Enhanced Analysis of Load Transfer Mechanism and Deformation Estimation for Ground Improvement Using Concrete Injected Columns

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I confirm that the work done in this thesis has been an original work which has not previously been submitted for an evaluation unless as acknowledged within the text.

I also affirm that I have authored the thesis. All assistance for my research and preparation of this thesis has been acknowledged. Moreover, I also affirm that all literature and sources of information used in this research are indicated.

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ABSTRACT

This thesis presents analytical solutions to predict the response of the load transfer platform (LTP) on columns stabilised soft soil subjected to any shape of pressure loadings. The effect of the bending and shear deformations of LTP and the nonlinear stress strain behaviour of soft soil are incorporated into the analytical model. The cracked reinforced Timoshenko beam is proposed and implemented to model LTP to consider the shear and flexural deformations. Soft soil is idealised by spring-dashpot system to include the time-dependent non-linear behaviour. The columns and geosynthetics are modelled with linear Winkler springs in the applied range of stresses and rough elastic membrane, respectively. Influence of negligible tensile strength compared to the compressive strength of granular materials in LTP is also considered. Furthermore, a parametric study has been conducted to investigate how the parameters such as the column spacings, the thickness of LTP, the tensile stiffness of geosynthetics, and the degree of consolidation of the soft soil affect the response of LTP on improved soft soil. Moreover, the results from the proposed cracked Timoshenko beam theory (capturing the combined shear and bending stiffness of LTP) have been compared with results from the Euler-Bernoulli model (capturing deflection due to bending only) and the Pasternak model (capturing deformation due to shear only).

This research also provides rigorous solutions to estimate the settlement of the soft soils under embankment load when double layer of geosynthetics reinforcements have been used in the load transfer platform. The response function of the system in plane strain condition has been attained by developing governing differential equations for the proposed mechanical model and its solutions. To develop analytical equations, the basic

differential equations of a Timoshenko beam subjected to a distributed transverse load and a foundation interface pressure, generated from the Kerr foundation model is applied. Furthermore, the suitability of the Kerr foundation model for engineering calculations of LTP are evaluated. In addition, the results from the proposed model simulating the soft soil as the Kerr foundation model are compared to the corresponding solutions when the soft soil is idealised by Winkler and Pasternak foundations. Additionally, to assess the overall behaviour of the multilayer geosynthetic reinforced granular layer as well as that of the single layer geosynthetic reinforced granular layer parametric studies are also carried out. The developed analytical model can be applied by practicing engineers to predict the deflection of the LTP and mobilised tension in the geosynthetic reinforcement.

In addition, this research presents the results of a numerical investigation into the performance of geosynthetic-reinforced column-supported embankment in soft ground. A three-dimensional finite-element model was employed to compare the results with a case study on a number of governing factors such as the downward and lateral movement of soft soil, the stress transferred to column, and the developed excess pore water pressure. The soft soil is represented by the Modified Cam-Clay model (MCC) while the linear elastic and perfectly plastic model adopting the failure criterion of Mohr-Coulomb is applied for medium dense to dense gravel, cobble soil, the granular platform and the embankment. By adopting Hoek-Brown model (HB) to simulate concrete injected columns, non-linear stress-strain relationship is considered in this study. It should be noted that the geometry and other physical properties of the soils and columns considered in this study have been adopted from Gerringong upgrade project, a ground improvement mission taken place in New South Wales, Australia.

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LIST OF PUBLICATIONS

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❖ Published Conference Papers

Ghosh B., Fatahi B., Khabbaz H., and Kamruzzaman A. H. M., (2016). 'Analysis of CMC-Supported Embankments Considering Soil Arching', Proceedings of the Geo-China 2016 International Conference, Shandong, China. ASCE Geotechnical Special Publication (**GSP 265**): 286–293.

Ghosh B., Fatahi B., and Khabbaz H., (2016). 'Mechanical Model to Analyse Multilayer Geosynthetic Reinforced Granular Layer in Column Supported Embankments', Procedia Engineering: Proceedings of The 3rd International Conference on Transportation Geotechnics, **143**: 387–394.

Ghosh B., Fatahi B., Khabbaz H., and Hsi G., (2015). 'Reinforced Timoshenko Beam Theory to Simulate Load Transfer Mechanism in CMC Supported Embankments', Proceedings of 12th Australia New Zealand Conference on Geomechanics, Wellington, New Zealand, 1099–1106.

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LIST OF ABBREVIATIONS

EB:	Euler-Bernoulli beam;
BH:	Borehole;
CD:	Construction day;
CIC	Concrete Injected Column;
CL:	Centreline;
CPT	Cone penetration test;
CS:	Cross section;
DMM:	Deep Soil Mixing Method;
EB:	Euler-Bernoulli beam;
GR:	Geosynthetic reinforcement
GRCS:	Geosynthetic reinforced column-supported;
HB:	Hoek-Brown;
I:	Inclinometer;
LTP:	Load transfer platform;

MC: Mohr-Coulomb;

MCC Modified Cam Clay;

NA: Neutral axis;

OCR: Over consolidation ratio;

PC: Pressure cell;

PSL: Pasternak shear layer;

PVD: Pre-fabricated drain;

SP: Settlement plate;

SRR: Stress reduction ratio;

TB: Timoshenko beam

VP: Vibrating wire piezometer;

NOMENCLATURE

The following notations are used in this research:

a: diameter of the pile (m);

a_r: area replacement ratio (non-dimensional);

A_c: plan area of the column (m^2);

A_p: plan area or cross section area of the column or pile (m^2);

A_h: cross section area of the granular layer in hogging region after cracking (m^2);

A_s: cross section area of the granular layer in sagging region after cracking (m^2);

A_r: cross section area of the geosynthetics (m^2);

A_w: plan area of CIC wall in plane strain (m^2);

C: shear stiffness of the beam (kN/m);

C_h : shear stiffness of the load transfer platform in hogging region (kN/m);

C_s: shear stiffness of the load transfer platform in sagging region (kN/m);

d: diameter of the column (m);

D: bending stiffness of Timoshenko beam (kN.m);

D_h: equivalent bending stiffness of the load transfer platform in hogging region (kN.m);

D_s: equivalent bending stiffness of the load transfer platform in sagging region (kN.m);

e_0: initial void ratio;

E: efficacy or Young's modulus;

E': effective stiffness (kN/m^2);

E_c: Young's modulus of the concrete injected column material (kN/m^2);

E_g: Young's modulus of the granular material in load transfer platform (kN/m^2);

E_r: elastic stiffness of the geosynthetic reinforcement (kN/m^2);

f_{ck}: 28-days compressive strength of concrete (MPa);

G: shear modulus of the soft soil (kPa);

h: thickness of the load transfer platform before cracking (m);

h_h: distance of the neutral axis from the compression surface of the load transfer platform for hogging moment (m);

h_h: distance of the neutral axis from the compression surface of the load transfer platform for sagging moment (m);

H: depth of the soft soil (m);

H: height of the embankment (m);

H_c: length of the columns (m);

H_s: depth of the soft soil (m);

I_h: second moment of inertia of the granular fill about neutral axis for hogging (m^3);

I_s: second moment of inertia of the granular fill about neutral axis for sagging (m^3);

J: stiffness of the geosynthetic reinforcement (kN/m);

K_0: lateral earth pressure coefficient;

K_p: passive earth pressure (kPa);

M: bending moment of the beam (kN.m);

n: modular ratio (non-dimensional) or stress concentration ratio;

k_c: modulus of subgrade reaction for the column ($kN/m^2/m$);

k_{0s}: initial modulus of subgrade reaction for the soft soil foundation ($kN/m^2/m$);

k_{1s}: stiffened modulus of subgrade reaction for the soft soil foundation ($kN/m^2/m$);

k_s: modulus of subgrade reaction for the soft foundation soil ($kN/m^2/m$);

k_{sc}: shear correction coefficient of the Timoshenko beam (non-dimensional);

k_l: modulus of subgrade reaction for the soft soil foundation attached to the bottom of shear layer ($kN/m^2/m$);

k_{sc}: shear correction coefficient of the Timoshenko beam (non-dimensional);

k_u: modulus of subgrade reaction for the soft soil foundation attached to LTP ($kN/m^2/m$);

K_c: equivalent modulus of the subgrade reaction for column (kN/m);

$(K_c)_{eq}$: equivalent modulus of the subgrade reaction for column (kN/m);

p: transverse pressure on the beam from super structure (kPa);

P_r: distributed load acting on geosynthetics between adjacent piles (kPa);

q: normal stress at the interface of the beam and the soft soil (kPa);

q_0: surcharge (kPa);

Q: shear force (kN);

s: centre to centre spacing between the two adjacent columns or piles (m);

s': clear spacing between the two adjacent columns or piles (m);

S_r: tensile stiffness of the geosynthetics (kN/m);

S_r^b: tensile stiffness of the bottom geosynthetic reinforcement (kN/m);

S_r^t: tensile stiffness of the top geosynthetic reinforcement (kN/m);

T: tension mobilised in the geosynthetic layer (kN/m);

U: degree of consolidation of the soft soil (%);

V: shear force in the beam (kN/m);

w: transverse deflection (m);

$\hat{w}$: deflection of the load transfer platform beyond which k_{0s} becomes k_{1s} (m);

y_h: distance between the neutral axis and the centroid axis of the load transfer platform in hogging region (m);

y_s: distance between neutral and centroid axes of the load transfer platform in sagging region (m);

y_r distance of the geosynthetic from the centroid axis of load transfer platform (m);

y_r^b: distance of the bottom geosynthetic layer from the centroid axis of load transfer platform (m);

y_r^t : distance of the top geosynthetic layer from the centroid axis of load transfer platform (m);

ε: strain in geosynthetics;

σ_c: stress transferred to pile (kPa);

σ_s: stress transferred to soil (kPa);

γ: unit weight (kN/m^3);

ρ: soil arching ratio;

υ: Poisson's ratio;

υ_g: Poisson's ratio of the granular material (non-dimensional);

υ_r: Poisson's ratio of the geosynthetics (non-dimensional);

υ_r^t : Poisson's ratio of the top geosynthetic reinforcement (non-dimensional);

υ_r^b: Poisson's ratio of the bottom geosynthetic reinforcement (non-dimensional);

λ: slope of the normal consolidation line;

κ: slope of the elastic swelling line;

θ: rotation angle of the cross section of the beam (radian);

ϕ: frictional angle (degree);

ϕ' effective friction angle;

ψ: rotation angle of Timoshenko beam (radian);

ψ': effective dilatancy angle;