USE OF COPPER AND IMPERIAL SMELTING FURNACE SLAGS AS STRUCTURAL FILLS IN REINFORCED SOIL STRUCTURES

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by

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Submitted

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This thesis is dedicated to Lotus feet's of

SHRI LORD VENKATESWARA

&

My Organization

CSIR – CENTRAL ROAD RESEARCH INSTITUTE

CERTIFICATE

This is to certify that the thesis entitled ñ**USE OF COPPER AND IMPERIAL SMELTING FURNACE SLAGS AS STRUCTURAL FILLS IN REINFORCED SOIL STRUCTURES"**, is being submitted by **Mr. P. SUBRAMANYA PRASAD** in the fulfillment for the award of the degree of **Doctor of Philosophy** of the Indian Institute of Technology Delhi. This is a record of the research work and is entirely carried out by him under my supervision and guidance. The research report presented in this thesis has not been submitted for the award of any other degree or diploma.

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ABSTRACT

Efforts are in progress worldwide to explore possible reuse of a wide range of waste materials as substitutes for natural resources. Copper slag (CS) and Imperial Smelting Furnace slag (ISFS) are industrial wastes generated during extraction of copper and zinc metal respectively. Efforts are made in the present study to experimentally evaluate the suitability of copper slag and imperial smelting furnace slag as structural fill in reinforced soil structures (RSS) in place of conventional fill material (CFM). Detailed physical, chemical, electrochemical characterization as well as shear strength characteristics of CS and ISFS are carried out and results are compared with locally available Badarpur sand (BS) and Yamuna Sand (YS) (natural reference materials). Experimentally determined gradation, physical and shear strength characteristics as well as electrochemical properties of CS and ISFS meet the standard specifications for structural fill of different Guidelines / Codes of Practice.

Large size pullout test apparatus was designed and fabricated for the present study. Thereafter, pullout tests were conducted to evaluate the interaction coefficient (pullout resistance factor (F*)/apparent interface friction coefficient ($\mu_{S/GSY}$)) between the reinforcement (Ribbed GI strips and geogrids (MGR, TT060, Flexa3 and Flexa5)) and selected structural fills (CS, ISFS). The influence of geogrid geometry, ultimate tensile strength and type of polymer (HDPE and PET) on the geogrid ï ISFS, geogrid - CS interactions are studied, and the results are compared with those for geogrids in natural reference materials. Tensile strength, rib thickness and polymer type of geogrid significantly affected the pullout behaviour. The interaction coefficient value (F*/$\mu_{S/GSY}$) of all reinforcements (Ribbed GI strips and geogrids) embedded in CS and ISFS are comparable with those of conventional fill materials.

A comprehensive analysis of the experimental results reported in this thesis and data available from literature is carried out using regression models (Multiple Linear Regression (MLR) Analysis and Non-Linear Regression (NLR) Analysis) and Artificial Neural Network (ANN) for modeling the interaction coefficient ($F^*/\ \mu_{S/GSY}$) between reinforcement (GI strips, geogrids) and structural fills. Comparative evaluation among the statistical models and ANN models for modeling interaction coefficient is presented. Finally, this study proposed an appropriate functional relationship between the interaction coefficient and the pullout test parameters obtained for the reinforcements (GI strip and geogrid) in selected structural fill materials. Further, influence of several parameters considered in the experimental study were quantified through partitioning of weight algorithm. ANN models performed better compared to statistical models for evaluating the factors influencing interaction coefficient ($F^*/\ \mu_{S/GSY}$).

The results of the present study encourage the construction industry in bulk utilization of CS and ISFS as structural fill in reinforced soil structures.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF NOTATIONS AND ABBRIVATIONS

L=Length

L_{eff} = Effective length

$\mathring{u}_v$ = normal stress

C_u = Coefficient of uniformity

D_{50} = Average particle size

W_r = Node width

W_t = Width of bar portion between two nodes

B_r = Node thickness

B_t = Thickness of bar portion between two nodes

S = Spacing between transverse ribs

R_s = Spacing between longitudinal ribs

n_t = Number of transverse ribs

n_{tb}= Number of nodes in a transverse element

T_F = Ultimate tensile strength of the geogrid

A_b = geogrid bearing area

DIC = Digital Image Correlation

PIV = Particle Image Velocimetry

$f_{S/GSY}$ = Interaction coefficient

$\mu_{S/GSY}$ = Apparent interface friction coefficient

PR = Pullout Resistance

RC = Relative compaction

D_{50} = Average grain size (mm)

B = bearing member thickness

F* = Pullout resistance factor

CS = Copper slag

ISFS = Imperial Smelting Furnace Slag

YS = Yamuna Sand

BS = Badarpur Sand

D_r = Relative density

RC = Relative compaction

HA = High adherence

WC = Water content

MC = Moisture content

HDPE = High density polyethylene

PET = Polyester ethylene

CD = Consolidated Drained

CU = Consolidated undrained

USCS = Unified Soil Classification System

SP = Poorly graded

ψ = Dilation angle

R^2 =Coefficient of determination

SSE = Sum Squared Error

MSE = Mean Squared Error

RMSE = Root Mean Squared Error

MAE = Mean Absolute Error

MARE = Mean Absolute Relative Error

BPNN = Back-Propagation Neural Network

MLR = Multiple Linear Regression

NLR = Non-linear Regression

RI = Relative Importance

NN: Neural Network

TR: Training

TT: Testing

V: Validation

ANN = Artificial Neural Network

CFM = Conventional fill material

RSS = Reinforced soil structures

MSEW = Mechanically stabilized earth walls

c_v = Coefficient of consolidation

k = Coefficient of permeability

m_v = Coefficient of volume change

DAQ = Data acquisition

LVDT = Linear variable displacement transducers