Advances in Transportation Geotechnics II

Editors: Seiichi Miura, Tatsuya Ishikawa, Nobuyuki Yoshida, Yoshio Hisari & Nagato Abe

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Advances in Transportation Geotechnics II

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Preface

The International Conference on Transportation Geotechnics (ICTG) was first held at the University of Nottingham in 2008 which had been selected as host by the International Technical Committee ISSMGE-TC 3 “Geotechnics of Pavements” of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The conference was a great success and significantly promoted co-operation and exchanges of information and knowledge concerning the geotechnical aspects of the design, construction, maintenance and monitoring of pavements and related transportation infrastructure.

The 2nd ICTG is being organized, under the auspices of the ISSMGE, by the local organizing committee composed of the Hokkaido Branch and the TC202 national committee of the Japanese Geotechnical Society (JGS), in association with the International Technical committee ISSMGE-TC202 “Transportation Geotechnics” of the ISSMGE.

The 2nd ICTG aims at contributing to creating new academic frameworks called Transportation Geotechnics which works more on practical issues such as design, construction and maintenance management of transportation infrastructure like roads, railways, and airfields. Also, it targets to deepen international relations through interaction and direct talks among leading researchers and technical experts by presenting their latest research achievements and exchanging their views.

Moreover, special sessions to discuss some issues essential for further development of transportation geotechnics (e.g. unsaturated soils, frost geotechnics, advanced laboratory testing) will be offered in close liaison with ISSMGE-TC101 (Laboratory Stress-Strain Strength Testing of Geomaterials), ISSMGE-TC106 (Unsaturated Soils), and ISSMGE-TC216 (Frost Geotechnics) of the ISSMGE, in addition to the topics addressed by the 1st ICTG.

This book contains 5 invited keynote lectures by 7 outstanding experts in the field and 140 contributed papers from 30 countries. The papers are divided into 11 specific topics:

1. Geotechnics for Pavement, Rail Track and Airfield
2. Geomaterial, including Nontraditional Materials
3. Asphalt Mixtures and Hydraulically-bound Materials
4. Earthworks for Transportation Facilities
5. Application of Geosynthetics
6. Laboratory Testing and In-situ Testing
7. Modeling and Numerical Simulations
8. Design, Construction and Maintenance
9. Performance Evaluation and Quality Control
10. Sustainability of Management and Rehabilitation
11. Risk Assessment and Environmental Issues

It is our earnest hope that as many as participants as possible, especially both young researchers and students join this conference so as to enhance their interests in Transportation Geotechnics and broaden their perspectives.

Besides, this conference is supported by a grant from the Ministry of Education, Culture, Sports, Science and Technology in Japan.

We would like to extend our sincere gratitude to all contributors for their high quality papers. The conference would not have been possible without the dedicated work of the organizing committee and many members of the international advisory board.

Lastly, we express our special thanks to invited speakers, authors of the precious and valuable contribution to the 2nd ICTG, the president of Hokkaido University, the president of JGS, the ISSMGE-TC202 members and other related TC members, and also to Prof. António Gomes Correia. We wish all the participants a fruitful and successful conference and a comfortable and enjoyable stay in Sapporo.

Seiichi Miura
Chairperson of 2nd ICTG

Tatsuya Ishikawa
Secretary General of 2nd ICTG

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Welcome address

WELCOME ADDRESS OF ISSMGE-TC 202 TRANSPORTATION GEOTECHNICS

On behalf of the International Technical committee ISSMGE-TC 202 "Transportation Geotechnics" of the Inter-national Society for Soil Mechanics and Geotechnical Engineering (ISSMGE), I welcome you to the 2nd Inter-national Conference on Transportation Geotechnics, here in Sapporo, Japan.

As background, ISSMGE-TC 202 (2009–2013) was preceded by the International Technical Committee ISSMGE-TC 3 "Geotechnics of Pavements", which was founded in 2001 by a proposal of the 2001–2005 ISSMGE Board. ISSMGE-TC 3 followed the previous activities of the European Technical Committee ETC 11 (1997–2001).

The Transportation Geotechnics Conference series began under the auspices of ISSMGE-TC 3 and was initiated in 2008 at the University of Nottingham, UK, as an International event designed to address the growing requirements of infrastructure for societies. The challenges addressed by this conference include obtaining a betterunderstanding of the interactions of roads, rails, airports and other ground transportation infrastructure with the goal of providing safe, economic, environmental and reliable infrastructure. Other topics included not only the design of new infrastructure but also the management and maintenance of aging assets in the face of issues such as climate change. This first event was a worldwide affair that included over 140 participants from more than 26 countries. The proceedings contain 100 reviewed papers and were published by CRC Press Taylors & Francis/A.Balkema. To continue the successful output of ISSMGE-TC 3, the 2ndInternational Conference on Transportation Geotechnicswas scheduled for 2012, at Sapporo, Japan, in recognition of the important work conducted by the TC 3 national committee of the Japanese Geotechnical Society. This conference became a component of one of the task forces of the terms of reference of ISSMGE-TC 202 (formerly known as TC 3) during the 2009–2013 term of the ISSMGE presidency of Prof. Jean-Louis Briaud.

In accordance with the goals of ISSMGE – TOC (Technical Oversight Committee), the 2nd International Conference on Transportation Geotechnics intends to promoteinteraction between academicians, researchers and practitioners, facing the development of improved solutions that apply research findings in a practical manner. The organisation is under the auspices of the ISSMGE and carried out by the Hokkaido Branch and the TC 202 national committee of the Japanese Geotechnical Society in association with ISSMGE-TC 202. The interactionsamong ISSMGE-TC 202 and other overlapping TCs working in fields related to transportation geotechnics have been established by its liaisons with ISSMGE-TC 101 (Laboratory Stress Strength Testing of Geomaterials), ISSMGE-TC 106 (Unsaturated Soils) and ISSMGE-TC 216 (Frost Geotechnics) of the ISSMGE and also with the International Geosynthetics Society (IGS). Furthermore, the support of IGS, Geo-Institute of ASCE and Transportation Research Boarding for this Conference is also very much recognized and appreciated. All these participations enlarge the goals of this conference covering not only the themes of the ISSMGE-TC 202 task forces planned for 2009–2013, but also with significance the themes of asphalt mixtures and hydraulically bound materials, laboratory testing and in situ testing, applications of geosynthetics, sustainability of management and rehabilitation and risk assessment and environmental issues. Furthermore, more specific topics are covered by three workshops devoted to: (1) Intelligent Compaction, (2) Challenges in Transportation Geotechnics in Extreme Climates and (3) Geotechnical Challenges in Rail Track and its Transitional Zones.

Continuing our tradition in international conferences, twospecial lectures and five keynote lectures are presented by invited speakers who hold leading academic and research positions. These lectures are designed to highlightthe major scientific and technological development trends, challenges and roadmaps in transportation geotechnics. In addition, several technical sessions are provided to address future development trends associated with the topics of this conference, as well as a special session to present the main advances of the task forces of ISSMGE-TC 202.

On behalf of ISSMGE-TC 202, I wish to express my appreciation to the organising committee for the substantial efforts that they have madeto provide the high-quality programme and documentation of this conference, which covers all major up-to-date topics and includes 140 technical papers, divided among11specific themes. These contributions represent an excellent source of state-of-the-art developments that enhance the wider application of geotechnics in design, construction, maintenance, rehabilitation, management, risk assessment and environmental related issues of pavements and railways. This material, along with the presentations and discussions at the Conference, will provide a worthy contribution in Transportation Geotechnics for the Society which is the fundamental aim of ISSMGE-TC 202. This material will be also a great support to accomplish the work planned in the TC 202 terms of reference (2009–2013), mainly to make guidelines and recommendations for practice, which will be prepared for the occasion of the 18th International Conference for Soil Mechanics and Geotechnical Engineering in Paris, France, September 2–5, 2013.

I should also state that the job of being chairman is not always easy, but in the case of theproduction of ISSMGE-TC 202, it has been a privilege and a pleasure to work with sucha dedicated team. I should highlight the ISSMGE-TC 202 members contributing to this Conference, listed below, and extend my appreciation also to the keynote speakers, authors and co-authors and all other persons that directly or indirectly make also a contribution. In particular I would like to convey my deepest gratitude to the organizing committee, especially toProf. Seiichi Miura, chairman, and to Dr. Tatsuya Ishikawa, secretary general, for their hard work to ensure the success of this conference. I wish all the participants a fruitful and successful conference and stay in Sapporo.

Prof. António Gomes Correia
Chair of ISSMGE-TC 202 (2009–2013)
Sapporo, Japan
10th September 2012

ISSMGE–TC 202 MEMBERS WITH WRITTEN CONTRIBUTIONS TO THE 2ND INTERNATIONAL CONFERENCE ON TRANSPORTATION GEOTECHNICS, SEPTEMBER 10–12, 2012.

Andreas Loizos (GR)
António Gomes Correia (PT)
Buddhima Indraratna (AU)
Carlo G. Lai (IT)
Donald Cameron (AU)
Eduardo Fortunato (PT)
Erol Tutumluer (USA)
Jean-Pierre Magnan (FR)
Marc Raithel (DE)
Nobuyuki Yoshida (JP)
Soheil Nazarian (USA)
Vikas Thakur (NO)

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Dr. Nobuyuki Yoshida (Co-Chair)
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Dr. Tatsuya Ishikawa (Secretary General)
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1 *Invited lectures*

1.1 *Special lectures*

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Trends and challenges in earthworks for transportation infrastructures

Prof. António Gomes Correia
C-TAC—Centre of Territory, Environment and Construction, University of Minho, Paris, France

Graduated in Civil Engineering from the Technical University of Lisbon—IST in 1977, and received a Doctor-Engineer Degree by "Ecole Nationale des Ponts et Chaussées"—Paris in 1985.

In 1987 he gained the specialist degree at the National Laboratory of Civil Engineering (LNEC), distinguished with Manuel Rocha Award.

In 2001 he gets the degree of specialist in Geotechnique attributed by the Portuguese Association of Engineers.

In 1998, he created the Geotechnical Research Centre at the Technical University of Lisbon—IST and it was its President until 2000.

Prof. Correia is since 2003 Full Professor at the University of Minho and from 2003 to 2007 he was Director of the Civil Engineering Research Centre at the University of Minho, and from 2004 to 2008 President of the Geotechnical Portuguese Society. He is from 2010 Director of the Research Centre of Territory, Environment and Construction. He is also from 2010 chair of the Doctoral program in Civil Engineering.

Prof. Correia was Vice-Chairman of COST 337—Unbound Granular Materials for Road Pavements, member of CEN TC227/WG4/TG2 on test methods for Unbound Granular Materials and a was also a member of COST 348—Reinforcement of Pavements with Steel Meshes and Geosynthetics.

Prof. Correia was from 1998 to 2001 Chairman of the ISSMGE—European Technical Committee—ETC 11—Geotechnical aspects in design and construction of pavements and rail track and from 2001 chairman of the International Technical Committee—TC 3—Geotechnics for pavements of the ISSMGE, renamed from 2009 as TC 202—Transportation Geotechnics.

Prof. Correia is involved in research, teaching and consulting in the general field of geotechnics and pavement engineering for 34 years. His work embraced transportation geotechnics, particularly soil and pavement geo-material properties, compaction and geotechnical and pavement modelling and design. He has over 330 technical papers published on these subjects.

Prof. Jean-Pierre Magnan
IFSTTAR, Paris, France

Graduated from "École Polytechnique" (Paris) in 1971 and from "École Nationale des Ponts et Chaussées" (Paris) in 1973 and received a Docteur-ès-Sciences Degree from University Pierre et Marie Curie (Paris) in 1984.

Prof. Magnan is Head of the Geotechnical Engineering, Environment and Risks Department of the French Institute of Science and Technology for Transport, Development and Networks (IFSTTAR), former Laboratoire Central des Ponts et Chaussées (LCPC), and Professor of Soil and Rock Mechanics at the École Nationale des Ponts et Chaussées.

Prof. Magnan is a member of CEN TC 250/SC7 (Eurocode 7), CEN TC 341 (Geotechnical Investigation and Testing), CEN TC 288 (Execution of Geotechnical Works) and CEN TC 396 (Earthworks) and chairman of the French Coordination Committee for Sandardisation in Geotechnical Engineering.

Prof. Magnan is involved in research, teaching and consulting in the general field of geotechnical engineering, in particular earth structures, natural risks, soil-structure interaction, soft or swelling soils, site investigations, modelling and design. He has over 300 technical papers published on these subjects.

ABSTRACT

The work of ISSMGE and particularly of the technical committees related with transportation geotechnics has been particularly attentive to industry issues affecting the design, construction, and management of transport infrastructures. These issues represents a major step forward in increase life-time and serviceability of transport infrastructures (roads, railways and airports) that is essential to reduce maintenance and consequently save costs and contribute for the quality of life. A major concern affecting these aspects is the earthworks that may represent up to 30% or even 40% of the construction costs. In this context, the challenge ahead of geotechnical transportation engineering is to ensure key quality measurements for all products and apply sustainable practices in using materials at construction sites. These aspects will be covered in this lecture through research and practical examples and demonstration projects.

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Mechanical behavior and earthquake-induced failures of volcanic soils in Japan

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Laboratory of Analytical Geomechanics
Div. of Environmental Field Eng.
Hokkaido University, Japan

Dr. Seiichi Miura is professor in the Faculty of Engineering, Hokkaido University.

He was born in Hokkaido, Japan where he obtained bachelors and masters degrees from Hokkaido University. After earning his Ph.D. in geotechnical engineering in 1984, he taught and was on the faculty of engineering at the Muroran Institute of Technology as associate professor and professor before returning to Hokkaido University in 1998.

Professor Miura has been involved in research in many areas such as laboratory testing method for the practical development of granular mechanics, soil liquefaction, slope stability, mechanical behavior of problematic ground (volcanic soil), and many others in geotechnical and earthquake engineering areas. He is the author or co-author of more than 350 published technical papers in journals and proceedings in these fields.

Prof. Miura received the Japan Geotechnical Society (JGS) Award in 1985 and 2010 for the study on stress-strain-strength anisotropy of sands and the design method of pile foundation constructed in composite ground, respectively. He has been currently immersed in a research on stability evaluation of slope and embankment subjected to rainfall and freeze-thaw actions based on field monitoring. Recent activities of academic society were the leader for JGS committee for ground damages induced by the 2003 Tokachioki Earthquake and the social action work for the various damages due to the Tohoku Pacific Earthquake (2011) as the vice president of Japan Society of Civil Engineers (JSCE).

ABSTRACT

This summarized the earthquake-induced damages and mechanical properties of volcanic soils, especially volcanic coarse-grained soils and volcanic ash soils distributed over Japan. Site investigations were conducted at various volcanic soil grounds of Japan. In addition to these in-situ tests, a series of laboratory tests on undisturbed and disturbed samples was also carried out to obtain the mechanical properties which are necessary to establish a seismic design standard for volcanic grounds. From the results of static triaxial compression test, plane strain compression test and cyclic undrained triaxial test on volcanic soils, it was understood that the effect of particle crushing on the cyclic and static strength–deformation behaviors of volcanic coarse-grained soils could not be ignored. Furthermore, particle breakage, cementation and sedimentary environment and their effects on the correlation between the sounding data and deformation-strength parameters evaluated from laboratory tests were also discussed.

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1.2 *Keynote lectures*

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Bituminous mixtures: From thermo-mechanical properties of components to structure calculation

Prof. Hervé Di Benedetto
University of Lyon, ENTPE, DGCB & LTDS (CNRS 5513), Lyon, France

Prof. Hervé Di Benedetto received his Diploma of Civil Engineer from the "Ecole Nationale des TPE" (ENTPE) in 1979. He is Doctor of Engineering in Soil Mechanics (1981) and "Docteur ès-Sciences" (1987), both from the University of Grenoble, France.

Prof. Di Benedetto's research focuses on the study of mechanical, thermo-mechanical and structural behaviour of geomaterials, including experimental and modelling aspects. He is working in the fields of soils mechanics and road engineering. He has been the supervisor of more than 40 PhD students and of a large volume of research works in collaboration with various private and public partners. He is author of more than 160 publications. He is the present Chair of TC 101 "Laboratory testing" of the International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE), first vice Chair of the International Society of Asphalt Pavements (ISAP) and Editor-in-Chief of the International Journal "Road Materials and Pavement Design".

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Soil suction measurements in highway subgrades

Prof. Delwyn G. Fredlund
Golder Associates Ltd, Saskatoon, SK., Canada

Quan Nguyen
Klohn Crippen Berger Ltd, Brisbane, QLD, Australia

Delwyn G. Fredlund has spent over 40 years conducting research into the behavior of unsaturated and expansive soils. Most of his career was spent at the University of Saskatchewan, Saskatoon, where he organized the Unsaturated Soils Group for research into all aspects of unsaturated soils behavior. Presently Del heads the Golder Unsaturated Soils Group linking the worldwide offices of Golder Associates. His research studies have involved all areas of unsaturated soil behavior; ranging from the flow of water and air through unsaturated soils to the shear strength and volume change of unsaturated soils.

Del Fredlund obtained his B.Sc. degree from the University of Saskatchewan, Saskatoon in 1962. He went to work for the Division of Building Research of the National Research Council in Saskatoon, Sask. He then went on to obtain his M.Sc. degree in 1964 from the University of Alberta, Edmonton.

In 1966 Del Fredlund accepted a position in the Department of Civil Engineering at the University of Saskatchewan, Saskatoon, Canada. In 1973 he obtained his Ph.D. after returning to the University of Alberta for his studies. During his career he supervised over 75 M.Sc. and Ph.D. graduate students. He became the Head of the Department of Civil Engineering at the University of Saskatchewan from 1989 to 1994. He has also been appointed as an Adjunct Professor at a number of national and international universities.

Dr. Fredlund's research studies have focused on unsaturated soil mechanics and the behaviour of unsaturated soils. He is the author, along with Dr. Harianto Rahardjo, of the book "Soil Mechanics for Unsaturated Soils", published by John Wiley & Sons in 1993. Dr. Fredlund published approximately 500 journal and conference research papers and has delivered many keynote lectures at conferences

Dr. Fredlund has been the recipient of numerous awards, among them the:
Prime of Life Achievement Award, University of Saskatchewan, September 2011
C.W. Lovell Lecture, 2009, Purdue University, Lafayette, Indiana.
Quigley Award, 2009, for the best paper published in the Canadian Geotechnical Journal in 2008.
Julian Smith Award for lifelong contribution to the engineering profession in Canada, 2009.
Zen Guo Xi Lecturer, 2007, Zhejiang University, Hangzhou, China.
T.H. Wu Lecturer, 2007, Ohio State University.
Order of Canada, 2004, from the Federal Government of Canada for his significant contribution to Canada and other countries around the world
Commemorative Medal for the Centennial of Saskatchewan, 2005
Terzaghi Award, 2005, given by the American Society for Civil Engineering
Dr. Fredlund has undertaken international programs of collaboration with countries such as China, Africa and Vietnam. He is also a member of the Canadian Academy of Engineering.
Presently, the primary focus of Dr. Fredlund's work involves bringing unsaturated soil mechanics into routine geotechnical engineering practice.

ABSTRACT

The performance of rural highways in Saskatchewan, Canada, constructed of a thin pavement structure is largely controlled by the strength of subgrade soil. The subgrade of these highways consists of compacted unsaturated soil and its strength is a function of net normal stress and soil suction. In situ soil suctions can be measured using indirect technologies such as thermal conductivity suction, (TCS), sensors. Thirty-two thermal conductivity sensors were installed under Thin Membrane Surfaces, (TMS), at two

highway locations in southern Saskatchewan, Canada. Soil suctions have been monitored at these sites for more than 10 years. The soil suction readings in the field showed a response to rainfall conditions at the test sites. Changes in soil suction on the shoulder of the road appeared to be mainly due to run-off and infiltration. Relatively constant equilibrium suctions were encountered below the pavement. Suction changes throughout the year were similar from one year to the next. The thermal conductivity TCS sensors performed well under harsh weather conditions including freeze-thaw conditions. An understanding of the soil suction and temperature change behavior of the subgrade throughout the year was obtained from the data.

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Performance evaluation of shock mats and synthetic grids in the improvement of rail ballast

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University of Wollongong, New South Wales, Australia
FTSE, FIEAust, FASCE, FGS, CEng, CPEng, DIC.

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University of Wollongong, Wollongong City, Australia.

Prof. Buddhima Indraratna is a graduate in Civil Engineering from Imperial College, University of London, and completed his PhD in Geotechnical Engineering at University of Alberta, Canada. Having worked in Civil Engineering Industry for a number of years, he decided to join academia. Currently he is Professor of Civil Engineering at University of Wollongong, Australia, and Research Director of the Centre for Geomechanics and Railway Engineering. Prof. Indraratna has been an active geotechnical consultant and a UNDP expert for various geotechnical projects in both Australia and overseas.

Prof. Indraratna was a recipient of Swedish Geotechnical Society award in 1999, Robert Quigley Honourable award from the Canadian Geotechnical Society in 2007 and IACMAG Excellent Contributions Award in 2008.

In 2009, Prof. Indraratna was honoured by the Business and Higher Education Round Table award for Outstanding Contributions to Rail Innovations by the Australian Commonwealth Government. In 2010, he delivered the E.H. Davis Memorial Lecture of the Australian Geomechanics Society for his distinguished contributions from Theory to Practice in Geotechnical Engineering. In 2011, he was awarded the prestigious Transport Medal by Engineers Australia for his contributions to transport infrastructure engineering.

Prof. Indraratna has been a Keynote Speaker and Invited Guest Lecturer at over 30 international conferences. He has published over 400 articles in refereed journals and conferences, and is the author of 5 books. He has supervised about 40 PhD students and 20 Postdoctoral Fellows in his career thus far.

Prof. Indraratna is a Fellow of the Australian Academy of Technological Sciences and Engineering, Fellow of Institution of Engineers Australia, Fellow of American Society of Civil Engineers and Fellow of the Geological Society, United Kingdom.

ABSTRACT

In Australia, railways offer the most prominent transportation mode in terms of traffic tonnage serving the needs of bulk freight and passenger movement. Ballast is an essential constituent of conventional rail infrastructure governing track stability and performance. However, in recent time, high traffic induced stresses due to dramatically increased train speeds and heavier axle loads cause excessive plastic deformations and degradation of ballast. This seriously hampers safety and efficiency of express tracks, for instance, enforcing speed restrictions and effecting more frequent track maintenance. The problem becomes severe under impact loading because it accelerates ballast breakage. Therefore, understanding the complex mechanisms involved with the transfer of impact loads on the substructure and their effect on ballast breakage and degradation are essential for predicting the desirable track maintenance cycle as

well as improving new track design. The measurement of track settlement is well established practice in conventional track monitoring systems, however, it is also important to monitor lateral deformations (parallel to sleepers) that affect track stability especially in the absence of sufficient confinement. Therefore, a field trial was conducted on a section of rail track in the town of Bulli (north of Wollongong City) to measure deformations and cyclic stresses. It was demonstrated that in the case of wheel flats, extremely high stresses would be transmitted to the ballast bed. Installing layers of synthetic materials such as rubber pads (shock mats) in rail tracks can lead to the attenuation of high impact forces and thereby mitigate ballast degradation. In order to evaluate the effectiveness of shock mats, a series of laboratory tests using a high capacity drop-weight impact testing equipment was carried out. The field trial further proved that the moderately-graded recycled ballast when used with a geocomposite layer was found to perform better in comparison to traditionally utilized highly uniform fresh ballast, with clear implications on reduced track maintenance costs and longevity. The results of large-scale direct shear tests also revealed that the appropriate application of geogrids significantly improved the performance of ballast. This keynote paper describes in detail, the results of large-scale laboratory testing of ballast and the observations from a full-scale instrumented field trial characterising the behaviour of rail ballast improved by shock mats and synthetic grids.

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GRS structures recently developed and constructed for railways and roads in Japan

Prof. Fumio Tatsuoka
Tokyo University of Science, Tokyo, Japan

Major academic experiences:

2004 to date: Professor of Geotechnical Engineering, Department of Civil Engineering, Tokyo University of Science

1973–2004: Associate Professor and Professor of Geotechnical Engineering, University of Tokyo

M. Tateyama
Railway Technical Research Institute, Tokyo, Japan

J. Koseki
Institute of Industrial Science, University of Tokyo, Tokyo, Japan

Research Interests:

a) Laboratory testing methods for geomaterials, including clays, sands, gravels and soft rocks
b) Deformation and strength characteristics, including rate effects, of geomaterials
c) Foundation engineering, including bearing capacity of shallow foundations
d) Ground improvement by cement-mixing and soil reinforcing with geosynthetics.

Major Society activities (in the past):

1. Secretary of the Japanese Geotechnical Society (1988–1993)
2. Editor in Chief; "Soils and Foundations", the Journal of the Japanese Geotechnical Society (1995–1999)
3. Editor in Chief; "Journal of the Japanese Society for Civil Engineers, Geotechnical Engineering Division" (1999–2001)
4. Chairperson, ISSMGE Technical Committee 29 on Laboratory stress-strain tests on geomaterial (1994–2001)
5. Vice President for the Asia Region of the International Society for Soil Mechanics and Foundation Engineering (2001–2005)
6. Vice President of the Japanese Geotechnical Society (2001–2002)
7. Vice President of the Japanese Society for Civil Engineers (2005–2006)
8. Chairman of the IGS Japanese Chapter (1997–2006)
9. Vice President of the International Geosynthetics Society (2002–2006)
10. President of the Japanese Geotechnical Society (2007–2008)
11. President of the International Geosynthetics Society (2006–2010)

Technical papers:
More than 450 technical papers have been published in "Soils and Foundations", "Geotechnical Testing Journal", "Géotechnique", "Journal of Geotechnical and Environment Engineering", "Ground Improvement Journal", "Geosynthetics International", "Geotextiles and Geomembranes" and other publications.

ABSTRACT

The construction of permanent geosynthetic-reinforced soil (GRS) retaining walls (RWs) with a staged-constructed full-height rigid facing for railways, including high-speed train lines, roads and others started about twenty five years ago in Japan. The total wall length is now more than 130 km, replacing conventional gravity-type or cantilever steel-reinforced concrete (RC) RWs and steel-reinforced soil RWs. Many were also constructed to reconstruct conventional type RWs and embankments that collapsed during recent earthquakes, heavy rains, floods and storms. It is proposed to construct GRS coastal dykes with lightly steel-reinforced concrete facings connected to geosynthetic reinforcement layers as tsunami barriers. By taking advantage of this GRS RW technology, a number of bridge abutments comprising geosynthetic-reinforced backfill were developed. The latest version for new construction, the GRS integral bridge, comprises a continuous girder integrated to a pair of RC facing, not using bearings, while the backfill is reinforced with geosynthetic reinforcement layers connected to the facings. Its high cost-effectiveness with a very high seismic stability is described. The first prototype was constructed 2011 for a new high-speed train line. It is proposed to construct GRS integral bridges and GR approach fills to restore conventional type bridges that collapsed by tsunami of the 2011 Great East Japan Earthquake Disaster and also to newly construct many for new high-speed train lines. Based on the GRS integral bridge technology, a new method to reinforce existing old conventional type bridges was developed; the backfill is stabilized by large-diameter nails connected to the abutments and then the girder is integrated to the abutments: i.e., nail-reinforced soil (NRS) integrated bridges.

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Sustainable pavement construction utilizing engineered unbound aggregate layers

Prof. Erol Tutumluer
Paul F. Kent Endowed Faculty Scholar
Director of International Programs
Department of Civil and Environmental Engineering
University of Illinois at Urbana-Champaign, Champaign, Illinois, US

Erol Tutumluer holds a B.S. (Bogazici University 1989), two M.S. degrees (Duke University 1991 and Georgia Tech 1993), and a Ph.D. (Georgia Tech 1995), all in civil engineering. Dr. Tutumluer is a transportation/geotechnical engineering professor and Paul F. Kent Endowed Faculty Scholar of Civil and Environmental Engineering (CEE) at the University of Illinois at Urbana-Champaign (UIUC). Professor Tutumluer has taught graduate and undergraduate courses in transportation soils engineering, subgrade soil and aggregate behavior and stabilization, introduction to transportation engineering, pavement analysis and design, and airport facilities design at the University of Illinois since 1996.

Dr. Tutumluer has research interests and expertise in transportation geotechnics, specifically testing and modeling of pavement and railroad track geo-materials, i.e., base/ballast unbound aggregates; recycled aggregates and their unbound applications, shape, texture, angularity characterization of aggregates using imaging and laser techniques, use of geosynthetics in pavements/railroad track, modeling of particulate media using discrete and finite element methods, artificial intelligence in the form of neural network modeling, mechanistic based pavement design, and nondestructive pavement evaluation. He has authored and co-authored over 190 technical papers in these areas.

Dr. Tutumluer is currently the Chair of the ASCE Geo-Institute's Pavements Committee. As an active affiliate of Transportation Research Board (TRB), Dr. Tutumluer was the 2000 recipient of the TRB's Fred Burgraff award for Excellence in Transportation Research and more recently, he was the 2009 recipient of the TRB's Geology and Properties of Earth Materials Section best paper award for his paper on nondestructive evaluation of constructed unbound aggregate layers. Dr. Tutumluer is currently the Chair of the AFP70 Mineral Aggregates TRB Committee.

Dr. Tutumluer is an Associate Editor of the ASCE Journal of Computing and International Journal of Pavement Research and Technology. In addition, he currently serves on the Editorial Boards for the ASCE International Journal of Geomechanics and the International Journal of Pavement Engineering (Taylor and Francis Group). Recently, Dr. Tutumluer served as the Conference Chair and Proceedings Co-editor of the 8th International Conference on the Bearing Capacity of Roads, Railways and Airfields (BCR2A'09) which was held at UIUC on June 29-July 2, 2009 (http://www.BCR2A.org).

2 *Geotechnics for pavement, rail track and airfield*

2.1 *Pavement*

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Characterization of highly compressible marine clay for road foundation

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ABSTRACT

Soft clay soils are commonly found in many parts of the world. Low permeable problematic soils are distributed across the world as expansive soils, dispersive soils, highly compressible clays, marine clays, sensitive clays, quick clays, saline/sodic soils, soft peat and etc. The occurrence of thick deposits of marine clay in the Northwestern part of Peninsular Malaysia, is due to the result of quaternary deposition. The presence of these poor ground condition has posed numerous technical challenges in the implementation of road and expressway projects.

This paper will first provide a literature review of the problematic soils in several regions in the Asia Pacific with the aim for gathering geotechnical knowledge for road foundation design. The main objective of this paper is to study the characteristics of marine clay in Northwestern Peninsular Malaysia based on field and laboratory test data gathered from the ground investigations. The sub-soils in the Northwestern Peninsular Malaysia consist of sedimentary soil deposits which form alternate layers of clay and sand. New empirical relations between the soil index properties and compressibility properties are presented. The empirical relations between Cc and moisture content can be established as (see Figure 1):

$$Cc = -0.0484 + 0.0134w \quad (1)$$

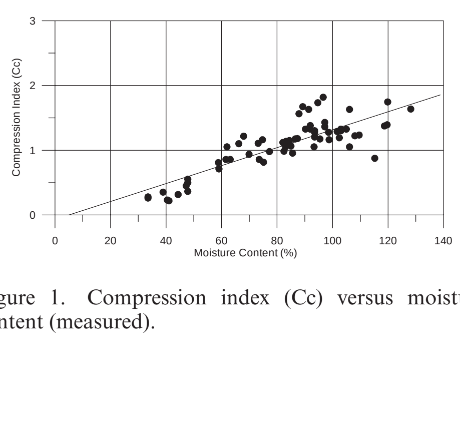

Figure 1. Compression index (Cc) versus moisture content (measured).

Where, Cc is the compression index, and w is the moisture content.

Regression analyses and statistical *t test* method are conducted on the empirical relationships for predicting the compressibility behaviors of marine clay in the study area. The statistical *t test* conducted for Cc and Cr data shows significant and non-significant deviation between the predicted and the actual field data respectively.

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Evaluation of the mechanical characteristics of recycled base layers produced by Full Depth Reclamation (FDR)

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ABSTRACT

Road rehabilitation usually leads to the creation of large volumes of waste and consumes a large quantity of mineral resources. In the province of Quebec (Canada) alone, over 4.5 M tons of road by-products were generated in 2008, of which almost all (>90%) consisted of asphalt pavement materials. From the perspective of sustainable development, recycling asphalt pavement materials is the most feasible solution to reduce the amount of waste generated (McGarrah 2007). However, there is still some reluctance towards the use of bituminous materials in road bases due to poor knowledge and understanding of their mechanical behavior, especially with regard to permanent deformation (Viyanant Chirayus et al. 2007; Werkmeister et al. 2001). There is therefore a need to assess the effect of RAP content on the mechanical properties of road bases, as this information is essential in the pavement design process.

This paper focused specifically on the effect of RAP content on the resistance to permanent deformation and on the stiffness of granular base materials. In addition, the effects of compaction and water content on bearing capacity were addressed.

The stiffness and permanent deformation behavior of recycled materials was investigated using repeated loading triaxial tests. Five mixtures composed of different RAP content and limestone aggregate were tested. An investigation into the effect of RAP content and stress state was performed in order to understand the role of each on the mechanical behavior of a reclaimed base layer. From the results obtained in this study (Figure 1), a model that relates the rate of deformation (B) to RAP content and stress level was proposed. This approach is fairly new for materials tested in Canada and allows calculating pavement reinforcement based on asphalt concrete thickness in order to decrease rutting sensitivity of reclaimed layers.

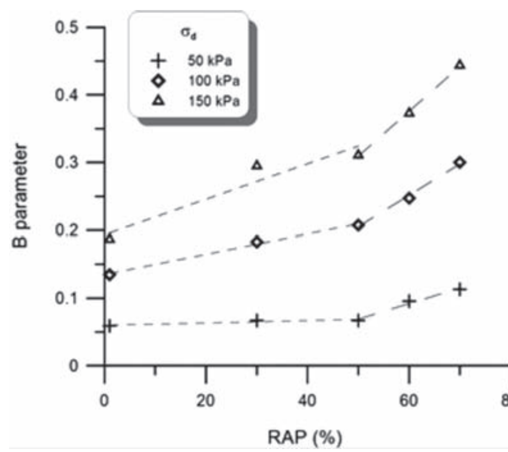

Figure 1. Relationship between B and RAP content for the three stress states.

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Effects of lime content and amelioration period in double lime application on the strength of lime treated expansive sub-grade soils

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ABSTRACT

The addition of lime into soils has been widely used to stabilize the expansive sub-grade soils. It is common practice to apply a half of the required lime amount and allow a certain time period for lime to react with soils (amelioration period) before applying the rest of lime and compacting the sub-grade. The optimum amelioration period is essential to minimize the construction delay and to gain the higher strength. According to the current specifications in Australia, it is required to have 24 hour amelioration period in double lime application. Construction industry is demanding to reduce the specified amelioration period to improve cost effectiveness and lessen overall construction time. However, there is no research based scientific evidence to support that the current 24 hour amelioration period of double lime application can be reduced. Therefore, this paper investigates the possibility of reducing 24 hour amelioration period based on UCS (Unconfined Compressive Strength) results obtained for two lime treated expansive soils

Index properties of two expansive soils used in this study are given in Table 1.

Each testing soil was first mixed with different lime contents (e.g.: 2, 4, 6 %). A soil mixed with a particular lime content and its optimum water content was compacted to achieve its maximum dry density after allowing different amelioration periods (e.g.: 0, 6, 12, 18, 24 hrs) to obtain soil samples to measure the Unconfined Compressive Strength (UCS).

Table 1. Physical properties of testing materials.

	Barcaldine soil	Emerald soil
Liquid limit (%)	64.2	61.0
Plasticity index (%)	40.2	37.0
Linear shrinkage (%)	18.8	20.0
Clay content (%)	17.1	32.3
USCS classification	CH	CH
Organic content (%)	6.85	6.50
Sulfate content (%)	2.70	0.14
Specific gravity	2.72	2.69
Optimum water content (%)	25.0	25.0
Maximum dry density (g/cm^3)	1.55	1.54
Lime demand (%)	4.0	4.0

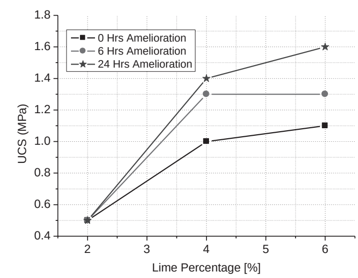

Figure 1. Effect of lime content on the strength gain of the lime treated Emerald soil.

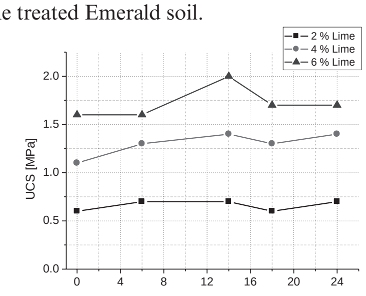

Figure 2. Effect of amelioration period on UCS of lime treated Barcaldine soil.

As shown in Figure 1, the strength (UCS) of treated soil increased with the increase in the mixing lime content. However, the rate of strength gain when increasing the lime content above the lime demand of the soil was not prominent compared to that of when increasing the lime content up to the lime demand. These results are consistence with the finding of Bell (1993). Thus, it could be economical to use the lime content equivalent to the lime demand of the soil when treating it with lime.

As shown in Figure 2, no significant strength gain was observed between UCS values of the specimens prepared following 14 hour and 24 hour amelioration periods. Therefore, for the tested soils, the current specified amelioration time of 24 hours can be reduced to 14 hours.

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The use of recycled crushed concrete as a road base material

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ABSTRACT

This paper investigates the performance of Recycled Crushed Concrete (RCC) as an unbound granular road base material. The analysis involves various laboratory tests to provide a comparison between RCC and standard high quality road base material. The testing involves a series of index and performance tests, including the Repeated Load Triaxial (RLT) test. The RLT results from testing a sample of RCC are summarized in Table 1 below.

The test results shown in Table 1 suggest that the RCC specification performs similarly to a standard high quality road base in terms of resilient modulus and plastic strains under repeated loading.

As part of this investigation, UCS testing was completed and suggests the presence of residual cement. The effect of residual cement is discussed, however further investigation is warranted. It is also found that there is little effect of source concrete strength on the performance of RCC as a granular material.

In addition to the completed material testing, an operational concrete recycling plant is analyzed, providing insight into material sourcing and processing. It is found that there are a number of construction considerations that are specific to RCC. In particular, measuring field compaction with a nuclear densometer requires special consideration due to the hydrogen content of the material (ReTAP, 1998). This necessitates calibration of the nuclear densometer.

This paper also discusses the advantages of utilizing RCC. This includes; environmental benefits such as minimizing land fill and reducing blasting of virgin rock, and the various cost savings comprising minimal tipping fees and benefits associated with the low specific gravity of RCC aggregate i.e. increased material coverage and transportation savings.

Table 1. Summary of RLT test for RCC sample.

RLT Output	RCC Result
Resilient Modulus	310 MPa
Plastic Strain at 1,000 cycles	0.67%
Plastic Strain at 50,000 cycles	4.57%
Plastic Strain at 100,000 cycles	6.22%

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Analysis of traffic-load-induced permanent settlement of highway embankment on soft clay ground

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ABSTRACT

As urban traffic develops rapidly, the road embankment settlement induced by urban traffic is paid more and more attention. Predicting the traffic-load-induced permanent settlement correctly especially on saturated soft clay ground has been a problem of desiderate to solve in the highway before construction. Setting up a model for calculating the cumulative plastic strain of saturated clay subjected to cyclic loading is the key work to permanent settlement analysis of soft subsoil induced by traffic load. Owing to a large number of cycles, complicated constitutive theory is no longer suitable, as a result, the empirical formula between the cumulative plastic strain and its main influence factors based on labora-tory test data is usually adopted.

Based on a series of isotropically and anisotropically consolidated static triaxial and cyclic triaxial tests performed on a typical Shanghai soft clay, considering static deviatoric stress level, dynamic deviatoric stress level, the first cyclic cumulative strain and the first cyclic normalized cumulative pore water pressure with confining pressure, this paper proposes new empirical equations to predict the cyclic cumulative strain and cyclic cumulative pore water pressure. Then a simplified method is introduced to calculate the long-term settlement of soft ground caused by traffic load, which is applied to predict the permanent settlement of S32 highway in Shanghai.

The calculation model for predicting the cumulative axial cyclic plastic strain and pore water pressure of saturated soft clay can be rewritten as:

$$\varepsilon^p = aD_d^m\left(\frac{p}{p_a}\right)^c N^b,\ \frac{u}{p_a} = a_u D_d^{n_u}\left(\frac{p_0'}{p_a}\right)N^{b_n} \tag{1}$$

Fig. 1 shows comparisons of experimental data for the cyclic cumulative strain and model predictions.

Cumulative settlement of soft soil subgrades due to traffic load can be divided into two parts: the settlement due to undrained cyclic cumulative deforma tion and the consolidation settlement due to the dissipation of undrained cyclic cumulative pore pressure. For practical purpose, the static deviatoric stress, confining stress and dynamic deviatoric stress are obtained by using the static finite element method. And the permanent settlement can then be calculated by the layerwise summation method. In what follows, the analysis of Shanghai S32 highway is taken as an example to illustrate the proposed calculation method (Fig. 2).

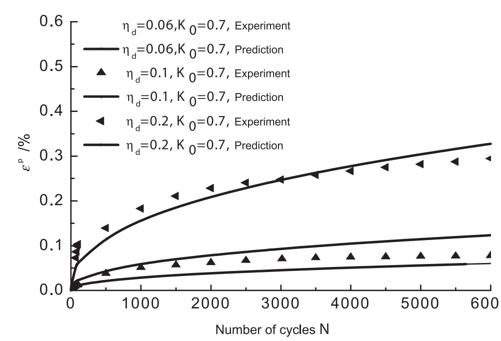

Figure 1. Relationship between ε^p and number of cycles under anisotropic consolidation ($\sigma_{3c}' = 200$ kPa).

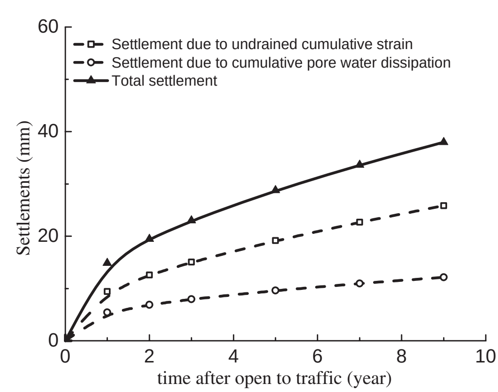

Figure 2. Cumulative settlements with the time opening to traffic.

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Effects of freeze-thawing on mechanical behavior of granular base in cold regions

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ABSTRACT

In snowy cold regions such as Hokkaido, the 0°C isotherm may penetrate deep into the pavement, thereby causing frost heave and swelling of the pavement surface, or cracking in the asphalt-mixture layer. Such phenomena specific to cold regions are thought to accelerate the deterioration of pavement structures and losing of the functions. However, the frost-heave phenomenon and the temporary degradation in the bearing capacity during the thawing season have not been sufficiently elucidated as well as the modeling of these phenomena. To develop an optimal design method against fatigue failure of asphalt pavement in cold regions, it is necessary to understand the mechanical behavior of subgrade and base course during freeze-thawing in detail.

This paper examine the change in the mechanical behavior of granular base caused by freeze-thawing and concurrent seasonal fluctuations in water content in terms of the deformation-strength characteristics of unsaturated base course materials subjected to freeze-thaw actions. For that purpose, a long-term field measurement and FWD tests for pavement structure subjected to freeze-thaw actions were conducted, and CBR tests for freeze-thawed base course material were carried out using a newly developed test apparatus. This paper also evaluates the influences of the change in the bearing capacity of granular base due to freeze-thawing on the fatigue life of pavement structures by employing the theoretical design method for pavement structures in consideration of the effects found in this study.

In conclusion, the following findings can be mainly obtained:

- The stiffness of granular base increases in freezing season and decreases due to increment of the water content in thawing season (Figure 1).

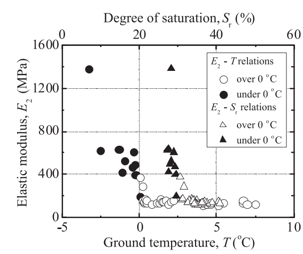

Figure 1. Effects of temperature and water content on stiffness of granular base.

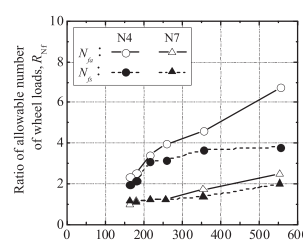

Figure 2. Effect of freeze-thaw on fatigue life of pavement (N_{fa}: Fatigue life against cracking, N_{fs}: Fatigue life against rutting, N4 & N7 : Japanese roadway categories).

- Seasonal fluctuations in water content of granular base due to freeze-thawing influence the bearing capacity of granular base strongly, in addition to the freezing of granular base.
- Change in the bearing capacity of granular base caused by freeze-thaw actions has a strong influence on the fatigue life of pavement structures in cold regions.
- Theoretical design methods for pavement structures, which can take into consideration the freeze-thaw action of granular base, are effective to use in areas with high freezing index and at pavement for low traffic volume (Figure 2).

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Characterization of hydrated cement treated crushed rock base as a road base material in Western Australia using disturbed state concept

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ABSTRACT

To design road pavement in Western Australia, Hydrated Cement Treated Crushed Rock Base (HCTCRB) is normally used as base course material. HCTCRB has been used and designed based on practical experience and empirical approach but these cannot explain the behaviour of HCTCRB base course. Currently, analysis and design and behaviour of structural pavement can be more reliable and more understood by the use of a mechanistic approach, one of which is the Disturbed State Concept (DSC). The DSC was chosen as a tool for modelling the response of HCTCRB because it believes that constitutive modelling of materials can be obtained by its versatile and unified approach.

The purpose of this study is to assess the mechanical characteristics of HCTCRB by modelling the results of laboratory tests using DSC. Conventional triaxial tests and Repeated Load Triaxial (RLT) tests, following the Austroads—APRG 00/33 test standard, were performed and the experimental results were used to construct the DSC equation for HCTCRB. Also, the effect of moisture content (at 90% and 80% OMC dry back condition) on the behaviour of HCTCRB was investigated. The results reveal that the resilient modulus characteristics of HCTCRB can be modelled by the use of the proposed DSC equation. Figure 2, for instance, shows the use of the DSC equation to back-predict the resilient modulus of HCTCRB specimen.

The graph indicates that the both DSC and K-θ model give consistent prediction of the resilient modulus when compared with the test results. However, the DSC model has more advantage over the K-θ model because its equation can be decomposed into the applied stress part and the resilient strain (ε_r) part, as shown below:

$$\frac{\sigma^a}{\varepsilon_r} = (1 - D)\frac{\sigma^i}{\varepsilon_r} + (D)\frac{\sigma^c}{\varepsilon_r} \quad (1)$$

Then ε_r can be used together with the results from the compressive strength test to predict the permanent deformation.

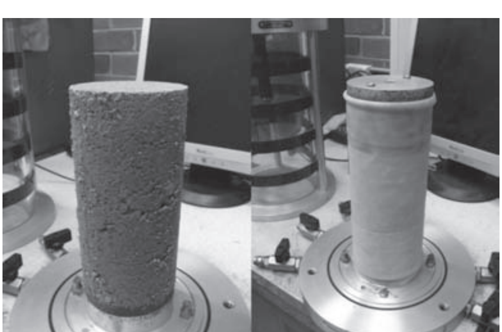

Figure 1. HCTCRB specimen.

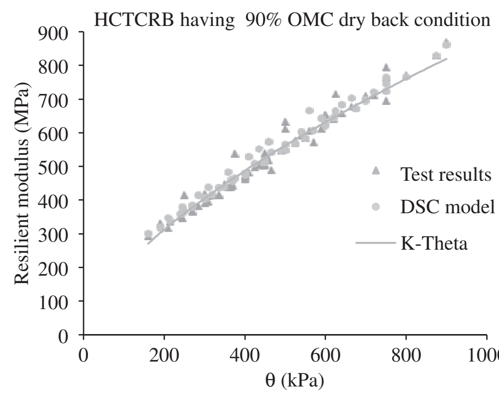

Figure 2. Prediction of the resilient modulus of HCTCRB having 90% OMC dry back condition.

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Role of resilient modulus constitutive models on response of pavements

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ABSTRACT

The development and implementation of mechanistic pavement design approaches, such as the Mechanistic-Empirical Pavement Design Guide (MEPDG) in the US, have been vigorously perused in the last twenty years. In a mechanistic approach, the relationship between the structural response (stresses, strains and deflections) and the physical parameters are described through a numerical model. Different software packages have been developed for estimating the response parameters of the pavements. These models are incorporated in several well-known computer programs with different levels of sophistication.

The materials can be modeled as linear or nonlinear in these algorithms. The resilient modulus (MR) test is commonly used to measure the modulus parameters of materials. The most common constitutive models used are the so-called universal models (a.k.a. k_1–k_3 model) that relate the modulus to the deviatoric stress, confining pressure or a combination of them. The procedures for conducting *MR* tests have been under continuous modification. These approaches differ in the specimen size, compaction method, loading time, stress sequence and the type and location (within or outside the confining chamber and mounted on specimen or platen-to-platen measurements). As such, they yield different k_1–k_3 values.

The main objective of this paper is to bring to the attention of the pavement engineers the implication of various *MR* test methods and constitutive models on the accuracy of the prediction of the response parameters (e.g., displacements) of pavement layers. The secondary objective is to discuss the need for transfer functions between the measured and estimated responses for geomaterials prepared to the same densities and moisture contents as the MR laboratory specimens.

To evaluate the appropriateness of the nonlinear numerical models and material constitutive models for estimating the response of a pavement, several small-scale pavements were constructed and tested under different loads, loading areas and moisture conditions. Extensive *MR* tests were also conducted at corresponding moisture contents. Nonlinear numerical structural models were then utilized with different constitutive material models to match the experimental responses.

The results from laboratory *MR* tests with different protocols yielded different stiffness (k_1–k_3) parameters. While the proposed model by the MEPDG underestimated the responses within the subgrade, the following nonlinear constitutive model provided the same patterns as the measured values as long as the inertial forces were considered.

$$MR = k_1' \; P_a \left[\frac{\theta}{P_a} + 1 \right]^{k_2'} \left[\frac{\tau_{oct}}{P_a} + 1 \right]^{k_3'}$$

In all cases, a transfer function was necessary to accommodate the differences in the stiffness properties due to differences between the field and laboratory compaction methods. This transfer function seems to be a function of the moisture content at the time of compaction as well as the moisture content at the time of evaluation. Even though not shown in this paper due to space limitation, testing with several materials so far has demonstrated similar pattern.

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A prediction method of plastic deformation development of subbase and subgrade in concrete pavement

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ABSTRACT

In concrete pavements, subbase and subgrade are required to provide uniform support for concrete slabs. However, permanent deformation at the top surface of subbase due to plastic strains in granular materials causes loss of the support. The aim of this study is to develop a method for predicting the plastic strains in subgrade and subbase.

The VESYS model that describes the plastic strain as a function of the number of load repetitions and elastic strain is employed in this study:

$$\varepsilon_p = I\,\varepsilon_e N^S \tag{1}$$

where, ε_p is plastic strain, ε_e is elastic strain, I and S are parameters determined from triaxial test.

The model was transformed to an incremental form (Figure 1) and incorporated into a 3 dimensional finite element program, Pave 3D (Figure 2).

Validity of the model was verified by comparing predicted and measured deflection developments in a repeated loading test on a test concrete pavement as shown in Figure 3.

Effects of the permanent deformation and the plastic parameters on the stress and deflection of concrete slab were examined. It was found that the plastic parameters affected elastic and permanent deflections significantly and they did slab stress slightly. Also, the plastic parameters of subgrade affected elastic and permanent deflections and those of subbase did slab stress.

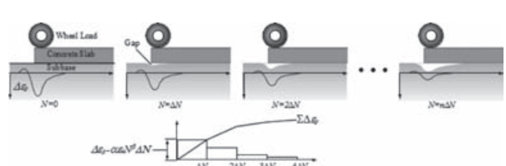

Figure 1. Incremental calculation method.

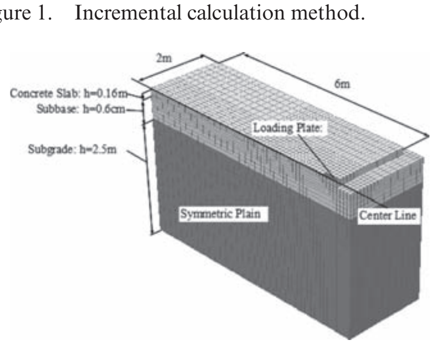

Figure 2. 3DFEM modeling of concrete pavement.

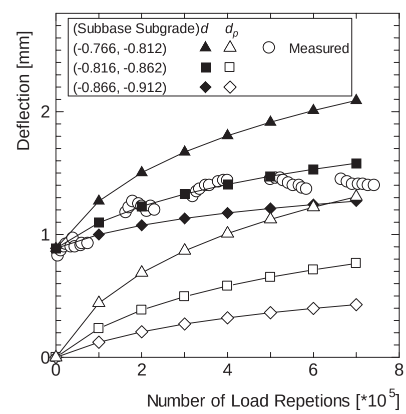

Figure 3. Validation of the method.

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Thick-layer construction using sandy soil as material and embankment performance evaluation: Assessment of rolling compaction test results

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ABSTRACT

In recent years, there have been significant advances in material handling (transport) equipment and leveling machine performance as earth-moving equipment is made in every larger sizes. Along with these advances, construction work to thicken embankment layers is also taking place in an increasing number of cases. This thick-layer construction is work that uses large vibrating rollers to thicken each layer within the embankment. This paper describes experimental work to thicken embankments using mountain sand and examines the results obtained from that work. Embankment thickening is compared in two cases; one using conventional thick-layer construction (t = 60 cm) and the other using mountain sand (t = 120 cm) in order to check limits on roll compacting effects. Results revealed that the same degree of compaction can be obtained to t = 90 cm with mountain sand. Moreover, compression tests and shear tests were made at the dry bulk density for this depth, to confirm the long-term compressibility and shearing characteristics. In these tests, we confirmed that the same performance was obtained as in conventional embankment work.

DYNAMIC OBSERVATION MEASUREMENT RESULTS DURING ONGOING CONSTRUCTION WORK

The compressibility during and after embankment thickening work is shown next. Construction work was performed at t = 90 cm and the embankment thickness was H ≈ 10 m. The compression amount was found using cross-arm type layer settlement meters placed at three point of GL-1.8 m, GL-4.5 m, and GL-7.2 m on the entire embankment. These meters were placed in each layer at intervals of 2.7 meters. In this placement method, the cross-arm is installed on the lowest end at the level where the 3-layer embankment ends and others placed at the second and third levels as the embankment work proceeds. The cross-arm on the lowest end therefore has a long measurement interval. Measurements of compression amounts were made for approximately a 1 year period from the start and compression applied at the end of embankment construction. Compression amounts for the three locations from the start of embankment construction as shown in Figure 1, are: A total settlement amount S = 10 mm at GL-1.8 m (S = 4 mm after embankment completion); a total settlement amount S = 17 mm at GL-4.5 m (S = 3 mm after embankment completion); and a total settlement amount S = 20 mm at GL-7.2 m (S = 5 mm after embankment completion). The compression ratio from the start of embankment work when each layer is set to H = 2.7 m was $\varepsilon = 0.4$ to 0.7%. The compression ratio after embankment completion was $\varepsilon_c = 0.15$ to 0.18%. These were the results as estimated from the initially assumed results of $\varepsilon_c = 0.1\%$ ($t = 5.2 \times 10^5$ min, $b = 1.9 \times 10^4$).

CONCLUSIONS

In the embankment thickening work using mountain sand from Chiba Prefecture, we first of all succeeded in obtaining the same degree of compaction at t = 90 cm when using a large vibrating roller (350 kN/m^2) as with the conventional method. Moreover, the creep ratio after site roll compacting was $\varepsilon_c = 0.1\%$ ($t = 5.2 \times 10^5$ min, $b = 1.9 \times 10^{-4}$) which is the same extent as results estimated from the indoor testing.

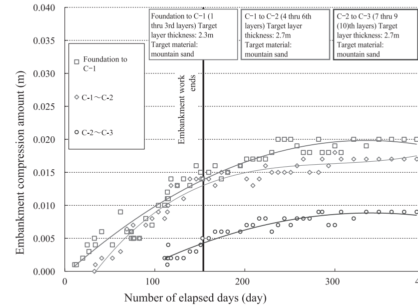

Figure 1. Measurement results from cross-arm type settlement meter (embankment work start to embankment completion to 1 year later).

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Effects of the environment-conscious pavements in Fukuoka University and its verification

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ABSTRACT

In this study, we conducted several tests to evaluate the performance of six types of pavements (drainage, heat-reflection, water-retentive, aesthetic and pedestrian-friendly pavements) constructed on the premises of the Fukuoka University. The pavements were evaluated on the following factors: (1) their ability to heat-reflection, (2) their ability to drain or retain water, (3) their aesthetic qualities and (4) how comfortable the pavements were for walking..

As global warming continues, problems such as heat islands and flooding of urban areas due to sudden rainfall are becoming major social concerns. In re-sponse, pavements that heat-reflection and retain water, as well as are aesthetically appealing and comforta-ble for pedestrians, have been created. In response to the need for forming a recycling culture, new pave-ment materials, which make effective use of recycled industrial byproducts, are being developed. In this study, we carried out trial construction of eight types of pavements on the campus of the Faculty of engineering at our university (Photographs 1–6), including six types of heat-reflection, water-retaining, aesthetically appealing, elastic pavement (for pedestrian comfort), commonly used dense-grade pavement and drainage (porous) pave-ment. We evaluate the performance of each pave-ment type through various experiments, and verify the effects of each type by using results of a ques-tionnaire survey conducted for faculty and students. In this paper, aesthetic pavement refers to a pave-ment treatment that does not simply leave the con-crete or asphalt bare, but rather is constructed to be conducive to the surroundings and harmonious with the scenery.

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Photograph 1. Heat-reflection pavement (A).

Photograph 2. Aesthetic pavement (B).

Photograph 3. Pedestrian elastic pavement (C).

Photograph 4. Pedestrian heat-reflection elastic pavement.

Photograph 5. Water-retentive pavement (F).

Photograph 6. Heat-reflection pavement (G).

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Study of suction in unsaturated soils applied to pavement mechanics

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ABSTRACT

High groundwater table exerts detrimental effects on the roadway pavement. This paper presents a real application of Soils Mechanics and Geotechnical Engineering in tropical climates, showing that the performance of a pavement is so influenced by its pore pressure and resilient modulus values. The measurement of resilient modulus has become increasingly accepted for characterizing engineering properties of pavement materials. This paper aims to correlate the phenomena of suction (matric, osmotic or both) with parameters used by Pavements Mechanics, studying the soils behavior when submitted to road loads, refining the mechanical (or rational) design of pavements inside of the climatic and regional conditions found in real situations of work. It presents an Experimental Program Methodology using a test-pit facility to study a Brazilian typical pavement design behavior. Paper filter is the technique which will be employed to obtain suction values due to its great range. Time Domain Reflectometry (TDR) will be also used to measure soil moisture along the test-pit profile.

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Cracking and flexural behaviors on cement treated crushed rock for thin flexible pavement

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ABSTRACT

Fatigue cracking is considered to be one of the most important types of distress affecting the performance of flexible pavements on major highways. This report analyses the results of a laboratory study of the static and fatigue response of a typical Western Australia Cement Treated Base (CTB) to evaluates its mechanical parameters i.e. flexural strength, flexural stiffness and tensile strains. Five different series of cement content were evaluated in the mix of 1%, 2%, 3%, 4% and 5%. Two major types of testing were conducted for the purpose of this study, i.e. Flexural Fatigue Tests (dynamic loading) and Flexural Beam Tests (static loading). The flexural fatigue tests were carried out with strain control mode. From the tests, the flexural stiffness for each specimen was calculated. The flexural stiffness was obtained from maximum tensile strains on the bottom of the specimens. The outcomes of the paper are as summarized as follow: First, 1% to 3% CTB was found out to be classified as modified material while 4% and 5% CTB are categorized as stabilized materials. Second, fatigue cracking phenomenon can be seen in stabilized materials (4% and 5% CTB) while other types of distress may affect the behavior of modified materials (1 to 3% CTB). Third, 4% cemented material is observed to be the most suitable material to perform under fatigue loading conditions. Fourth, a series of recommendations are presented for further research i.e. the Flexural Fatigue Test be conducted at a suitable (lower) strain value instead of the 400 $\mu\varepsilon$ magnitude used in this research.

In conclusion, reflections on the objectives set out in Section 3 of this report are discussed below.

1. Under fatigue loadings, CTB with cement contents ranging from 1% to 3% are categorised as modified materials as their average flexural stiffness has a value of less than 1,000 MPa. Four percent and five percent cemented materials are categorised as lightly bound materials as their average flexural stiffness values ranged from 1,500 MPa to 3,000 MPa. There is a significant increase in flexural stiffness from the modified to stabilised materials.
2. The flexural stiffness values of modified materials (1 to 3% CTB) were considerably low (less than 1,000 MPa) and moderately constant throughout the test. The reduction in stiffness of these materials was not significant. From this particular study, it can be concluded that modified materials are not limited by fatigue loading, i.e. it is not the dominant distress mode. Other types of distress mode may limit the performance of modified materials (1 to 3% CTB), therefore further research is required.

Stabilised materials (4 and 5% CTB) have a high flexural stiffness from 1,500 MPa to 3,000 MPa, however, stiffness values decreased signficantly during itntial loadings thus the stabilised materials exhibit the behaviours of fatigue life development, i.e. the crack initiation phase. Thus the fatigue phenomenon (fatigue cracking) is obvious in these materials.

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Jet grouting deformability modulus prediction using data mining tools

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ABSTRACT

Jet Grouting (JG) technology, one of the most efficient soft soils improvement methods, has been widely applied in important geotechnical works due to its versatility. However, even after some years of experience, there are still some important limitations to overcome. A major is related with the absence of rational approaches to accurately design its mechanical properties (Shibazaki 2004).

In the present work, three different Data Mining (DM) techniques, i.e., Artificial Neuronal Networks (ANN), Support Vector Machines (SVM) and Multiple Regressions (MR) are trained in order to predict Elastic Young Modulus (E_0) of JG samples collected directly from JG columns (JGS). It is shown that the complex relationships between E_0 and its contributing factors can be approximated using DM tools, particularly by SVM and ANN.

By performing a detailed sensitivity analysis based in Cortez & Embrechts (2011) methodologies over the SVM model, understandable knowledge is extracted. Figure 1 shows that age (t, days), cement content (C), void ratio (e) and inverse of dry density ($1/\rho_d$, $m^3 \cdot kg^{-1}$) of the mixture are key variables on E_0 prediction of JGS. Moreover, such analysis shows that t effect follow an exponential law with a concave shape.

Measuring the interaction level between t and the remains variables, the highest interaction was observed with Water/Cement ratio (W/C) showing the importance of both variables on deformability behavior study of JGS.

Taken into account the achieved results, the pro-posed models, particularly SVM, can be seen as a starting point to describe rationally the actual empirical knowledge related to JG mixtures behavior. Furthermore, DM tools are useful for a better understanding of the JG mixtures behavior, as well as to optimize both quality and costs of the soil improvement. Hence, these approaches will be applied in future works to predict JG columns diameter.

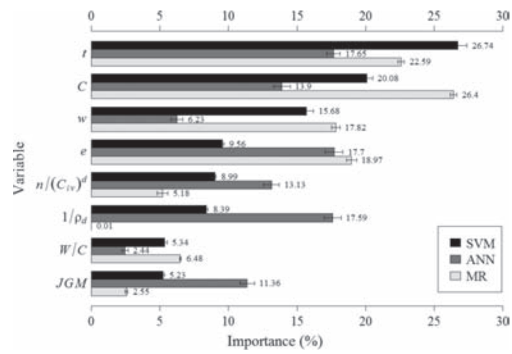

Figure 1. Comparison of the relative importance of each variable according to MR, ANN and SVM models in the E_0 prediction.

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The authors wish to thank to "Fundação para a Ciência e a Tecnologia" (FCT) for the financial support under the strategic project PEst-OE/ECI/UI4047/2011 and the doctoral Grant SFRH/BD/45781/2008. In addition, the authors would like to thank the interest and financial support by Tecnasol-FGE.

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Full-scale accelerated loading test for load distribution on subgrade due to CFA stabilized base

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ABSTRACT

The authors developed Cement Foamed-Asphalt (CFA) stabilizing method for using cement in the state of slurry to prevent cement from scattering while spreading and mixing it from an environmental viewpoint, and conducted full-scale accelerated loading test on CFA stabilized base with powdery or slurried cement in order to verify their durability and load distribution capacity. In this paper, the durability and the load distribution capacity of CFA stabilized base with powdery and slurried cement was evaluated using soil pressure and vertical strain on the top of subgrade at full-scale accelerated loading test.

The vertical strain on the top of subgrade caused by moving wheel was illustrated based on the horizontal distance between the wheel and the instrument in Figure 1, respectively.

The angle of load distribution was obtained as shown in Figure 2. First, the affected range was identified by drawing two tangents to the response curve for the soil pressure or the vertical strain in Figure 1 (b). Then, a isosceles triangle was drawn with the base of the affected range and the peak of the center of contact area between the pavement surface and the tire, as shown in Figure 1 (a). Half

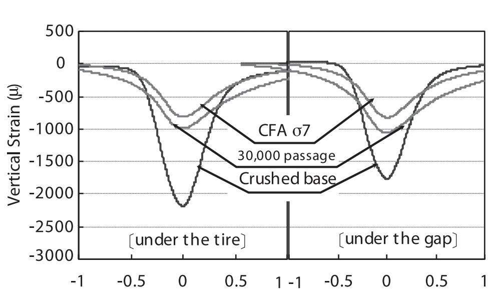

Figure 1. Vertical strain during passage of wheel.

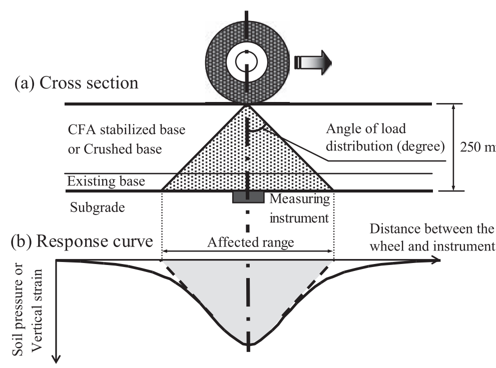

Figure 2. Method for calculating angle of load distribution.

of the angle at the peak of the triangle was defined as the angle of load distribution.

The main finding from this study are follows:

- The results of the accelerated loading test show that either powdery or slurried cement essentially has the same stabilization effect and CFA stabilized base with either type of cement is considerably durable to the design traffic volume.
- Stabilizing the crushed base with CFA reduces both the soil pressure and the vertical strain that occur on the top of subgrade and the variance in subgrade response under the tire and under the gap between the tires are reduced by CFA stabilization.
- From the angle of load distribution calculated based on the affected ranges of the soil pressure and the vertical strain on the top of subgrade by moving wheel load, stabilizing the crushed base with CFA increases the angle of load distribution, or enhances the bearing capacity.
- CFA stabilization greatly contributes the prolongation of the pavement life on rutting by reducing the damage of subgrade.

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Failure on a roadside dip slope with partial anchorage system

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ABSTRACT

The 15° dip slope at mileage 3.1 K of Freeway No. 3 in Taiwan had a tremendous mass movement about 200,000 m^3 on April 26, 2010 (TGS 2011). This disaster left 4 people dead and led to road close for emergency repair. This horrible event gave an impact on the current maintenance mechanism used by freeway agency for no significant storms or earthquakes are observed on the eve of the catastrophe.

As typical concerns, the slip plane develops along the impermeable shale below sandstone strata plotted in Figure 1. The sensitivity analyses focus on 3 possible causes, friction angle on the slip plane in shale, anchorage efficiency, and drainage condition shown in Table 1.

The sensitivity relations reveal that the long-term softening friction angle in shale is approaching the lower bound, 15°, in Figure 2. The Factor of Safety (FS) around 1.1 still stands on the safe side under the worst anchorage efficiency of 0.5 in report (TGS 2011). This result implies that groundwater pressure could play a key role to induce this dip slope failure.

Another sensitivity analysis (in Figure 3) indicates that friction angle, 18°, in shale corresponds to the highest water head, 0.25 m, at slope failure moment. The degrading friction angle in shale can be definitely identified as the range limited from 15° to 18°.

Table 1. Various ranges of factors friction angle, anchorage efficiency, and drainage condition.

Factors	Friction angle	Anchorage efficiency	Drainage condition
Range	14°~28°	0~1.0	0~0.1

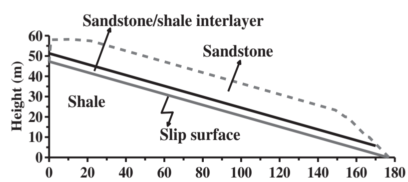

Figure 1. Dip slope profile along the sliding direction.

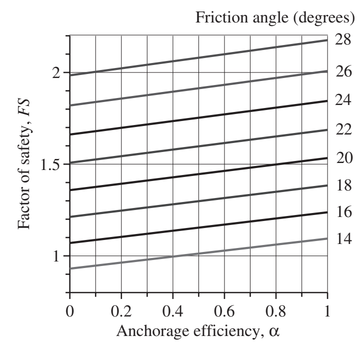

Figure 2. Sensitivity relation among factor of safety, friction angle, and anchorage efficiency.

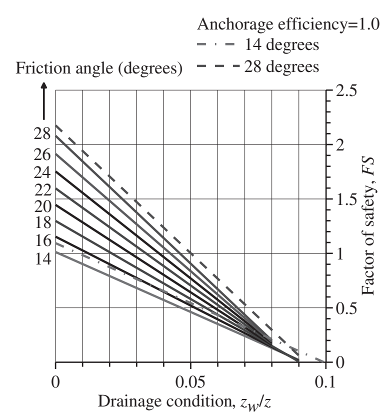

Figure 3. Sensitivity relation among factor of safety, friction angle, and drainage condition under anchorage efficiency = 0.5.

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2.2 *Rail track*

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Advances in Transportation Geotechnics II – Miura et al. (eds)
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Establishing linkages between ballast degradation and imaging based aggregate particle shape, texture and angularity indices

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ABSTRACT

In ballasted railroad track, repeated wheel loads transferred from crossties to the ballast layer cause abrasion and degradation of the aggregates over time. In majority of ballasted track used by freight trains in the US, such particle breakage and aggregate degradation primarily contributes to the fouled content in the ballast layer to alter the gradation and morphological particle shape, surface texture and angularity properties. These changes weaken the bearing capacity of the ballast layer and eventually cause track geometry problems. The common practice in the laboratory, as well as in computational models, is to analyze new, clean ballast aggregates, which usually have higher angularity, superb particle interlock, and therefore sufficient shear strength. This paper focuses on recent research efforts at the University of Illinois aimed at investigating ballast performance associated with degradation and fouling levels in the field by analyzing both clean and deteriorated ballast particle size distributions and morphological properties.

Los Angeles (LA) abrasion tests were conducted on the common granite and limestone type ballast materials with different number of turns applied, i.e., 100, 250, 400, 550, 700, and 1000, to simulate particle crushing or degradation trends with increased track usage. Sieve analyses consistently performed after the LA abrasion test clearly captured the ballast degradation trends, which were then successfully linked to before and after test values of imaging based aggregate shape properties. Among the quantifiable aggregate shape indices were the Flatness and Elongation (F&E) ratio, Angularity Index (AI), and the Surface Texture (ST) index well established in previous studies using the University of Illinois Aggregate Image Analyzer. At around 400 turns of the LA abrasion test, the original uniform ballast gradations generally became "well-graded" according to the Unified Soil Classification System and approximately the two thirds of the particle angularity index were lost when compared to the full 1000 turns of the LA abrasion drum. No clear trend was observed for changes in aggregate surface texture indices. In an attempt to link the decreased AI values and F&E ratios of the abraded aggregates to reduced shear strength properties, ballast shear box sample densities played an important role; the much higher densities of the abraded ballast sample actually produced increased shear resistance in the direct shear tests. Accordingly, future ballast research should target similar packing orders and/or achieved sample densities to focus on studying only the effects of particle shape and angularity on shear strength.

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Laboratory tests on a ballasted rail track reinforced by geosynthetics

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ABSTRACT

In order to reduce the Life Cycle Cost of railway infrastructure, many research works deal with Track support structure. Development and implementation of several subgrade improvement methods allowing limited traffic interruption and privileged recourse to local material are one of the objectives the French National Railway company (SNCF). In this aim, SNCF, SOLETANCHE-BACHY and LCPC have investigated the potential benefits from the reinforcement of ground by vertical soil-cement columns. SOLETANCHE BACHY have designed a tool to achieve soil-cement columns following the execution requirements by SNCF: the columns had to be built from the top of the railway structure within the space between sleepers.

From a mechanical point of view, stiff zones could be created at the column location and damaged the ballast which would involve maintenance additional works. Also, SNCF has investigated the ballasted rail track reinforcement by geosynthetic to reduce stiff zones. Laboratory tests have been performed to verify the influence of the column location and the efficiency of geosynthetics on the reduction of stiff zones effects.

From devices and experiments performed in this field (Brown et al. 2007, Kennedy et al. 2009), the authors modified a Railway Accelerated Fatigue Testing (RAFT) bench to perform tests simulating stiff zones beneath ballast layer. A RAFT bench has been adapted to perform tests simulating stiff zones beneath ballast layer (Fig. 1). The RAFT bench includes rail track sections consisting in two rails on two sleepers used in the field. Cyclic loading is applied to the centre sleeper of the track at a range of typical track frequencies from a hydraulic actuator that can load up to 120 kN at 10 Hz. Track settlement, stress and settlement under ballast layer are monitored during each test.

Tests performed with and without stiff zones show that stiff zones modify the distribution of stress under ballast layer and generate differential settlement. Tests performed with or without geosynthetics located at the base of ballast layer for various stiff zones configurations highlight that geosynthetics erase stiff zones effects. The efficiency of the geosynthetic reinforcement depends on the combination and the location of geosynthetics used. Full-scale experiments will be carried out to validate these results.

Figure 1. RAFT bench.

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Evaluation of a linear elastic 3D FEM to simulate rail track response under a high-speed train

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ABSTRACT

The development of tools and methodologies that can accurately predict the behavior of high-speed lines has become one of the main issues of research in the past few decades

This work presents the simulation of a high-speed track using commercial FEM software. The goal is to study if the utilization of this software is adequate to reproduce the dynamic behavior of a rail track subject to the passage of a high-speed train.

To have comparison data, a case study was chosen where measurement data was available in the literature (Degrande & Schillemans, 2001). The models were created using software TNO Diana (2005) and only elements present in this software were used. The materials were considered linear elastic. The simulation intended to reproduce the accelerations at the rail and nearby soil that were measured during the passage of a high speed train.

Taking advantage of the linear elastic properties of the model, only the response to unitary wheel loads was computed and the consideration of a full train passage was calculated in post processing. The computed response at the sleeper agreed very well with the experimental measurements.

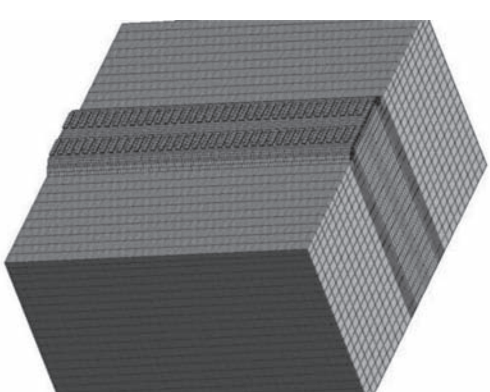

Figure 1. Finite element mesh of the 3D model.

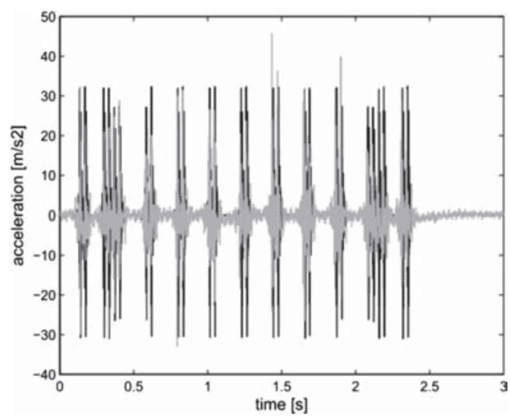

Figure 2. Computed (black) and measured (gray) response at the sleeper due to the passage of a Thalys HST at 314 km/h.

While still showing some appreciative agreement with measurements, the response at the soil was not so accurate. This is explained by the uncertainties in the definition of the damping and the consideration of only the quasi-static component of the load.

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Improvement of rail track subgrade using stone columns combined with geosynthetics

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ABSTRACT

This study seeks to identify the effectiveness of ground improvement using stone columns combined with reinforcing geosynthetics, in controlling settlement of soft soils when placed under the dead loads of the rail structure and the large live loads of freight trains. Geosynthetics are the polymer reinforcement materials which have recently been developed to improve the soil stability as an alternative solution for soil improvement. This technique can be accompanied by other ground improvement methods such as stone column construction. According to Fatahi and Khabbaz (2011), the ballasted track using blended ballast with geogrids, placed between sub-ballast and subgrade, can achieve its optimum performance, which has even less settlement than the fresh ballast without geogrids. The employed numerical study assesses the relationship between the column position in the track cross section and the overall settlement of the ballasted rail formation.

In this study, to investigate the influence of stone columns pattern and spacing in conjunction with geosynthetics on deformation of track due to the train load, finite element modeling using PLAXIS ver. 9 (2008) is employed. The model geometry is established considering a typical ballasted track cross-section with concrete sleepers as recommended on the NSW rail network. Depth of each layer from top to bottom including rail, sleeper, ballast, and sub-ballast are 0.1 m, 0.15 m, 0.3 m, and 0.15 m, respectively. The subgrade depth is assumed to be 10 m to examine the rail track performance. The gauge length of the track is 1.4 m. Figure 1 illustrates the cross section of the rail employed in the finite element model.

The findings of this research indicate that the cross-sectional configuration of stone columns has a profound impact on the level of soil improvement achieved. Columns spaced more closely together at the centre of the track give a greater level of settlement control. With the effectiveness of configurations with 2 columns making them uneconomical to implement when located more than 1 m from the track centre. The results also showed that when improved columns are combined with a single layer of geogrids, positioned between the sub-grade and sub-ballast, noticeable gains in settlement control were achieved. The addition of another layer of geogrids, positioned between the sub-ballast and ballast layers, showed insignificant improvement and hence, would not be considered economical for practical application.

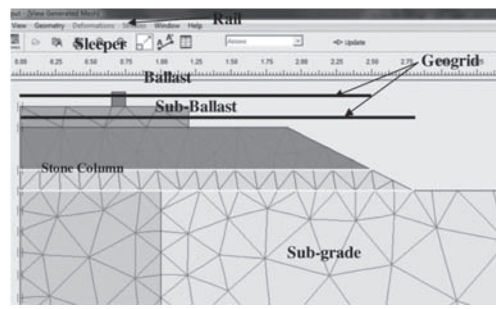

Figure 1. Typical cross-section of track.

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Seismic damage assessment of an airport runway based on non-linear FEM analysis with special reference to crack occurrence

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ABSTRACT

This study is focused on seismic damage to an airport runway due to ground shaking. The runway of Noto Airport in Japan developed a lot of cracks due to the 2007 Noto Hanto Earthquake (see Figure 1). The evaluation of crack occurrence is very important to examine the seismic performance of an airport runway. Conventional study (Hata *et al.*, 2009; 2010) reveals that the maximum velocity gradient obtained from 3-dimensional (3-D) non-linear dynamic FEM analysis, which includes the embankment and the bedrock below the runway, is an effective index for the evaluation of crack occurrence. The execution of 3-D dynamic analysis, however, is not suitable for a practical design. Thus, in this study, the applicability of 2-D dynamic FEM analysis for the evaluation of crack occurrence was investigated, with special reference to the selection of cross section for the 2-dimensional (2-D) analysis. At the current stage of the study, the following conclusions were obtained.

– The directions for which the 2-D results are consistent with the 3-D results (see Figure 2) are perpendicular to the contour lines in the original topography before the construction.
– It is important to pay attention to the original geographical features in selecting cross sections for 2-D analysis.

Figure 1. Aerial photograph of Noto Airport.

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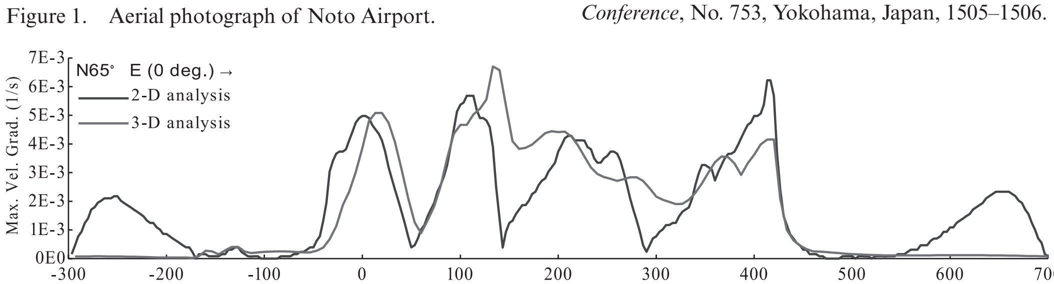

Figure 2. Comparison of the computed maximum velocity gradients on the Noto Airport runway by 2-D and 3-D FEM analyses.

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Influence of moisture content on cyclic plastic deformation characteristics of recycled crusher-run material under moving wheel loads

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ABSTRACT

In Japan, natural crusher-run material is employed in pavements for base course layer. Nowadays, in order to economize the cost of pavements, recycled crusher-run material made from construction waste is also used as base course material for low volume roads. Therefore, it is the need of pavement engineers to evaluate mechanical response of recycled crusher-run in order to construct quality roads with minimum cost. The laying of recycled crusher-run material as base course layer can save huge cost on pavement construction. It is also noticed that stress state induced through traffic loads inside pavements is not exactly reproduced in conventional laboratory tests. Moreover, there are not sufficient studies that examine behavior of base course material under unsaturated conditions, which is more prevalent in pavement structure.

This research paper proposes a testing method to determine cyclic plastic deformation characteristics of unsaturated recycled crusher-run material used in base course layer, and accordingly examines the effect of moisture content under single-point loading and moving-wheel loading. Besides considering mechanical response of unsaturated recycled crusher-run material, cyclic plastic deformation behavior of natural and recycled crusher-run material is also compared and analyzed. A series of laboratory element test using multi-ring shear apparatus, which can take in to account rotation of principal stress axis, were carried out on recycled crusher-run material under different degrees of saturation. Loading conditions of multi-ring shear tests were determined by employing Japanese paved road model. Figure 1 shows permanent axial strain behavior of unsaturated specimens under two types of loading. Permanent axial strain for single-point loading and moving-wheel loading is considered at 400th number of loading cycle. The experimental results show that, moisture content has obvious effect on cyclic plastic deformation of recycled crusher-run material. It is indicated in Figure 1 that cyclic plastic deformation considerably increases due to rotation of principal stress axis under moving-wheel loading tests when compared with single-point loading tests. Therefore, principal stress axis rotation has a significant influence on cyclic plastic deformation of unsaturated base course material. The results also indicated that natural crusher-run material has lesser permanent axial strain when compared with recycled crusher-run material under each cyclic loading method and at same degree of saturation. In this regard, Figure 2 shows the relationship under moving-wheel loading test.

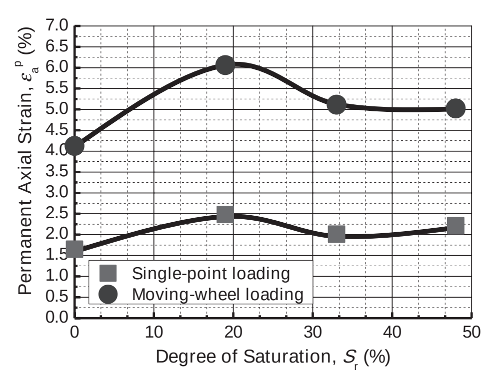

Figure 1. S_r – ε_a^p relationship (Recycled crusher-run material).

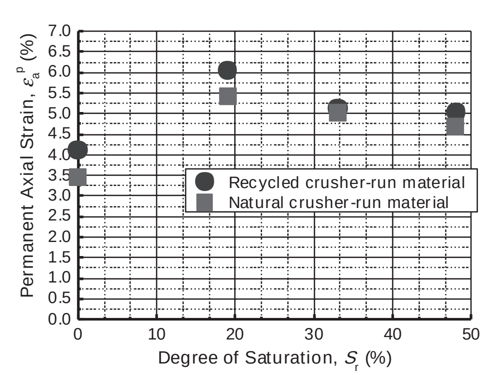

Figure 2. S_r – ε_a^p relationship under moving-wheel loading test.

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Development of integrated RC roadbed for slab track on clay subgrade

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ABSTRACT

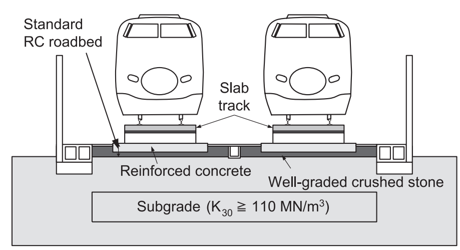
In Japan, slab tracks on earth structures are applied with RC (Reinforced Concrete) roadbeds to reduce settlement and deformation (Ando, et al., 1999). To avoid excessive settlement and deformation, a high bearing capacity for subgrade is essential.

In the case of embankment, quality of soil material and compaction control is most important. In the case of natural ground, bearing capacity of subgrade is estimated from N-value obtained by SPT (Standard Penetration Test). In cases where the N-value is lower than 4, ground improvement using a method such as deep mixing is necessary.

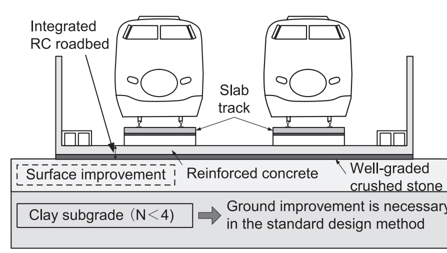
However, a soft diluvial clay layer with a low N-value was detected on the part of a Tohoku-Shinkansen line under planning. In this case, ground improvement is necessary in order to conform to earth structure design standards. An alternative would be to use ballasted track instead of slab track. However, ground improvement increases the initial cost and ballasted track increases the maintenance cost. The results of a preliminary survey indicated that the diluvial clay layer was in a sufficiently over-consolidated condition, and it was presumed that no residual settlement would be induced by train loads. If slab track can be introduced only with surface improvement of the subgrade, it will become possible to reduce the overall life cycle cost significantly.

To apply slab track on clay subgrade, we developed double-line-integrated RC roadbed to reduce settlement and deformation. Figure 1 shows cross section of double-line-integrated RC roadbed and standard RC roadbed. The standard RC roadbed in design standard has 3.2 m-wide reinforced concrete under slab track. While on the other hand, double-line-integrated RC roadbed has 11 m-wide reinforced concrete under double line slab track.

We carried out detailed ground investigations to evaluate the performance of the integrated RC roadbed on the soft diluvial clay. We further carried out on-site cyclic loading tests involving the application of a vibration machine. Based on the results of these investigations and tests, we carried out FEM analysis to evaluate the deformation characteristics of the concrete roadbed. The results clarified that the integrated RC roadbed was able to appropriately support slab track on the soft diluvial clay subgrade.



(a) Standard RC roadbed



(b) Double-line-integrated RC roadbed

Figure 1. Cross section of slab track on RC roadbed.

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Effect of ground properties and embankment height on the embankment failure behavior during earthquake

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ABSTRACT

For railway, the safety measure against disaster has been promoted steadily since it was opened to traffic. However Mid Niigata Prefecture Earthquake in 2004 caused the train derailment without serious damage of structures. This accident caused the need to install the derailment prevention guard system and to improve and balance the seismic proof performance of different structures. Thus, the new seismic proof countermeasure for embankment is needed considering the deformation level and failure mode.

After Southern Hyogo Prefecture Earthquake in 1995, the Design Standard for Railway Structure—seismic design (1999) was reviewed. In this standard, the seismic performance of embankment is classified into the 4 grades for the subsidence based on the restoration ability. And the failure modes of embankment can divide the amount of embankment settlement into the ground subsidence and the embankment compression. Thus, the clarification of the failure mechanism contributes to select the effective countermeasure.

In this study, for interpreting the deformation mechanism of the embankment classified in the De-formation Level 3 (under 500 mm settlement after huge earthquake occurred), the dynamic centrifugal model tests under different condition (embankment height, ground properties) were carried out and the obtained results are simulated by the soil-water coupling finite deformation analysis (GEOASIA).

As results of these examinations, the main conclusions were summarized as follows:

1. In the de-formation behavior of the embankment in Deformation Level 3, the embankment deforms prominently while the ground deforms slightly.
2. The deformation mode of the embankment in Level 3 can be classified into 2 patterns, one is that both toes of the embankment expand (shown in Case 2) and the other is that the circular slip in the slope occurs.
3. At the top of the embankment slope around 2m depth, the shear strain generated smaller than other part of the embankment. That is, this range behaved as soil mass, and it suggested effective to suppress the top of the slope as seismic proof reinforcement for this failure mode.

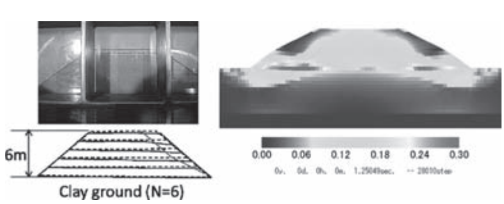

Figure 1. The failure modes of embankment
(Embankment 6 m height, clay ground 6 N-value)
(Left: Centrifuge modeling test, Right: Finite deformation analysis).

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Railroad foundations—verifications and analysis of the dynamic stability

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ABSTRACT

For the assessment of earth structures with respect to cyclic/dynamic loading due to railroad traffic in the past the definition "dynamic stability" was used. This definition however includes also the progressive settlement of the track as a result of the soil behaviour under dynamic loading due to railroad traffic, although this is not equal with a loss of stability but rather is equal with a gradual loss of the serviceability.

The "failure" of an earth structure under dynamic loading (railroad traffic) due to gradually progressive settlements is therefore defined as the "dynamic long-term stability" resp. the "dynamic serviceability". As opposed to this intensive, short-term dynamic loads or substantial shear- and volumetric changes after only a few load cycles combined with a clearly reduction of the dynamic stiffness can occur (for instance also at earthquakes). This is defined as a loss of the "dynamic short-term stability". From the technical point of view it is essential, that a failure of the short-term dynamic stability and unallowable shear strains are urgent to be prevented.

In the paper a procedure for the verification of the dynamic shear strains was described. As a decisive criterion the calculated and/or measured shear strain γ in the substructure/subsoil under dynamic loading is evaluated, see Figure 1.

Decisive for the verification of the dynamic stability and therefore in the end for the determination of required improvements or stabilization measurements is the definition of the accepted shear strain limit. This limit has to be defined taking into account safety aspects as well as economic aspects.

A comparison of calculated and measured shear strains was shown in an example with an approximately 8 m thick soft layer consisting of peat and very weak clays and silts.

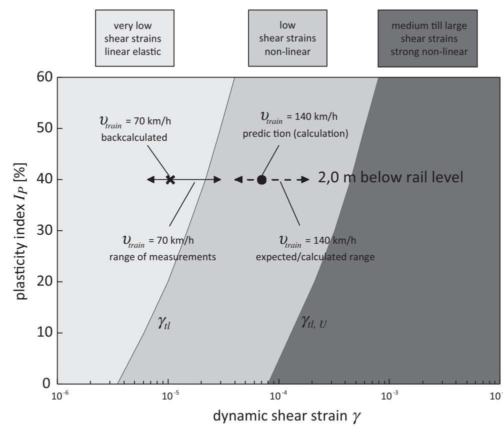

Figure 1. Evaluation of the dynamic stability of subsoil by means of the dynamic shear strain.

Summarising it should be noted that with the illustrated procedure a computational approach based upon a reproducible theoretical basis for the determination of the dynamic stability of earth structures of railroad tracks now is available. The determination of the necessary input parameters with sufficient accuracy however is generally limited taking into account the range of variation of the soil parameters and the experimental techniques.

Therefore the calculation method should always be calibrated using measurements. This makes it possible to create a realistic prediction of the shear strain based upon a recalculation of the soil parameters.

Beside the application of complex calculation procedures also the assessment of the calculation results by an experienced geotechnical consultant is required in particular since a calculative prediction of long-term deformations due to cyclic/dynamic loading is currently not possible.

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Design method for railway bases reinforced with geogrid

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ABSTRACT

Railways, that are often built on soft soils, present peculiar characteristics in terms of loads applied to subgrade: a single train may produce hundreds wheels loads in few seconds, that is a train produces rapid, repeated and cyclic loads; loads are first distributed from rails to sleepers, then from sleepers to ballast, and finally from ballast to subgrade; loads are always applied to the same area. The effect of such loads on soft soils generates absolute and differential settlements, which may quickly degrade the quality of the railway segment. Reinforcing geogrids may be used for stabilizing the railway base, in such a way as to decrease settlements and to increase the railway lifetime. All the available literature on geogrid reinforcement of railway tracks is synthetically presented and critically analyzed: full scale laboratory tests; instrumented railway tracks; theoretical and numerical models. By studying and analyzing all these data a design method for geogrid reinforcement of railway bases has been developed, which allows to take into account the wheel load, the number of passages, the railway geometry, the geotechnical characteristics of subgrade and the geogrid properties. The proposed design method is an extension of the Leng–Gabr method, that was developed for geogrid reinforcement of unpaved rod bases. The present method is based on the same engineering principles of the Leng—Gabr method, with adaptations dictated by the railway peculiar geometry and loads, taking into account the results of the available research programs. The design method affords a quick estimation of the required thickness of ballast and subballast in the reinforced and unreinforced cases.

Assuming that the wheel load P produces a load p uniformly distributed over an equivalent circular area of radius a ($p = (4/\pi)\, P/a^2$), and that the degradation of the base with the number of passes is given by the following formula:

$$\lambda_2 = \frac{\tan \alpha_N}{\tan \alpha_1} = \frac{1}{1 + k_2 \log N}$$

where: α_N = angle of load distribution at the N-th loading cycle, α_1 =initial angle of load distribution (for N = 1); N = number of load cycles, k_2 = coefficient that defines the degradation of λ (or of $\tan \alpha$).

The required thickness of the geogrid reinforced ballast is given by the following formula:

$$h = \frac{0.85a\,(1 + k_2 \log N)}{\tan \alpha_1}\left(\sqrt{\frac{p}{mN_cC_u}} - 1\right)$$

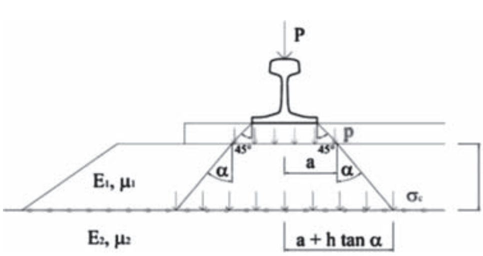

Figure 1. Schematic of the model for the reinforcement of ballast.

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Evaluation of train running stability on slab track with vibration exciter

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ABSTRACT

Inspection of railway tunnel was periodically conducted within limited time of night. The strict filed condition becomes a great burden of inspection work. Especially, the inspection of civil engineering structures for Japanese bullet train so called Shinkansen is important due to the degradation of the above structures. To make the inspection efficient and increase the ride quality of Shinkansen, the slab track has been adopted. The slab track is supported on the roadbed concrete attached with Cement Asphalt (CA) mortar. Figure 1 shows the schematic figure of slab track.

The paper describes inspection and evaluation methods of slab track in Shinkansen tunnel using frequency characteristics obtained from vibration test and inspection train, respectively. For the inspection method, Fourier spectrum of roadbed concrete can be obtained from the vibration test. Simple example in the vibration test shows the validity of this test. For the evaluation method, two factors were used: one is an area of Fourier spectrum obtained from the vibration test and the other is vertical displacement increment on the rail between 10 m in the rail direction. These two factors obtained from the field measurements shows correlation. Finally, a relationship between the above two factors was categorized as 4 parts, such as fair condition of both the track and ground under roadbed concrete, poor condition of ground under roadbed concrete, serious condition of track and serious condition of ground under roadbed concrete, as shown in Figure 2. The proposed evaluation method practically useful for the maintenance of slab track in the Shinkansen Tunnel.

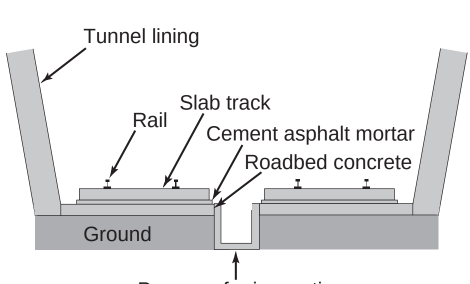

Figure 1. Cross section of slab track in tunnel for bullet train.

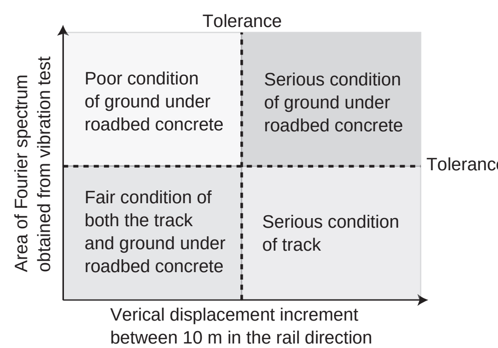

Figure 2. Slab track evaluation using area of Fourier spectrum and vertical displacement increment in the rail direction.

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Modelling and application of polyurethane geocomposites for high-speed ballasted railway tracks including transition zone dynamics

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ABSTRACT

The running of high-speed trains on ballasted railway tracks requires excellent track geometry and reliability. Three-dimensional polyurethane geocomposites have been used at many sites across the UK to help solve traditional ballast maintenance issues that arise at critical track assets like switch and crossings and transition zones (Figure 1). History shows that operational train speeds tend to eventually follow maximum train speeds, suggesting that trains travelling at ultra-speed (hereby defined by speeds over 400 km/hr) on ballasted track could become a reality in the near future. In the UK High Speed 1 operates up to 300 km/hr and operational speeds up to 400 km/hr are being considered for UK High Speed 2. Whether to construct a ballasted track or concrete slab-track is often one of the most difficult decisions to be made at the consultation and design phases of a new line. Regardless of which track type is chosen the need to ensure excellent track geometry is paramount (Esveld, 2001). While ballasted tracks allow track maintenance to take place with relative ease they cannot provide the track geometry reliability that concrete slab-track can. However, there are still concerns expressed over the long-term performance of concrete slab-track.

If ballasted tracks are to be used then it is highly desirable to provide track reinforcement and stability at critical track locations like switch and crossings (turnouts), expansion joints, transitions, curves, level crossings and general improvements in track stability for high-speed (Woodward et al. 2005). In this paper the application of three-dimensional polyurethane reinforcement of railway ballast, called *XiTRACK*, is described as a means to strengthen the ballasted track at these critical locations especially for high-speed. The technology uses specialised rapidly reacting polymers that are able to reinforce the ballast in all weather conditions and even during scheduled train operations. The paper describes how the system works and presents typical track installations.

In addition the paper describes work done on transition modelling using the DART3D finite element software. The effect of the change in track stiffness is highlighted through numerical simulations; this is then compared to simulations of voiding and sleeper settlement problems. The effect of problems like 'hanging sleepers' is shown to represent a major factor in transition behavior, particularly for high-speed. The use of polyurethane reinforcement of ballast is therefore shown to be of particular benefit.

Figure 1. Application of 3D polyurethane reinforcement at a bridge transition on the Stansted to London line UK.

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Study on the settlement characteristics and reinforcement technology of unsaturated soil ground of high-speed railway

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ABSTRACT

The restricting of post-construction settlement of railway subgrade is a key technology to designing and constructing high-speed railway. The consolidation settlement of unsaturated soil ground is more than saturated soil, so it is difficult to control post-construction and plan construction period. In this article, author monitors the variance of settlement of the typical unsaturated silty clay or silt ground in Jiaozhou peninsula and northern China, analyses the settlement law of unsaturated soil ground, and examines reinforcement effects on ground by the use of dynamic compaction and soil-cement pile. The outcome of experiment shows that, the settlement of the shallow ground within the depth of six metres is more than sixty percent of the whole for the unsaturated silt or silty clay ground. Having been reinforced by dynamic compaction and soil-cement pile, the unsaturated soil ground meets the design requirement of high-speed railway subgrade.

As Figure 1 and Table 1 show, the construction period of untreated ground is short, but the settling velocity is fairly fast; next is soil-cement pile ground; the filling period of dynamic compaction ground is long, but the settling velocity is the slowest. Therefore, it should be set enough deposit period for the dynamic compaction. Comparing to dynamic compaction, the settlement of usaturated subsoil reinforced with soil-cement pile decreased, and the consolidation settlement velocity sped up. It is therefore beneficial to control the post-construction settlement of unsaturated silty clay or silt soil ground by soil-cement pile. It should be given priority to adopt this reinforcement measure in engineering practice.

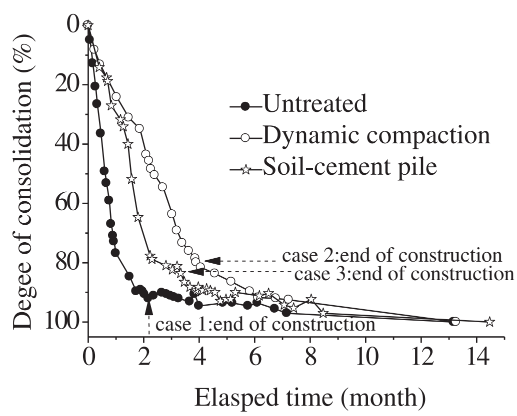

Figure 1. Degree of consolidation-time curves.

Table 1. Comparison of settlement of reinforcement area.

	Subgrade height	Construction velocity	S_0/S^*	S_1/S^*	S2/S*
Case	m	mm/day	%	%	%
Case 1	7.53	0.12	96.3	2.1	1.6
Case 2	7.43	0.064	77.3	15.5	7.2
Case 3	7.66	0.079	87.9	6.9	5.2

*S = ultimate settlement; S_0 = settlement during the filling period; S_1 = settlement during deposit period; S_2 = post-construction settlement.

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2.3 *Airfield*

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Development of high durable grout for airport prestressed concrete pavement

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ABSTRACT

Many airports in Japan have been constructed on the reclaimed land with dredged soft soil. Flatness of pavement surface at such locations gradually tends to degrade due to uneven ground settlement. As the ground settlement had been anticipated in design of apron, it has been recognized as suitable to apply Prestressed Concrete (PC), shown in Figure 1. When it is necessary to modify the slope of the PC pavement that has degraded due to ground settlement, the Lift-up Method is applied to the pavement. The PC slabs are jacked up and grout is injected beneath the slabs within one night. However, there were some cases where the grout beneath the edge of slabs is pulverized by repeated aircraft loadings and they were squeezed out with rain water through joints of the slab edge, which results in preventing aircraft from running safely.

The aim of this study is to develop the grout for injection beneath the slabs in terms of workability and fatigue durability. A series of model tests was conducted with the mixture of the grout currently used in airports and organic fiber as a new material. In addition, higher early strength grout was also used. In laboratory tests, promising fiber mixed grout was determined by changing mixing rate and the length of the fiber. Then, confirming the durability, model tests were conducted by repeatedly loading a wheel on model slab. In the tests, the model was put in water and strain condition was set to be the strain expected in Tokyo International Airport. Then full scale grout injection test was conducted to confirm the workability with the slab as large as in airport.

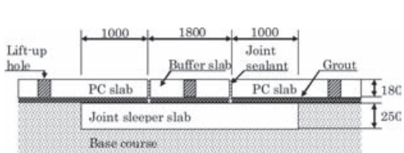

Figure 1. Typical structure of PC pavement.

Based on the results of a series of model tests, the following conclusions were drawn.

1. Tests for workability and a full-scale injection test confirmed that the workability of the fiber-mixed grouts with a fiber length of 3 mm and a mix ratio of 0.05 volume percent was the same as that of a conventional grout.
2. It was confirmed that the resistance to repetitive loading of grout mixed with aramid fibers according to the above specification was improved. In other words, the grouts had greater resistance to pulverization. Further, the use of higher early-strength grout would most likely allow the resistance to be met sooner.
3. Fiber-mixed grout with 3 mm fibers at a mix ratio of 0.05 volume percent was not pulverized even after 40,000 repeated loadings to twice the flexural strain level (400 μ) of the grout undersurface at the Tokyo International Airport.

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Determination method of ground model for reclaimed land with dredged clay and evaluation by settlement record of Kita-Kyushu Airport

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ABSTRACT

In a rapid construction for a reclaimed land with dredged clay, it is necessary to apply a ground improvement to accelerate the consolidation of clay ground. In this case, the ground condition and consolidation parameters of reclaimed clay ground are needed for the design of ground improvement. In ordinary cases, these are determined by the results of ground survey and soil tests. In the rapid construction, however, the design of ground improvement has to be performed during the reclamation without the actual information of the complete ground, because the time from the completion of reclamation with dredged clay to installation of vertical drains is too short to perform detailed soil investigation.

In this paper the followings are described;

i. The outline of determination method of ground model and consolidation parameters of dredged clay ground by the reclamation analysis (Yoshida, et al., 2008),
ii. The monitoring results of ground settlement of airfield after its opening,
iii. The prediction of residual settlement by the log t method using the monitoring results, and,
iv. The assessment of the determination method shown in i).

Figure 1 shows the location of monitoring points and ground settlement of airfield for 3 years from its opening on March 2006. The dark part shows the range over 5 cm, and the light dark is the range from 2.5 to 5 cm. The significant settlement occurs in the Construction Area-II where the reclamation with dredged clay ended in March 2002.

In the point No. 5, the maximum settlement of 7 cm was measured for 3 years after the opening. Based on the field measurement, the future settlement for additional 27 years was predicted as 14 cm (21 cm for 30 years after the opening). The allowable value of residual settlement of airfield from the planned elevation for 30 years after the opening was 35 cm when the design of vertical drains was performed. This 35 cm in the design involved 20 cm of secondary consolidation and 15 cm of primary one. The predicted secondary consolidation settlement is almost the same as that in the design. The effectiveness of the design method used in the project was confirmed.

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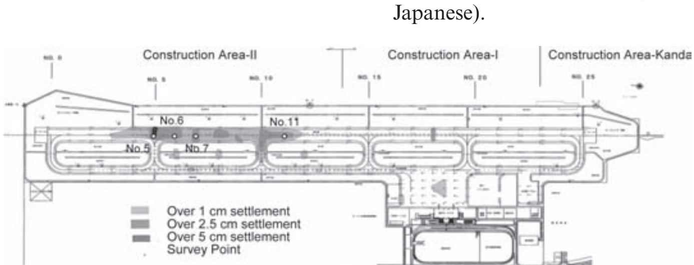

Figure 1. Settlement behaviors of airport field for three years from after opening.

3 *Geomaterial, including nontraditional materials*

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Performance assessment of clay soil stabilized with recycled gypsum based on SEM and XRD

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ABSTRACT

The use of waste and recycled materials as alternative stabilizing materials in earthwork projects has a long history. Gypsum waste plasterboard is considered one of these wastes and more than 1million tons of gypsum waste is produced in Japan annually during the three stages of production, construction and demolition (Ahmed et al. 2011a). This can pose a serious problem in Japan since the disposing of gypsum wastes requires sending to controlled landfill sites according to Japanese environmental regulations and this increases the cost of their disposing. Besides, gypsum wastes in wet environment have a negative effect on the environment due to the generation of hydrogen sulfide and the release of fluorine, which can exceed the permitted limits (Ahmed et al. 2011b; Ahmed et al. 2011c; Kamei & Horai 2008). The use of recycled gypsum, produced from gypsum waste plasterboard, as a stabilizer material for ground improvement projects is initiated in Japan recently. This application is considered one of the appropriate solutions that aims to eliminate the huge quantities of gypsum waste plasterboards and to avoid the cost of their disposal in landfill sites while preserving the environment. Although the incorporation of recycled gypsum in ground improvement projects has many advantages, it poses many challenges since gypsum is a soluble material. Therefore, it is essential to explore the microstructure and mineralogical compositions of clay soil stabilized with recycled gypsum in order to achieve successful results. To achieve this purpose, recycled gypsum was mixed with furnace cement type-B or lime, in dry state, in different ratios to prevent the solubility of gypsum. Subsequently, different contents of these admixtures were mixed with clay soil to mold cylindrical stabilized soil specimens and then subjected to different curing times before testing. SEM and XRD were used to investigate microstructure and mineralogical composition respectively, while unconfined compression test was used to investigate the compressive strength. Test results showed that the addition of recycled gypsum improves the strength of clay soil compared to identical untreated samples. The improvement in strength based on compressive strength results in agreement with the results of SEM images and XRD. The formation of ettringite increases with the increase of recycled gypsum content in soil mixture. XRD results showed that the improvement in strength is not only due to the formation of ettringite but also due to the formation of calcium carbonate and hydrate calcium sulphate in soil mixture. Curing time has a significant effect on the formation of ettringite and the improvement of strength especially in the early curing times. The initial improvement in strength is related to the potential of gypsum for water absorption while the permanent improvement is related to the formation of ettringite and calcium carbonate in soil mixture.

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Blended recycled clay masonry and crushed concrete aggregate in bases

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ABSTRACT

This paper presents the engineering characteristics of a blend of Recycled Clay Masonry (RCM) with Recycled Concrete Aggregate (RCA). The proportion of RCM was 20% of the total aggregate mass. Testing included saturated hydraulic conductivity, drying shrinkage, static triaxial shear strength and Repeated Loading Triaxial Testing (RLTT). RLTT was conducted as a multi-stage test, which included 66 stress stages for resilient modulus and 3 stress stages for permanent strain development. The specimens were tested at three moisture levels and at a dry density ratio of 98% of Maximum Dry Density (MDD). Cohesion varied between 54 and 76 kPa, and the angle of friction exceeded 50°.

The RLTT consists of two phases of testing, permanent strain testing followed by resilient modulus testing. Permanent strain testing consists of three stress stages, each performed at different deviator stresses and at a constant confining pressure of 50 kPa. Applied deviator stresses are 350, 450 and 550 kPa. Each stage consists of 10,000 load repetitions. The resilient modulus testing consists of 66 stress stages with 250 repetitions. The results of permanent strain and resilient modulus are shown in Figure 1.

The May and Witczak model (1981) provided a good fit to the modulus data as in Figure 2. Resilient modulus and permanent strain were sensitive to moulding moisture content and stresses. Based on the behavior of each sample in the RLTT, general applications of the material were made for various traffic levels.

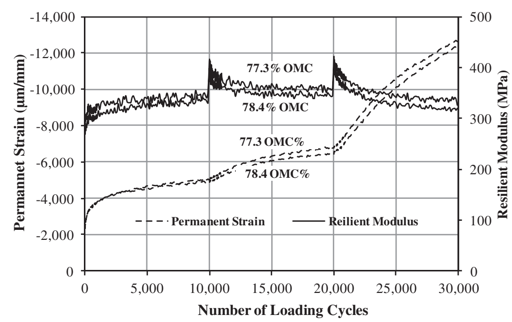

Figure 1. Permanent strain & resilient modulus at 80% target moisture content.

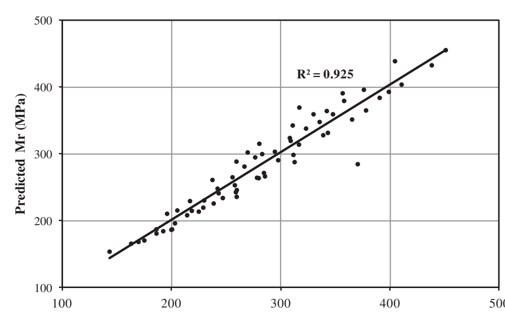

Figure 2. Comparison of measured and predicted moduli for material prepared at 77% OMC.

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Evaluation of non-traditional stabilizers with silty-clay desert soil

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ABSTRACT

This study focuses on measuring changes in engineering properties of silty-sand Loot desert soils when treated with three nontraditional products and two traditional stabilizers-the former were ionic stabilizer, and two polymer types and the latter were lime and cement. The Unconfined Compressive Strength (UCS) was the main experimental framework of this research. Each specimen based on its mechanism was cured at different situations, polymers had dry curing and other stabilizers had wet curing. For objective comparisons of test results and simulating the effect of first rainfall in desert area, half of 28-day-cured-UCS samples were immersed for 7 days before testing. Results, as can be seen in Figure 1, showed that except cement, other stabilizers did not significantly improve UCS in immerse condition. Cement-treated samples at 6%, 8% and 10% demonstrate high potential to have an acceptable UC strength in both of most and immersed conditions.

Figure 2 indicates that polymers only at dry curing condition improved strength of samples more than cement with a different mechanism of failure which occurred only in high percentage (3% ≤) of polymer, i.e. under high-pressure failure happens at high axial strain. Significant decrease in UC strength of polymer-treated samples after immersion, see figure 1and 2, is attributed to weakness of hydrogen bounding to neutralize electrically clay mineral and ineffectiveness of polymer particles to considerably decrease the permeability of polymer-treated soils.

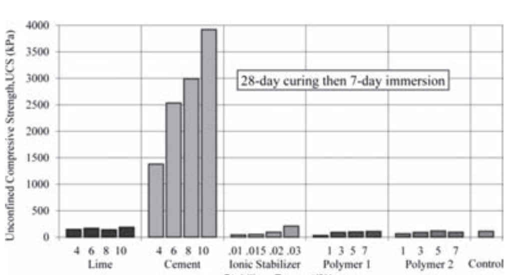

Figure 1. UC strength of 28-day cured treated with ionic stabilizer, polymers lime and cement after 7 day immersion.

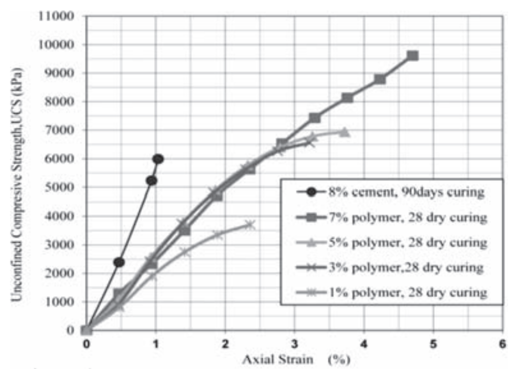

Figure 2. Stress–strain diagram of different percent polymer after 28 days curing.

Supplemental observations by SEM did not show any trace of formation of ettringite mineral in the treated sample with cement and lime that supposedly must be formed in similar concentration to sulfate salts. SEM samples treated with Ionic stabilizer show a slight weathering (increasing in clay-size particles) in treated samples after 90 day moist curing that may be implicated in Tropical Weathering (e.g. muscovite and feldspar are weathered to finer mineral like illite) or increase in sulfate Mineral, due to addition of ionic stabilizer and then Mannheim process (Butts, 1997).

Soil mineralogy and upward trend that UC lime treated soil or cement samples gain strength indicated that illite and cholorite mineral have high potential for pozzolanic reaction that was revealed after 60 moist curing.

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Mechanical characteristics of hydrated cement treated crushed rock base for Western Australian road base

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ABSTRACT

Hydrated Cement Treated Crushed Rock Base (HCTCRB) is made by blending standard crushed rock and cement (2% by mass of crushed rock). It is mixed and stockpiled at the optimum amount of water for the specific hydration period. After the hydration period it is retreated to break the bonds generated during hydration to maintain the properties of the unbound material. HCTCRB is expected to provide higher strength and lower moisture sensitivity than that of Crushed Rock Base (CRB), while avoiding the bound properties and fatigue cracking in cement treated base.

This paper aims to present the resilient modulus (M_R) of HCTCRB using repeated load triaxial tests according to the Austroads standard test method, AG:PT/T053. The experiments were conducted to study the influences of various factors during production process (i.e. cement content, mixing moisture content and hydration period) on the HCTCRB properties. To examine the impact of cement content, specimens were prepared using cement content of 1%, 2% and 3% by mass of crushed rock at the individual Optimum Moisture Content (OMC). The effects of hydration period and moisture content were studied by producing HCTCRB with 2% cement content. The hydration periods in this study ranged from 7, 14 and 28 days. The amount of water used for crushed rock-cement mixtures at the initial stage of HCTCRB manufacture were varied from 100%, 110% and 120% of the OMC resulted from moisture and dry density relationship of CRB-cement mixture.

The M_R results revealed that all CRB and HCTCRB samples exhibited the stress-dependent behavior and can be fitted well with the K-θ model. The M_R of CRB ranged between 100 and 300 MPa. All HCTCRB samples showed superior performances to that of CRB more than triple. The M_R values for all HCTCRB samples varied between 350 to 1500 MPa.

In terms of cement content, the similar trends of Unconfined Compressive Strength (UCS) and M_R results indicated that the HCTCRB samples with 2% cement showed the highest strength whilst the 3% cement-sample provided the poorest performance even though it contained the greatest cement content amongst these three samples. This occurrence was a consequence of higher water consumption during hydration reaction resulted in drier material. Thus it could not be compacted properly as a result of insufficient water to lubricate the material grains during compaction. The samples of 1% and 2% cement still contained suitable amount of water and could be compacted and made the more qualified specimens than that of 3% cement content.

The UCS tested results of all HCTCRB samples were lower than lower limit of the UCS specified for modified granular material which indicated 700–1500 kPa of 28-day UCS. Even though HCTCRB could not be classified as a modified granular material, it is still suitable for base course layer as their M_R values are much higher than that of the traditional base course.

Finally, the experimental results also revealed that hydration periods and moisture contents affected the mechanical properties of the HCTCRB. However, the related trends correspond to the different hydration periods and moisture contents still cannot be concluded convincingly. It is assumed that the retreated process to break the cementitous bonds of the hydrated mixtures mainly caused the uncertainty properties of HCTCRB.

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Study on effect of mixing condition on strength of mixture of dredged soil and steel slag

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ABSTRACT

In recent years, a shortage of dredged soil landfill is one of the serious issues in coastal construction in Japan. To avoid the issue, it is strongly desired to study on applications for dredged soil in several types of geomaterial. Mixture of Dredged Soil and steel slag (MDS) is one of the applications and has the potential to become widely-used geomaterial in future. For example, it is considered a way to increase ground level for an intertidal flat and seagrass bed in a coastal area. Many researchers have been studying various properties of MDS, and the outline of characteristics of MDS has already been clarified (Hayashi et al., 2011, Chan et al., 2011). MDS has a self-hardening property, and it could be expected to have large strength after mixing. It has been thought that the major cause of the self-hardening is a chemical reaction between f-CaO and Si contained in steel slag and dredged soil respectively. However, it was reported that the strength of MDS obtained by in-situ tests were smaller than by laboratory tests in some cases.

Because MDS is a composite material, it is important to study on the relationship between the inner structure and the mechanical behavior of MDS for precise estimation of its strength. The relationship could be affected by a mix proportion of steel slag to dredged soil. Also non-uniformity of a specimen submitted to an examination could be one of the key issues for mechanical properties of MDS.

In the present study, mechanical behavior of MDS was investigated considering inner structure and uniformity observed by X-ray CT scanner. Specifically, to study on the effect of the mix proportion on the strength of MDS, several series of unconfined compression tests were conducted. In the tests, specimens were made of different crude materials, with various mix proportions, and by a variety of mixing methods. And, a model test was conducted to study on solidification range of MDS. In addition, MDS made at construction site was observed by X-ray CT scanner. The findings from the test results were as follows:

– MDS obtained larger strength with higher f-CaO content included steel slag.
– If the initial water content of MDS was larger, the strength of MDS was smaller.
– There was optimum dry weight ratio between steel slag and dredged soil to get MDS with high strength.
– Use of fine fraction content of steel slag would be effective to achieve high strength.
– If the specimen was non-uniform, the strength would be smaller and the test result would be unstable.
– Not only the images taken by the X-ray CT scanner but also the numerical data, Gray level, were effective to evaluate uniformity of the MDS specimens.

From the model tests on solidified area of MDS, it was found that solidification of dredged soil would start from the face in contact with steel slag, and solidified area enlarged gradually with time. Moreover, the observation by X-ray CT scanner revealed that the MDS made at the construction site was pretty uniform.

Through the results, valuable information about inner structure and mechanical properties of MDS was derived. Also the effectiveness of X-ray CT scanner for observation of inner structure was confirmed.

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Mechanical characteristics of foamed bitumen mixtures in Western Australia

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ABSTRACT

Increased popularity of foamed bitumen as a stabilising agent in recent years has resulted in a necessity of research into the mechanical characteristics of foamed bitumen mixture rather than material itself. In Western Australia (WA), City of Canning is one of the few councils vigorously promote foamed bitumen stabilization and conduct many related field construction activities (Leek 2011). Even though successfully constructive experiences of foamed bitumen stabilization had been gained in the field, the current foamed bitumen pavement layer design theory was mainly relied on empirical method yet this design model is unacceptable due to its inputs deriving from monotonic loading tests rather than cyclic loading tests which are now widely used in mechanistic design attempt that is believed to better simulate real traffic loading conditions (Siripun et al. 2010). Consequently, an apparent knowledge of the entire mechanical characteristics of foamed bitumen mixtures under both monotonic and dynamic loading is very important to gain the efficiency of such materials.

This project aims to briefly investigate shear strength (static tri-axial test), resilient modulus and permanent deformation (repeated loading test) in terms of various additives content (foamed bitumen and active filler) under Western Australian laboratory conditions. It is anticipated to gain a primary understanding of mechanistic characteristics of foamed bitumen mixtures in WA and make possible contribution to the development of mechanistic design method.

Crushed Rock-Base (CRB) and Crushed Limestone (CLS) are virgin materials sourced from a local Perth quarry, and are representatives of the materials that are commonly used as a base course and sub-base course in Western Australian road pavement structural system. The amounts of the additives being tested were 0, 2 and 4% (by weight of aggregate) foamed bitumen and 0, 1 and 2% (by weight of aggregate) hydrated lime. All the required tests were carried out with a cyclic tri-axial apparatus consisting of a main set and a removable chamber cell, based on the standard method of Austroads APRG 00/33–2000 (Austroads 2004) with some slight modifications. Test results indicated the basic mechanical properties of foamed bitumen mixtures under Western Australian laboratory conditions.

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Recycled concrete aggregate as a base course material in Western Australian road

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ABSTRACT

Recycled crushed concrete and demolition materials have been trailed successfully as a road construction material in a number of locations in Western Australia, but industry acceptance of the material has been minimal. Specifications of such materials currently in use have been modified from commonly used specifications for new quarried products, and remarkably, there have been some doubts about the long term performance and quality control of such recycled products. This paper analyses the performance of recycled concrete pavements that have been constructed in Western Australia, and details the extensive laboratory testing program undertaken to model the product and compare its performance to conventional quarry products. Field testing demonstrates good quality control and performance of recycled crushed concrete and demolition materials superior to conventional quarry products and the laboratory results shows very close characteristics between both materials. The loading tests were carried out in terms of the resilient modulus and the permanent de-formation tests to provide insight into the resilient and permanent deformation characteristics of this material under real traffic loading conditions. The static tests were undertaken to identify the Mohr-Coulomb failure envelope which describes the maximum capacity of the material to withstand external loads and to assess its strength parameters in terms of cohesion-c and internal friction angle-Ø.

The main conclusions and recommendations from this study can be summarized as 1) C&D can be characterised as a granular mate-rial which has a slight cohesion (c) of 84.25 kPa and an internal friction angle (Ø) of 49.52°. Following these results, C&D waste provides excellent shear strength parameters, 2) The permanent deformation characteristic of C&D waste show slightly higher settlement than that of CRB based on the Austroads—APRG 00/33 test standard, 3) Recycled roadbase materials sourced from re-cycled demolition materials can provide a good quality high strength base for roads based on the pavement trial investigation, 4) Recycled base materials are likely to give an increased asphalt fatigue life, but some minor block cracking may be the compromise, and 5) Further research into the source of the concrete and its effect on stiffness and long-term performance is required.

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A method for accelerating the solidification of granulated blast furnace slag

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ABSTRACT

Granulated Blast Furnace Slag (GBFS) solidifies when it reacts with water. This characteristic is known as a potential hydraulic reaction. Most GBFS used to backfill quay walls does solidify, (Kikuchi 2003) but a post-construction follow-up survey showed that GBFS solidification is a lengthy process (Kikuchi et al. 2005). We can use GBFS to counter liquefaction if the GBFS solidifies quickly and easily. Some treatment is necessary before GBFS can be used as a self-hardening material.

In this study, we mixed Powdered Granulated Blast Furnace Slag (PBFS) with GBFS. Previous research has shown that GBFS mixed with PBFS solidifies in a short period (Kikuchi et al., 2007).

There are several issues to consider when determining what mixture of GBFS and PBFS is most appropriate: (1) there is a possibility that the material will separate during construction, (2) the material may separate after construction because of water flow, (3) separation of the mixture is likely to affect how the GBFS solidifies, (4) the flow of pore water can affect solidification, and (5) if the ground water changes from seawater to fresh water, the GBFS may solidify differently (Kikuchi et al. 2010). In this paper, mixture of Prior Homogeneous Mixing Treatment (PHMT) is introduced and issues (1) and (5) in using PHMT are discussed.

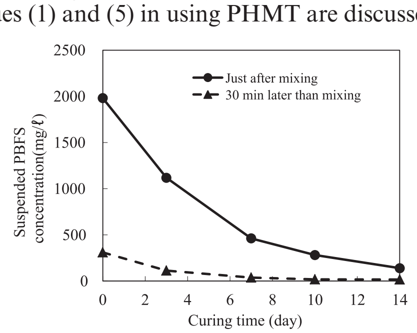

Figure 1. Change in suspended PBFS concentration with curing time.

Table 1. Experiment condition.

Case	Condition
Case 1	Supplying sea water for 8 weeks
Case 2	Supplying sea water for 6 weeks, then supplying pure water for 2 weeks
Case 3	Supplying pure water for 8 weeks
Case 4	Using pure water for making the ground and supplying pure water for 8 weeks

Table 2. Converted unconfined compression strength (kN/m^2).

Case	Maximum	Average	Standard deviation
1	1060.2	331.4	189.4
2	550.8	244.9	107.9
3	500.7	130.5	99.5
4	493.9	213.4	102.9

In the mixing PHMT process, 8% to 10% PBFS is mixed with the GBFS, then water is added to achieve a 10% water content ratio and the mixture is cured in air for about a week.

This paper demonstrates the superiority of this process. PHMT decreases the separation of the GBFS/PBFS mixture (issue (1), Fig. 1) and produces sufficient unconfined compression strength with about 2 months of curing in seawater (issue (2), Table 1, 2), which occurs automatically when GBFS is used to backfill quay walls in ports. We conclude that PHMT-treated GBFS solidifies at an accelerated rate and can be used to prevent liquefaction.

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Improvement of swelling-collapsible behaviors of silty clay by calcium carbide residue

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ABSTRACT

The natural soil in northeast Thailand is silty clay, which is deposited from clay *stone. The soil in the dry state exhibits* excellent engineering characteristics with high bearing capacity. However, the soil bearing capacity decreases when the water content increases. The change in water affects the swell and collapse of the soil mass significantly. The chemical stabilization is one of the extensively used techniques to improve the engineering properties of the upper soil. The resistance to compression and consequent strength development increase with increasing curing time. Portland cement is commonly used for this stabilization. A high unit cost and energy intensive process of Portland cement are the driving forces for the alternative cementitious additives.

The Calcium Carbide Residue, CCR is a waste product from acetylene gas factories, which is rich in $Ca(OH)_2$. Because clayey soils contain high amount of natural pozzolanic materials (silica and alumina), the CCR can be used as a soil stabilizer and the stabilized clay becomes a construction geomaterial. The engineering characteristics of $Ca(OH)_2$ rich materials stabilized silty clay are attributed to three basic reactions which are cation exchange, flocculation and aggregation, and pozzolanic reaction. The cementing property is identified as a pozzolanic reaction.

This research aims to study the effect of influential factors such as water content, CCR content and curing time on the physical and engineering properties of the problematic clay stabilized with the CCR. The engineering properties involved are soaked and unsoaked strength, swelling and collapsible behavior, and unsoaked and soaked bearing capacity. The possible mechanism controlling the engineering properties is then illustrated. This study is useful as fundamental for facilitating the engineering decision on the mix proportion of soil, water and CCR.

The following conclusions can be drawn as follows:

- The CCR can react with natural pozzolanic materials, resulting in the improvement of the engineering properties of the CCR stabilized clay. This stabilized silty clay can be considered as a construction geomaterial. The soil improvement swelling and collapsible behaviors by the CCR can be classified into two zones: Firstly, the swelling and collapsible strains decrease with an increase in the CCR content. Secondly, they increase with an increase in the CCR content.

The CCR fixation point, which is simply obtained from the laboratory test can be used to identify the first zone. The CCR fixation point indicates the capacity of the clay to absorb Ca^{2+} ions and react with $Ca(OH)_2$. The applicability of the fixation point has verified by the available test results of the clayey soils stabilized with the $Ca(OH)_2$ rich material.

The increase is because of the excess CCR that remains in the soil. The excess CCR or the free lime has unsoundness properties, therefore, the high free lime (CCR content > CCR fixation point) causes the CCR stabilized clay to swell

- The CCR enhances the chemical bond (attractive forces) among the clay particles. The OWC is the suitable mixing state, providing the best engineering properties (highest strength and bearing capacity and lowest water absorption, swelling and collapse). The lower water content

is not enough for pozzolanic reaction while the higher water content causes the high water/stabilizer ratio, *W*/*S*.

– The water absorption induces the repulsive forces (expansion of the diffusion double layer) as indicated by the increase in the swelling pressure. The samples compacted on the dry side of optimum shows higher water absorption potential (repulsive forces) than those on the wet side due to lower degree of saturation. Consequently, the samples compacted on the dry side exhibits poorest engineering properties although they possess practically the same attractive forces as the samples compacted on the wet side.

– Base on the test results the compacted naturally silty clay soil is classified as the overconsolidated uncemented soil and the CCR stabilized clay can be classified as the cemented soil.

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Effects of compaction condition on seismic performance of dike embankment and its evaluation

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ABSTRACT

Japan has been subjected to a large number of earthquakes. Recent big earthquakes such as Hyogo-ken Nambu Earthquake in 1995 and Tohoku-Pacific Ocean Earthquake in 2011 caused serious damages to many type of structures including embankment. Since Hyogo-ken Nambu Earthquake, a concept of seismic design against strong-motion has been positively applied to construct a various kind of infrastructures. Therefore, an idea of performance-based design was introduced which replaces the previous concept of the specification-based design. However, presently, it is difficult to adapt seismic performance-based design on compacted soil embankment. One of the reasons can be that there are many types of material used in embankment construction thus resulting in different physical property, strength-deformation, and permeability which makes difficult to adapt seismic performance-based design. Keeping in view the wide variety of material, dynamic behaviors of compacted embankment subjected to earthquake has not been yet fully studied.

At present in Japan, the degree of compaction D_c (%) has generally been employed as a designing index for constructing embankments. According to the design standard, main objective to construct stable embankment is to achieve degree of compaction set by the design. However, a few researchers point out that difference of water content at compaction w_i (%) under keeping the same dry densities has some influence on mechanical characteristics such as strength, deformation, stiffness and permeability (Hirakawa et al. 2008, Matsumura et al. 2011, Miura et al. 2011). Thus, such studies can be quite useful for the design of embankment but especially, there is almost no research that reveals dynamic response of compacted soils under a variety of compaction conditions as well.

In this research, an attempt is made to examine seismic response of compacted soil embankment under different compaction condition such as water content at compaction w_i and degree of compaction D_c. In this regard, a series of cyclic undrained triaxial test was carried out on saturated sandy-silt soil, which is named as I soil in this paper. This soil contains 68.1% of fine particles which pass through sieve size of 75 μm. Maximum particle size of testing material is 2.0 mm. Table 1 shows the physical properties of I soil. The specimens were compacted at the optimum water content w_{opt}, drier condition and wetter condition than w_{opt} with different compaction energies E_c (kN/m^3) to each specimen. As a result, it is revealed that not only the increase of D_c significantly improves strength-deformation properties but difference of w_i has considerable influence on cyclic strength-deformation characteristic even at the same degree of D_c.

Table 1. Physical property.

Sample name: I soil	
Soil particle density, ρ_s	2.578 g/cm^3
Natural water content, w_n	35.0 %
Liquid limit, w_l	46.8 %
Plastic limit, w_p	34.5 %
Plasticity index, I_p	12.3
Maximum grain size, D_{max}	2.0 mm
Fine fraction content, F_c	68.1 %

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Experimental study on deformation characteristics of granular materials made from recycled glass bottles under traffic loading

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ABSTRACT

In Japan, most of transparent and brown colored glass bottles are recycled. On the other hand, other colored glass bottles are not effectively recycled, since it is difficult to reproduce uniformly-colored homogeneous glass bottles from them. Thus, these glass bottles become wastes after single use. In order to reduce the amount of the waste of glass bottles, a new technology has been introduced to recycle glass bottles into granular materials to be used as geomaterials.

In order to use the material as backfill material of under ground pipes, not only high liquefaction resistance but also sufficient stiffness under traffic loading is needed, because backfill of under ground pipes is usually made at subbase of roads.

In this study, therefore, one-dimensional cyclic loading tests were carried out to evaluate the deformation characteristics of this material under traffic loading. In the tests, effects of "bedding error" (Tatsuoka & Kohata 1994) due to possible existence of loose zones near the top and bottom ends of the specimen that contact with rigid platens were concerned. In order to evaluate these effects on the deformation properties under cyclic loading, specimens with different heights were tested. The test results were analyzed in terms of the residual strain after the cyclic loading and the constrained modulus during the cyclic loading. In doing so, a simplified assumption was employed that the specimen can be divided into two parts; one is a bedding error layer that corresponds to the loose zones as mentioned above, and the other is a normal layer that is free from the effects of bedding error.

In addition, possible effects of particle crushing were investigated by measuring the gradation curves of some of the specimens before and after the cyclic loading.

The test results were also compared with those from relevant field loading tests in order to evaluate the applicability of the estimation method of the residual strain based on one-dimensional cyclic loading tests (Komatsu et al., 2006, Nishikawa et al., 2006).

Based on the test results and analysis, the following conclusions were obtained.

1. Residual strain of the granular material made from glass bottles after cyclic loading to simulate the traffic loads is 0.1~0.2%. It is in good agreement with the results of field loading test.
2. Particle crushing of the glass material due to the simulated traffic loading was not noticeable under the test conditions employed in this study.
3. The above performances suggest that the tested glass material can be used as a backfill material which is subject to traffic loading.

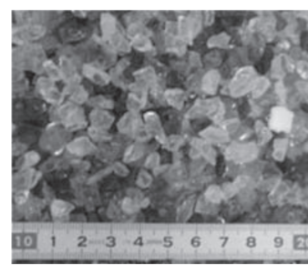

Figure 1. Granular material made from recycled glass bottles having diameters in the range of 5 to 10 mm.

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Dynamic centrifuge model tests on quay wall backfilled with granular treated soil

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ABSTRACT

Granular treated soil, which is dredged clay mixed with cement and polymer, has been developed for the effective use of the dredged soils (Kiyota et al. 2000; Kawai et al. 2002). Particles of the granular treated soil, of which size is 1 to 10 mm, are relatively large compared with ordinary sand. In this study, a series of dynamic centrifuge tests on applicability of the granular treated soil to quay-wall backfill was conducted in a centrifugal acceleration field of 50 G.

A schematic representation of the model ground is illustrated in Figure 1, which shows the prototype scale corresponding to the centrifugal acceleration. The conditions of the backfill are shown in Table 1.

In the dynamic test, the amplitude of the input waves was increased in a stepwise manner. Figure 2 shows the relationships between the cumulative horizontal displacement of the caisson and the input acceleration amplitude on the prototype scale. Displacement in Case 3 was considerably larger than that in the other cases. It can be thought that this large displacement was caused by liquefaction in the backfill of loose sand and high earth pressure. The displacement in Case 1 was reduced to half that seen in Case 2 when the input acceleration was large. It can be considered that the earth pressure from the backfill of granular treated soil during vibration was lower than that from dense sand because of its low unit weight and small response acceleration.

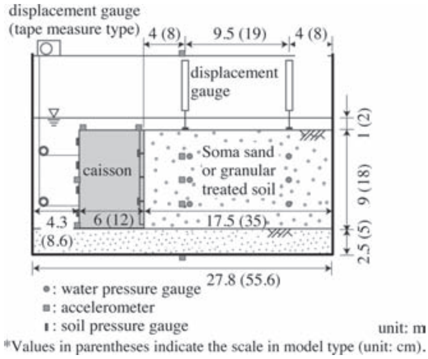

Figure 1. Schematic view of model ground.

Table 1. Test cases.

	Backfill material	Initial relative density (%)	Void ratio *e*
Case 1	Granular treated soil	–	3.08
Case 2	Soma sand (Cat. 5)	95	0.73
Case 3	Soma sand (Cat. 5)	53	0.90

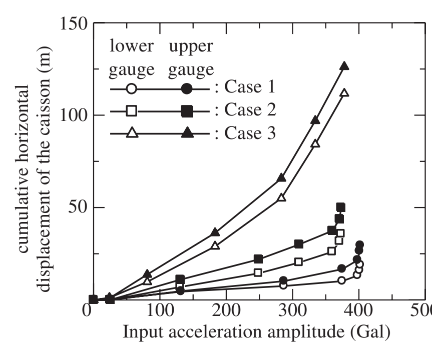

Figure 2. Relationship between cumulative horizontal displacement of the caisson top and input acceleration amplitude.

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Characterization of gold mine tailings for utilization in development of the rural infrastructure

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ABSTRACT

This paper presents the results of chemical, mineralogical, physical and geotechnical characterization of gold mine tailings from Barrick Bulyanhulu Gold Mines (BGM) for assessing its suitability for re-use in development of the rural infrastructure.

The chemical analysis shows that silicates (SiO_2) constitute about 50% of the oxides, followed by aluminates, Al_2O_3 (13%). SO_3 content was observed to be between 12%–19%. Soluble sulphates are responsible for formation of acid when subjected to reaction with air and water. The presence and dominance of quartz suggest stability of the tailings against solubility and weathering.

Mineralogical analysis shows that the major constituents of the tailings are quartz and muscovite [$(K,Ba,Na)_{0.75}(Al,Mg,Cr,V)_2(Si,Al,V)V_4O_{10}(OH,O)_2$] subordinated with clinochlore [$Mg,Fe)_6(Si,Al)_4O_{10}(OH)_8$]. Quartz and muscovite dominate the composition. These are silicate-bearing minerals which are stable and hence not prone to weathering under ambient condition.

Consolidated undrained (CU) triaxial test was done on undisturbed samples of tailings. The effective angle of internal friction ranges from 29° to 38° and cohesion ranges from 12 to117 kN/m². Results of the triaxial tests are summarized in Table 1.

A trial cement-stabilization scheme revealed 7-days soaked UCS of 280 kN/m² for 4% cement content. UCS values (strength) increase with increasing cement contents, as shown in Figure 1.

The research findings have revealed a potential of using the tailings in various infrastructural works, including production of bricks/block, mortar for masonry uses and filler material for asphalt and cement concretes. It may also be suitable (upon further research) for production of slurry seal for pavement repair and maintenance or used as a fill material in pavement construction. The tailings are less hazardous to the environment, as far as land application is concerned.

A parallel study has been launched on environmental acceptability of the stabilized tailings for different uses and level of exposure to the human being and the environment. Also, the second phase of this study has started on engineering properties and performance of cement stabilized tailings should be carried out for the different possible uses, especially for development of the rural infrastructure.

Table 1. Results of CU triaxial test on tailings samples.

Parameter	Tailings age and depth								
	2 WEEKS		3 MONTHS		6 MONTHS		1 YEAR		4 YRS
Depth	0 m	1 m	0 m	1 m	0 m	1 m	0 m	1 m	0 m
C′	33.8	70.8	83.3	96.3	84.1	117.4	12.0	67.9	48.1
Φ′	33.8	29.1	32.9	32.6	30.4	38.2	35.6	36.3	33.3

* C' in kN/m²; ** Φ' in degrees

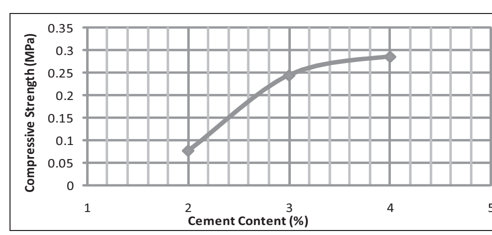

Figure 1. Variation of UCS with cement content.

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Mechanical characteristics of composite geomaterial mixed with lightweight granular material

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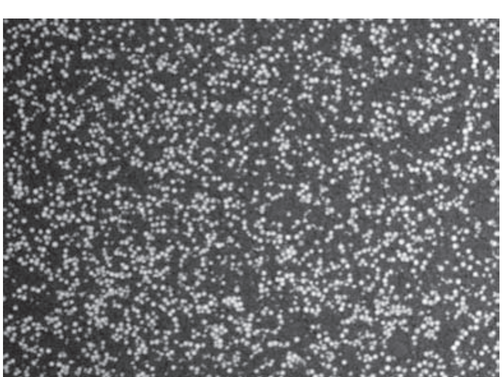
ABSTRACT

The soil in Japan, which is soft in large part, is often not suitable to build structures on it or to utilize as ground materials for building earth structures unless it is processed. Composite materials, the mixtures of soil and other materials and artificial materials and waste matter in recent years and to attribute new functions, are used as a countermeasure against this, and the Lightweight Geomaterial Mixed with EPS beads (LWGME) is one of the composites. A lightweight banking method with LWGME is expected to reduce environmental loads by reusing construction generated soils and to shorten construction periods and exceed in economic efficiency by reduction of the soil improvement range. However, as LWGME contains EPS beads with high compressibility (Photograph 1 shows state of LWGME), it is pointed out that it shows a different mechanical characteristics from the general geomaterials, which is dealt with in previous researches. Mori et al. (1993) clarified through the cyclic loading test that LWGME is applicable to the filled-up ground and subgrade if the load is about 50% or less in the unconfined compression strength. Moreover, our preceding study (Minegishi et al. 2008) showed that constructing road embankment with the cement stabilizer rate of 7% confirmed the improvement of its stability. At the present time, however, the concrete design standard and the design parameter in using LWGME for road embankment is not in advance.



Photograph 1. Lightweight geomaterial mixed with EPS beads.

In addition, the tendency of a design method of the pavement changes from the experiential to the theoretical with the multilayer elasticity theory. While the former method has used design CBR as the material condition, the latter considers the deformation modulus and poisson's ratio. This modulus is known to be affected by various factors and show different values, and therefore it is necessary to grasp the accurate modulus in order to prevent committing an error in designing a pavement structure.

In this study, as a part of our studies to make clear the design parameter and applicability of LWGME to subgrade, conducts the unconfined compression test, triaxial compression test, cyclic triaxial test, and box shear test to find out the mechanical characteristics of LWGME.

On assumption of utilizing the construction generated soil, Kanto loam, a sort of volcanic cohesive soil with high moisture content, was used as the base material. This was mixed with EPS beads with an amount of 2.01%, 2.04% and 2.07%, and Portland cement with that of 25%, 30% and 35% (both in mass ratio). This combination ratio was calculated by the result of the pretest, setting CBR as 3% and wet density as 1.1 g/cm^3. The test specimens were made to be 5 cm in diameter and 10 cm thick with a rammer of 2.5 kg, tamped down in the purpose-built mold five times for each three layers. The mechanical characteristics of the specimens, seven days after mixing and curing them, were examined by conducting four types of tests.

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Change in mechanical characteristics of embankment material by compaction control and its evaluation

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ABSTRACT

In recent years, due to earthquakes and heavy rains have been frequent collapses of embankment structures have happened. In order to prevent the collapses of embankment, it is well known that sufficient compaction of soil and draining the void water from embankment are very important. In design and construction of the embankments, the compaction management has been essentially based on the density information because it is widely recognized relationship between mechanical properties and various degrees of compaction for many soils. However the collapse of embankment does not decrease in recent years, reinspection about the mechanical behavior of the compacted soil is important for indication the validity of the compaction management.

In this study, the mechanical properties of an embankment material, which is denoted as I soil in this paper, were investigated. Mass of density of soil particle, ρ_s is 2578 kg/m^3. The liquid limit and plastic limit are 46.8% and 34.5%, respectively. The maximum grain size is 2.0 mm. The finer content of this soil is 68.1%. The mechanical properties of compacted specimens such as undrained strength, shear modulus and permeability coefficient were measured by a series of laboratory tests. The specimens were saturated and consolidated before measuring the mechanical properties. Figure 1 (a), (b) and (c) illustrate the results about maximum deviator stress, $q_{\max}$, shear modulus, G_{BE} and permeability coefficient, k at σ_c' of 50 kPa. From those figure, it can be recognized that the differences of density and water content at compaction affected the mechanical characteristics.

In this paper, the mechanism of change in mechanical properties due to differences in compaction conditions is described in terms of microfabric of compacted soil. Based on the test results, it is guessed that the geometry of soil particles is related to the mechanical behavior of compacted soil.

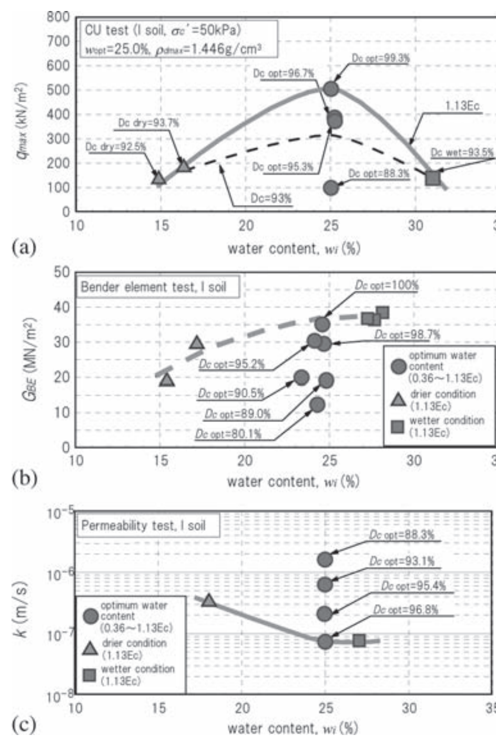

Figure 1. Relationships between the mechanical property and water content at compaction of *I* soil at σ_c' of 50 kPa: (a) $q_{\max}$-w_i; (b) G_{BE}-w_i; (c) k-w_i.

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4 *Asphalt mixtures and hydraulically-bound materials*

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Influences of in situ HMA compaction on its performances

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ABSTRACT

Some performance—based procedures were developed for the design and maintenance phases among the three phases of design, construction and maintenance in Japan. For the construction phase, however, generally the specification—based procedures in which all the sampled values of volume, size, quality, etc. of the construction work must satisfy the criteria at inspection have been adopted. Accordingly, the inspection results are either acceptable or unacceptable, and an interim result does not usually exist.

The method of payment for the performance of paving work at airports is studied by focusing on the density, one of the criteria in the inspection for paving work. First, the test data on the cored samples taken from the Hot Mix Asphalt (HMA) layers placed at an airport were collected, and the density, Marshall stability, etc. were measured. Next, the method of payment for the performance of paving work adopted in USA was applied to this paving work. Then, the performance of the work was quantified based on the number of load repetitions to fatigue failure of HMA. In addition, the influence of the number of samples on the results of the inspection for the paving work was examined.

Thirty cores were extracted from the HMA layers of an airport asphalt pavement in Japan, for which the structure and material properties were identical irrespective of position, as shown in Figure 1. The average and sample standard deviation of the degree of compaction in the surface course is 98.9% and 1.83%, respectively. Their performance was assessed by applying the above-mentioned construction quantification system used in USA.

The influence of the performance of HMA in the surface course on the amount of payment was then investigated. Namely, a Lot Pay Factor (LPF) was calculated at 98% of the specification lower tolerance limit of the degree of compaction. It was found that the percentage of material within specification limits (PWL) and LPF were 69% and 85%, respectively.

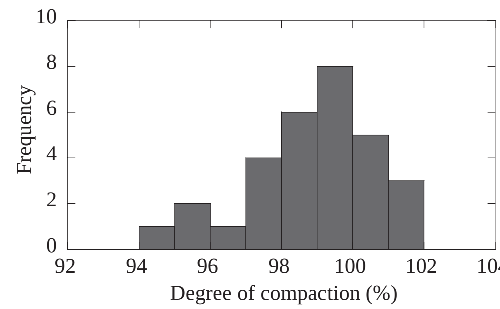

Figure 1. Frequency of degree of compaction for cored samples.

The difference in the fatigue life arising from the degree of compaction could be grasped. The fatigue life in the case of 95.6%, 98% degree of compaction falls to about 80%, 90% of that in the case of 100% degree of compaction, respectively. It is clear that the change in the fatigue life is conspicuous compared to the change in the degree of compaction; that is, the difference in one point of degree of compaction corresponds to a difference of about four points of fatigue life.

Relative fatigue failure repetitions were examined in the case of five and ten samples to investigate the influence of the number of samples on the performance quantification. It is found by comparing these two cases that as the number of samples increases, the variation of the relative fatigue failure repetitions decreases and the accuracy of the performance quantification increases.

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Characterization of emulsion bitumen stabilized aggregate base

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ABSTRACT

Stabilization of road aggregate base using emulsion bitumen is a common alternative when constructing and/or rehabilitating low volume pavements. The Emulsion Aggregate Mixture (EAM) is a combination of virgin/recycled mineral aggregate and a compatible type of emulsion (anionic or cationic) produced through cold mixing. The engineering behavior of the emulsion aggregate mixture is primarily influenced by aggregate gradation, properties of bitumen emulsion, environment temperature, and moisture content. Since there is no any unified laboratory method for EAM design, further research is needed to clearly characterize the mechanical and engineering properties of these mixtures. In this study, a well-graded crushed limestone was treated with SS-1hp type anionic emulsion bitumen. According to Table 1. Thompson (1995) mixture design procedure was followed to determine the required bitumen emulsion content based on aggregate gradation properties.

Several laboratory tests including gradation, Atterberg limits and compaction, i.e. moisture-density, were conducted on the virgin as well as emulsion stabilized base aggregate. According to a special curing procedure that was followed, the level of moisture susceptibility could be adequately specified for the EAM samples. Performance tests, such as indirect tensile strength and permanent deformation, and a new advanced directional resilient modulus test were conducted to evaluate the engineering properties of dry and wet cured EAM and virgin aggregate specimens. The findings from this study indicated that emulsion stabilization could adequately improve the bearing capacity of the pavement base/subbase by increasing the strength properties and reducing the tendency to deform under applied traffic loading. Directional resilient modules test results showed not only hardening characteristics behavior for EAM with increased stress states but also the horizontal to vertical resilient modulus ratios were considerably higher for the EAM samples tested. Such an increasing trend in the horizontal to vertical modulus ratios for the EAM was an indicator of improved shear strength properties when used within a pavement base/subbase layer.

Table 1. Emulsion aggregate mixture design properties.

Index	Value*
Required emulsion content in the mixture (%)	7.00
Residual asphalt content in the mixture (%)	4.23
Optimum mixing moisture content (%)	5.00
Maximum dry density at OMMC (gr/cm^3)	2.226

*All values are percentages by weight of dry aggregate.

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Effects of mineral fillers on rheological properties of asphalt binders

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ABSTRACT

Asphalt binders during mixing, construction or in-service of asphalt mixtures do not exist alone, but are admixed with mineral matter varying immensely in mineralogical and physical properties. Mineral filler or dust suspensions in asphalt binders form asphalt mastics which act as a matrix for coating the larger mineral aggregates. Since asphalt binder specifications for material grading, acceptance and construction control practices for asphalt mixtures are based on engineering properties of the neat binder, an analysis as to whether neat asphalt binders or asphalt mastic should provide pertinent information for material characterization and construction indices for asphalt mixtures is presented. Analysis of the effects of type and content of mineral fillers on the rheological properties of asphalt mastic to the penetration grade No. 70 neat asphalt binder designed to meet the JTG F40-2004 specification of China is demonstrated. Three different mineral fillers, or dust were separately dry mixed at dust to binder ratios ranging from 0.0 to 1.5 in ratio increments of 0.3% by measuring the weight of asphalt to get the desired binder content.

Analysis of test results show that asphalt mastic consistency properties are well-defined linear functions of mineral filler type and content. Hydrated lime mastics showed more significant effects than those for Portland cement and limestone tested at the same mineral filler content. Penetration and ductility shows a linear reduction at increased hydrated lime content of 4.8 (0.1 mm) and 8.2 cm per 0.1% of hydrated lime increment respectively while softening point increases at the rate of 4.7°C.

Figure 1 illustrates the asphalt mixtures mixing and compaction temperatures master curve developed for neat asphalt binder penetration grade 70 for use with hydrated lime, limestone and Portland cement at any mineral filler to binder ratio content.

The main findings from this study are as follows:

– Mineral fillers affect the rheological properties of asphalt binders by type and content.
– Hydrated lime shows more significant effects on rheological properties of asphalt binders compared to limestone and Portland cement.
– Equi-viscous concept can be used to determine the asphalt mixtures mixing and compaction temperatures on asphalt mastic with mineral fillers.
– Asphalt grading specifications based on penetration grade system should be done on asphalt mastic at the designed type and content of mineral filler other than on neat binders.

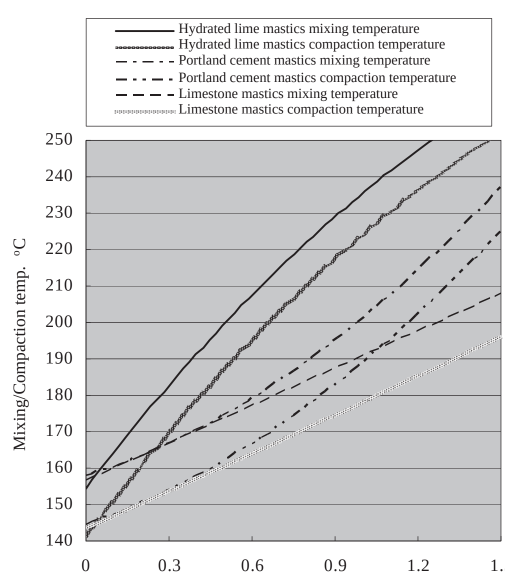

Figure 1. Mixing and compaction temperature master curve for pen.70 asphalt binder.

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Behaviour of asphalt mixture under large amplitude cyclic loading

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ABSTRACT

The aim of the research presented in this paper is to provide information on the behaviour of asphalt mixture under large amplitude cyclic loading and influence of large strain level pre-deformation on complex modulus E* and complex Poisson's ratio ν* that are linear viscoelastic parameters. A special cyclic loading path (Figure 1) is applied during homogeneous test on cylindrical specimen (height 14 cm & diameter 7.5 cm) kept at constant temperature (T = 25.8°C).

The test includes loading periods, unloading periods, rest periods and the measurement of complex modulus and complex Poisson's ratio of the material at different frequencies and different strain levels. A few loading/unloading cycles in large strain domain (up to 6% strain in compression and 0.6% strain in tension) at constant strain rate were carried out during the loading/unloading periods. After each loading/unloading period, a rest period was applied and the axial stress was maintained at 0 MPa. The measurements of complex modulus and complex Poisson's ratio were performed in applying some small strain amplitude sinusoidal cycles (less than 1E-4), with frequency sweep from 0.03 Hz to 10 Hz. These measurements were realized at the beginning of the test and after each rest period. The results are analysed in stress-axial strain axes and volume-axial strain axes. Trends similar to the one observed for unbound granular materials are obtained. The evolution of complex modulus and complex Poisson's ratio (norm and phase angle) during the test was also studied. The values are compared with the stiffnesses and the Poisson's ratios at the beginning of large loading cycles.

From the obtained results, the following conclusions can be drawn:

– A "limit" curve can be drawn in axial stress-axial strain and volumetric strain-axial strain axes.
– Trends similar to the one observed for unbound granular materials are obtained in the axes volumetric strain-axial strain. The material first contracts then dilates when loading.
– Values of the tangent Poisson's ratio correspond to asymptotic values of the norm of complex Poisson's ratio for small frequencies.

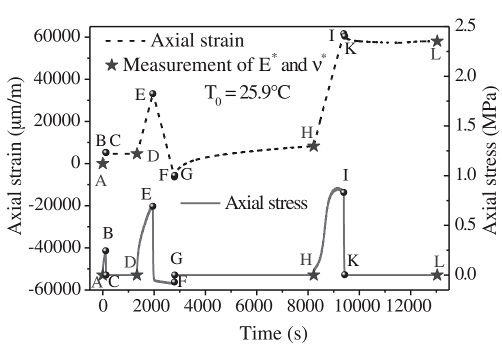

Figure 1. Axial strain and stress loading path.

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Effect of water on the strength of bituminous mixes with waste concrete aggregates

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ABSTRACT

Waste Concrete Aggregate (WCA) from demolished concrete contain porous cement mortar to the surface of the fresh aggregates. This highly porous cement mortar contributes to the variation in the quality of the WCA. The properties of WCA used in this study are given in Table 1. Paranavithana & Mohajerani (2006) reported that the properties of asphalt concrete with WCA are encouraging. The durability of bituminous mix is influenced by many factors including effect of water. Failure of the bond already formed, resulting in the displacement of the asphalt cement from the aggregates due to moisture, is referred to as stripping (Kennedy et al. 1983). Moisture damage can manifest itself through various failure mechanisms. These include rutting, fatigue, raveling, and potholes.

Bituminous mix with WCA is feasible option from the standpoint of stability and stiffness in dry condition but limited information is found on the effect of water on the strength of bituminous mixes with WCA. This paper presents some of the findings of an investigation of effect of water on the strength of compacted bituminous mixes with WCA. The following bituminous mixes were prepared. Fine aggregate and filler were same in this mixes.

Mix I: Contain crushed basalt aggregates as CA.
Mix II: Contain WCA from crushed basalt as CA.
Mix III: Contain WCA from crushed gravel as CA.

The Optimum Bitumen Content (OBC) for Mix I, II and III were 5.5%, 8.0% and 8.5% respectively.

To investigate the effect of water on the compressive and tensile strength of bituminous mixes, specimens were prepared and tested according to the procedures specified AASHTO T165-86 and T283-89.

Table 1. Properties of coarse aggregates.

	Coarse Aggregates (CA)		
Properties	Fresh basalt	WCA from basalt	WCA from crushed gravel
Bulk sp. gravity	2.79	2.38	2.27
Absorption, %	0.81	5.74	6.38
L.A. Abrasion, %	12	30	40

Table 2. Tensile strength test results for three mixes.

Mix Types		I	II	III
Average indirect	S_1	101.5	99.0	98.4
Tensile strength (psi)	S_2	80.7	63.4	61.1
Tensile strength ratio, TSR, %		79.5	64.0	62.1

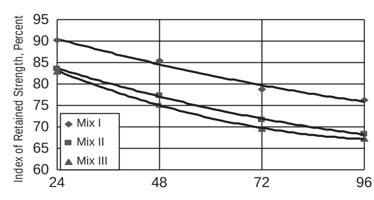

Figure 1. Relationship between Index of Retained Strength (IRS) and soaking period for three mixes.

The relationship of index of retained strength and soaking periods for three mixes is shown in Figure 1. A summary of the indirect tensile strength test results for the three mixes is presented in Table 2.

CONCLUSIONS

1. Some of the measured properties satisfy the recommended limits for IRS of 75% (Asphalt Institute 1981) and TSR of 60–80% (Lim 2003).
2. WCA is more moisture susceptible than conventional aggregate however, bituminous mixes with WCA can give satisfactory results when subjected to lower soaking periods.

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New X-ray CT evaluation method of engineering characteristics of asphalt mixture

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ABSTRACT

Recently, studies on aggregate profile and crack propagation using X-ray CT have been reported. However, no researches have been reported on the quality control of asphalt pavements. The objective of this paper is to propose evaluation indexes such as bitumen content and gradation of the quality evaluation for asphalt mixtures using X-ray CT.

The following approach was employed in this study; 1) Eight specimens of several types of asphalt mixtures were prepared; 2) Five cross sections of these specimens were scanned by X-ray CT with five cross sections; 3) Threshold values and 4 segmentation images obtained by the CT-values in order to discuss the internal behavior.

For example, Figure 1. shows CT images of the asphalt mixture at the center of the specimens, Figure 2. shows a histogram of CT-value, Figure 3. shows threshold values, and Figure 4. shows 4 segmentation images according to the different mixture type.

This paper presents the results of our X-ray CT test. As a result, CT image and 4 segmentation images expressed the distribution of aggregate, bitumen and void. In addition, histograms of CT-value and 4 segmentation images made from CT images expressed the difference in bitumen content and mixture type visibly. The results of this study will contribute to improving quality evaluation of asphalt mixtures.

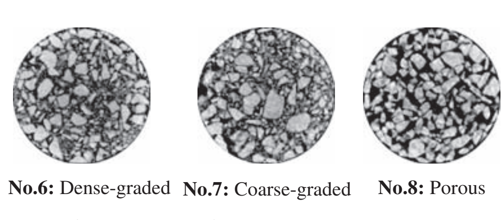

Figure 1. CT image of asphalt mixture according to the different mixture type.

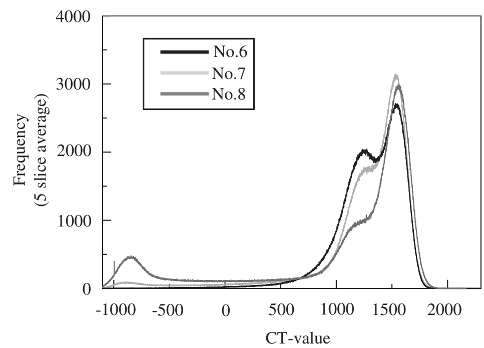

Figure 2. CT-value distribution according to the different mixture type.

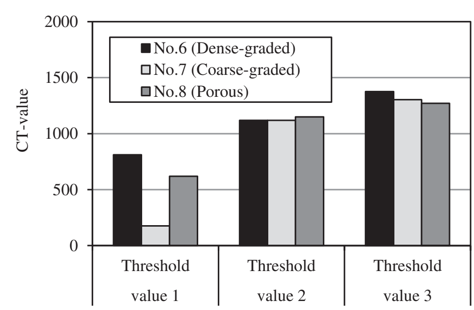

Figure 3. Threshold values according to the different mixture type.

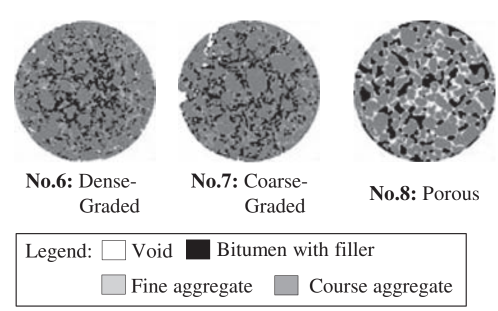

Figure 4. 4 segmentation images according to the different mixture type.

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A study of developing new tests to evaluate compaction property and deformation resistance for slipform paving concrete

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ABSTRACT

In the Slipform Paving Method (SFP), slipform pavers with multiple functions such as spreading, compacting, casting and finishing the surface of concrete are used and concrete is continuously placed without using any formwork or rails. SFP is more advantageous than side form paving as it needs neither the installation nor the removal of formwork and rails, simpler work process owing to fewer construction machines required and less manpower required for paving, and it provides greater construction capacity. In Japan, labor saving has recently been required because of the shortage and aging of workers, and cost reduction has also been required. Construction using SFP has been increasing since the mid-1990s mainly for the construction of continuous reinforced concrete decks in composite pavements on expressways.

The concrete used for SFP (SFPC) needs to be self-supporting at the end and maintain its shape the moment the paver passes. SFPC should therefore be controlled more strictly than side form concrete because slipform pavers are machines of relatively simple structure and are used for placing concrete without using any formwork. The property of fresh concrete during construction (workability) is especially important. Excellent compaction property and deformation resistance are essential to SFPC. Evaluating compaction property and deformation resistance by slump and air content tests is, however, difficult. No test methods have yet been established in Japan for evaluating these parameter of SFPC.

Then, the authors have examined test methods for evaluating the compaction property and deformation resistance of SFPC. In the developed test method, a flow table used in mortar flow tests, which are generally adopted for testing, and formwork used in California Bearing Ratio (CBR) tests were used. The developed method enables field testing because simple equipment is used that can be hand-carried and requires no electricity. The method enables quantitative evaluation of compaction property and deformation resistance. Compaction test is shown in photograph 1 and Deformation resistance test is shown in photograph 2.

Photograph 1. Compaction test.

Photograph 2. Deformation resistance test.

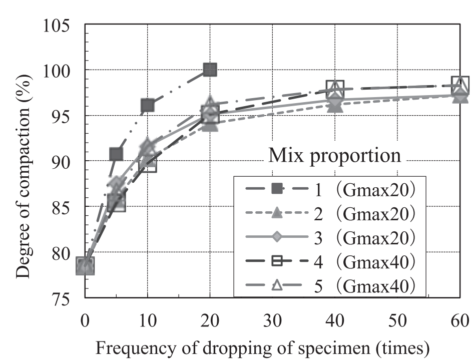

Figure 1. Relationship between the frequency of weight dropping and the degree of compaction (An example of a test result).

The developed evaluation method revealed that SFPC with equivalent slump and air content had varying compaction property and deformation resistance according to the material and mix proportion. The effectiveness of the evaluation test also proved effective. The applicability of the test to the judgment of workability was also found since the state of field construction of slipform paving concrete was in agreement with the results of evaluation. Now, these tests are used for the mixing correction and construction management.

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Interpretation and application of repeated torsional shear test on asphalt mixtures

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ABSTRACT

In this paper, repeated torsional shear tests were carried out on the cylindrical specimens of three different types of asphalt mixtures, polymer-modified dense-graded asphalt, dense-graded straight-asphalt and polymer-modified porous asphalt mixtures. Based on the results, plastic flow resistance, the tenacity from stripping ititiation up to rupture and durability (the number of repetitions to reach a certain shear strain level), etc. were evaluated in a comparative manner.

Figure 1 illustrates the relationships between average shear strain and the number of load applications together with some annotations. Almost all the test results exhibited that average shear strain increased rapidly at the beginning, then more or less at a constant rate and again rapidly as approaching to rupture. From a straight-line approximation of the relationship between average shear strain and the number of load applications in each stage gives two inflection points for plastic flow and stripping. The former is the intersection of the consolidation and plastic flow lines and the latter is the intersection of the plastic flow and stripping lines. The inclination of plastic flow line is related with plastic flow resistance of asphalt mixtures: the smaller the inclination, the larger the plastic flow resistance. Similarly, a smaller inclination of stripping line implies an asphalt mixture with a greater tenacity from stripping initiation up to rupture.

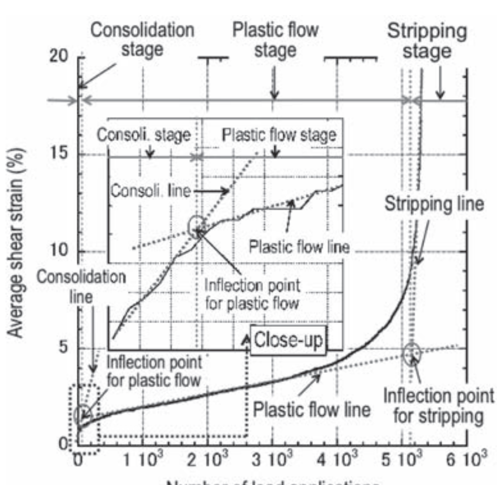

Figure 1. Illustrative relationship of average shear strain with number of load applications.

The main findings from this study are follows:

– The polymer-modified dense-graded asphalt mixture possesses the highest plastic flow resistance and the straight-asphalt mixture the lowest. This is supported by the magnitudes of their dynamic stability.
– The polymer-modified dense-graded asphalt mixture exhibits the highest tenacity from stripping initiation up to rupture.
– The number of load applications at the inflection point for stripping is the largest in the polymer-modified dense-graded asphalt mixture.
– Asphalt mixtures with a higher deformation rate during the consolidation stage deforms at a higher rate during the plastic flow stage.
– Asphalt mixtures experiencing a smaller shear strain at the inflection point for stripping could sustain a larger number of load applications.

Since the number of test data is limited; thus, accumulation of more test data appears necessary for these findings to be justified. Currently, asphalt mixtures with various polymer-modified binders are being tested and whether or not the effects of these various binders can be differentiated using these evaluation indices is under investigation.

5 *Earthworks for transportation facilities*

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A study on the structural assessment of pavement damaged by the Tohoku Earthquake and liquefaction and causes of the damages

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ABSTRACT

At 14:46 on March 11, 2011, an M9 earthquake struck the coast of the Tohoku region of eastern Japan. In this study, the damages to road pavement by the large seismic motion of the earthquake and the liquefaction of the subgrade were analyzed and classified by the morphology of the damage and causes. The pavement of roads in areas affected by the earthquake and/or that suffered liquefaction was surveyed by using Falling Weight Deflectometer (FWD). The survey showed that the pavement of roads designed for large traffic volumes of heavy vehicles was less affected by the earthquake and liquefaction than the thin pavement of roads designed for small traffic volumes and pedestrian paths. The paper also reports the damages to road pavement and public facilities caused by the huge tsunami that engulfed the coast one hour after the earthquake. Measures for mitigating damages to pavement during earthquakes and by liquefaction are also proposed.

In Kajima and Kamisu Cities, Ibaraki Prefecture, which is located near Kasumigaura Lake, liquefaction caused highways of even deep pavement (Photo 1) to subside and manholes and pedestrian paths of thin pavement to float. A drainage canal under a pedestrian path along a municipal highway, which was connected to a prefectural highway, rose due to liquefaction.

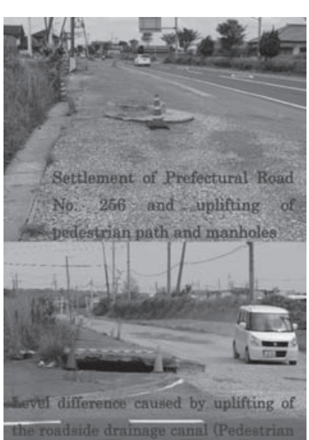

Photo 1. Liquefaction damages in Horiwari, Kamisu City.

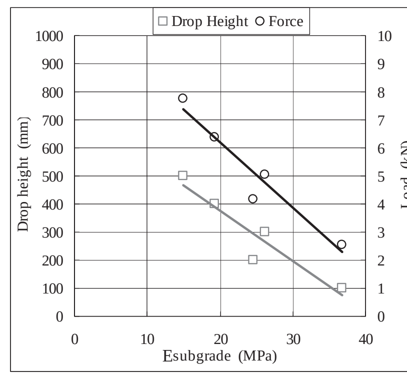

Figure 1. Re-liquefaction processes in loading test by PFWD.

A weight of 10 kg was dropped on a loading plate of 200 mm diameter from various heights starting from 100 mm. The modulus of elasticity (E subgrade) determined from the load and deformation is shown in Figure 1. When the weight was dropped from 100 mm, the modulus of elasticity was 34 MPa. As the load was increased by increasing the height from which the weight was dropped, the sand lost its bearing capacity uniformly against the load, showing a process similar to re-liquefaction.

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A study on increased layer thickness for embankment construction using ordinary compaction machinery

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ABSTRACT

The number of large-scale earthworks with high embankments has increased as the scale of works has grown in recent years. Accordingly, it is expected that the implementation of efficient earthwork projects will lead to reduced construction costs and positive economic effects brought by early placement into service. Against such a background, the authors considered increasing the lift thickness of each embankment layer from the standard thickness in the interests of efficiency and leveraging economic potential. In addition, in contrast to the usual technique of increasing the lift thickness of embankments using large rollers, on-site test construction was conducted using a standard roller on an actual embankment construction site to expand the scope of application.

On-site test construction was conducted using soil types classified as coarse-grained soil and volcanic ash soil. The results indicated that gravelly soil with a gravel content of 60% or more may not be suitable for increasing the lift thickness of embankments, as it was difficult for the compaction effect to reach deeper parts, while sandy soil and gravelly soil with a gravel content of less than 60% were found to be suitable for the purpose. It was also found that volcanic soil may be unsuitable for increasing lift thickness, or that the current standard value for it may be too large.

Based on these on-site test construction results, this study presents a flow (Fig. 1) of consideration concerning the number of roller passes during test construction and increased embankment lift thickness.

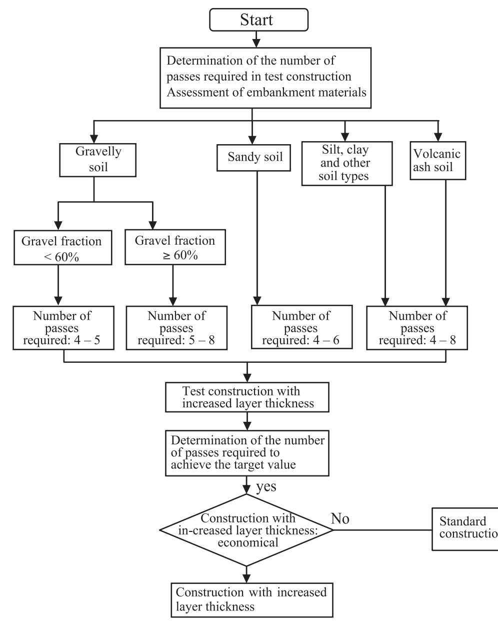

Figure 1. Procedure for examining the applicability of construction with increased layer thickness.

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Influence of the drainage in the reinforced soil wall during seepage flow

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ABSTRACT

Reinforced soil wall has been applied to lots of soil structure, because it has been economical solution to various geotechnical problems and it has high performance for seismic load owing to flexible structure. In the design method of such soil structure, ground water in the backfill has been considered that it drained rapidly and certainly to prevent the degree of saturation of backfill increasing which cause serious deformation and destruction of soil wall. Therefore, the constructed drainage into a soil structure must survive until structures that applied reinforcement techniques will service stop. Recently, not only the amount of rain but also intensity of rainfall has been increased, however, it is important to consider a change in the function of drainage and to assess the performance of reinforced structure due to rainfall. The rainfall type on slope failure is divided into two patterns on spread process of saturation area in the ground. One type of rain which classified impact rain has large intensity of rainfall and it often causes a surface of ground to saturate. Another type of rain is called continuous rain and it generates the seepage flow in the ground.

In this study, a series of centrifuge model tests were carried out to clarify the reinforce mechanism of the multi-anchor reinforced soil wall during seepage flow, and to verify the contribution of drainage to the performance of such soil structures. Following conclusions were obtained.

1. The factor of safety, which calculated by means of the pull-out resistance against the mobilized tensile strength, represented suitably the failure mode of multi-anchored soil wall due to seepage flow. Namely, the process of unstableness of soil wall calculated in the conventional design method was established by centrifuge model tests.
2. A smaller shear deformation of backfill and the smaller settlement of the top surface of soil wall were observed with the larger drainage subjected to the seepage flow.
3. The appropriate construction of drainage was important to prevent the ground water behind facing wall rising and to keep earth pressure constant without increasing by increase the pore water pressure.

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The effect of dry unit weight, suction, and imparted energy on the modulus of a compacted mixture of sand and kaolin

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ABSTRACT

During construction the field compaction characteristics are evaluated based on a minimum deviation interval from the pre-established laboratory key parameters (i.e. Maximum Dry unit weight, or MDD and Optimum Moisture Content, or OMC). Although controlling the quality of compaction with those criteria has been well established, problems related to poor compaction still occur (i.e. differential settlements, increase in pavement roughness). This, in turn, often deems necessary the execution of costly and time consuming post-construction maintenance because the verification of compaction control can cover limited area (typically less than less than 1% of the actual compacted area NCHRP 676, 2005).

Recently, Intelligent Compaction Control (ICC) technologies have emerged to address this problem. Various manufacturers have equipped their compaction roller drums with an accelerometer based measuring systems (i.e. vibratory rollers), which are able to record the soil response (i.e. soil stiffness or modulus) while the soil is being compacted (Anderegg, 2000) (Fig. 1).

Although this novel method looks promising the effects of dry unit weight, moisture content, matric suction, and the energy used to compact the soil are still not understood very well.

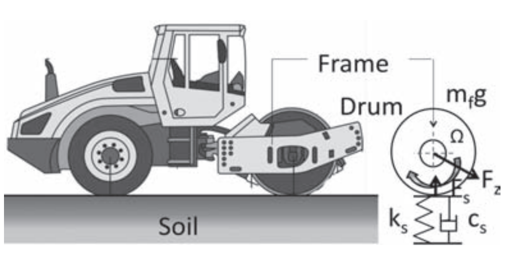

Figure 1. Illustration of a conceptual model of the interaction between soil and a vibratory roller.

Table 1. Main properties of the sand-kaolin mixture.

Properties	Sand-kaolin soil
Liquid limit (%)	21
Plasticity index	15
Specific gravity (G_s)	2.63

In this paper the soil modulus of compacted beach sand and a commercial mixture of kaolin soil were investigated (Table 1).

A non-destructive technique using Bender elements was used to determine the small-strain modulus, whereas the matric suction was evaluated using the filter paper method. The results of the tests showed that while the influence of compaction energy on the low moisture content range was clearly evident (i.e. increase in energy translated into an increase in the modulus), at OMC and higher moisture contents the role of matric suction seemed more significant (i.e. smaller values of modulus were obtained for increasing energy levels). This modulus-energy-suction(or moisture) relationship seems to indicate that applying additional energy to the lift (i.e. passes by the roller) does not necessarily lead to superior soil shear stiffness and that if the placement moisture is kept in smaller intervals centered at OMC compaction process may be more efficient (i.e. smaller variation on the soil modulus).

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Proposal of control criteria for embankment compaction in Hokkaido

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ABSTRACT

As the quality of embankments is correlated to their strength and density, which can be determined easily at low cost, methods based on the degree of compaction are widely used in quality control. In light of recent increased demand for a safe, secure social infrastructure, there is growing interest in road embankment and riverbank structures that have sufficient strength to withstand earthquakes and severe storms brought by abnormal weather conditions. The authors studied the relationship between the degree of compaction and the strength of the embankment type mainly used in Hokkaido, and determined variations in density and materials at execution sites.

The results showed that:

1. The adhesion strength and internal friction angle tend to increase with higher levels of dry density. When density is uniform, both adhesion strength and the internal friction angle decrease with higher levels of water content.
2. Density measurement based on impact acceleration testing should not be applied to materials whose water content at the time of construction is 1.2 times or more greater than the optimum water content, and whose cone index is found to be 300 kN/m^2 or smaller in trafficability testing.
3. Embankment quality control based on impact acceleration is appropriate for materials with high gravel content if gravel correction is not required.
4. While single embankment layers usually consist of a uniform material, different layers may be made of different materials. As the materials used in testing and actual construction may also differ, correspondence should be checked carefully.
5. As density varies greatly at different construction sites, average values should be used rather than single minimum values, and the current reference value for embankment quality control should be increased.
6. Current reference values should be reconsidered for materials whose maximum dry density cannot be determined.
7. At sites where over-compaction is likely, the status of embankments must be observed, and density should be measured using the core cutter method as necessary.

The authors therefore believe that the current criteria should be reviewed, and propose control criteria that match the actual situations of the embankment type adopted by the Hokkaido Regional Development Bureau.

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Numerical study on dynamic interaction between embankment and consecutive culverts

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ABSTRACT

Multi-arch culverts embankment (Figure 1) is a new type of filling structure where several precast arch culverts are installed continuously in the direction of the road extension. The key of the successful design is to estimate the practical interval between installed arch culverts and to clarify the interactive behavior between filling material and precast structure in considering the seismic influence.

In this study, dynamic FEM analysis has been carried out to investigate the influence of spacing between arch culverts. The objective structure represented a fill of 5.0 m to be constructed on a 7.5 m thick sandy ground with overburden height of 0.7 m above the arch culvert. Unit interval L between the precast arches was expressed as a function of the culvert height H. Results with consecutive arch culverts were compared to the cases without precast arch culvert and with an arch culvert.

Subloading t_{ij} model (Nakai and Hinokio, 2004) was used to simulate the foundation ground and filling. This model can properly describe the influence of the intermediate principal stress, the dependence of the direction of plastic flow on the stress paths, density and confining pressure on the deformation and strength of soils. While modeling of culvert, nonlinear moment-curvature relation was simulated using the AFD model (Zhang and Kimura, 2002), which considered the axial-force dependency according to variable axial force of the structure.

The input ground motions used in this study is the time history of acceleration measured in the centrifuge model test when 1 Hz sin wave was inputted by controlling the displacement of vibration table.

From this numerical study, following conclusions can be draw:

1. When earthquake-proof stability of arch culvert is examined, the generation of bending moment at the foot is especially important, and the influence of the installation interval on the fill between arch culverts was remarkable in the foot. (Figure 2)
2. In case with a wide unit interval, large bending moment is already generated in the initial state because of the self-weight of the surrounding soil, and large maximum bending moment is generated compared with the case with narrow unit interval.
3. When the installation interval is wide, the amount of the subsidence at the center of the unit becomes large.

Figure 1. Multi-arch culverts embankment.

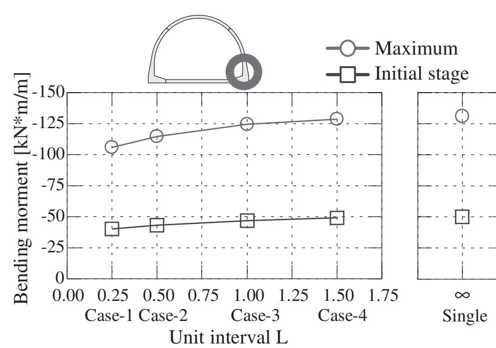

Figure 2. Initial and maximum bending moment at the foot.

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Relationship between compaction equipment and compaction results

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ABSTRACT

Compaction greatly affects the quality of embankments after their construction. Embankment compaction is usually conducted using compacting machines, which come in a range of types with various specifications. Accordingly, it is important to select models appropriate for the relevant site conditions and embankment materials to ensure sufficient compaction. In this study, a variety of materials were compacted using six machine types, and the relationship between the number of passes and the degree of compaction was evaluated.

Compaction was conducted using different machines in test construction to evaluate changes in the number of passes required and the degree of compaction. Materials and machines adopted in actual embankment work in areas around the test site were used. The test was conducted in Hokkaido using six types of compacting machines (vibrating rollers, combined rollers, hand-guide rollers, tire rollers, rammers and bulldozers) for a total of 72 cases.

According to the experiment result, no significant difference was seen between the average numbers of passes for gravelly and sandy soil when combined rollers, hand-guide rollers, tire rollers and bulldozers were used. These four types are considered to have similar compaction effects for both types of soil.

For vibrating rollers, the average number of passes required to achieve 90% compaction tended to be smaller on gravelly soil (Figure 1). Vibrating rollers are forced-vibration-type compacting machines, and this kind of vibration provides a high compaction effect by facilitating soil particle movement. This forced vibration was thought to be especially effective on gravelly soil.

The experiment result where different machines were used for compacting the same materials shows that machines with stronger forced vibration and higher contact pressure can achieve the necessary compaction rate with fewer passes.

The following findings were obtained: (1) Combined rollers, hand-guide rollers, tire rollers and bulldozers display similar compaction effects for both gravelly and sandy soil. (2) Vibrating rollers are suitable for compaction of gravelly soil. (3) Machines with stronger forced vibration and higher contact pressure can achieve the necessary compaction rate with fewer passes.

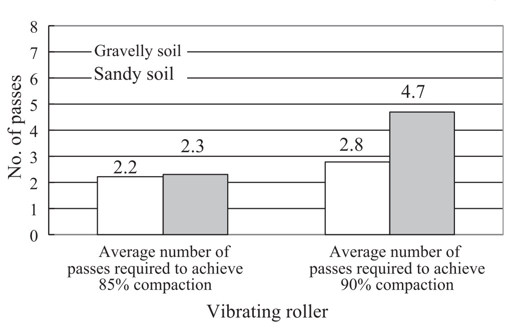

Figure 1. Average numbers of passes required to achieve 85 and 90% compaction (divided into gravel and sandy soil).

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6 *Application of geosynthetics*

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Monitoring and predicting the seismic behaviors of geosynthetic reinforced soil retaining structures

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ABSTRACT

The seismic response of Geosynthetic Reinforced Soil Retaining Structure (GRSRS) becomes a significant issue after several damaged earthquakes lately. In this study, 3 seismic instruments are arranged to monitor the acceleration time histories of the GRSRS built in FoGuang University, Ilan, Taiwan (Figure 1). The recorded acceleration data are subsequently used for the comparison purpose with the numerical analysis of GRSRS using FEM.

This study illustrated the in-situ investigations and the numerical simulations for the GRSRS under different sizes of earthquakes. The conclusions of this study are as follows:

1. According to the monitored results, it is found that the acceleration on the top portion is higher than those at middle portion and at the ground surface of the GRSRS. The recorded site amplification factor is 1.5 to 1.75 for the study GRSRS built in FoGuang University under a small earthquake. This is the same as the concept of site amplification effect under small to medium earthquakes.

Figure 1. The GRSRS site photo in Fo-Guang University.

2. From the predicted results by PLAXIS, the accelerations under two famous earthquakes demonstrate that the peak accelerations in the GRSRS are lower than the peak ground surface accelerations. The site amplification factor is 0.71 for the 921 Earthquake, while the site amplification factor is 0.91 for the 331 Earthquake.
3. From the predicted results by PLAXIS, the maximum tensile force is 19.10 kN/m under static condition. Using the 921 Earthquake record, the predicted maximum tensile force is 57.85 kN/m. Using the 331 Earthquake record, the maximum tensile force is 35.61 kN/m. It is noted that the predicted maximum tensile force in the reinforcement of GRSRS in Fo-Guang University is 57.85 kN/m using 921 Earthquake record, which is acceptable for stability consideration.
4. Based on the attenuation law theory, site amplification effect is an intensity-level dependent function. The highly non-linear behavior of ground soil is automatically taken into account in the intensity-level dependent function. This can be the reason for the diverse tendency of the site amplification factors measured and predicted in this study for the GRSRS.
5. Observing the measured data and the predicted results of the study GRSRS built in FoGuang University under different earthquake scales, it is concluded that the site amplification factor for acceleration can not be represented with a simple factor. As a result, it is recommended that the seismic numerical simulation is needed for each GRSRS during the design phase to guarantee the overall stability.

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Effects of subbase geogrid reinforcement on residual deformation characteristics of asphalt pavement

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ABSTRACT

This study focuses on the residual deformation of the asphalt pavement subjected to traffic load. Stress distribution in the subbase layer as well as residual deformation characteristics of the base aggregates during wheel loading was investigated by performing of a series of laboratory wheel loading tests on asphalt pavement. Furthermore, the effects of geogrid reinforcing technology on the residual deformation characteristics of the asphalt pavement structure were also examined in the present study.

The following trends of stress conditions as well as movements of the aggregates in the conventional unreinforced subbase during wheel loading were obtained;

1. The load from a passing wheel generates pulses of normal and shear stresses in the subbase. The normal stress shows a single pulse. However, the shear stress has a double pulse with a sign reversal.
2 Particularly in shear stress, the direction as well as the value depends on the position of the vehicle. Therefore, the direction of the principal stress in the subbase rotates continuously during a passing wheel load.
3. Figure 1 shows the typical movements of the subbase aggregates at different depths in the subbase, obtained from image analysis. The subbase aggregates moved not only vertically but also horizontally corresponding to the stress conditions mentioned above.

Residual deformation of the subbase is closely related to the stability of the surface asphalt layer. Therefore, reducing aggregate movement using soil improvement technology is important for maintain the long-term stability of the pavement structure. The following trends in the effects of geogrid reinforcing of the subbase can be obtained in the present study;

4. It was also confirmed that there were pulses of normal and shear stresses in the reinforced subbase during a passing wheel load. The principal planes rotated continuously relative to the movement of the roller.

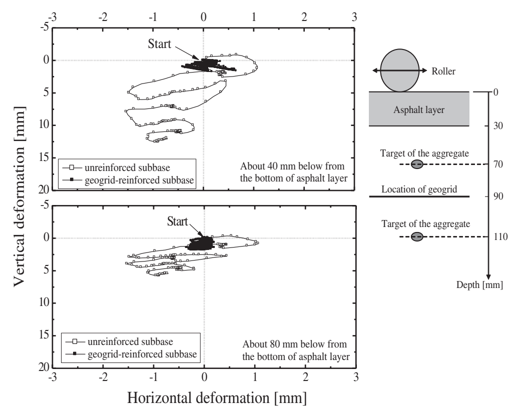

Figure 1. Movements of the subbase aggregates due to wheel loading.

5. Movements of the subbase aggregates in the reinforced subbase were significantly reduced, although the stress conditions in the subbase did not differ much from those described above in 4). It could be seen that horizontal movements as well as residual settlement of the subbase aggregates caused by wheel loading became extremely small due to the geogrid layer in the subbase (Figure 1).

In this study, it was confirmed that geogrid reinforcement technology can effectively improve the stability of pavement structure by reducing the movement of aggregate subjected to wheel loading.

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Performance of a Bearing Reinforcement Earth (BRE) wall and its numerical simulation

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ABSTRACT

The bearing reinforcement (Figure 1) is regarded as a cost-effective earth reinforcement. A full-scale test on a bearing reinforcement earth wall was performed at the campus of Suranaree University of Technology. The wall was 6 m high, 9 m long and 6 m wide at the top, and 21 m long and 12 m wide at the base. The field measurement of the bearing reinforcement earth wall by Horpibulsuk et al. (2011) was taken for the numerical simulation. The BRE wall was modeled as a plane strain problem. The geotextile elements, which cannot resist the bending moment, were employed to simulate the bearing reinforcement. The soil/bearing reinforcement interface parameter, *R*, was from the back analysis of the laboratory pullout tests by Horpibulsuk and Niramitkornburee (2010). The elastic perfectly-plastic model was used to simulate the constitutive relation of the interface between soil and bearing reinforcement. Detail of the simulation can be referred to Suksiripattanapong et al. (2012). The *R* values are 0.65 and 0.75 for 2 and 3 transverse members, respectively. The facing panel was modeled as a beam element. The soil-facing panel interface, *R*, was taken as 0.9.

Overall, the behavior of the BRE wall is simulated satisfactorily and agreed well with the predictions. The changes in foundation settlements, bearing stresses, and tensions in the reinforcements during and after construction are in good agreement with the measured ones. The bearing stress distribution is approximately trapezoid shape as generally observed for embankments found on hard stratum. The foundation settlement is almost uniform due to the effect of high stiffness of the foundation and reinforcements. The maximum tension (possible failure) plane is bi-linear and very close to that recommended by AASHTO (2002) for inextensible reinforcements. In practice, this recommended maximum tension plane is acceptable to examine the internal stability of the BRE wall. The knowledge gained from this study can be applied to other BRE walls with different wall heights, foundations and features of bearing reinforcements.

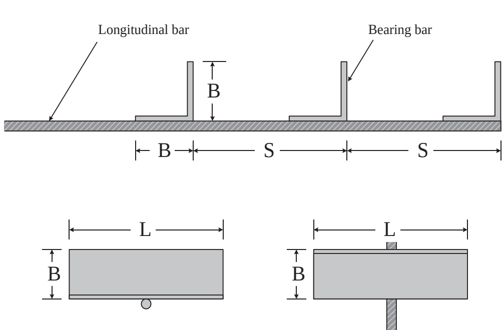

Figure 1. Configuration of the bearing reinforcement (Horpibulsuk & Niramitkornburee 2010).

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Rural road maintenance using geotextile available in developing countries

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ABSTRACT

In developing countries, people in rural area are constrained to access to the markets and social services due to the road conditions that can't keep the trafficability especially during rainy seasons. The authors devised the strategy to improve the trafficability of the rural roads, which is to encourage the communities along the road to work on roads by providing the road maintenance method utilizing the locally available material and minimizing the use of any machinery equipment. As such road maintenance, "Do-nou" which is Japanese term for soil bags, can be said one of the geotextile available rural area in developing countries, were applied to build the base course.

Through the tensile strength tests on the woven bags for crops, fertilizers and seeds available in rural area of the developing countries, it was found that those bags own enough tensile strength to apply the base course.

The full scale driving tests were conducted to evaluate the efficiency of the reinforcement by laying "Do-nou" as base course. The settlement of base course reinforced with 2 layers of "Do-nou" was reduced to 33 % of that consists of gravel with no reinforcement.

Then, the road maintenance using "Do-nou" technology was applied to the several projects in rural area of the developing countries. The communities who acquired the road maintenance method were motivated and empowered to initiate their own development scheme, such as the continuous works for road maintenance. The small scale contractors also accepted "Do-nou" technology to be applied to the maintenance of road infrastructures.

These applications of "Do-nou" technology enabled communities to maintain rural roads continuously by themselves leading to keep the accessibility to social services. This can be viewed as a step to reduce poverty in developing countries.

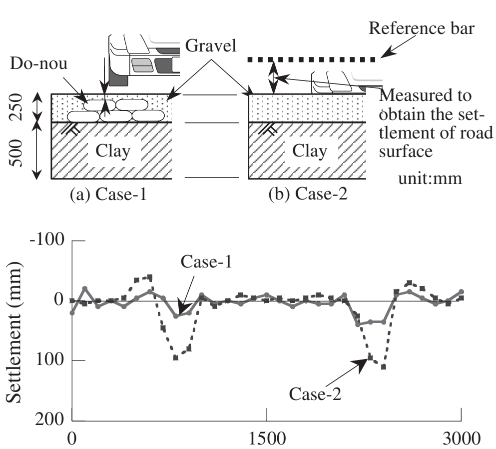

Figure 1. The settling of the road surface after a vehicle passes 10 times.

Figure 2. Demonstration of spot improvement using "Do-nou" with the staff of LBT training institute and contractor.

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Effectiveness of geotextiles in unsurfaced pavements over weak subgrade evaluated from accelerated field testing

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ABSTRACT

This paper presents findings from a recently completed research study at the University of Illinois that evaluated the performances of three different open-graded aggregate materials with large top-size particles (also referred to as **C**oarse **A**ggregate **S**ubgrade or **CAS** materials) for unsurfaced pavement and construction working platform applications. Geotextile separation and reinforcement of the aggregate-subgrade interface was considered in the experimental design to improve load distribution within the aggregate layer and prevent material migration across the layer interface.

Three test sections, each 4.6-m long, were constructed by first placing a 305-mm thick CAS layer over a weak subgrade of controlled strength (CBR = 1%), and subsequent capping by a 152-mm thick dense-graded crushed limestone layer. The constructed test sections were loaded to failure along two wheel paths separated by a distance of 244 cm through unidirectional application of a 44.5-kN single wheel load using the University of Illinois **A**ccelerated **T**ransportation **L**oading **A**ssembly (ATLAS). A 274-cm wide geotextile strip was placed under one of the wheel paths to evaluate its effectiveness as a separation layer at the CAS-subgrade interface.

Figure 1 shows the rut accumulations in the three test sections upon testing under unreinforced conditions. Interestingly, the intermediate size aggregate in Section 2 performed the worst among the three CAS materials. The largest size CAS material in Section 3 performed the best due to bridging of the large aggregates across the 305-mm thick engineered subgrade layer.

The wheel path trafficking performances were greatly improved in all the test sections under reinforced conditions (see Figure 2). Section 2 sustained 159 load applications before accumulating approximately 100 mm of rutting compared to 63 load applications in the unreinforced case due to more uniform load distribution. Unlike the unreinforced wheel path, no sudden increase in the rut depth with increased number of load applications was noticed. Subsequent excavation of transverse trench sections across the wheel paths showed significantly reduced subgrade intrusion into the CAS layer for sections constructed with geotextiles placed at the CAS-subgrade interface.

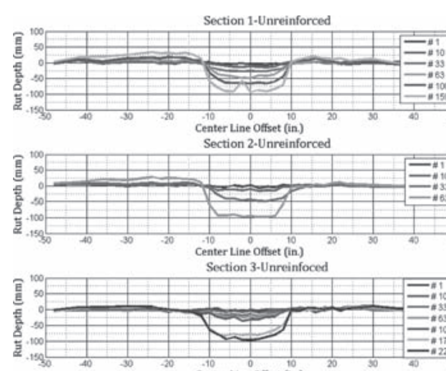

Figure 1. Rut developments in the test sections due to unidirectional ATLAS loading under unreinforced (no geotextile) conditions (1 in. = 25.4 mm).

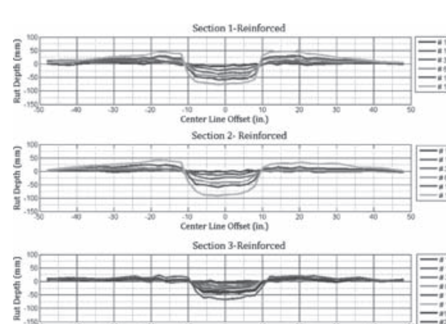

Figure 2. Rut developments in the test sections due to unidirectional ATLAS loading under reinforced (with geotextile) conditions (1 in. = 25.4 mm).

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Effect of geosynthetic drainage layers on the recovery rate of pavement surface modulus

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ABSTRACT

Water infiltration in pavement is inevitable and has a significant effect on the mechanical properties of the soil and aggregate composing the unbound layers. In northern regions, the saturated state of the structure is likely to occur during the thawing periods. A solution is thus to provide adequate drainage in order to prevent the increase in excess pore pressure (Doré & Zudbeck 2009) by introducing, among other approaches, drainage layers in the pavement structure. Even though the studies conducted in the last 25 years have presented interesting results on the possible positive influence of the addition of geocomposite drainage layers within the pavement structure, pavement experts and decision makers are still skeptical regarding the real benefits generated by the use of this technology. The goal of this study is thus to improve the current knowledge of the performance of geocomposite drainage systems in order to assess if the additional investment required for such systems is compensated by a significant improvement of the pavement performance. The assessment has been done using both laboratory and field tests that allowed detailed monitoring of the mechanical responses of drained pavement sections compared to undrained reference sections. The comparison was done using mainly Falling-Weight Deflection (FWD) measurements and Multi-Depth Deflection measurements (MDD).

In the field, a total of 5 different test sections, each having a 770 mm pavement structure, were constructed in a 30-meter long concrete pits that enables the control of the water table level. Geomembrane blankets were placed in three of the five sections; two at the interface A (Fig. 1) between the base and subbase layers and one at the interface B (Fig. 1) between the subbase and subgrade layers. The only distinction between the two first sections was the composition of the base in virgin material and recycled material (50/50) respectively. The fourth section had a vertically positioned lateral geocomposite layer placed on the edge of the

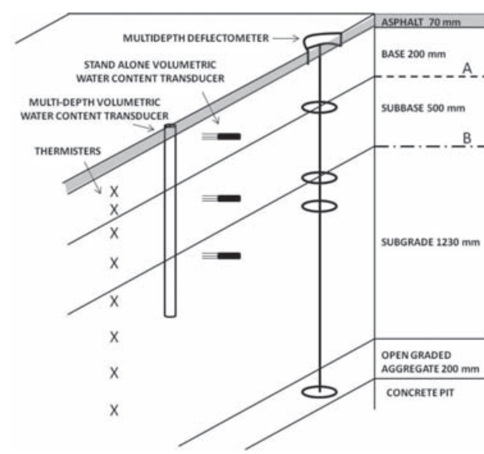

Figure 1. Schematic illustration of the field test sections and of the instrumentation layout.

asphalt layer following the interface C (Fig. 1). The fifth section was the reference section and did not contain any geocomposite technologies.

The observations made in the early stage of this study, both in the laboratory work and field investigation, support the hypothesis of a faster improvement in the structural response of pavement sections that include geocomposite drainage systems. Two additional test sequences will be done at the field test site in the spring and in the summer 2012 in order to fully assess the benefits related to the use of geocomposite drainage systems in pavements under various seasonal conditions.

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Seismic performance of geotextile reinforced soil wall with double facing system

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ABSTRACT

This paper shows the results of the dynamic centrifuge model test that is carried out to confirm seismic stability of a geotextile reinforced soil wall. The wall has a double facing system with a vertical layer to absorb the deformation between the facing concrete panels and reinforced backfill as shown in Figure 1. The facing concrete panels and reinforced backfill are connected by the polyester fiber belt-shaped reinforcements (called connection belt). After constructing the reinforced backfill and facing concrete panels to a predefined height, the single sized crushed stones are filled to the thin vertical space between the reinforced backfill and facing concrete panels. After that, this vertical layer plays the role of a drainage layer. Figure 2 shows the schematic view of the wall.

To confirm seismic behavior of the wall, the dynamic centrifuge model test for the wall is carried out. In this test, the 20.6-meters-high models of the wall under the 50 G centrifugal field are constructed. The test investigates the influences of presence of the facing concrete panels, presence of the connection belts and length of geotextile installed in the reinforced backfill on the seismic stability of the wall. Figure 3 show the deformation of the wall after shaking. The structural characteristics of the wall obtained from this test are as follows; 1) the facing concrete panels and reinforced backfill behave as a unified structure and are sufficiently stable, 2) by installing the facing panels and the connection belts, the deformation of the wall becomes smaller, because the constraint effect of the wall further increases, 3) the wall has high seismic performance even when the length of geotextile is designed as an unisometric arrangement, 4) it seems that the allowable displacement of the wall is 4% of wall height. These characteristics of the wall will be considered to evaluate the design method of the wall hereafter.

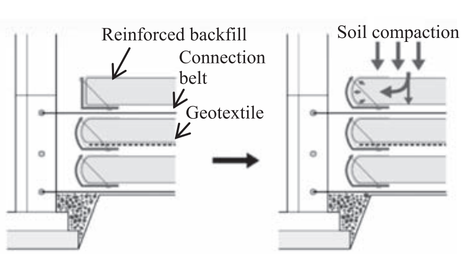

Figure 1. Double facing system.

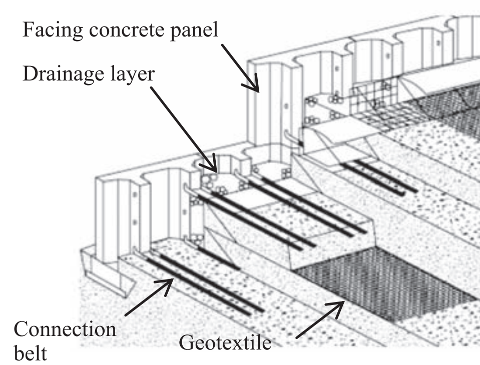

Figure 2. Schematic view of geotextile reinforced soil wall.

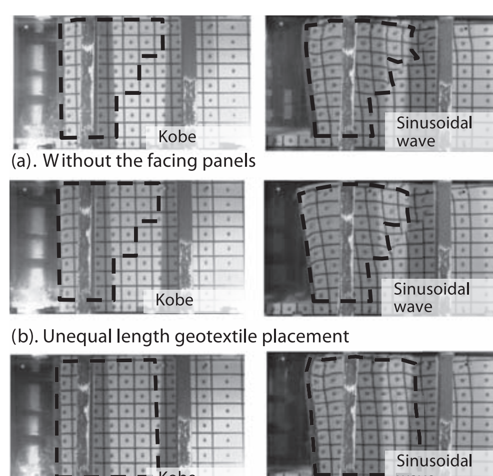

Figure 3. Deformation of the wall after shaking.

7 *Laboratory testing and in-situ testing*

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Solidification of dredged marine clay under varied mix conditions: A laboratory study

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ABSTRACT

Dredged marine clay, treated with binders like cement, can be reused in various geotechnical applications as sound geomaterial. By adding and mixing binders with the clay, the soft material can be transformed into stronger and stiffer stratum for load bearing. Admittedly advancement in machinery and computerized operations have significantly improved the mixing process, but individual factors contributing to the mixing condition still leave room for further refinement of the effectiveness.

This paper describes a series of laboratory tests, mainly unconfined compressive strength tests complemented with X-ray CT (Computer Tomography) scans, conducted on cement-stabilised dredged clay specimens of varied uniformity. The variation in uniformity was introduced via different Water/Cement (W/C) ratios, number of cement layers in the initial state as well as the number of mixing cycles adopted. The wide spectrum of specimens tested allowed a comprehensive cross-comparison of the results, which in general, showed that while mixing effort is crucial, the initial conditions of clay's consistency and binder's distribution do affect the solidification mechanism to certain extents.

The primary findings of the study can be summarised as below:

i. The mixing water content remains the dominant factor in strength gain of the mixture.
ii. Initial non-uniform distribution of the binder (e.g. cement) can be effectively rectified with increased mixing efficiency, on condition that sufficient workability is facilitated by the mixing water content.
iii. The mixture's uniformity appears to be more influenced by the mixing efficiency than the initial distribution of binder, where the latter's effect did not provide significant head start as expected in terms of strength gain.

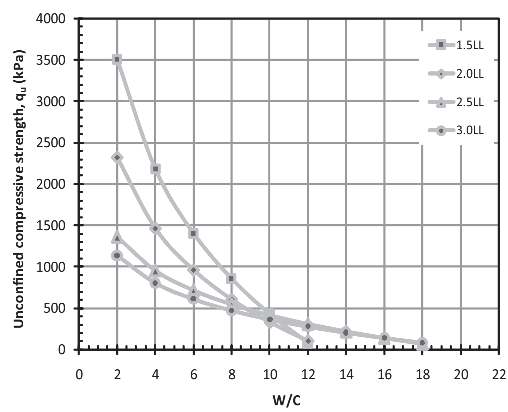

Figure 1. Plots of q_u—W/C for various mixing water contents.

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The influence of moisture on the detection of de-bonding in asphalt pavements using Ground Penetrating Radar (GPR)

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ABSTRACT

De-bonding in both concrete and asphalt pavements can contribute to premature failure of the pavement structure. Several non-destructive methods exist to detect and assess areas of de-bonding, such as impact testing, infra-red thermography, seismic methods or the use of Ground Penetrating Radar (GPR). Each technique, however, has limitations and there is no comprehensive approach to guarantee de-bond detection.

GPR has advantages over several of the other de-bond location techniques, and can rapidly collect data from the full depth of large lengths of pavement. The success of GPR is affected by the nature of the de-bond (as is the case for other techniques), and the presence of disintegrated material, air or moisture at the de-bond can significantly improve the chances of detection. The extent to which the presence of moisture at the de-bond affects success has not been thoroughly researched, and this paper describes a study conducted to establish how GPR data is influenced by moisture at de-bond locations in asphalt.

The study described consisted of a laboratory investigation on asphalt core samples, taken from in-service pavements. A series of controlled tests were conducted whereby the amount of moisture present in asphalt material below the de-bond location was increased, in order to measure the influence on the amount of radar energy reflected from the de-bond as moisture levels changed. The measure of GPR energy reflected from the de-bond (and hence the ability to locate the de-bond within the pavement material) is governed by the 'reflection coefficient', which is affected by the amount of moisture present. GPR data was collected at various de-bond moisture conditions, and the significance and influence of moisture presence in de-bonded asphalt pavements could be determined.

The results illustrated the influence of moisture on GPR data recorded from de-bonded pavement layers, and indicated the potential for success of GPR in both de-bond location and in the detection of moisture ingress into intact asphalt layers. The scope of the investigation undertaken was small scale in nature, but it is intended that the findings of the study will lead to further comprehensive testing and analysis.

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Improving the use of unbound granular materials in railway sub-ballast layer

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ABSTRACT

The rational use of materials to be applied in the supporting layers of railway tracks is an important aspect that can contribute to reduce the life cycle cost of such infrastructure. In recent construction and renewal rail track projects carried out in Portugal, the sub-ballast layer has been typically implemented in the track structure, using Unbound Granular Materials (UGM). This layer and the characteristics of the materials play a fundamental role in the track behaviour. Nevertheless, there is a lack of consensus worldwide on the requirements established for such materials. In Portugal and in other European countries, very stringent requirements based on empirical tests have been adopted, making it difficult to find materials that fulfil such requirements. There is also evidence that some of these materials, which do not comply with all the requirements, can still be considered as appropriate for sub-ballast.

Within the scope of this study, the construction of a new railway section was supervised. During construction, it was difficult to obtain the desired quantity of granite material for the 30 cm thick sub-ballast layer that would fulfil the requirements and still comply with the contract deadline. As an alternative, another structural solution was used that considered the replacement of the bottom 15 cm of granite material sub-ballast layer by limestone material which did not comply with some requirements. In order to study the feasibility of this change, to evaluate its consequences and establish new quality assurance indicators, several studies were developed, such as *in situ* characterization (Figure 1) and cyclic triaxial load tests on different UGM.

Although the limestone UGM revealed relatively higher particle fragmentation comparing with the granite UGM, tests performed during quality control showed that the constructed sub-ballast layer using both UGM met the performance related specifications of the design. Regarding cyclic triaxial load test results, the limestone showed a good performance, in terms of both resilient behaviour

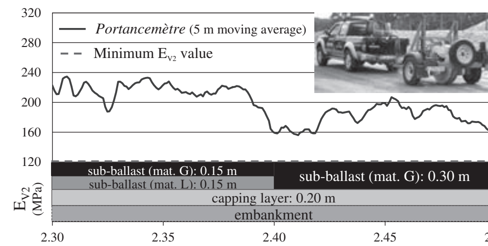

Figure 1. Deformation modulus (E_{V2}) obtained with the *Portancemètre* on the surface of the sub-ballast layer.

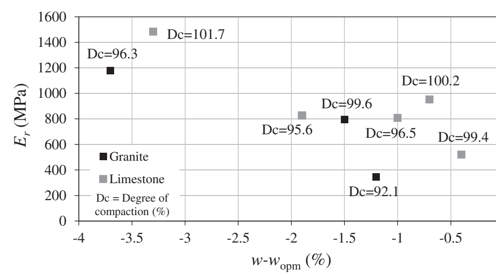

Figure 2. Influence of the water content (difference to the optimum value) on the resilient modules (E_r) obtained in cyclic triaxial load testing for granite and limestone UGM.

(Figure 2) and permanent deformation. Thus, it can be concluded that the use of the tested limestone UGM as sub-ballast is feasible, providing that its particle size does not change during the construction process.

Though previous studies also have reached similar conclusions, there is still little confidence and acceptance in results from mechanistic studies, such as those presented here, in order to contribute to implementing changes in materials specification, namely regarding their suitability for various applications. Therefore, it is necessary to develop further similar studies to obtain adequate performance indicators and to design and construct economic and environmentally sustainable transport infrastructures.

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Measurement of the deformation behavior of asphalt mixture by using a high-speed camera

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ABSTRACT

Traffic load to a road surface occurs in an extremely short time period. A vehicle with a tire contact length of 20 cm requires only 0.012 s at a traveling speed of 60 km/h, or 0.036 s at 20 km/h, to have its all wheels pass a given point.

Asphalt mixture which receives major impacts from temperature and loading time behaves in a complex manner during hot summer or at high temperatures over 30°C. Such behaviors are one of the key factors in understanding how rutting and other problems occur and damage road pavements.

Deformation in asphalt mixture is usually measured using strain gauges or LVDT. However, these instruments only give representative values at measurement points or a total deformation of the specimen. It is impossible with them to obtain planar measurement of the complex behavior of asphalt mixture.

The authors looked into the possibility of using a high speed camera for planar measurement of micro behavior of asphalt mixture under instantaneous load.

A high speed camera capable of capturing 1,000,000 images per second was used in this study at a speed of 200 images per second (sampling rate: 5 ms) to match the test loading rates of 20 and 50 mm/minute. By comparing the images taken during the loading process with those taken immediately before the loading, transfer amounts at multiple points on the specimen surface at different loading times were determined. Strain was calculated from the transfer amounts at the positions and for the lengths of the attached strain gauges, and the calculation results were verified against the measurement results by the strain gauges for the validation of the proposed method. The authors used Particle Image Velocimetry (PIV) for the image analysis of transfer in this study.

Since tonal difference is important for accurate image analysis, cylindrical core specimens (100 mm diameter × 100 mm high) for this test were cut out of wheel tracking test specimens. The specimens were made of dense graded asphalt mixture 13 (with polymer modified asphalt type II).

Figures 1 and 2 show strain measurements by the PIV analysis and those by the gauges. A good fit was found between the two.

These results demonstrate that the PIV analysis on the high speed images provides:

1. planar measurement of the behavior of the surface of asphalt mixture specimens;
2. time-series observation of changes during an extremely short time loading; and
3. strain calculation which well fits the measurement by strain gauges.

It should be noted, however, that the analysis results can contain errors in a minute strain range (loading time ≤ approximately 0.3 s) where transfer in the specimen surface is extremely small. This can lead to variation in Poisson's ratio since it is based on strain values calculated from transverse transfer which is smaller than that in the vertical loading direction.

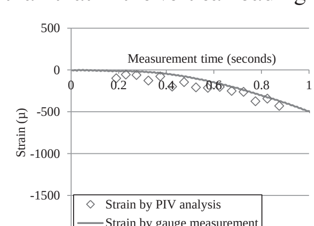

Figure 1. Strain measurements (loading rate: 20 mm/minute).

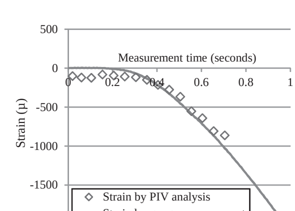

Figure 2. Strain measurements (loading rate: 50 mm/minute).

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Development of medium-size triaxial apparatus for unsaturated granular base course materials

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ABSTRACT

In snowy cold regions, the 0 °C isotherm may penetrate deep into the pavement, thereby causing the upheaval of pavement surface or cracking in the asphalt-mixture layer mainly arising from the frost heave of subgrade. Furthermore, the water content rises due to the inflow of thaw water or thawing of ice lenses, and as a result, the bearing capacity of the subgrade and base course temporarily degrades during the thawing season. Such phenomena specific to cold regions are thought to accelerate the deterioration of pavement structures and losing of the functions. Therefore, to evaluate the physical properties and hydro-mechanical characteristics of unsaturated base course materials, which is suffered from seasonal fluctuation in the water content at real foundations, is of great significance.

However, the mechanical behavior of unsaturated base course materials which has maximum particle size of almost 40 mm has not been clarified by laboratory element tests enough so far. This is because laboratory element tests for unsaturated soils with large-size specimens are quite time-consuming due to the ceramic disk with very low permeability usually used in the test apparatus for unsaturated soils. Therefore, it is indispensable for the detail examination of deformation-strength characteristics of unsaturated base course materials to develop a new medium-size triaxial apparatus for unsaturated soils, which can reduce testing time than before.

Based on such circumstances, we developed a new medium-size triaxial apparatus for unsaturated soils, which adopts the pressure membrane method with hydrophilic microporous membrane filters instead of the pressure plate method with ceramic disks. This paper evaluates the applicability and utility of a testing method using the medium-size triaxial apparatus to laboratory element tests for mechanical properties of unsaturated granular base course materials in terms of the validity of test results and the reduction of test time. For that purpose, a serious of water retention tests (Figure 1) and triaxial

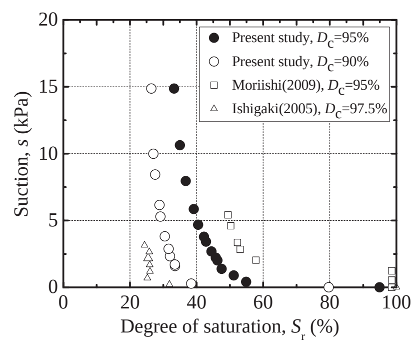

Figure 1. Soil-water characteristic curves of C-40.

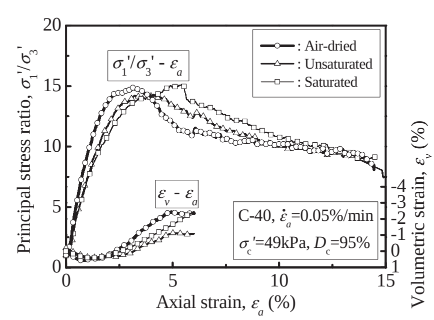

Figure 2. Stress-strain relationships of C-40.

compression tests on unsaturated sand and crusher-run (Figure 2) were carried out in this study.

In conclusion, the following findings can be mainly obtained:

– Water retention characteristics and deformation-strength characteristics of unsaturated sand and crusher-run obtained from this study conform well to the past experimental data.
– Proposed testing methods using the newly developed test apparatus are highly useful in water retention tests and triaxial compression tests in terms of the reduction of total testing time as compared with the conventional testing methods.

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Characterization of polymer modified asphalt for rutting and cracking potential using dynamic shear rheometer

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ABSTRACT

Asphalt aggregate mixture and its structural design are two key components of flexible pavement design. Asphalt is only 4 to 5% in mix by weight but it plays a vital role in defining the pavement performance. Viscous and elastic properties of asphalt affect the rutting and cracking characteristics of flexible pavements. Rutting is a major reason of premature deterioration of asphalts pavements in warm climatic regions of Pakistan whereas fatigue and thermal cracking is a common problem in cold regions. These problems arise in asphalt pavements due to improper mix design and lack of asphalt characterization. Polymer modification typically improves binder ductility, thereby providing a binder that is more durable to pavement stresses and deformation (Bahia et al. 2001).

The main objective of this study is to characterize the virgin and polymer modified asphalt for cracking and rutting potential considering different climatic regimes in Pakistan. The analysis includes synthesizing testing results, VTS analysis, prediction of phase angle and viscosity using Witczak models (Javed et al. 2007). Two virgin asphalt samples i.e. Attock 60/70 and 80/100 as well as Attock 60/70P (Polymer Modified Asphalt) were obtained from Attock oil refinery. Six PMA samples were prepared in the laboratory by blending 1.35%, 1.7% and 2% of Elvaloy® RET polymer with Attock 60/70 and 80/100. Tests were conducted using Dynamic Shear Rheometer at single frequency of 10 rad/s both at intermediate and high temperature range (7, 13, 19, 25, 31, 37, 46, 52, 58, 64, 70, 76, 82°C) following the standard procedure (AASHTO TP5[1] 1994). The results showed that polymer modified asphalt has more resistance to permanent deformation or complex shear modulus and more elastic component as compare to virgin asphalt. This indicate that polymer modified asphalt would be suitable to control rutting and fatigue cracking in asphalt concrete pavements.

Conventional binder tests (penetration and viscosity tests) were also performed on all the asphalt samples and Viscosity Temperature Susceptibility (VTS) parameter values were calculated. The VTS values indicated that there is significant decrease in temperature susceptibility of asphalts binder with the polymer modification. The optimization technique was used to fit the Witczak phase angle and viscosity models and values of fitting parameters were obtained. The prediction of phase angle and viscosity using Witczak models revealed that these models have good predictability both for virgin and modified asphalt. Testing and analysis results revealed that there is rapid increase in resistance to deformation and elastic properties of polymer modified asphalt at the initial content of polymer i.e. 1.35–1.70%. But with further addition of polymer content, only slight change occurred in virgin asphalt properties. Therefore, it can argue that the optimum content of Elvaloy® RET polymer for modification is lying between three mentioned values. Polymer modification provides asphalt that is more durable to enhance performance of pavement structure in extreme climatic conditions by reducing rutting and cracking potential of asphalt aggregate mixtures. Furthermore addition experimental studies need to conduct at different frequencies in order to check the visco-elastic behavior of polymer modified asphalt under different loading conditions.

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Full scale model tests on slab track constructed on embankment

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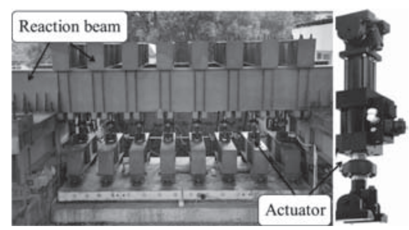
ABSTRACT

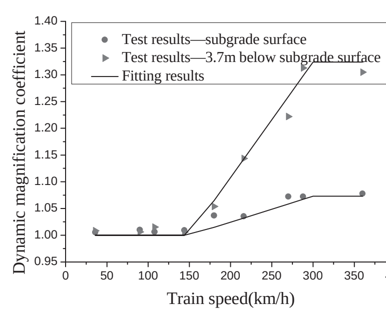
High-speed railways have been widely used as a kind of safe and convenient transportation among many countries in recent years. However phenomenon of track and subgrade deterioration during high-speed running of trains is increasingly outstanding. And the track irregularity caused by uneven settlement will aggregate dynamic interaction between wheel and rail.

There are a number of uncertainties affecting the dynamic response of slab track-subgrade system, including material characteristic of track structure and subgrade. As load excitation of the slab track-subgrade system, the simulation mode of train load directly influences the mechanical behavior of the system (Brown 1996; Gräbe & Clayton 2009). A variety of loading tests with physical model of track structure and embankment have been performed by many researchers (Momoya.Y et al. 2008; Ishikawa et al. 2011). However, these researches have their limitations of reflecting the train speed and real dynamic response due to the model scale and loading simulation apparatus.

In this paper, a full scale physical model of slab track-subgrade system has been established according to the practical engineering design methods, which contains a complete set of measuring system, such as dynamic soil pressure cells, layered settlement transducers and accelerometers. Then, a new simulation method of high-speed train traffic loadings is proposed, using a distributed loading system to represent the movement of wheel axle loads of trains. Some preliminary testing results are presented to show the capacity of the testing apparatus. The load sharing ratio of fastening system is studied by a single wheel axle load acting on the rail, and the stiffness of fastening system is also acquired. Dynamic response of slab structure under different train speed has been studied on the dynamic test platform, shown in Figure 1.



(a) Loading simulation system



(b) The relationship between dynamic magnification coefficient and train speed

Figure 1. Dynamic response of train's moving loads.

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Shakedown behavior of unbound granular material under repeated portable FWD loading

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ABSTRACT

This paper presents an elastic and plastic behavior of Unbound Granular Materials (UGMs) under repeated portable FWD loading by shakedown theory to improve the framework on accuracy for the evaluation of stiffness of UGM. According to the theory, the magnitude strain of UGMs is liable to show almost no progressive accumulation of permanent strains under repeated loading if the magnitude of the applied loads does not exceed a limiting value, called the shakedown load. The growth of permanent strain was shown to level off by the 10th cycle load application (Fig.1) at the same strain level using Portable FWD (PFWD) and a conventional triaxial compression test. Therefore, this PFWD loading test is said to have attained a state of shakedown. By visualization method, the photos were taken at the cross section of a test box before and after loading by PFWD. One picture was captured in no-loading condition at the beginning and the other was in the condition after unloading at the last cycle of loading/unloading. Displacement vectors model was estimated by two kinds of pictures in PFWD (Fig. 2) and PBT. They revealed the soil particle displacements are larger in the vertical direction compared with using Plate-Bearing Test (PBT).

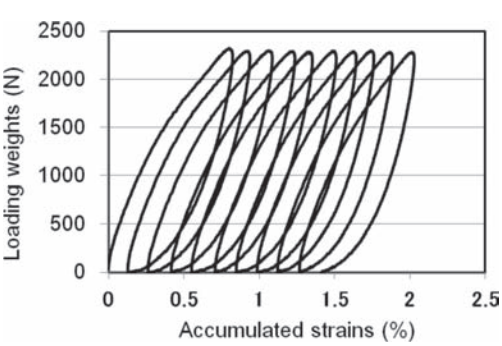

Figure 1. Accumulation strain versus loading weight under repeated load PFWD tests.

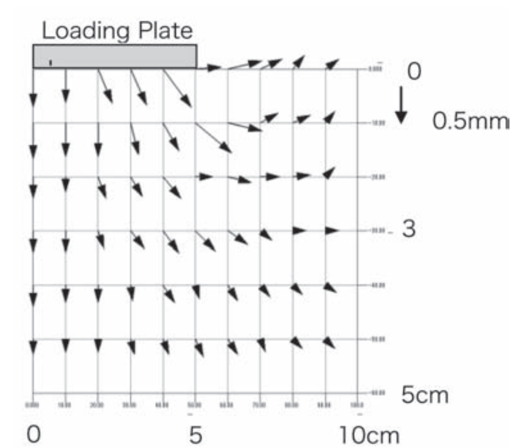

Figure 2. General shape of occurring displacement after unloading at the last cycle using PFWD.

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Surface free energy components of aggregates from contact angle measurements using Sessile Drop method

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ABSTRACT

Contact angle measurements are increasingly becoming important in analyzing the interaction energy between the surfaces of different geological materials both in dry and as well as wet conditions. One field where this new approach has been applied is the moisture damage in asphalt pavement mixtures. The moisture damage is simply known as the loss of bonding strength between asphalt binder and aggregate, and as well as within the binder itself in the presence of moisture. Two laboratory testing devices and methods are currently used in determining the surface free energy components of aggregates and binders. The Wilhelmy Plate (WP) is usually employed for inferring the surface free energy parameters of asphalt binders and the Universal Sorption Device (USD) is usually used for inferring the surface free energy values of aggregates.

This paper presents a new Sessile Drop (SD) testing device that can be used to measure contact angles directly on asphalt binder and aggregate specimens. The new device has been employed for measuring contact angles and calculating surface energy parameters on an Oklahoma limestone aggregate. The device was used in capturing video images of liquid drops on smooth, flat aggregate surfaces. The instrument is fully automated and can be controlled with the provided software on a computer. The software analyzes the drop shapes and sizes for measuring contact angles and determining various surface chemistry quantities of solids. The new device is accurate, reliable, practical, and economical, and it can be easily adopted in a geotechnical laboratory for contact angle measurements.

The laboratory tests indicate that while the results on aggregate specimens from the new device are in agreement with the results in the literature on clay and talc minerals, they are not in agreement with the results obtained on similar aggregates using the universal sorption device. The differences may probably be attributed to the spreading pressure term used in the universal sorption device testing approach and need to be investigated in detail.

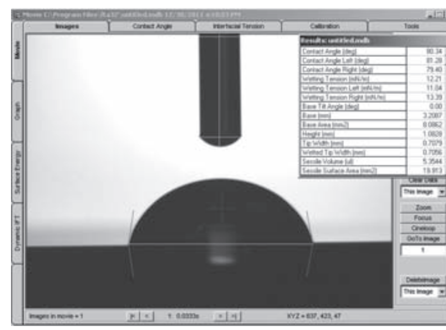

Figure 1. A liquid probe deposited on the specimen surface.

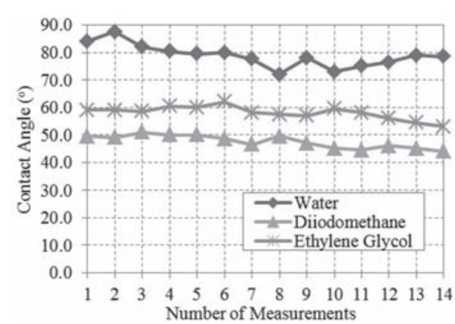

Figure 2. Contact angle measurements on the limestone.

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Advances in Transportation Geotechnics II – Miura et al. (eds)
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Influence of reclaimed materials on base course quality

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ABSTRACT

Influence of reclaimed materials on base course quality is studied.

We firstly checked what is contained in reclaimed cement concrete. It is found that containing ratio of each foreign materials are very small (less than 0.2%).

Secondly, it is examined how these materials may affect on base course qualities with base course in full scale. It is founded that comparing with RC-40, deformations of base course with foreign materials are large, and bearing capacities of base course with those are small.

Photo 1. Test pavement condition after loading test.

Photo 2. Handy FWD.

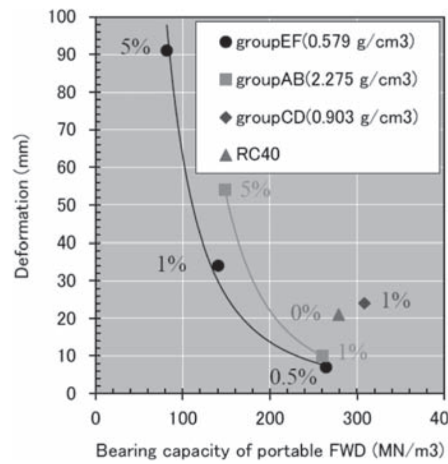

Figure 1. Relation between deformation and bearing capacity.

Lastly, tentative evaluation method for base course with recycled aggregate is proposed.

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Advances in Transportation Geotechnics II – Miura et al. (eds)
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Fundamental study on the simple evaluation methods for particle size distribution and maximum/minimum void ratio of sand-gravel mixtures

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ABSTRACT

Deformation properties of soil materials are influenced by many parameters including gradation curve and void ratio. In railway tracks, ballasts are sometimes mixed with finer materials which mainly come from soil layers underlying the ballasts. Void ratio of ballasts change with addition of fines. In this paper, a simple evaluation method for particle size distribution of soil materials including fine materials was proposed using an image analysis technique. The proposed method can evaluate gradation curves accurately for gravel and medium size sand. Moreover, two numerical methods were adopted to evaluate maximum and minimum void ratio of sand-gravel mixtures. Accuracy of numerical methods was studied with laboratory experiments.

Image analyses were conducted using Image J software. Granular materials were assumed to be ellipse shape in 2D images. Volume of particles was estimated with an assumption. Then, gradation curves by the image analysis were evaluated using volume of particles. As particles pass parallel to sides and as well as through diagonal of sieves in sieve analysis, the grain size for granular materials in image analysis was defined accordingly. Figure 1 shows gradation curves evaluated by the two methods for gravel. In Figure 1, grain size of b and $(0.5b^2 + 0.5c^2)^{0.5}$, where b and c are minor axis and thickness of ellipsoid respectively, are equal to the cases where all particles pass parallel to sides and through diagonal of sieves respectively. A size correction factor was assigned to grain size evaluated in image analysis (i.e., 0.86 for gravel) to represent sieve analysis conditions.

Maximum and minimum void ratio characteristics were evaluated using two numerical methods (Suzuki et al. 1984 and Lade et al. 1998) and laboratory experiments for sand-gravel mixtures. Figure 2 shows the results of void ratios for sand-gravel mixtures when Toyoura sand was used.

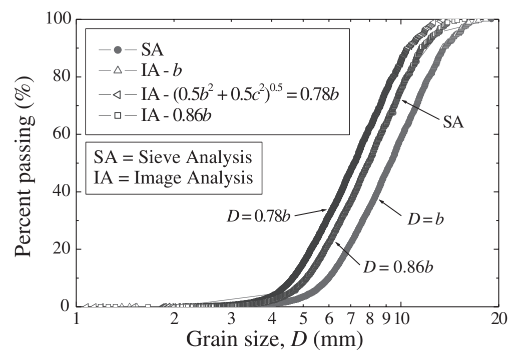

Figure 1. Gradation curves of gravel.

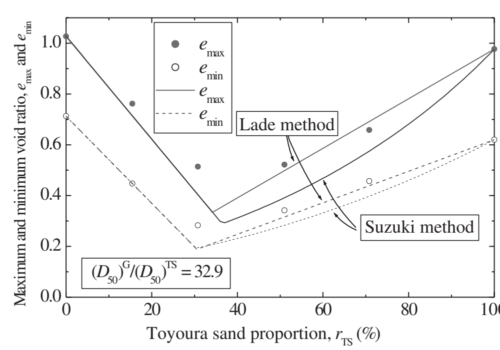

Figure 2. Maximum and minimum void ratios of sand-gravel mixtures vs. Toyoura sand proportion.

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In-situ measurement of damping ratio spectra from the inversion of phase velocities of P and S waves in cross-hole seismic testing

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ABSTRACT

Recently obtained exact solutions of Kramers-Kronig relations (Meza-Fajardo & Lai, 2007) establish a direct, functional relationship between material damping ratio and the speed of propagation of seismic waves. Specifically, determination of material damping ratio spectra from phase velocity measurement of P and S waves through geophysical in-situ testing seems particularly attractive. This paper aims at providing a preliminary validation for an underway work of the authors whose ultimate goal is setting up a reliable methodology for the in-situ measurement of damping ratio from standard cross-hole seismic testing.

Figure 1 illustrates the comparison of three different estimations of phase velocity dispersion: (i) the solution of K-K relations defined within the paper, (ii) rheological normalized phase velocity dispersion estimation by making use of corresponding rheological model (Moczo et al. 2004), and (iii) numerical normalized phase velocity dispersion obtained directly from the numerical simulation of the seismic cross-hole test by normalizing it by the factor of $(M_{R/\rho})^{0.5}$. If the inverse process is desired by making use of the solution of K-K, the damping ratio spectrum can be recovered as illustrated in Figure 2. It can be observed from Figure 1 and Figure 2 that the precision and the accuracy of the developed numerical implementation of K-K solutions for determining damping ratio and phase velocity are excellent.

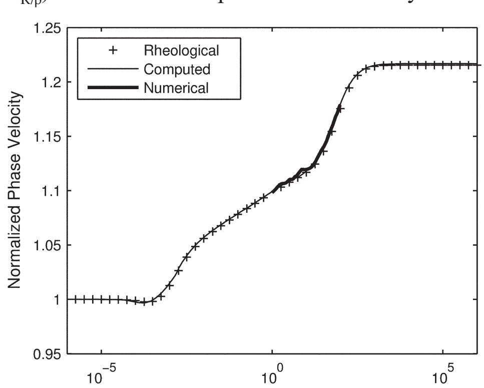

Figure 1. Comparison of normalized phase velocity dispersion.

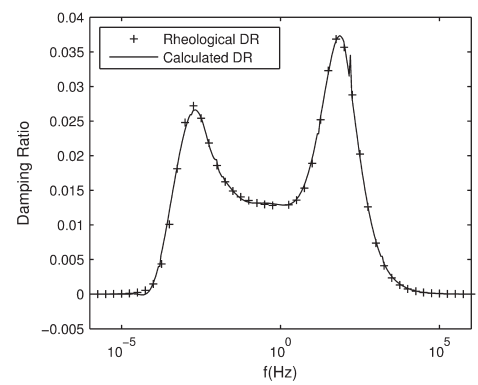

Figure 2. Comparison of rheological and computed DR.

This work also includes a real in-situ comparison of the results of down-hole test with the data published by Micheals (2006) obtained from GeoInstitute's Denver 2000 data collected in 8 August 2000. Although the experimental data have been obtained for a limited frequency band, the in-situ validation of the proposed numerical implementation of closed form K-K solution is also encouraging.

Efforts are underway for an application of the methodology to high-quality, cross-hole seismic data. For accurate predictions it is required to have: (i) a broad-band frequency spectrum at the source and (ii) receivers characterized by a flat response in the frequency domain as broad as possible. Also an in-depth investigation is required onto the aspects related to dynamic soil-borehole interaction at high frequencies.

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A study on cyclic triaxial test method for coarse granular materials

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ABSTRACT

Large coarse granular materials have been continuously used for large scale geotechnical structures. Safe design and construction of these infrastructures are very important. However, the test evaluation on the property of coarse granular materials has not been reasonably conducted because it is difficult to test in the laboratory for large grain size materials. The first reason is that it is difficult and expensive to make large scale test equipment. The second reason is that it is labor intensive to prepare samples and test. However, it is required to accurately evaluate dynamic property of the materials to reasonably design and construct in consideration with various vibration factors including earthquake. This study will investigate how the application of the parallel grading method affect elastic modulus of the coarse granular materials by conducting cyclic triaxial test in small strain level. Along with this, the effect of test methods including load frequency, and loading mode were evaluated.

If the maximum grain size is relatively large in comparison with the diameter of specimen, any alternative method such as parallel grading method, matrix model and scalping- replacement method can be used to adjust the grain size.

The most popular method is parallel grading method. Therefore, this was reviewed first. It might underestimate minutely compared to the result of the specimen with original grain size. But the difference was not that significant.

In case of grain size distribution with under maximum grain size 100 mm, it could be determined that the elastic modulus evaluation test method by parallel grading method is effective if the test samples have same density with the original samples.

However, if possible, it will be necessary to test with the materials of grain size distribution and maximum grain size similar to actual materials.

It could be determined that the effect of load frequency on elastic modulus is not that significant.

Elastic modulus reduction curves were different according to the loading mode. Therefore, the loading mode should be determined considering the field conditions such as the application and loading type.

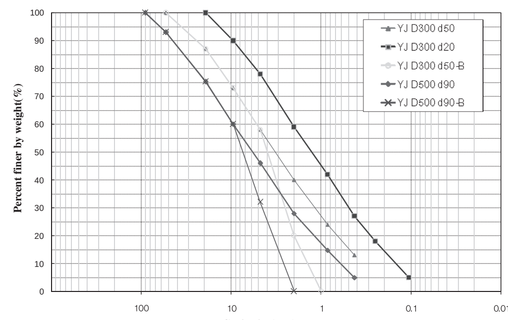

Figure 1. Grain Size Distribution (GSD).

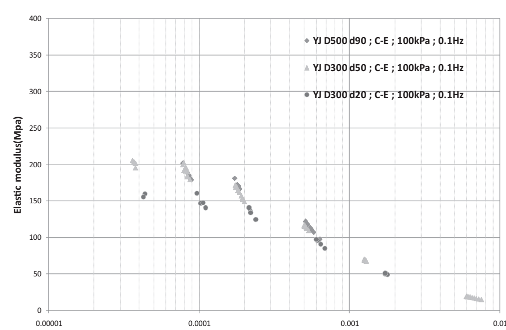

Figure 2. Test results (Parallel grading method).

Comparison between parallel grading method, matrix model and scalping-replacement method will be conducted later.

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Advances in Transportation Geotechnics II – Miura et al. (eds)
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Large-scale triaxial tests of dense gravel material at low confining pressure

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ABSTRACT

Four dense specimens of gravel material were tested at low confining pressure and different deviator stress patterns at large-scale triaxial apparatus. Specimens were prismatic shape with dimensions of 50 cm in height and 23 cm times 23 cm in cross-section. They were prepared at density equal to approximately 95% of the maximum density at optimum moisture content. Stress conditions with very low confining pressure were used to simulate specific conditions at road and railway embankments.

Strains were measured locally at the specimen using vertical and horizontal Local Deformation Transducers (LDT). The first two challenges of research were proper attachment of LDT at membrane of specimen and elimination of friction between specimen and rigid plates of top cap and pedestal. The use of extra plate to increase contact area between hinge and membrane and use of double lubrication layers at both ends of the specimen were suggested therefore and proved in this research.

Besides confirmation of proposed solutions paper presents results of loading tests showing similar effects of overloading and preloading by large number of load cycles upon the deformation behavior of specimen. Appearance of nonlinear almost-elastic behavior of specimen after noticeable one-time overloading or large number of preloading cycles with load amplitude less than deviator stress was observed. Due to the overloading and preloading, stress-strain relationship shape also changes from convex to concave.

Table 1. Details about specimens.

Specimen	IIS-0A	IIS-0C	IIS-0E	IIS-0F
Dry density, (g/cm^3)	2.018	2.035	2.053	2.074
% of ρ_d by Proctor	93.1	93.9	94.7	95.7
Void ratio, (–)	0.33	0.32	0.31	0.29
Moisture content, (%)	4.93	4.85	3.73	4.17

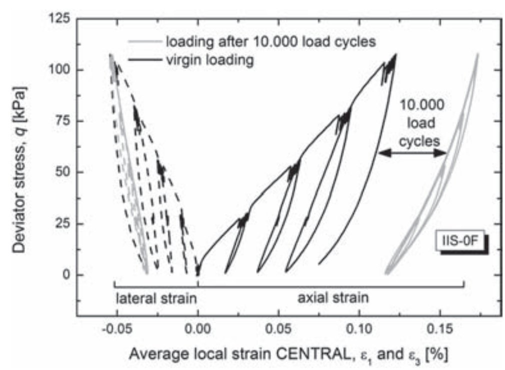

Figure 1. Typical change of stress-strain relationship caused by large number of load cycles. Dashed lines denote lateral strains. The same loading pattern was used before and after cyclic loading.

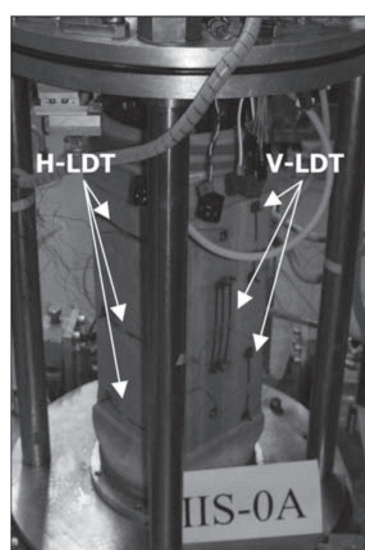

Figure 2. Prismatic specimen in large-scale triaxial apparatus.

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Characteristics of in-situ dynamic stresses of pavement subgrade under portable falling weight deflectometer test

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ABSTRACT

This paper has summarised and enhanced the understanding on the dynamic stress characteristics within soil subgrade material under PFWD tests, by in-situ measurement of vertical and confining stresses. Besides, several crucial findings were yielded, (1) The different natures of the PFWD applied stress and soil stress indicate the variations of vertical stresses within the soil mass are influenced by other factors apart from the applied stress alone; (2) Beyond the distance of one times the PFWD plate diameter from the source of load, the $E_{(PFWD)}$ stays fairly constant, this corresponds to a vertical stress ratio (stress measured/stress applied by PFWD) of about 0.2; (3) The horizontal confining stresses are highest at the location of the source of load and reduce dramatically away from the source; (4) The drop height of mass was found to impose a moderate influence on the E_{PFWD}, which is different from the findings provided by some of the previous researchers and (5) The confining stress has the strongest correlation with $E_{(PFWD)}$, being followed by vertical stress and deviator stress.

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Accumulation of excess pore water pressure and post-cyclic settlement of saturated soft clay subjected to multi-directional cyclic simple shear

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ABSTRACT

In this paper, normally consolidated samples of Kaolin were tested under undrained uni-directional and multi-directional cyclic simple shears. The effect of cyclic shear direction (or phase difference) on the accumulation of excess pore water pressure during cyclic shear and on the recompression after cyclic shear were investigated. The estimation method of the excess pore water pressure ratio and the post-cyclic settlement by using cumulative shear strain is presented. The validity and advantage of this method are confirmed.

TEST RESULTS AND DISCUSSIONS

At the same number of cycles, cumulative shear strain G^* which is newly defined as the accumulation of shear strain, increases in proportion to the shear strain amplitude. The relations of cumulative shear strain versus shear strain amplitude γ and number of cycles n can be expressed by $G^* = n\,(3.920\,\gamma + 0.0523)$ and $G^* = n\,(5.995\,\gamma + 0.3510)$ for uni-directional and multi-directional cyclic shears, respectively.

Shear strain amplitude, phase difference and number of cycles have significant effect on the development of excess pore water pressure in cohesive soils. The excess pore water pressure ratio increases with the number of cycles and after the same number of cycles, the larger the shear strain amplitude and phase difference, the higher the excess pore water pressure ratio increases. However, by using the cumulative shear strain, the discrepancies in excess pore water pressure ratio become negligible for all phase differences. Therefore, it is suggested that the excess pore water pressure ratio is a function of cumulative shear strain and by using this shear strain parameter, the influence of cyclic shear direction on the accumulation of excess pore water pressure is possibly eliminated.

Similarly, the settlement following undrained cyclic shear increases with the phase difference, shear strain amplitude. The difference in vertical settlement between uni-directional and multi-directional shears is seen throughout the large range of shear strain amplitude (γ= 0.1%–2.0%). Meanwhile, the relations between the vertical settlement and cumulative shear strain become unique for all phase differences indicating that the effect of cyclic shear direction on the post-cyclic settlement can be eliminated by using this strain path parameter. By using conventional method, the change of the void ratio in recompression stage is independent of shear strain amplitude and so different values the recompression index, $C_{dynU} = 0.062$ and $C_{dynM} = 0.077$ are obtained for uni-directional and multi-directional cyclic shears, respectively. However, by using cumulative shear strain, only one value of the compression index $C_{dynU} = C_{dynM} = C_{dyn} = 0.067$ was obtained for both uni-directional and multi-directional cyclic shears. These values satisfy the relation as $C_{r,cy} = 0.225 \times C_c$, where C_c is the virgin compression index, which was obtained by stress-controlled cyclic direct simple tests on normally consolidated Drammen clay (Yasuhara et al. 2001). The vertical settlement induced by uni-directional and multi-directional cyclic shears can be estimated by using these indices.

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Determination of air-entry value for different compacted unsaturated soil

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ABSTRACT

The soil-water characteristic curve is a relationship between soil moisture and soil suction obtained by the axis translation technique or vapor pressure technique which is a key feature in unsaturated soil mechanics. The axis translation technique consists of increasing the ambient air pressure to values greater than atmospheric pressure, so as to translate the pore-water pressure into the positive range. White et al. 1970 have provided the original concepts for the three identifiably different stages of desaturation; the boundary effect stage, the transition stage and the residual stage of unsaturation for soil-water characteristic curve. The air-entry value refers to the matric suction corresponding to the beginning of desaturation which is the first point of the important stage of the soil-water characteristic curve. This value of suction identifies the point at which air enters the largest pores of the soil. Conceptually, the air-entry value represents the largest differential pressure between the air and water pressures that is required to cause desaturation of the largest pores in a soil (i.e., "air entry") (Vanapalli et al. 1999). The air-entry value depends on soil properties (i.e., density, grain size distribution, soil structure, aggregation, initial water content, compaction method and stress history). Nishimura et al. 2011 performed the SWCC tests using pressure membrane technique for compacted sand with various relative densities. The compacted unsaturated sand showed that the air-entry value increased linearly with the relative density.

This study focuses on the influence of dry density on the air-entry values of different compacted un-saturated soils. The SWCC tests were conducted using a pressure membrane technique. A relatively low matric suction up to 20 kPa was applied to soil specimen. Determination of the air-entry value was attempted during the drying process within the range of matric suction from 0 kPa to 20 kPa. In addition, the relationship between the air-entry value and dry density is discussed.

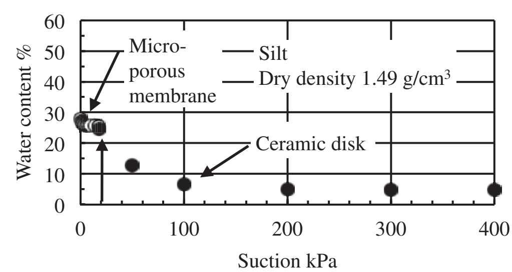

Figure 1. SWCC obtained from the pressure membrane and pressure plate techniques for silt.

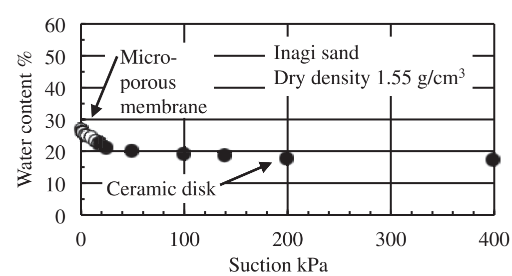

Figure 2. SWCC obtained from the pressure membrane and pressure plate techniques for inagi sand.

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Experimental study on responses of saturated clay to traffic loading

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ABSTRACT

Traffic moving loading produces continuous rotation of principal stress axes that may lead to additional plasticity and then produce more significant permanent deformation in saturated soft clay. To reduce the settlement induced by traffic loadings, it is of great significance to explore the behaviors of saturated soft clay involving rotation of principal stress axis. In this study, Dynamic Hollow Cylinder Apparatus (DHCA) is selected to simulate the rotation of principal stress induced by traffic moving loading, which reproduces a heart-shaped stress path in the deviatoric stress space. In order to achieve the heart-shaped stress path, the stress component is applied in different prescribed periodic mode. Meanwhile, a series of undrained cyclic triaxial shear tests were also done under some common load conditions. Finally, observations from two cyclic shear tests are presented to demonstrate the influence of continuous rotation of principal stress axes. It is shown that the dynamic stress level plays a key role on permanent deformation. At a high level of dynamic stress, undrained heart-shaped cyclic loading (involving rotation of principal stress axis) may reproduce plastic creep and eventually tend to be like incremental failure after a very high number of load cycles. Compared with undrained cyclic triaxial loading, heart-shaped cyclic loading tends to generate larger permanent axial strain and higher accumulated pore pressure, probably due to that a huge number of cyclic rotations of principal stress direction may lower plastic shakedown limit to plastic creep response.

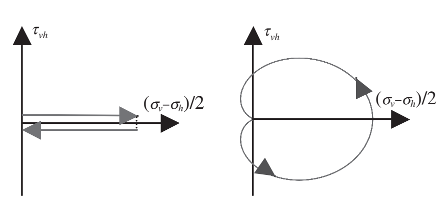

Figure 1. Deviatoric stress paths caused by traffic loading and cyclic triaxial loading.

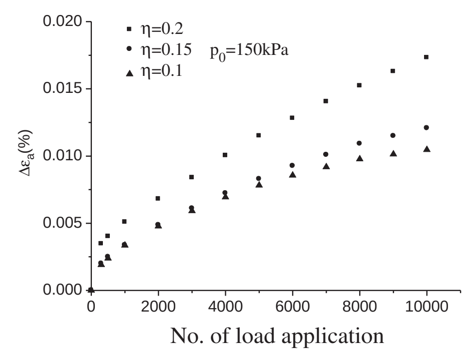

Figure 2. Difference of permanent axial strain ($\Delta\varepsilon_a$) induced by two types of cyclic loadings.

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Influence of underground structures on cavity formation due to various conditions of water flow

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ABSTRACT

Many cave-in accidents happen nowadays in urban roads. Cave-in means sudden collapse of the ground like a pitfall. The accidents are serious problem because it sometimes injures people. It is known that expansion of underground cavities causes of such accidents. Underground cavities have expanded in the ground without being noticed. Then finally surface ground is collapsed when cavities have reached near the surface ground. Many cavities were found close to underground structures. Some of those cavities were caused due to breakages of buried structures such as sewer pipes. Soil is flowed out from cracks of pipes with water, and then cavity is formed. However, in many cases, obvious breakages were not found in underground structures when a cavity was formed. It is not clear why cavities were generated around buried structures even if they didn't have clear damages, but is empirically suggested that water flows more easily around underground structures than in other part of the ground (Referring to Figure 1) Soil is carried with water flow around buried structures, which might cause a cavity around underground structures.

In order to study the influence of an underground structure on formation of cavities due to water penetration, a series of model tests was conducted with a small soil chamber in various conditions. The soil chamber has an opening at the bottom, from which soil can be flowed out. A block simulating the underground structure was placed into the soil chamber. Then repetition of small amount of water flow or steady flow was given in the ground. Then deformation of the model ground was observed and the weight of drained soil was measured. Position of the block, relative density of soil and direction of water penetration were changed.

From a series of model test, it was clarified that position of the block and direction of water flow has large influence on cavity formation and the ground around the block had high water content. Examples of the ground deformation were shown in Figure 2. It was suggested that the wooden block had large influence on generation of the cavity when the block was placed as blocking the water flow to the opening, because concentration of water flow surroundings the block caused saturation of the model ground around the block, where effective stress decreased. During effective stress was decreasing, loosening (low density area) was expanded in the model ground. Then water penetration collapsed the ground and the cavity expanded surroundings the block.

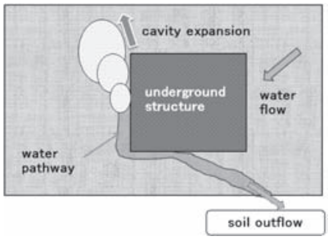

Figure 1. Empirical supposition of generation of cavity due to water pathway surroundings a buried structure.

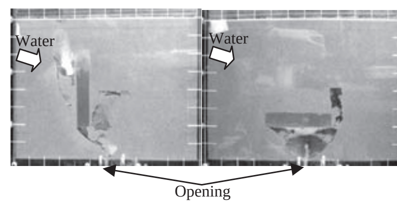

Figure 2. Examples of ground deformation.

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Geotechnical behavior of cement treated soils from southern coast line of Caspian Sea

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ABSTRACT

In recent years, due to population growth, a suitable land for construction is hard to find. For improving and optimum use of locally available soils, great competition among civil engineers has been created. Distribution of problematic soils and those with high moisture and low efficiency pose a lot of problems in construction projects. All improvement techniques are seeking for an increase in density and shear strength, providing stable condition, reduction of soil compressibility, controlling the groundwater flow or increasing the rate of consolidation. This study made an extensive laboratory testing of effectiveness of cement treatment on geotechnical parameters of soils encountered in southern coast line of Caspian sea, including Gorgan Loess, Rasht Clay and Anzali Sand. The Laboratory work included the addition of different percentages of Portland cement type II (2.5, 5, 8% dry weight of soil) to the natural soils and performing laboratory tests such as Standard Proctor Test, Unconfined Compressive Strength Test (UCS), Consolidated-Drained Triaxial Test (CD) and Large Scale Direct Shear Test on both non-treated and cement treated samples. Addition of cement caused significant improvement in unconfined compressive strength and modulus of elasticity. Triaxial test results indicated that while cement treatment improved shear strength remarkably, the type of failure varied greatly from ductile to brittle behavior. Non-treated, 5%, and 8% cement treated soils displayed ductile, planar, and splitting type of failure, respectively. The large scale direct shear test results showed significant improvement in shear strength. Besides, brittle behavior of cement treated samples has been observed. Cement treatment increased the cohesion parameter remarkably in triaxial tests, but friction angle decreased (or remained constant) by increasing the cement content while in large scale direct shear test both cohesion and friction angle parameters were increased greatly. Eventually, it was observed that failure envelope trend of cement treated samples is non-linear and some failure criteria such as modified Griffith theory (1962) and also the criterion suggested by Johnston (1985) can describe the soil cement behavior, satisfactorily.

Table 1. Geotechnical properties of the testing soils.

Soil properties	Rasht	Anazli	Gorgan	Standard methods
Soil group	CL	SP	CL-ML	ASTM D422–63
Passing no. 200	83	1.5	98.5	ASTM D422–63
Specific Gravity	2.72	2.68	2.7	ASTM D854
LL (%)	48	–	25	ASTM D4318
PL (%)	26	NP	20	ASTM D4318
PI (%)	22	–	5	ASTM D4318
Insitu density (g/cm^3)	1.89	2.08	1.63	ASTM D1556
Natural water content (%)	30	14	18	ASTM D2216
Maximum dry density (g/cm^3)	1.58	1.85	1.7	ASTM D698
Optimum water content (%)	22	7.5	14	ASTM D698

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An innovative approach for continuous measurement of cemented sand stiffness immediately after layer compaction

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ABSTRACT

Quality control of cemented sand layers is usually made by means of in-situ tests performed at the reference ages as 28 days, assessing a performance criterion, such as stiffness. The authors of this paper have adapted a methodology that has been recently developed for concrete and cement paste, which allows the continuous monitoring of stiffness since the fresh state of the cement-based material and can reduce the time lag between the actual compaction of the layer and the instant at which conformity is checked. The methodology is termed EMM-ARM (Elasticity Modulus Measurement through Ambient Response Method) and consists of placing the tested material inside an acrylic mould, which is in turn setup as a simply supported beam (Azenha et al., 2010). By monitoring the accelerations of the composite beam at mid-span, it is possible to perform output-only modal identification, thus obtaining a continuous record of the first flexural resonant frequency of the beam. The corresponding E-modulus (E) of the studied material can be continuously and quantitatively assessed by applying the dynamic equation of motion.

In this work, a mixture of a uniform sand, with 91.7% retained material between the 0.425 mm and 0.25 mm sieves, 7% of ordinary Portland cement CEM I 42.5 R and 9% of water (proportions measured in relation to the mass of dry sand) was compacted with a manually operated cylinder compactor inside a wooden box with inner dimensions 1.5 × 1.0 × 0.3 meters. Two EMM-ARM beams were performed by distinct in-situ sampling methodologies: the first involved the lateral introduction in the layer of a 900 mm long PVC tube with inner diameter of 47 mm and wall thickness of 1.5 mm (EMM-ARM TH); the second used a prismatic polycarbonate mould with inner dimensions of 900 mm long and cross-section of 40 mm × 40 mm (EMM-ARM PI) inside a sampler, that was vertically pressed into the compacted layer. A third beam, with prismatic cross–section, was performed without direct sampling from the layer (EMM-ARM PR). The strategy for filling the mould attempted to reconstitute the same compaction degree of the actual layer. In order to perform comparisons with the two EMM-ARM methodologies two cylinder shaped specimens for unconfined cyclic compression (UCC) were collected directly from the layer.

The evolution of E-modulus of the sand-cement during the first 28 days of age, obtained through the three beams, together with the discrete E-modulus from UCC tests is presented on Figure 1. In regard to EMM-ARM TH, the agreement with UCC tests is remarkable at all tested ages, with absolute stiffness differences always remaining below 5%. This is a very good indication regarding the feasibility of using this kind of geometry and sampling technique, which end up being simple and cheap. It thus reveals a strong potential for in-situ application, allowing sound estimates of the expectable stiffness at later ages (e.g. 28 days; 90 days) based on data collected at early ages (e.g. at 7 days).

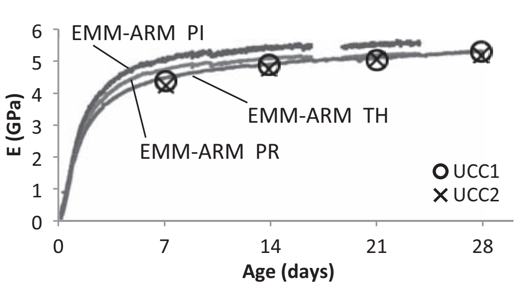

Figure 1. Results of the continuous E-modulus monitoring with EMM-ARM methodology and discrete values obtained in the UCC tests.

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A study on the design of highway bridge pile foundations in volcanic ash ground

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ABSTRACT

To provide a safe and reliable road network, structural foundations need to be built utilizing performance-based design, and must appropriately reflect the characteristics of the ground. In Japan, foundations to be constructed in volcanic ash ground are generally designed in accordance with the standards for sandy soil. However, it has been found that volcanic ash soil is crushable and has mechanical characteristics different from those of sandy soil. Accordingly, 14 vertical and 6 horizontal load tests were conducted using actual piles to clarify the bearing capacity and deformation characteristics of piles in volcanic ash ground. The results indicated a trend showing that pile shaft friction and horizontal subgrade reaction were lower for pyroclastic flow deposits (among volcanic ash soils) than for sandy soil. Based on these findings, a method to be used in future road bridge pile foundation design was studied in consideration of the mechanical characteristics of volcanic ash soil.

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The case studies of damage investigation of the 2011 East Japan earthquake disaster using the vehicle for exploring under roads by GPR

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ABSTRACT

The 2011 off the Pacific coast of Tohoku Earthquake and after quakes and tsunami have wreaked immense damage on Tohoku area of Japan. Lifelines stalled after earthquakes, such as electric, gas, water or telephone. It caused a huge impact on people's life. Because of long-time duration of strong motion, many depressions were occurred on road surface and deformation of soil was feared in many places. In this paper, we will report two case studies of surveys conducted on the earthquake affected area for estimating the state of under road structures using multi-channel vehicle-borne Ground Penetrating Radar (GPR). Our vehicle-borne GPR system "Road Visualizer" has 6 antennae on trailer towed by passenger vehicle and RTK-GPS, HD Video cameras for locating the measuring positions. By using vehicle-borne GPR system, more cost-effective surveys of wide area are possible, and appropriate management of survey results would contribute to effective maintenance of under road structures. GPR survey was applied to detect cavities or loosen part of soil and gave information for prioritize the emergent restoration of infrastructures.

1 INTRODUCTION

The 2011 East off the pacific coast of Tohoku Earthquake and its aftershocks have wreaked immense damage on Tohoku area and large part of East Japan. The largest earthquake has been measured at magnitude (Mw) 9.0 occurring on March 11, 2011, also the largest earthquake in history of Japan. The tsunami brewed up by this massive earthquake has caused tremendous damage at the coastal area. One of the characteristics of this earthquake was its long duration and a lot of repetition of aftershocks and it caused wide-range ground disasters such as soil liquefaction and land subsidence. In these situations, survey methods should be able to cover the wide area rapidly. The GPR (Ground Penetrating Radar) has applicability for such surveys to detect underground structures and ground deformation such as cavities at shallow part. GPR can measure with non-contact to ground, so rapid survey can be performed. The vehicle-born GPR can cover several dozen kilometers in a day without regulation of traffic, while man-towing measuring method can cover several kilometers. The GPR data acquisition system can collect data with high-speed rate, one scan data par 2.5 cm with around with traffic speed. In this paper, we will introduce two case studies of surveying the under roads structures suspected to be damaged at the Tohoku Earthquake using vehicle-borne GPR system (Fig. 1).

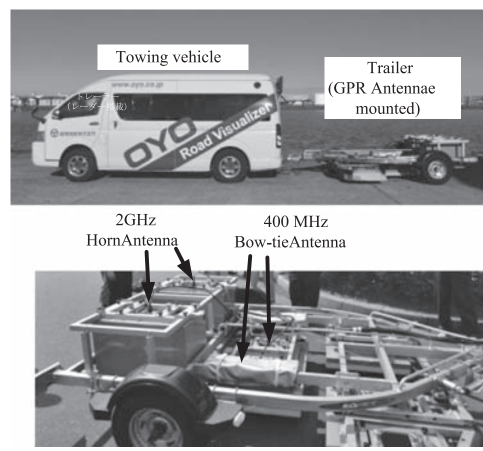

Figure 1. The appearance of vehicle-borne GPR system "Road Visualizer".

In the first case of crossroads survey, soil deformation around the under road passage was feared from visual inspection of surface. Vehicle-borne GPR survey was able to detect cavities or loosen soil part, and narrow down the range of restoration area effectively. In the second case of detecting cavities in a seaport dock, GPR result was conjugated to create priorities of emergency constructions. Cavities occurred at shallow part were extracted for restoring preferentially. Both cases show that deformation assumed to be caused by strong motion tend to be occurred near underground structure. The vehicle-borne GPR method which can survey wide area rapidly is important for estimate damage extent, especially at an initial motion of restoration.

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Intact soft clay responses to cyclic principal stress rotation in undrained condition

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ABSTRACT

Many loading conditions in geotechnical engineering are involved with cyclic rotation of principal stress direction. While soil behavior under such condition is not well known yet. A series of load-controlled triaxial-torsional shear tests were carried out on Hangzhou intact soft clay through ZJU-5 Hz hollow cylinder apparatus, as indicated in Table 1, influence of shear stress ratios and cyclic frequencies was studied.

As the combination of vertical and torsional stress, stress paths with continues rotation of principal stress direction were simulated (Fig. 1). Dynamic behavior of intact soft clay under cyclic principal stress was investigated.

The following conclusions can be made. The magnitude of frequency and deviator stress of cyclic loading involved with principal stress rotation had significant effects on dynamic strain behavior of intact clay. Specimens with lower frequency or larger deviator stress would quickly approach failure after fewer cycles in the study range of this paper. There existed a threshold value of strain, after which the strain developed abruptly with the increase of loading cycles. For a given cyclic stress ratio the threshold strain decreased as the frequency decreasing. However no threshold value in pore water pressure accumulation was observed. Stiffness degradation existed in the case of intact clay undergoing cyclic principal stress rotation with constant deviator stress. And after the threshold strain the stiffness degradation became more dramatically (Fig. 2).

Table 1. Test programme.

Test no.		Shear stress $q = (\sigma_1 - \sigma_3)/2$	Stress ratio q/P	Frequency
Series I	C1	60 kPa	0.4	0.2Hz
	C2	60 kPa	0.4	0.1Hz
	C3	60 kPa	0.4	0.05Hz
Series II	C4	55 kPa	0.37	0.2 Hz
	C1	60 kPa	0.4	0.2Hz
	C5	70 kPa	0.47	0.2Hz

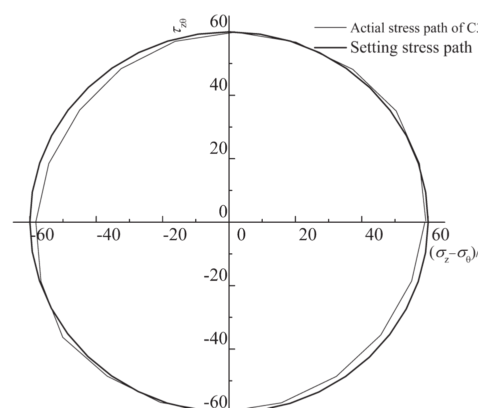

Figure 1. Real stress path in stress space for C3.

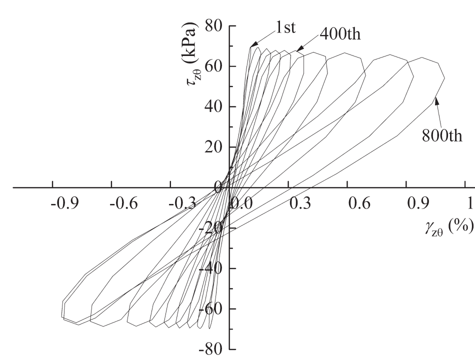

Figure 2. Shear stress-strain relationship of C5.

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Challenges for transportation geotechnics in extreme climates of Kazakhstan and Korea

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ABSTRACT

The frost susceptibility of the soil in condition of Kazakhstan is the important topic. This paper present data about freezing heaving of Kazakhstan soil. The method of determining frost heaving also introduced in this paper. There is testing of the Kazakhstan soil in the freezing room for frost heaving. Also the results comparing with the results of Korean clay soil. There are determination of the main parameters of the soil which include: temperature throw soil specimen, penetration of the froze, heaving rate and amount, heaving pressure. Throw these data we can understand that the soil conditions in extreme climates of Kazakhstan and Korea can create challenges for transportation geotechnics.

The test of determination of frost heaving in the freezing chamber is very important. By this test procedures we can determine main characteristic of the Kazakhstan soil. Also comparing Kazakhstan soil data with Korean soil data and doing some conclusions in the article. There are determination of the main parameters of the soil which include: temperature throw soil specimen, penetration of the froze, heaving amount. These data is important for understanding the extreme climatic condition to geotechnic of transportation in Kazakhstan and Korea. Table 1 presented soil properties of tested soil.

Main figures presented in this paper include determination of characteristic of the Astana soil and Korean soil. There are some conclusions about soil characteristics of comparison of Astana and Korean soil. By this comparisons are done some conclusion about Astana soil throw comparing with Korean soil. The figures show difference of the data and properties of the soil. For example the difference of the frost penetration about 3 cm between Astana and Korean soil. The reason of this difference is that granular content, water content, not frozen water content aren't similar Astana and Korean soil. Therefore data of frost penetration, heaving amount, temperature throw soil specimen have difference each other. Throw this comparison finding frost susceptibility properties of the Astana soil and evaluation.

Throw these laboratory experiments are done some proposes to construction in Astana. Frost susceptibility of Astana soil is not so much dampageable to foundation of building in Astana. Road construction can get more deformation and have sensitivity to frost susceptibility. Therefore should create methods for safety using of the roads and another buildings which foundation is very shallow.

Table 1. Properties of soil specimen.

Description	Kazakh	Korean
Specific gravity γ(kN/m^3)	2.62	2.63
Natural water content w_n(%)	21	–
Particle size passed No.200	52%	66%
Liquid limit LL (%)	27.01	50.50
Plastic limit PL (%)	17.75	31.94
Maximum dry unit weight γ_{dmax}(kN/m^3)	1.79	1.27
Optimum water content w_{opt}(%)	15.9	32.25
USCS	CL	MH

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8 *Modeling and numerical simulations*

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Discrete element modeling of asphalt mixture

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ABSTRACT

The macromechanics of an asphalt mixture are largely dependent on the micromechanics among its components: bitumen, graded mineral aggregate and air. Therefore, it is important to build a model to properly represent the microstructure of asphalt mixture. Over the past two decades, the discrete element method has been used to simulate the microstructure of asphalt mixtures by many researchers.

Three methods were used: a highly idealized method (Collop et al. 2006; Collop et al. 2007), a randomly created polyhedron method (Liu & You 2009), a the image based method (Adhikari & You 2008). In the highly idealized method, aggregates are simulated as balls with uniform radius. Therefore the grading of aggregate was not considered. Also the contact bond used to bond the particles cannot provide moment resistance and stop the particles rolling. In the randomly created polyhedron method, aggregates are simulated with randomly created polyhedron assemblies made with a large number of particles, which is time consuming. The image based method is laboratory dependent, expensive laboratory equipment is needed and well trained technicians are required. This paper aims to produce a validated discrete element model for simulation of a uniaxial compression test of a realistic asphalt mixture, and to improve the understanding of the micromechanical behavior of realistic asphalt mixtures.

This paper discussed the use of discrete element modeling to simulate constant strain rate uniaxial compression tests for realistic asphalt mixture comprising of graded aggregate. A numerical sample preparation procedure was developed to represent the physical specimen Figure 1(a). Parallel bonds have been used in the elastic modeling to give moment resistance at contacts figure 1(b). The uniaxial constant strain rate loading and unloading test has been simulated. The effects of normal to shear contact stiffness ratio on the bulk properties, the parallel bond radius, number of particles and their position, and loading speed have been investigated. A modified Burger's model was used to introduce time dependent contact stiffnesses with the ability of transmission of moment. The two ball clump has been used to investigate the effect of particle shape. The constant strain rate uniaxial compression tests have been undertaken in the laboratory, the axial stress-strain response has been measured to compare with the numerical modeling results.

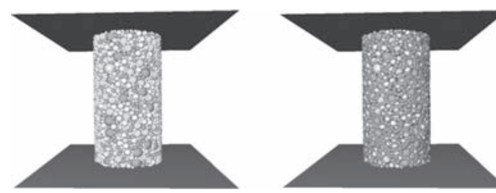

Figure 1. (a) Sample; (b) Sample with parallel bonds.

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Investigating geogrid-reinforced ballast using laboratory pull-out tests and discrete element modelling

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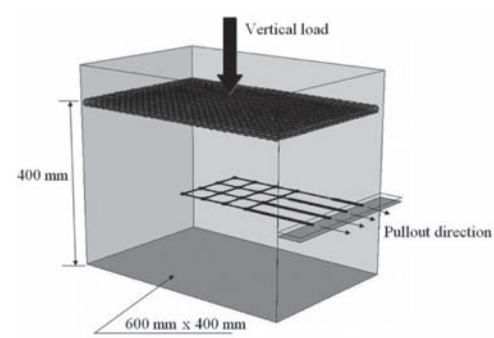
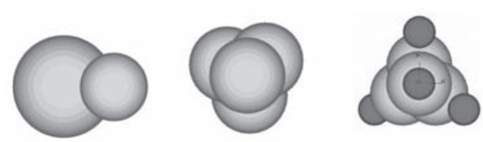
ABSTRACT

Geogrids have been successfully used for the reinforcement in railway track over the past decades. A geogrid can be placed within the ballast layer to reduce ballast deformation and extend the maintenance cycle by a factor of about 3.0, or at the top of the subgrade to increase the bearing capacity of the track foundation (Tensar 2009). The conventional geogrids are produced with high stiffness in longitudinal and transverse directions with square apertures to suit the ballast grading. The large box pull-out test is considered to be suitable means of investigating the fundamental mechanics of ballast/geogrid interactions.

This paper presents an evaluation of the interlocking behaviour of geogrid-reinforced railway ballast. Experimental large box pullout tests were conducted to examine the interaction between ballast and the biaxial geogrid. The Discrete Element Method (DEM) has then been used to model the interaction between ballast and geogrid by simulating large box pullout tests and comparing with experimental results. For the DEM simulations, a ballast particle is modelled using different shapes of clumps and a two-layer geogrid model using parallel bonded balls are presented as shown in Figure 1. The micro-parameters of the geogrid model are calibrated in terms of stiffness and strength by performing tensile and rotational tests on the geogrid. The DEM simulation results have been shown to provide good predictions of the pull-out resistance and examine the effect of clump shape on the pull-out resistance and also the distribution of contact forces. Therefore, the calibrated geogrid model and clumps as ballast particles hold much promise for investigating the interaction between geogrids and ballast and therefore optimising performance.



(a)



(b) (c) (d)

Figure 1. DEM of large box pullout test: (a) embedded geogrid specimen and simulated surcharge; (b) 2-ball clump as a ballast particle; (c) 4-ball tetrahedron clump as a ballast particle; (d) 8-ball tetrahedron clump as a ballast particle.

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Numerical modeling of "soil-mixing" columns used for railway subgrade reinforcement

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ABSTRACT

Nowadays, the rail network operated in France is about 30 000 km of old so-called "classic lines" and 2000 km of high-speed lines (LGV). The network owners and the operators (RFF and SNCF) must ensure an efficient and fully secure use of this network while addressing on the one hand to an increasing demand for capacity (axle load and frequency of trains) and also a requirement of control operating costs.

Therefore, many existing railways require upgrading before the opening for new traffic conditions. Currently the renewal maintenance techniques need the track removal with mandatory traffic interruption which leads to high costs. Thus, the project RUFEX, for which the work presented in this paper is developed, aims at studying the feasibility of platform improvement without track removing with soil-mixing columns and better understand its performance and reduce the maintenance costs.

Hence, the main objective of this paper is to present the numerical modeling of the railway track subgrade reinforcement with vertical soil-cemented columns. The finite element method is used to identify the main load transfer mechanisms specific to this type of reinforcement technique and to analyze the impact of the columns on the behavior of the railway track structure in terms of bearing capacity, deformability and dynamic response. Other important aspect of the modeling is to verify that the columns do not create "stiff points" in the global response of the track under moving loads, which could contribute to an increase of the track degradation due to dynamic vehicle-track interaction problems.

Thus, in order to optimize design, parametric studies were carried out to determine: the most efficient pattern (diameter and spacing between columns); the impact of the cemented soil mechanical properties during hardening process in track settlement under traffic load.

The numerical simulation results have to highlight two major aspects regarding the effectiveness of the reinforced railway track under moving load: firstly, the impact of local reinforced on the creation of stiff points, regarding the spatial pattern of soil-mixing columns and mechanical properties; and secondly the optimization of number and length of columns in order to reduced as much as possible maintenance costs.

Numerical simulations showed that in terms load transfer mechanisms in soil-mixing columns, the cementation effects (increasing of the columns Young's modulus) impacts directly the initial stiffness of the load settlement curve and the maximum mobilized resistance, specially, due to an increased base resistance mobilization. Thus the balance between shaft and base resistance mobilization under vertical loading will depend on cementation time. In addition, the parallel between soil-mixing columns behavior and pile is appropriate but one should note that the soil mixing is not a rigid inclusion so the interaction between shaft interface conditions and base is important. And much smaller base resistance could be mobilized compared with a pile for which all pile head displacement is transferred to the base.

The interface soil-structure conditions also highly affect the shaft and base resistance mobilization. Nonetheless, for this type of columns, installed *in-situ* with gravitary injection, it is expected that the soil-structure surface is a rough one.

In terms of the impact of soil-mixing columns reinforced track under moving load, one can note that columns's space discretization is very important. The reinforced railway track has to work as a homogenized structure. In order the creation of stiff points is minimized. In order to reduce subgrade reinforcement costs through the soil mixing technique, numerical simulations showed that there is an optimum ratio for the soil improvement mechanical properties (E_{col}/E_{soil}) which reduces railway settlement.

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Modelling cemented sand using DEM

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ABSTRACT

Naturally cemented sand occurs through a number of processes, and as such, samples exhibit high variation in density and degree of cementation (Airey 1993). Additionally there are difficulties extracting natural specimens while avoiding disturbance. Artificially cemented soil (Figure 1) is commonly used in subbase layers in pavement construction, primarily due to the improved performance.

Much of the available research on cemented sand has been carried out at conventional pressures (typically under 1 MPa), with less data available on behaviour under high pressures. Results of consolidated drained high-pressure triaxial tests carried out at the University of Nottingham (Marri, 2010) are presented. The tests were performed on specimens with Portland Cement contents ranging from 0–15% dry weight, across confining pressures of 1, 4, 8 and 12 MPa, with the separate effects of confining pressure and cement content discussed.

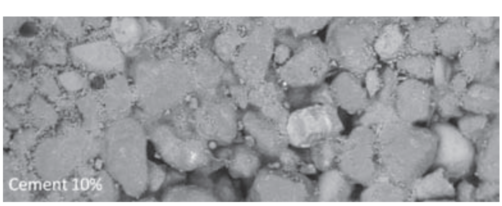

Figure 1. Scanning electron micrograph of artificially cemented sand.

Discrete Element Method (DEM) is a widely used tool for modelling granular materials, and is used in this study in conjunction with laboratory work to investigate the behaviour of cemented sand under high pressures. DEM simulations of drained triaxial tests with confining pressures up to 12 MPa have been completed, which feature a flexible membrane to allow the correct specimen deformation and failure modes. The inclusion of particle bonding enhances the strength characteristics of the material; with these effects reducing as confining pressure is increased.

In this paper, the bond strength as well as various bond strength distributions have been investigated, and using the distribution which results in the most realistic macroscopic response, the correct qualitative behaviour has been reproduced. Observing the deviatoric stress response, and monitoring the individual particle rotations, the specimens exhibit very brittle behaviour at lower confining pressures and more ductile behaviour at higher confining pressures as the bonds break prior and during shearing. The correct transition from brittle to ductile behaviour is witnessed.

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Modelling of sand behavior in drained cyclic shear

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ABSTRACT

An elasto-plastic constitutive model capable of simulating both monotonic and cyclic drained torsional shear behavior of sand is presented. The Generalized Hyperbolic Equation (GHE) has been employed to model the drained monotonic behavior of sand. The cyclic shear behavior is modelled by combining the GHE with extended Masing's rules considering the hardening behavior of sand during drained cyclic loadings and the damage to soil skeleton at large stress levels. A modified stress-dilatancy relationship that relates the ratio of plastic volumetric strain increment to plastic shear strain increments $(-d\varepsilon^p_{vol}/d\gamma^p_{z\theta})$ to shear stress ratio $(\tau_{z\theta}/p')$ is employed to simulate the volumetric strain of sand during drained cyclic torsional shear loading. The proposed model is verified through simulation of a series of drained cyclic torsional shear tests on hollow cylindrical Toyoura sand specimens. Comparison of experimental stress-shear strain relationships with its simulation suggests that, after considering the damage at large stress levels and hardening behavior during cyclic loadings, the proposed model can reasonably simulate the stress-shear strain relationship of Toyoura sand. In addition, the simulation of volumetric strain is significantly improved and becomes consistent with the corresponding experiment data after employing the modified stress-dilatancy relationship.

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Innovative sleeper design analysis using DEM

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ABSTRACT

Railway tracks have always been the object of studies in order to reduce their maintenance and cost. The sleeper-ballast interaction is the object of a particular attention. The sleeper is one of the components of the railway track easily modifiable. The approach to treat this kind of problem is usually empirical or involves continuous numerical models with a limited success given the discrete nature of ballast materials. In this paper however a discrete element model using realistic particle shapes (Ferellec & McDowell, 2008, 2010a, 2010b) is used to simulate a standard box test. The test simply consists of applying a cyclic vertical load, typical of train passing, on a section of sleeper embedded in a bed of ballast confined in a box (Fig. 1a).

Different section shapes of the sleeper (Fig. 1b) are then analyzed. The first one is the rectangular typical concrete or wooden sleeper shape. The second one is identical to the rectangular one in terms of dimensions but without a base, somewhat similar to the steel sleepers available in the industry. The purpose of these two models is to provide a reference for comparison with the subsequent new designs. The purpose of the following shapes is to spread the load more laterally and not mainly vertically like the rectangular one. The third model is trapezoidal. The fourth model is a rectangular model which edges have been trimmed at the base. All models present an identical vertical projection and are embedded at the same depth. Four box test simulations were performed and compared. They gave information about the force distribution inside the ballast and the deflection of the sleeper during the cyclic loading.

These simulations showed that it is possible to modify the load distribution inside ballast using different shapes of sleeper section. The shape of the sleeper affects the particle contact force network and the deflection of the sleepers in different ways. The trimmed sleeper, consisting of a rectangular sleeper which base edges have been trimmed, presents the best performance both in terms of settlement and load distribution inside the ballast. The lower average value of contact force in that case indicates that it would also probably reduce the amount of particle breakage inside the ballast.

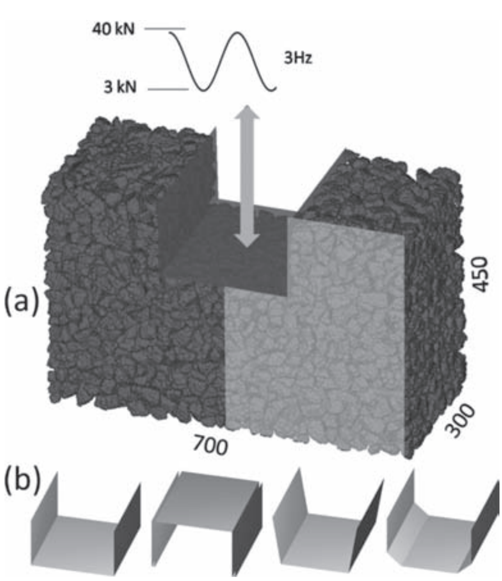

Figure 1. Box tests configuration (a) and sleeper sections (b).

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Influence of the soil properties variability on the railway track response under moving load

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ABSTRACT

The aim of this work is to numerically assess the influence of the random variability of railway track properties on the track response under moving load. A 2D dynamic finite element model with modified width plane strain condition of the railway track is performed. Soil mechanical behavior is considered as linear elastic as a first approach. The probabilistic characterization of the Young's Modulus from different track layers is obtained from *in-situ* dynamic cone penetration tests Panda (Gourvès, 1991) performed on a classical line by SNCF (*French National Railway Corporation*) coupled with empirical relations proposed in the literature for the different soil materials (Chua 1988; Lunne et al. 1997). Latin Hypercube Sampling (LHS) technique with correlation control (Iman & Conover 1982) is used as a non-intrusive approach to the probabilistic dimension. A theoretical squared exponential correlation function with correlation length of 1 m is proposed to model spatial variations. The homogeneous case is also considered in order to evaluate the influence of the correlation length on the results.

Numerical simulations are carried out using GEF-Dyn code. The effect of soil variability on the track global stiffness is obtained at small speed, as to simulate a track global stiffness measurement. Results in terms of the spatial coefficient of variation for both cases are presented on Table 1. These simulations showed that the output's variability are much smaller than input's one. The correlation distance seems to play an important role on this variance reduction, i.e. variations of stiffness the railway track imposes to the moving load. Simulations for different correlation lengths will evidence the influence of this parameter on the variance of the track stiffness.

Moreover, a global sensibility analysis based on the Fourier Amplitude Sensitivity Test (FAST) (Saltelli et al. 1999) was performed. It showed that around 80% of the output variance is due to the variance of the supporting soil for the homogeneous case. These results highlight the importance of taking into account natural soil spatial variability on railway track models. The same analysis may also be conducted for the random field case.

Table 1. Results for small speed dynamic case.

		CV_k
Dynamic case	Homogeneous	10.5%
	$\theta_y = 1$ m	5.5%

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Comparison between a 3-D finite element pavement model and the mechanistic-empirical pavement design guide for asphalt pavements

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ABSTRACT

The new design guide, Mechanistic-Empirical Pavement Design Guide (MEPDG), is an improved methodology for pavement design and the evaluation of paving materials. However, in spite of significant advancements to pre-existing traditional design methods, the MEPDG is known to be limited in its accurate prediction of mechanical responses and damage in asphaltic pavements due to the use of the axi-symmetric layered elastic theory for pavement structural analyses, simplified constitutive relations and damage characteristics for the paving materials model, and the use of circular tire loading configurations. To model pavement performance in a more realistic manner, this study attempts Finite Element Modeling (FEM) to account for three-dimensional pavement structure, viscoelastic paving materials, and actual tire loading configurations.

Figure 1 presents the comparison of pavement life between the MEPDG and FEM at the critical rut depth of 6.35 mm. As shown in the figure, the finite element mechanistic model produced a longer life than the MEPDG approach. This is not surprising, since the MEPDG accounts for pavement damage due to truck loading by incorporating pavement responses with the rutting transfer function, which is an empirical model to characterize damage and failure; while the finite element mechanistic model determines the pavement life by accounting for only one source of energy dissipation, which is due to the viscoelastic asphalt layer. The accuracy of pavement performance results from the mechanistic approach can be improved by considering other sources of energy dissipation in the model, such as cracking and aging. The life of the pavement will be shorter and closer to reality.

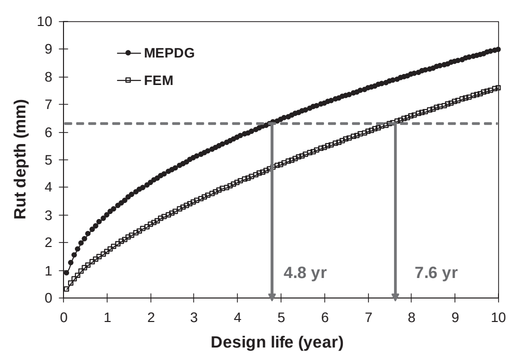

Figure 1. Comparison of pavement performance and life (MEPDG vs. FEM).

The main findings of this study are as follows:

- Although MEPDG is currently the optimal method for the pavement design, the FEM—based mechanistic approach enables to consider more realistic condition.
- One of the major advantages of the mechanistic modeling approach is that it can reduce the empirical aspects of performance prediction models based on a more scientific rigor.
- Furthermore, the need for extensive laboratory and field work can be reduced, since the predictions rely upon computer simulation and the fundamental material properties of individual layers.

However, because the current stage of the model merely takes into account energy dissipation due to material viscoelasticity and does not provide any sources of energy dissipation in the form of damage and due to environmental effects, it has limitations that are left to future work.

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Centrifuge modelling of an embankment stabilised with discretely spaced reinforced concrete piles

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ABSTRACT

This paper focuses upon the discrete piling method, whereby a line of spaced piles are installed across the width of a failing slope, inducing soil arching in the failing soil mass and halting movement. This technique has already been successfully trialled within the UK and abroad, both on natural and manmade slopes surrounding major arterial infrastructure. However, the effect of pile location upon the slope is not yet thoroughly understood from a design perspective, with many publications making conflicting recommendations as to the optimal position (Table 1).

A programme of centrifuge tests was undertaken to determine the effect of pile line position, pile type and installation technique upon the degree of slope improvement observed in a representative clay embankment. A means of casting reinforced bored model concrete piles, with interface properties, bending capacity and flexural stiffness representative of full scale piles when in the centrifuge, was first developed, following similar previous work for precast model concrete driven piles (Knappett et al., 2010). Slopes were tested both with and without the presence of model bored or driven piles, respectively, in various locations, and the slope deformation of each model measured at each slope height (g–level) using particle image velocimetry techniques.

The results obtained consistently showed that regardless of pile type or location, some improvement in slope movement is always achieved over the unreinforced case. Pile position has a significant influence over the magnitude of this observed improvement, with the greatest enhancement in slope stability achieved when piles are placed towards the slope toe. The degree of improvement is then observed to decrease as the pile line is moved upslope, with piles placed at the crest offering the least improvement to slope integrity. The bored piles were also found to slightly outperform the driven piles, the reasons for which are discussed.

Table 1. Optimal pile position recommendations.

Reference	Position	Methodology
Hassiotis et al. (1997)	Near-crest	Limit equilibrium
Lee et al. (1995)	Toe & crest	Limit equilibrium
Ausilio et al. (2001)	Toe	Limit analysis
Cai & Ugai (2000)	Midpoint	FEA*
Won et al. (2005)	Midpoint	FEA*
Wei & Cheng (2009)	Midpoint	FEA*

* Finite Element Analysis

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3D-DEM simulation for shaking table test of ballasted test track

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ABSTRACT

We challenged a series of numerical shaking table test by 3D-DEM using discrete element ballasted track as shown in Figure 1. This model composed of 19044 ballast grains attaining the measured density value of the well-compressed ballast layer. Those ballast grains are clump spheres, composed of 10 spheres with various diameters referring the scanned data of the 3D shape of actual ballast grains. Furthermore, those ballast grains follows the same grain size distribution standard for ballast grains.

Then we observed not only sleeper behavior but also ballast grains behavior under horizontal excitation. Comparison the simulation results with the previous experimental study suggested that the quantitative accuracy should be examined in future work.

However, simulation results shows qualitatively similar tendency with previous experimental study as follows.

– The more the maximum acceleration increase, the more the relative displacement and vibration amplitude of sleeper increase.
– Ballast shoulders are deformed, especially for the case of the 800gal excitation as shown in Figure 2.

Then we explained that the numerical experiment gives some information which cannot be obtained from only experiments as follows.

– Numerical results show the trend of the number of contact points varying during horizontal excitation, and the tendency is different with the maximum acceleration as shown in Figure 3. Especially at the ballast shoulders, ballast grains lose contact points between each other.
– Numerical results show the distribution of contact force between model elements. Especially the DEM can simulate heterogeneity of granular assemblage.

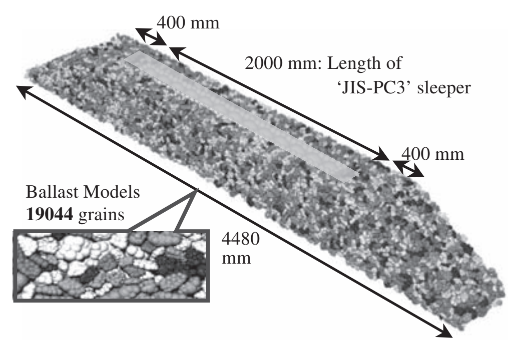

Figure 1. Discrete element ballasted track model.

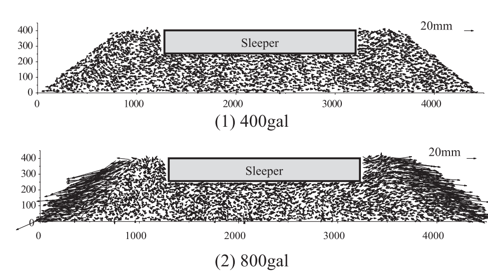

Figure 2. Distribution of residual displacement of ballast elements.

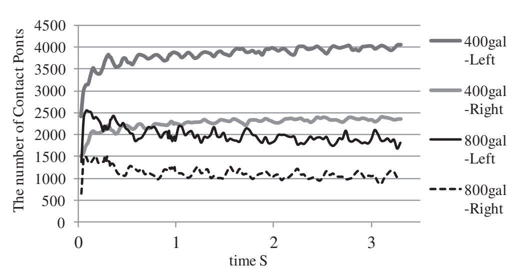

Figure 3. Time history of the numbers of contact points at the ballast shoulder.

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Performance analysis of EPS test embankment

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ABSTRACT

The Muurla EPS full scale test embankment was one of the test sites of the EPStress research program (Saarelainen 2003). The Muurla site was selected, because it had high traffic intensity, the amount of heavy traffic was relatively high and the design life of the road was short, with a maximum of 10 years. The aim of the Muurla embankment was to study, how an EPS embankment without a concrete plate works under a heavy traffic loading.

The test site was situated on a temporary single line connection between the new motorway part and a single line road. The minimum thickness of the granular layers above EPS was 700 mm to avoid skidding due to ice formation on the road surface during winter time. To stiffen the upper part of the structure the upper part of the base layer was chosen to be a composite stabilized crushed rock layer (thickness 150 mm). (Korkiala-Tanttu 2003).

The structure was design to have a relatively short service life (4.5 years for composite). The structure was built in years 2001–2002. The test structure was in use for nearly six years after which it was dismantled in 2008.

The evenness of the surface was measured four times during the service life of the structure. In average the IRI had increased from 1.3 mm/m in 2004 to 1.7 mm/m in 2008. The rut depths were smaller in the lane to Helsinki, where the pavement layers were thicker than on the lane to Turku. The annual rut depth growth was 2.3 mm/a in the EPS-embankment area. Also the damages were remarkably lower on the lane to Helsinki. (Kivikoski & Juvankoski 2008).

Based on the traffic data, the back-calculated resilient module and the measured layer thickness the performance was analyzed with numerical methods. The program Plaxis 2010 was used for the analysis. Due to the lack of realistic material properties Mohr-Coulomb model has been applied for unbound materials. According to the numerical calculations the elastic deformations in the upper part of the EPS under the wheel line was about 0,7% with the dual wheel load of 50 kN. So high strain level means, that some permanent deformations in the EPS will happen, as the measurements proved. The calculated vertical stress in EPS was around 130 kPa with this high wheel load.

The calculated vertical stress levels in the unbound layers were from 5% to 9 % bigger in the left lane (to Turku) and even 11% in the composite layer. Also the deviatoric follow the same trend, except on composite layer. Due to the non-linear stress-deformation behaviour of unbound materials these differences in stress state are large enough to exhibit the clearly weaker performance of the left lane compared to the right lane, in spite of the somewhat higher traffic amount.

The numerical calculations address that even relatively small changes in layer thickness can cause higher stresses and bigger deformations in the layers and thus weaker performance. Especially this behaviour is enhanced in this case where the design margins are very small.

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Dynamic response for critical velocity effect depending on track supporting stiffness

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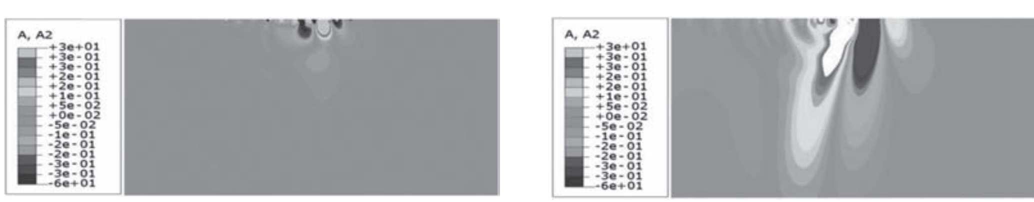
ABSTRACT

The critical velocity effect on railway trackbed means the amplification of vibration energy when the train running-speed and group velocity of ground surface wave are superimposed. It is called a pseudo-resonance phenomenon of time domain. In the past, it is not issued because the train speed is low and the ground group velocity is higher. But since the high-speed train is introduced, critical velocity is reported as causing a track irregularity. So far, theoretical analysis has been performed because of the complexity of formation process. However, it requires reasonable consideration which is similar to the actual track and trackbed conditions. In the present paper, finite element analysis to verify the critical velocity effect is performed with the consideration of each track structure and trackbed supporting stiffness. As a result, the deformation amplification caused by the critical velocity effect is verified as the supporting stiffness and track supporting system.

According to the response analysis depending on the trackbed stiffness (10–300 MPa) while train runs at 300 km/h, the maximum displacement was 0.47 mm which was amplified up to 50 times more than the non-critical velocity. The trackbed displacement was significantly more amplified at the critical velocity range. When the trackbed stiffness exceeds the critical velocity, the maximum displacement was reduced exponentially. And according to the response analysis of the concrete track, no amplification occurred at the same band as the ballast track, which was attributable to the fact that the concrete track has greater support and flexural stiffness than the ballast track.



(a) Non-critical velocity band

(b) Critical velocity band

Figure 1. Vertical acceleration response for the critical velocity effect.

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Numerical analysis of settlements at bridge approaches

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ABSTRACT

As well known, driving comfort on road, especially in high-speed grade, is a rising issue all over the world. It has been reported by that the primary cause of bump is differential settlement between bridge and embankment, and these settlement comes from poor compaction, improper materials, poor drainage, and high embankment and so on [Briaud et al. (1997); White et al. (2007)]. However, Allen et al. (1985) and White et al. (2005) pointed out that differential settlement problems may not be solved simply with management on compaction quality and materials. This means that differential settlement is a result of complicated interaction between soils, structures, and numerous relevant factors.

In order to find out the cause of the differential settlement on the bridge approaches, a series of 3-dimentional numerical studies were conducted. Several cases including different abutments heights wing wall types, and inclinations of original ground levels were considered in this study.

Based this study, the settlements at the approach end and the embankment were increased with abutment height, and a larger wing wall reduces settlements on the approach. The slope of the original ground was not a major effect on the settlement of the approach. Among these 3 factors, the abutment height was the most important effect on the settlement of the bridge approach.

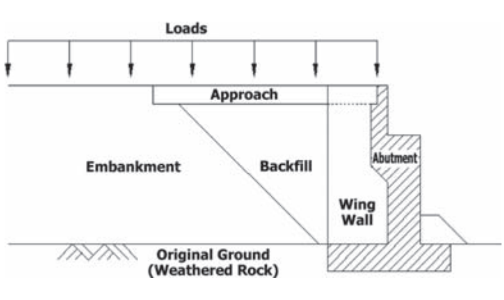

Figure 1. Schematic of numerical analysis.

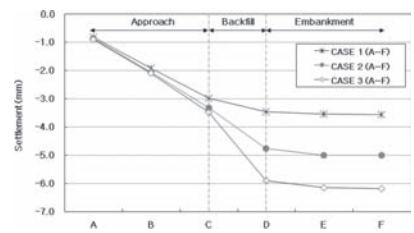

Figure 2. Settlements according to various abutment heights.

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The use of geotechnical instrumentation and finite element analysis for assessment of bridge foundation stability due to breccia resliding over clayshale

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ABSTRACT

Breccia Re-sliding over clayshale has become the most responsible causes of landslides phenomena in the Semarang (Central Java) Area. Creep is the common type of land movement causing progressive damages to buildings and infrastructures, however in some cases, sudden landslides may be triggered due to infiltration of rain water into the breccia layer due to its high permeability (Rahardjo, 2003). On the other hand, the thick deep layer of clay-shale is practically impermeable. Clayshale is thin laminated claystone or mudstone which can slake or degrade due to exposure to air and water. The Penggaron Bridge is located in this area, and just after completion of the bridge landslides occurred which caused delay of the commissioning of the bridge due to safety reason. The authors were involved to investigate the causes and the consequences of the landslide for assessment of the safety of the bridge and to recommend action for the safety of the bridge. The main task of the geotechnical analysis are to ensure (1) whether the ground movement would still occur, (2) location, direction and rate of movement (3) the magnitude of additional loads on piles caused by the ground movement and (4) decision for strengthening of the bridge foundation. Foundation monitoring and 2D and 3D finite element analysis were conducted. The results of study concluded that even though the ground are still moving, no damages were found in the foundation except due to workmanship, additional forces causing by the ground movement are so far still under pile cross section capacity, however new piles were constructed to prevent the foundation from further damage including the installation of additional geotechnical instrumentation.

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Shear strain development and pore pressure distribution in sandy model slope under repeated rainfall

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ABSTRACT

In order to establish the time prediction method of shallow landslide due to rainfall, it is important to modify the stress-strain relation in the slope due to absorbing of soil. The effect of stress history according to repeated also should be taken into account for the model. In order to examine the mechanical modeling of shear deformation of sandy slope under repeated rainfall, the deformation of the soil and movement of soil-water in the sandy model slope under repeated rainfall was monitored in this study, and some analyses on the relation between deformation and soil-water content are tried for seeking some constitutive law between the deformation and soil-water conditions in the slope under repeated rainfall.

Experimental facts were made clear as follows.

Surface displacement increased at and after the increase of Ground Water Level (G.W.L.). Shear strain increased not with the increase of V.W.C. or decrease of suction but after those in the slope.

Shear strain increased under constant suction, while shear strain variation was very small at wetting or drying process at shallow layer. On the contrary, shear strain increased with the decrease of suction at wetting process and it stayed almost constant with the increase of suction at drying process at deeper layer (Figure 1). Shear strain stayed almost constant up to minimum suction at latest wetting process (yield value) in next wetting process, while it started increase if it exceeded the yield value at deeper layer (Figure 1).

Surface displacement increased remarkably with the increase of G.W.L., and then it stayed almost constant with the decrease of G.W.L. at drying process. At next wetting process, surface displacement made small increase with the increase of G.W.L up to maximum G.W.L. of latest wetting process while it remarkably increased with the increase of G.W.L. if it exceeded the maximum G.W.L. at latest wetting process (Figure 2). The relation between surface displacement and G.W.L. just before the failure can be modified as hyperbolic (Figure 2).

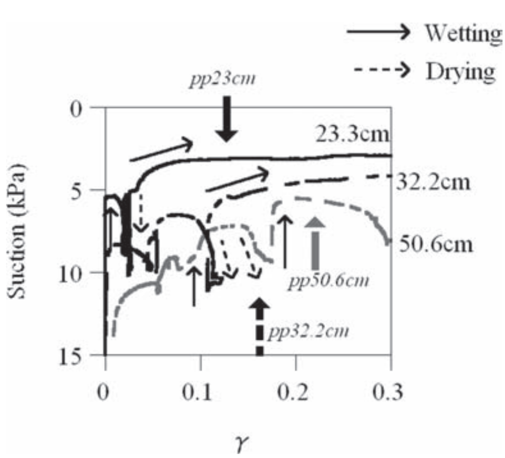

Figure 1. Relation between shear strain and suction. At deeper layer γ: Shear strain.

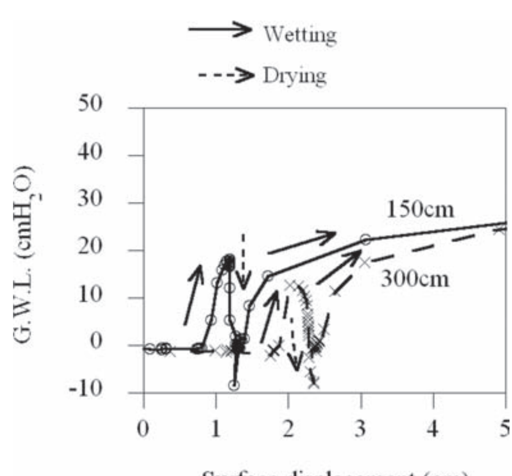

Figure 2. Relation between surface displacement and G.W.L.

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Physical model of surcharge loading to the intersecting ridge between two slopes

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ABSTRACT

The present study aims to investigate the pressure distribution induced by surcharge loading to the intersecting ridge of two slopes. The load transfer mechanism of dead load was studied by applying bearing balls along the foregoing slope ridge through the physical model of a rectangular bin as shown in Figure 1.

Dry silica sand was poured into a flat-bottom bin through an 8-cm-diameter plastic bottle having a screened bottom of 1 mm. A vacuum with a sharp nozzle was employed to suck sand from the centerline to the 20 cm depth.

Figure 2 shows the comparison of pressure profiles obtained from the experiment and theory adopted from Flamant (1892). The change in vertical pressure at the floor of the model $\Delta\sigma_z$ due to bearing ball surcharge resting on the ridge at h = 9 cm was normalized by its initial overburden pressure γH and plotted against χ which is the distance from the centerline along the floor normalized by half-length $L/2$. Four different solid lines represent incremental pressures caused by bearing ball loading of 25, 50, 75 and 100 N, which are calculated the adopted theory. Other four sets of series of incremental pressure at distinctive symbols were measured by pressure gauges. The pressures appear to concentrate beneath the center of the surcharge load and tend to decrease as increasing horizontal distance away from the centerline. It can be deduced that the theoretical pressures proposed in the present study shows an acceptable agreement with the experimental results.

The experimental results show that Flamant solution for a semi-infinite elastic body acceptably agrees with the experiment; thus, load transfer pattern can be suitably characterized by elliptic type governing equation. The surcharge load, which could be idealized to traffic load passing V-shaped valley, exerted to the ridge of sand valley mostly transferred to the basal support with insignificant interference to the neighboring steep slopes.

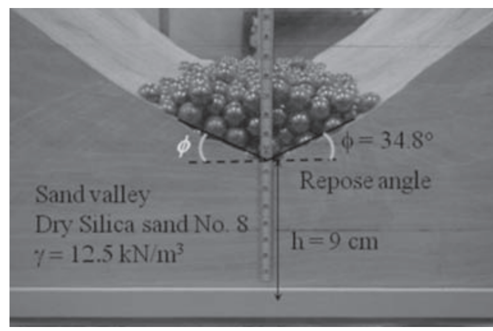

Figure 1. Physical model of load transfer mechanism.

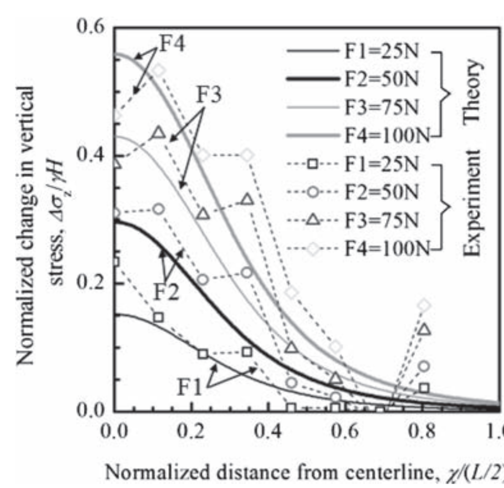

Figure 2. Comparison of stress distribution of physical model.

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On 1G slope failure model tests due to rainfalls: Difference of failure patterns due to difference of densities of a subsurface sand layer

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ABSTRACT

In this research, in order to investigate failure behavior of typical natural slopes, series of rainfall model tests were conducted in 1 G field (see Table 1). Each model consists of a subsurface shallow sand layer and a relatively hard foundation like a typical natural slope (see Fig 1). Pore water pressures (PWPs) and displacements of the slope were measured during the model tests. In this paper, we mainly focus on the relationship between densities of subsurface sand layer and failure patterns (Case 3, 4 and 5).

From the model tests, we could obtain following results and discussions:

1. Failure occurred in all cases. In Case 3 ($D_r = 0\%$), the sand mass moved along the slope and a clear, large but shallow failure finally occurred. It was recognized as a typical surface failure.
2. The horizontal deformations of the sand mass were dominant in Case 5 ($D_r = 50\%$). After the first failure appeared at the toe of the slope, in sequence the slip surfaces appeared and they progressed to the upper parts of the slope. The behavior was a so called progressive failure.
3. The sand mass moved intermediate direction between Cases 1 and 3 in Case 2 ($D_r = 25\ \%$).

Table 1. Conditions of model tests.

Case	Rainfall intensity (mm/hr)	Sand layer D_r (%)	ρ_d(g/cm^3)	w (%)	S_r (%)
1	25	0	1.350	10.6	29.8
2	25	50	1.495	9.8	32.9
3	**50**	**0**	**1.350**	**11.0**	**33.6**
4	**50**	**25**	**1.423**	**10.0**	**30.2**
5	**50**	**50**	**1.495**	**10.0**	**33.6**
6	100	0	1.350	12.9	34.9
7	100	50	1.495	9.8	32.9

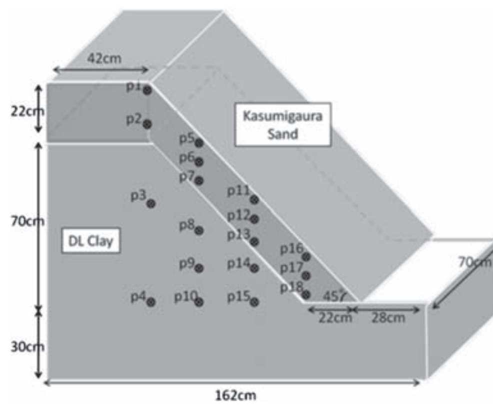

Figure 1. Model slope configuration used in 1G tests.

However other failure processes were similar to those of Case 3. In Cases 2 and 3, these failures occurred within saturated zones.

4. Pore Water Pressures (PWP) rose up faster with an increase in the relative densities. The PWP values in Case 1 had been keeping negative values for a long time.
5. There was a clear seepage surface in Case 5 and the surface appeared on a relatively high level portion of the slope surface. Meanwhile the seepage surface in Case 3 did not appear on the slope surface. The seepage surface in Case 4 also appeared on the slope surface but the level was lower than that in Case 5.

Now, we are trying to simulate the model test results using saturated-unsaturated consolidation analysis method proposed by authors. Comparing simulation results to model test results, some applicability of the analysis method will be verified. Finally we will evaluate slope stability due to rainfall using this analysis method.

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Effect of deformed wick drain in soft ground improvement for embankments in Vietnam

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ABSTRACT

Deformation of wick drains or Prefabricated Vertical Drains (PVD) due to consolidation settlement during preloading can reduce or shut off entirely discharge capacity of PVD. Consequently, degree of consolidation of soft soil is diminished with time during consolidation. This study takes variation of q_w due to PVD deformed during consolidation process under preloading into account for soft ground improvement using PVD. Effect of deformed PVD on discharge capacity was investigated by back analysis using the field monitored data of the two complete soft ground improvement projects using PVD: the approaching embankment of the Phu My bridge project, and the embankment of Vo Van Kiet boulevard in Ho Chi Minh City, Vietnam.

This study utilized the Plaxis 2D software to simulate consolidation settlement with PVD using the equation proposed by Tran & Mitachi (2008) and a spreadsheet for Hansbo's (1981) theory. The simulations were compared with the field monitored settlement. Figure 1 shows the simulation result at km 16 + 900 in the Vo Van Kiet boulevard project.

The findings indicate that it can consider PVD performing ideally at a field settlement of 0.5 m or less. When the embankment has experienced at a field settlement of 1.5 m or more, several factors such as PVD deformation and smear effects should be taken into account for field consolidation analysis using the PVD for soil ground improvement in Vietnam. More projects should be investigated to confirm these results in future works.

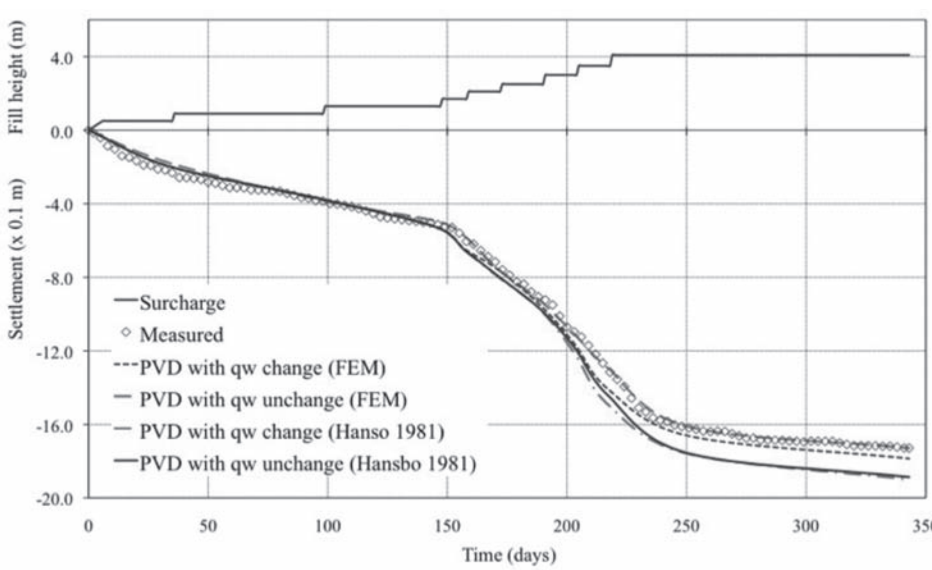

Figure 1. Back analysis for the cross-section of Vo Van Kiet Boulevard's embankment at km 16 + 900.

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Shaking table test and effective stress analysis of bridge pile foundation with seismic isolation rubber in liquefied ground

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ABSTRACT

During an earthquake, pile foundations in liquefaction can become heavily damaged at the boundary division of ground classification—liquefied ground and non-liquefied ground—because of the inertial force of the corresponding superstructure, liquefaction, and lateral flow. Consequently, such piles can potentially collapse. Such pile damages have been observed in surveys conducted for past earthquakes.

In the 2011 earthquake that occurred off the Pacific coast of Tohoku (March 11), liquefaction occurred in Urayasu City, which is located in the Tokyo Bay area, and in the Miyagi, Fukushima, and Tochigi prefectures. This liquefaction seemed to damage pile foundations. In Onagawa Town in Miyagi prefecture, a pile was torn from the soil by a tsunami. The main cause of the collapse was the great wave by the tsunami, but it appears that the pile resistance to the tsunami was minimal because the ground around it had become loose.

We confirmed through the shaking table test that a local section force was exerted on the pile at the layer boundary. So we developed seismic resistance in the pile foundation by using seismic isolation rubber at the place where the section force is exerted—on the intermediate part of the pile. And in order to check the validity of the modeling of the seismic isolation rubber in the effective stress analysis of the pile foundation, a reappearance analysis of the shaking table test was carried out; it was shown that the performed experiments were mostly reproducible using this analysis technique.

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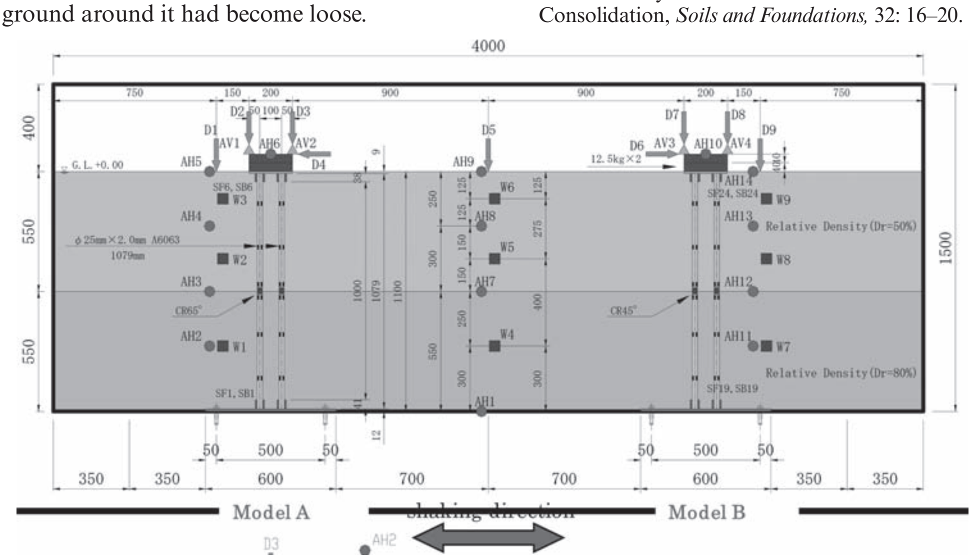

Figure 1. Cross-section drawing of the experiment model.

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9 *Design, construction and maintenance*

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A study on materials and environmental conditions for mechanistic-empirical design method of asphalt pavement in cold snowy regions

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ABSTRACT

Bearing capacity of pavement is affected by environmental conditions such as freezing and thawing. Accordingly, it is necessary to duly consider the related environmental effects in addition to the influence of materials themselves when applying mechanistic-empirical design method for asphalt pavement in such regions.

In this study, characteristic values of granular materials, soil and asphalt mixtures in normal, freezing and thawing periods were examined, as inputs for the application of mechanistic-empirical design method for asphalt pavement in cold snowy regions.

To examine changes in the characteristics of materials, field investigations of paving on actual roads with various thicknesses and materials were conducted, in addition to field investigations on test roads and laboratory tests on asphalt mixtures, granular subbase materials and subgrade soils.

The results of this study are summarized below.

1. The elastic modulus for granular subbase materials (such as 0–40 crusher-run) should be set to 100–400 MPa (average value: 250 MPa) according to the results of back-calculation analysis in FWD investigations on site.
2. The elastic modulus for subgrade soils was 30–140 MPa. However, as there were various kinds of subsoil, the elastic modulus should be set appropriately based on the results of laboratory tests or FWD in reference to this range.
3. The elastic modulus for granular subbase materials (such as 0–40 mm crusher-run) was approximately 2,000 MPa during freezing periods, which was higher than the corresponding value for normal periods.
4. The bearing capacity of granular subbase materials (such as 0–40 mm crusher-run) decreased during thawing periods, and the preservation ratio of the elastic modulus was 0.75–0.97 of the optimum water content condition. The value should be set appropriately based on the results of laboratory tests and FWD data in consideration of the reduced bearing capacity seen during thawing periods.
5. It was suggested that the preservation ratio of the elastic modulus for subgrade soils was also reduced due to thawing. However, as the degree of such reduction differed with soil quality, the value should be set appropriately based on the results of laboratory tests and FWD data in consideration of the reduced bearing capacity seen during thawing periods.

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Limerick Tunnel approach roads—geotechnical design & performance of bridge transitions

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ABSTRACT

The Limerick Tunnel project is located in SW Ireland and includes approximately 10 km of approach roads, four interchanges, two toll plazas and ten major bridges. Much of the road and both toll plazas are constructed on embankments up to 10 m high within the River Shannon flood plain. The ground conditions consist of very soft organic silts (typically 10 to 25 kPa shear strength) up to 13 m deep. A combination of vertical drains plus temporary surcharge to reduce the long term creep was generally adopted to maintain settlements within acceptable limits. The embankments were carefully built at controlled rates in multiple stages with continuous monitoring of performance by means of piezometers, inclinometers, settlement plates and survey monuments. In some sections the use of a basal geosynthetic reinforcement was necessary. A more detailed description of the design, construction and performance of embankments along the project is contained in Buggy & Curran (2011).

At the transition zones either side of bridges a combination of full or partial excavation of the soft alluvium, variable surcharge heights up to 4 m, geosynthetic reinforcement and short sections of pile supported embankment was used to meet the stricter performance requirements. The paper describes the geotechnical designs adopted at transitions to three bridge structures founded on piles where the approach embankment rests on soft alluvium.

Ladd (1989) compared reductions in the rate of secondary compression C' (following surcharging) to the normally consolidated rate C_α (NC) (without surcharge). The degree of reduction, or improvement ratio C'_α / C_α(NC), depends on the degree of 'over-consolidation' achieved by use of a surcharge. Long term laboratory oedometer testing of creep following surcharge removal was performed at UCD and the results were published by Conroy et al. (2010). More recently a case history from surcharged embankments in Hamburg Germany has revealed a very similar improvement in creep behaviour based on 6 years of field data (Chaumeny et al, 2011).

Limited post construction performance data from the transition zones at Limerick Tunnel is presented in Table 1. A baseline survey was performed in early July 2010 just prior to the opening of the road and a further set of readings was obtained 20 months later in February 2012. In general the initial creep settlements are modest at less than 10 mm.

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Table 1. Summary of surcharge heights, AAOS, primary & secondary creep settlements at bridge transitions.

Structure/Chainage (m)	Alluvium depth (m)	Max. Embankment Height (incl. max surcharge height) (m)	Estimated primary settlement (mm)	Measured primary settlement (mm)	Adjusted amount of surcharge AAOS (%)	Estimated 35 year secondary creep settlement (mm)	Measured 1.7 year secondary creep settlement (mm)
2+850 (B05 N Approach)	7.3	7.6 (2.5)	1340	1513	30–40	25–27	2–13
8+040 (B09 S Approach)	12.5	9.6 (2.5 to 4.0)	2110	1475	43–60	21–28	0–3
8+280 (B09 N Approach)	7.8	9.4 (4.0)	1620	1793	50–60	31	5–16
9+020 (B11 S Approach)	8.5	12.1 (2.5)	1490	1534	20–25	53–59	1– 6

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Design loads on railway substructure—comparative parametric investigation on the influence of fastening stiffness (European and Japanese)

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ABSTRACT

The existing international bibliography -German, French, AREMA methods-includes various methods for a realistic estimation of loads on track superstructure and the reactions/actions on the sleepers. The magnitude of loads derived from these formulas could not justify the systematic appearance of cracks at 60% of the sleepers in the Greek network. This generated the need of a more exhaustive investigation of the extensive appearance of cracks on sleepers, that would lead to the development of a new methodology for the calculation of the actions on the sleepers by the author (Giannakos 2004 method), which would be able to simulate and explain the phenomena that have been observed in the Greek network. In this paper a comparative parametric investigation is presented for the influence of fastening stiffness on the estimation on Design Loads on Railway Superstructure and Substructure. Japanese and European data are compared.

In Figure 1 the Giannakos (2004) method results successfully predicted the extended cracking of the U2/U3 ties calculating actions over the cracking threshold and in some cases over the failure threshold are compared to the results of the French, German and American methods. The four methods are applied for a comparison of the European and Japanese fastenings. In Figure 2 the actions on track are depicted for the case of Japanese fastening with pad of second kind (60 MN/m).

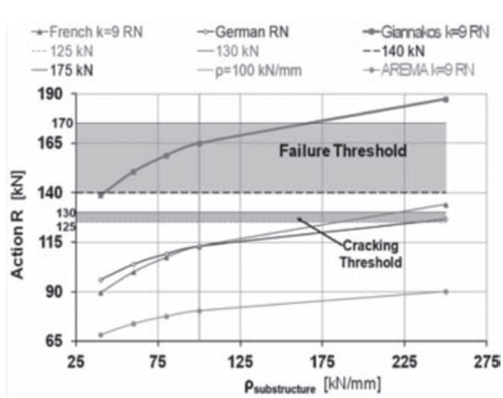

Figure 1. Comparison of the results of the 4 methods (German, French, AREMA, Giannakos) for U2/U3 sleepers with RN fastenings and 4,5 mm pad.

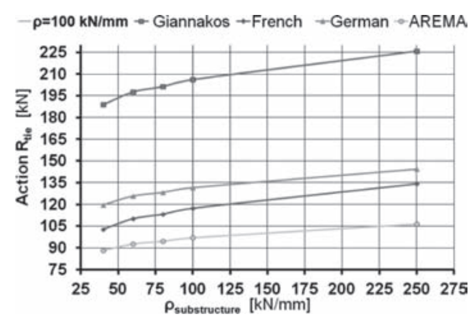

Figure 2. Actions on the track panel calculated by the four methods for Japanese fastening with pad of second kind (60 MN/m).

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Proposal of maintenance options to meet the pavement failure characteristics in Bangladesh

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ABSTRACT

The study proposes maintenance options to overcome road failures in Bangladesh. In the study, failure characteristics were identified qualitatively by studying the failed roads. It was found that failure of roads occur due to vehicle movement through the pavement during the period of flooding. The study has formulated two ways to manage a flood effected road. One way is to minimize the damage for flooding by imposing axle load restriction. Another way is to rehabilitate the flood-effected roads in line with failure mechanism. For axle load restrictions, damage done by a standard axle load was determined by both Mechanistic-Empirical (M-E) and Empirical (E) methods. Damage done by a standard single axle load during dry condition and flooding condition was compared. It was found that damage by a standard axle load during flooding is approximately 6.9 times compared to dry condition for a district road, as in Figure 1. Additional damage by a standard axle during flooding condition was proposed to minimize by axle load restriction. The study has found that axle load should be restricted to approximately 60 percent of the legal axle load to minimize 45 days flooding damage, as in Figure 2.

Additionally, the study by mechanistic-empirical method has found that a flood effected district road failed for rutting damage. It has suggested that 6 cm increase in the existing aggregate base layer and 5 cm increase in sub-base layer would be sufficient to sustain 45 days flooding. Moreover, the study with empirical methods has found that recurrent 45 days flooding in a district road could lead to a loss of 2.15 years of pavement life. The outcomes of the study will guide road maintenance management to ensure a sustainable and serviceable road network.

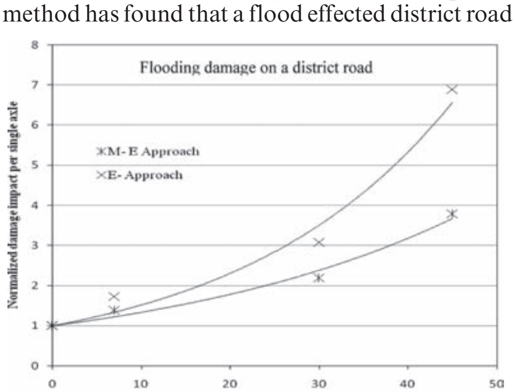

Figure 1. Normalized damage impact for a district road per single axle.

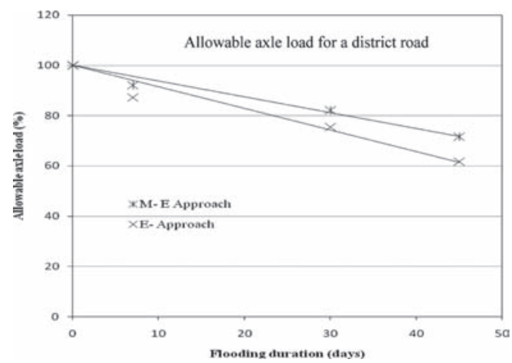

Figure 2. Allowable axle load for a district road to minimize flooding damages.

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The dynamic analysis to human-vehicle-road system for bump at the end of bridge

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ABSTRACT

The differential settlement between bridges and approaches produce the common bump at the end of the bridge approaches. And it goes along worldwide problem. In spite of numerous researches and efforts, the existing methods and procedures may not describe and explain the bump problems comprehensibly in ergonomic aspect. It is important for expressway agencies how to characterize bridge approach settlement and to evaluate existing bumps including their effects on discomfort to drivers and maintenance rating criteria.

The methods accounting for the motorist driving the road have been proposed. Das et al. (1999) proposed that bridge approaches rating system based on IRI (International Roughness Index), and larger than 10 cause poor drivability. White et al. (2005) also suggested bridge approach index using both IRI and differential settlement area. The human-vehicle-road response is also begun to be adopted in bump evaluations because driving discomforts belong to the human's feeling not to road itself.

To evaluate bump at the end of bridge approaches and to characterize differential settlement, the dynamic analysis to human-vehicle-road system were carried out. The appropriate procedure and index to evaluate transient vibration were investigated.

Parametric studies have been carried out with the driving speed, direction to bridge approaches, differential settlement. Their effects on driving discomforts have been investigated. A few cases of field exploration are also discussed. Driving discomforts was a complicated human's feeling affected by various factors. And several factors were interrelated with each other.

The MTVV (the Maximum Transient Vibration Value) was resultant measurement from the differential settlement and the approach gradient, and the other factors. The measured MTVV of 1.0, 1.5, and 2.0 indicated slight bump, readily recognizable bump, and significant bump. The approach gradient was also major factor to the driving discomfort. The readily recognizable to significant bump was identified at the greater than 1/125 of approach gradient, and the MTVV was 1.5 at the condition. They show good agreement with driver's feeling during passing through the end of bridges. The MTVV may be used to explain driving discomforts properly with further investigations.

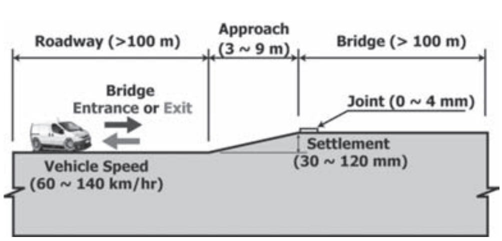

Figure 1. Schematic view and parameters in analysis.

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Design and construction of deep excavation engineering adjacent to the subway tunnel in Shanghai soft soil

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ABSTRACT

With the rapid development of the urban subway traffic in Shanghai China, the deep excavations are usually adjacent to the running subway tunnels. The strict deformation demands must be need by the excavation engineering. The designing of excavation adjacent to subway tunnel are controlled by deformation not by strength. The design and construction of the excavation of No. 1788 of west Nanjing road adjacent to the Shanghai Rail Transit Line 2 subway tunnel was introduced in this paper. The tunnel bottom is located at the depth of 14.7~16.4 m, with the outer cross-section diameter of 6.2 m. Up- and down-line tunnels both sits beside the project site. The distance from the tunnel lining to the basement boundary line of this project is 10.4~13.4 m, as seen in Figure 1.

For the protection of adjacent subway tunnel, the additional settlement of the tunnel induced by the excavation can not exceed 20mm according to the requirement of the government. Considering the protection of adjacent tunnels, The Top-down with zoned excavation design scheme is selected. many special measurements were applied to the designing of pit project.

Dual-purpose diaphragm walls are used both as the retaining structure for the foundation pit. A separation diaphragm wall is constructed near dividing the foundation pit into two separate ones, i.e. Zone I and Zone II. Including the proposal of down-top method with zoned construction with a

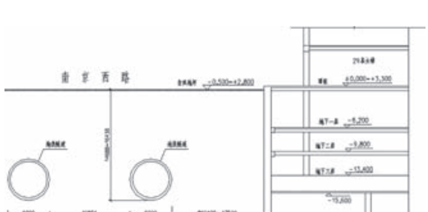

Figure 1. Relationship between the subway tunnel and deep excavation.

Figure 2. Vertical view photo of engineering after the excavation.

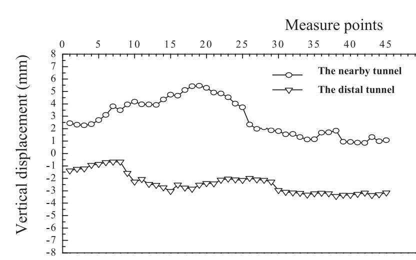

Figure 3. Vertical displacement of subway tunnel after the excavation.

temporary diaphragm wall inside the excavation engineering, prediction the additional deformation of tunnels by numerical analysis and detailed in situ monitoring of the pit and tunnels during excavation. The protection of the adjacent tunnels is successful after the end of the deep excavation, as seen in Figure 2.

According to the in situ monitoring data, the maximal lateral settlement of diaphragm wall near the tunnels is 22 mm.The maximal settlement of the tunnels is uplift about 5.5 mm. as seen in Figure 3. The protection of the adjacent tunnels is successful and it testified the validity of the designing and construction of the excavation engineering in soft soil.

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Railway track stiffness measurements at bridge transition zones

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ABSTRACT

Railway bridge approaches often exhibit localized roughness. The transition zone requires more maintenance than regular track, and the problems caused by settlement may lead to the need for speed restrictions. Several types of structures are being built to minimize settlement of the bridge approach. In Finland, the most common type of structure is a transition slab.

Tampere University of Technology together with the Finnish railway maintenance company VR Track Ltd has conducted stiffness measurements on several bridge approaches. The study included 20 bridges on the Tampere-Seinäjoki and Seinäjoki-Oulu railway lines. The vertical displacement of the sleepers at the bridge approaches was measured using accelerometers. On some bridges, the measurements were done both before and after the maintenance, and the effect of the maintenance has been compared in this paper.

Track stiffness measurements are relatively difficult to obtain. Accelerometers were chosen as instruments because they are fairly inexpensive to purchase and the method does not need any reference points, which are time consuming and laborious to build. The measurement arrangement consisted of 16 accelerometers, a data logger, a laptop computer, and a power supply unit. The accelerometers were installed on the top surfaces of the ends of several consecutive sleepers as shown in Figure 1. Only vertical displacement was measured.

The most of the bridges were monitored only once, three of the bridges were monitored again two years after the improvement work and the Ähtävänjoki bridges was monitored three times (Fig. 2). Remarkably, the transition zone improvement work did not yield smaller sleeper displacements at this particular bridge. Probably the most important factor that reduced track stiffness near the bridge ends was the new ballast layer that compacted over time.

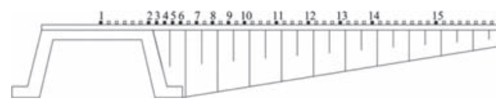

Figure 1. Schematic of sensor layout.

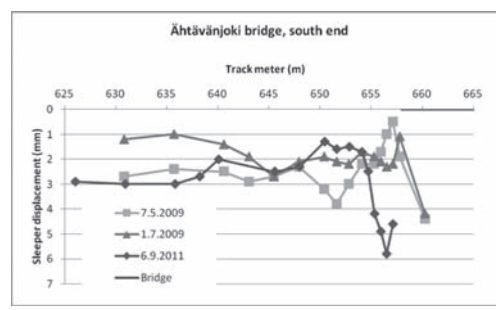

Figure 2. Example of measurement results from Ähtävänjoki Bridge approach. The improvement work was conducted after the second measurement.

Sleeper displacement on a good quality track was found to be typically 0.5 to 2 mm when it is measured from the end of the sleeper. Other studies (Nurmikolu et al. 2010) have shown that the sleeper displacement is usually 0.5 mm smaller in the middle of the sleeper. It was found that the quality of subsoil dominates the measurement results if the support of the sleepers is homogeneous and the embankment is fairly shallow. If the embankment is high, the effect of soft soil is reduced. Voids under the sleepers affect the results dramatically, especially in bridge transition zones.

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Quality assessment of high water content embankment slope based on compaction energy

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ABSTRACT

The site investigation was focused on quality assessment of initially built artificial medium-sized embankment slope as a case study. The construction company used the bucket of excavator to build and maintain the slope by pushing and tamping on the slope without considering the quality and energy. At the mean time, the embankment had high initial water content of more than two times the optimum water content obtained by moisture-density standard compaction curve. In order to understand the behavior of high moisture content embankment slope, three different slopes were further recreated using the bucket of excavator through increasing compaction by tamping method. At the same time, smooth roller was used to pass on the top of the embankment and divided into three zones based on increasing the number of passes. In-situ nuclear density meter and portable Falling Weight Deflectometer (FWD) were carried out to measure dry density and stiffness of the entire embankment. In-situ water contents were determined in the laboratory by soil sampling. Analyses confirmed that however increase in dry densities increased with increasing compaction, stiffness reduced at the highest water content around the embankment. Then, a triangulation model is proposed to check the effect of stiffness at variable water content at the same degree of compaction.

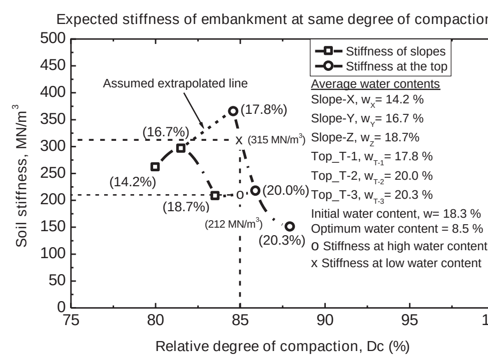

Figure 1. Triangulation model to interpret expected stiffness of embankment at the same degree of compaction.

Figure 1 represents relative degree of compaction of the embankment against stiffness in the triangulation model on the basis of the site investigation. In the model, water content exceeded 16.7% led to decrease in stiffness of the slope. The top of the embankment shows decrease in stiffness when water content was exceeded 17.8%. Results showed that stiffness were decreased as water contents were exceeded by 18%. The advantage of this model is that it can predict the differences in stiffness of the site at the same degree of compaction when encounter to the variable water contents. In this instance, figure shows that at 85% of degree of compaction, stiffness is approximately 212 MN/m^3 at the bottom when it intersects the line of water contents between 18.7% and 20.3%. At the mean time, the stiffness is increased nearly to 315 MN/m^3 when the same degree of compaction intersects the upper part where water contents lie in between 16.7% and 17.8%. Hence, the triangulation model can able to explain the role of water content to increase/decrease in stiffness of the ground.

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Effect of traffic overloading and stiffness of unbound aggregates on pavement performance

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ABSTRACT

Flexible pavements with hot mix Asphalt-Concrete (AC) surfacing constitutes the majority of road pavements around the world predominantly due to its low initial/maintenance cost, easy and quick construction, superior riding quality and skid resistance, etc. Flexible pavements are considered to be the most complex among the civil engineering structures. The design and performance considerations of flexible pavements includes a multitude of potentially influencing variables including the complex behavior of pavement geomaterials in each layer and subgrade soils, dynamic traffic loads and climatic conditions etc. Deficient knowledge or inadequate assembling and/or inappropriate handling of these variables in the design as well as construction stages may adversely affect the performance of flexible pavement structures.

This study explores the damaging influence of traffic overloading, over inflated truck tires and properties of unbound pavement layers on the performance of flexible pavements. Field data pertaining traffic loading (Table 1), pavement geomaterials and climatic conditions from Pakistan was analyzed as a case study using the Mechanistic-Empirical (M-E) design framework based on GAMES (General Analysis of Multi-layered Elastic Systems). Results were presented in terms of Relative Damage Factors (RDFs).

Based on the analysis of results it was found that the performance of flexible pavements is sensitive to not only traffic loading and tire inflation pressure, but also significantly to the stiffness of unbound pavement layers. The damaging influence of increase in tire pressure keeps on magnifying with each axle load increment as shown in Figure 1. The flexible pavement performance against distresses such as fatigue cracking and rutting is significantly affected by the stiffness of unbound base course and subgrade, respectively as shown in Figure 2. The Design RDF for the Legal axle load (118 kN) and the mean observed axle load (145 kN) on single axle with dual tires, with mean observed tire pressure of 896 kPa was 5.80 and 11.95, respectively. The damage factors derived in this study can be readily used for network level pavement management.

Table 1. Load and tire pressure conditions.

Analysis conditions	Range
Axle load	58 kN–176 kN
Tire inflation pressure	551 kPa–965 kPa

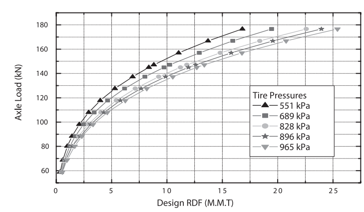

Figure 1. Representative Design RDFs for all loads and Tp ranges.

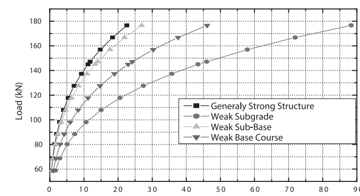

Figure 2. Design RDFs under various geo-material conditions (Tp 828 kPa).

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A conceptual model for reliability analysis of pavement foundations

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ABSTRACT

The reliability of a system is a concern in many engineering areas. A Reliability Analysis (RA) evaluates the probability of a particular behaviour in a time period, with the knowledge of the input parameters randomness (uncertainties).

The structural engineering field has seen his design methodologies updated based on RA and probability theory. On the other hand, in geotechnical engineering and particularly in pavement geotechnics, its application has been delayed because of all the inherent variability of the soil and type of the multilayer system. Nevertheless, because of regulation codes and social concerns, geotechnical and pavement engineers need to increase their ability to deal and incorporate these methodologies in design (Christian 2004). Therefore, the authors aim, with this paper, to demonstrate and explain a way to insert the variability and uncertainties in the pavement foundation design process. In this process involving subgrade of linear structures, like roads, one should take into account uncertainties that come from the soil intrinsic variability, soil spatial variability, errors in calculations models (theoretical approaches and predictions) and human errors (Baecher & Christian 2003). The biggest advantage when using RA in the design is that it quantifies and gives information about the parameters that mostly influence the unwanted behaviour under study. In order to apply the reliability theory to a pavement design problem, the basic methodology of RA can be accomplished by the following steps:

– select a target reliability index or acceptable probability of failure,
– identify the significant failure modes and formulate its functions (performance functions). In pavement foundation the performance can be assessed by the rutting at the surface of the granular layer, by the maximum deflection under a standard axle load or by an allowed stress or strain on the top of the subgrade,
– define calculation models,
– select random variables and its statistical values and
– finally estimate the reliability of each failure mode and compare it to the target.

To assess the uncertainties in subgrade (soil), one needs to take into account that it may need to be as-sessed on a site specific basis. This implies investments and therefore, sensitivity analysis are recommended to help engineers on decision making concerning the selection and study of the uncertain variables in a full RA.

An application example of FWD (Falling Weight Deflectometer) backcalculation and sensitivity analysis is presented to illustrate this relative influence of variables in the overall response of the pavement foundation structure and consequently how important these results will be. For further details refer to Lopez-Caballero *et al.* (2011). The sensitivity analysis was accomplished by applying Fourier Amplitude Sensitivity Test and Monte Carlo Simulation methods. The results demonstrated a possible correlation between elastic modulus of subgrade(soil) and granular layer under the application point of FWD load, useful information for further calculations and improvement of the analysis. The sensitivity analysis enhanced the importance of each deformability modulus of each layer in the computed deflection basin. This allows a more directional study of the variables to consider in a posterior full RA.

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Transportation infrastructure on soft sensitive clays: Some essential aspects and examples

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ABSTRACT

Soft sensitive clays in Norway may be a major threat to nearby transport infrastructures due to their tendency to remold when being loaded to failure. Soft sensitive clays deposits may cause catastrophic events, due to the possibility of small landslides initiating a fast and extensive retrogression process, which may involve massive soil movements on the order of millions of cubic meters. An example is shown in Figure 1. In this paper, effort is made to demonstrate these using some simple examples and analytical solutions. The paper shows that the very fundamental properties like undrained shear strength (Cu), shear strain (γ) at the intact (Cu_i) and the remolded state (Cu_r), soil

Figure 1. The Lyngen slide (2010).

sensitivity (S_t) and the stiffness parameters of soft sensitive clays are closely interrelated. Therefore, the mechanical behavior of soft sensitive clays requires an integrated study of these parameters because results only based on individual parameters could be misleading. This is elaborated using the concept of remolding energy.

The remolding energy can simply be defined as the strain energy required to remold a material. The area covered by the shear stress (τ)–γ curve represents the second-order work or the strain energy dissipated during the deformation process i.e., the required remolding energy.

An analytical solution for the calculation of the required remolding energy (RE) for sensitive clays as follows:

$$RE = Cu_r \times \gamma_r - \frac{Cu_r^2}{2G} + \frac{1}{2}\left[\left(S_t - 1\right) \times Cu_r\right]^2 \times \left[\frac{1}{G} + \frac{1}{S}\right]$$

Here G is the secant shear modulus, and γ is the hear strain, where the subscripts i and r represent the peak and the residual strain levels, respectively. The average softening modulus is represented by S.

The required remolding energy provides a better basis for understanding the flow susceptibility of soft sensitive clays. This study emphasizes use of the remolding energy concept on the estimation of retrogression distance. A systematic study should be carried-out in light of field and laboratory data to explore this concept. This type of study will promote safer and economical design and execution of transportation infrastructure.

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10 *Performance evaluation and quality control*

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Permanent strain testing of recycled concrete aggregate for evaluation of unbound bases

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ABSTRACT

This paper presents the results and analysis of permanent strain testing from Repeated Load Triaxial Testing (RLTT) conducted on three base products; two crushed concrete or Recycled Concrete Aggregate (RCA) materials and a local Virgin Aggregate (VA). The objective of testing was to study the impact of change in stresses on permanent deformation of the investigated materials using three different permanent strain testing protocols from Australian and New Zealand road authorities. A series of permanent strain tests were performed under drained conditions on cylindrical specimens, which had been statically compacted at different levels of moisture content. Duplicate specimens were tested at 60, 80 and 90% of Optimum Moisture Content (OMC) and a dry density ratio of 98% of Maximum Dry Density (MDD) from Modified Proctor compaction testing. On-sample measurements were made of sample deformation (refer Figure 1). Permanent strain was found to be dependent on both moisture content and applied stress. In terms of accumulative permanent strain or the rate of permanent strain, it was found that the two RCA products performed better than the VA for the three permanent strain testing approaches. Some results are presented in Table 1.

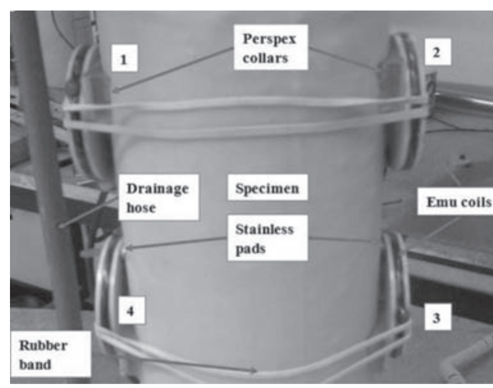

Figure 1. Emu sensor coils mounted on specimen.

Table 1. Permanent strain testing results for all products.

Material	Sample No.	MDD	OMC	DDR	RMC	Incremental permanent strain (μm/m)			Resilient modulus (MPa)		
						Stage			Stage		
		t/m^3	%	%	%	1	2	3	1	2	3
ARR	90	1.92	11.5	97.1	95.0	4479	376	533	437	473	504
	80			97.3	84.6	2519	291	365	482	520	546
	60			97.6	60.0	2314	139	164	594	694	756
RCO	90	1.99	11.0	97.2	88.9	4493	2317	9708	371	378	366
	80			97.1	83.2	4186	1174	2681	383	389	388
	60			97.6	60.9	3621	135	267	568	653	745
VA	90	2.16	7.0	97.2	90.3	27586	26364	Failed	257	301	Failed
	80			97.2	79.2	10517	2908	6081	311	332	349
	60			97.7	59.1	6810	695	867	358	405	448

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Performance of the double layered D-mix pavement

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ABSTRACT

This paper reports on the results of a two-year follow-up study of the Double layered drainage asphalt mixture (henceforth, D-mix) pavement laid in an industrial area in Kawasaki City. The paving work was carried out to evaluate the environmental noise reduction effect and longevity of performance of Double layered D-mix pavement.

For test paving, the 510 m long section of the northeast-bound line was divided into three 170 m long subsections for 3 types of D-mix pavement: a Double layered D-mix pavement section ("Double layered section"), a D-mix pavement with 25% void space ("25% void section"), and D-mix pavement with 20% void space ("20% void section"). The test paving was carried out on the 12.75 m wide roadway. Figure 1 shows a typical cross section of the test construction site, and Figure 2 shows the pavement structure of each D-mix pavement type. As illustrated in the figure, the Double layered section is composed of a 30 mm thick upper layer with 25% void space, containing the aggregate particles of up to 5 mm diameter and a 40 mm thick lower layer with 20% void space, containing the aggregate particles of up to 13 mm diameter.

Table 1 shows the periods and scope of study. D-mix performance restoration experiments for Lane 1 were carried out twice: 13 months and 22 months after the construction, and the same experiment for Lane 2 were conducted 22 months after the construction. The pavement surface was covered with snow and was hence damaged by tire chains. The following paragraphs report on the items listed in Table 1, as well as the sound absorption characteristics of the asphalt mixtures used, and prediction of the road traffic noise.

It is premature to draw a conclusion from the study results obtained during the first 22 months that the Double layered D-mix paving outperforms conventional D-mix paving methods in all senses. Judging from all the information obtained thus far, however, the Double layered D-mix pavement is at least sufficiently durable and has greater tire noise reduction effect than the conventional D-mix pavement, and that the tire noise reduction effect of the Double layered D-mix pavement lasts longer than the conventional D-mix pavement.

Table1. Period and scope of study.

Measurement time	Measurement item
Before the construction	Environmental noise measurement
Right after the construction	Environmental noise measurement Tire noise (Lane 2) Field permeability Rut depth
In the 13th month after the construction	Tire noise (Lane 2) Field permeability Rut depth
In the 13th month after the first performance restoration work (Lane 1)	Field permeability
In the 22nd month after the construction	Tire noise (Lane 2) Field permeability Rut depth
In the 22nd month after the first performance restoration work (Lane 1 and 2)	Field permeability

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A study on repair design method of porous asphalt for the Japanese motorways

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ABSTRACT

Porous asphalt has been widely used over a decade as a standard road surface for the nationwide toll motorways operated by NEXCO. Currently its stockpile is approximately 70% of the total road surface in 2010. However it is difficult to appropriately estimate structural condition only from outlook of its road surface, unlike dense asphalt pavements. In fact unfamiliar distresses suddenly and intermittently take place in several years, such as partial plastic flow and particles of binder layer mix blowing up from its porosity, as shown in Photo 1. Before getting into these final life stages of porous asphalt, an efficient and non-destructive method that can accurately evaluate structurally damaged layers has been strongly needed. The sample cores of bituminous layers are often so fractured that the assumption of multi-layered elastic theory seems unfit to apply. Moreover because there is inevitably mathematical error in back-calculation, which affects accuracy of the evaluation, deflection basin parameter was applied as structural distress index in this study.

Photo 1. Blow-up of binder mix's particles through surface porosity.

According to FWD surveys in repair sections for all over NEXCO, porous asphalt tends to give higher deflections than dense graded pavements. Also higher deflections are seen in pavements with granular subbase than those with cement-treated. From this observation, it was revealed that the structural evaluation should be achieved for the combinations of surface and subbase types.

In order to clarify the relation between the deflection basin parameter and bituminous layers' distress condition, cores were sampled from the FWD loading point and subjected to laboratory mechanistic tests. It was found that damaged and sound cores are distinguishable in a relation between bituminous cores' thickness and a deflection basin index (D_0–D_{900}) divided by cores thickness. Because it was also found that decrease of this index goes with the increase of binder layer's indirect tensile strength, it is speculated that the index can be used to appropriately determine repair thickness by setting mix criteria for identifying to replace with new materials. Based on this finding, a method of estimating which layers to repair was successfully developed. Figure 1 is a final output as repair criteria for PA having granular subbase layer.

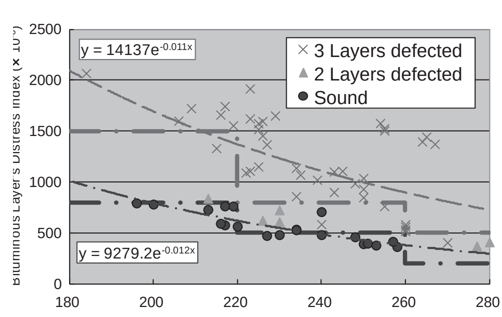

Figure 1. Bituminous layer's distress index and design thickness as repair criteria for PA having granular subbase layer.

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Trafficability during thaw on minor roads in Finland

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ABSTRACT

There are about 25 000 km of public gravel roads, of them ca. 50% under the risk of lowered trafficability, and ca. 30% under annual load limits. Moreover, we have also private gravel roads 300,000 km (forest, farm and similar rural roads). Costs for forest business were estimated to be about 100 million euros annually. The losses were devided in biological losses (blue mould, colour damage etc.), in the disturbance of transports, and in the interruptions in forest harvesting.

The length of thaw period in Finland depends on the freezing index (frost penetration) of the winter, the accumulation of thaw index during thaw period and on annual average air temperature.

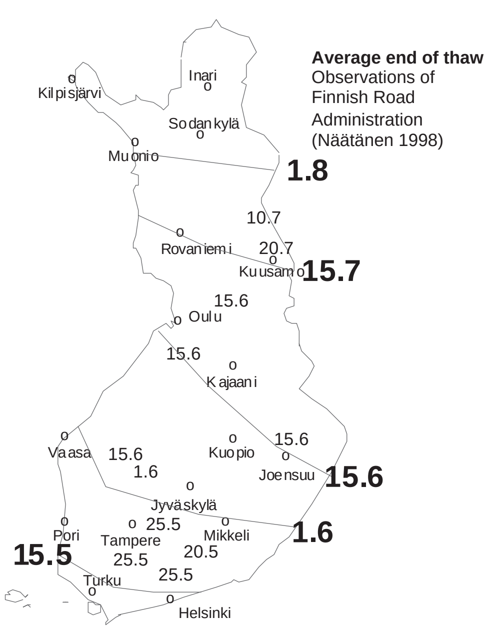

Figure 1. Estimated date for the end of thaw according to site data (Saarelainen 1999).

Trafficability (the risk of pavement damage) during thaw period is affected by the reduced pavement response during thaw period. The development of pavement response during thaw period and the safe number of overpasses can be estimated from the measured pavement response, which can be carried out using FWD-measurements.

Irreversible, plastic deformations are increased with increasing total deformations. The modelling is discussed on the basis of some full-scale test series in Finland in recent years. Strategies to improve trafficability conditions were discussed. One possibility might be to improve the real-time information on thaw at site. This may enable damage-free transports on thawing roads. Improved information also tells on local improvement needs and enables the application of correct improvement measures.

The needed research and development includes eg. the rational use of road weather station data for monitoring local thaw development in real time, the determination of trafficability (damage risk) in the road net in time and at site, modelling deformations in pavement materials and layers and measurement and determination of model parameters.

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11 *Sustainability of management and rehabilitation*

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Pavement maintenance management on the Hanshin Expressway network

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ABSTRACT

The Hanshin Expressway is an urban toll expressway network that stretches through the Hanshin Area from Osaka to Kobe in Japan.

Pavements on the Hanshin Expressway are made primarily of asphalt mixtures, and concrete pavements are used only in tunnels. Asphalt pavements are not as durable as concrete pavements, and their service life is usually as short as 10 to 20 years.

For this, special care is required in the maintenance of asphalt pavements. This paper discusses how asphalt pavements on this expressway network are maintained and managed and also introduces some approaches (using modified asphalt, using binder with higher durability and studying on fiber containing mastic asphalt) at Hanshin Expressway for pavements with longer life, as more durable asphalt pavements are increasingly needed in Japan.

Figure 1. Hanshin Expressway network.

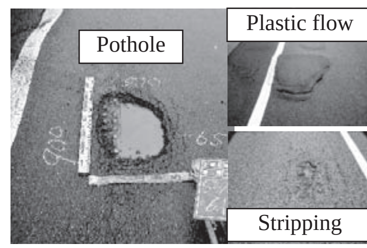

Figure 2. Pothole & plastic flow & stripping.

Figure 3. Samples of different fiber types.

Table 1. Properties of modified asphalts.

	Modified asphalt type II	High-viscosity modified asphalt
Penetration (25°C), 1/10 mm	40 or above	40 or above
Softening point, °C	56 to 70	80 or above
Ductility (15°C), cm	30 or above	50 or above
Flash point, °C	260 or above	260 or above
Change in mass after thin film oven test, %	–	0.6 or above
Retained penetration after thin film oven test, %	65 or above	65 or above
Toughness (25°C), N•m	8.0 or above	20 or above
Tenacity (25°C), N•m	4.0 or above	15 or above
Density, g/cm³	Described in the test report.	Described in the test report.
Viscosity at 60°C, Pa•s	–	20000 or above
Optimum mixing temperature, °C	Described in the test report.	Described in the test report.
Optimum compaction temperature, °C	Described in the test report.	Described in the test report.

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Analytical redesign potential of flexible pavements utilizing the in-situ characteristics of unbound materials

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ABSTRACT

In accordance with international experience and practice, during the design procedures for flexible pavements, the estimation of the elastic modulus of the unbound granular materials is often associated with the modulus of the subgrade.

For the design of new flexible pavements and in the expanding field of pavement structural evaluation using Non Destructive Testing (NDT's), there is a continuing need for an adequate means to characterize the unbound granular material in terms of searching for adequate input parameters for analytical flexible pavement design or rehabilitation design purposes.

For conventional granular materials that cannot accept tensile stresses, as shown in a typical 3-layer static model Figure 1, the values of the modulus E_{gr} cannot vary significantly from the modulus of the subgrade layer E_{sg}.

In reality however, the unbound material can only accept minor tensile stresses in part because of the developed friction forces from the interlocking of the aggregate.

Previous research including (Gomes Correia & Loizos, 2004) has shown that improved compaction contributes significantly to the limited tensile strength of the material arising from aggregate interlocking. This condition creates for a satisfactory time-frame a pseudo tensile strength, which contributes to prolonging the life of the granular materials and consequently the pavement.

It is clear that the variation in the ratio E_{gr}/E_{sg} is an important indicator to characterize not only the required level of the in-situ compaction of the corresponding pavement layers, but also to the limited tensile strength of the unbound material.

The present research study attempts to estimate a critical modulus of the unbound material, taking into consideration the layer thickness, the in-situ mechanical characteristics of the individual layers, as well as the limited capacity of the unbound pavement materials to assume tensile stresses, induced after the construction of the flexible pavement is completed.

Based on the concept of the allowable pseudotensile stress (σ_{r-gr}) [Loizos, A. 2004] an extensive statistical analysis of representative pavement design input data was performed. It is worthwhile to note that the proposed analytical relationship essentially contains the range of pavement cross-sections in that it includes indirectly the changes in the a/h_i ratio and specifically the a/h_{AC} ratio, which are definitive in the framework of the development of the critical stresses at the surface of the individual pavement layers. Finally, the below equation reflects the outcome of the analysis in a generalized form:

$$E_{gr}/E_{sg} = c_1 + c_2{*}\, h_{gr}^{\,2.85} + c_3{*}\, E_{sg}^{\,-0.80} + c_4{*}\, h_{AC}^{\,1.80} + c_5{*}\, E_{AC}^{\,0.80}$$

where c_1, c_2, c_3, c_4 and c_5 are constants that can be defined.

Further research using in situ data is ongoing in order to improve the proposed relationship in terms of a potential implementation for optimal pavement redesign purposes.

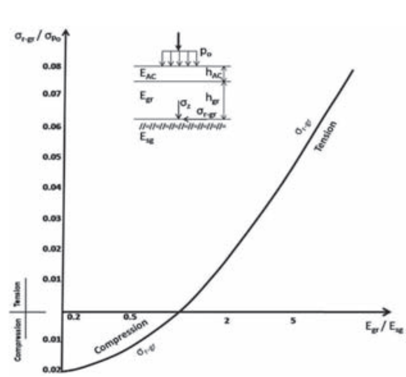

Figure 1. Effect of the elastic modulus E_{gr} and the E_{gr}/E_{sg} ratio on the developed stresses σ_r

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Study on inspection method for railway existing retaining walls using vibration testing

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ABSTRACT

In Japan, there are many old existing railway structures. Therefore, development of proper maintenance and inspection methodologies are required. Current inspection method on existing retaining structures is visual inspection, while it is difficult to evaluate a structural health of the retaining walls quantitatively. Based on the background above, a series of model test on retaining wall is carried out so as to develop inspection method for railway existing retaining walls.

In the series of the model test, a set of vibration test using newly developed small scale exciter (Figure 1) was also conducted. Models of leaning type and masonry type retaining wall were placed on the horizontal subsoil consisting of dense air dried silica sand. The total height of the model retaining wall was 1 m while the embedded depth was 0.2 m (Figure 2). Vibration tests using the developed small scale exciter were carried out in each loading and unloading steps. Horizontal displacement was applied to the shear soil chamber using three horizontal hydraulic loading jacks.

Changes of transfer function of the amplitude of the leaning type retaining wall models is shown in Figure 3. Transfer functions at the initial state and at the displacement amplitude of 80 mm were compared in these figures. At the initial state, the clear peak state could be observed around 40 Hz both in leaning type and masonry type retaining walls.

In the case of the leaning type retaining wall, the value of frequency at the peak amplitude decreased with the increase of the displacement and the value of the peak amplitude at the displacement of 80 mm was larger than the one of the initial state.

It was found from the model tests that the vibration characteristics of the retaining wall were affected by the structural health of the retaining wall. Moreover, in the case of the masonry type retaining wall, the importance of the facing rigidity was also highlighted.

These results indicated that the small scale vibration test could be applicable to evaluate the structural health of the existing retaining structures.

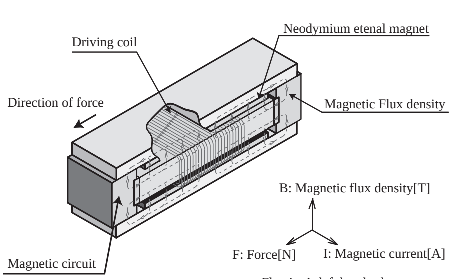

Figure 1. Outline of developed small scale exciter.

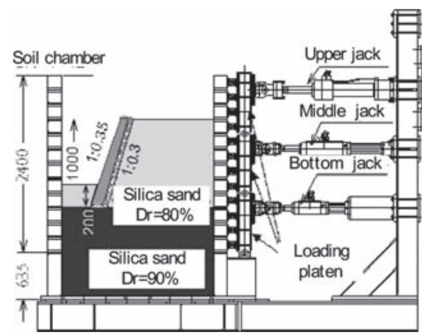

Figure 2. Layout of test apparatus.

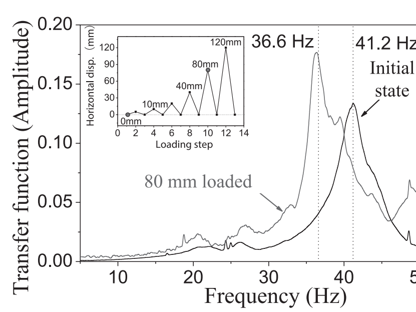

Figure 3. Change of vibration characteristic of leaning type retaining wall model.

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D-runway construction in Tokyo Haneda Airport—Hybrid structure of piled pier and reclamation fill

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ABSTRACT

Tokyo International Airport (Haneda Airport) was developed by reclaiming land on the sea. The D-runway is located 600 m offshore from the previous airport island (Photo 1).

One of the remarkable features of the D-runway is its hybrid structure, consisting of piled pier and reclamation fill. The former section was adopted in the river mouth of the Tama River to ensure a flow rate during times of flooding. This piled pier section was constructed by assembling jackets (Photo 2) which were prefabricated in a factory yard to shorten the construction period. On the other hand, the latter section, i.e. the man-made island, is actually a high embankment. Its elevation at the offshore end of the D-runway was required to be higher than A.P.+17.1 m, because airplanes have to pass over large ships navigating in the vicinity.

In the construction of the D-runway, not only the ground improvement technologies (SD: Sand Drains, SCP: Sand Compaction Piles, and CDM: Cement Deep-Mixing method) but also the new developed construction materials (pneumatic mixing cement treated soil and air-foam treated lightweight soil) were successfully utilized (Figures 1 and 2).

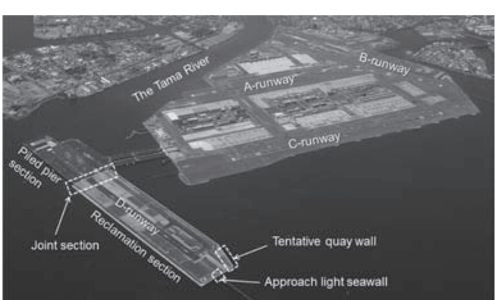

Photo 1. The D-runway and previous airport facilities of the Tokyo Haneda Airport.

Photo 2. A scene of installation of a jacket unit.

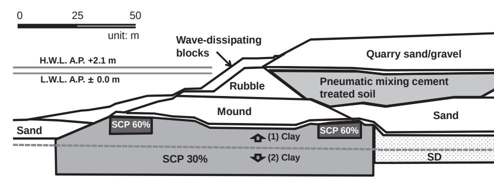

Figure 1. A typical cross-section of the mild slope rubble seawall (general seawall section). SCP: Sand Compaction Piles; SD: Sand Drains.

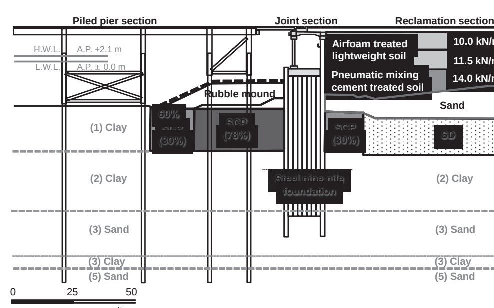

Figure 2. Cross-section of the joint structure between the reclamation and piled pier sections.

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12 *Risk assessment and environmental issues*

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Soil liquefaction vulnerability mapping due to seismic activity using geo-statistics, GIS and geotechnical data

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ABSTRACT

Liquefaction is an earthquake ground failure mechanism that occurs in loose, saturated granular sediments and has caused extensive damage to the ground. Soil liquefaction vulnerability mapping is the process of estimating the response of soil layers under earthquake excitations and the variation of earthquake characteristics on the ground surface. Ground conditions play important roles in the prediction of hazards caused by earthquake. Thus to evaluate seismic hazards for a wide area, ground formation history along with soil properties must be known. This paper describes the ground conditions and behavior as a result of earthquake. In this paper, Geographical Information System (GIS) is used to obtain soil liquefaction hazard map. Spatial variations of soil properties are estimated from the available borehole locations where SPT N-values, water table depth and grain size distribution are known. In addition, geo-statistics is helpful to produce the soil liquefaction vulnerability mapping over the entire region using nearby borehole data. Geomorphological land classification components are investigated to attain soil liquefaction hazard map. Methodologies of hazard assessment and the resulting maps will be presented in this paper. These maps are useful for assessing the approximate zones affected by hazards and for disaster prevention planning.

The Kuki city of Saitama Prefecture is targeted as a case study in this paper. Saitama Prefecture has been affected by several destroying earthquakes of magnitudes greater than eight in the past times.

At March'2011 Gigantic Tohoku Pacific Earthquake, Kuki City observed 0.202 g PGA. Using this PGA, borehole data are analyzed and maps are drawn in GIS environment. After applying Kriging method of interpolation, Liquefaction potential surface map is produced as shown in Figure 1. It shows low liquefaction risk at south-west part of the city. However, the north-east part of the city shows more likely to liquefaction. In addition, it shows that severity of damage increases with increase in PGA value. Water level also plays an important role for liquefaction. The ground where the water level is so close, it's likely to be liquefied more.

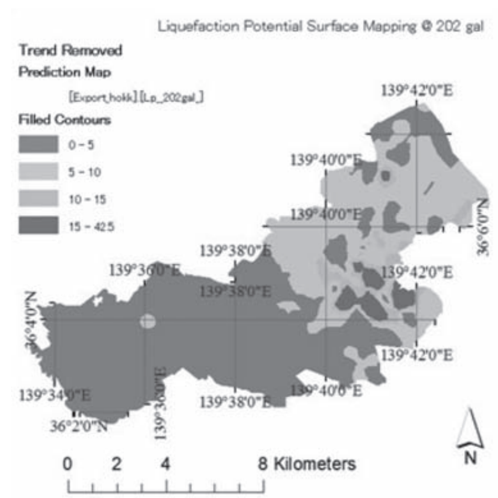

Figure 1. Liquefaction potential surface mapping of Kuki City.

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Evaluation of soil liquefaction potential along Tabriz Metro Line 2 based on Idriss-Boulanger and Japanese Highway Bridges methods

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ABSTRACT

This research has been carried out to evaluation of liquefaction phenomenon along the TURL2 route, based on the Standard Penetration Test results, by the latest method in liquefaction potential evaluation (Idriss & Boulanger 2008) and comparing these results with Japanese Highway Bridges method.

With comparison of the achieved results from both methods, it can be shown that the occurrence of liquefaction is possible for some parts during strong motions, based on the two mentioned methods, but they do not have the same results.

According to the results, it was found that Japanese Highway bridges method determines liquefied sandy soils and may cause the parts which don't have the capability of liquefaction experientially determines liquefied.

Comparing the used data by Idriss and Boulanger (2008) for their studies and developing of their method, with TURL2 data, can be finding that the Idriss and Boulanger evaluation method is suite for liquefaction evaluation in TURL2. Also Idriss and Boulanger method is based on $(N1)_{60}$ and error and trial process, the results can be near to the reality.

The liquefaction potential of more than 100 boreholes along TURL2 with acceleration 0.35 g for earthquake magnitude 7.5 was studied. Practically in the layers that NSPT is more than 30, liquefaction has not been observed. Considering the liquefaction risk analysis with Iwasaki et al. (1982) method, the mostly liquefaction risk takes place with high degree in lower depths and near to ground in the length of the TURL2 investigations.

After liquefaction evaluation for TURL2, sample boreholes have been concluded among all boreholes and the results have been showed in Figure 1. Results show that at some horizons along TURL2, liquefaction will happen during strong motions. In the comparison of the obtained results from current methods that the soil type is silty sand to sandy silt such as Qaramalek area, Abbasi Street, Ghods Street, Shariati Street and Akhuni Cross, the liquefaction risk is high.

According to geology studies and geotechnical investigations, Mehran River has an important role in deposition of liquefiable soils.

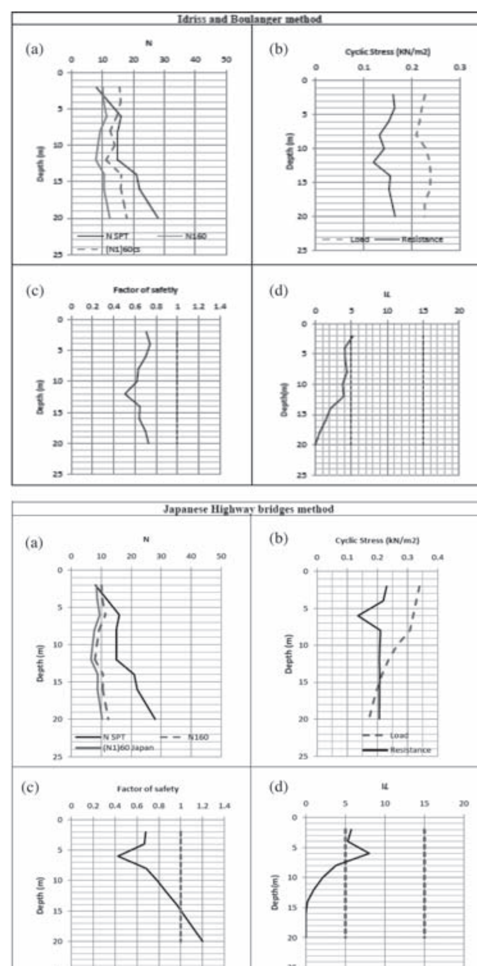

Figure 1. Comparison of results in the borehole C2B1; (a) N_{SPT} Correction; (b) Liquefaction Load and Resistance condition; (c) Safety Factor; (d) Liquefaction Index.

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Stability evaluation of soft cliff subjected to wave erosion

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ABSTRACT

This paper aims at clarifying failure mechanisms of coastal soft cliff and proposing a method of stability evaluation. Series of 1 g model and centrifuge tests to grasp the feature of slope failure due to wave erosion were conducted on the model cliff having the corresponding strength with that of soft cliff. In this study, the effects of mechanical properties (the height, the angle and fabric anisotropy of slope) on failure mechanism for short-term events such as storms were investigated.

In this study, series of 1 g and centrifuge tests were conducted using a wave paddle system developed based on wave maker theory in order to grasp failure mechanisms of soft cliff due to wave erosion. The compression strength of 90 kPa was tentatively adopted as a typical strength of soft cliff for 1g model test. Model materials to construct model cliff were Toyoura sand and a quick drying Portland cement, because the existence of granular soils in fluid has been a key factor for evaluating such erosion phenomenon (Sunamura, 1983; Kamphuis, 1987). Test conditions for 1 g and centrifuge tests are summarized in Table 1 and Table 2, respectively.

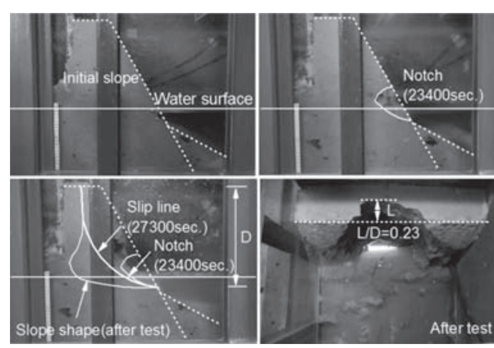
Photograph 1 illustrates typical deformation behavior for the model cliff at wave height of $H = 52$ mm. As shown in the photograph, the notch is extended by the increase of wave cycles N_c, thereafter slope failure is rapidly caused. This indicates that soft cliff has a tendency for rapid recession and its failure is induced by wave erosion. In addition, failure mode appears to be surface slope failure,

Table 1. Test condition (1 g model test).

Test conditions (model scale: 1/30)	
Cliff angle	60°
Cliff height (Breadth)	433 mm (373 mm), 700 mm (604 mm)
Angle of bedding plane, β	0°, 30°, 45°, 90°
Cement content	1.0%–2.0%
Wave height	37 mm-89 mm
Wave frequency	0.55 Hz, 0.37 Hz
Water depth	0.18 m

Table 2. Test condition (centrifuge test).

Test conditions (model scale: 1/20)	
Cliff angle	60°, 65°, 70°
Cliff height (Breadth)	220 mm (227 mm), 208 mm (197 mm), 200 mm (172 mm)
Angle of bedding plane, β	0°
Cement content	5.0%
Wave height	5 mm–20 mm
Wave frequency	1 Hz
Water depth	0.1 m



Photograph 1. Deformation behavior for model cliff (1 g model test).

based on horizontal recession ratio (the horizontal distance/the depth of slip line (slope height from toe); L/D) of 0.23. The similar tendency was obtained from a series of centrifuge tests.

In the consideration of the above experimental results, prediction methods on the failure were detailedly discussed in this paper.

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Rainfall characteristics inducing shallow failure on road slope in Korea

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ABSTRACT

Rainfall is well known triggering factor of slope failures. In Korea, frequent shallow failures on road cut slopes occur every year by the intensive rainfall during summer season. As failure occurs without any previous sign and often evolves into a fast mass movement down the slope, there exists high potential of fatalities to road users. Although effect of rainfall characteristics on shallow slope failure should be considered in dealing with the problem, complexities involved in slope failure and the unforeseen rainfall characteristics make the problem very difficult to deal with adequately. One way of mitigating the risk is to give an early warning to road users based on an empirical rainfall threshold by monitoring the rainfall. In this study, the characteristics of rainfall triggering shallow failures on road slopes in Korea are analyzed and rainfall thresholds are suggested.

Rainfall parameters such as peak intensity, cumulative rainfall, average intensity and duration were used to characterize the rainfall events triggering shallow failures on road slopes. From analysis of 258 rainfall records, the rainfall parameters were ranging from 6.5 to 92.5 mm/hour for peak intensity, from 76.4 mm to 759.5 mm for cumulative rainfall, from 7 to 255 hours for duration and from 1.19 to 22.2 mm/hour for average intensity. Examination of rainfall records to scrutiny showed that combination of rainfall parameters rather than single parameter should be used to represent the slope failure triggering rainfall characteristics. By relating these parameters, rainfall thresholds from peak intensity-cumulative rainfall relation and average intensity-duration relation for shallow slope failures were suggested.

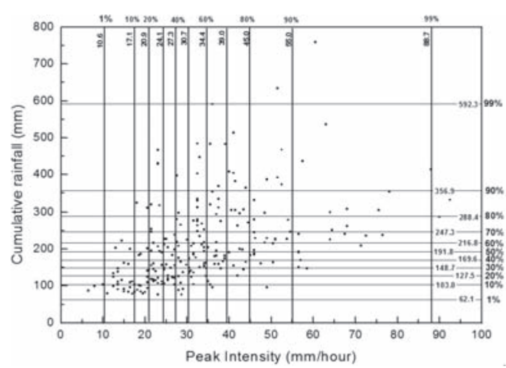

Figure 1. Rainfall threshold in peak intensity-cumulative rainfall amount relationship.

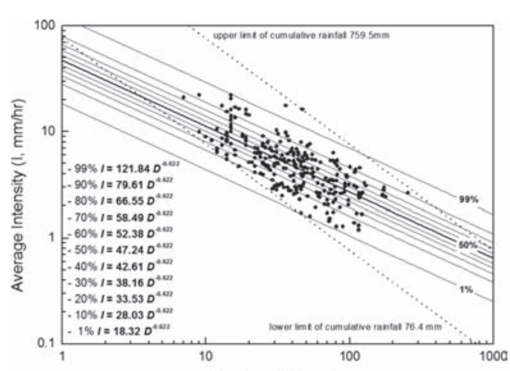

Figure 2. Rainfall threshold in average intensity-duration relationship.

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Modeling of transportation and leaching behaviour of contaminants in stabilized tailings

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ABSTRACT

Stabilized gold mine tailings are being investigated for their environmental acceptability for reuse in development of the rural infrastructure in Tanzania. The study aims at establishing optimum binder content that will effectively retain leaching inorganic hazardous substances within stabilized tailings and developing a mathematical model to describe the release of heavy metals from cement-stabilized gold mine tailings. Preliminary characterization and stabilization of the tailing have revealed that tailings can be stabilized using cement to produce a material with geotechnical properties suitable for use in construction works.

The release behavior of waste materials depends the type of the materials. Two types of materials are distinguished: monolithic and granular materials. Monolithic materials include cemented products (e.g. cement stabilized tailings, concrete, bricks and coated materials). They often show diffusion controlled release. Granular materials usually show percolation dominated release (release due to percolation of water though the product). In Figure 1, van der Sloot & Dijkstra (2004)[1] report a combination of the processes that cause release of constituents to the water phase as: (i) chemical processes (dissolution of minerals, adsorption and availability); (ii) physical transport processes (advection, surface wash-off, and diffusion). Figure 2 shows typical results of a leaching model for tailings.

Preliminary characterization of BGM tailings showed existence of varying concentrations of heavy metals in the tailings, including Arsenic (As), Copper (Cu), Iron (Fe), Lead (Pb), Mercury (Hg), and Zinc (Zn). The tailings pH was found to be affected by age, ranging from 7.0 (for 2 weeks tailings) to 3.9 (for 4 years tailings). This rapid change in pH is thought to be attributed to by generation of acid mine drainage in the tailings. It is important to establish a means to completely immobilize the contained heavy metals and other contaminants and establish a model to predict and describe the leaching behavior.

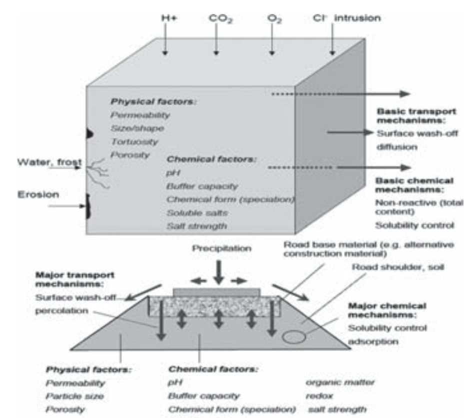

Figure 1 Material-specific and external factors influencing the release of contaminants from monolithic and granular materials (adopted from van der Sloot & Dijkstra, 2004).

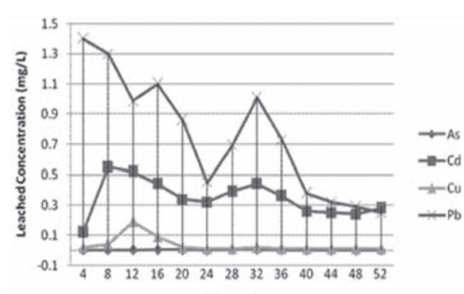

Figure 2 Typical results of a leaching model for tailings (Source: OZ Minerals Australia Ltd & ATC Williams, 2009[2]).

[1]van der Sloot, H.A. & Dijkstra, J.C.L. 2004. Development of Horizontally Standardized Leaching Tests for Construction Materials: A Material Based or Release Based Approach? *Identical Leaching Mechanisms for Different Material.* ECN-C--04-060.

[2]OZ Minerals Australia Limited & ATC Williams (2009), Dugald River Zinc Project, Queensland. Geochemistry and Leach Testing of Tailings.

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Internal erosion in dikes alongside roads and railways

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ABSTRACT

The internal erosion of soil results from seepage flow. It appears to be the main cause of severe hydraulic failure for dikes alongside roads and railways. All around the world, 46% of dams present a risk of internal erosion (Foster & Fell 2000). In France, 70 critical cases have already been detected. When internal erosion is suspected, the delay to failure is hardly predictable. Then, authorities should be able to develop effective emergency action plans to prevent casualties. Previously, it is necessary to understand phenomena of internal erosion.

Three main processes can be identified: backward erosion, concentrated leak and suffusion. This study deals with the description of the suffusion process. Suffusion is an internal erosion process where fine soil particles are displaced by seepage flow through the soil matrix. A state of the art can be found in the literature (Fell & Fry 2007) and several laboratory studies have been carried out on the subject (Wan & Fell 2004). Generaly, the initiation of internal erosion is determined by a critical hydraulic gradient (Terzaghi et al. 1996, Vardoulakis & Papamichos 2001). But internal erosion has been found in precise conditions of particle size for granular materials, and different granulometric criteria have been proposed (Lafleur 1999, Monnet 1998). This approach involves that the amount of eroded material needs to be quantified.

In this paper, we present a new experimental device named Cross Erosion Test (CET), which is devoted to the measurement of the initiation of the suffusion (Fig. 1). The test consists of the injection, in a first drilling, of clear water and the recovery, in another drilling, of water charged with particles. In a first part, this experiment is calibrated with a numerical simulation (Fig. 1). In a second part some preliminary experimental results are analysed.

Concluding remarks show the possibility to characterize internal erosion into a specific soil. This technique can be transposable, in-situ, to consider risks of internal erosion in earthworks.

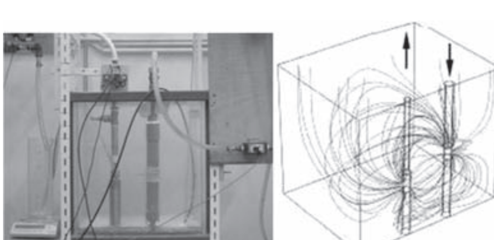

Figure 1. The cross erosion test and the water flow.

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Mineral barriers against natural contamination from excavated rocks

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ABSTRACT

The use and disposal of large amount of materials that are used in infrastructure engineering, such as road and railway construction, has become an important issue in Japan. This is because of the growing interest in saving space in landfills and reducing the use of new natural resources. Thus, reusing excavated materials has become a solution that reduces the amount of waste rocks, as well as the use of new material. However, when rocks and soils are reused in geotechnical applications, such as embankments, the potential for pollution or natural contamination should be considered. In Japan particularly, several types of metals such as As and Pb are present in higher concentration compared to the average level found in the world. Moreover, in mountainous areas of Japan, there are numerous rock formations which may contain pyrite (FeS_2) and other minerals that may contain high amount of As and Pb. Therefore, acid rock drainage with subsequent As, Pb and other metals leaching becomes a critical issue. To prevent this environmental problem spreading, constructing an adsorption layer is considered a relatively new and cost-effective measure (Katsumi et al. 2008).

The barrier performance of Geosynthetic Clay Liners (GCL) containing Na-bentonite, zeolite (clinoptilolite), and ferrihydrate permeated with artificial Acid Rock Drainage (ARD) are reported in this study based on hydraulic conductivity tests (Figure 1 and 2). The hydraulic conductivity (k) of GCL permeated with distilled water was 1.4×10^{-11} m/s and it increased one order of magnitude when permeated with ARD. The k of zeolite permeated with water was 3.0×10^{-10} m/s and it increased 10 times when it was permeated with ARD. The k of ferrihydrate was 7.3×10^{-9} m/s in water permeation case and this value remained constant after ARD permeation. From chemical effluent analysis, it was observed that metals start leaching out the system after 5 to 10 PVF. The metal retention order differed for each mineral. For bentonite it was Cu ≈ Al > As >> Pb >> Fe > Zn, while for zeolite it was Al ≈ Cu > As > Fe > Zn > Pb, and for ferrihydrate it was As > Al > Cu > Fe > Pb ≈ Zn. These tree minerals appear to be good candidates for ARD treatment.

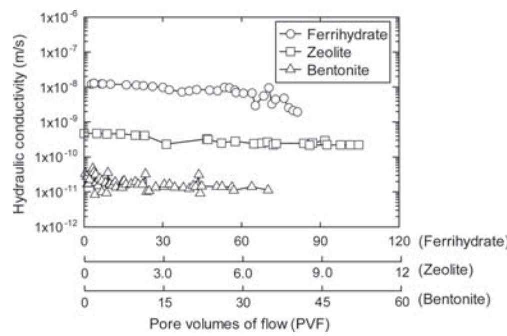

Figure 1. Hydraulic conductivity of GCL, zeolite, and ferrihydrate permeated with water (control).

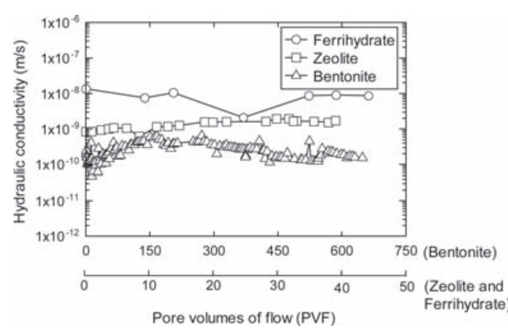

Figure 2. Hydraulic conductivity of GCL, zeolite, and ferrihydrate permeated with ARD.

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An appropriate stress test to estimate the long term performances of high speed rail structures

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ABSTRACT

High Speed Rail (HSR) projects are multiplying and need technological innovations to be economically, socially and environmentally reliable. The reuse of in-situ materials treated with lime and/or hydraulic binders for the capping layer of HSR infrastructures is a process in accordance with sustainable development policies. If the stress path generated by HSR loads in the treated capping layer (Fig. 1) is now well characterized (Preteseille et al. in prep), the long term mechanical performances of these treated materials are not well defined. For the design of HSR structures, an estimation of these performances must be known.

In this article, stress paths induced by fatigue tests referenced from the literature are studied and compared with those obtained in the HSR capping layer. The usual tests used to characterize mechanical parameters of treated materials are the unconfined compression strength, the direct tensile and the indirect diametral tensile tests (Gnanendran & Piratheepan 2010), but they are not suitable to reproduce the stress path in the HSR structure. Others tests, like the triaxial, the beam bending and the two-points bending tests, that are commonly used in building and public works industry (pavement, concrete…) have been adapted to estimate long term performances of treated materials (Dac Chi & Mulders 1984, Larson & Nussbaum 1967)). But once again, calculations show that they are not able to reproduce the HSR stress path.

The principle of a new test consisting in a slab laid on a track bed is presented. Calculi show that this time, the sought stress path is accurately reproduced (Fig. 2).

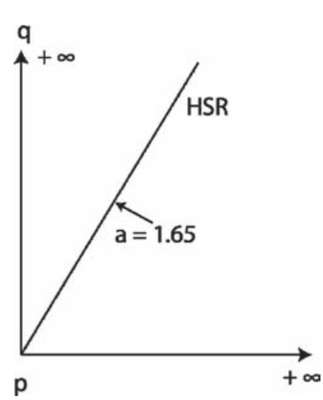

Figure 1. Stress path at the bottom of the capping layer in an HSR structure.

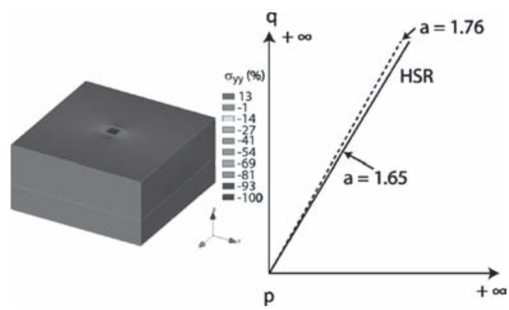

Figure 2. Stress path induced by the slab bending test compared with the HSR one.

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Analysis of ground loosening behaviour in expansion of underground cavities: Laboratory experiments in sandy soil

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ABSTRACT

The reported disasters related to road cave-ins have been increasing in all over the world for last few decades. Most of road subsidence in urban areas is taken place by internal erosion, which occurs due to leakages in buried sewer pipes, drain pipes, buried structures and abundant service pipes. Specially, numbers of such defects are increased with the age of pipe, and pipes exceeding 50 years age is rapidly increasing in Japan with enhancing the future risk. (Kuwano et al. 2006)

The exact mechanism of this collapsing behaviour and variation of engineering parameters of such ground is not yet found clearly. The reason is, after road cave-ins it is difficult to conduct detail investigations in that location, because the fast road restoration is always mandatory. However, ground loosening is a significant process which is always connected with ground subsidence.

Knowing the variation of mechanical properties of loosened ground which is associated with cavities, it will be easier to assess and confirm the cavities in suspicious areas. Therefore, main objective of this analysis is to conduct a detailed quantitative investigation on variation of mechanical properties of loosed ground which is accompanied with underground cavities.

Specially, sand is a commonly used material for backfilling of underground pipes and therefore, properties of loosened Toyoura sand was evaluated by laboratory tests. Specimens of 75 mm in diameter, 150 mm in height with relative density of around 60% were used. Underground cavity was simulated by an artificial cavity by introducing a water soluble material (Glucose, $C_6H_{12}O_6$) in to triaxial specimen and dissolving it gradually by passing of water.

The stress condition of the erected specimen was increased from 25 to 50 kPa under isotropic condition and controlled at 50 kPa till shearing. Prior to inserting water, small cyclic loading was applied axially with 11 cycles which has peak to peak strain amplitude of 0.001%. Then water was inserted from bottom to top and drainage was allowed from bottom. Another small cyclic loading was applied on drained specimen followed by shearing up to 16–20% of axial strain.

Small scale axial and radial strain was monitored by using Lateral Displacement Transducers and Clip Gauges respectively and large scale axial strain during shearing was measured by an External Displacement Transducers. Young's modulus and Poisson's ratio was evaluated by stress and strain based on small strain cyclic loading.

This paper mainly discusses about two experiments and one is having a cavity and the other is a controlled specimen without a cavity. This contributes to compare the variation of stress-strain relation, Small Strain Modulus, Poisson's ratio, volumetric strain and strength reduction of the loosed ground which is accompanied with cavity with the normal ground.

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Advances in Transportation Geotechnics II deals with the geotechnics of roads, railways and airfields. Providing economic and sustainable transportation infrastructures for societies is highly dependent on progress made in this field. These contributions to the 2nd International Conference on Transportation Geotechnics (Hokkaido, Japan, 10-12 September 2012), held under the auspices of the International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE), cover a broad range of technical topics, including those addressed by the first conference held in Nottingham, UK in 2008.

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Advances in Transportation Geotechnics II will be of interest to professionals and academics involved in geotechnical and pavement engineering of roads, railways and airfields.

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