical analyses, a field investigation has been carried out over problematic soils in Dholera, Gujarat, India to understand the effect of geocell in real-field conditions. Ten new pavement sections were constructed at Dholera, comprising two unreinforced test sections and eight reinforced sections with various geocell configurations over untreated and lime-treated subgrades. The performance of these sections was assessed using plate load tests and a falling weight deflectometer. Finally, based on field outcomes, a

design chart has been developed for an economical geocell-reinforced pavement section for Dholera, India, in compliance with IRC specifications. The study provides valuable insights into the role of geocell materials in pavement infrastructure, supporting its viability as a durable and sustainable option for pavement construction.

Keywords: Pavement, Geocell, Expansive subgrade, Lime treatment, Geocell configuration, Loading condition

सार

तेज़ी से बढ़ती जनसंख्या और औद्योगिक विस्तार के कारण, सड़कों का निर्माण कमजोर उपमूल पर किया जा रहा है, जो असमान धंसाव, कम कतरण शक्ति, और उच्च संपीडनशीलता के लिए प्रवण होते हैं, जिससे समय से पहले सड़कें खराब हो जाती हैं। इन चुनौतियों का समाधान करने के लिए, जियोसेल्स मिट्टी को स्थिर करने की एक व्यापक रूप से अपनाई गई विधि बन गए हैं।

इस अध्ययन का उद्देश्य भूकोष-प्रबलित सड़क की प्रदर्शन का पूरी तरह से परीक्षण करना और इसके प्रदर्शन पर प्रभाव डालने वाले प्रमुख कारकों का पता लगाना है, जिसे प्रयोगात्मक और संख्यात्मक विश्लेषणों के संयुक्त दृष्टिकोण से किया जाएगा। यह अध्ययन प्रबलित और अप्रबलित खंडों के पूर्ण-स्केल मॉडल परीक्षण से शुरू होता है, जिसके बाद तीन-आयामी सीमित तत्व कार्यक्रम PLAXIS 3D का उपयोग करके संख्यात्मक विश्लेषण किया जाता है। इस अध्ययन में विभिन्न लोडिंग परिस्थितियों के तहत भूकोष-प्रबलित और अप्रबलित सड़कों पर पूर्ण-स्केल यांत्रिक परीक्षण किए गए। इन परीक्षणों को चिकनी और बालू वाली उपमूल मिट्टी पर निर्मित सड़कों पर किया गया, जिसमें वेल्ड दूरी (SW = 330 मिमी, 356 मिमी, और 445 मिमी) और भूकोष की ऊँचाई (H = 75 मिमी, 100 मिमी, 150 मिमी, और 200 मिमी) में भिन्नताएँ थीं। इसके अतिरिक्त, एक सीमित तत्व मॉडल विभिन्न मापदंडों के प्रभावों का अध्ययन करता है जो प्रबलित सड़क के प्रदर्शन पर प्रभाव डालते हैं, जैसे कि आधार सामग्री और पहिये के संपर्क क्षेत्र का व्यास। अध्ययन किए गए प्रतिक्रियाओं में विभिन्न सड़क परतों में तनाव वितरण, भूकोष दीवारों में उत्पन्न विकृतियाँ, और धंसाव की विशेषताएँ शामिल हैं। प्रयोगात्मक और संख्यात्मक विश्लेषणों से प्राप्त परिणामों के आधार पर, गुजरात के धोलेरा में समस्याग्रस्त मिट्टी पर एक क्षेत्रीय जांच की गई है ताकि वास्तविक-क्षेत्र परिस्थितियों में भूकोष के प्रभाव को समझा जा सके। धोलेरा में दस नई सड़क खंडों का निर्माण किया गया, जिसमें दो अप्रबलित परीक्षण खंड और आठ प्रबलित खंड शामिल थे, जिनमें विभिन्न

भूकोष विन्यास अप्रक्रियोजित और चूने से उपचारित उपमूल मिट्टी पर आधारित थे। इन खंडों का प्रदर्शन प्लेट लोड परीक्षण और गिरते वजन डिप्लेक्टोमीटर का उपयोग करके आंका गया। अंत में, क्षेत्रीय परिणामों के आधार पर, धोलेरा, भारत के लिए एक आर्थिक भूकोष-प्रबलित सड़क खंड के लिए डिजाइन चार्ट विकसित किया गया है, जो IRC विनिर्देशों के अनुरूप है। यह अध्ययन सड़क अवसंरचना में भूकोष सामग्री की भूमिका पर मूल्यवान जानकारी प्रदान करता है, जिससे यह सड़क निर्माण के लिए एक टिकाऊ और स्थिर विकल्प के रूप में इसकी व्यवहार्यता का समर्थन करता है।

कुंजीशब्द: सड़क, भूकोष, प्रसारी उपमूल, चूना उपचार, भूकोष विन्यास, भार की स्थिति

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LIST OF ABBREVIATIONS

AIV	Aggregate impact value
APT	Accelerated pavement tests
B	Type of base material
BIS	Bureau of Indian Standards
CBR	California Bearing Ratio
CD	Consolidated drained
CFEI	Combined flakiness and elongation index
CTE	Coefficient of thermal expansion
DFC	Dedicated Freight Corridor
DMIC	Delhi-Mumbai Industrial Corridor project
DP	Drucker-Prager
DSIR	Dholera Special Investment Region
EPS	Expanded Polystyrene
FDM	Finite difference method
FE	Finite element
FEM	Finite element method
FWD	Falling weight deflectometer
GSB	Granular subbase

HDPE	High-density polyethylene
HPU	Hydraulic power unit
HS	Hardening Soil
HSM	Hydraulic service manifold
IRC	Indian Road Congress
IS	Indian Standards
LCR	Layer coefficient ratio
LE	Linear Elastic
LL	Liquid limit
LVDT	Linear variable differential transformers
LWD	Light weight deflectometer
MC	Mohr-Coulomb
MCC	Modified Cam Clay
MDD	Maximum dry density
MEPDG	Mechanistic-empirical pavement design guide
MIF	Modulus improvement factor
MMC	Modified Mohr-Coulomb
MORTH	Ministry of Road Transport and Highways
MSA	Million standard axles
NPA	Noval polymeric alloy
OLC	Optimum lime content

OMC	Optimum moisture content
PI	Plasticity index
PLT	Plate load test
RAP	Recycled asphalt pavement
RDRR	Rut depth reduction ratio
SLR	Service Life Ratio
SN	Structural number
TBR	Traffic benefit ratio
USCS	Unified soil classification system
WA	Water absorption
WMM	Wet mix macadam

LIST OF NOTATIONS

Basic SI units are given in parentheses.

a	Loading plate radius (m)
α	Horizontal angle of the tension force (°)
C	Cohesion (kPa)
C_c	Coefficient of curvature (dimensionless)
C_i	Interface cohesion (kPa)
C_u	Coefficient of uniformity (dimensionless)
D	Loading plate diameter (m)
d	Geocell pocket diameter (m)
Δ	Deflection value below the loading plate (m)
D_{50}	Particle diameter (m)
D_{10}	Effective particle diameter (m)
E	Modulus of elasticity (kPa)
E_{50}^{ref}	Secant stiffness at a 50% stress level (MPa)
E_{oed}^{ref}	Tangent stiffness at oedometer loading (MPa)
E_{ur}^{ref}	Unloading/reloading stiffness (MPa)
ε_l	Elastic resilient strain (dimensionless)
ε_p	Plastic deformation (m)
ε_e	Elastic recovery (m)
ϕ	Friction angle (°)
ϕ_i	Interface friction angle (°)

γ	bulk unit weight (kN/m ³)
G_s	Specific gravity (dimensionless)
h	Height of geocell (m)
I_D	Relative density (dimensionless)
IF_{BC}	Bearing capacity improvement factor (dimensionless)
L	Width of loading area (m)
μ	Poisson's ratio (dimensionless)
M	Tensile stiffness (kN/m)
M_r	Resilient modulus (MPa)
N	Seam strength (N/m)
ψ	Dilation angle (°)
P	Total vertical load applied to the pavement base layer
p_a	Atmospheric pressure (kPa)
PD_{base}	Permanent deformation value at base layer (m)
$PD_{subbase}$	Permanent deformation value at subbase layer (m)
$PD_{subgrade}$	Permanent deformation value at subgrade layer (m)
q	Change in applied pressure (kPa)
SW	weld spacing (m)
$\sigma_{d(cyc)}$	Cyclic deviator stress (MPa)
σ_3	Confining stress (kPa)
σ_B	Bulk stress (kPa)
σ_{oct}	Octahedral normal stress (kPa)
σ_d	Deviator stress (kPa)

σ	Maximum vertical stress at the subgrade layer for a particular loading cycle (kPa)
τ_{oct}	Octahedral shear stress (kPa)
θ	Load dispersion angle ($^{\circ}$)
T	Tension force (N/m)
t	Base layer thickness (m)
u	Placement depth or cover thickness (m)