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Title:

Development of a Technical Management Tool for Settlement and Stability Behaviour of Municipal Solid Waste Landfills

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Thesis submitted for fulfilment of requirements for the degree of Master of Engineering

December 2014

Certificate of Authorship/Originality

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Abstract

Landfilling is a common method of disposal of municipal solid waste (MSW). Landfills are engineered structures consisting of bottom liners, leachate collection and removal systems, and final covers. With an expanding world and the remarkable growth of industry, the demand for larger and higher capacity landfills is rapidly increasing. As available space becomes scarce in urban areas, development on the top of or adjacent to old landfills has become increasingly common. Redeveloping on or adjacent to a closed landfill can be challenging and complex. In this regard, it is necessary to review a wide variety of engineering and geotechnical considerations for landfill redevelopment including settlement, foundation systems, gas and leachate management, and utility considerations, etc. Among various factors, which would be considered in redeveloping landfill sites, settlement is the most important factor from the perspective of structural and geotechnical stability.

Prediction of the long-term settlement of MSW for the final cover design as well as end-use facility design such as recreational facilities, industrial/commercial facilities is necessary. In addition, estimation of settlement is needed to assess the stability of leachate and gas collection pipes, drainage systems, landfill storage capacity, and the overall landfill operating costs. Excessive settlement may cause fracture in the cover system and may also cause damage to the leachate and gas collection pipes.

Many researchers studied the compression response of MSW and proposed different approaches to predict immediate settlement and time dependent settlement under load. Today, there are many published landfill settlement models. The research has been developed from simple soil mechanics based model to the constitutive model of waste. The stages of waste, which primarily only consider the primary and secondary settlements are improved with the development of constitutive model for long term settlement predictions.

In this study, the critical and comprehensive literature review about the landfill settlement and compressibility is provided. It is concluded that current methods of settlement prediction have serious shortcomings in accounting for the organic (biodegradable) portion of waste streams and the many factors that control its

decomposition; they are also unable to account for changing landfill conditions such as rates of filling or changes in waste type that have major effects on settlement rates and magnitude. The existing methods are therefore difficult to use in a predictive manner and require recalibration for changing waste streams.

In this study, a technical management tool for MSW closed landfills has been developed using MATLAB graphical user interface, which aims to understand the process of long term settlement in landfills considering various related parameters, whilst it calculates different properties of wastes, and determines the landfill slope stability under various conditions. Furthermore, to illustrate the role of these parameters in settlement, a detailed parametric study considering variations of different parameters have been conducted in term of the settlement change over time as affected by influencing parameters. This parametric study showed that the variation of parameters can lead to significantly different settlements in landfills. Therefore, it is necessary to carefully select the parameter values for accurate prediction of landfill settlements. Moreover, in order to increase the understanding of the landfill behaviour and to quantify the significance of different parameters, a sensitivity analysis has also been performed to study the sensitivity of the models to variation of input parameters such as the unit weight, the landfill height, the waste properties, and the factors, affecting the biodegradation process of landfills. The results of this sensitivity analysis indicate that there are two prominent characteristics, having significant impacts on the overall landfill settlement. These characteristics are the landfill height and the compressibility parameters, while two other parameters including the gas diffusion coefficient and the van Genuchten parameter have trivial effects when compared to their relevant normal operating point (NOP). However, some other parameters have different degree of impact on the landfill settlement.

In this research, a numerical study has also been carried out by applying PLAXIS 2D for prediction of slope stability of landfills. Additionally, a detailed parametric study is conducted to investigate the influence of the slope geometry on the safety factor (SF) considering the variation of waste geotechnical properties, the landfill height, and the waste compaction conditions, in order to develop a set of design charts in terms of variations of the SF with various heights, the slope inclinations, the effective cohesions of the waste, and the effective friction angles.

Finally, the field data related to Tehran landfill has been collected for the validation of this landfill technical management tool (LTMT). It has been found that LTMT and its adopted model can be effectively used for MSW landfill settlement estimation. It should be noted that using this technical management tool, the effect of different parameters and conditions on settlement can be investigated. It is expected that the parametric study, which has been carried out in this research, can be applied in landfill redevelopment projects to predict the long term behaviour accurately, resulting in reduced construction and maintenance costs.

This dissertation concludes that the most important and influential parameters in landfill redevelopments and prediction of MSW landfill settlement incorporating gas generation and leachate production are the landfill height, the compression ratio, the lift thickness, the waste composition, and the age of MSW.

This dissertation is dedicated to my son

Amir Koorosh Nemati

who really gave me the reason to continue….

Acknowledgements

I would like to express my special appreciation and sincere gratitude to my supervisor A/Prof Hadi Khabbaz who has been a tremendous mentor for me. I would like to thank him for encouraging my research. Obviously, this research would not have been completed without his guidance and continuous support.

I would like to go on to thank Dr. Behzad Fattahi for his great comments on my research.

I gratefully acknowledge Tehran Municipality, for providing me useful information which allowed me to carry out some parts of my research.

A special mention of thanks to my friends for their constant support and cooperation during my study. Their timely help and friendship shall always be remembered.

I also wish to express my deep gratitude to my family for their support and encouragement.

Finally, I am thankful to my son Amir Koorosh for giving me happiness during my studies. I owe him lots and lots of fun hours.

LIST of Publications

During the course of this research, a number of publications have been made which are based on the work presented in this thesis. They are listed here for reference.

- Tahmoorian F., Khabbaz H. , Nemati S., "Numerical Study of Slope Stability of Instrumented Tehran Sanitary Landfill", International Journal of GEOMATE, 2014.
- Tahmoorian F., Nemati S., "Long-time Settlement Model of Waste Soils for Iranian Landfills", 4th International Conference on Geotechnique, Construction Materials and Environment, Brisbane, Australia, 2014.
- Nemati S., Tahmoorian F., "Environmental Problems of Iranian Landfill at Seaside of Caspian Sea", International Journal of GEOMATE, 2014.
- Nemati S., Tahmoorian F., Hasanli E., "A Case Study on Environmental Problems of Iranian Landfills", 4th International Conference on Geotechnique, Construction Materials and Environment, Brisbane, Australia, 2014.
- Tahmoorian F., Khabbaz H., "Parametric Study and Sensitivity Analysis of Long Term Settlement of Municipal Solid Waste Landfill Coupled With Landfill Gas Pressure and Leachate Flow", 15th International Waste Management and Landfill Symposium, Cagliari, Italy, 2015 (Abstract has been accepted).
- Tahmoorian F., Khabbaz H., "Numerical Analysis of Slope Stability of Instrumented Tehran Sanitary Landfill", Abstract has been submitted to 4th GeoChina International Conference, Shandong, China, 2016.
- Tahmoorian F., Khabbaz H., "Design, Construction, and Redevelopment of Instrumented Tehran Sanitary Landfill", Abstract has been submitted to 4th GeoChina International Conference, Shandong, China, 2016.
- Tahmoorian F., Khabbaz H., "Parametric Study of Long Term Settlement of Municipal Solid Waste Landfill Coupled with Landfill Gas Pressure and Leachate Flow", Abstract has been submitted to 5th International Conference on Geotechnique, Construction Materials and Environment, Osaka, Japan, 2015.
- Tahmoorian F., Khabbaz H., "Lifecycle Performance Assessment of MSW Landfills through Settlement Prediction", Abstract has been submitted to 2nd International Conference on Performance-based and Lifecycle Structural Engineering (PLSE 2015), Brisbane, Australia, 2015.

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List of Notations and Symbols

The following symbols including their definitions are used in this report:

Acronyms:

BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
CS	Centre Space
FEM	Finite Element Method
FT	Forward Time
GCL	Geosynthetic Clay Liner
LCS	Leachate Collection system
LTMT	Landfill Technical Management Tool
MB	Methanogenic Biomass
MC	Moisture Content
MSW	Municipal Solid Waste
NMOC	Nonmethanogenic Organic Compound
SBP	Soybean Peroxidas
SF	Safety Factor
TOC	Total Organic Carbon
VFA	Volatile Fatty Acids
VOC	Volatile Organic Compounds

Latin Letters:

A	Factor representing the final total settlement
a	Primary compressibility parameter
b	Secondary compressibility parameter
b	Coefficient of mechanical creep
b	Coefficient of secondary mechanical compression
B	Interactive constant associated with the biodegradation of organics
B	Factor representing the initial settlement rate
c	Secondary mechanical compression rate
c	Rate constant for mechanical creep
C_1	Slope of the strain versus log-time curve
$\mathrm{C}_{\alpha\mathrm{i}}$	Compression index (function of stress level and degree of decomposition)
C_{β}	Biodegradation index
C_c	Primary compression index
C_α	Secondary compression index
$C_{\alpha e}$	Modified secondary compression index

C_{ce}	Modified primary compression index
$C_{\alpha1}$	Intermediate secondary compression ratio
$C_{\alpha2}$	Long term/final secondary compression ratio
$C_{\alpha f}$	Creep index
C_i	Initial mass of the biodegradable waste
C^*	Compressibility parameter
${C_c}^*$	Compression ratio
${C_\alpha}^*$	Swelling ratio
C'_α	Modified coefficient of secondary compression in terms of strain
D	Gas diffusion coefficient
d	Secondary biological compression rate
$d\varepsilon_v^e$	Volumetric strain due to elastic
$d\varepsilon_v^p$	Volumetric strain due to plastic
$d\varepsilon_v^c$	Volumetric strain due to time dependent mechanical creep
$d\varepsilon_v^b$	Volumetric strain due to biodegradation effects
$d\varepsilon_{vc}$	Volumetric strain increment
E_{dg}	Total compression due to waste degradation
E_m	Secant modulus
e	MSW void ratio
e_0	Initial void ratio of waste
e_p	Void ratio at the end of primary compression
f_{sj}	Initial solids fraction for each waste group
G	Rate of generation of gas per unit volume of waste
G_{si}	Initial overall specific gravity of waste solids
G_{sj}	Specific gravity of jth group of the waste solids
H	Design thickness
H_0	Initial thickness of the waste layer
H_i	Height of solid waste after initial compression
H_p	Height of solid waste after primary compression
h	Matric potential
h_i	Post compression height of layer i
$\frac{H_0}{H_i}$	Relative height corresponding to the existing overburden pressure (σ_0)
$\frac{\Delta H}{H_i}$	Change in relative height corresponding to the stress increment ($\Delta\sigma$)
K	Coefficient of permeability
k	Intrinsic permeability
k	First-order degradation constant
k_g	Unsaturated gas conductivity
k_w	Unsaturated hydraulic conductivity
k_{gs}	Saturated gas conductivity
k_{ws}	Saturated hydraulic conductivity

k'	Decomposition factor
k'	Post filling decay
L_0	Volume of gas a unit mass of waste could produce
m	Molar mass of the landfill gas
m	Van Genuchten parameter
m'	Rate of increase of waste thickness with time
m_a	Mass of air
m_w	Mass of water
m_s	Mass of solids
m_v	Coefficient of volume change
M'	Reference compressibility
N'	Rate of compression parameter
n	Van Genuchten parameter
n	Number of lifts in the landfill
n	Porosity in the landfill
n_i	Initial landfill porosity
p	Van Genuchten parameter
P	Pressure beyond atmospheric pressure
P_a	Atmospheric pressure
P_0	Existing overburden pressure acting at midlevel layer
R	Universal gas constant
S	Total settlement of waste
S_e	Effective saturation
S_{ic}	Settlement due to immediate compression
S_{pc}	Settlement due to primary compression
S_{sc}	Settlement due to secondary compression
T	Average landfill temperature
t	Time since beginning of filling
$\mathrm{t_b}$	Time for completion of biological compression
$\mathrm{t_c}$	Construction period
$\mathrm{t_c}$	Time of completion of filling
$\mathrm{t_{cb}}$	Time for the creep at the end of biological degradation
t_e	Time duration for evaluation of compression
t_i	Duration of filling of layer i
t_{is}	Time at the end of initial settlement period
$\mathrm{t_p}$	Time for primary compression
$\mathrm{t_r}$	Reference time
$\mathrm{t_1}$	Time for completion of primary compression
$\mathrm{t_2}$	Time for completion of secondary compression
$\mathrm{t_3}$	Time for total period of time considered in modeling
t_s	Time at which the slope of the strain versus logarithm time curve changes to a steeper slope

t'	Time elapsed since loading application
t''	Time elapsed since waste disposal
u_a	Excess-gas pressure
u_0	Pore-gas pressure at $t = 0$
U_p	Primary settlement of waste for design thickness
U_d	Decomposition settlement at time $t \leq$ tc after start of filling
$(U_d)_{t \geq t_c}$	Post decomposition settlement at time tpc larger or equal to tc
$V_{i,N}$	Initial volume of each layer of waste in the landfill
$V_{S,N}$	Volume of the waste layer considering spatial and temporal variation
v_a	Volume of air
v_w	Volume of water
v_s	Volume of solids
v	Total volume
w_c	Weight of component c
w_j	Gravimetric water content
w_t	Total weight of waste components
y	Depth below the landfill surface

Greek Letters:

α	Van Genuchten parameter
α	Fitting parameter (=0.00095H +0.00969)
β	Fitting parameter (=0.00035H+ 0.00501)
β	Correlation coefficient of compression due to biodegradation
β	Fraction of waste mass that can potentially be converted to gas
ε_p	Strain resulting from instantaneous response to applied load
ε_c	Time-dependent strain due to mechanical creep
ε_b	Time-dependent strain due to biological decomposition
ε_{pi}	Strain in lift i resulting from instantaneous response to loading from overlying lifts
ε_{ci}	Strain at time t in lift i due to mechanical creep associated with the stresses from self-weight and the weight of overlying lifts
ε_{bi}	Strain at time t in lift I due to biological decomposition of lift i
ε_v	MSW volumetric strain
$\varepsilon_{tot-dec}$	Total amount of compression due to decomposition of biodegradable waste
$\varepsilon(t)$	Strain at time t
ε_0	Initial strain
ε_i^e	Elastic strain
ε_i^p	Plastic strain
ε_i^c	Time-dependent creep strains
ε_i^d	Time-dependent degradation induced strain

θ_r	Residual moisture content
θ_s	Saturated moisture content
σ'	Effective stress
σ	Compressive stress depending upon waste height, density, and external loading
σ_0	Existing overburden pressure acting at midlevel of the layer
σ_v	Vertical overburden stress
λ/b	Rate of secondary compression
λ	First order decay constant
λ_j	First order kinetic constant for the jth group
μ	Dynamic viscosity of water
γ	Unit weight of MSW
γ_a	Average unit weight of MSW
γ_c	Unit weight of component c
γ_i	Unit weight of lift i
γ_w	Specific weight of water
γ_t	Unit weight ofwaste at a given time under confinement
ρ_s	Density of MSW solids
ρ_{sp}	Density of paste particles
ρ_w	Density of water
ρ_s	Density of solid waste
ρ_i	Density of the waste for each layer
τ	Parameter related to the rate of gas production
κ	Bulk viscosity of the solid waste
Δh_i	Long term settlement of waste layer i
ΔP	Increase in overburden pressure acting at midlevel layer
Δv	Volume variation
$\Delta\sigma$	Increment of overburden pressure acting at midlevel of the layer from the construction of an additional layer
$\delta\sigma'$	Difference in effective stress
$\Delta\gamma_c$	Increase in unit weight of component c