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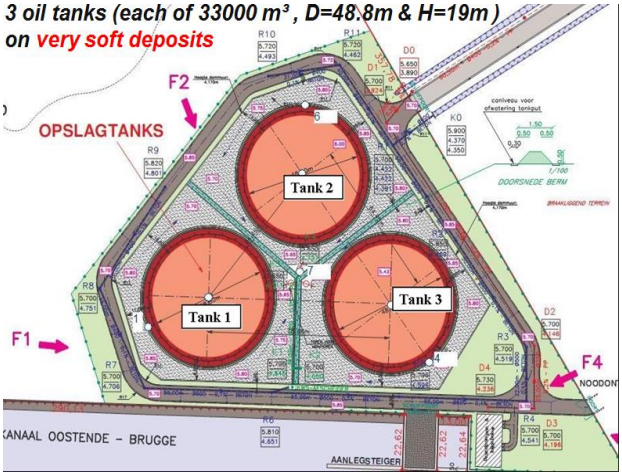


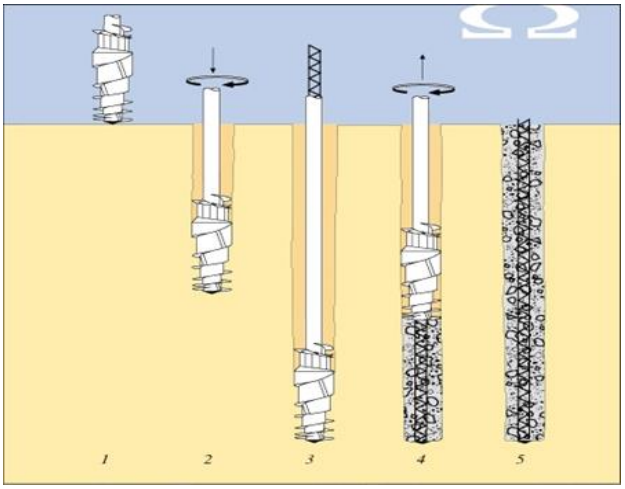


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# GEOTECHNICAL ENGINEERING

# March 2018 Issue to Honour Prof Madhira Madhav

**For his Contributions in Geotechnics through Indian Geotechnical Society, ISSMGE and Universities in IIT Kanpur, IIT Bangalore, Saga etc**

**Prof. M.R.Madhav**, Visiting Professor, IIT, Hyderabad, Professor Emeritus, J.N.T.U, Hyderabad, Resource Person, Rajiv Gandhi University of Knowledge Technology, Chairman, Research Council, CSIR-CRRI, and Advisor/Consultant to Energy Infratech, Halcrow, KSK Infra, etc., retired as Professor of Civil Engineering, IIT, Kanpur. He graduated in Civil Engineering from Andhra University in 1960, obtained the Master of Engineering and the Doctorate of Philosophy degrees from the Indian Institute of Science, Bangalore in the years 1961 and 1967 respectively. Prof. Madhav worked at several universities - Sydney, Australia; Concordia, Canada, Saga, Saga, Japan; Ghent, Belgium, Queen's, Belfast, etc.. He was an Associate at the International Center for Theoretical Physics, Trieste, Italy, Vice President for Asia, International Society of Soil Mechanics & Geotechnical Engineering, advisor to Navi Mumbai SEZ, CRRI, New Delhi.

Prof. Madhav's research interests span the whole gamut of Geotechnical Engineering. He guided more than 45 doctoral and several master's theses and final year projects. He co-edited books entitled 'Lowlands - Development and Management' and on 'Foundations and Soft Ground Engineering Challenges in Mekong Delta, and authored more than 500 publications in refereed international and national journals and conferences.

Prof Madhav is well known internationally as a researcher, teacher and consultant. He established schools of research at IIT, Kanpur, and JNTU, Hyderabad in Geotechnical Engineering, was associated closely in developing the schools of research at the Institute of Lowland Technology, Saga and IIT, Hyderabad. His work on Modelling and Numerical Analyses of Geotechnical and Ground Engineering Problems is monumental. He has contributed to the Practice of Geotechnical Engineering as a Consultant and to the Indian Geotechnical Society as a Member of the Executive Committee, as a Reviewer for and Editor of the Indian Geotechnical Journal and as President.

Prof. Madhav delivered Keynote/Plenary Lectures, Chaired Technical Sessions in several International and National Conferences, was a Panelist in the XIII, XV and XVI International Conferences on Soil Mechanics and Geotechnical Engineering at New Delhi (1994), Istanbul (2001) and Osaka (2005). He delivered the prestigious Annual Lecture of the IGS, Keynote Lecture at the 12$^{th}$ Asian Regional Conference at Singapore, the Inaugural Miura Lecture at Busan, etc. He is Life Fellow of the Indian National Academy of Engineering, the Indian Geotechnical Society, The Institution of Engineers (India), etc. He is recipient of the Keucklemann Award of the IGS, the Prof. Mehra Research Award of the University of Roorkee, Pundit Jawaharlal Nehru Birth Centenary Research Award of CBIP, the Doctor of Science degree of the Indian Institute of Science, Distinction in Engineering Technology from the Central Board of Irrigation and Power, IGS – Prof. Dinesh Mohan Prize, etc. He was the President of IGS, and the Vice President for Asia of ISSMGE, the Vice President (1998-2010) and currently (2010 onwards) the President of the International Association of Lowland Technology. He has been awarded the Honorary Fellowship and Diamond Jubilee Honour by the Indian Geotechnical Society. He received the prestigious Bharat Ratna M Visweswaraya Award by Government of AP & Institution of Engineers

(I) AP State Centre, Gopal Ranjan Research award of IIT, Roorkee for Innovative and Outstanding Research, Outstanding Researcher Award from IANAMG, IGS-MS Jain Prize for Innovations in Piling, Vishwakarma Award for Academic Excellence from Construction Industry Development Council, IGS – H C Verma Diamond Jubilee Award for Innovative Instrument Design, the Distinguished Alumnus Award from the Indian Institute of Science, Bangalore in August 2014 (the second graduate from Civil Engineering) and the Prof. Dinesh Mohan Award for Excellence in Geotechnical Practice, etc. and delivered the most prestigious IGS-Ferroco Terzaghi Oration. Most recently, Prof. Madhav delivered the first Victor de Mello Goa lecture. Prof. Madhav pursues Origami as his hobby.

# Preface

This Issue contains sixteen papers, the first ten was acquired by Profs Madhavi Latha and Murali Krishna to honour Prof Madhira Madhav and the other six are directly contributed papers to our Journal Office.

The first paper is by Harry G. Poulos on Rational Assessment of Modulus of Subgrade Reaction: The concept of modulus of subgrade reaction has been employed within the engineering world for almost 150 years. It has been especially embraced by structural engineers who have found it convenient to represent the behaviour of the ground supporting their structures by elastic springs. Despite the best efforts of the geotechnical profession to dissuade our structural colleagues from using this flawed concept in foundation design, requests to provide a modulus of subgrade reaction continue almost unabated. Given this situation, a suitable response is to provide such values via a rational process of evaluation, rather than by empirical correlations which have little theoretical basis and which may not be applicable to the foundation being considered.

This paper sets out an approach to the estimation of values of modulus of subgrade reaction for various types of foundation. The key points made are that the modulus of subgrade reaction (k) is not a fundamental soil property, but varies with the foundation type, foundation dimension, and type of loading. k can be related to the Young's modulus of the supporting soil and to the foundation dimensions, but for pile groups, account must be taken of the reduction in k because of group effects arising from pile-soil-pile interaction. It is also emphasized that careful distinction must be made between the modulus of subgrade reaction, k, and the spring stiffness K.

The second paper is by S**.** Basack, B. Indraratna and C. Rujikiatkamjorn on Effectiveness of Stone Column Reinforcement for Stabilizing Soft Ground with Reference to Transport Infrastructure: The use of stone columns for soft soil stabilization has numerous advantages compared to other methods. There are many factors controlling performance of stone columns including column geometry and particle morphology. The reinforced soft ground supporting transport infrastructure like the railways and highways is subjected to cyclic loading, usually initiating a partially drained condition. The study reveals that the stone columns are more effective in mitigating the built up of cyclic excess pore water pressure compared to conventional vertical drains. This paper presents a brief overview on the rigorous theoretical and experimental studies carried out by the Authors to investigate the effectiveness of stone column reinforcement for stabilizing soft ground with particular reference to transport infrastructure.

The third paper on Pile design and group behavior; a case study of large tank foundations in soft soil conditions is by W.F. Van Impe, P.O. Van Impe and A. Manzotti: The paper presents the case study on the construction of three 48m diameter oil tanks in Ostend (Belgium), each founded on a group of 422 displacement cast in-situ screw piles. The three tanks are close enough to each other to induce interaction. Monitoring of the tanks' movements has been performed during the hydro-testing of the steel tanks and during the subsequent working stage of the tanks. The bearing layer of the pile group is a 5m thick stiff sand layer at a depth of about 20m, overlain by a very heterogeneous soft clayey/silty fill containing sand pockets, and underlain by very thick slightly over-consolidated clay. Some short and long term settlement prediction of the tanks have been done, assuming soil parameters derived from the CPT data on site, and compared to the measured settlements. The initially derived soil parameters are then re-evaluated in order to predict the long term settlement for the full life span of the construction.

The fourth paper is by V Sivakumar on Granular Columns for Geotechnical Applications: Soft clay deposits are globally widespread and often coincide with strategic transport links and growing urban developments. These soft deposits are often waterlogged and are composed of clay with varying degrees of silt, sand and organic matter. These soils have low undrained shear strength and high compressibility, contributing to construction

problems in relation to stability and settlement. Granular columns, also referred to as flexible piles, are one of the techniques widely considered in the industry for improving soft deposits for low-moderate structural loading. The purpose of this article is to highlight some of the key investigations carried out in the topic of granular columns at Queen's University Belfast, the UK.

The investigations focused on several aspects: (a) the interaction between columns and surrounding clay (b) containment of columns in geo-grid for enhanced strength performance (c) settlement performance under single or multiple column configuration (d) stress distribution under the footing and along the column (e) assessment of consolidation and creep settlement under constant loading and (f) granular columns for anchoring purposes and therefore stabilization of slopes. Overall observations are: settlement improvement factors were moderate under isolated loading, but granular columns are very effective in providing pull-out capacity in the form of anchors.

The paper entitled Ground Engineering Using Prefabricated Vertical Drains: A Review is the fifth paper by V.A. Sakleshpur, M. Prezzi, and R. Salgado: Improvement of soft ground by preloading with prefabricated vertical drains (PVDs) is a common practice in the field of ground engineering. PVDs accelerate the consolidation process of soft soils by providing a shorter drainage path for the pore water and thereby increase the strength and stiffness of soft soils over time. This paper presents a review of recent analytical, laboratory, numerical and field studies performed using preloading with PVDs for improvement of soft ground. The focus of the paper is on conventional PVDs without the use of vacuum, thermal and electro-osmosis techniques. Summary tables, which provide quick and easy access to the latest information from various research efforts, have been prepared and discussed. The review is complemented by two case histories that highlight the performance of PVDs in the field.

The sixth paper is on Soil Reinforcement under Oblique Pull- An updated Discretization by S Patra & J.T. Shahu: Reinforced soil structures are gaining popularity for a variety of reasons mainly because it is safe, economical, aesthetic and rapid in constructions. However, the actual behaviour of these structures at failure is still not properly understood. The present study attempts to evaluate the internal stability of these structures against pullout failure. Kinematics of failure suggests that the failure surface intersects the reinforcement obliquely causing an oblique pullout of the reinforcement. In this paper, an updated discretization technique is used to determine the pullout capacity of an inextensible reinforcement resting on a linear elastic Pasternak subgrade and subjected to an oblique end force. A parametric study is conducted and a new factor, length correction factor is introduced in the present analysis. The correction factors have a significant influence on the pullout response especially for high values of obliquity and end displacement. Present analysis thus gives a more realistic value of pull out capacity which is required for the internal stability analysis and design of reinforced soil structures. A case study is also presented to validate the proposed analysis. The maximum reinforcement tension is predicted for top few reinforcements using the proposed method and the AASHTO Simplified Method. The present analysis gives a better prediction of the mobilized reinforcement tension compared to the AASHTO method.

The paper by Madhavi Latha G and Manju G. S. is the seventh paper on Effect of Facing Slope on the seismic response of Geocell Walls: This paper presents the effect of slope angle of facing on the seismic response of retaining walls with geocell facing. Keeping the dimensions and configuration of geocell layer same, shaking table model tests were carried out with vertical and battered walls retaining sand backfill. In case of battered walls, geocell layers were laid with an offset, resulting in an overall slope of the wall. Vertical walls were constructed with geocell layers stacked vertically above each other. Gravel was used as infill material in geocells. Models were subjected to different levels of ground motion conditions by controlling the acceleration and frequency of shaking. Acceleration amplitudes of 0.2g and 0.3g with frequencies ranging between 1 Hz and 7 Hz were used in the model tests. Response of models was monitored with cyclic shaking at intended acceleration and frequency by measuring the face deformations and acceleration amplifications along the height

of the retaining wall, Results from model tests showed that battered walls perform better than the vertical walls since the measured deformations and acceleration amplifications were comparatively low in battered walls. The improved performance of battered walls is due to the increased stiffness and increase in dynamic impedance caused due to shifting of moment of inertia of pressure distribution at the back of the wall in case of walls battered towards the backfill.

The eighth paper is on Evaluation of Resilient Modulus of Geosynthetic Reinforced Layers Using Repeated Load Triaxial Tests by Sudheer S Prabhu, Lekshmi Suku and G L Sivakumar Babu: The stiffness and strength of the pavement layers are the major parameters that influence the design of highway pavements which in turn decides the thickness of various pavement layers. Studies have shown that the thickness of the base layer plays a crucial role in limiting the rutting of the in situ subgrade soil. Due to the lack of availability of aggregates, there is a dire need to minimize the thickness of the base. Geosynthetics in the form of geogrid and geocell have long been used for reinforcing unbound base/subbase layers in paved and unpaved roads and have been found to be effective in reducing the base thickness. A few laboratory studies have been conducted to evaluate the different aspects of geosynthetic reinforced base layers, and further studies are required to examine the behavior of these reinforced sections under elastic and plastic shake down range. The purpose of the current study is to evaluate and compare the resilient modulus of geogrid reinforced, geocell reinforced and the unreinforced granular base under repeated loading using the Repeated Load Triaxial tests. The response of aggregate under repeated loading expressed in terms of resilient modulus is a key parameter in the new Mechanistic Empirical Pavement Design Guide (MEPDG). The permanent strains of aggregates are also compared in the study to get an overall idea about the reinforcement effect in the granular base.

The paper by Ritwik Nandi and Deepankar Choudhury is the ninth paper on Seismic Analysis of Reinforced Soil Wall Considering Oblique Pullout of Reinforcements: A Review: Several methods are available for stability analysis of reinforced soil structures. However, most of these methods mainly concentrated on the horizontal pullout of the reinforcement in spite of the evidences available that show the failure surface of reinforced soil structure will always intersect reinforcement layers diagonally due to the failure kinematics. It will cause oblique/transverse deformation to reinforcements across the failure surface. In the present paper, state-of-the-art review of earthquake stability analysis of reinforced soil-wall by employing the oblique/transverse pull of reinforcements is discussed. Formulations that are developed in various studies to determine the mobilization of diagonal pullout resistance of reinforcements, the amount of drag force triggered in the reinforcement sheets due to instability in the structure and the factor of safety against pullout are presented. A comparative study is also carried out between existing models and methods that are used in determining the seismic stability of reinforced soil structure subjected to diagonal pullout of soil reinforcements. The comparative study shows the effect of various models and methods on the factor of safety against reinforced soil-wall stability and the influence of different parameters i.e., horizontal seismic acceleration, internal friction angle of soil, interface friction angle of soil and reinforcement, relative subgrade stiffness factor etc. Depending on the model used in analyses, the computed factor of safety may vary significantly.

The tenth paper is by Nevin Koshy, S. U. Sushalekshmi, Susmita Sharma, Jeevan Joseph, Vikas, D. N. Singh, Bhagwanjee Jha and M. Singh on Characterization of the Soil Samples from the Lonar Crater, India: The Lonar crater and its enclosed lake have been a universally recognized young and well preserved meteoritic formation in the state of Maharashtra, India. Previous studies on the uniqueness (salty and alkaline nature) of sediments (the crater soil) and the lake water, hint at its creation by meteor impact and post-impact induced hydrothermal interaction between the meteor and the then earth surface in the region. Also, the earlier reports confirm the sediments as basaltic rock, in nature. However, not many efforts have been made by the present generation of researchers for detailed chemical and mineralogical characterization of the sediments, which may reveal an analogue relationship between the crater sediments and a meteor (the lunar or the Martian soil) from the space. In this context, the present study attempts to understand the characteristics of the soil samples extracted from the crater region, with respect to their physical, chemical, mineralogical, electrical and magnetic properties. The

findings also shed light into the response of the crater samples when subjected to different energy fields (viz., mechanical, chemical, electrical and X-rays). Based on a critical synthesis of the results, the characteristics (viz., alkalinity, saltiness, geological-structural properties, water-sediment interaction) of the sediments have been showcased and evaluated for their partial conformity with extraterrestrial objects (i.e., the meteors).

The eleventh paper by J. Jayapal & K. Rajakopal is on Encased Columnar Inclusions in Soft Grounds - A Review: Even before the evolution of soil mechanics, the research on mitigating the problems induced by soft soils has started. The granular column is one of the promising ground improvement technique widely accepted as a solution to soft soil problems all over the world. Recently the performance of it is improved by encasing with geosynthetic products like geogrid and geotextiles. This paper gives an insight into the technical aspects of encased granular columns by reviewing the advancements that have happened in the published literature. The focus of this paper is more on the problems associated with soft clay deposits, although granular columns can also be employed to mitigate liquefaction in saturated loose sand deposits. Discussions on the key technical aspects associated with encased granular columns and its applicability in the field are provided.

The twelfth paper by P. A. Faby Mole, S. Sireeshand M. R. Madhav on Influence of Shear Stiffness of Geocell Mattress on the Performance of Strip Footings- A Numerical Study**:** A modified Pasternak model was proposed to predict the behaviour of a strip footing resting on a geocell reinforced granular layer overlying weak soil, especially considering the variation of shear stiffness of the geocell mattress. Both linear and nonlinear responses of the geocell reinforced beds were considered in the analysis. Results from the present model were validated with independent experimental load-deformation responses. The model parameters viz. inverse of normalized shear stiffness of the geocell and inverse of normalized ultimate bearing capacity of foundation soil were varied for the parametric study. It was found that the shear stiffness of the reinforced granular bed i.e. the product of shear modulus and the height of the geocell reinforced granular bed plays an important role in improving the performance of the foundation system. Design charts are presented in the form of improvement factors for the practical range of shear layer width, shear stiffness of the geocell reinforcement and ultimate bearing capacity of the soft soil**.**

The thirteenth paper is on Interference of Two Closely-Spaced Footings on Finite Sand Layer by Macharam Rohith, Sasanka Mouli, and Umashankar Balunaini: Bearing capacity of footing is influenced by the presence of adjacent footing. In this study, two closely-spaced strips, square, and circular footings are modelled in finite elements using commercially available software - PLAXIS 2D and 3D. Analysis is done considering both smooth and rough footing bases. The effect of spacing between the footings is examined for footings resting on both semi-infinite and finite sand layers. In addition, angle of shearing resistance of foundation soil is varied from 30° to 40° to investigate its effect on the bearing capacity. Bearing capacity of footings with rough base are found to attain a peak value at a particular spacing indicating the “blocking effect”. For square and circular footings, interference due to spacing is found to be insignificant compared to strip footing. Interference factors for rough footings are found to be higher than that for smooth footings.

The fourteenth paper on Stone Columns/Granular Piles for Improving Liquefiable Sites: Case studies are by A. Murali Krishna, A. Madan Kumar, Utpal Kr. Baruah: Liquefaction is considered as a major hazard among different seismic risks. Ground improvement methods are commonly adopted to improve the liquefiable sites. The paper presents various aspects of liquefaction mitigation strategies to be implemented for liquefaction susceptible sites with focus on granular inclusions. A short discussion on liquefaction susceptible soils and its evaluation followed by outlines of the ground engineering applications is presented herein. Mechanisms that function at sites treated with stone columns/granular piles for liquefaction mitigation are discussed. Design aspects of granular piles for liquefaction mitigation are outlined. Few case studies, wherein stone columns have been adopted for improving the liquefiable sites, are presented. The paper concludes and highlights the effectiveness of granular inclusions in improving the liquefiable sites through various mechanisms.

The paper on Biogeotechnological Methods for Mitigation of Liquefaction is the fifteenth by S. Wu, B. Li, J. He and J. Chu: Liquefaction of granular soils during earthquake has long been identified as one of the major geohazards. Conventional soil improvement methods for mitigating liquefaction such as dynamic compaction or deep mixing are costly for large-scale applications. Recently some biological processes have shown significant influence on both the physical and chemical performance of geotechnical systems. Two types of biogeotechnological methods, biocementation and biogas desaturation, have been experimentally examined in this study. For the former, a microbial induced carbonate precipitation (MICP) process has turned one cubic meter of loose sand into sandstone-like material. The shear strength of the sand is greatly improved whereas the permeability is reduced at the same time. For the later, tiny inert gas bubbles are generated microbiologically within liquefaction prone ground to increase the resistance of sand to liquefaction. A series of shaking table model tests on biogas treated sand have demonstrated that this biogas desaturation method is effective for reducing pore pressure generation and shaking induced settlement during cyclic loading. When the degree of saturation of the soil is controlled to be around 90%, the generation of pore pressure in sand and the potential for liquefaction could be largely contained.

The last paper in this issue is the sixteenth paper on A Critical and Comparative Study on 2D and 3D Analyses of Raft and Piled Raft Foundations by V. Balakumar, Min Huang, Erwin Oh and A. S. Balasubramaniam: The piled raft foundation has gained a very high level of acceptance as a foundation system whenever settlement alone governs the design. In the design of piled raft many of the traditional methods could not be applied due to the complex nature of interactions involved. Hence there is a need to use detailed three dimensional finite element analyses for the final design. But in the initial stages of design a simpler but effective analytical process need to be used to save the computational efforts. Since the primary requirement in the piled raft design is the design of optimum pile group to achieve the desired settlement reduction, through number of trials, the applicability of simpler two dimensional analyses are examined to save the computational efforts during the initial trials. It was found that simple two dimensional analyses provide results of acceptable accuracy for the design office requirements.

**Madhavi Latha**
**Murali Krishna**

# ACKNOWLEDGEMENTS

Sixteen papers are contained in this issue. The first ten was acquired by Profs Madhavi Latha and Murali Krishna to honour Prof Madhira Madhav and the other six are directly contributed papers to our Journal Office. No doubt the material contained herein would be most valuable to our profession. The editors have adequately described the contributions in the preface. They are to be congratulated for these contributions.

**Dr. Teik Aun Ooi**
**Prof. San Shyan Lin**
**Prof. Kwet Yew Yong**
**Dr. Noppadol Phienwej**
**Prof. A. S. Balasubramaniam**

# GEOTECHNICAL ENGINEERING

## March 2018: Guest Editors

**Edited by: Madhavi Latha & Murali Krishna**

**Madhavi Latha**

Madhavi Latha is a Professor at IISc, Bangalore. She obtained her Ph.D. degree from IIT Madras. Prior to joining IISc in 2003, she was an Assistant Professor at IIT Guwahati for a year. Her research areas include geosynthetics, earthquake geotechnical engineering and rock engineering. She has so far supervised 10 Ph.D. students and published more than 150 technical papers. She is one of the geotechnical consultants for the world's highest railway bridge being constructed in Jammu, India. She is a member of ISSMGE Technical Committee on soil structure interaction and retaining walls and IGS Technical Committee on soil reinforcement. She is currently the Editor-in-chief of the Indian Geotechnical Journal.

**Murali Krishna**

Dr. A. Murali Krishna is a faculty member in Department of Civil Engineering at Indian Institute of Technology (IIT) Guwahati, since 2008. He obtained Doctoral degree from Indian Institute of Science Bangalore for his Ph. D work on "Shaking table tests on Geosynthetic reinforced soil retaining walls". He received his M.Tech degree from IIT Kanpur and B.Tech degree from Sri Venkateswara University, Tirupati. His research interests include: Earthquake Geotechnics, Geosynthetics and Ground Improvement, Site characterization and Numerical and Physical modelling of geotechnical structures. Dr. Murali Krishna supervised 4 Doctoral students and 20 Masters Students. He co-authored nearly 150 publications of technical papers in International/National Journals and Conference/Seminar Proceedings including book chapters. He is a recipient of BRNS Young Scientist Research award, BOYSCAST fellowship and HERTAGE fellowship. Dr. Murali Krishna is currently serving as an 'Executive Member' of the IGS and Member of TC 203 of ISSMGE, since 2011. He is the executive member of ISRM (India) and ISET. Dr. Murali Krishna organised national and international workshops and short courses. He is a reviewer for several national and international journals.

# GEOTECHNICAL ENGINEERING

## March 2018: Issue to Honour Prof M. R. Madhav for his Contributions in Geotechnics Through Indian Geotechnical Society, ISSMGE and Universities in IIT Kanpur, IIT Bangalore, Saga etc.

**Edited by:**
**Madhavi Latha & Murali Krishna**

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1. Pile design and group behaviour: a case study of large tank foundations in soft soil conditions
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# GEOTECHNICAL ENGINEERING

## Paper Contribution, Technical notes and Discussions

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Geotechnical Engineering Journal accepts submissions via electronic. The manuscript file (text, tables and figures) in both words and pdf format together with the submission letter should be submitted to the Secretariat and copied to the Editor-in-Chief, Geotechnical Engineering Journal, c/o School of Engineering and Technology, Asian Institute of Technology, Room no. 211, AIT Library, Asian Institute of Technology, P.O. Box 4, Klong Luang, Pathumthani 12120, Thailand. Email: seags@ait.ac.th. Papers under review, accepted for publication or published elsewhere are not accepted. The guidelines for author are as follows:-

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14. REFERENCES

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