e-Newsletter

ASCE
AMERICAN SOCIETY OF CIVIL ENGINEERS
INDIA SECTION

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ASCE-IS North Region Core Committee Meeting

Standing L-R
Honey Mehra, Parth Aich, A.K Keshari, Arif Siddiqui, S.K Vij, T.C Harjai, N.T Rao, S.M Abbas

ASCE-IS North Region core committee held a meeting at Central Officers Services Institute, Vinay Marg Chanakyapuri, New Delhi on February 2nd 2013. The agenda of the meeting was to brief the members about the regional constitution / bye laws and to plan the regional activities for Quarters 1 and 2 of 2013.

Meeting was started with the president briefing the members about the regional constitution and bye laws followed by discussions on three major activities 1. Increasing Membership base 2. Students chapter 3. Technical programs / lecture series were discussed candidly during the meeting and path forward was determined.

It was decided that immediate efforts would be made to launch the student chapters at IITT Delhi and Jamia Mili Islamia and following up with lecture series and other programs at these institutions. Dr. AK Keshari and SM Abbas will be leading the efforts in launching the student chapters at IITT and JMI Delhi respectively.

Members unanimously decided to conceive a Technical seminar on a generic civil engineering topic in August 2013.

A detailed Minute of meeting is being issued separately to all the regional members to make them aware of the planned activites in Q1 and Q2 of 2013 so as motivate them for enthusiastic participation in future activities.

IN THIS ISSUE

There were three lectures delivered by eminent speakers on different fields of civil engineering during December 2012 in the Department of Civil Engineering, Indian Institute of Science, Bangalore.

The Programs were organised by under the aegis of ASCE - India Section - Southern Region

1. Innovative use of geosynthetic layers to extend service lives of pavements

The first lecture was on "Innovative use of geosynthetic layers to extend service lives of pavements" and was given by Prof. Rajib B. Mallick, from Worcester Polytechnic Institute (WPI) Worcester on Thursday, 17th December, 2012 at 11:00 am. The speaker presented the results of a study that was conducted to evaluate the concept of using an insulation layer along with a relatively high reflectivity surface for insulating pavements from extremes of temperature. Combinations of geosynthetic (as insulation) with and without chip seals (with partially exposed light colored aggregates as high reflectivity surface) were studied. It was concluded that a geosynthetic reinforced chip seal and/or a sufficiently thick geosynthetic layer can provide significant amount of insulation to asphalt pavements, and hence reduce the potential of high and low temperature distresses. The effects of high temperature on the potential of both rutting and aging, and hence cracking potential of asphalt pavements are discussed. There was good interaction between the speaker and the participants. A memento was presented by Prof.G.L.Sivakumar babu on behalf of ASCE-IS-Southern Region to Prof. Rajib B. Mallick.

2. Integrated Geophysical Method for Power Transmission Pole-Like Structures

The second lecture was on "Integrated Geophysical Method for Power Transmission Pole-Like Structures" and was given by Prof. Shen-En Chen, University of North Carolina at Charlotte, Charlotte, USA on Thursday, 19th December, 2012 at 11:00 am. In the lecture he discussed transmission pole structures that are rapidly erected with limited geotechnical explorations. Despite the importance, it is not practical to use the conventional borehole methods of subsurface exploration, which is labor-intensive and costly, to estimate soil properties and foundation capacity. Failure of a foundation can lead to the loss of an entire transmission line structure leading to the loss of power for downstream community. To ensure the stability of these structures, which are typically directly embedded or anchored with helical anchors.

Geophysical testing method was suggested as a rapid soil exploration method. His presentation described the use of a semi-empirical and elasticity-based design technique coupled with Spectral Analysis of Surface Wave (SASW) technique to provide subsurface information for the design of anchor foundations and directly embedded foundations. Based on small-strain wave propagation, SASW determines shear wave velocity profile that is correlated to anchor holding capacity and embedment depth. He presented a reliable technique with a pilot project involving over 400 anchor installations and showed that it can be implemented into transmission line structure designs. There was good interaction between the speaker and the participants. After the lecture, Prof. P. Anbazhagan presented a memento on behalf of ASCE-IS-Southern Region to Prof. Shen-En Chen.

3. Analytical representations of field-scale solute transport in heterogeneous unsaturated soils

The third lecture was on "Analytical representations of field-scale solute transport in heterogeneous unsaturated soils" and was given by Prof. Rao S Govindaraju from the School of Civil Engineering, Purdue University, USA on Monday, 28th December, 2012 at 11:00 am. In his lecture, he presented concepts and methods to describe field-scale transport of solutes under transient flow fields resulting from rainfall events over unsaturated soils. Analytical solutions are developed to describe purely advective vertical transport of a conservative solute along the principle characteristic of the flow field that is developed from a sharp front approximation for water movement. These local solutions are upscaled to field-scale solute transport by adopting a log-normally distributed spatial hydraulic conductivity field to replicate natural heterogeneity in many fields. Analytical expressions are developed for temporal moments and the mean behavior of solute transport at the field scale. Comparisons with experimental observations and Monte Carlo simulations find that the proposed method shows promise for describing field-scale solute movement in unsaturated soils. After the lecture, Prof. D Nagesh Kumar presented a memento on behalf of ASCE-IS-Southern Region to Prof. Rao S Govindaraju.

HEAD QUARTERS NEWS

ASCE Releases Final Failure to Act Report

As a preface to ASCE's 2013 Report Card for America's Infrastructure, which will be released on March 19, the Society unveiled during a teleconference on January 15 its fifth and final report in the Failure to Act series, The Impact of Current Infrastructure Investment on America's Economic Future, which addresses the comprehensive impacts of underinvesting in infrastructure in the U.S.

ASCE Names New Faces of Civil Engineering for 2013

Finding and nurturing future leaders are a primary concern for any organization and, indeed, for any profession. ASCE offers assistance in this regard by calling attention to younger individuals possessing extraordinary talent and ability.

Three Declare as Candidates for Nomination for ASCE President-Elect

Three individuals have declared themselves as candidates for nomination for the office of ASCE president-elect in this year's elections:

Anthony M. Puntin, P.E., F.ASCE
Robert D. Stevens, Ph.D., P.E., F.ASCE
Mark W. Woodson, P.E., L.S., F.ASCE

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Forensic Geotechnical Engineering

Forensic analysis in geotechnical engineering involves scientific and legalistic investigations and deductions to detect the causes as well as the process of distress in a structure, which are attributed to geotechnical origin. Such a critical analysis will provide answers to "what went wrong, when, where, why, how, and by whom". It also gives strong inputs to improve future designs and also assists in identifying the qualifications and expertise required for the staff. As forensic analysis is basically a back analysis based on failure observations, the normally adopted standard procedures of testing, analysis, design a nd construction are not adequate for the forensic analysis in majority of cases. The forensic geotechnical engineer (who is different than the expert witness) should be able to justify his conclusions in a court of law. Hence he has to be not only fully knowledge in his field of specialization including his communication skills, but should also be familiar with legal procedures.

With the above points in view, ISSMGE, under the presidentship of Prof. Pedro Pinto during his term 2005 – 2009 constituted a technical committee styled as TC 40 under the Chairmanship of Dr.V.V.S.Rao, India. This TC was extended as TC 302: FGE for one more term 2009-2013 by the present president, Prof. J. Briaud. Accordingly, the terms of reference comprised of:-

Prepare a book either as a manual or as an introductory guide on the forensic procedures to be followed in failure investigations pertaining to geotechnical engineering. The book shall contain procedures for systematic scrutiny of every stage of planning, investigations (both field and laboratory), evaluation and selection of design parameters, analysis and design, construction techniques adopted, detailed documentation regarding quality control, problems encountered including meteorological conditions, etc.

To achieve the above objective, the following task forces with their respective Leaders are constituted.

TF 1: Collection of data - P.W.Day

TF 2: Characterization of distress. – David Starr

TF 3: Development of failure hypothesis. – J. Mecsi

TF 4: Diagnostic tests. – W.F.Lee

TF 5: Back analysis – Popescu

TF 6: Observation method of performance evaluation – Y. Iwasaki

TF 7: Reliability aspects. – GLS Babu

TF 8: Legal Issues – D.S.Saxena

TF 9: Case Histories. – Hwang.

TF 10: Technical Susceptibilities – Rob Jessep

During the past four years, the committee has organized three international seminars: September 24-25,2010 in Budapest (organized by Prof. Mecsi), December 14-15, 2010 in Mumbai (organized by Prof. Babu) and, July 14-15, 2011 in Osaka (organized by Prof. Iwasaki). Apart from these seminars, separate sessions on FGE were also conducted during ARCs in Hong Kong and I Kolkatta.

Dr.V.V.S.Rao, Chair,TC302

A fourth international seminar was organized in Bengaluru, India, during 10 – 12 January,2013. Experts from fifteen countries presented special lectures. Prof. Askar Zhussupbekov, Vice President, Asian region of ISSMGE inaugurated the seminar and Dr. Suzanne Lacasse gave the main key note lecture. In all forty one papers were presented in twelve sessions. Over 140 delegates attended the seminar and made it a grand success.

The following is the list of theme lectures, invited lectures and contributed papers presented during the conference.

Inaugural Lecture

1) Forensic Geotechnical Engineering – Theory and Practice by Dr. Suzanne Lacasse-Høeg.

Theme Lectures

1) Performance-based design in geotechnical engineering by Prof. Malcom Bolton.
2) Learning from the past: The ancient Egyptians and geotechnical engineering by Dr. Sheriff Wissa.
3) Forensic Geotechnics – some case studies from Singapore by Prof. C F Leung.
4) Legal aspects regarding management of soil risk by Prof. Katzenbach.

Prof. Askar inaugurating the seminar by ringing a bell.
Prof. GLS Babu(Secretary,TC302) Prof. G.N.Gandhi.(President, IGS), Prof. Askar (Vice President, ISSMGE), Dr.V.V.S.Rao (Chair,TC302)

TC 302 executives withProf. Askar, Dr. Suzanne Lacasse and Prof. Bolton during the Bengaluru seminar

5) Caisson failure induced by wave action by Prof. Eduardo Alonso.
6) Forensics of pile foundations subjected to earthquake induced byProf. M. Gopal.
7) Stability of landfill capping systems on steep slopes - lessons learned from practice by Prof. Georg Heerten.
8) Forensic geotechnics of failing petroleum tanks by Prof. William Van Impe.
9) The role of uncertainty in forensic geotechnical engineering by Prof. Robert Gilbert.
10) Attempts to protect personal houses from seismic liquefaction by Prof. Ikuo Towhata.
11) Analysing Ground – Beyond a Mechanistic Approach by Prof. M R Madhav.

Invited Lectures

1) The Reasons of Extremely Unusual Occurrence of Full Destroying of a House in the Residential District Besoba in Soil Ground Conditions of Karaganda City by Dr. A. Zhussupbekov.
2) Distress in Reinforced soil walls- An appraisal by Prof. G V Rao.

Task Forces

1) Role of collection of data in Forensic analysis by Dr. P.W.Day.
2) Characterisation of failure at a large landslide in SE Queensland by geological mapping, laboratory testing, instrumentation and monitoring by Mr. David Starr.

Key Speakers:

Dr. Suzanne Lacasse

Prof. Malcom Bolton

Dr. Sheriff Wissa

3) Special material properties and circumstances on the serious Geotechnical Disasters by Prof. J Mecsi.
4) Failure Analysis of A Highway Dip Slope Slide by Prof. Wei F. Lee.
5) Effects of Vibration by Demolition to nearby Machine Shop Floor - Wave Measurement for Dynamic Property of Ground by Prof. Yoshi Iwasaki.
6) Reliability analysis in Forensic Geotechnical Engineering by Prof. G L Sivakumar Babu.
7) Forensic Engineering, Legal Considerations, and Property Damage Assessment from Construction Vibrations by Dr. Dhirendra S. Saxena.
8) Technical shortcomings causing geotechnical failures by Mr. Rob Jessep.
9) Guidelines for Forensic Geotechnical Engineering by Dr. VVS Rao.

Contributed Papers

1) Analyses of Unexpected Settlements of Large Oil Tanks in the Rotterdam Port by J.L. Bijnagte, H.J. Luger.
2) Investigation of Soil Saturation and Compaction Homogeneity in the failed soil nailed wall and fill using Ground Penetrating Radar by Anbazhagan P. Naresh Dixit P S., Deepu Chandran and A Murali Krishna.
3) Forensic Geotechnical Investigations for Floor Failure of an Industrial Building near Bhopal, India - A Case Study by S.B. Suri, Nakul Dev, Thomas Joseph & Jancy Mathew.
4) Deep Excavations and Managing the Risk of Damages in the Proximate Vicinity by R. Katzenbach, C. Bergmann, F. Clauss and M. Seip.
5) Recent Approaches of Back Analysis for Addressing Geotechnical Issues by Dauji Saha, Ranjan Kumar, Kapilesh Bhargava and Sekhar Basu.
6) Post-liquefaction data collection and analyses for earthquakes in New Zealand by Md. Mizanur Rahman and T. G. Sitharam.
7) Penetration of Mudmats for Fixed Offshore Platforms - Case Studies by Rupam Mahanta and R. K. Ghanekar.
8) Need for Forensic Engineering in Earthquake Geotechnics – Case Studies from 2001 Gujarat Earthquake by S K Prasad, Towhata, I., Chandradhara, G. P., Vijayendra, K. V. and Honda T.
9) Forensic analysis of failure of Retaining Wall by G. L. Sivakumar Babu, Raja J, B M Basha and Amit Srivastava.
10) Performance a Full Raft Foundation Constructed on Soft Clay by I.V. Anirudhan and S.V. Ramaswamy.
11) Design and Construction of Diaphragm Walls Embedded in Rock for a Metro project by N. Kumar Pitchumani, Dr. Makarand G. Khare, Sridhanya, KV.

There was a very good interaction between the speakers and delegates throughout the three days of the seminar. A lively banquet along with a grand folk dance program added glamour to the seminar.

Structura 2013
by Student Chapter Vellore Institute of Technology

Structura 2013 was a one of its kind national level Symposium dedicated entirely to Civil engineering, organised by the American Society of Civil Engineers - Indian Section - Southern Region, Vellore Institute of Technology. Spanning two full days, January 19 & 20, the symposium attracted college students from all over the country and can be proudly regarded as a huge success.

The inauguration, with a guest lecture by Dr. Devdas Menon (Senior Professor, IIT Madras) as its star attraction, saw an audience of more than 300. The same can be said for the valedictory ceremony where once again, the centre stage was stolen by a brilliant lecture by N. Raghavan (ex CEO of L&T Ramboll).

The two day workshop in Project Management which specialized in providing experiential and interactive learning conducted by Experts Hub industrial Development Centre, made students technically sound and well equipped in handling their workplace scenario.

The premier event was Civil MUN, a simulation of the actual United Nations where the participants were faced with crises related to Civil Engineering and they needed to come up with profound and technically sound solutions. The presence of debaters from various colleges further increased its quality. Beton Flo was an event which was never before seen in recent times and was another major attraction of the Symposium. This event utilized futuristic and unconventional raw materials to float concrete.

Strassen Karte, was an event where the participants needed to design an ideal transportation system and was received with yet another warm response.

Urbanistica, as the name suggests, was a town planning based event where one had to act as a master planner, draft and scale the city to one's own plans and come out with a self-sustainable town. This event received critical acclaim.

Another thought provoking event was Crane Wars, where robotics was infused with civil know how. This was an event where robots were designed to be used to make different structures.

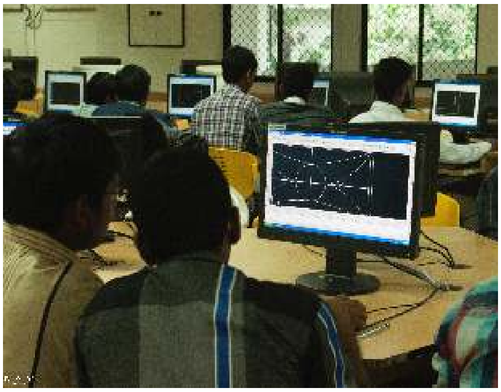
To test the workmanship skills of students, Modeling events were held which included making of inclined structures and Bascule Bridge. Structures were tested for stability and endurance.

Civil Quiz was a technical quiz that covered each and every cornerstone of the Civil Engineering branch and tested how peak the participants' knowledge level reached.

The CAD contests received interesting and intriguing designs perfectly fitting the problem statement given beforehand.

With the view of giving young researchers a boost, we had a presentation of research papers by under graduate and graduate students judged by a highly experienced panel.

In spite of being an infant in the arena of well-established technical fests, Structura 2013 witnessed an overwhelming response from students all over the country. Structura has definitely carved a niche and has thus helped live up to its motto; Imagine, Create and Inspire.



Performance of Composite Covers of Landfills Subjected to Differential Settlements: Centrifuge Study

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Abstract

Performance of composite cover systems subjected to differential settlements was studied through a series of centrifuge model studies at 40 gravities. Model barrier materials were selected in such a way that it represents the prototype materials widely used in landfills. The thickness of model clay barrier was 15mm which is equal to 0.6m in prototype dimensions. Tests were conducted with continuous geomembrane and overlapped geomembrane sheets in order to study the effect of overlaps on the sealing efficiency and integrity of clay barrier at the onset of differential settlements. Composite barrier with continuous geomembrane layer was found to sustain large distortions without any water breakthrough whereas clay barrier experienced a water breakthrough at a distortion level of 0.056. It was found that there is a relative displacement between overlapped geomembrane sheets at the zone of maximum curvature and a water breakthrough was observed at a distortion level of 0.10.

Keywords: Geomembranes; differential settlements; composite liner; landfills; clay barrier; centrifuge models.

Introduction

Geomembranes are one of the widely used geosynthetic in landfills. The thickness of geomembrane used in landfill covers can vary from 0.75 to 3mm (Qian et al. 2002). Defects in geomembranes in the form of wrinkles, holes, installation defects particularly at seams are widely reported (Rowe, 2005; Take et al. 2007). Regardless of all the precautions taken while manufacturing, transportation, handling, storage and installation; defects in geomembranes in the form of wrinkles, puncturing and seams formed while joining two geomembranes are inevitable. The wrinkles or defects in the geomembrane may lead to increased leakage and may no longer have direct contact with the clay barrier and also considering the long term i.e., after at least many decades, the geomembrane can deteriorate completely. This can compromise the sealing efficiency of barrier by increasing the leakage through it (Take et al. 2007). A thicker geomembrane provides more resistance to forces induced by settlement of contained waste and with increasing thickness, the permeability decreases (Corbet and Peters, 1996). Zhu et al. (2009) reported the tensile strain in geomembranes around a circular structure subjected to differential settlements and the degree of wrinkling based on conventional membrane theory and wrinkled membrane theory. The wrinkles induced in the geomembrane and the parameters affecting the degree of wrinkling were explained. It was reported that the overlying pressure, the interface strength of the geomembrane, the differential settlement, the radius of the circular structure and the tensile stiffness of the geomembrane can affect the degree of wrinkling, tension and strain in the geomembrane.

The main property of a seam or overlap is that it must ensure a continuous seal between two geomembrane sheets to prevent liquid or gas to escape through the impervious layer installed in landfills. Consequently discontinuity, unbonded areas and lack of adhesion between the geomembrane sheets must not be found within a seam (Rollin and Fayoux, 2005). There are three primary methods of field seaming of geomembrane panels: (i) Adhesive seaming, (ii) Chemical fusion seaming and (iii) Thermal fusion welding. Adhesive seaming is the oldest and simplest method of sealing geomembrane panels. This process involves coating each surface of the panels to be joined with a bodied solvent adhesive. The coated pieces are then placed together and pressure is applied by a roller or other device to mate the pieces together and create a bond. Chemical fusion welding utilizes a chemical fusion agent (solvent) to dissolve the surfaces of the pieces of material to be joined. The chemical fusion agent is introduced between the two sheets to be welded, and while the surface of the material is molten, pressure is applied to mate the two surfaces together. This provides a homogeneous bond between the two sheets after the fusion agent evaporates. This method is used extensively in the fabrication and installation of geomembranes. Thermal fusion welding has been used in Europe for many years. Its use for the field welding of geomembranes in the United States began around 1990. Thermal fusion welding consists of a hot wedge or hot air device that heats the surface of the material to a molten state, while traveling along the length of the seam. Pressure rollers follow the heating device to press the two pieces of geomembrane together while the surfaces of each sheet are melted. This provides a homogenous bond between the two pieces. A large number of seam failures associated with the installation of a textured high density polyethylene (HDPE-T) geomembrane of an ongoing clo-

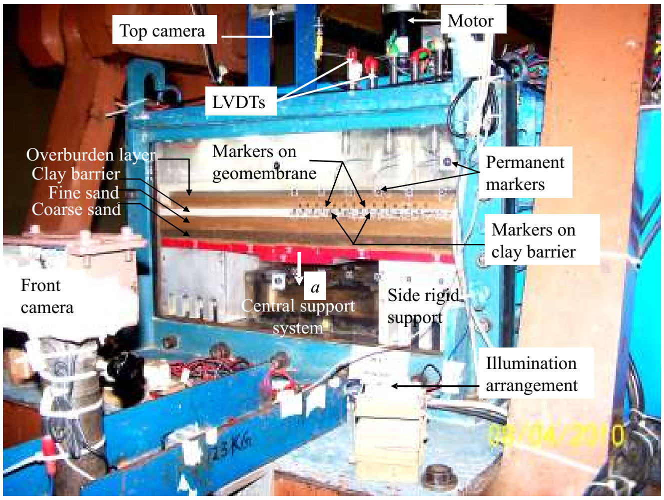


Figure 1. Centrifuge model test setup

sure of an eastern Pennsylvania landfill and the probable causes of seam failures such as the presence of dirt within the seams, inadequate grinding of the textured surfaces for extrusion seaming and inadequate heating were reported by Craig and Peggs (1997).

Even though, the geomembranes are widely used in landfill construction as a barrier, the sealing efficiency at the onset of differential settlements is not understood. Differential settlements are common in a MSW landfill due to the ongoing bio-degradation of the waste. Hence the performance of composite at the onset of differential settlements needs to be studied to ensure the integrity of the barrier.

Differential settlement of clay barriers have been studied by several investigators by conducting either full-scale model tests (Edelmann et al. 1999; Gourc et al. 2010) or centrifuge model tests (Jessberger and Stone, 1991;Rajesh and Viswanadham, 2011). However, studies pertaining to the deformation behavior of composite barriers subjected to differential settlements in a centrifuge are limited. Very recently, Divya (2012) reported the influence of intact geomembrane layer on the hydro-mechanical behaviour of landfill covers by varying thickness of the clay barrier by performing centrifuge model tests. Considering the practical difficulties and time delay in performing full-scale model tests and also the limitations of reduced scale model tests for simulating stress dependant phenomenon, centrifuge model tests were used to study the deformation behaviour of barriers in the present study. Hence, the motivation behind this study is primarily to evaluate the deformation behavior and sealing efficiency of geomembrane overlying clay-based landfill covers subjected to bending conditions due to differential settlements in a geotechnical centrifuge. In the present study, an attempt has been made to evaluate the performance of composite covers of landfills with and without geomembrane overlaps and the observed behavior was verified by performing a finite element analysis of a composite cover subjected to differential settlements

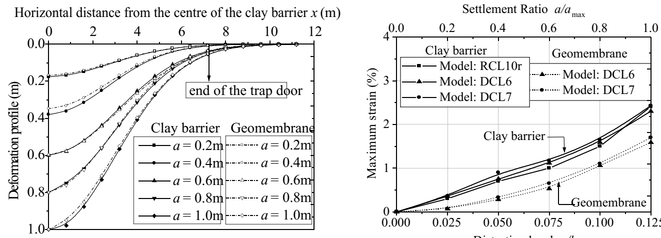
Centrifuge Model Tests

Centrifuge modeling technique is adopted in the present study to simulate identical stress conditions in the model barrier (of reduced scale 1/N) as that of prototype by subjecting to N times acceleration due to gravity in a controlled environment. The centrifuge tests reported herein were performed at an acceleration field of 40 gravities by the 4.5 m radius beam centrifuge having a capacity of 2500 g-kN available at Indian Institute of Technology Bombay.

A blend of kaolin and sand in the ratio of 4:1 (i.e. 80:20) by dry weight was selected as a model clay barrier material, as it represents the bandwidth of properties of clay used in landfill covers (Benson et al. 1999). The liquid limit of the model soil was 38% and plasticity index was 16%. The maximum dry unit weight was 15.9 kN/m3 and the corresponding OMC was 22% (according to standard Proctor compaction). Model geomembrane was selected by scaling down the linear dimensions by 1/N times the prototype material. Another important property is tensile stress-strain characteristics of model geomembrane. The scale factor for the tensile load in model geomembrane in a centrifuge is Tg /Tmg = (εg Eg tg)/ (εmg Emg tmg) = N, where subscript m stands for model dimensions (Divya, 2012).

A model geomembrane of thickness (tmg) 0.135 mm which corresponds to 5.4 mm in the prototype dimensions was selected by comparing the model tensile stress-strain characteristics with the prototype geomembrane characteristics reported by Qian et al. (2002). The initial stiffness Jg was obtained from the tensile load-strain curve by extending the initial linear portion of tensile load-strain curve and the value of Jg was 480 kN/m in prototype dimensions, at 40g. The ultimate strain was 450% and calculated considering the gauge length segment of the model geomembrane specimen. The ultimate tensile stress of the model geomembrane was 28,148 kN/m2.

In the present study three centrifuge tests were described which shows the response of a clay barrier at the onset of differential settlement with and without geomembrane. The differential settlements were induced by using a Motor based Differential Settlement Simulator (MDSS) developed at IIT Bombay (Rajesh, 2010; Rajesh and Viswanadham, 2011). The MDSS system consists of central support system comprises of screw jack, gear train, shafts and bearings; side support system comprises of aluminum side box, hinge plate connected to side box using a mechanical hinge; and a rear side support system which serves as a platform to mount motor and central LVDT which measures the settlement of trap door plate. The hinged plates were made to rest on a trap-door settlement plate. Several studies were reported on the use of trap-door systems to induce settlement (Jessberger and Stone, 1991; and Costa et al. 2009). A strong box having internal dimensions 720mm in length, 450mm in breadth and 440mm in depth houses the MDSS system. The back and rear walls of the container were formed with well machined stainless steel plates and they were welded to well-machined mild-steel plate stiffeners. In order to view the front elevation of the model clay barrier during the centrifuge tests, the front side of the container was made with a transparent 50mm thick Perspex sheet. A thin layer of white petroleum grease was applied to reduce the friction and adhesion between the inner walls of the container and soil layers. Model clay barrier of 15 mm (0.6 m) was prepared on top of 30mm coarse sand layer followed by 30mm fine sand layer drained for 9-10 hours and separated by thin filter papers. These layers are referred herein as sacrificing layers and are used to induce smooth continuous differential settlements to the overlying barrier and to avoid stress concen-



a) Deformation profile for Model: DCL6　　b) Max. strain for Models: DCL6, DCL7, RCL10r

Figure 2. Deformation profiles and strain variation for clay barrier and geomembrane at different settlement stages.

tration at the onset of differential settlements. An overburden of 25kN/m2 was induced with the help of fine sand layer of 27mm thickness at a dry unit weight of 15 kN/m3 and a calculated quantity of water was added so that it forms 10mm free standing water on the sand surface. Discrete markers were embedded 5mm below the top surface of the model clay barrier at 20mm centre to centre and also on the geomembrane. One digital photo camera was mounted along with the model to view the front elevation to monitor the crack development across the barrier and a Charged Couple Device (CCD) video camera was placed on the top to view the portion of top surface of the model and to register the depletion of water level during the centrifuge test. In order to measure the water infiltration at the onset of differential settlement during centrifuge tests, five pore pressure transducers (PPT) were placed above the model barrier surface. Further, seven numbers of linearly variable differential transformers (LVDT) were provided towards the right half section of the model barrier at 50mm intervals starting from the centre of the clay barrier for obtaining the deformation profiles. Figure 1 shows the details of the model test package along with the model barrier and geomembrane before inducing differential settlements. A settlement rate of 1mm/min and a maximum central settlement, amax of 25 mm (1m) was induced in the present study.

Out of the three centrifuge model tests described in the present study, Model RCL10r represents test with clay barrier without any geomembrane on top. Model DCL6 and DCL7 were provided with geomembrane layer above the clay barrier surface. Model DCL6 is tested with continuous geomembrane, whereas model DCL7 was tested with overlapped geomembrane sheets on the top of clay barrier. For model DCL7 geomembrane sheets were overlapped in the laid direction with a bentonite seal in between. Digital image analysis was carried out using GRAM++ software (GRAM++, 2004). The coordinates of the markers were obtained from the high resolution pictures of the front elevation of the model captured at various stages of the central settlements with reference to the co-ordinate of the permanent markers using map edit module of GRAM++ software. In order to get deformation profiles and strains along the geomembrane layer, plastic markers were stuck with an adhesive. A deformation profile was fitted for the marker positions at various central settlement values a, and it was found to match the exponential equation of the normal distribution. Only right hand portion of the model clay barrier was selected due to the symmetry.

Figure 2a shows the deformation profiles for the clay barrier surface w(x) and geomembrane layer wg(x), for a 15mm (0.6m) thick barrier provided with a continuous geomembrane (Model: DCL6). Strain variation along the clay barrier surface can be computed using combined bending and elongation method (Lee and Shen, 1969). The outer fiber strain along the clay barrier surface was obtained by $\varepsilon_{of}(x) = \varepsilon_l(x) \pm \varepsilon_\kappa(x)$. $\varepsilon_l(x)$ is the strain due to change in length along the length of barrier which is obtained from the first derivative of deformation profile of clay barrier w(x), and is equal to $[(1+ [w(x)]2)^{1/2} -1]$ and $\varepsilon_\kappa(x)$ is the strain due to change in curvature of the clay barrier which is equal to Rof.ε(x)d; where Rof is the neutral layer coefficient = 2/3, ε(x) is the curvature along the length of the clay barrier, and d is the thickness of the clay barrier. Similarly strain in the geomembrane along its length was computed by using $\varepsilon_g(x) = \varepsilon_{lg}(x) \pm \varepsilon_{\kappa g}(x)$. The elongation strain $\varepsilon_{lg}(x)$ in the geomembrane was obtained from the deformation profile of geomembrane, wg(x) as $[(1+ [wg\varepsilon(x)]2)^{1/2} -1]$. The curvature strain in geomembrane $\varepsilon_{\kappa g}(x)$, was obtained from the neutral layer coefficient Rg = 1/2, curvature of geomembrane $\varepsilon_g(x)$ and thickness of geomembrane tg as $R_g.\kappa_g(x)t_g$. The curvature strain in geomembrane was negligible due to small thickness of geomembrane. The maximum outer fiber strain value along clay barrier surface and strain along geomembrane at different settlement stages are plotted in Fig. 2b.

The hydraulic performance of the clay barrier was obtained by measuring the change in height of water on the top of the barrier surface using the PPT's placed on the top surface of the clay/geomembrane. Volume per unit width of water was obtained by performing the numerical integration of the area under measured water profile. Ratio of volume of water at any settlement stage, v to the initial volume of water, v0 is defined as the volume ratio. Figure 3 shows the variation of volume ratio with distortion level a/l and settlement ratio a/amax for the model clay barriers with and without geomembrane. Limiting distortion level a_{lim}/l is defined herein as the ratio of central settlement at which a drastic change in water volume above barrier was observed to the influence length l which is obtained by back tangent method. In the case of a barrier provided with a continuous geomembrane, no significant water breakthrough was observed even after subjected to a distortion level of 0.125. However, the clay barrier without any geomembrane was observed to experience a catastrophic water breakthrough at $a_{lim}/l = 0.056$ and the corresponding strain ε_{lim} was 0.76% (Rajesh and Viswanadham, 2011). When geomembrane sheets were overlapped, water breakthrough was observed at higher distortion levels and at $a_{lim}/l = 0.10$ and corre-

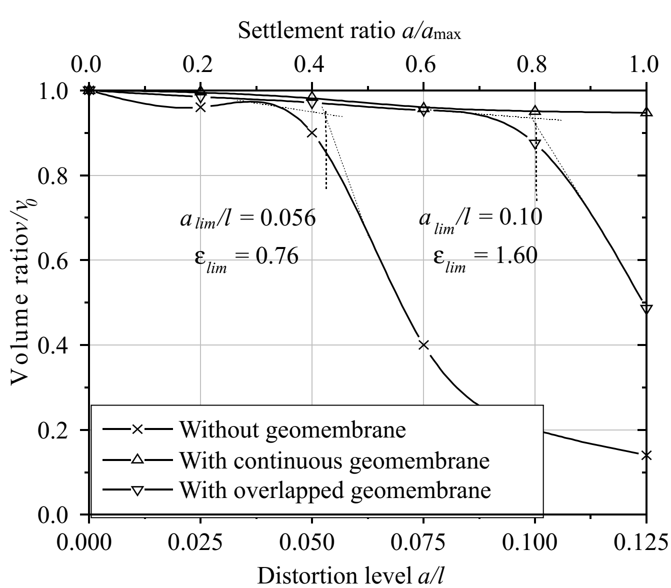


Figure 3. Variation of volume ratio with distortion level a/l and settlement ratio a/amax.

sponding ε_{lim} was 1.6%. This may be attributed to the relative movements between the geomembrane sheets undergoing differential settlement.

Further, in order to understand the relative displacements of geomembrane overlaps provided at the zone of maximum curvature (i.e. at hinge axis) or in the tension zone, displacement vectors of markers on either side of hinge axis with and without geomembrane overlaps were compared for different settlement stages. The distance between two markers is s mm initially at a/l = 0 at 40g. Subsequently, with an increase in a/l, distance between the same markers change to (s+s) mm; wherein (s+s) mm includes both horizontal and vertical component of distances. In the case of geomembrane with overlaps or improper joints, an adequate care was taken while selecting markers stuck to geomembrane sheets. Figure 4 presents variation of (s/s) with a/l and a/amax. As can be noted for model with continuous geomembrane, a very

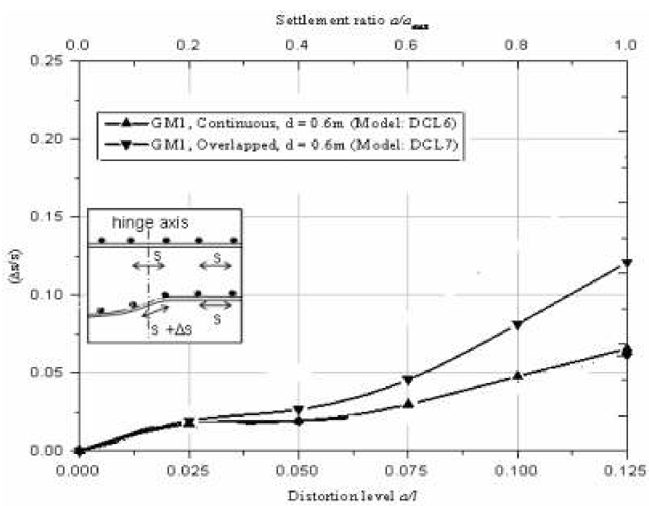


Figure 4. Variation of (s/s) with a/l and a/a_{max} for barriers with continuous and overlapped geomembrane

limited increase in (s/s) was noted a/l and a/amax. The value of (s/s) for a/l = 0.1 and a/amax = 0.8 correspond to only 0.045-0.048. Similarly for model DCL7 it is 0.08. This increase in (s/s) for centrifuge models with geomembrane resulted in an increase in infiltration ratio at the onset of a limiting distortion level alim/l = 0.1. However, till models are subjected to a/l = 0.1, sealing provided by means of thick bentonite paste along geomembrane overlaps have restrained changes in infiltration ratio.

Conclusions

Clay barrier of 15mm (0.6m) thickness were observed to lose its integrity in terms of sealing efficiency when subjected to differential settlements with wide cracks extending to full depth of clay barriers once the distortion level reaches 0.056. Composite barriers maintain the sealing efficiency even after subjected to a distortion level of 0.125. When there are overlaps within the geomembrane, the sealing efficiency of the composite barrier was found to lose at higher distortion level. For a clay barrier provided with geomembrane overlaps, the relative displacements in the tension zone are found to be clearly evident and resulted in an increase in infiltration ratio. The limiting distortion level was found to be of the order of 0.1 and the corresponding strain at water breakthrough was of the order 1.6% for a 0.6m thick barrier provided overlapped geomembrane. The reason can be the infiltration of water through overlaps of geomembrane which has got displaced due to the induced differential settlements to the model clay-based landfill cover system. This indicates that the presence of overlaps along the length of the geomembrane (especially at the zone of the maximum curvature) can affect the sealing efficiency of a clay-based landfill cover systems

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"Mr. Nilangshu Bhusan Basu (on left), Principal Chief Engineer, Planning and Development Department, The Kolkata Municipal Corporation, Kolkata is seen here with our Honorable Prime Minister, Dr. Manmohan Singh. Mr. Basu drew his kind attention to the feature article that appeared in the July/August 2012 edition of ASCE's flagship Civil Engineering magazine on Kolkata's ongoing Victorian-age Sewer Rehabilitation Project funded under the JNNURM program. Mr. Basu spent a few minutes explaining the challenging and complicated nature of this civil engineering undertaking. His co-author of the article was Ayanangshu Dey, Ph.D, CEng M.ASCE, the current Secretary of ASCE India Section."

Photo Courtesy: Planning and Development Department, The Kolkata Municipal Corporation, Kolkata