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Introduction by J.P. Giroud

I started designing geomembrane-lined containment structures in 1971. In the 1970s and early 1980s, an important part of my activities consisted of developing new design concepts using geomembranes, such as: a geotextile cushion under a geomembrane in ponds (1971); a geomembrane placed directly on a compacted clay layer, thus forming a composite liner in a small dam (1973); a double liner constructed using two geomembranes, with a gravel leakage collection layer between them, in a large water reservoir (1974); and a double liner constructed using two geomembranes, with a geonet leakage collection layer between them, in an underground water reservoir (1981).

Another part of my activities in the 1970s and early 1980s consisted of performing theoretical analyses to predict the behavior of geomembrane liners under various circumstances such as uplift by wind or subsidence of the underlying soil. Then, in the early 1980s, due to the growing use of geomembranes for the containment of liquids with the potential to contaminate the ground, the evaluation of the rate of leakage through liners, and in particular through geomembrane defects, became a very important topic. Ever since the publication of "Impermeability: the Myth and a Rational Approach" (1984) I have devoted a significant part of my research effort to the development of methods for leakage evaluation, and more generally liquid migration control using geosynthetic liner systems.

The eight papers on this subject published in this Special Issue of Geosynthetics International are the continuation of work I did in 1986 and 1987 with Dr. Bonaparte, which was presented in several papers published in 1989. As the methods presented in the 1989 papers were used extensively by landfill designers, the need for improved methods and complementary methods appeared. This led to the papers presented in this Special Issue, which is organized as follows:

- In the first three papers, the considered liner is a geomembrane used alone, which is often the case for the primary liner of double liner systems.
- In the last five papers, a composite liner is considered. The composite liner consists of a geomembrane on a low-permeability soil which can be a compacted clay layer, a geosynthetic clay liner, or both.

Some of the eight papers were written with landfill liner systems in mind and contain the word "leachate" in their titles, whereas other papers were not and contain the word " liquid" in their titles. All the titles could, or perhaps should, contain the word "liquid" because the methods presented herein are directly applicable to all liquids that have approximately the same viscosity as water (i.e. the aqueous liquids such as leachate) and can be adapted to liquids that have a different viscosity. The papers presented in this Special Issue should not be regarded as a complete discussion of the topic of liquid migration control using geosynthetic liner systems. Many papers on this topic, some very important, have been published by other authors. Furthermore, some aspects of liquid migration control are not discussed herein such as the diffusion of chemicals through geomembranes, a subject on which extensive research is currently in progress and on which important papers have been published by other authors.

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, T.R. Sanglerat, J.F. Beech, R.C. Bachus, T.N. Sargent, P.C. Lucia, R.J. Dunn, E. Kavazanjian and D.M. Hendron. I also want to say that the publication of this issue would not have been possible without the contribution of my co-authors, T.D. King, from Tesoro Petroleum Company, and the others from GeoSyntec Consultants: K. Badu-Tweneboah (2 papers), R. Bonaparte, B.A. Gross, T. Hadj-Hamou, M.V. Khire (3 papers), J.A. McKelvey (3 papers), N.S. Rad, T.R. Sanglerat and K.L. Soderman (3 papers). It is certainly very rewarding for me to work with professionals of this caliber.

Finally, I am grateful to S.L. Berdy who produced the excellent figures and K. Holcomb who ensured flawless word processing, with the help of A. Mozzar and N. Pierce for several of the papers. I also want to acknowledge the excellent work done by the unknown soldiers of Geosynthetics International, the anonymous assessors, who reviewed the papers and provided so many valuable comments. Last but not least, I express my gratitude to T.S. Ingold, Editor, and R.J. Bathurst, Co- Editor, of Geosynthetics International for giving me the opportunity of grouping these eight papers in the same issue published as a Special Issue, and to K. Labinaz, Production Editor of Geosynthetics International, who provided two rounds of editing, with her usual precision, to ensure not only the correctness of each paper, but, also, the consistency of the Special Issue.

J.P.G.

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

SPECIAL ISSUE ON LIQUID MIGRATION CONTROL USING GEOSYNTHETIC LINER SYSTEMS

The prime objective of Geosynthetics International is dissemination of the best available information on current geosynthetics technology, be this research work, design innovation, new materials, or construction practice. This objective is being successfully achieved through the publication of unsolicited papers that are combined to produce individual issues of Geosynthetics International covering a spectrum of topics with a geosynthetics component. Readers also benefit from the publication of the occassional issue comprising a set of refereed papers that cover different aspects of a specific topic or a group of topics with a related theme. The topic or theme of such special issues is not arrived at by editorial dictum, but by the suggestions of individuals or groups of authors who are prepared to produce quality papers in their area of expertise.

As with any other papers published in Geosynthetics International, the quality of the content is reviewed by a team of independent assessors working in tandem with members of the Editorial Board. Following this route, the first special issue, Volume 2, No. 6, dealt with the design of geomembrane applications, whilst this special issue covers design aspects of geosynthetic liner systems used for liquid migration control. A third special issue, scheduled for publication next year, tackles a wide range of geosynthetic topics based on the common theme of earthquake engineering. It is with pleasure we introduce this second special issue of Geosynthetics International which, since it runs over 200 pages, is a double issue.

The papers presented in this issue give detailed cover of various aspects of liquid migration control with particular emphasis on solutions to leakage problems associated with geomembrane defects. Of particular note is the first paper, entitled “Leachate Flow in Leakage Collection Layers Due to Defects in Geomembrane Liners”, which presents a very simple and elegant relationship between leakage rate, hydraulic conductivity, and the required thickness of the leakage collection layer. Equally, the second paper, entitled “Liquid Migration Through Defects in a Geomembrane Overlain and Underlain by Permeable Media”, provides an outstanding extension of Bernoulli’s equation for the common case in which the medium overlying the geomembrane defect is not infinitely permeable.

Indeed, the eight complementary papers in this special issue give designers a powerful collection of analytical solutions to practical liquid migration control problems with these solutions being well illustrated through design examples. We hope this special issue will become a standard reference for designers, and we thank Dr. Giroud and his co-authors for their hard work in preparing what should become a landmark issue of Geosynthetics International.

Technical Paper by J.P. Giroud, B.A. Gross, R. Bonaparte and J.A. McKelvey

LEACHATE FLOW IN LEAKAGE COLLECTION LAYERS DUE TO DEFECTS IN GEOMEMBRANE LINERS

ABSTRACT: This paper provides analytical and graphical solutions related to the flow of leachate in a leakage collection layer due to defects in the overlying liner (i.e. the primary liner of a double liner system). The defects are assumed to be small (e.g. holes in geomembrane liners). It is shown that leachate flows in a zone of the leakage collection layer (the wetted zone) that is limited by a parabola. A simple relationship is established between the rate of leachate migration through the defect and the maximum thickness of leachate in the leakage collection layer; this relationship depends on the hydraulic conductivity (but not on the slope) of the leakage collection layer. Equations are provided to calculate the average head of leachate on top of the liner underlying the leakage collection layer (i.e. the secondary liner of a double liner system), which is useful for calculating the rate of leachate migration through that liner. Finally, the case of several leaks randomly distributed is considered, and equations for the surface area of the wetted zone and the average head are given for this case. Parametric analyses and design examples provide useful comparisons between the three types of materials used in leakage collection layers: gravel, sand and geonets.

KEYWORDS: Geomembrane, Defect, Leachate migration, Leachate collection, Leakage, Leakage collection, Liner system, Double liner, Geosynthetic leakage collection layer.

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Technical Paper by J.P. Giroud, M.V. Khire and K.L. Soderman

LIQUID MIGRATION THROUGH DEFECTS IN A GEOMEMBRANE OVERLAIN AND UNDERLAIN BY PERMEABLE MEDIA

ABSTRACT: An analytical method is proposed to evaluate the rate of advective liquid migration through a defect in a geomembrane that is overlain by a permeable medium and underlain by a highly permeable medium (i.e. a medium significantly more permeable than the overlying medium). The rate of liquid migration calculated using the proposed analytical method approaches the rate calculated using the classical Bernoulli's equation for free flow through an orifice if the hydraulic conductivity of the medium overlying the geomembrane tends toward infinity. Graphs for typical sizes of geomembrane defects show that the rate of liquid migration calculated using the proposed method is always less than that calculated using Bernoulli's equation, and sometimes significantly less (when the liquid head is small and/or the hydraulic conductivity of the permeable medium overlying the geomembrane is small). For a given hydraulic conductivity of the overlying permeable medium, as the liquid head on top of the geomembrane increases, the rate of liquid migration calculated using the proposed method approaches that calculated using Bernoulli's equation. In the case of landfills, the paper shows how the proposed method can be combined with an equation giving the head of leachate on top of the geomembrane liner. The resulting equation makes it possible to select an optimum leachate collection material to minimize leachate migration through defects in the geomembrane liner. Design examples are presented to illustrate the analytical method.

KEYWORDS: Geomembrane, Defect, Liquid migration, Leakage, Leachate collection, Analytical.

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Technical Paper by J.P. Giroud, M.V. Khire and J.A. McKelvey

RATE OF LEACHATE MIGRATION THROUGH A DEFECT IN A GEOMEMBRANE UNDERLAIN BY A SATURATED PERMEABLE MEDIUM

ABSTRACT: The leakage collection layer located beneath a geomembrane liner in a landfill may not have enough flow capacity to convey the leachate migrating through a geomembrane defect without becoming filled with leachate in a certain area around the defect. The presence of leachate in the leakage collection layer at the location of the geomembrane defect reduces the head loss through the defect and, consequently, reduces the rate of leachate migration through the defect. This paper presents an equation to evaluate this effect. The equation depends on the size of the defect in the geomembrane and the characteristics of the leakage collection layer: hydraulic conductivity, thickness and slope. Numerical applications show that the reduction of the leachate migration rate is generally negligible in the case of gravel leakage collection layers because they are thick and highly permeable. In contrast, with geonet and sand leakage collection layers, there are cases where the reduction is not negligible.

KEYWORDS: Geomembrane, Defect, Leakage collection layer, Analytical, Leachate migration, Leakage rate.

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Technical Paper by J.P. Giroud

EQUATIONS FOR CALCULATING THE RATE OF LIQUID MIGRATION THROUGH COMPOSITE LINERS DUE TO GEOMEMBRANE DEFECTS

ABSTRACT: Equations available to date for calculating the rate of liquid migration through a composite liner due to geomembrane defects require the use of graphs to obtain the value of one of the terms of the equations for the case where the liquid head is larger than the thickness of the low-permeability soil component of the composite liner. In this paper, it is shown that the terms that require graphs can be expressed analytically, which leads to a new set of equations that provides an entirely analytical means of calculating the rate of liquid migration through composite liners. This new set of equations is particularly useful when the liquid head is large compared to the thickness of the low-permeability soil component of the composite liner, which is often the case when the low-permeability soil associated with the geomembrane to form a composite liner is a geosynthetic clay liner. A numerical example is given.

KEYWORDS: Liquid migration, Leachate migration, Leakage, Composite liner, Equations.

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Technical Paper by J.P. Giroud, T.D. King, T.R. Sanglerat, T. Hadj-Hamou and M.V. Khire

RATE OF LIQUID MIGRATION THROUGH DEFECTS IN A GEOMEMBRANE PLACED ON A SEMI-PERMEABLE MEDIUM

ABSTRACT: This paper provides an equation for calculating the rate of liquid migration through a defect in a geomembrane underlain by a semi-permeable medium. In the context of this paper, a semi-permeable medium is a medium that has a hydraulic conductivity greater than k_G and smaller than k_B, where k_G is the hydraulic conductivity above which Giroud's equation is not valid and k_B the hydraulic conductivity below which Bernoulli's equation is not valid. Giroud's equation is an equation that gives the rate of liquid migration through a defect in a geomembrane underlain by a low-permeability medium, and Bernoulli's equation is the equation that gives the rate of free flow through an orifice and which is used to calculate the rate of liquid migration through a defect in a geomembrane underlain by a very permeable medium. The equation for semi-permeable media presented in this paper was obtained by interpolation between Giroud's equation and Bernoulli's equation.

KEYWORDS: Geomembrane, Defect, Liquid migration, Leakage, Semi-permeable medium, Analytical.

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Technical Paper by J.P. Giroud, K.L. Soderman and K. Badu-Tweneboah

OPTIMAL CONFIGURATION OF A DOUBLE LINER SYSTEM INCLUDING A GEOMEMBRANE LINER AND A COMPOSITE LINER

ABSTRACT: A number of landfills are designed with a double liner system that includes a geomembrane liner and a composite liner. The design engineer must select which of these two liners should be the primary liner. A comparative study is presented in this paper to help determine which configuration is preferable. The comparative study consists of comparing the rate of leachate migration through two double liner systems having the following inverse configurations: (i) a double liner system where the primary liner is a geomembrane liner and the secondary liner is a composite liner; and (ii) a double liner system where the primary liner is a composite liner and the secondary liner is a geomembrane liner. The composite liner considered in the study consists of a geomembrane on a geosynthetic clay liner (GCL). The comparison between the two liner systems is based only on advective flow through geomembrane defects (i.e. defects in the geomembrane liner as well as defects in the geomembrane component of the composite liner). Other factors that may have an impact on the selection of a liner configuration, such as diffusive flux and construction issues, are not considered in the comparison. The study shows that, from the viewpoint of minimizing the advective flow of leachate through geomembrane defects, it is preferable to use the configuration where the primary liner is a composite liner.

KEYWORDS: Double liner, Composite liner, Landfill, Leachate migration, Theoretical analysis.

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Technical Paper by J.P. Giroud, K. Badu-Tweneboah and K.L. Soderman

COMPARISON OF LEACHATE FLOW THROUGH COMPACTED CLAY LINERS AND GEOSYNTHETIC CLAY LINERS IN LANDFILL LINER SYSTEMS

ABSTRACT: The purpose of this paper is to provide an approach for comparing the effectiveness of geosynthetic clay liners (GCLs) and compacted clay liners (CCLs) used in association with geomembranes to form composite liners. Comparing the effectiveness of these two types of composite liners is required in "equivalency demonstrations" intended to demonstrate that a geomembrane-GCL composite liner is equivalent to a conventional geomembrane-CCL liner prescribed by a regulation. In the first part of the paper, the contribution of the geomembrane is ignored and the paper presents analytical evaluations of advective leachate flow through GCLs, low-permeability soil layers (such as CCLs), and two-layer systems including a GCL and a low-permeability soil layer. The analyses presented explain why some calculations typically performed for landfill liner system design or for equivalency demonstrations lead to the paradoxical result that the advective flow of leachate is greater when a GCL is placed on a layer of low-permeability soil than when the GCL is placed on a layer of high-permeability soil. The second part of the paper presents an analytical method for comparing the effectiveness of a composite liner including a GCL and a composite liner including a CCL. This analytical method enables design engineers to compare the effectiveness of various composite liners without neglecting the beneficial effect of the geomembrane. A parametric study presented in the paper shows that neglecting the geomembrane liner in equivalency demonstrations (which is frequently done in the current state of practice) penalizes composite liners that incorporate a GCL.

KEYWORDS: Liner system, Flow rate, Compacted clay liner, Geosynthetic clay liner, CCL-GCL comparison, Composite liner.

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Technical Paper by J.P. Giroud, N.S. Rad and J.A. McKelvey

EVALUATION OF THE SURFACE AREA OF A GCL HYDRATED BY LEACHATE MIGRATING THROUGH GEOMEMBRANE DEFECTS

ABSTRACT: When a geosynthetic clay liner (GCL) is used in a composite liner, the bentonite of the GCL may be hydrated by moisture from the underlying medium and by leachate migrating through defects in the overlying geomembrane. When hydration caused by the underlying medium is negligible, the GCL is hydrated only in areas associated with geomembrane defects. This paper provides a method to evaluate the fraction of the GCL surface area that is hydrated by leachate migrating through geomembrane defects. Results presented in this paper show that, in most usual cases, the GCL is hydrated only in a small fraction of its surface area when the only cause of hydration is leachate migrating through defects in the overlying geomembrane. The method presented in this paper is not applicable when a GCL is placed in contact with a soil that retains water by capillarity, since this water may migrate into the GCL; the method is essentially applicable to GCLs placed on top of a relatively dry and highly permeable leakage collection layer (gravel or geonet). The study presented in this paper also shows that hydration of the bentonite by leachate migrating through defects in the overlying geomembrane takes only days. From this it is concluded that the size of the hydrated area located around each geomembrane defect is governed by the largest leachate head in the history of the liner.

KEYWORDS: Geomembrane defect, Leakage, Leachate migration, Geosynthetic clay liner, Bentonite, Hydration.

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