

**STATIC AND DYNAMIC PROPERTIES OF MUNICIPAL SOLID
WASTE FROM WASTE DUMPS AT DELHI**

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**DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI**

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WASTE FROM WASTE DUMPS AT DELHI**

by

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DEPARTMENT OF CIVIL ENGINEERING

Submitted

in fulfillment of the requirement of the degree of Doctor of Philosophy

to the



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*This thesis is dedicated to the
Knowledge feet of
SHRI LORD UMAMAHESWARA
&
My Father
LATE. SHRI. B. PRATHAPUDU*

CERTIFICATE

This is to certify that the thesis entitled “**Static and Dynamic Properties of Municipal Solid Waste from Waste Dumps at Delhi**” being submitted by **B. Janaki Ramaiah** to the Indian Institute of Technology, Delhi for the award of degree of **Doctor of Philosophy** is a bonafide record of research work carried out by him under my supervision and guidance. The thesis work, in my opinion, has reached the requisite standard fulfilling the requirement for the degree of Doctor of Philosophy.

The results contained in this thesis have not been submitted, in part or full, to any other University or Institute for the award of any degree or diploma.

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(B. JANKI RAMAIAH)

ABSTRACT

Engineering properties of the municipal solid waste (MSW) from waste dumps/landfills in India is very limited. Static and dynamic properties of emplaced MSW from two dump sites at Delhi are evaluated. A comprehensive field and large-scale laboratory studies are conducted on MSW disposed at Ghazipur and Okhla dumps that are in operation for about 20 to 30 years. Field measurements included: cone penetration tests, shear wave velocity (V_s) profiles and the unit weight through large test pits at different locations of these two dumps. Composition, physical properties and a detailed mechanical characterization of the collected MSW samples were carried out in the laboratory.

Mechanical characterization includes: the evaluation of compressibility parameters, shear strength under both drained and undrained conditions, and strain dependent modulus reduction and material damping ratio curves. The above engineering properties of MSW are evaluated using the: (i) large direct shear (DS) apparatus and (ii) large-scale static-cum-cyclic triaxial (TX) apparatus. The size of the specimen tested in DS apparatus is $304.8 \times 304.8 \times 203.2$ mm and that in monotonic and cyclic triaxial testing is 150 mm in diameter and 300-306 mm in height. Composition analysis revealed that the soil-like or soil-sized (<20 mm) and gravel sized fractions dominated the composition by dry weight near the surface at these two dumps.

Cone penetration tests with pore pressure measurement (CPTu) are conducted to assess the in-situ soil behavior type (*SBT*) and to capture the existence and nature of leachate at these two dumps which are very crucial for stability assessment. The CPT data of MSW reported from different countries is collected and observed that most frequent *SBT* of MSW is similar to that of sandy silt and silty sand type soils.

Shear wave velocity was measured in-situ using the SASW, MASW and MAM techniques at Ghazipur and Okhla dumps. The V_s at both the dumps increased with depth. Measured V_s profiles are compared with the data reported for MSW from different countries. A large database of in-situ V_s of MSW landfills reported till date in the literature is collected and a simple and ready-to-use linear model for the variation of V_s with depth is proposed for preliminary use.

Large-scale one-dimensional (1D) mechanical compression tests conducted in a large DS box indicated that the MSW at these two dumps exhibited low compressibility which can be attributed to relatively low quantities of compressible elements such as plastics, rubber and paper coupled with high fractions of soil-like materials and gravel sized materials.

Shear strength of MSW under drained conditions is evaluated using DS shear apparatus as well as TX apparatus. Over 49 DS tests and 30 drained triaxial compression (TXC) tests are conducted to investigate the effect of composition or fiber content, age, confining pressure or normal stress and density on the shear strength of MSW. The role or importance of fibrous materials on the mobilized shear strength in DS and TXC testing is discussed. The MSW collected from the dump sites did not exhibit a definite peak value representing failure stress both in DS and TXC tests. Hence, strain or displacement dependent shear strength parameters are presented and use of these parameters in the stability assessment of the dumps is discussed. The obtained shear strength parameters are compared with the published data reported for MSW from different countries.

The undrained response of MSW is studied through consolidated undrained TXC tests. Striking similarities between MSW and fibrous peats related to the effect of fibrous materials on the excess pore pressure behavior during undrained tests as well as the cross-anisotropic behavior are presented. A large database on mobilized shear strength of MSW

reported from 43 waste dumps/ landfills located in 19 different countries is collected and a simple linear model for shear strength of MSW is proposed for preliminary engineering analysis.

Over 100 strain-controlled CTX tests under undrained conditions are conducted to develop the modulus reduction (G/G_{max}) and material damping ratio (λ) curves for MSW at these two dumps. Effect of composition or fiber content, age, confining pressure and loading frequency on the stiffness and damping behavior of MSW is also investigated. The G/G_{max} and λ curves obtained from this study are in good agreement with the data reported for MSW in the literature.

One-dimensional seismic response analyses of Ghazipur and Okhla dumps were carried out for the postulated seismic events. Results of the analyses revealed the amplification potential of solid waste, which needs to be taken into account during the design of a final cover system. Stability assessment of critical cross sections at Ghazipur and Okhla dumps under static and seismic loading is carried out and seismically induced permanent deformations are computed using the standard Newmark sliding-block approach. Results indicated that the slopes of these two dumps are currently stable under the existing conditions.

Finally, conclusions from the current work are presented, limitations are highlighted and future research direction to overcome the deficiencies in the current work is suggested.

सार

भारत में बर्बाद डंप / लैंडफिल से नगरपालिका ठोस कचरा (MSW) की इंजीनियरिंग गुण बहुत सीमित हैं। दिल्ली में दो डंप साइटों से विस्थापित MSW के स्थैतिक और गतिशील गुणों का मूल्यांकन किया जाता है। गाज़ीपुर और ओखला डंप पर निपटाए गए MSW पर एक व्यापक क्षेत्र और बड़े पैमाने पर प्रयोगशाला अध्ययन किया जाता है जो लगभग 20 से 30 वर्षों के लिए ऑपरेशन में हैं। फील्ड माप में शामिल हैं: शंकु प्रवेश परीक्षा, कतरनी लहर वेग (वीएस) प्रोफाइल और इन दोनों डंप के विभिन्न स्थानों पर बड़े परीक्षण गड्ढे के माध्यम से इकाई वजन। रचना, भौतिक गुण और एकत्र एमएसडब्ल्यू नमूनों का एक विस्तृत यांत्रिक लक्षण वर्णन प्रयोगशाला में किया गया था।

यांत्रिक लक्षण वर्णन में हैं: संपीड़न मापदंडों का मूल्यांकन, सूखा और अनियंत्रित दोनों स्थितियों के तहत कतरनी की ताकत, और तनाव पर निर्भर मापांक में कमी और भौतिक भिगोना अनुपात घटता। एमएसडब्ल्यू के उपरोक्त इंजीनियरिंग गुणों का मूल्यांकन निम्न प्रकार से किया जाता है: (i) बड़े सीधी कतरनी (डीएस) उपकरण और (ii) बड़े पैमाने पर स्थिर-कम-चक्रीय त्रिकोणीय (TX) तंत्र। डीएस उपकरण में परीक्षण किया गया नमूना का आकार $304.8 \times 304.8 \times 203.2$ mm है और यह कि मोनोटोनिक और चक्रीय त्रिकोणीय परीक्षण में 150 मिमी व्यास और 300-306 मिमी की ऊंचाई है। संरचना विश्लेषण से पता चला है कि मिट्टी की तरह या मिट्टी के आकार (<20 mm) और बजरी आकार के आकाओं की सतह पर इन दो डंप पर सतह के पास सूखे वजन पर हावी है।

ताकना के दबाव माप (सीपीटीयू) के साथ शंकु परीक्षण का परीक्षण इन-सीटू माती व्यवहार प्रकार (एसबीटी) का मूल्यांकन करने के लिए किया जाता है और स्थिरता आकलन के लिए बहुत महत्वपूर्ण हैं जो इन दो डंपों पर मौजूद लीचेट के अस्तित्व और

प्रकृति को कैप्चर करने के लिए किया जाता है। एमएसडब्लू के सीपीटी आंकड़े विभिन्न देशों से एकत्र किए जाते हैं और यह देखा जाता है कि एमएसडब्लू का सबसे अक्सर एसबीटी रेतीले गाद और सिल्लि रेत प्रकार मिट्टी के समान है।

गाजरपुर और ओखला डंप पर SASW, MASW और MAM तकनीकों का उपयोग करके कतरनी वेग वेग को मापा गया। दोनों डंप पर बनाम गहराई से बढ़ी मापा वीएस प्रोफाइल की तुलना विभिन्न देशों से एमएसड के लिए की गई डेटा के साथ की जाती है। एमएसडब्लू के भूमिगत विवरणों के एक बड़े डाटाबेस में आज तक की गई सूचना साहित्य में एकत्र की जाती है और प्रारंभिक उपयोग के लिए गहराई के साथ वीएस के भिन्नता के लिए एक सरल और तैयार-से-उपयोग वाली रेखीय मॉडल का प्रस्ताव है।

बड़े डीएस बॉक्स में आयोजित बड़े पैमाने पर एक-आयामी (1D) मैकेनिकल संपीड़न परीक्षण ने संकेत दिया कि इन दो डंप पर एमएसडब्लू कम कॉम्बिटीसिटी का प्रदर्शन करता है जो कि प्लास्टिक, रबड़ और कागज जैसे कॉम्बिनेबल तत्वों की अपेक्षाकृत कम मात्रा के लिए जिम्मेदार ठहराया जा सकता है मिट्टी जैसी सामग्री और बजरी आकार की सामग्री के अंश

निचोड़ की स्थिति के तहत एमएसडब्ल्यू की कतरनी ताकत का मूल्यांकन डीएस कतरनी उपकरण के साथ-साथ टेक्सस उपकरण के मूल्यांकन के लिए किया जाता है। एमएसडब्ल्यू की कतरनी ताकत पर संरचना या फाइबर सामग्री, उम्र, सीमित दबाव या सामान्य तनाव और घनत्व के प्रभाव की जांच के लिए 49 से अधिक डीएस परीक्षणों और 30 सूखा triaxial संपीड़न (TXC) परीक्षण किए जाते हैं। डीएस और टेक्ससी परीक्षण में जुटाई गई कतरनी शक्ति पर रेशेदार सामग्री की भूमिका या महत्व पर चर्चा की गई है। डंप साइटों से प्राप्त एमएसडब्लू ने डीएस और टेक्ससी टेस्ट दोनों में विफलता तनाव का प्रतिनिधित्व करने वाले एक निश्चित चोटी मूल्य का प्रदर्शन नहीं किया। इसलिए, तनाव

या विस्थापन निर्भर कतरनी शक्ति पैरामीटर प्रस्तुत किए जाते हैं और इन मापदंडों का उपयोग डंप के स्थिरता मूल्यांकन में किया जाता है। प्राप्त कतरनी शक्ति पैरामीटर को विभिन्न देशों से एमएसड के लिए रिपोर्ट किए गए प्रकाशित आंकड़ों के साथ तुलना की गई है।

एमएसडब्लू की अनियंत्रित प्रतिक्रिया का अध्ययन समेकित निक्षेपित टेक्ससी टेस्ट के माध्यम से किया जाता है। रेशेदार पदार्थों के प्रभाव से संबंधित एमएसडब्लू और तंतुमय पीटों के बीच हड़ताली समानताएं अनियंत्रित परीक्षणों के साथ-साथ पार-अनिसोट्रोपिक व्यवहार के दौरान प्रस्तुत किए गए हैं। एमएसडब्लू की गतिशील कतरनी शक्ति पर 19 विभिन्न देशों में स्थित 43 कचरे के डंप / लैंडफिल की सूचना मिली है और प्रारंभिक इंजीनियरिंग विश्लेषण के लिए एमएसडब्ल्यू की कतरनी ताकत के लिए एक सरल रेखीय मॉडल प्रस्तावित किया गया है।

इन दो डंप पर एमएसडब्ल्यू के लिए मापांक में कमी (G/G_{max}) और भौतिक भिगोना अनुपात (λ) घटता विकसित करने के लिए 100 से अधिक तनाव-नियंत्रित सीटीएक्स परीक्षणों का संचालन किया जाता है। संरचना या फाइबर सामग्री का प्रभाव, उम्र, सीमित दबाव और लोड होने की आवृत्ति एमएसडब्लू के कठोरता और भिगोना व्यवहार पर भी जांच की जाती है। इस अध्ययन से G/G_{max} और λ क्यूवर्स साहित्य में एमएसडब्लू के लिए रिपोर्ट किए गए आंकड़ों के साथ अच्छे समझौते हैं।

गाज़ीपुर और ओखला डंप के एक-दिवसीय भूकंपी प्रतिक्रिया का विश्लेषण किया गया भूकंपीय घटनाओं के लिए किया गया था। विश्लेषण के परिणामों ने ठोस कचरे की प्रवर्धन क्षमता का खुलासा किया, जिसे अंतिम कवर सिस्टम के डिजाइन के दौरान ध्यान में रखा जाना चाहिए। गाज़ीपुर और ओखला डैप्स में स्थिर और भूकंपीय लोडिंग में महत्वपूर्ण क्रॉस सेक्शन के स्थिरता आकलन किया जाता है और मानक न्यूमार्क फिसलने-ब्लॉक

दृष्टिकोण का उपयोग करके भूकंपीय प्रेरित स्थायी विकृतियों की गणना की जाती है। परिणाम दर्शाते हैं कि मौजूदा दो स्थितियों के ढलानों वर्तमान में स्थिर हैं।

अंत में, वर्तमान कार्य के निष्कर्ष प्रस्तुत किए जाते हैं, सीमाएं उजागर हो जाती हैं और वर्तमान कार्य की कमी को दूर करने के लिए भविष्य की अनुसंधान दिशा का सुझाव दिया जाता है।

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NOTATIONS

σ'_{v0}	Effective vertical stress
σ'_0	Effective confining stress
σ_d	Cyclic deviator stress
σ_c	Effective confining pressure
σ_e	Peak cyclic stress in extension
σ_a	Average cyclic stress
σ'_c	Effective isotropic consolidation stress
σ'_m	Mean effective stress
τ_h	Double amplitude cyclic shear stress
γ_c	Shear strain
ε_a	Axial strain
τ_{hv}	Cyclic shear stress
ε_c	Axial strain in compression
ε_e	Axial strain in extension
ε_{DA}	Double amplitude axial strain
δ_c	Cyclic axial deformation in compression
δ_e	Cyclic axial deformation in extension
ω	Angular frequency
$\Delta\theta$	Phase difference
ρ	Mass density
μ	Poisson's ratio

A_L	Area of hysteresis loop
A_T	Area of the shaded triangle
B	Skempton's pore pressure parameter
c'	Cohesion intercept
CD	Consolidated Drained
\overline{CU}	Consolidated Undrained
CTX	Cyclic Triaxial Tests
CDAS	Control and Data Acquisition System
CRMP	Common Receivers Mid Point
λ	Material damping ratio
E_{sec}	Secant Young's modulus
f	Frequency of loading
FoS	Factor of Safety
g	Acceleration due to gravity
G_s	Specific gravity
G_{max}	Small strain shear modulus or maximum shear modulus
K_0	Coefficient of earth pressure at rest
L	Length of specimen
M_w	Earthquake Magnitude
P_a	Atmospheric pressure
MHA	Maximum Horizontal Acceleration
PP_i	Initial pore pressure before start of consolidation
SASW	Spectral Analysis of Surface Waves
V_s	Shear wave velocity
V_0	Initial volume before consolidation

ε_v	Volumetric strain
q_c	Tip resistance
f_s	Sleeve friction
R_f	Friction Ratio
u_2	Dynamic pore pressure or penetration pore pressure
SBT	Soil Behavior Type
D_s	Constrained Modulus
C_c'	Compression ratio or Modified Compression Index
c'	Apparent cohesion intercept
ϕ'	Effective friction angle
R_u	Pore pressure ratio for slope stability analysis
r_u	Excess pore pressure ratio
u	Excess pore pressure
D	Diameter of the specimen
α_h	Horizontal seismic coefficient
α_y	Yield acceleration