Static & Dynamic Characterization of Unreinforced and Reinforced Municipal Solid Waste (MSW Fines) for Geotechnical Applications

Thesis submitted in partial fulfillment for the Award of Degree

Doctor of Philosophy

By

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(Mr. Sanjay Singh Rawat and Mrs. Pratibha Rawat)

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ABSTRACT

Municipal solid waste (MSW) management is a leading challenge for humans currently. As we not only have to deal with the daily generated waste but also must find the solutions for already generated waste which still lying somewhere on the earth's surface. Landfilling which use to be the most viable option to get rid of our waste is no longer an acceptable disposal option left. Poor waste management and increasing waste generation have become environmental and health hazards. Now, this piled-up waste from decades in these landfills causes an alarming situation and can't be ignored. Other than sanitary landfills there are numerous unsanitary landfills and open dump sites which create more dangerous situations in the environment. One of the ways to deal with it could be extracting the waste from the landfills and recirculating the material and land cost in the economy, through enhanced landfill mining techniques. The most abundantly excavated material from sanitary landfills or open dump sites is the municipal solid waste (MSW) fine fractions which consist of more than 50% of the waste composition. These fine fractions also called "MSW fines/soil-like material" have the potential to be used as a bulk replacement for construction/geomaterials. Before this material can be used in bulk in fields as geomaterials in structures, it is important to check the behaviour of the considered material under realistic loading conditions (monotonic or dynamic). The heterogenic characteristic of the MSW is the major factor that influences all the other parameters and makes this material more unpredictable and challenging to reuse. The material characteristic of the MSW is very specific to the site it has been collected (origin of the waste), so it requires specified pilot projects to deal with the waste locally. The data from these pilot projects can be

further helpful to predict or model general geotechnical parameters (static or dynamic). Contributing to this objective a comprehensive experimental program has been planned. The MSW fines (particle size less than 4.75 mm) which contribute to the major portion of the decomposed waste and closely resemble the soil have been the focus of the study. The sample was collected from the local site Ramana in Varanasi. After segregation and processing, about 60% of waste was characterized as MSW fines. The basic physical, chemical, and geotechnical characterization of the waste categorize the MSW fines as lightweight, non-plastic silty sand-type material with good shear strength properties (cohesion and friction angle from 31.37 to 42.19 kPa and 26.69° to 30.74°, for relative compaction of 95 to 99% respectively) with an organic content of 5.9% and slight acidic behaviour. The study on MSW fines has been continued under static and cyclic loading conditions for unreinforced and reinforced categories. A set of 100 strain-controlled cyclic triaxial tests under consolidated undrained conditions were performed to study the cyclic behaviour of the considered MSW fines. The sensitivity of different parameters (relative compaction, effective confining pressure, cyclic shear strain, and loading frequency) on dynamic properties (dynamic shear modulus (G) and damping ratio (D)) of the MSW fines was evaluated. The MSW fines were reinforced with randomly distributed fibers which were also part of the waste collected from another site Karsada, Varanasi. These fibers were mixed to the MSW fines in 0.5, 1, 2, 4, 8, and 10%. The static and dynamic strength of the composite mix was evaluated to find the optimum percentage of fiber content in the mix. Through static strength tests, the optimum fiber content can be decided as 8%. But, the improvement in dynamic shear strength can’t be seen as governed by the dynamic shear modulus of the material. The inclusion of fibers enhances the damping parameter of the MSW fines and can be used as shock absorbers but does not help in excess pore water pressure dissipation. It can be concluded from the results that under static conditions, these waste fibers work satisfactorily and can be used as backfill or embankment material but has limited applications in high seismic zones.

Moreover, the small-strain shear modulus of unreinforced and fiber-reinforced MSW fines was evaluated through the laboratory bender element apparatus. The data evaluated from the laboratory tests were further used to develop empirical correlations for the unreinforced and fiber-reinforced MSW fines. Based on the experimental test results, the excess pore water pressure (r_u) model for the fiber-reinforced MSW fines was established. A cubic polynomial model was applied to correlate the normalized small-strain shear modulus (G_R/G_{UR}) and normalized shear strength (τ_R/τ_{UR}) of the reinforced and unreinforced MSW fines. Nonlinear models were fitted for the normalized shear modulus and damping ratio with cyclic shear strain for both the unreinforced and reinforced MSW fines. Further, the dynamic shear modulus data obtained from the cyclic triaxial tests of the unreinforced and reinforced MSW fines was used for the prediction model of MSW fines (dynamic shear modulus) through two machine learning techniques, i.e., Artificial neural network (ANN) and Gaussian process regression (GPR). The GPR model predicts better results for the dynamic shear modulus of unreinforced and reinforced MSW fines. The sensitivity analysis of the considered parameters on the dynamic shear modulus of MSW fines also correlated with the experimental results.

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NOMENCLATURE

AASHTO- American association of state highway and transportation officials

AI- Artificial intelligence

ANN- Artificial neural network

B- Skempton's pore pressure parameter

BE- Bender element

BPNN- Backpropagation neural network

c- Cohesion

C&D- Construction and demolition

C.C.- Cross-correlation

CBR- California bearing ratio test

Cc- Coefficient of curvature

C_c- Compression index

CD- Consolidated drained

CIF- Central instrument facility

CIPET- Central institute of plastic engineering and technology

COD_d- Dissolved chemical oxygen demand

COD_t- Total chemical oxygen demand

CPCB- Central pollution control board

CPT- Cone penetration test

CSR- Cyclic stress ratio

CTX- Cyclic triaxial

Cu- Coefficient of uniformity

CU- Consolidated undrained

C_v- Coefficient of consolidation

D- Material damping ratio

DI- Deionized

DOC- Dissolved organic carbon

DS- Direct shear

DSS- direct simple shear

DST- Direct shear test

e- Void ratio

EDTA- Ethylene diamine tetra acetic acid

EDX- Energy dispersive x-ray

ELFM- Enhanced landfill mining

ELV- End of the life vehicle

EPR- Evolutionary polynomial regression

f- Loading frequency

FAO- Food and agriculture organization

FC- Fiber content

FL- Fiber length

G- Secant/ dynamic shear modulus

G/G_{max}- Normalized shear modulus reduction

GDP- Gross domestic product

G_{max}- Small strain shear modulus

GP- Genetic programming

GPR- Gaussian process regression

GRU- Gate recurrent unit

G_s- Specific gravity

HDPE- High density polyethylene

INDOT -Indiana department of transportation

IRC- Indian road congress

IS- Indian standard

IW- Industrial waste

k- Coefficient of permeability

kN- Kilo newton

kPa- Kilopascal

LBR- Laboratory leach bed reactors

LFM- Landfill mining

LFMSF -landfill-mined soil fraction

LSTM- Long short-term memory

MAM- Microtremor analysis method

MASW- Multichannel analysis of surface waves

MBT- Mechanically biologically treated

MC -Moisture content

MDD- Maximum dry density

MICP -Microbiologically induced calcium carbonate precipitation

ML- Machine learning

ml- Millilitres

MNRE- Ministry of new and renewable energy

MoEF &CC- Ministry of environment, food, and climate change

MPa- Megapascal

MSW- Municipal solid waste

MSWC -MSW compost

MT- Million metric tonnes

N- Number of cycles

NJDEP -New jersey department of environmental protection

N_L -Initial cycles of liquefaction

NP- Non-plastic

NTPC- National thermal power corporation limited

OMC- Optimum moisture content

P.P.- Peak-to-peak

p′- Mean effective stress

PAH- Polycyclic aromatic hydrocarbons

PCC- Pollution control committees

PETE- Polyethylene terephthalate

PI- Plasticity index

PWP- Pore water pressure

q- Deviator stress (dynamic loading case)

q_{max}- Maximum deviator stress

q_u- Unconfined compressive strength

R- Reinforced

RBF- Radial basis function

RC- Resonant column

RCTS- Resonant column torsional shear

RDCSCC- Residential direct contact soil clean up criteria

RDF- Refuse-derived fuel

RE- Reinforced earth

REEs- Rare earth elements

RNN- Recurrent neural network

r_u- Excess PWP (pore water pressure) ratio

S.S.- Start-to-start

SASW- Spectral analysis of surface waves

SEM- Scanning electron microscope

SEPA- Swedish environmental protection agency

SLM- Soil-like material

SM- Silty sand

SPCB- State pollution control board

SPT- Standard penetration tests

SR- Strength ratio

SS- Simple shear

SVM- Support vector machine

SWM- Solid waste management

TDS- Total dissolved solids

TOC- Total organic carbon

TPD- Tonnes per day

TX- Triaxial

UCS- Unconfined compression test

UR- Unreinforced

US TCLP- United states toxicity characteristic leaching procedure

USCS- Unified soil classification system

USEPA- United states environmental protection agency

UU- unconsolidated undrained

V_p- Compression wave velocity

V_s- Shear wave velocity

WST- Weight sounding test

WtE- Waste-to-energy

XRD- X-ray diffraction

XRF- X-ray fluorescence

Δu = Change in pore pressure

ΔW- Dissipated energy/ unit volume

$\Delta \sigma_c$ = Change in confining pressure

λ- Wavelength

ρ- Material density

δ– Degradation index

ε- Axial strain

ϕ - Internal friction/ Angle of friction

γ- Shear strain

μm- micrometer

σ'_c=Effective confining pressure

σ_c- Confining pressure

σ_d- Deviator stress (static loading case)

σ_v- vertical stress

τ- Shear strength