Pontifícia Universidade Católica do Rio de Janeiro

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Experimental Study of Soils Reinforced with Crushed Polyethylene Terephthalate (PET) Residue

Dissertação de Mestrado

Dissertation presented to the Programa de Pós-Graduação em Engenharia Civil of the Departamento de Engenharia Civil, PUC-Rio as partial requirement of Mestre em Engenharia Civil.

Advisor: Profª. Michéle Dal Toé Casagrande

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I dedicate this Master Dissertation to my beloved parents Ubirajara and Vilma, and to my safe harbor, my sister Carolina.

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Abstract

Louzada, Nathalia dos Santos Lopes; Casagrande, Michéle Dal Toé (Advisor**). Experimental Study of Soils Reinforced with Crushed Polyethylene Terephthalate (PET) Residue**. Rio de Janeiro, 2015. 127 p. MSc. Dissertation – Departamento de Engenharia Civil, Pontifícia Universidade Católica do Rio de Janeiro.

This study presents the behavior of soils reinforced with crushed PET (Polyethylene Terephthalate) residue through experimental study. Three soils were used: a coluvionar soil, a clean and poorly graduated sand and a bentonite. Physical characterization, chemical and mechanical tests (isotropically consolidated-drained triaxial and direct shear) were performed for each material and mixtures. The triaxial test was performed on samples of clayey soil compacted within the maximum dry density and optimum moisture content with ratios of 0, 10, 20 and 30% of fine crushed PET and 3,0 and 5,0% of PET flakes, by dry weight of soil. The triaxial tests on sand samples were made to a relative density of 50% and 10% of water content, and with 0, 10 and 20% fine crushed PET, by dry weight of soil. The direct shear tests with bentonite were made with ratios of 0 and 30% of fine crushed PET and 3,0 and 5,0% of PET flakes, by dry weight of soil. The results have shown that the PET content and level of confining stress have influence on the final mechanical behavior of the mixtures. With both residue of PET, the mixtures present a satisfactory behavior, increasing or maintaining the shear strength parameters similar to the pure soil. Thus, for the clayey mixtures, the fine crushed PET content of 30% and the PET flakes content of 5% are more effective, once they increase the strength parameters. For sandy mixtures the PET inclusions is more effective with 10% of fine crushed PET at lower confining stresses and the optimum content is 10%. For bentonite mixtures the PET inclusions is more effective for PET flakes and the optimum content is 5. Therefore, the use of PET waste for soil reinforcement could minimize the current problems of waste disposal, contribute with the reduction of consumption of natural resources and give a noble use for this material.

Keywords

Triaxial tests; polyethylene terephthalate (PET); soil reinforcement; direct shear test; PET flakes; fine crushed PET.

Resumo

Louzada, Nathalia dos Santos Lopes; Casagrande, Michéle Dal Toé (Advisor**). Estudo Experimental de Solos Reforçados com Resíduos de Politereftalato de Etileno (PET)**. Rio de Janeiro, 2015. 126 p. MSc. Dissertation – Departamento de Engenharia Civil, Pontifícia Universidade Católica do Rio de Janeiro.

O presente estudo apresenta o comportamento dos solos reforçados com PET em pó e triturado, através de ensaios de laboratório. Foram utilizados três solos: um solo coluvionar, uma areia limpa e mal graduada e uma bentonita. Caracterização física, química e ensaios mecânicos (triaxiais CIU e cisalhamento direto) foram realizadas para cada material e misturas. O ensaio triaxial foi realizado em amostras de solo argiloso compactado com porcentagens de pó de PET de 0, 10, 20 e 30% de PET triturado de 3,0 e 5,0%, por seco peso de solo. Os ensaios triaxiais, em amostras de areia foram feitas a uma densidade relativa de 50% e 10% de teor de umidade, e com 0, 10 e 20% de pó de PET, em relação ao peso seco do solo. Os ensaios de cisalhamento direto com bentonita foram feitos com porcentagens de 0 e 30% de pó de PET e 3,0 e 5,0% de PET triturado, por peso seco de solo. Os resultados mostraram que o teor de PET e nível de confinamento têm influência sobre o comportamento mecânico final das misturas. Com ambos os resíduos de PET, as misturas apresentam um comportamento satisfatório, aumentando ou mantendo os parâmetros de resistência ao cisalhamento semelhantes ao solo puro. Assim, para as misturas argilosos, a mistura com 30% de pó de PET e a com 5% de PET triturado são mais eficazes, uma vez que nelas observou-se maior melhora nos parâmetros de resistência. Para misturas de areia a inclusão PET é mais eficaz com 10% de pó PET em tensões confinantes menores e umidade ótima de 10%. Para misturas bentonita, a inserção de PET é mais eficaz para o PET triturado na porcentagem de 5%. Portanto, o uso de resíduos de PET para o reforço do solo poderia minimizar os problemas atuais disposição do resíduo, contribuir com a redução do consumo de recursos naturais e dar um uso nobre para este material.

Palavras Chave

Ensaio triaxial; polietileno tereftalato (PET); solo reforçado; cisalhamento direto; PET triturado; pó de PET.

Contents

List of Figures

List of Tables

List of Abbreviation

ABIPET	Brazilian Association of the PET Industry
ABNT	Brazilian Association of Technical Standard
CBR	California Bearing Ratio
CD	Consolidated Drained
CEMPRE	Corporate Commitment to Recycling
CID	Consolidated Isotopically Drained
CU	Consolidated Undrained
EDXRF	Energy Dispersive X-Ray Fluorescence Spectrometer
EPS	Expanded polystyrene
LVDT	Linear Variable Differential Transformer
MR	Resilience Modulus
MSW	Municipal Solid Waste
MVV	Volumetric Change Gauge
NBR	Brazilian Standard
PE	Polyethylene
PET	Polyethylene Terephthalate
PP	Polypropylene
PS	Polystyrene
PUC	Pontifical Catholic University
PVC	Polyvinyl chloride
RBV	Relationship Voids Bitumen
RT	Tensile Strength
SEM	Scanning Electron Microscope
SUCS	Unified System of Soil Classification
UCS	Unconfined Compressive Strength
UU	Unconsolidated Undrained

List of Symbols

Gs	Specific weight
e	Void index
e_{max}	Maximum void index
e_{min}	Minimum void index
C_u	Coefficient of uniformity
Cc	Coefficient of curvature
D_{10}	Effective diameter
D_{50}	Mass-median-diameter
t_f	Minimum time of failure
L	Specimen height
ν	Shear velocity
‘	Relative to effective stress
”	Inches
#	Number
ε_a	Axial strain
ε_v	Volumetric strain
τ	Shear stress
σ_1,σ_3	Main stresses, major and minor
σ'_c	Effective confining stress
σ_v	Deviator stress
ϕ’	Friction angle
c’	Cohesion
B	Skempton parameter
p’	$(\sigma'_1 + \sigma'_3)/2$ (Normal average effective stress)
q	$(\sigma'_1 - \sigma'_3)/2$ (Deviatoric stress)
h	Final height of the specimen.
h_i	Initial height of the specimen.

%	Content
ml	Milliliters
mm	Millimeter
cm	Centimeters
m	Meter
t	Ton
Kton	Kilo ton
mm/min	Millimeter per minute
min	Minute
gr	Gram
g/cm^3	gram per cubic centimeter
kg	Kilogram
kg/m^3	Kilogram per cubic meter
kgf/m^2	Kilogram force per square meter
kN	Kilo Newton
kPa	Kilo Pascal
°C	Degrees Celsius
Vvp	Volume of voids
Vma	Voids in the mineral aggregates
H_2O	Water
SiO_2	Silica
Al_2O_3	Aluminum Oxide
Fe_2O_3	Iron Oxide (Hematite)
SO_3	Sulfur Trioxide (Sulfuric Oxide)
TiO_2	Titanium Dioxide
CaO	Calcium Oxide (Lime)
K_2O	Potassium Oxide
V_2O_5	Vanadium Pentoxide
ZrO_2	Zirconium Dioxide (Zirconia)
ZnO	Zinc Oxide
CuO	Copper Oxide
CH	Organic Matter, PET, Carbon, Water
$(C_{10}H_8O_4)_n$	Polyethylene Terephthalate

Tm_2O_3	Thulium Oxide
Cl	Chlorine
S	Sulfur
Si	Silicon
Ca	Calcium
Fe	Iron
Tm	Thulium
Cu	Copper
C	Carbon
Al	Aluminum
Ti	Titanium
K	Potassium
V	Vanadium
Zr	Zirconium
Zn	Zinc

“Nobody's perfect enough, that cannot learn from the other and no one is totally devoid of values that cannot teach something to his brother"”

- Saint Francis of Assisi-