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Ground Stabilisation Techniques for Problematic Soils and Unstable Rocks

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AUSTRALIAN GEOMECHANICS SOCIETY

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TIMETABLE

8:30 Registration

9:00 Opening address

GROUND IMPROVEMENT (PART I)

9:05 Keynote Lecture

Ground improvement for transportation infrastructure in Australia

Buddhima Indraratna (UOW)

9:35 Presentation

Case study of seven ground improvement techniques implemented at coal export terminal at Kooragang Island, Australia

Iain Robertson (Keller Ground Engineering)

9:55 Presentation

Design of high strength geotextiles for basal reinforcement

Idy Li (EIC)

10:15 Questions

10:35 Morning tea

GROUND IMPROVEMENT (PART II)

10:55 Invited Lecture

Deep dry soil mixing performance and quality control acceptance criteria

Patrick Wong (PKW Geosolutions)

11:20 Presentation

Determining the effect of ground improvement using impact rolling for varying site conditions

Declan McHale (Infra Tech Group)

11:40 Presentation

A new calculation approach to design flexible facing system for soil nailing

Marco Cerro (Maccaferri)

12:00 Presentation

Shallow ground improvement for a new rail depot / maintenance facility in Sydney, NSW

Bryn Thomas (GHD)

12:20 Questions

12:40 Lunch

GROUND IMPROVEMENT (PART III)

13:20 Keynote Lecture

Soft Soil Engineering in Practice
Jeff Hsi (EIC)

13:50 Presentation

Treatments of existing abutment RSW using permeation grouting and horizontal soil nailing

Bosco Poon (GHD)

14:10 Presentation

Soil stabilization using Lignosulfonate

Jayan S. Vinod (UOW)

14:30 Presentation

Ground improvement for International Container Terminal project at Webb Dock Port Melbourne

Kejing Chen (AECOM)

14:50 Questions

15:20 Afternoon tea

GROUND IMPROVEMENT (PART IV)

15:30 Presentation

Some effects of stone column installation

Richard Kelly (SMEC)

15:50 Presentation

Ground control for a deep basement excavation in Sydney GPO fault zone

David Oliveira (Jacobs/Coffey)

16:10 Presentation

Case study of deep excavation and shoring design for Sydney Metro Northwest

Jim Yang (Hyder/John Holland)

16:30 Presentation

An innovative geotechnical monitoring system for soft ground treatment on W2B Pacific Highway Upgrade project

Henry Zhang (PB/LOR)

16:50 Questions

17:05 Closing address

17:15 Close



Canopy Tube installation at Wynyard Walk - Keller Ground Engineering



Dynamic Compaction and Wick Drains at Perth Stadium - Keller Ground Engineering



Jet Grouting over canopy of Brisbane tunnel - Keller Ground Engineering



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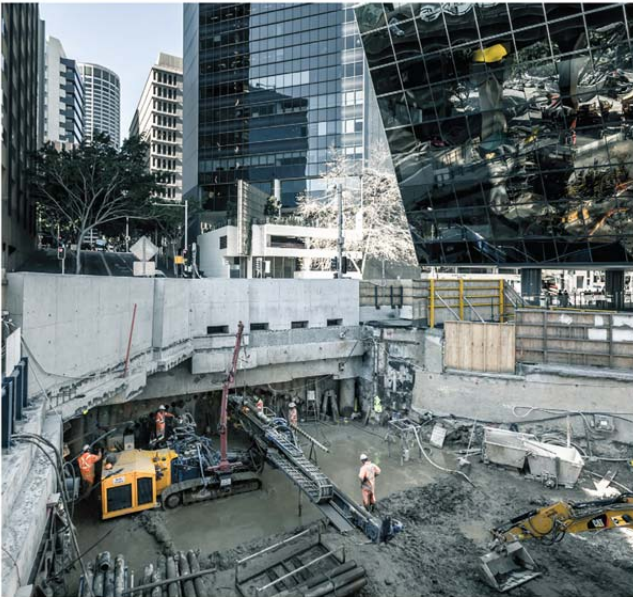
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Ground Stabilisation Techniques for Problematic Soils and Unstable Rocks

PREFACE

This document contains papers for the 20th annual symposium organised by the Sydney Chapter of the Australian Geomechanics Society. It is hoped that the symposium will keep practicing geotechnical engineers, engineering geologists, and other engineering professionals informed of recent developments in this field. It also recognises the need to gather together the experience of those practicing throughout Australia and to allow transfer of knowledge and sharing of their experiences.

These symposia continue to be one of the best forms for bringing together the key stakeholders of the Australian geological and geotechnical community. The main objective of the symposium, held on 11 November 2016, is to advance the knowledge in design and construction towards more cost effective ground improvement techniques in urban infrastructure environment.

Contributors include academics, practicing consultants, designers, suppliers and contractors. The papers present novel design and construction technologies for the performance monitoring of various ground improvement techniques applicable to soft soil and unstable rocks as well as new research results and case histories on construction.

This symposium is the cooperative effort of many authors and qualified reviewers. The editors and organising committee wish to thank the authors, who have generously contributed their time to prepare the various papers and the colleagues of the authors, who have assisted with time, secretarial, drafting and other facilities. Appreciation is also extended to our sponsors for their support. Without them the Symposium would not be possibly the best ongoing forum for the Australian Geomechanics and groundwater community.

Cholachat Rujikiatkamjorn, Sam Mirlatifi, Hadi Khabbaz, Tristan Mcwilliam and Adrian Hulskamp

On behalf of the AGS Symposium Organising Committee,
The Australian Geomechanics Society, Sydney Chapter

Annual Seminars of AGS Sydney Chapter

No.	Date	Topic	Chairman & Organising Team
1	1997	Pavement Design Beyond 2000	A Leventhal
2	1998	Recent Developments in Piling Practice in Sydney	P Andrews
3	1999	Flexible Retaining Walls: Design to Prevent Failure	P Andrews and P Hewitt
4	2000	Computer Methods	P Hewitt and J Carter
5	2001	Excavation Retention	T Walker and P Hewitt
6	2002	Landslide Risk Management	B Walker and T Walker
7	2003	Geotechnical Instrumentation and Construction Works Compliance Testing	G Scholey and T Walker
8	2004	The Engineering Geology of the Sydney Region – Revisited	G Scholey, M Parmar, G Young and G McNally
9	2005	Geotechnical Aspects of Tunnelling	H Buys and T Gourlay
10	2006	Soft Ground Engineering	H Buys, R Moyle and P Hewitt
11	2007	Engineering Advances in Earthworks	R Moyle, R Lindbeck and H Liu
12	2008	Foundation Design and Construction	R Moyle, R Lamont and B Ewers
13	2009	Geosynthetics – New Materials for Modern Infrastructure	B Ewers, H Buys and H Liu
14	2010	Seismic Engineering- Design for Management of Geohazards	C Rujikiatkamjorn, J McIlveen, R Lamont and M Haysler
15	2011	Coastal and Marine Geotechnics- Foundations for Trade	C Rujikiatkamjorn, J McIlveen, G Blumberg, J Smith and C Y Tey
16	2012	Advances in Geotechnical Aspects of Roads and Railways	H Khabbaz, C Y Tey, O Stahlhut and C Rujikiatkamjorn
17	2013	Retaining Structures: Recent Advances and Past Experiences	H Khabbaz, C Rujikiatkamjorn, M van Uden, C McColgan and S Mirlatifi
18	2014	Resilient Geotechnics	H Khabbaz, C Rujikiatkamjorn, S Mirlatifi, C McColgan and M van Uden
19	2015	Recent Developments and Experiences with Groundwater and Excavation	C Rujikiatkamjorn, S Mirlatifi, Katarina David, A. Hulskamp, and M van Uden
20	2016	Ground Stabilisation Techniques for Problematic Soils and Unstable Rocks	C Rujikiatkamjorn, S Mirlatifi, A. Hulskamp, T Mcwilliam and H Khabbaz

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[All papers have been refereed in accordance with the full DETYA review process, unless stated otherwise.]

SELECTED METHODS OF GROUND IMPROVEMENT FOR AUSTRALIAN TRANSPORT INFRASTRUCTURE

Buddhima Indraratna¹, Ana Heitor², Cholachat Rujikiatkamjorn³ and Rui Zhong⁴

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ABSTRACT

In coastal regions of Australia, high population densities and increased traffic have led to a substantial expansion of transportation infrastructure. These developments have necessitated the use of ground improvement techniques in response to environmental legislation and the need for sustained performance. In this paper, a brief overview of innovative ground improvement techniques in major areas such as railway embankments, port reclamation, and landfill operations is provided. Ballasted rail tracks are often placed on freshly quarried aggregate because it is resilient enough for cyclic and impact loads. However, ballasted layers often need periodic maintenance due to deformation and degradation, and while recycled ballast is a cheaper and environmentally viable option, its strength must be investigated beforehand, and different types of geosynthetics to improve the stability and drainage of railway tracks under high cyclic loading also need assessing. Field tests to measure the in-situ stresses and deformations of ballast have been carried out on sections of instrumented heavy haul track at Bulli and Singleton. Stabilization of soft subgrade soils using prefabricated vertical drains (PVDs) and stone columns is also needed to improve the overall stability of track and reduce differential settlement during operation. The effectiveness PVDs can be seen via field measurements and finite element analyses. Due to an increase in trade activities at the Port of Brisbane, Queensland (Qld), new facilities on Fisherman Islands at the mouth of the Brisbane River were constructed (reclamation) on the new outer area (235ha) adjacent to the existing port facilities. A vacuum assisted surcharge load and conventional surcharge scheme in conjunction with PVDs helped to reduce the required consolidation time through the deeper subsoil layers. The design of this combined vacuum and surcharge fill system and construction of the embankment are described in this paper. A 45 ha reclamation at the Outer Harbour extension of Port Kembla in Wollongong, NSW, gave us the opportunity to examine the potential use of coal wash (CW) and steel furnace slag (SFS) as predominant reclamation fill, while laboratory investigations indicated that an optimum CW-SFS mixture would meet most of the geotechnical specifications needed for an effective structural fill. A field application at Penrith Lakes, NSW, of a new methodology using the shear wave velocity (V_s) (i.e. Multichannel Analysis of Surface Waves MASW) and matric suction (u_a-u_w) or moisture content was investigated. The laboratory results and the results from preliminary field testing indicate that V_s and (u_a-u_w) trends could predict the compaction characteristics of the soil. The use of sustainable approaches for ground improvement such as bio- engineering, and recycled tyres with waste granular material, is also presented and discussed in this paper.

SOFT SOIL ENGINEERING IN PRACTICE

Jeff Hsi

EIC Activities, Level 19, 177 Pacific Highway, North Sydney, NSW 2060, Australia

ABSTRACT

Engineering development on soft soils has grown rapidly in recent years, spurred by an increasing demand on land space for infrastructure expansion. However, the combination of poor strength, high compressibility and low permeability characteristics inherent to soft soils form a problematic suite of conditions, placing overlying structures at risk of excessive deformation and instability. Managing these conditions is particularly challenging to designers and constructors. This paper presents a summary of the critical findings and conclusions gained through the author's own experience in designing embankments over soft soils. Particular emphasis is placed on the interpretation of geotechnical parameters using empirical correlations to validate test results and design assumptions, and specific design considerations that may impact on the performance of embankments built on soft soils. This paper also discusses design criteria, methods for settlement and stability control, commonly used ground stabilisation techniques, and approach to manage soft soil risks. The purpose of the paper is to provide suggestions towards a holistic approach to soft soil engineering based on the author's experience. Examples are also provided to illustrate the author's views and findings, which are not intended to be exhaustive.

CASE STUDY OF SEVEN GROUND IMPROVEMENT TECHNIQUES IMPLEMENTED AT COAL EXPORT TERMINALS ON KOORAGANG ISLAND, AUSTRALIA

Ming Lai¹, Ondrej Synac², Iain Robertson³ and Derek Avalle⁴

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ABSTRACT

This paper describes a case study in which various ground improvement techniques were implemented to enable the development of one of the world's largest coal export facilities. To service the Hunter Valley coal industry, Coal Export Terminals (CET) with associated rail and coal handling/train unloading infrastructure have been constructed on Kooragang Island, Newcastle, New South Wales, Australia, in the last decade. The coal terminal expansion has brought about fundamental geotechnical challenges. Kooragang Island was formed by dredging and infilling between and around former islands and delta features of the Hunter River estuary. The presence of recent estuarine and alluvial soft clay deposits combined with variable thicknesses of fill comprising dredged materials, coal washery reject and steel slag, introduced significant geotechnical issues in relation to bearing capacity, stability and long term total and differential settlements. To support combined stacker/reclaimers with up to 24m high coal stockpiles, rail loop realignment and a new rail flyover, Ground Improvement was required to address the above issues. In order to limit the post-construction settlements and to satisfy the settlement criteria for machinery and railway operation, a suite of seven ground improvement techniques has been employed to suit the specific performance requirements, programme and geotechnical conditions across the site. These consisted of Wick Drains, Dry Bottom-Feed Stone Columns, Wet Top-Feed Stone Columns, Dynamic Replacement, Mass Soil Mixing, Deep Soil Mixing and Rigid Inclusions. All of the above methods were successfully applied over the course of an eight year development period on a design and construct basis. The process of using ground improvement techniques, their construction restraints and geotechnical design considerations are discussed. The performance based on monitoring data collected under operating conditions is presented.

DESIGN OF HIGH STRENGTH GEOTEXTILES FOR BASAL REINFORCEMENT WITHIN EMBANKMENTS

Idv Li¹ and Jeff Hsi²

*¹Senior Engineer – Geotechnical, ²Technical Principal – Geotechnical,
EIC Activities, Level 19, 177 Pacific Highway, North Sydney, NSW 2060, Australia*

ABSTRACT

High Strength Geotextiles (HSG's) are commonly used as basal reinforcement within embankments and structures founded upon weak ground. The polymeric composition of these products can bring high magnitudes of tensile strength to the system to prevent against slope instabilities and bearing type failures. HSG's are "passive" forms of reinforcement, whereby activation of its capacity occurs whence destabilising forces are applied, causing the reinforcement to undergo tensile strain. The polymeric materials in HSG's undergo creep, i.e. deformation under sustained application of constant tensile loads. The combination of strain-dependent and time-dependent behaviours in HSG's are a complex mix of material characteristics which make them complicated to design with. The complexity of their behaviour has resulted in greatly varying design methods adopted in industry. The source of difference is often linked to how creep is addressed in the selection of HSG, and how its strain-dependent behaviour is accounted for. This paper discusses the design methodologies referred to in BS8006 (Code of Practice for Strengthened/Reinforced Soils and other Fills), which follows a limit state design process to ascertain the design loads to be carried by HSG's and methods on how to assess the design strength of proprietary products. The authors generally support the methodologies adopted in BS8006 with suggestions on limiting criteria and how these can be assessed.

DEEP DRY SOIL MIXING PERFORMANCE AND QUALITY CONTROL ACCEPTANCE CRITERIA

Patrick K. Wong¹ and Richard, B. Kelly²

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² SMEC Pty Ltd, QLD, Australia, DrRichard.Kelly@smec.com

ABSTRACT

The variability in strength and compressibility of in situ deep soil mixing (DSM) of soft soils can be greater than the variability of the natural soil. To achieve economy, sustainability and performance of DSM, it is essential that construction be carried out using an appropriate QA/QC program.

This paper presents the results on the use of DSM columns to support several embankments over soft clay in the Ballina Bypass and Pimlico to Teven Pacific Highway projects. The DSM work was carried out under the Roads and Maritime Services (RMS) Specification, with QA/QC testing procedures developed specifically for these projects. Embankments with contrasting performance are compared to the quality control test results which comprised laboratory testing of core samples as well as in situ test results such as pull-out and push-in vanes and conventional cone penetration tests. Settlement monitoring indicated that good performance is achieved where the acceptance criteria are met. Predicted settlements under embankment loading were generally less than predicted settlements. The observed settlement in an area with high organic content was twice the predicted value, although in all cases, post construction settlement met the performance objectives.

Based on these results, recommendations on QA/QC testing procedures are made with the aim of improving economical and sustainable construction of the DSM ground improvement technique for soft soils.

Determining the Effect of Ground Improvement using Impact Rolling for Varying Site Conditions

Sanjive Narendranathan¹, Simon McBeath², Rusiru Dalugoda³ and Declan McHale⁴

¹Principal Geotechnical Engineer²Geotechnical Engineer, r, ³Team Leader (Consulting), ⁴Team leader (Construction)
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ABSTRACT

Deep compaction techniques have been in use for a number of years. There are a number of deep compaction techniques that can be applied in ground improvement. These range from the traditional drop weight to eccentrically shaped (impact) rollers. It is generally accepted that either of these techniques would affect some degree of ground improvement in non-cohesive soils. The depth of ground improvement would be dependent on a range of factors including mechanical characteristics of the soil i.e. PSD, Atterberg limits and the location of ground water table. To date anyone undertaking deep ground improvement using impact rolling techniques does not have a way of predicatively determining the depth of ground improvement in different soil and ground water conditions. It is the authors' intent to present a series of case studies where deep ground improvement using impact rolling techniques was successfully utilised across a variety of ground and phreatic conditions. The degree of improvement was evaluated in terms of CPT Tip Resistance (Qc), Young's modulus (E) and bearing capacity.

The intent of these case studies is to investigate relationships between the degree of improvement and potential contributing factors including the soil properties, the weight of the impact rolling module used, the number of roller passes and the location of the water table. These relationships are developed for a series of non-cohesive soil conditions specifically well graded sand, uniformly graded sand and crushed limestone, and are presented as nomographs.

These nomographs will provide a guidance to predictively determine the number of passes required to effect ground improvement to a given depth for a particular soils type in various phreatic conditions.

A NEW CALCULATION APPROACH TO DESIGN FLEXIBLE FACING SYSTEM FOR SOIL NAILING

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ABSTRACT

According to the experience of several researchers, under certain conditions the soil nailing facing system can be developed with nails in cooperation with steel mesh (i.e. flexible structural facing). The goal of this system is to improve the slope face stability and allow the vegetation to grow. A simple design approach was introduced a few years ago that analysed the behaviour of the mesh by comparing the maximum volume of debris that can move among the nails to the maximum volume that can be held by the mesh. Even if it took into account the real interaction between mesh and soil, such procedure was quite rudimentary by solving the non-linearity of the load - displacement problem. Recently, a new design approach using forces generated by the soil pushing on the mesh was proposed considering the most unfavourable case between the two wedge analysis and the single wedge, one for slope failure mode (according to the standard BS 1006 – 2010). Concerning the mesh resistance, thanks to the library of load-displacement curves for different mesh types generated by the new UNI 11437 (2012) Standard and to the introduction of the “scale effect” that modifies nail spacing and mesh behaviour accordingly, the new approach overcomes the non-linearity of the problem and allows a more realistic calculation approach.

For sure the methodology is not perfect, but at least it allows appreciating the Ultimate Limit State and the Serviceability Limit State with a simple calculation. This paper analyses the main calculation steps and concepts of this new approach implemented in the new Bios 2 software which is used by Maccaferri for the design of flexible facing of cut and natural slopes.

SHALLOW GROUND IMPROVEMENT FOR A NEW RAIL DEPOT / MAINTENANCE FACILITY IN SYDNEY

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ABSTRACT

A new rail maintenance and stabling facility comprising rail sidings and associated maintenance buildings / facilities is to be constructed in a heavily urbanised area in Sydney, NSW. The site will be on a raised earthworks development platform for flood mitigation purposes.

Ground conditions include variable non-engineered surficial fill over up to 4m thickness of variable density alluvium (dune sands) overlying dense to very dense Botany Sands above deep alluvium to over 40m depth with a shallow groundwater level. Some site areas have been previously loaded by former development.

Identified geotechnical risk relates to potential unacceptable ground surface settlement of the development due to embankment loading of low density variable surface soils against the need to limit total and differential settlement of rail track-slab and building foundations within specified design and operational tolerances for a design life of 75 years.

A ground improvement solution was required to improve these surface soils to reduce the potential for both total and differential settlement under loading from the proposed earthworks and structures. The achievement of differential settlement criteria is critical to the long term performance of the track slab system, particularly at the interfaces with buildings.

This paper describes the site ground conditions, the ground improvement options considered and the selection of high energy impact compaction (HEIC) as the optimal solution for the proposed site development. HEIC trials including performance validation of the ground improvement are described. Site specific Specifications were then developed for HEIC construction phase works. The trials also included noise and vibration monitoring to define construction control limits and buffer zone distances from sensitive adjacent areas including residential properties and a heritage building.

Significant cost savings and construction programme benefits are realised utilising shallow ground improvement methods compared to the other ground improvement options considered.

TREATMENTS OF EXISTING ABUTMENT RSW USING PERMEATION GROUTING AND HORIZONTAL SOIL NAILING

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ABSTRACT

The construction of Bangalow Interchange on the Pacific Highway Upgrade Project was undertaken using a staged approach. All traffic was initially diverted onto the northbound carriageway of the existing Pacific Highway whilst the southbound carriageway was decommissioned and excavated down to a maximum of 6.7m below the existing fill embankment surface. A temporary soil nail retaining wall was required to support the vertical cut face at the median. The temporary wall and the northbound carriageway would be decommissioned after the interchange construction work.

One challenge to the temporary design was the presence of a Reinforced Soil Wall (RSW) at the abutments of the existing twin bridges over Bangalow Road. The proposed temporary wall alignment was to cut through the middle of the RSW block in order to allow the eastern half of the RSW block, along with the southbound bridge, to be removed. The diverted traffic was to travel over the existing northbound bridge, which would be supported by the remaining western half of the RSW block. One further challenge was that the existing RSW abutments were designed to support the bridge sill beams without any pile foundations.

This paper focuses on the design treatment of the existing bridge abutment subjected to partial demolition of the abutment RSW. Initially, the adopted strategy was to inject low pressure permeation grout into the existing RSW block prior to excavation. A grouting trial was conducted, which indicated that because of the presence of the relatively high fines content within the existing RSW, the injected grout was unable to permeate through the RSW fill to form a coalesced grouted mass. An alternative support system using horizontal soil nailing was subsequently adopted through the vertical cut of the abutment RSW. The design of the horizontal soil nails would not only need to satisfy the stability requirements but also require controlling the movements of the RSW to within a tolerable limit. A comparison of the survey monitoring results with the design predictions of the wall movements is outlined.

SOIL STABILIZATION USING LIGNOSULFONATE

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ABSTRACT

Chemical stabilisation of soil using commercial admixtures is a common technique often adopted by industry to improve the behaviour of erodible and unstable deposits such as those forming the subgrade for roads and rail infrastructure. Although traditional alkaline admixtures such as cement, gypsum, lime have been effective in strengthening and stiffening the natural formations of transport and other civil infrastructure, the consequential impact on the soil and groundwater chemistry has been an environmental concern for many years. While being cost-effective, these alkaline and sometimes corrosive admixtures have directly contributed to substantial rise in the soil and groundwater alkalinity (pH about 8-9) apart from the significant reduction in soil porosity (void space) thus adversely affecting the growth and development of certain native vegetation and sub-surface fauna. In contrast, the use of non-toxic lignosulfonates (LS) with much smaller quantities has been reported to achieve similar results without harming the environment.

Lignosulfonate is a soluble dark brown liquid, and it is a by-product of the timber and paper industry. The use of lignosulfonate as a soil stabilizer has significant advantages in relation to traditional admixtures with respect to soil and groundwater environment quality. This is because lignosulfonate is readily diluted in water and causes no pH change in the soil upon treatment. Furthermore, it is also non-corrosive to metals and non-flammable, and classified as non-hazardous. An additional benefit is associated with the reduction of brittle behaviour during shear loading that is well known for alkaline mixtures. This paper showcases a number of applications of LS in controlling erosion and swelling of expansive soil for which the use of lignosulfonate has yielded comparable and in cases superior performance to that of traditional admixtures.

PRELOADING GROUND IMPROVEMENT FOR AN INTERNATIONAL CONTAINER TERMINAL PROJECT AT WEBB DOCK PORT MELBOURNE

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ABSTRACT

In this paper, a case study is presented for preloading ground improvement for an automated stacking container development at Port Melbourne, Victoria, a reclaimed site underlain by high compressible marine clays referred to locally as Coode Island Silt (CIS). The paper has firstly reviewed the site reclamation history, followed by consolidation back analysis using PLAXIS 2D to study the historical settlements associated with the previous reclamation and land use and their effect on the future development with and without the adoption of preloading. A decision was then made to adopt a preloading program that involved the application of up to 5.5 m high compacted earth fill (110 kPa which is equivalent to more than twice of the maximum design load for the containers) for a period of 2 to 3 months, targeting to remove over 40% of the potential total settlement under the container stacking loads. The paper also discusses some of the instrumentation, such as settlement plates and vibrating wire piezometers that was employed to verify the target settlement. The study concluded that the design intention has been achieved by the completed preloading ground improvement program.

EFFECTS OF STONE COLUMN INSTALLATION

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ABSTRACT

Lateral soil displacements caused by stone column installation can be estimated using analytical methods. These analytical methods have been used to assess lateral movements measured during installation of single stone columns and generated by installation of a group of columns. The analytical methods were able to closely match lateral displacements during installation of single stone columns but were less accurate for group installation. Excess pore pressures generated by installation of the group of stone columns was also measured and the peaks could be reasonably approximated using analytical methods. Installation of the group of columns was also simulated using finite element methods. A numerical model based on in-situ and laboratory test data produced similar results to the analytical methods. Refinement of the parameters to better fit the measured data required a four order of magnitude increase in the permeability. It is speculated that such an increase in permeability is created by fracturing of the soft clay during installation of the stone columns. A finite element limit analysis was performed to assess whether the soft clay would be squeezed into the columns. The results of the assessment suggest that it is unlikely that the soft clay would penetrate further than about 2 rows of stone particles.

GROUND CONTROL FOR A DEEP BASEMENT EXCAVATION IN SYDNEY'S GPO FAULT ZONE

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ABSTRACT

The use of the underground space in major cities often involves complex systems with significant interaction between new excavations and existing structures such as buildings, services and tunnels. Such a complexity significantly increases when excavating in poor quality or unstable rock masses. Such ground conditions can be found in a fault zone or areas with high locked-in horizontal stress, both commonly observed in Sydney. This paper presents the geotechnical design challenges and construction outcomes of a deep excavation for a 38-storey mixed-use tower with 3 basement levels in the Sydney CBD. The challenges included excavating in the immediate vicinity of heritage listed buildings and rail tunnels built circa 1930. Two distinct excavation zones were inferred during the geotechnical site investigation, including both poor rock mass related to the GPO fault zone and good quality sandstone. An additional challenge was imposed by a 14 m deep excavation of a vehicle lift shaft with unsupported horizontal spans of 10 m, i.e. without internal support such as anchors or struts. Details of the design approaches and methods of analysis are discussed. These included a 3-Dimensional (3D) finite element (FE) analysis for prediction of ground movements and impact assessment. A structural frame model was used to simulate the effects of waler beams in 3D, hence it could be used as an input in the 2-Dimensional (2D) finite element model of the excavation. Finite Element Limit Analysis (upper and lower bound theory) was also adopted to estimate global factors of safety. A comparison between Class A predictions of ground movements developed during design and impact assessment stages and onsite measurements taken during and after excavation will be discussed. These include field data from two inclinometers, one horizontal extensometer installed in the vicinity of the rail tunnels and survey targets around the perimeter of the excavation. Photos taken during construction are presented to illustrate the challenges and successful outcome. These include some snapshots of the GPO fault zone, completed excavation with multiple ground support and ground control measures.

A CASE STUDY OF DEEP EXCAVATION AND SHORING DESIGN FOR SYDNEY METRO NORTHWEST

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ABSTRACT

This paper will provide a project overview of the Sydney Metro Northwest (formerly the North West Rail Link) project and the underground station excavation retention design and construction works, including the key requirements set out in the scope of works and technical criteria (SWTC). Based on the assessment of the geological conditions a soldier piled wall shoring system was adopted for all five new underground stations and one of the two services facility shafts for ease and speed of construction. During the Castle Hill Station excavation a new planar wedge instability mechanism was considered to be credible based on the additional geological data, with the original three-dimensional block instability being no longer suitable. This led to redesign of the south wall stabilisation works based on the updated geological model and input parameters. The instrumentation and monitoring plan was also adjusted to ensure the required additional support provided would be adequate for the safety of the station box excavation. The monitored lateral movements at the capping beam and at the inclinometers were within the trigger values, indicating that the retention system constructed was robust.

AN INNOVATIVE GEOTECHNICAL MONITORING SYSTEM FOR SOFT GROUND TREATMENT ON W2B PACIFIC HIGHWAY UPGRADE PROJECT

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ABSTRACT

This paper presents an innovative geotechnical monitoring system for soft ground treatment for the on-going Woolgoolga to Ballina (W2B) Pacific Highway Upgrade project. This \$4.3 billion project is Australia's largest regional infrastructure project and will upgrade about 155 kilometers of highway to four lane, divided road. The project starts about six kilometers north of Woolgoolga (north of Coffs Harbour) and ends approximately six kilometers south of Ballina.

One of the major challenges on this project is the construction of road and structures over soft compressible ground with a total length of over 25 kilometers in 1 to 2 years' time. During construction, the short term slope stability and settlement performance will be monitored by a total of 1500 instruments taking up to 10 million measurements. This will enable the team to take early preventive actions to maintain slope stability, to protect public safety and existing structures during construction, and to ensure that the projected long term settlement is within acceptable limits.

Following the standard file based approach, the instrumentation data was estimated to produce up to 80,000 files to be manually handled. To efficiently process the data, limit the potential for manual errors and reduce the turnaround time, Pacific Complete developed an instrumentation and monitoring (I&M) system using its project integration platform, automatically warehousing the data on the project servers and presenting real time dashboard to the team using Qlik Sense and its GIS extension. In addition to providing high availability, transparency and reliability of the information, this system is expected to realize savings of \$2.5M in manual handling of the information alone. The system can be progressively extended to support direct data download from automated instruments, more instrument types, single and multiple instruments alerts, and refined graphs to suit the requirements of linear infrastructure geotechnical monitoring.

Compared to the traditional copy and paste method using Excel, the benefits of this I&M system include fast processing of massive data on a daily basis, automatic integration with GIS maps, chainage, instrument type and locations, lateral displacement plots, settlement plots (both predicted and measured) in longitudinal sections, ratios of lateral to vertical displacement and fill height plots, pore pressure plots and existing road/structure movement plots.

CONSOLIDATION AND CREEP OF SOFT ESTUARINE CLAY IN NEWCASTLE

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ABSTRACT

Soil mixing and other intrusive ground improvement techniques are often go-to solutions for problematic soft soils. However, it is very much worthwhile to undertake detailed project specific studies and use advanced constitutive soil models to demonstrate that expensive ground improvement techniques are not always required. This paper looks at a case study where the Soft Soil Creep model was used in Plaxis to simulate the soft Estuarine Clay found at Kooragang Island, Newcastle and prove that deep soil mixing is not necessary for a rail embankment design. A review of field/laboratory tests and back analysis of field monitoring data from a trial embankment were undertaken to derive design parameters of the Estuarine Clay and understand its consolidation and creep behaviour. Site history and aging of the Estuarine Clay were then modelled using Soft Soil Creep model in Plaxis, which allows calibration of the stress state conditions at present time with field conditions. The calculated soil strength profile and past ground movements were able to be correlated with available data including cone penetration tests, shear vanes, inclinometer and extensometer readings. Predictions from the Soft Soil Creep model demonstrate a more sensible representation of current site conditions compared with using basic soil models. This realistic design approach assures confident in optimising the rail embankment design, which brings massive savings on construction costs from eliminating the need for deep soil mixing. The use of an appropriate advanced constitutive soil model, combined with a rigorous study of site specific data, has proven to reduce conservatism in design and substantially benefit real projects.

MECHANICAL STABILIZATION OF UNBOUND LAYERS: EFFECT OF GEOGRIDS ON LOW STRAIN BEHAVIOUR OF GRANULAR MATERIALS AND ESSENTIAL CHARACTERISTICS FOR OPTIMUM PERFORMANCE IN PERMANENT ROADS

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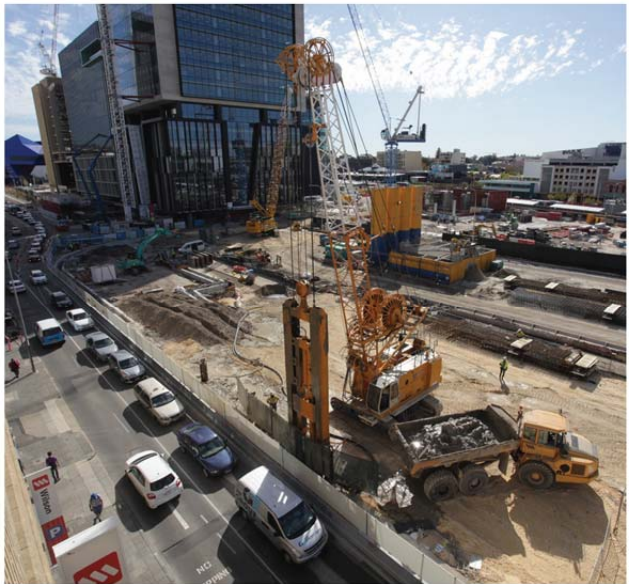
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ABSTRACT

The use of geogrids in mechanically stabilized earth (MSE) structures and for trafficked areas over soft soils is well known. The essential characteristics of geogrids for MSE have well established over many years and are incorporated into national and international codes and standards. However, the mechanisms by which geogrids function in permanent roads and therefore the essential characteristics of geogrids operating at low strains in this application have often been disputed. This paper will present results from several recent research projects that identify the stabilization mechanisms that operate and identifies essential characteristics for geogrids in this function. A comparison is made between the stabilization function of geogrids and tensioned membrane reinforcement function of geogrids and the significance of this functional difference in the selection of essential geogrid characteristics for specification purposes. Such an understanding is essential if specifications are to protect designs that utilise the benefits of mechanical stabilization to increase pavement life.



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