MŰEGYETEM 1782

STABILITY ISSUES OF LANDFILLS

PhD thesis

Gabriella Varga

Technical University of Budapest

Departement of Geotechnics

Supervisor:

Dr. József Farkas

Budapest

September, 2010

TABLE OF CONTENTS

1. IMPORTANCE OF THE RESEARCH PROJECT

Environment protection and conservation are very important in the 21st century. This is even more important in waste management design and construction where deposition of heterogeneous waste must be achieved in a way that minimizes its environmental impact. Therefore positioning and construction of landfills, their day-to-day maintenance as wells as their utilization are all very important in Hungary, the European Union, and all over the world.

Majority of municipal solid waste (app. 54%) is deposited in landfills in Hungary, similarly to most other countries. Urbanization, economic growth, and the continuing improvement in living standards have all contributed to the fast increase of municipal solid waste.

More waste coupled with increasing prices of land forced engineers to design higher and steeper landfills for better utilization. Changes in the size of landfills result in increased sheer strength. In the analysis of long term behaviour of landfills, slope stability analysis plays a major role because the gas and leachate pipes, the monitoring and lining systems can easily get damaged.

In Hungary most landfills are located in rural areas, which decrease the possibility of damages to human life in case of a failure. However, economical damages may bring unbearable consequences. The variety of failure causes and the sophisticated relations between physical, chemical and biological processes make it almost impossible to create general design recommendations.

The heterogeneity of waste body makes it difficult for engineers to model its behaviour. Age, unit weight, classification and compaction methods all influence mechanical behaviour of MSW. Nevertheless, detailed knowledge of waste properties is needed to predict the change of MSW shear properties over time. It is important to formalize design guidelines suited for Hungarian conditions, evaluate the conditions of waste bodies in the country, and define their shear strength parameters.

2. ORGANIZATION OF THE THESIS

Studying the geotechnical aspects of MSW is very important in Hungary because, according to European Union directives, all landfills that pollute the environment were mandated to close down by 2007 and all other landfills had to meet high EU standards by 2009. Based on these directives three quarters of all landfills had been closed down by 2009 and their recultivation are still in progress. The government aims to replace the closed down landfills, which are primarily small in size, with modern, large landfills that are designed for a long lifecycle. It is highly desired to discover the degradation process with regards to shear strength parameters for better cover system design, layout of biogas pipelines, and the construction of new landfills. Based on these results safety issues can be addressed and an economically viable maintenance can be achieved.

My thesis focuses on determining soil mechanics parameters of Hungarian waste bodies with regards to their degradation phase. This is very important for the stability analysis of landfills. Shear strength is defined as a function of the proportion, characteristics, and orientation of reinforcing elements.

Well-established soil mechanics procedures, i.e. drilling are very cumbersome and expensive for determining the behaviour of MSW. Laboratory capacity also limits the application of such tests. We have applied CPT and CPTu probing in order to reduce the number of tests and the overall costs. Given the limiting circumstances, designing landfills based on CPT probing may produce new insight for engineers.

I aim to define the correlation between CPT probing and tests based on drilling in order to define the degradation phase and soil mechanics parameters of MSW.

I have analyzed the Hungarian and international literature. I have defined shear strength parameters for MSW samples of different degradation phases in a purpose-built, oversize direct shear test equipment.

In order to define the reinforcing impact on shear strength of material of greater size and strength, I have sheared "artificially placed" samples in direct shear equipment of size 200 x 200 x 150 mm. I have experimented with reinforcing material of different mass percentage, material, and dimension, and applied 1D and 2D reinforcements. I have also varied the angle between the reinforcing material and shear direction.

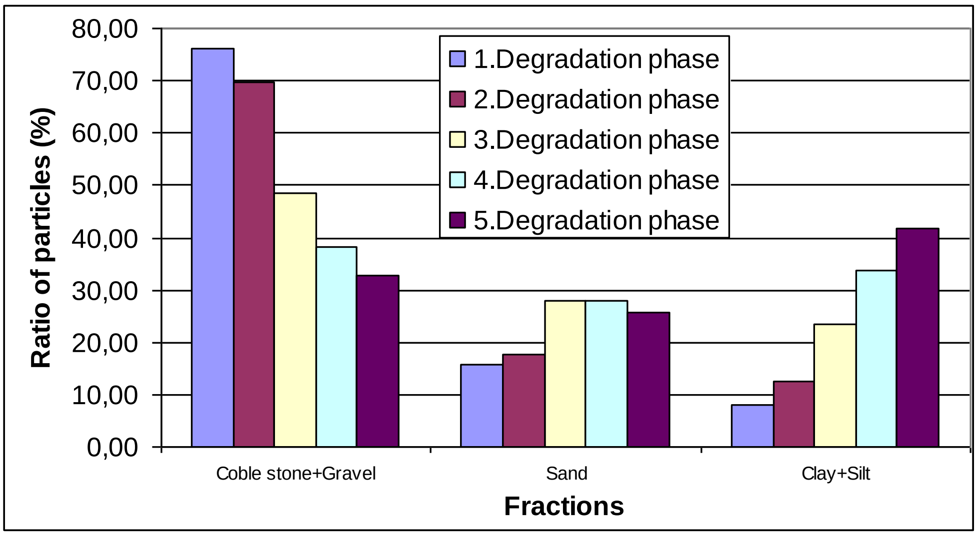
In order to analyze the behaviour of MSW, CPTu probing, dynamic probing and large diameter drilling have been performed at various points in the Regional Landfill of Pusztazámor. I then have evaluated and compared the results.

3. THESES

1. Summary of Thesis No. 1

Based on grain size distribution tests I have concluded that the grain size distribution curve shifts upward by the advancement of degradation. This can be explained by shredding of the particles and the degradation of organic elements. Some of the particles turn into gas or liquid during the degradation process, which compacts the waste body even more. Degradation has a major shifting impact on the grain size distribution curve. The figure below depicts soil fractions as a function of degradation.

As we can see the ratio of coarse grained soils has decreased by more than 50 %, while the ratio of fine grained soils has increased fivefold. The ratio of sand was between 16-26%. From the results I can conclude that the phase of degradation can be well estimated from grain size distribution test results for the waste bodies under examination. The composition, the age, the pre-selection techniques and the type of waste have major impact on grain size distribution, so it would be useful to compare the results of my research with test results from other examined landfills.



I formulated the ratio of shared fractions as a function of degradation in the following table.

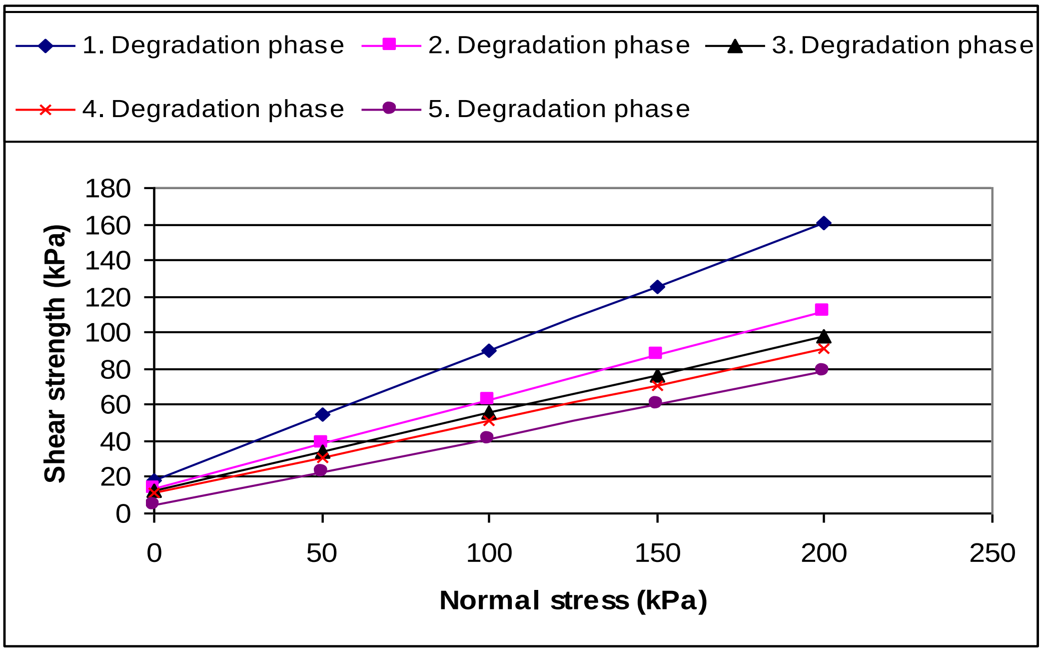
	Degradation phase				
	1.	2.	3.	4.	5.
Course grained soil (%)	66-86	58-75	40-58	30-45	25-40
Sand (%)	10-25	11-27	20-35	20-35	20-35
Fine grained soil(%)	5-15	8-18	15-30	25-40	35-50

Based on this table the degradation phase can be estimated from grain size distribution test results in the waste analyzed in this research. Shear strength parameters for stability analysis can be estimated more accurately knowing the degradation phase of waste. The number of expensive and difficult shear tests can be minimized with the help of estimating the degradation phase from grain size distibution test results using proper engineering practices.

2. Summary of Thesis No. 2

Laboratory tests were used to confirm that shear strength of waste is significantly influenced by its decomposition phase. With the advancement of degradation internal friction of waste greatly decreases, while the cohesion of waste decreases less significantly, which may result in stability problems for landfills.

Based on laboratory tests I have drawn up shear strength envelopes for waste with different density, composition, and degradation phase. This envelope helps to determine the safety factor of a landfill for the entire degradation process and the geometry of landfilling can be modified to take the current safety factor value into account. Using this table long-term stability of landfills can be calculated, stability problems can be avoided, which produces financial benefits as well. Based on these equations shear strength of waste can be calculated if the degradation phase is known.

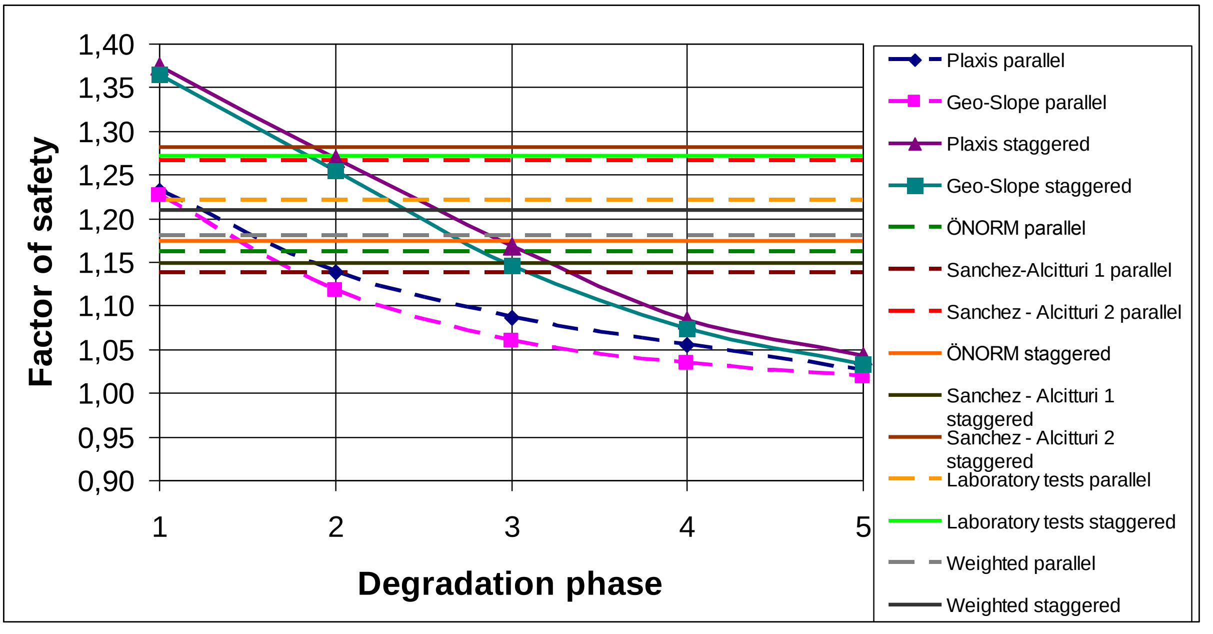


Shear strength envelopes help to determine the degree of degradation in the light of normal stress and shear strentgh calculated from laboratory tests. Knowing the phase of degradation is very useful for gas utilization and helps maximizing the economy of its retrieval. Application of shear strength envelopes is beneficial for both engineering and economical aspects in case of landfill design and operation.

3. Summary of Thesis No. 3

Numerical tests were used to confirm that the degree of decomposition affects the stability of landfills. I have compared literature recommendations with results coming from laboratory tests performed on Hungarian solid waste. My model divides the waste body into five layers according to the degree of decomposition.

I used PLAXIS and GEOSLOPE program in my simulations then I compared their results. I have found that the factor of safety decreased significantly with the advancement of degradation.



The results show that the factors of safety computed from literature recommendation parameters are close to the 2nd or 3rd degree decomposition parameters determined by my simulations. With the advancement of decomposition, the factor of safety may be smaller than the results coming from literature recommended parameters, which may compromise the stability of landfill.

Accordingly, I propose that the stability of bioreactors should be determined with shear strength parameters defined as a function of degradation (and time). Commonly applied fresh waste- or average-based parameters may generate unjustifiably high safety factors, which may result in unexpected stability problems. Literature recommendations should be treated uniquely in every landfill with careful considerations.

4. Summary of Thesis No. 4

Numerical simulations have been performed to prove that the geometry of landfilling has a major impact on slope stability. In order to achieve the highest stability I recommend deposition strategies that respect the degradation phase of waste.

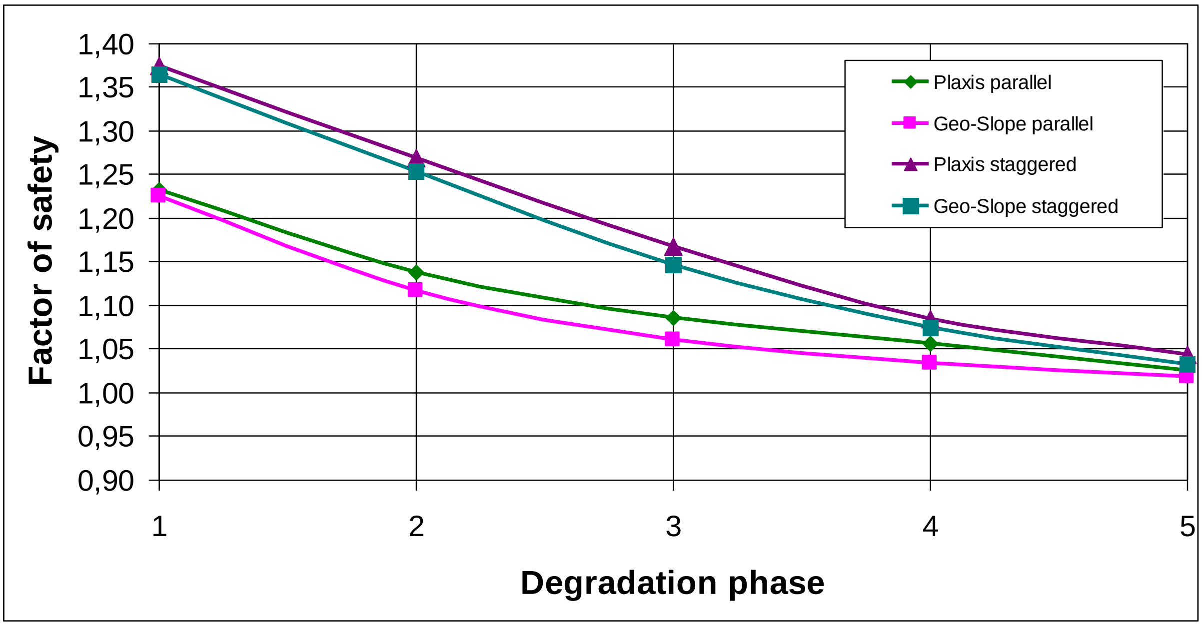
My model divided the waste body into five layers and three different geometries were simulated. I have used PLAXIS and GEOSLOPE program in my simulations then compared their results.

I have found that the geometry of landfilling has a major impact on slope stability.

In case of aslope landfilling technique the slope became unstable already in the first phase, while stability of the totally filled up landfill was sufficient. I conclude that stability calculations are very important in deposition procedure design, otherwise unexpected failures may happen.

Based on my comparisons I conclude that the safety factor is higher in the staggered geometry in all stages of degradation. In the final stage when the whole waste body reaches the last degradation phase and waste structure under examination is uniform, the staggered landfill still showed a slightly higher safety factor. It shows that the geometry of landfilling technique plays a major role in its stability. I recommend the usage of staggered geometry for landfills.

I have performed our simulations both with PLAXIS and GEOSLOPE. The results of the two sets of simulations are very close despite their different approaches. It shows the reliability of the generated geotechnical model.



I have created a geotechnical model to determine the time (degree of degradation) dependent stability of bioreactor landfills. The model is suited for:

- examining and optimizing the deposition strategy
- predicting the time dependent changes of
    - stability,
    - potentially instable waste body ,
    - surface settlement.
- creating a monitoring strategy and related alarm levels.

5. Summary of Thesis No. 5

I propose a calculation method based on laboratory tests to determine shear strength of reinforced waste as a function of the amount, the material, and the dimension of reinforcing elements, as well as the angle between the reinforcing material and shear direction. I confirm that the impact of the reinforcing elements can be modelled as extra cohesion in case of geotechnical examinations.

I have evaluated my results with the help of the Mohr-Coulomb failure criteria (τ=σ*tg(φ)+c). Using one dimensional reinforcing elements the largest increase of friction angle was 18,5%, while the increase of cohesion reached 242%. Results produced by two-dimensional reinforcing elements were very similar. My calculations have confirmed that reinforcing material produces added cohesion in waste.

Afterwards, I have performed the calculations treating the reinforcing effect as cohesion. Shear strength of reinforced a sample can be determined as an aggregate of shear strength of a sample without reinforcement and the shear strength sustained by the reinforcing elements.

$$\tau=\sigma*tg(\varphi)+c+E$$

where E is the shear strength sustained by the reinforcing elements.

Based on my laboratory tests I have determined shear strength formulas for waste in case of paper and plastic (1D and 2D) reinforcing fibres.

	Plastic (1D)	Paper (1D)
σ>100 kPa (α=0°)	$\tau=\delta*tg(\varphi)+c$	$\tau=\delta*tg(\varphi)+c$
(α=45°)	$\tau=\delta*tg(\varphi)+c+(24,7*x+30,3)/2$	$\tau=\delta*tg(\varphi)+c+(28,2*x+24,3)/2$
(α=90°)	$\tau=\delta*tg(\varphi)+c+(24,7*x+30,3)$	$\tau=\delta*tg(\varphi)+c+(28,2*x+24,3)$
σ<100 kPa (α=0°)	$\tau=\delta*tg(\varphi)+c$	$\tau=\delta*tg(\varphi)+c$
(α=45°)	$\tau=\delta*tg(\varphi)+c+\frac{\delta}{100}(24,7*x+30,3)/2$	$\tau=\delta*tg(\varphi)+c+\frac{\delta}{100}(28,2*x+24,3)/2$
(α=90°)	$\tau=\delta*tg(\varphi)+c+\frac{\delta}{100}(24,7*x+30,3)$	$\tau=\delta*tg(\varphi)+c+\frac{\delta}{100}(28,2*x+24,3)$

	Plastic (2D)	Paper (2D)
σ>100 kPa (α=0°)	$\tau=\delta*tg(\varphi)+c$	$\tau=\delta*tg(\varphi)+c$
(α=45°)	$\tau=\delta*tg(\varphi)+c+(30,6*x+49)/2$	$\tau=\delta*tg(\varphi)+c+(36,5*x+58,5)/2$
(α=90°)	$\tau=\delta*tg(\varphi)+c+(30,6*x+49)$	$\tau=\delta*tg(\varphi)+c+(36,5*x+58,5)$
σ<100 kPa (α=0°)	$\tau=\delta*tg(\varphi)+c$	$\tau=\delta*tg(\varphi)+c$
(α=45°)	$\tau=\delta*tg(\varphi)+c+\frac{\delta}{100}(30,6*x+49)/2$	$\tau=\delta*tg(\varphi)+c+\frac{\delta}{100}(36,5*x+58,5)/2$
(α=90°)	$\tau=\delta*tg(\varphi)+c+\frac{\delta}{100}(30,6*x+49)$	$\tau=\delta*tg(\varphi)+c+\frac{\delta}{100}(36,5*x+58,5)$

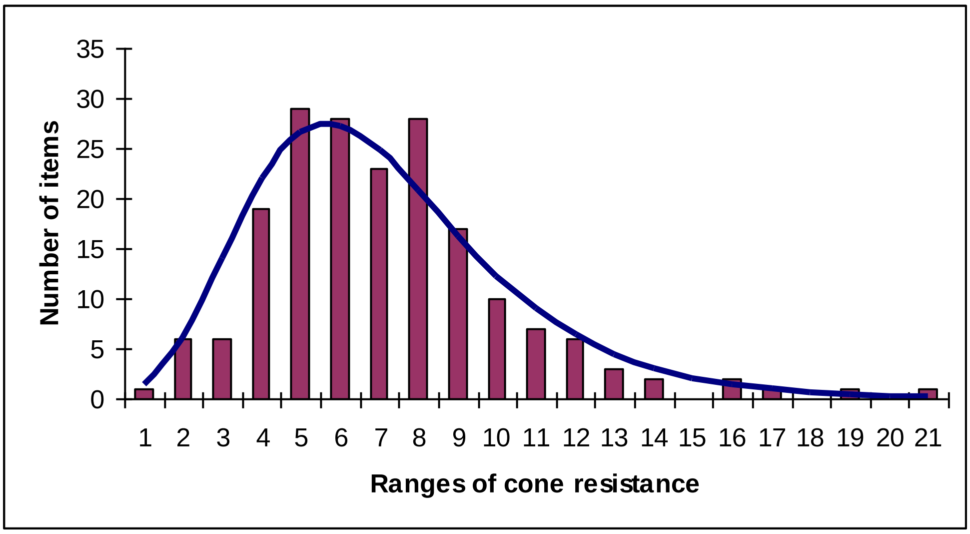
In the equations x denotes the mass percentage of reinforcing elements. Shear strength of waste samples can be determined as a function of the mass percentage of reinforcing elements using normal stress values of the above table. Results may also be determined as a function of the orientation of reinforcing elements. Based on these results E is assumed to be changing linearly as a function of α.

The results are limited to the waste samples that I have examined but we can assume that other waste bodies show similar results given the Hungarian landfilling and pre-selection process.

6. Summary of Thesis No. 6

I have used statistical methods to prove that the distribution of cone resistance coming from CPTu tests is lognormal.

The validation of the distribution was performed by mathematical statistical methods based on the methods published by Dr. László Réthári. I have examined the logarithm of cone resistance with the Pearson diagram, where the results based on K criteria showed normal distribution. I got the same results using the β_1- β_2 co-ordinate system. Based on these results the distribution of cone resistance is lognormal.



I conclude that the methods used for analysing the results of CPTu tests for soil cannot be applied because they were developed for normal distribution. Instead of normal distribution I propose to use lognormal distribution to determine characteristic values.

$$q_{ck} = \exp(q_{cm\ln} - 1{,}64 \cdot \sigma_{\ln})$$

where q_{cmln} is the average of the logarithm of cone resistance,

σ_{ln}: is the deviation of the logarithm of cone resistance.

Characteristic values belonging to 5% probability and 95% confidence level may be calculated based on the distribution functions. Based on the above results statistical methods may replace estimations when determining the values (characteristic values) that are utilized in landfill design.

4. PUBLICATIONS

English language journal article published in Hungary, refereed

1. Varga G., Czap Z.: Soil models: Safety Factors and Settlements. Periodica Polytechnica. Ser.Civ.Eng. Vol. 48, No.1-2. 2004. pp.53-64.

To appear:

2. Varga G.: Geotechnical Aspects of Bioreactor Landfilles. Periodica Polytechnica. Ser.Civ.Eng. (Elfogadó nyilatkozat mellékelve).

Hungarian language journal article published in Hungary, refereed

3. Czap Z., Varga G.: Cut slopes and embankments. Modern computational modelling. Mélyépítő Tükörkép, Október, 2003. pp.10-11.
4. Varga G., Czap Z.: Finite element analysis of landfills. GTM (Gazdasági Tükörkép Magazin) 2010 III. X. évf. 52-53.o.
5. Varga G. 2010: Determination of shear strength of waste bodies based on CPTu test results. GTM (Gazdasági Tükörkép Magazin) 2010 III. X. évf. 52-53.o. (To appear).

Hungarian language journal article published in Hungary, non-refereed

6. Varga G., Czap Z., Mahler A.: Long-term stability of cut slopes. Közlekedésépítési Szemle. 59 évf. 3. szám 2009. pp.. 17-21.
7. Varga G. 2010: Determination of shear strength of waste bodies with reinforcing elements. Közlekedésépítési szemle. (To appear).

International conference papers in English, refereed

8. Varga G., Czap Z., Farkas J.: Applications of Different Soil Models for Sheet Pile Wall Measurements. Proceedings of the 5th International PhD Symposium in Civil Engineering. Delft, 16-19 June 2004. pp. 953-959.
9. Varga G., Czap Z., Mahler A.: Stability of cut slopes in cohesive soils. Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering. Alexandria, Egypt, 5-9 Octobre 2009. pp. 1566-1569.

To appear:

10. Varga G.: Stability Analysis of Bioreactor Landfills. Proceedings of the XVth European Conference on Soil Mechanics & Geotechnical Engineering (XV ECSMGE).

International conference papers in English, non-refereed

11. Varga G.: The Future of Hungarian Flood Management with Respect to the European Union Water Framework Directive. I.Ph.D. Civilexpo. Budapest 2002. pp. 171-178.
12. Varga G., Czap Z.: Modelling of clay: settlements and stability factors. Active Geotechnical Design in Infrastructure Development. XIIIth. Danube-European Conference on Geotechnical Engineering. Ljubljana. 2006.

Conference papers in Hungarian

13. Varga G.: Flood-control system of Hungary. ÉPKO2003, Nemzetközi Építéstudományi Konferencia. Csíksomlyó, 2003. pp. 295-300.
14. Varga G., Czap Z., Mahler A.: Long-term stability of cut slopes. Dr. Kézdi Árpád Emlékkonferencia kiadványa. BME Geotechnikai Tanszék, Budapest, 2008. pp. 122-132.
15. Varga G., Czap Z., Módos J. 2010: Determination of shear strength parameters of waste bodies. Geotechnika Konferencia, Ráckeve. (CD-ROM).

Conference short papers

16. Varga G.: Flood Management Under the EU Water Framework Directive. Budapest, 2002.
17. Varga G.: Flood Management of Hungary with Respect to the EU Water Framework Directive. Magyar Hidrológia Társaság. Szolnok, 2003.
18. Czap Z., Varga G.: Applications of Different Soil Models for Stability of Cut Slopes and Embankments for Geotechnical Design IX. Magyar Mechanikai Konferencia. Miskolc, 2003.
19. Varga G.: Applications of Different Soil Models for Stability Experiments. 2nd International Young Geotechnical Engineers' Conference. Mamaia, 2003.
20. Czap Z., Varga G.: Applications of Different Soil Models for Stability of Cut Slopes and Embankments for Geotechnical Design Geotechnika2003 konferencia. Ráckeve, 2003.
21. Varga G., Czap Z., Mahler A. 2008: Long term stability in clay-cut slopes.Geotechnika2008 konferencia. Ráckeve, 2008.

Science Student Assocation Conference paper

22. Mahler A., Varga G.: Bearing Capacity of Bored Piles Based on Cone Penetration Test Results. TDK konferencia. Budapest, 1999.

5. SELECTED INDUSTRIAL PROJECTS

1. Kistarcsa, Batthány utca, Medical center. Soil mechanics study. 2003.
2. Salgótarján, Strabag Rt. Design of Asphalt Mixing Site. Soil mechanics study 2003.
3. Újhartyán, Design of Artificial Lake. Soil mechanics study 2004.
4. Budakalász, Erdőhát u. Wet basement cause analysis. Soil mechanics study 2004.
5. Budapest, IX. Design of Concrete Mixing Site. Soil mechanics study 2004.
6. Zebegény, Design of Gymnasium. Soil mechanics study 2004.
7. Design of Damjanich street in Gödöllő. Soil mechanics study 2006.
8. Budaörs, Industry Park, design of production line hall and office. Soil mechanics study 2006.
9. Budapest, XIV. Egressy út 46/b, design of the construction of an extra level on top of a multi-storey building. Soil mechanics study 2006.
10. Design of the extension of national route 4. Soil mechanics study 2007.
11. Szentes, Cycle bridge design. Soil mechanics study 2007.
12. Budapest, III. Berzsenyi Dániel utca, design of an apartment block with underground garage. Soil mechanics study 2008.

13. Budapest, IX. Drégely utca, design of an apartment block. Soil mechanics study 2008.
14. Gyöngyös, Design of a round-about intersection. Talajmechanikai szakvélemény 2008.
15. Budapest, Törökvészi út, design of garage extension. Soil mechanics study 2008
16. Budapest, design of Zsigmond Király College Library building. Soil mechanics study 2008.
17. Malomsok, Windpower park. Soil mechanics study 2008.
18. Szigetszentmiklós – Taksony bicycle route bridge over Duna- Tisza canal. Soil mechanics study 2008.
19. Budapest, IX. Thaly Kálmán utca, design of day nursery building. Soil mechanics study 2009.
20. Szentendre, design of the extension of the medical center. Soil mechanics study 2009.
21. Budapest, II. Rómer Flóris utca, elevator design. Soil mechanics study 2009.
22. Dunaharaszti – Szigetszentmiklós design of bicycle route. Soil mechanics study 2009.
23. Budapest, Üllői út 757., design of medical center. Soil mechanics study 2009.
24. Budapest, III. Csillaghegyi út, factory hall with crane. Soil mechanics study 2010.
25. Debrecen, extension of Kenézy Hospital Emergency Department. Soil mechanics study 2010.
26. Abony, design of the Catholic Community Center. Soil mechanics study 2010.
27. Dunavarsány, design of City Hall. Soil mechanics study 2010.
28. Soroksár, extension of Post Office number 1. Soil mechanics study 2010.