Static and Cyclic Behavior of Granular Piles Foundation Composed of Tire chips - Aggregates Mixture in Soft Soil

Thesis submitted in partial fulfilment

for the award of Degree

Doctor of Philosophy

by

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DEDICATION

I DEDICATE MY DISSERTATION WORK

TO MY SON, NEPHEWS,

AND FAMILY.

For their endless love, devotion, support, and inspiration.

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ABSTRACT

In rapidly advancing economies like India, a substantial need exists for large-scale infrastructure projects such as high-speed railways, road transport network, airport runways, hydraulic structures, port areas with container yards, oil storage tanks, and large-scale industrial facilities. These developments are crucial for driving the country's economic growth. However, the execution of these projects encounters several challenges, primarily the scarcity of suitable subgrade strata, particularly soft ground conditions. These soft soils are undesirable for infrastructure development due to their low bearing capacity and excessive settlements unless treated. Ground improvement techniques serve as potential alternatives to address these conditions. Among the various methods employed to enhance in-situ ground conditions, granular piles encased with geosynthetic materials are well-established and widely utilized.

Conversely, End-of-Life Tires (ELTs) represent an unwanted type of solid waste that grows annually, posing significant health and fire risks in stockpile form. Consequently, engineers have increasingly focused on alternative strategies to manage substantial volumes of ELTs. Repurposing ELTs helps reduce landfill waste, conserve natural resources, minimize fire and health hazard, and promote sustainability. Incorporating ELT-derived materials as substitutes in civil engineering, particularly in geotechnical applications, has been a recurring practice for several years.

Therefore, this study highlights a novel approach to addressing two significant challenges in geotechnical engineering and environmental sustainability. Soft soils, characterized by low shear strength, high compressibility, and poor drainage, require improvement for various construction applications. Simultaneously, the global accumulation of End-of-Life Tires (ELTs) has raised serious environmental concerns.

This study investigates an effective solution: recycling ELTs into tire chips and utilizing them in granular piles to enhance soft soil properties.

This research primarily examines the behavior of granular piles composed of various mix proportions of tire chips and aggregates in improving soft soil and determines the optimum mix proportion. Tire chips of cubical size 10 mm × 10 mm × 10 mm and aggregates passing through 12.5 mm but retained on 10 mm were used. The aggregates and tire chips were mixed using volumetric mix proportions (tire chips: aggregates) (%) of 0:100, 25:75, 50:50, 75:25, and 100:0, respectively.

The optimum mixture of tire chips and aggregates was determined in terms of index properties and shear properties from large direct shear tests under normal stresses of 50 kPa, 100 kPa, and 150 kPa, respectively. The significant results from the large scale direct shear tests showed that the percentage decrease in shear strength of the mixture due to the addition of 25% tire chips by weight is 4.6%. Additionally, the angle of internal friction slightly decreased by 3°, and the cohesion value increased by 3.1 kPa due to the addition of 25% tire chips by weight.

A series of 1-g laboratory model tests were performed on single granular piles with and without geosynthetic encasement under static and cyclic loading conditions. Combi-grid was employed as an encasement for the granular piles. The optimum mix proportion was determined in terms of ultimate load intensity (q_{us}) and bulging behavior of the composite soft ground under static loading, cyclic-induced settlement (S_c), settlement reduction ratio ($S_{c,r}$), and accumulation of excess pore water pressure (P_{exc})under cyclic loading. Key findings reveal that under static loading, the efficiency of ordinary granular piles (OGP) closely approached unity with up to 25% tire chips content. In comparison, vertically encased granular piles (VEGP) exhibited efficiencies exceeding unity with up to 100% tire chips content. Similarly, the efficiency of OGP with (25% tire chips + 75% aggregates) is 86.7%, with a loss of 12.3% in settlement reduction compared to OGP with 100% aggregates.

Based on the above three criteria, this study demonstrates the optimum tire chip content replacement for aggregates as 25% by weight, equivalent to 44% by volume, offering a cost-effective and environmentally friendly solution.

This study also includes a parametric analysis of the effects of different principal parameters on the cyclic behavior of granular piles composed of the optimum mixture (25%tire chips + 75% aggregates). Various parameters were scrutinized, including the selection of encasement materials (geotextile, geogrid, and combi-grid), the best configuration for granular piles, cyclic loading frequency (f_{cy}), cyclic loading amplitude (q_{cy}), length-to-diameter (L/D) ratios, granular pile end conditions, and the strength of the surrounding soft soil. The main findings indicate that ordinary granular piles (OGP) performed effectively when subjected to lower frequency and amplitude loading, smaller L/D ratios, and end-bearing conditions. The combi-grid encasement notably improved the cyclic performance of granular piles by substantially reducing the cyclic-induced settlement on improved soft beds across all examined factors.

Additionally, static and cyclic loading tests were conducted on groups of granular piles composed of the optimum mix proportion (25% tire chips + 75% aggregates) under axisymmetric conditions to replicate field conditions. Twelve granular piles were installed to examine principal parameters, such as the selection of geosynthetic materials and cyclic loading characteristics, including cyclic loading amplitude (q_{cy}) and cyclic loading frequency (f_{cy}). Key findings from static model tests indicate that the load-bearing capacity is significantly increased with the installation of a group of ordinary granular piles (= 58%) and substantially increased with combi-grid encasement (= 335%). Similarly, in the case of cyclic loading, the effectiveness of

OGPs in enhancing the performance of a soft soil bed is greater when subjected to lower cyclic loading frequencies and smaller cyclic loading amplitudes. Combining combi-grid encasement enhanced the cyclic performance of a group of granular piles by substantially minimizing cyclic-induced settlement (S_c) across both principal parameters f_{cy}, and q_{cy}, similar to the single granular pile. Additionally, in both single and group granular piles, the increased cyclic stress on the surrounding soft soil led to the development of excess pore water pressure, which is significantly reduced with the help of combi-grid encasement in all test cases.

To validate the behavior of single and grouped granular piles under static loading in terms of load intensity-settlement and bulging patterns, numerical analysis was performed using Plaxis 3D software, and the results were well matched with each other.

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NOTATIONS AND ABBREVIATIONS

NOTATIONS

English symbols

A	Total area within the unit cell
A_{GP}	Area of the granular pile
A_r	Area replacement ratio
c	Cohesion (kPa)
D	Diameter of granular pile
D_e	Effective diameter
D_p	Diameter of the loading plate
e	Void ratio
E	Modulus of elasticity of soil
E_{oed}	Oedometer modulus
f_{cy}	Cyclic loading frequency
F_{mp}	Improvement factor
G	Shear modulus
G_{ag}	Specific gravity of aggregates
G_s	Specific gravity
G_{tc}	Specific gravity of tire chips
I_D	Relative density
I_p	Plasticity index
J	Secant stiffness
K_p	Passive coefficient
$k_{p_{mp}}$	Passive coefficients for a granular pile with any mix

	proportion
L	Length of granular pile
L_1	Length of vertical encasements
L_2	Length up to which horizontal discs provided
n	Stress concentration ratio
N	Number of loading cycles
P	Train axle load
P_{exc}	Excess pore water pressure
p_t	Tire chip content
q_{cy}	Cyclic loading amplitude
q_{us}	Ultimate bearing capacity of an OGP
s	Spacing of granular piles
S_c	Cyclic induced settlement
$S_{c,r}$	Settlement reduction ratio
S_u	Undrained shear strength
S	Spacing between horizontal discs.
S_{EGP}	Settlement of encased granular pile
S_{OGP}	Settlement of ordinary granular pile
t	Thickness of the combi-grid
V_m	Volume of mold
V_s	Volume of the mixture
V_{tc}	Volume of tire chips
V_v	Volume of voids
w	Water content
w_L	Liquid limit

w_p	Plastic limit
W_{ag}	Weight of aggregates
W_{tc}	Weight of tire chips

Greek symbols

σ_{GP}	Stress in the granular pile
σ_{SB}	Stress in the surrounding soft soil bed
γ_d	Dry unit weight
μ	Poisson's ratio
σ_d	Vertical cyclic stress on the subgrade
α	Speed coefficient
ϕ	Angle of internal friction
ψ	Dilatancy angle
σ	Normal stress
τ	Shear stress at failure
γ	Shear strain
β	Ultimate load intensity ratio

ABBREVIATIONS

NHDP	National Highway Development Programme
PMGSY	Pradhan Mantri Gram Sadak Yojna
GP	Granular pile
OGP	Ordinary Granular Piles
VEGP	Vertically Encased Granular Piles
GT	Geotextile
GG	Geogrid

CG	Combi-grid
ELT	End-of-Life Tire
MRAI	Material Recycling Association of India
TDF	Tire Derived Fuel
USCS	Unified soil classification system
UCS	Unconfined compressive strength
OMC	Optimum moisture content
(0% TC + 100% AG)	(0% tire chips + 100% aggregates)
(25% TC + 75% AG)	(25% tire chips + 75% aggregates)
(50% TC + 50% AG)	(50% tire chips + 50% aggregates)
(75% TC + 25% AG)	(75% tire chips + 25% aggregates)
(100% TC + 0% AG)	(100% tire chips + 0% aggregates)
HEGP	Horizontal encased granular piles
CEGP	Combined encased granular piles
CSR	cyclic stress ratio
PPT	Pore Pressure Transducer
EPT	Earth Pressure Transducer
ET	Encasement type
OS	Only soil
EB	End bearing
GTGP	Geotextile encased granular piles
GGGP	Geogrid encased granular piles
CGGP	Combi-grid encased granular piles
FEA	Finite element analysis