Geosynthetics International: Vol. 7, No. 4-6, 2000

Foreword by T.S. Ingold and R.J. Bathurst

SPECIAL ISSUE ON LIQUID COLLECTION SYSTEMS

It is with much pleasure that we present this special triple issue of Geosynthetics International, which deals with the design of liquid collection systems and in particular those used in landfills. This complements two preceding special issues dealing with "Design of Geomembrane Applications" (Volume 2, No. 6, 1995) and "Liquid Migration Control Using Geosynthetic Liner Systems" (Volume 4, Nos. 3-4, 1997). The first contribution to this special issue is the state-of-the-art paper "Hydraulic Design of Geosynthetic and Granular Liquid Collection Layers", which provides guidance to design engineers and researchers alike. The equations presented in this paper provide the basis for much of the technical issues addressed in the remaining papers of this special issue. The second paper presents a method for establishing the equivalency between granular and geosynthetic liquid collection layers. This paper, which may be helpful to regulators and designers alike, suggests that the state of practice be reconsidered where a simple hydraulic transmissivity equivalency is used to determine that two liquid collection layers are equivalent. The third paper presents a useful relationship between compressibility of geotextile drainage media and the presence of soil particles entrapped in those geotextiles. This paper complements the state-of-the-art paper mentioned above. The relationship provided in the paper titled "Effect of Thickness Reduction on Geosynthetic Hydraulic Transmissivity" is a helpful tool for predicting the long-term behaviour of geosynthetic drainage media. Use of this relationship may save hundreds of hours of hydraulic transmissivity testing. The fifth and sixth papers, "Hydraulic Design of Geosynthetic and Granular Liquid Collection Layers Comprising Different Two Slopes" and "Design of Liquid Collection Layers with Radial Flow", respectively, deal with two design situations that occur in some landfills and are based on actual design situations faced by the authors. The paper on liquid collection layers comprising two slopes should assist design engineers since it provides a simple approximate solution to a very complex problem. The paper on radial flow should be of assistance to design engineers, educators, and students, since it clearly defines the concepts of confined and unconfined flow through the use of detailed examples. The paper "Criterion for Acceptable Bentonite Loss From a GCL Incorporated Into a Liner System" is also based on a design situation faced by the authors and provides a rigorous analysis of the impact of bentonite loss from a GCL on the potential clogging of an underlying geosynthetic drainage medium. Last, but not least, is a somewhat surprising paper on the design of pipes. Who would think that an original paper on the velocity of water in pipes could still be written? The paper provides a remarkably simple relationship between the velocity of liquid in a pipe and the flow rate. This relationship is particularly useful for checking that a pipe incorporated in a leakage detection system is able to ensure rapid leakage detection. All the papers appearing in this special issue have been submitted to the strict peer-review system, which has ensured the ongoing high standards of quality of Geosynthetics International. We take this opportunity to express our gratitude to the reviewers who made a special effort under strict time constraints to review the papers submitted for the special issue. This collection of papers provides a wealth of information on the design of liquid collection systems and, hence, is consistent with the prime objective of the Journal, which is to disseminate the best available information on geosynthetics technology. We believe this special issue will become a standard reference for design engineers and researchers, and we thank all the authors who participated in this outstanding work.

T.S. Ingold, Editor R.J. Bathurst , Co-Editor

Introduction by J.P. Giroud

I first found the need for improving the current methods for designing drainage layers in 1974, when I designed the first double liner system constructed using two geomembranes, for a large water reservoir in France. This liner system included a gravel leakage collection layer between the two geomembranes; designing this layer was a challenge. I had to face a similar challenge in 1980 when I designed the first entirely geosynthetic liner system, composed of a geonet between two geomembranes, for a large underground water reservoir in the United States. Furthermore, in 1983, when I became increasingly involved in the design of liner systems for landfills in the United States, I discovered that incorrect methods were used to calculate the depth of liquid in the leachate collection layers. Clearly, the state of practice had to be improved, and I started working on the subject. Also, the work I did on leakage evaluation from 1984 to1997 showed that a key factor in minimizing leakage is to limit the depth of liquid on top of liners, which requires an accurate design of liquid collection layers. A wide variety of topics pertaining to liquid collection layers are addressed in this special issue: calculation of liquid depth in liquid collection layers, equivalency between granular and geosynthetic liquid collection layers, comparison between confined and unconfined flow, influence of several parameters on the flow capacity of geosynthetic drainage media, potential clogging of geosynthetic drainage media by bentonite particles migrating from a geosynthetic clay liner, velocity of liquids in pipes, etc. However, the papers presented in this special issue should not be regarded as a complete discussion of the topic of liquid collection systems. Many papers on this topic can be found in the technical literature. Furthermore, some aspects of liquid collection systems are not discussed herein such as filtration, a subject on which papers have been published by a number of authors. Even though the papers presented in this special issue include analytical developments and detailed discussions, the main goal of these papers is to provide practical information that can be readily used by design engineers. Accordingly, simple equations and graphical solutions are provided, and their use is illustrated by numerous examples. To complete a work of the magnitude of this special issue, it is useful to have a deadline. The distinguished Chinese colleagues who invited me to present a keynote lecture at the Fifth Chinese Conference on Geosynthetics in November 2000 did provide me with such a deadline. They suggested that I talk about landfills with special emphasis on the use of geosynthetics in liquid collection layers, a subject that would logically require that the special issue be ready by the time of the Conference. Also, the fact that the information presented in this special issue would be useful to many engineers engaged in the design of projects that would affect the life of so many in China, encouraged me to diligently pursue the work undertaken. Accordingly, I would like to dedicate this special issue of Geosynthetics International to the Chinese engineers who design

applications of geosynthetics. I wish to acknowledge the support of GeoSyntec Consultants for the preparation of this special issue and express my gratitude to its Chief Executive Officer and President, R. Bonaparte, and its Principals and Associates. I also want to say that the publication of this issue would not have been possible without the contribution of my co-authors, J.F. Beech, R. Bonaparte, J.E. Dove, B. Palmer, G.N. Richardson, K.L. Soderman, A. Zhao (four papers), and J.G. Zornberg (two papers). It is certainly very rewarding for me to work with professionals of this caliber. In addition, I must say that it was a great pleasure and honor to cooperate with E.M. Palmeira, a rising star in our discipline. Also, the special issue greatly benefited from the participation of M.A.G. Gardoni, who just completed her Ph.D. thesis at the University of Brasilia. Finally, I am grateful to R. Ortiz who produced the excellent figures for this special issue and K. Holcomb who provided assistance for all delicate aspects of word processing. Last but not least, on behalf of all authors, I express our gratitude to T.S. Ingold, Editor, and R.J. Bathurst, Co-Editor, of Geosynthetics International for giving us the opportunity of grouping and publishing these eight papers in one special issue, and to K. Labinaz, Production Editor of Geosynthetics International, who successfully met the double challenge of ensuring not only the correctness of each paper, but, also, the consistency of the special issue.

J.P.G.

Technical Paper by J.P. Giroud, J.G. Zornberg, and A. Zhao

HYDRAULIC DESIGN OF GEOSYNTHETIC AND GRANULAR LIQUID COLLECTION LAYERS

ABSTRACT: The present paper provides equations for the hydraulic design of liquid collection layers. A first series of equations gives the maximum thickness of the liquid collected in a liquid collection layer. These equations are used in design to check that the maximum liquid thickness is less than an allowable thickness. Some of the equations make it possible to rigorously calculate the liquid thickness, whereas other equations, which are simpler, give an approximate value of the liquid thickness. A second series of equations makes it possible to calculate the required hydraulic conductivity of the liquid collection layer material and the required hydraulic transmissivity of the liquid collection layer. These equations are useful for selecting the material used to construct the liquid collection layer. The equations provided in the present paper include reduction factors to quantify the decrease in flow capacity of liquid collection layers due to thickness reduction (caused by the applied stresses) and hydraulic conductivity reduction (caused by clogging). Practical recommendations and design examples are presented for both geosynthetic and granular liquid collection layers.

KEYWORDS: Liquid collection layer, Leachate collection layer, Leakage detection and collection layer, Drainage layer, Thickness, Granular, Geosynthetic.

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REFERENCE: Giroud, J.P., Zornberg, J.G., and Zhao, A., 2000, "Hydraulic Design of Geosynthetic and Granular Liquid Collection Layers", Geosynthetics International, Special Issue on Liquid Collection Systems, Vol. 7, Nos. 4-6, pp. 285-380.

Technical Paper by J.P. Giroud, A. Zhao, and R. Bonaparte

The Myth of Hydraulic Transmissivity Equivalency Between Geosynthetic and Granular Liquid Collection Layers

ABSTRACT: Design engineers often assume that a geosynthetic liquid collection layer and a granular liquid collection layer having the same hydraulic transmissivity are equivalent. In the United States, such equivalency is often mandated by regulations for leachate collection layers and leakage detection and collection layers used in landfills. This approach is based on the assumption that two liquid collection layers having the same hydraulic transmissivity have the same flow capacity. As shown in the present paper, this is true only in the case of confined flow. A theoretical analysis described in the present paper shows that, in the case of unconfined flow (which is the usual design case), two liquid collection layers that have different thicknesses and hydraulic conductivities (such as granular and geosynthetic liquid collection layers) cannot have the same flow capacity (i.e. cannot be equivalent) if they have the same hydraulic transmissivity. To be equivalent, the thinner liquid collection layer (generally, the geosynthetic liquid collection layer) should have a greater hydraulic transmissivity than the thicker liquid collection layer (generally, the granular liquid collection layer).

KEYWORDS: Liquid collection layer, Leachate, Leakage detection, Drainage layer, Hydraulic conductivity, Hydraulic transmissivity, Equivalency, Granular, Geosynthetic.

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REFERENCE: Giroud, J.P., Zhao, A., and Bonaparte, R., 2000, "The Myth of Hydraulic Transmissivity Equivalency Between Geosynthetic and Granular Liquid Collection Layers", Geosynthetics International, Special Issue on Liquid Collection Systems, Vol. 7, Nos. 4-6, pp. 381-401.

Technical Paper by E.M. Palmeira and M.G. Gardoni

THE INFLUENCE OF PARTIAL CLOGGING AND PRESSURE ON THE BEHAVIOUR OF GEOTEXTILES IN DRAINAGE SYSTEMS

ABSTRACT: Nonwoven geotextiles have been used for drainage and filtration in geotechnical engineering works for many years. Concerns related to drainage capacity and clogging potential still remain as factors that restrain a broader use of geotextiles for drainage systems, particularly in major engineering projects. This paper presents the test results of the hydraulic characteristics of partially clogged geotextiles under pressure. Partial clogging can occur during spreading and compaction of soil on geotextiles or throughout the service life of the drainage system. Geotextile specimens, artificially clogged in the laboratory and exhumed from actual field works, were tested to assess their normal and longitudinal permeabilities under different levels of soil impregnation and normal stresses. The results obtained showed that partial clogging significantly influenced the mechanical and hydraulic characteristics of nonwoven geotextiles and that soil impregnation was not necessarily detrimental to the geotextile longitudinal permeability under stress. Comparisons of test and predicted results, confirmed that the expression reported by Giroud in 1996 is a useful tool for the prediction of nonwoven geotextile permeabilities under virgin and soil impregnated conditions. Data on the impregnation levels of geotextile specimens exhumed from actual field works are also presented and discussed.

KEYWORDS: Geotextile, Drainage, Filtration, Clogging, Laboratory testing, Permeability.

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REFERENCE: Palmeira, E.M. and Gardoni, M.G., 2000, "The Influence of Partial Clogging and Pressure on the Behaviour of Geotextiles in Drainage Systems", Geosynthetics International, Vol. 7, Nos. 4-6, Special Issue on Liquid Collection Systems, pp. 403-431.

Technical Paper by J.P. Giroud, A. Zhao, and G.N. Richardson

EFFECT OF THICKNESS REDUCTION ON GEOSYNTHETIC HYDRAULIC TRANSMISSIVITY

ABSTRACT: A new theoretical relationship that quantifies the reduction in hydraulic transmissivity resulting from a reduction in geosynthetic thickness is presented. It is shown that the proposed relationship is in good agreement with experimental data on geotextiles and geonets. This relationship is useful to predict hydraulic transmissivity reduction from the results of compression tests on geosynthetics. This is particularly useful when the thickness reduction is

due to creep, because it is impractical to conduct hydraulic transmissivity tests over a long period of time.

KEYWORDS: Geosynthetic, Geonet, Geotextile, Thickness, Hydraulic transmissivity, Hydraulic conductivity, Theoretical, Reduction factor.

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REFERENCE: Giroud, J.P., Zhao, A., and Richardson, G.N., 2000, "Effect of Thickness Reduction on Geosynthetic Hydraulic Transmissivity", Special Issue on Liquid Collection Systems, Geosynthetics International, Vol. 7, Nos. 4-6, pp. 433-452.

Technical Paper by J.P. Giroud, J.G. Zornberg, and J.F. Beech

HYDRAULIC DESIGN OF GEOSYNTHETIC AND GRANULAR LIQUID COLLECTION LAYERS COMPRISING TWO DIFFERENT SLOPES

ABSTRACT: Liquid collection layers used in landfills often comprise two sections with different slopes. Typically, one of the slopes is much steeper than the other one. The steeper slope is generally the downstream slope in a landfill cover and the upstream slope in a leachate collection layer. The liquid collection material is generally a geosynthetic (such as a geonet) on the steep slope and is either a geosynthetic or a granular material (such as sand or gravel) on the other slope. Design methods are available for the case where there is a drain that promptly removes the liquid at the toe of each of the two sections. This paper provides a method to design the liquid collection layer for the case where there is no drain at the connection between the two sections, i.e. when the only drain is at the toe of the downstream section. The method consists of analytical expressions for calculating the maximum thickness of liquid under steady-state conditions in each of the two sections of the liquid collection layer. Design examples are presented and practical guidance is provided for the use of a transition zone between the two sections when needed.

KEYWORDS: Liquid collection layer, Drainage, Landfill, Slope, Leachate collection, Landfill cover, Geosynthetic, Geonet, Geocomposite, Analytical, Design.

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REFERENCE: Giroud, J.P., Zornberg, J.G., and Beech, J.F., 2000, "Hydraulic Design of Geosynthetic and Granular Liquid Collection Layers Comprising Two Different Slopes", Geosynthetics International, Special Issue on Liquid Collection Systems, Vol. 7, Nos. 4-6, pp. 453-489.

Technical Paper by J.P. Giroud and A. Zhao

DESIGN OF LIQUID COLLECTION LAYERS WITH RADIAL FLOW

ABSTRACT: The present paper provides equations for the design of liquid collection layers sloping radially toward a sump located in a corner of the liquid collection layer. It is pointed out that an equation currently used by some design engineers is not correct because it corresponds to the case of confined flow, which is not the type of flow that should take place in a liquid collection layer; this equation leads to grossly underestimated values of the required thickness and hydraulic transmissivity of liquid collection layers. A detailed discussion of the difference between confined and unconfined flow is presented. Design examples are provided.

KEYWORDS: Liquid collection layer, Leachate collection layer, Leakage collection layer, Drainage layer, Geosynthetic, Geonet, Geomat, Geocomposite, Radial flow, Gravity flow, Confined flow, Unconfined flow, Sump.

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REFERENCE: Giroud, J.P. and Zhao, A., 2000, "Design of Liquid Collection Layers With Radial Flow", Geosynthetics International, Special Issue on Liquid Collection Systems, Vol. 7, Nos. 4-6, pp. 491-527.

Technical Paper by J.P. Giroud and K.L. Soderman

CRITERION FOR ACCEPTABLE BENTONITE LOSS FROM A GCL INCORPORATED INTO A LINER SYSTEM

ABSTRACT: The following case is considered in the present paper: a geosynthetic clay liner (GCL) used in the composite primary liner of a double-lined landfill is overlain by a geomembrane and underlain by the secondary leachate collection layer, which consists of a geonet. If bentonite particles migrate downward out of the GCL, through the geotextile(s) that separate(s) the bentonite layer from the geonet, they penetrate into the secondary leachate collection layer. Depending on the amount of bentonite particles migrating from the GCL, these particles may decrease the hydraulic transmissivity of the secondary leachate collection layer. Also, the loss of bentonite particles from the GCL may decrease the performance of the composite liner. The present paper provides theoretical analyses of these detrimental effects of bentonite particle loss, which lead to an acceptance criterion that can be used to evaluate the results of tests performed to determine if the geotextile(s) that separate(s) the bentonite from the geonet is (are) suitable or if another (or additional) geotextile is necessary.

KEYWORDS: Geosynthetic clay liner (GCL), Bentonite loss, Landfill liner, Composite liner, Leachate collection layer, Liquid collection layer, Acceptance criterion, Laboratory test, Geotextile, Filter.

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REFERENCE: Giroud, J.P. and Soderman, K.L., 2000, "Criterion for Acceptable Bentonite Loss From a GCL Incorporated Into a Liner System", Geosynthetics International, Special Issue on Liquid Collection Systems, Vol. 7, Nos. 4-6, pp. 529-581.

Technical Paper by J.P. Giroud, B. Palmer, and J.E. Dove

CALCULATION OF FLOW VELOCITY IN PIPES AS A FUNCTION OF FLOW RATE

ABSTRACT: There are many design situations where the rate of flow in a pipe is known and the average velocity of the liquid in the pipe must be calculated. The classical method to determine the average velocity of flow in pipes as a function of the flow rate is based on Manning's equations. This method requires an iterative process or the use of cumbersome tables or graphs. A direct relationship between the average velocity of flow and the rate of flow in pipes is proposed. To the best of the authors' knowledge, this is the first time that such a direct relationship is proposed. The derivation of the relationship and its practical use are presented. Comparisons of the flow velocities calculated using the proposed relationship and flow velocities rigorously calculated using the iterative process show that a great degree of precision is obtained even when the flow rate is very small compared to the maximum flow capacity of the pipe. This is important because the traditional method is not precise when the flow rate is small, and there are many applications (such as pipes used in leakage collection systems beneath a landfill liner) where liquid flows in a pipe that is almost empty. The proposed method is explicitly analytical and can easily be programmed on a pocket calculator.

KEYWORDS: Pipe, Geopipe, Flow rate, Flow velocity, Liquid collection, Leakage collection.

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REFERENCE: Giroud, J.P., Palmer, B., and Dove, J.E, 2000, "Calculation of Flow Velocity in Pipes as a Function of Flow Rate", Special Issue on Liquid Collection Systems, Geosynthetics International, Vol. 7,