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General Report — Session 7: Soil Property Improvement and Environmental Contamination

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SOIL PROPERTY IMPROVEMENT AND ENVIRONMENTAL CONTAMINATION

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GENERAL REPORT—SESSIONS 7A AND 7B

INTRODUCTION

Session 7a of the conference deals with case histories of soil property improvement; expansive and collapsible soils; for earthquake mitigation, use of lightweight materials, application of geo-synthetics; freshly loaded filled ancient marshy lands; the effects and risks of foundation; and site characterization.

As the theme of Session 7a suggests, the 49 papers accepted for this session cover a wide range of ground improvement techniques, with applications ranging from roadway design and construction to mitigation of seismic risks. The techniques and applications described in these papers can be broadly grouped as follows:

- Cement grouting
- Cement stabilization
- Chemical grouting, including the use of lime slurry, natrium hydroxide, polyvinyl acetate solution, polyurethane resin, and sodium silicate
- Electro-osmosis
- Geosynthetic reinforcement, including the use of geotextiles, geogrids, and waste plastic
- Ground freezing
- In situ densification, including the use of blasting and dynamic compaction
- In situ replacement, including the use of compaction grouting, deep soil mixing, jet grouting, lean concrete columns, rammed aggregate piers, sand columns, sand compaction piles, and stone columns
- Lime stabilization
- Mechanical replacement
- Rigid piles and fill
- Vacuum preloading
- Wick drains
- Other, including centrifuge and computer modeling, desaturation of granular soils by air injection, suction-controlled drying, and wetting of swelling soils

Some of these categories may be broader than those normally used in geotechnical practice in an effort to capture and classify the contributed papers. Table 1 assigns each of the Session 7a papers to a category.

Session 7b of the conference involves case histories and problems of environmental contamination, with an emphasis on the geotechnical and hydrological management and remediation of solid, hazardous, and low-level radioactive wastes, including liner cover systems and landfill closure for brownfield development. The four papers accepted for Session 7b cover subjects encompassed by the session theme. Because few papers were accepted for this session, no attempt was made to group them in the same way as the Session 7a papers.

PAPER REVIEW

The 53 papers in Sessions 7a and 7b are briefly summarized in Table 2. A general reporter summary and discussion of each paper follow.

Paper #7.01a by S. Shababoddin Yasrobi, Ali Reza Zandieh, and Mehrzad Mortezaiy describes a laboratory study of the effects of adding 13% by weight of two polyvinyl acetate solutions to dune sands. Samples were prepared, cured, and tested in unconfined compression at different times after sample preparation. The unconfined compression was observed to increase rapidly with time and gain about 90% of the long-term resistance within 7 days of sample preparation. A fivefold increase in unconfined compressive strength was observed between samples tested at 1 day and 28 days after sample preparation.

Paper #7.02a by Runglawan Rachan and Suksun Horpibulsuk describes a field study and a laboratory study on the use of recycled pavement materials for low-cost road repairs. Field and laboratory samples were made using recycled pavement and cement. An approximate 3% addition

Table 1. Summary of Ground Improvement Techniques Described in Session 7a Papers

Technique	Property Improved	Material Type	Paper No.
Chemical grouting (polyvinyl acetate)	Strength	Sand	7.01a
Cement stabilization	Strength	Recycled pavement	7.02a
In situ replacement (compaction grouting)	Strength, compressibility	Sand, clay	7.03a
In situ replacement (sand compaction piles)	Strength, seismic hazard mitigation	Coal ash, sand, clay	7.06a
Chemical grouting (polyurethane resin)	Strength	Rock mass, man-made structures	7.07a
Cement stabilization	Thermal resistivity	Sand	7.09a
Geosynthetic reinforcement (polypropylene woven geotextile)	Strength	Gravelly silts and sands	7.11a
Chemical grouting (lime slurry)	Swell potential	Clay	7.12a
Chemical grouting (sodium silicate)	Strength, compressibility	Calcareous (limestone) rock	7.14a
Chemical grouting (natrium hydroxide)	Strength, compressibility	Clay	7.15a
Geosynthetic reinforcement	Strength	Sand	7.16a
In situ replacement (sand columns)	Strength, compressibility	Clay	7.17a
In situ replacement (stone columns)	Strength, compressibility	Clay, sand	7.18a
Geosynthetic reinforcement (geogrids)	Strength, compressibility	Clay	7.19a
Chemical grouting (sodium silicate), cement grouting, ground freezing	Strength, compressibility	Fill, volcanic soils, soft tuff	7.20a
Mechanical replacement	Collapse potential	Silt/loess	7.21a
Cement and lime stabilization	Strength, collapse potential	Sabkha	7.22a
In situ densification (dynamic compaction)	Strength, compressibility	Alluvial deposits	7.25a
Wick drains	Drainage	Marine clay	7.26a
In situ replacement (compaction grouting)	Strength, seismic hazard mitigation	Sand	7.27a
Other (laboratory and field testing)	Seismic hazard evaluation	Debris, clay	7.28a
Other (laboratory and field testing)	Seismic hazard evaluation	Clay	7.29a
In situ replacement (deep soil mixing)	Strength, compressibility	Clay	7.30a
In situ replacement (lean concrete columns)	Strength, compressibility	Clay	7.31a
In situ densification (dynamic compaction)	Strength, compressibility	Reclaimed soils	7.32a
Other (field testing)	Seismic hazard evaluation	Sand	7.34a
Geosynthetic reinforcement (geogrid, geotextile)	Strength, compressibility	Clay, sand	7.35a
In situ densification (blasting)	Strength, compressibility	Sand	7.36a
Vacuum preloading	Strength, compressibility	Clay	7.39a
Cement stabilization	Strength, compressibility	Clay	7.41a
Other (suction-controlled drying and wetting)	Strength, compressibility	Swelling clay	7.42a
Other (bentonite addition)	Flexural strength	Bottom ash	7.43a
Cement grouting and micropiles	Strength, compressibility	“Confused”	7.45a
Other (field testing)	Seismic hazard evaluation	Granular	7.46a
Other (laboratory testing)	Shear and compressional wave velocities	Loess	7.47a
Other (computer modeling)	Not applicable	Various	7.48a
Other (centrifuge modeling)	Not applicable	Double porosity clay fill	7.50a
Other (empirical observation)	Not applicable	Loess	7.52a
In situ replacement (excavation, dynamic compaction, cement stabilization)	Strength, compressibility	Loess	7.53a
Cement grouting	Strength	Various	7.54a
Other (laboratory testing)	Pressure distribution	Granular	7.55a
Ground freezing	Strength	Various	7.56a
Electro-osmosis	Strength, compressibility	Clay	7.58a
Rigid piles and fill	Strength, compressibility	Clay	7.59a
Other (desaturation by air injection)	Seismic hazard mitigation	Sand	7.60a
Other (sheetpile, pipe piles)	Ice protection	Clay, silt	7.61a
In-situ replacement (rammed aggregate piers)	Strength, compressibility	Organic and fine-grained soils	7.66a
Geosynthetic reinforcement (waste plastic)	Strength	Gravel/flyash subbase on expansive clay	7.68a
In situ replacement (jet grouting)	Strength, compressibility	Clay, silt	7.69a

Table 2. Papers Accepted to Sessions 7a and 7b

Author(s)	Title	Field(s) of Application	Content Summary	Approach	Country
#7.01a S. Shababoddin Yasrobi Ali Reza Zandieh Mehrzad Mortezaiy	Effect of Polymeric Stabilizers on the Compressive Strength of Dune Sand	Road construction	Study of benefits of adding polyvinyl acetate solution to stabilize dune sands	Laboratory testing	Iran
#7.02a Runglawan Rachan Suksun Horpibulsuk	Compressive Strength of Repaired Road by Recycling Technique of Pavement Materials	Pavement rehabilitation	Recycled pavement and cement mixed to produce low-cost pavement replacement.	Field and laboratory samples, laboratory testing	Thailand
#7.03a Byung-Sik Chun Duhee Park Yong-Gu Jang Jong-Nam Joo-Heon Lim	Improvement Characteristics of Ground using C.G.S. through Field Case Study	Ground improvement	Evaluation of soil (sand and clay) improvement through compaction grouting at seven sites	Field testing before and after improvement	South Korea
#7.06a San-Shyan Lin Chih-Jung Chien	Use of Sand Compaction Piles for Improvement of a Coals Ash Pond	Ground improvement	Use of sand compaction piles to increase lateral pile resistance and mitigate seismic hazards	Field testing before and after improvement	Taiwan
#7.07a Matthew J. DeMarco	Polyurethane Resin (PUR) Injection for Rock Mass and Structure Stabilization	Stabilization/rehabilitation of rock masses and historically significant structures	Experimental use of PUR injection for stabilization of rock tunnel portal and dry-laid laid stone masonry retaining wall	Experimental field study	US
#7.09a Muawia A. Dafalla	Improvement of Thermal Resistivity of Desert Sand for use in High Voltage Cable Beddings and Foundation in Arid Zones	Insulation of underground electrical cables	Cement stabilization of desert sand to improve thermal properties	Laboratory study	Saudi Arabia
#7.11a Jonathan Wu Kanop Ketchart	Investigating Failure of a Geosynthetic-Reinforced Soil Wall in Black Hawk, Colorado	Failure investigation	Determination of the causes of failure of a polypropylene-woven geotextile reinforced soil wall and recommend remediation	Field observations and monitoring, laboratory testing and analyses	US Thailand
#7.12a J.M. Kate	A Case Study on Rectification of Damaged Structures on Expansive Soil Deposits	Reduction of swell potential	Stabilization of swelling soils by lime slurry and creation of an impervious zone around structures using LDPE liner and concrete	Field and laboratory study	India
#7.14a B.M. Al-Khailany R.R. Al-Omari W.F. Sagman	Geological Alterations and Chemical Treatment of a Polluted Limestone Foundation	Neutralization of the adverse effects of sulphuric acid infiltration	Study of chemical composition of rock and identification of adequate chemical treatment (sodium silicate grout)	Laboratory study	Iraq
#7.15a F.E. Volkov	Strengthening of Clay Soils of Buildings Based under Reconstruction by means of Alkalization	Increased bearing capacity, settlement reduction	Addition of alkali solutions to clay to improve adhesion, angle of internal friction and modulus of deformation	Laboratory study	Russia
#7.16a Gareth Michael Swift David Russell V. Jones	The Design and Construction of a Reinforced Embankment on Soft Compressible Soil	Slope stability and settlement	Construction of a leachate retention pond on top of existing waste above soft alluvium.	Laboratory testing, analysis, and design	United Kingdom
#7.17a Stavros A. Savidis Frank Rackwitz Maik Schuessler	Design and Construction of Granular Soil Columns for Ground Improvement of Very Soft Soils for Road Embankment	Increased bearing capacity, settlement reduction	Stabilization of embankment built on peats and very soft organic silts using sand columns; laboratory modeling of sand column/soft soil interaction	Laboratory testing and modeling, analysis, and field monitoring	Germany
#7.18a Mounir Bouassida Lassaad Hazzar	Comparison between Stone Columns and Vertical Geodrains with Preloading Embankment Techniques	Embankment stabilization	Cost and schedule comparison between the use of wick drain and surcharge and the use of stone columns without surcharge	Field and laboratory investigations and analysis	Tunisia
#7.19a Jose L.M. Clemente Tianfei “Tyler” Liao Thomas Nixon	Geogrid-Reinforced Soil Mat for Temporary Support of Heavy Equipment	Increased bearing capacity	Field investigation, analysis, design, construction and field monitoring of geogrid-reinforced granular mats for support of heavy equipment	Field investigation, analysis, and field monitoring	US
#7.20a Vittorio Manassero Giuseppe Di Salvo	A Combination of Artificial Ground Freezing and Grouting for the Excavation of Large Size Tunnels below the Table	Strength increase, deformation reduction	Chemical grouting and ground freezing used to stabilize the soil and rock and enable tunneling for the Naples Metro extension in practically dry conditions	Field and laboratory testing, field trial, and monitoring	Italy

Author(s)	Title	Field(s) of Application	Content Summary	Approach	Country
#7.21a A. Stanciu N. Boti I. Lingu O. Donciu	Case Study of a Water Tank Behaviour on an Improved Collapsible Soil	Mitigation of collapse potential	Estimate of thickness of collapsible soil removal based on laboratory testing data and analyses followed by field implementation and monitoring	Laboratory testing and analysis	Romania
#7.22a Omar S.B. Al-Amoudi	Testing and Stabilization of Saline Sabkha Soils	Strength increase, settlement reduction	Improvement of Sabkha soils using cement and lime	Laboratory study	Saudi Arabia
#7.25a Liaqat Ali Sarfraz Ali	Enhancement of Bearing Capacity by Dynamic Compaction	Increased bearing capacity, settlement reduction	Enhancement of bearing capacity by dynamic compaction to improve the subsurface conditions to a depth of 5 m	Field investigation	Pakistan
#7.26a Bak Kong Low	Settlement Analysis of Chek Lap Kok Trial Embankments with Probabilistic Extensions	Settlement acceleration	Detailed discussion of settlement of trial embankment with vertical drains at Chek Lap Kok airport, Hong Kong	Field and laboratory testing, analysis, and field monitoring	Singapore
#7.27a Adel M. El-Kelesh Tamotsu Matsu Ken-ichi Tokida	Effectiveness of Compaction Grout Piles in Improving Foundation Soils of Existing Runway	Strength increase, settlement reduction	Case study of compaction grout pile at Tokyo International airport at the intersection area of runways A and B	Field and laboratory testing, analysis, and field monitoring	Japan
#7.28a Antonio Cavallaro Salvo Grasso Michele Maugeri	Dynamic Geotechnical Characterization of Sangiuliano Di Puglia Seismic Area	Seismic hazard evaluation	Seismic response analysis using different site characterization techniques and analytical approaches	Field and laboratory testing	Italy
#7.29a Antonio Cavallaro Salvatore Grasso Valentina Lentini Michele Maugeri	Geotechnical Characterization of a Soft Clay Soil Subjected to a Preloading Embankment	Preloading, settlement reduction	Discussion of site characterization, analysis, and construction of a preloading embankment on a soft clay profile	Field and laboratory testing, analysis, and field monitoring	Italy
#7.30a R.D. Verastegui Flores W.F. Van Impe P. Afschrift W. Cromheeke	Performance of Deep Mixing Improvement of Alluvial Soft Soil	Settlement reduction	Deep soil mixing using Portland cement, composite cement, and blast furnace cement mixed with quicklime on a soft alluvial deposit for embankment support	Field and laboratory testing, field trial, and monitoring	Belgium
#7.31a Franklin Fong Chad M. Davis	Case History—Settlement Mitigation for Mat Foundation using Lean Concrete Columns	Settlement reduction	Lean concrete to reduce compressibility and stiffen the supporting soil for a 34-story high-rise condominium tower in San Diego, California	Field and laboratory testing, analysis	US
#7.32a Hamid Reza Nouri Hamid Ali-Elahi Mehdi Jalili Ehsan Seyedi Hosseininia	Evaluation of Empirical Relationships for Dynamic Compaction in Liquefiable Reclaimed Silty Sand Layers using Pre/Post Cone Penetration Tests	Increased bearing capacity, settlement reduction	Ground improvement (dynamic compaction) of reclaimed ground behind a quay wall in a seismically active region	Field testing	US Iran
#7.33a Syed Faiz Ahmad	Ground Improvement of a Beach Structure Complex by means of Stone Columns—A Saudi Arabian Case History	Increased bearing capacity, settlement reduction	A case study related to ground improvement by stone columns; marked improvement shown through pre- and post-installation SPT tests and full-scale plate load tests	Field testing	Saudi Arabia
#7.34a M.L. Rainone P. Torrese P. Signanini, G. Vessia C. Cherubini R. Madonna	Estimation of the Vs Parameter by means of SPT tests: Experiences carried out within the VEL Project (Tuscany Region, Italy)	Seismic hazard evaluation	Comparison between shear wave velocity results from Down-Hole testing and predictions utilizing the standard penetration test N value	Field testing	Italy
#7.35a Sao-Jeng Chao	Performance Study on Geosynthetic Reinforced Shallow Foundations	Increased bearing capacity, settlement reduction	The benefits of geosynthetic reinforcement (nonwoven geotextile and geogrid) to improve bearing capacity studied for sand and clay soils	Laboratory modeling, field trials, and FEM analysis	Taiwan
#7.36a Ulrich La Fosse	Earthquake Mitigation by Blast Densification	Increased bearing capacity, settlement reduction	Ground improvement through densification of loose soils by blasting	Field testing	US

Author(s)	Title	Field(s) of Application	Content Summary	Approach	Country
#7.39a A.K.L. Kwong X.F. Han L.G. Tham P.K.K. Lee W.B. Zhao	A Field Study on Under Water Vacuum Preloading Method	Preloading, settlement reduction	Large-scale field experiment to verify the suitability of vacuum preloading at a site consisting of soft clayey stratum up to about 7.0 m depth; vacuum preloading used in conjunction with vertical drains	Field and laboratory testing, field trial, and monitoring	Hong Kong
#7.41a Chee-Ming Chan Siti Hajarahani Abdulla	A Study of Cement-Stabilised Columnar System in Standard Oedometers	Settlement reduction	A study on settlement behavior of cement stabilized; stabilization by cement reducing the compressibility of the soft clays by half	Laboratory testing and analysis	Malaysia
#7.42a Hossein Nowamooz F. Masrouri	Swelling Soils Behavior in Cyclic Suction-Controlled Drying and Wetting	Behavior of swelling soils	Experimental results on swelling properties of two compacted and natural swelling clayey soils with different micro and macro structures	Laboratory testing	France
#7.43a Sanjeev Kumar Miton Adhikari	Load-Deformation Behavior of Bentonite Amended Bottom Ash in Bending	Embankments, compacted liners	Experimental results on the flexural strength of a bentonite/bottom ash mixture	Laboratory testing	US
#7.45a Timothy J. Myers Hristo K. Dobrev John Szturo Wayne Duryee	Improvement of Soil and Rock Properties for Foundation Support for Missouri Interchange Project	Foundation support	Grouting improvement program with small-diameter piles in hard and complex geological environment for support of several bridge foundations for the Missouri interchange project	Field investigation and testing	US
#7.46a David Rees Gillette William O. Engemoen	Review of In Situ Measurements as Indications of Liquefaction Potential at Numerous Sites	Seismic hazard evaluation	Comparison of various in situ techniques for liquefaction assessments	Field testing and analysis	US
#7.47a Dimitar Antonov	Laboratory Seismic Wave Investigations on Improved Loess Soils as Engineered Barriers in the Radioactive Waste Repository Case	Engineered fill	Laboratory program to evaluate seismic velocities of loess through the addition of various additives to demonstrate that such soils could be improved sufficiently to allow them for use as engineered barriers against radionuclide migration	Laboratory testing	Bulgaria
#7.48a Behzad Fatahi Buddhima Indraratna Hadi Khabbaz	Case Study on the Influence of Trees on the Ground Behaviour	Soil/moisture behavior	A case study on the influence of transpiration on ground behavior	Numerical, field, and laboratory modeling	Australia
#7.50a Jan Najser Jan Bohac Emma Pooley	Construction of Motorway on Double Porosity Clay Fill	Embankment stability and settlement	Description of the mechanical behavior of a trial embankment built as part of the construction of a new motorway on double porosity clay fills extending to depths of 30 m	Field and laboratory testing, field trial, and monitoring	Czech Republic Switzerland
#7.52a Dimcho Evstatiev Jordan Evlogiev	Underground Facilities in Loess	Underground construction in loess	Discussion of advantages of underground construction in loess formations, compared with other soils, of the Danubian plain in Bulgaria	Literature review and laboratory experimentation	Bulgaria
#7.53a Dimcho Evstatiev Mariana Nedelcheva Jordan Evlogiev	Foundation Work of a High TV Tower in Collapsible Loess	Foundation construction in loess	Construction of the foundation of a TV tower in Rousse (Bulgaria) on collapsible loess formation; foundation solution consisted of a soil-cement cushion system on heavily tamped soil at depth of 14.5 m	Field and laboratory testing, analysis, and field monitoring	Bulgaria
#7.54a Fernando da Casa Martín F. Celis D'Amico E. Echeverria Valiente P. Chías Navarro A. García Bodega	Excavation for Underground Parking in Seville, Treatment with Reinforced Injections	Excavation stabilization	Use of cement grouting to create a soil/cement mass subsequently used as a gravity retaining structure for a deep excavation	Field and laboratory testing and analysis	Spain
#7.55a F. Di Credico P. Signanini P. Torrese	Some Interesting Results about Behaviour of Granular Media	Theoretical evaluation	Literature search and laboratory experiments using carbon paper and photoelasticity to measure stress intensity from granular materials contained in silo-shaped structures	Literature review and laboratory experimentation	Italy

Author(s)	Title	Field(s) of Application	Content Summary	Approach	Country
#7.56a Dong K. Chang Hugh S. Lacy	Artificial Ground Freezing in Geotechnical Engineering	Strength increase, deformation reduction	Very useful summary of the state-of-the-practice in ground freezing using liquid brine; presentation of two unique case histories of ground freezing from the Boston Central Artery	Literature review and field monitoring	US
#7.58a Sven Hansbo	Soil Improvement by Means of Electro-Osmosis	Strength increase, settlement reduction	Concise review of the theory and relevant equations for the design of a system using electro-osmosis; discussion of two case histories in a fair amount of detail, providing much quantitative information	Literature review, analysis, and field monitoring	Sweden
#7.59a M. Nunez D. Dias C. Poilpre R. Kastner	Soft Ground Improved by Rigid Vertical Piles. Experimental and Numerical Study of two real Cases in France	Strength increase, settlement reduction for embankments	Case studies on soft ground improvement by rigid vertical piles to allow rapid embankment construction	Field and laboratory testing, numerical analysis, and field monitoring	France
#7.60a Hideaki Yasuhara Mitsu Okamura Takamasa Moritou Kochi Yoshinori	Evolution of Soil Desaturation by Air-injection Technique and Its Evaluation via Multiphase Flow Simulation	Seismic hazard mitigation	Examination of the effects of air injection on the desaturation of sands	Model studies and analytical analysis	Japan
#7.61a Alp Gökalp Rasin Düzceer	Ice Protection Barrier Construction in Caspian Sea	Ice protection	Description of barriers successfully used to protect artificial islands constructed for oil drilling in the Caspian Sea from ice flows formed during the winter	Field investigation, analysis, and design	Turkey
#7.66a M.J. Hossain M. Alamgir M.A. Mahamud	Field Investigation on the Performance of Rammed Aggregate Pier in a Soft Ground of Bangladesh	Increased bearing capacity, settlement reduction	Field investigation of the benefits of rammed aggregate pier on the behavior of footings on soft ground	Field investigation and plate load testing	Bangladesh
#7.68a D.S.V. Prasad G.V.R. Prasada Raju	Utilisation of Waste Plastics in Flexible Pavement Construction Laid on Expansive Soil Subgrade	Pavement construction	Description of low cost approach to subbase courses for flexible pavements on expansive subgrade soils; description of the benefits of using waste plastic strips measuring 12 mm x 6 mm x 0.5 mm as reinforcement for a gravel subbase course and a flyash subbase course.	Field trial and monitoring	India
#7.69a Ken Ivanetich Lisheng Shao	Jet Grouting for Mass Treatment to Support an Aggregate Stockpile Building over Very Soft Clays	Settlement reducton	Use of jet grout columns and construction of a 1.8 m thick engineered fill pad to improve the subsurface conditions for foundation support	Field and laboratory testing and field trial	US
#7.01b Sanjay Das Indra Prakash	Assessment of Groundwater Hazards in a Costal District of Gujarat, India	Hydrogeology	Investigation of groundwater hazards in a coastal district., including evaluations of the effects of salt water ingress, bedrock type, and industrial pollution.	Groundwater survey, testing, and analysis	India
#7.03b R.Jeffrey Dunn	Lessons Learned from Closing Three Major Landfills—The Devil Really is in the Details	Landfill closure	Outline of lessons learned from the closure of sanitary and hazardous waste landfills at three sites	Empirical	US
#7.09b B.N. Moolchandani	Geotechnical Engineering, Subject Areas with General and Specific Examples of Existing Structures in India and a Case Study of Environmental Geotechnology through Recharging Surface Ground Water at Source (Check on Ground Water Pollution/Water Contamination)	Runoff water recharge	Description of runoff water recharge system to augment aquifer capacity	Empirical	India
#7.10b Derrick A. Shelton David A. Schoenwolf Nisha P. Mohanan	Redevelopment of a Municipal Solid Waste Landfill: Engineering Design Challenges	Land development	Detailed description of field and laboratory investigation, analysis, design, and field monitoring of urban land development over three closed landfills	Field and laboratory testing and analysis	US

of cement to the study samples was sufficient to achieve a target unconfined compressive strength. Additionally, field-roller-compacted samples were noted to present unconfined compressive strengths in the range of 0.55 to 1 of the respective strengths obtained from hand-compacted samples. The paper also outlines a suggested procedure for using hand-compacted samples as a quality control tool for pavement recycling.

Paper #7.03a by Byung-Sik Chun, Duhee Park, Yong-Gu Jang, Jong-Nam, and Joo-Heon Lim describes the use of compaction grouting to improve subsurface conditions at seven sites in South Korea. Pre- and post-treatment field testing between compaction grouting columns disclosed densification and/or increase in undrained strength as follows: SPT N values increased by about 20% at all seven sites, dynamic cone penetration test blow counts increased between 20% and 30% at two sites, field vane shear tests disclosed an increase of 43% at three sites, and CPT results showed an increase of 19% in point resistance at three sites. Customary practice when using compaction grouting in soils with more than 20% fines is to ignore possible densification effects from the compaction grouting installation. The observed densification suggests that compaction grouting installation can further improve what the compaction grouting columns themselves provide, even in clayey soils.

Paper #7.06a by San-Shyan Lin and Chih-Jung Chien describes the use of sand compaction piles to improve the subsurface conditions beneath a coal ash pond prior to installation of large-diameter (1.2 m) bored piles for support of cylindrical domes to be built within the footprint of the pond. The sand compaction piles provided increased lateral load capacity for the bored piles and also mitigated liquefaction hazard. It was observed that installing sand compaction piles results in substantial increases in SPT N values, even in the coal ash, which contained more than 50% fines. The paper also includes results from instrumented load tests on two large-diameter bored piles installed to a depth of 36 m, for which the instrumentation included rebar gauges installed at eight locations along the pile length. Test results showed the load distribution along the pile length.

Paper #7.07a by Matthew J. DeMarco describes the experimental use of polyurethane resin (PUR) injection for rehabilitation/stabilization of rock mass and other historically significant structures. The paper includes an overview of polymer products, applications of PUR to civil and mining projects, a comparison of PUR and cementitious grout, and a brief assessment of environmental issues associated with using PUR. Test cases described in the paper include stabilization of a rock mass for a highway tunnel and of a dry-laid stone masonry retaining wall. It is stated that PUR applications appear to have met their intended goals of being rapidly-deployed, cost-effective, superior ground stabilization methods that meets aesthetic objectives of concrete-sensitive settings.

Paper #7.09a by Muawia A. Dafalla provides an excellent summary of the thermal properties of sands and shows the effects of sand gradation on thermal properties. Well-graded sands tend to show lower thermal resistivity than poorly graded sands. In extremely hot climates, thermal resistivity of sand of any gradation tends to increase beyond acceptable values because of moisture depletion. This can adversely affect buried electrical cables, where sand is often specified for trench bedding. A costly alternative to sand bedding is building concrete cable ducts to keep thermal resistivity below the target value of 120^{o}C-cm/watt, commonly specified for underground electrical cable protection in very hot climates. This paper describes a cost-effective application of 5% cement by weight to poorly graded dune sand, which can bring the thermal resistivity value down to or below 120^{o}C-cm/watt. The paper also includes data on the thermal resistivity properties of numerous sand deposits in Saudi Arabia, as well as trench bedding procedures commonly adopted there.

Paper #7.11a by Jonathan Wu and Kanop Ketchart provides an interesting case history related to the investigation of the failure of a geosynthetic-reinforced soil wall. The geosynthetic used for wall construction consisted of a polypropylene woven geotextile, the backfill consisted of locally available gravelly silts and sands, and the wall face consisted of manually placed rock blocks. The wall geometry shown in Figures 3 and 4 of the paper is in itself quite challenging for the construction of any type of retaining structure. The wall was built during a period of severe cold weather, and the results of the investigation indicated that the backfill was not properly compacted. An existing water pipeline was abandoned in place just behind the middle section of the wall. Water from this pipe most likely caused the backfill to become wet, resulting in significant settlements behind the wall and bulging of the wall face. Based on the results of laboratory testing of the backfill material, it is believed that the excessive settlements and wall bulging would not have occurred without wetting from the abandoned pipeline, despite the poor compaction. The wall had to be completely demolished and rebuilt using proper compaction control, and the abandoned pipeline had to be removed. The rebuilt wall has since performed satisfactorily. This is an excellent example of a failure investigation that made use of field observations and measurements, laboratory testing, and analyses.

Paper #7.12a by J.M. Kate describes the application of lime slurry to stabilize the foundations of one- to four-story structures. Signs of distress included wall cracks as wide as 25 mm and distorted floors. Soils at the site had free swell indices ranging from 33% to 70%, liquid limits ranging from 55% to 66%, and swelling pressures ranging from 65 to 85 kPa for undisturbed samples. The swelling pressure of remolded samples ranged from 210 to 290 kPa, and these values were reduced to below 13 kPa with the addition of 4% lime by weight. It was also determined that the seasonal moisture variation zone extended to a depth of 2 m below grade. Lime slurry was injected along the outside perimeter of affected structures using 50 mm diameter holes drilled to a depth of 1.7

m. Lime slurry was also injected along the inside perimeter and throughout the interior of structures with heavily damaged floors. In addition, an impervious zone extending 2 m outside the building walls was created by installing a concrete-covered LDPE liner. The liner extended into a 1.75-m deep trench backfilled with concrete to create a plinth.

Paper #7.14a by B.M. Al-Khailany, R.R. Al-Omari, and W.F. Sagman describes an interesting laboratory study of applying sodium silicate grout to stabilize a limestone rock formation that was severely weakened by the infiltration of concentrated sulphuric acid. Monitoring of foundation movements revealed that significant heave and settlements coincided with known leakages and infiltration of concentrated sulphuric acid. Foundation movements, in turn, caused cracks within connections, resulting in increased leakage and additional movements. Rock coring revealed that the limestone's consistency had become dough-like at certain depths. An extensive laboratory study that included petrographic analysis and X-ray diffraction was conducted to identify constituent minerals in the rock samples to help identify the best-suited chemical treatment (sodium silicate). The addition of sodium silicate to the recovered samples resulted in a significant increase in strength and neutralization of the sulphuric acid. The paper also includes a careful study of the rock's geological alterations caused by the concentrated sulphuric acid.

Paper #7.15a by F.E. Volkov describes improvement in strength of clay soils resulting from alkalization. Failure occurs in the silicon-oxygen-aluminum system when caustic soda is added to aluminosilicates. This results in outflow of silicon and aluminum oxides and formation of a new solid phase of natrium hydroaluminosilicate. The addition of 2.4 to 10 N alkali solutions to clay was found to improve its adhesion, angle of internal friction, and modulus of deformation. The method is economical and efficient to strengthen soils.

Paper #7.16a by Gareth Michael Swift, David Russell, and V. Jones succinctly describes the approach taken to construct a leachate retention pond on top of existing waste above soft alluvium. The paper includes stability and settlement analyses of the 4.5 m high embankment surrounding the 32,000 m^2 pond. Attention is paid to estimating and measuring a complex porewater pressure regime. The design and construction include a wide range of geofabrics, including geotextiles, geogrids, geocomposites, geopipes, geomembranes, and geosynthetic clay liners, all of which are clearly illustrated.

Paper #7.17a by Stavros A. Savidis, Frank Rackwitz, and Maik Schuessler describes a very detailed analytical, field monitoring, and laboratory study of the effects of installing sand columns to increase the strength of and reduce the compressibility of very soft soils. The paper first provides a case history of the use of sand columns installed into very soft peats (moisture content of up to 430%) and organic silts (undrained strength of less than 8 kPa) to support a new highway embankment. Conventional slope stability analysis results, and results using Plaxis, are presented and discussed. Plaxis results indicate a 45% reduction in settlement as a result of sand column installation. These columns were installed using a closed-end steel pipe with a retractable bottom that could be opened to release the sand as the pipe was withdrawn. The embankment was constructed with a surcharge to help accelerate settlements. Field monitoring disclosed settlements of 300 to 400 mm before the surcharge was built, versus a Plaxis prediction of 280 mm. The settlements measured 430 to 570 mm after construction and surcharge removal, which compared well with the Plaxis-predicted value of 580 mm. It is noted that placement and removal of the surcharge induces some degree of overconsolidation in the soils surrounding the sand columns. The second part of the paper describes a well-planned and well-implemented research program to study soil–sand column interaction. The research program included conventional laboratory tests as well as a large-scale laboratory model test. The large-scale test used site soils and simulated the field installation of sand columns, and the main conclusions drawn from it were that (a) long-term settlements are strongly influenced by the creep behavior of soft soils, (b) long-term settlements are also influenced by overconsolidation (surcharge placement and removal), and (c) sand column density does not seem to influence the soft soil–sand column interaction.

Paper #7.18a by Mounir Bouassida and Lassaad Hazzar describes an interesting case of a bridge approach using embankment over soft soils. Subsurface conditions for one of the approaches included using an upper layer of soft, compressible soils extending to a depth of 8 to 10 m. Two options were considered for embankment stabilization and schedule reduction. The first option consisted of using wick drains to depths of 10 m and building the embankment and a surcharge in stages. The wick drains would reduce the rate of consolidation, and the surcharge would reduce or eliminate post-construction settlements. The second option consisted of reinforcing the soft soils by installing stone columns to a depth of 10 m. These columns would reduce the rate of consolidation and settlement values and would eliminate the need for surcharging the embankment. Careful analyses described in the paper indicate that stone columns would result in a shorter construction schedule by achieving better acceleration of settlements than the wick drains. A cost comparison also suggested that the stone columns would be less expensive to install, in part because no surcharge would be required. However, a decision was made to use wick drains because of material and equipment availability. Wick drain installation and embankment construction had been completed and settlement monitoring just begun at the time the paper was written; therefore, a comparison between predicted and measured settlements was not possible. Hopefully, the authors will provide an update at the conference.

Paper #7.19a by José L.M. Clemente, Tianfei "Tyler" Liao, and Thomas Nixon describes the successful use of a geogrid-reinforced granular soil mat for temporary support of heavy equipment at a nuclear station. The proposed solution was instigated by a replacement transformer being stored on site on a concrete slab supported by piles extending to the bedrock. (The presence of this replacement transformer is not discussed in the paper.) The results of a subsurface investigation in the storage area for the heavy equipment disclosed the presence of an upper, weak clay layer extending to a depth of about 8 m below grade. The estimated allowable bearing pressure for this clay layer was about 60 kPa. The heavy equipment was to be supported by concrete blocks, resulting in bearing pressures of around 290 kPa. The ground improvement solution included construction of a geogrid-reinforced granular fill mat with a thickness of 0.9 m and placement of a steel plate beneath the concrete blocks to reduce the pressure at the bottom of the granular mat to approximately 60 kPa. The internal stability of the geogrid-reinforced granular mat was checked to arrive at the appropriate number of geogrid layers. Settlements of the concrete blocks were monitored while the heavy equipment was in storage. The measured settlements were larger than anticipated but remained within tolerable limits. It was observed that the concrete blocks underwent some tilting, caused by the use of short equipment support beams placed on them and extending to about the midpoint of the concrete blocks. If this technique is used again, it is recommended that equipment support beams be used that extend to the outside edge of the concrete blocks.

Paper #7.20a by Vittorio Manassero and Giuseppe Di Salvo provides a very detailed description of soil improvement methods used to enable construction of a 40 m section of tunnel of the Naples Metro extension under existing buildings. Subsurface conditions were very challenging and included loose uniform fine sand underlain by highly fractured and permeable weak rock (tuff) under a 27 m hydrostatic head. Details are provided about the materials, application, and results from cement and chemical grouting and ground freezing to stabilize the soil and rock and to enable tunneling in practically dry conditions.

Paper #7.21a by A. Stanciu, N. Boti, I. Lingu, and O. Donciu describes an interesting case of collapse potential mitigation for a concrete water tank built on loess. The paper details the soil's conditions and properties, as well as predicts waterfront advance and settlement from potential water leakage. These predictions were used to determine the thickness of soil removal and replacement beneath the tank. Instrumentation was installed to monitor possible waterfront advances as well as tank settlements after filling. Other water infiltration mitigation measures included surface drainage around the tank. Unfortunately, the paper does not discuss monitoring results and actual tank performance. It will be interesting to see a follow-up paper that presents monitoring results and compares them with the predictions made in this paper.

Paper #7.22a by Omar S.B. Al-Amoudi reviews sabkha soils and their occurrence in coastal and continental areas throughout the world. The author suggests that using distilled water in determining the geotechnical properties may not be appropriate. Improvement using cement and lime is investigated for Saudi sabkha soils at both optimum and high water content. The author sees CBR and unconfined compression tests as the most appropriate tests to evaluate the sabkha soils.

Paper #7.25a by Liaqat Ali and Sarfraz Ali describes the enhancement of bearing capacity by dynamic compaction. A site west of Islamabad was improved using heavy circular tampers of 20 tons falling more than 16 m. Standard penetration tests were performed before and after dynamic compaction, and the process was found to improve the site to a depth of 5 m.

Paper #7.26a by Bak Kong Low discusses a case study of settlement analysis of a trial embankment at Chek Lap Kok airport, Hong Kong, which consists of reclamation fill on marine clay. The objective of the test fill was to investigate the feasibility of reclamation over soft marine clay and the effectiveness of vertical drains in accelerating consolidation. The test area was divided into regions. In one region, the marine clay was not treated; in the other regions, vertical drains were installed at various spacings. The author then made the settlement analysis for comparisons with the instrumented settlement versus time records of the marine clay. The spreadsheet-based reliability approach is presented in this paper. The program for deterministic analysis uses Barron's solution for equal vertical strain of consolidation from radial drainage and Carillo's equation for combined radial and vertical drainage. The author has considered these practical algorithms for predicting the rate of settlement because, even in the relatively simple approach adopted here, 15 or more parameters were required. Comparisons were made with results from Monte Carlo simulations. In the deterministic analysis, the agreement between the computed results and the instrumented results was better for the 1.5 m spacing vertical drain region than for the 3.0 m spacing vertical drain region. The results of reliability analysis in this study depend on the consolidation model adopted and proper input, including model uncertainty and statistical input estimation. More discussion could have been included on model uncertainty and estimation of statistical inputs. Properties of the reclaimed area vary from place to place; therefore, the model's reliability shall be checked in general.

Paper #7.27a by Adel M. El-Kelesh, Tamotsu Matsu, and Ken-ichi Tokida discusses a case study of a compaction grout pile at Tokyo International Airport at the intersection area of runways A and B. The subsoil conditions show a liquefiable zone during earthquakes. A pretreatment investigation and an assessment of the liquefaction potential revealed that the foundation is highly variable and consists of alternate layers of liquefiable and non-liquefiable soils. For this condition, compaction grout piles proved economically effective, with which only liquefiable layers are treated. In many areas, sand compaction piles were used to minimize liquefaction potential; however, at the intersection part of runway B, compaction grout piles were used for ground treatment to avoid obstructing air traffic during the execution of work. Drilling and grouting work composed of 190 mm OD steel casing pipe and bolted caps was installed in the top 0.16 m of the pavement at the grout hole locations. The drilling/injection pipe (73 mm OD) was guided by the casing during both drilling and injection operations. The upstage compaction grouting technique was adopted, with a depth interval of 0.33 m. The grout mix consisted of fines: aggregate, cement, and water. The water-to-cement ratio was adjusted to foster a slump value less than 5 cm. The grout mix was then injected below the average rate of 0.04 m^3/min with a maximum injection pressure of 6.0 MPa. A cumulative pavement heave value of 7.0 cm was considered a limiting criterion. The authors conclude that this method is suitable and economical for the existing site conditions. Additional discussion of cost comparison among various soil improving techniques, as well as laboratory test results of the grout mix selected for injection, would have been helpful. Injection pressure is very important with compaction grouting, so the basis for selecting grout pressure should also have been discussed in more detail.

Paper #7.28a by Antonio Cavallaro, Salvo Grasso, and Michele Maugeri is an interesting paper about seismic response in the Molise region of Southern Italy. Several field and laboratory tests were performed to characterize the subsurface conditions. It would be interesting if the authors had further elaborated on the differences between the down-hole seismic measurements and the seismic DMT. Ground response analysis was performed using two different codes: a 1-D non-linear code (GEODIN) and an equivalent linear code (EERA). The response spectra discussed in the paper differentiate between the non-linear and equivalent linear codes. It would be interesting to also hear the authors' views on these differences.

Paper #7.29a by Antonio Cavallaro, Salvatore Grasso, Valentina Lentini and Michele Maugeri discusses site characterization for preloading technique analysis of a soft clay. Soil was subjected to a preloading embankment for the construction of an industrial electronics building in the industrial area of Catania (Sicily, Italy). An instrumented circular test embankment 2.5 m high was constructed on a clay deposit. Based on the results, a reinforced concrete building for an electronics industry was built successively. The site consists of fine alluvial deposit with clay fraction predominantly ranging from 2% to 54%, down to a depth of 95 m. The silt fraction ranges from about 50% to 100%, with a moisture content around 54% to 84%, plastic limit approximately 27% to 46%, and plasticity index ranging from 22% to 41%. Static and dynamic parameters were compared by in situ and laboratory tests. A mechanical cone penetration test shows very poor mechanical characteristics of the subsoil. Typical values of cone resistance are in the range of 0.01 to 0.49 MPa. Small strain shear modulus was determined from SDMT and down-hole (DH) tests, and the equivalent shear modulus was determined in the laboratory by means of the Resonant Column Test (RCT). Also, the small strain shear modulus is determined by the theory of elasticity using various well-known relationships. The authors conclude that all the considered methods show very different shear modulus (G_0) values; however, SDMT instruments are much more stable and repeatable than those used in the DH test.

Paper #7.30a by R.D. Verastegui Flores, W.F. Van Impe, P. Afschrift, and W. Cromheeke is a well-written documentation of a laboratory and field study on the use of deep soil mixing for embankment stabilization. The paper well-describes the subsurface conditions that included an upper layer of soft clays (silty clay with $s_u \leq 60$ kPa to a depth of about 3 m, and peat with $s_u \leq 30$ kPa to a depth of about 8 m). A laboratory investigation was conducted of the unconfined compressive strength of site soils mixed with different combinations of unslaked lime and cement. Trial deep mixing columns were also installed using different combinations of unslaked lime and cement. These trial columns were later exhumed for inspection. The laboratory study and trial deep mixing column program provided the basis for the construction of four trial embankments. One embankment was built on untreated soil, and the other three embankments were built on soil improved with deep mixing columns that employed different combinations of unslaked lime and cement. Settlement monitoring results indicated that using the deep mixing columns effectively reduced settlements, and the deep mixing columns that used the highest binder dosage (200 kg/m^3) provided the most settlement reduction (about 65% when compared with the settlements of the trail embankment on untreated soils).

Paper #7.31a by Franklin Fong and Chad M. Davis describes a case history of soil improvement for construction of a 34-story building above a 5-level underground garage in an urban environment. Construction of the garage required placement of foundation mat on a compressible silt/clay layer, the bottom of which sloped in one direction, creating a variable thickness of compressible soil that exacerbated differential settlement issues. A comparison of several foundation alternatives, including piling, indicated that lean concrete columns could effectively provide sufficient bearing capacity and reduce settlements of the proposed mat foundation to within tolerable limits. Lean concrete column installation and mat foundation construction have been completed, but sufficient settlement monitoring data was not available at the time the paper was written. Therefore, a comparison between predicted and measured settlements was not possible. The authors state that settlement monitoring is proceeding on a bi-weekly to monthly basis, and a follow-up paper will summarize these results and compare actual versus estimated values. It would be valuable if the authors could provide an update at the conference.

Paper #7.32a by Hamid Reza Nouri, Hamid Ali-Elahi, Mehdi Jalili and Ehsan Seyedi Hosseininia is an interesting analysis on ground improvement using dynamic compaction for reclaimed ground behind a quay wall located in a seismically active region. The paper highlights the need for trial dynamic compaction areas and the need for real-time evaluation of results during production dynamic compaction. Those results can then be used to revise the applied energy through compaction patterns, drop height, hammer weight, and number of passes. Pre- and post-CPT measurements were taken to mark ground improvement.

Paper #7.33a by Syed Faiz Ahmad presents a case study related to ground improvement by stone columns in sabkha soils at Al-Khobar, Saudi Arabia. A total of 3,119 stone columns were installed by the vibro-replacement technique. Pre- and post-penetration tests and full-scale plate load tests conducted on the project site indicated marked improvement in soil bearing capacity after the installation of stone columns.

Paper #7.34a by M.L. Rainone, P. Torrese, P. Signanini, G. Vessia, C. Cherubini, and R. Madonna is an interesting paper that compares direct shear wave velocity results from down-hole testing with shear wave velocity predictions using the standard penetration test N value. Testing was performed in the Tuscany region in Central Italy. As with many other studies in the past, results showed that correlations relating N values to V_s are poor. The authors attribute this poor correlation with the type of measurement related to strain; direct V_s measurements are at very small strains, whereas N values are determined by driving a spoon through the soil (higher strain), as well as by differences in gradation. A conclusion the reader may draw is that if V_s data is required for a project, it should be measured directly rather than estimated through correlations with other data.

Paper #7.35a by Sao-Jeng Chao describes experimental laboratory work combined with numerical analysis (FEM) and field testing to evaluate the benefits of geosynthetic reinforcement to improve foundation conditions over weak soils (sands and clays). Laboratory work included modeling sand and clay samples with geosynthetic reinforcement. Bearing capacity test results on geosynthetic-reinforced sand models disclosed bearing capacities 1.6 to 4.5 times greater than bearing capacities of unreinforced sand. Test results on geosynthetic-reinforced clay models disclosed efficiency ratios of 2.5 to 3.8. FEM modeling of the laboratory experiments disclosed efficiency ratios of about 1.5 for the sand model and 2.5 for the clay model; i.e., the FEM analysis could not predict the higher efficiency ratios measured in the laboratory experiments. Unfortunately, it is not clear what geosynthetic was used in these models. The paper includes the results of a field test on geosynthetic-reinforced fill for a roadway. The reinforcement consisted of a layer of nonwoven geotextile placed directly on the subgrade and a layer of geogrid placed directly on the geotextile. This test proved that a thinner layer of fill could be used if the geotextile and geogrid were placed on the subgrade.

Paper #7.36a by Ulrich La Fosse is an interesting paper that describes ground improvement through densification of loose soils by blasting. The project described was fast tracked and included a geotechnical consultant, a blasting subcontractor, a drilling subcontractor, and a cone sounding subcontractor. Because of the fast-track nature, it was recognized that pre- and post-CPT comparisons may not prove effective in determining ground improvement because of limited time. Thus, settlement (volumetric strain) was used as the primary indicator of ground improvement. Because the project was completed some time ago, it would be helpful if the authors could comment on the behavior of the structure in terms of measured settlement.

Paper #7.39a by A.K.L. Kwong, X.F. Han, L.G. Tham, P.K.K. Lee, and W.B. Zhao describe a large-scale field experiment carried out approximately 2.0 km south of the Shenzhen Bao'an International Airport. The site consists of soft clayey stratum to about 7.0 m in depth, below which firm stratum is available. The water table was found at about 1.5 m below ground level. The field experimentation consists of installation of prefabricated vertical drains in an equilateral triangular grid of 1.2 m to a depth of 7.0 m. Internal drainage pipes were provided in the sand cushion layers to provide a passage for the prefabricated vertical drains with the external vacuum pumps. Vane shear tests and cone penetration tests were conducted before and after vacuum preloading to determine the operation's effectiveness. Other instruments such as piezometers, vacuum sensor inclinometers, settlement plates, and extensometers were installed to monitor the performance of the system. A custom-made geomembrane was laid under water to separate the water from the PVDs and all pipes. After the construction of vertical drains and instrumentations, a vacuum was applied for about 3 months, during which time the variation of vacuum pressure and water pressure was measured along with variation of pore water pressure with depth. After completion of the field experiment, maximum surface settlement represented about 13% of soft layer thickness. Also, undrained shear strength of the soil was increased significantly with the substantial decrease in water content. Additional discussion on adopting this method with reference to soil types and economical viability with reference to other methods would have enhanced the paper. The paper could also have included a discussion of the criteria that were adopted for selection of vacuum pressure with reference to the test area.

Paper #7.41a by Chee-Ming Chan and Siti Hajarahani Abdulla describes settlement behavior of cement-stabilized Malaysian clay. It was found that stabilization by cement can reduce the compressibility of soft clays. An addition of 10% cement could reduce total settlement by one-half. An equal-strain approach was used to predict the settlement of the stabilized columnar system based on a columnar inclusion test in the oedometer.

Paper #7.42a by Hossein Nowamooz and F. Masrouri presents experimental results on two compacted and natural swelling clayey soils. The micro and macro structures of the soils and the swelling pressure were quite different. The osmotic technique was used to impose controlled suction, ranging from 0 to 10 MPa. Because of the long length of time needed to reach the equilibrium state, three cycles of wetting and drying were carried out in the oedometer apparatus. Several successive swelling and shrinking cycles were applied under various constant vertical net stresses; then, the followed stress paths were illustrated for the two soils. Also the recorded variations of the void-versus-suction ratio were illustrated. The plastic strain evolution as a function of suction cycles was deduced. An interesting result noted regarding the compacted soil was that the highest shrinkage accumulation occurred during the first cycle of wetting and drying; this accumulation increased with applied stress. The equilibrium state was reached with small swelling accumulation. For natural soil, the decrease in suction was accompanied by significant expansion and accumulation of swelling for all specimens. However, the amount of swelling accumulation decreased with increasing applied stress. The number of wetting–drying cycles required for the natural soil to reach equilibrium, characterized by an elastic behavior of the tested soils, was greater than for the compacted soil. Overall, the paper highlights the coupling between hydraulic cycles and the observed mechanical behavior of two different swelling soils. It substantially contributes to the framework of a French research project and contains a succinct reference list.

Paper #7.43a by Sanjeev Kumar and Miton Adhikari describes a laboratory testing program to evaluate the load-deformation behavior of a bottom ash/bentonite mixture. The emphasis of the study is on the flexural strength of the tested mixture as it relates to understanding the cracking of earth embankments and compacted clay liners when subjected to bending stresses caused by uneven settlements. Pulverized coal combustion (PCC) bottom ash has physical characteristics similar to those of natural sand. Mixing bentonite with bottom ash results in a material that behaves similarly to a clayey sand. In the study, samples were prepared using 15% bentonite by dry weight and 18% moisture content. Unfortunately, the paper does not detail the testing equipment or testing procedure, but it does indicate that the samples were subjected to a flexural load and that flexural deformations (it is questionable if the authors are also referring to flexural) were measured. Flexural load verus deformation curves are presented for samples prepared and tested immediately after mixing bentonite and bottom ash and for samples tested 28 days after mixing the two. The 28-day tests were required to measure the strength increase with time, resulting from chemical reactions in the mixture. All test results indicated a steady, almost linear, increase of flexural load as the samples deformed, until a peak was reached. The behavior then became nonlinear as the failure load was approached. The peak flexural load was considered the failure load and was usually accompanied by the formation of a transverse crack at the center of the specimen. Results indicated failure loads 43% higher for mixtures tested after 28 days of initial preparation than for mixtures tested immediately after preparation. The former samples also showed much smaller deformations at failure. The calculated modulus of rupture also increased with time and reached a peak for samples tested 60 days after the bentonite/bottom ash mixture was prepared.

Paper #7.45a by Timothy J. Myers, Hristo K. Dobrev, John Szturo, and Wayne Duryee describes a grouting improvement program using small-diameter piles in hard and complex geological environments to support several bridge foundations for the Missouri Flat Road Interchange project. Geological conditions that included abandoned mines and suspected mine shafts were detailed and illustrated. A high mobility grouting (HMG) was used in fractured rock, whereas a low mobility grouting (LMG) was used in voided conditions. Ground treatment essentially aimed at filling mine voids and preventing collapse in massive ground. To confirm the design and make necessary adjustments, four design verification piles were installed in the same manner insubstantially different soil profiles. All installation parameters were précised, and the scheme of installation was illustrated: grout components and transportation to the site. The quantity of injected grout by increments and the duration of rest time using three typical intensities were reported. Typical-cased micropile cross section and elevation were specified; electronic record keeping during drilling and composition of grout used for micropile installation were also detailed. Because of the very complex geological conditions, foundation treatment was not entirely successful. Therefore, an alternate micropile installation was determined to make the casing advancement feasible by the installation, when necessary, of reinforcing steel with associated hardware. At each bent, one selected micropile was chosen for proof testing. Successful design should comply with three specified acceptance criteria. This case history explains how to overcome challenges related to hard geological conditions by appropriate advanced installation, especially with monitor while drilling (MWD) and real-time observation when using a suitable soil improvement technique.

Paper #7.46a by David Rees Gillette and William O. Engemoen is a very interesting paper that compares various in situ techniques for liquefaction assessment. Objectives were to first evaluate consistency among techniques; compare individual indirect results with direct results, such as soil density; and then ascertain the in situ methods that are most common in the industry. It was concluded that for the cases reported, the closest agreement was between the standard penetration test and cone penetration test sounding. It was also determined that more than one method should be employed to evaluate liquefaction potential.

Paper #7.47a by Dimitar Antonov describes a laboratory program that evaluated seismic velocities of loess by introducing various additives. The purpose was to demonstrate that such soils could be improved sufficiently to allow them for use as engineered barriers against radionuclide migration. Significant increases in V_p and V_s were realized by the addition of ordinary Portland cement, zeolite, and bentonite.

Paper #7.48a by Behzad Fatahi, Buddhima Indraratna, and Hadi Khabbaz presents a case study on the influence of transpiration on the ground behavior. Vegetation, an ancient method of improving the stability of slopes, is recaptured to increase the shear strength of the subgrade beneath rail tracks. The model proposed for predicting the rate of root water uptake was included in a numerical analysis using the ABAQUS finite element code to examine the distribution of soil suction and the profile of the moisture content near a single Black Box tree. Soil suction, root distribution, and potential transpiration are three independent features considered in the root water uptake model. To validate the model, an array of field measurements was conducted at a site in Victoria, Australia, and resultant data has been compared with the numerical predictions. Results calculated using the soil, plant, and atmospheric parameters of the numerical model compared favorably with the field and associated laboratory measurements, justifying the assumptions upon which the model was developed.

Paper #7.50a by Jan Najser, Jan Bohac, and Emma Pooley describes the mechanical behavior of double porosity clay fills. A trial embankment had been constructed on a old landfill, and its behavior was monitored by survey and geotechnical instrumentations. The case study reported was of a Northern Bohemia (Czech Republic) open pit mining of coal. The clay overburden was excavated in irregularly shaped lumps; diameters varied from a few millimeters to 50 cm. The lumps were then placed in large spoil heaps outside of the mines. Mine pits were also backfilled with excavated soil after examining them, using a maximum lift thickness of 200 m. The defining feature of the landfill is its double porosity structure. Total porosity of the fill is approximately 70%. A trial embankment, built as part of the construction of a new motorway between Prague (Czech Republic) and Dresden (Germany), crosses an area containing open-pit mines and is where a partly backfilled mine pit had been used as a fly ash lagoon. The thickness of the clayey fill under the embankment was 30 m. In situ monitoring of the trial embankment showed highly variable, non-uniform behavior. After a surcharge application, the landfill exhibited large initial settlement followed by small deformations accompanied by creep. The hydrostatic leveling profile indicates significant differential settlement, which could have been caused by variation in intergranular porosity. The study was also carried out using a centrifuge modeling technique, which also indicated similar behavior, because the permeability/drainage path controls dissipation of excess pore pressure.

Paper #7.52a by Dimcho Evstatiev and Jordan Evlogiev focuses on advantages of underground construction specifically in loess formations, compared with other soils, in the Danubian plain in Bulgaria. In a large (about 12,000 m^2) territory in North Bulgaria near the Danube River, loess presents the best conditions for underground construction. The mean thickness of loess layers is 50 m, but it reaches 100 m in some locations. Based on clay fraction, five types of loess soils could be identified. Meanwhile, eight loess horizons, separated by seven fossil soils, were also identified. Typical changes in grain size distribution based on depth are illustrated. Dominant minerals and chemical properties are detailed; for example, the alkaline reaction was not found to be very significant. Overall, Bulgarian loess soils are characterized by favorable grain size and mineral composition. Loess profiles are provided to illustrate the eight horizons in elevation and plan. Basic geotechnical properties of loess are detailed; in particular, high porosity has a negative effect on underground structures, and when moistened, loess becomes collapsible. From a technological viewpoint, loess is easily excavated. It is agreed that all improvement techniques can be practiced either to increase bearing capacity or to enhance the stability of constructions in loess formations. The seismic aspect is also discussed in the paper; available data confirms underground structures suffer less earthquake damage than constructions on the ground surface. The authors examine the construction of underground facilities in loess, specifically in the city of Rousse, by typical case histories: near surface dwellings, galleries, and temples. The possibility of near-surface radioactive repositories in loess are briefly discussed. The paper concludes with the fact that loess stratigraphy and lithology are well known, and a good data basis is available for both geotechnical and geological exploration. Years of accumulated experiences in China and the US confirm the suitability of loess for underground construction. The authors only cite Bulgarian references published in English, despite the fact many European references regarding loess soils are available.

Paper #7.53a by Dimcho Evstatiev, Mariana Nedelcheva, and Jordan Evlogiev describes the construction of a TV tower foundation in Rousse (Bulgaria) on a collapsible loess formation. Because of the high cost of piled foundation systems, the adopted solution consisted of a soil-cement cushion system on heavily tamped soil at a depth of 14.5 m. Two design challenges had to be addressed: high seismicity and loess collapsibility attributed to moistening. Because of these challenges, a 20-year monitoring system was established to record the settlement during and after the tower's construction. A geodetic network was also installed in the tower to monitor deformation. In parallel, loess layers were sampled to follow the moistening of the loess base resulting from water infiltration during different periods. The authors succinctly describe the stages of construction of the foundation system and report, in detail, the engineering-geological conditions, especially parameters of loess layers regarding the evolution of their deformability when affected by moistening. After several earthquakes that caused oscillations of the tower, its recorded behavior did not show visible damage in the structure. From the recorded settlement curves, it was concluded that the most significant settlement happened during tower construction. The settlement evolution then slowed during the monitoring period. Settlement predictions using analytical and numerical methods were compared with recorded values, and an acceptable agreement between predictions and measurements was observed. It was also concluded that acceptable settlement is expected under the heavy tamped compacted loess under the foundation. The main lesson learned from this case study is that moistening, resulting from permeating surface water and a damaged water supply and sewerage (WSS) system, made it necessary to dry and strengthen a backfill embankment with quick columns and inject cement-sand mortar in cavities formed under a concrete sidewalk around the tower and the gap in between. The authors only cite Bulgarian references in this paper.

Paper #7.54a by Fernando da Casa Martín, F. Celis D'Amico, E. Echeverria Valiente, P. Chías Navarro, and A. García Bodega is a difficult-to-read case history about the use of cement grouting to create a soil/cement mass that acted as a gravity retaining structure for a large excavation. The excavation was for the construction of an underground parking garage in an urban environment. Unfortunately, it seems that the paper was written in Spanish, then translated into English using a translation software.

Paper #7.55a by F. Di Credico, P. Signanini, and P. Torrese describes a literature search and laboratory experiments using carbon paper and photoelasticity to measure “stress intensity” from granular materials contained in silo-shaped structures. The experimental results are qualitative, and the paper seems to be geared toward an academic audience; i.e., it is unclear what practical applications the authors had in mind.

Paper #7.56a by Dong K. Chang and Hugh S. Lacy provides a very useful summary of the state of the practice in ground freezing using liquid brine. For designing and constructing a ground freezing project, the paper outlines the requirements for appropriate site investigation, unfrozen and frozen soil laboratory testing, ground freezing parameters, and system, thermal, and structural design. Potential ground expansion and thawing effects are addressed as well as monitoring and evaluating the performance of the frozen ground structure. Two unique case histories of ground freezing from the Boston Central Artery are presented.

Paper #7.58a by Sven Hansbo provides a concise review of the theory and relevant equations for the design of a system using electro-osmosis. Two case histories are covered, providing much quantitative information. Highlights of the case history are that three to four times as much electricity was consumed in the field tests as predicted from lab results, and gas evolution from certain soils can affect the effectiveness of the process. The paper is targeted toward an audience with at least a working knowledge of the topic of electro-osmosis; it provides no information on the advantages or disadvantages of this technique or when and why it should be used. In addition, the most current reference is dated 1975, suggesting that perhaps this technique has not been very commonly used. It would be interesting to have an update with more recent applications.

Paper #7.59a by M. Nunez, D. Dias, C. Poilpre, and R. Kastner presents two case studies on soft ground improvement using rigid vertical piles. Rigid pile reinforcement has been strongly developed in France during the past few years; however, comparison among several design methods showed important variations in results. Column-supported embankments have been used to allow quick embankment construction over soft soils. It has three components: (1) embankment materials, (2) a load transfer platform, and (3) vertical elements extending from the LPT to the stiff substratum. The surface and embankment loads are partially transferred to the piles by arching, which occurs in the granular material comprising the embankment. This causes homogenization and reduction of surface settlement. In this paper, two cases are presented of the use of rigid pile reinforcement to ensure stability of embankment and roads. First, the authors cite the Rampe de Glain, in Bayonne, France, consisting of a 270 m street that connects a complex to a main road. Differences between ground levels of the project and the main street were as great as 12 m; therefore, a high embankment was necessary to make the connection. To minimize the settlement and ensure stability, a group of piles (vibro-concrete columns) was constructed. Site investigation results show the first 7 m of highly compressible subsoil. General geotechnical/survey instruments were used to monitor the site. Numerical analysis was also employed using Plaxis software by simulating soils as nonlinear elasto-plastic material with a hardening soil model. Experimental data revealed that the settlements were greater than expected. The influence of several parameters acting in this reinforcement technique is still unknown. The second case study involved an urban site near the River Seine, about 35 km northwest from Paris. It consisted of the construction of two residential buildings, a new road, and a street for pedestrians. The streets were built on a fill that had an average height of 3.5 m. The site subsurface conditions consisted of alluvial deposits over plastic clays, marls, and silts. Piles 35 cm in diameter were driven using the back auger technique. An experimental stretch was monitored with various survey/geotechnical instruments. Numerical analysis using 2D and 3D FLAC models was performed to predict settlement and stresses. The embankment fills and substratum were modeled as linear-elastic perfectly plastic constitutive material with Mohr-Coulomb failure criteria. Soft soils were modeled with the modified Cam Clay model. The axisymmetrical 2D model seems sufficient to make accurate predictions of settlement and performance of the rigid inclusions soil reinforcement system. Additional discussion of numerical modeling and soil input models for such analysis would have enhanced the paper.

Paper #7.60a by Hideaki Yasuhara, Mitsu Okamura, Takamasa Moritou, and Kochi Yoshinori describes model tests that inject air into saturated sands to examine the effects air injection has on sand desaturation. Numerical analyses were performed to assess the applicability of the model as a predictive tool. If feasible, this would be another technique to be considered for the mitigation of liquefaction. However, results were somewhat mixed; predictions and measurements of saturation were in agreement, but airflow predictions were significantly lower than actual experimental measurements.

Paper #7.61a by Alp Gökalp and Rasin Düzceer describes the concept of ice protection barriers, which have been successfully used to protect artificial islands constructed for oil drilling in the Caspian Sea. Without these barriers, winter ice flows build up against the islands, potentially affecting them detrimentally. The barriers themselves are of conventional sheet pile and are of soldier pile design. The logistics of construction in a harsh environment and the description of the huge quantities of materials shipped from hundreds of kilometers away make for an interesting paper.

Paper #7.66a by M.J. Hossain, M. Alamgir, and M.A. Mahamud describes a field experimental study of manually installed rammed aggregate piers in loose/soft soils. The subsurface profile indicated the presence of about 3 m of loose silty sand underlain by 1.5 m of soft clay and 4.5 m of organic clay. Rammed aggregate piers, 0.75 m in diameter, were excavated manually; the walls of the hole were stabilized by locally made burned clay rings, a practice that seems unsafe and probably would not be used in most western countries. The piers extended to a depth of 4.15 m; i.e., just above the top of the organic clay layer. Four load tests were performed on 1.68-m square footings built at a depth of 0.75 m below grade. One test was performed on the existing soils (no piers were installed), one test was performed with one pier beneath the center of the footing, one test was performed with two piers at the mid-length of two opposing footing sides, and the last test was performed with three piers beneath the footings. Test results indicated that the bearing capacity for a 25 mm settlement increased with a greater number of piers. It is noted that the size of the footing (1.68 m) and the length of the supporting piers (3.4 m) are such that probably most of the foundation load was carried by the combined soil/pier material. Using larger footings would require a much longer pier, and it is unclear whether longer piers can be safely and effectively installed using the procedure described in the paper. Ultimately, the paper illustrates a technique of ground improvement that can be implemented at very low cost but in unsafe conditions.

Paper #7.68a by D.S.V. Prasad and G.V.R. Prasada Raju describes a low-cost approach to subbase courses for flexible pavements on expansive subgrade soils. Waste plastic strips measuring 12 mm x 6 mm x 0.5 mm were used as reinforcement for a gravel subbase course and a flyash subbase course. Field trials of the subbase course were run using cyclic plate load tests. One set of field trials employing a gravel subbase course and a waste plastic reinforced gravel subbase course demonstrated that the optimum benefit of waste plastic reinforcement was achieved by adding 0.3% to 0.4% waste plastic. Similar field trials using a flyash subbase course and a waste plastic reinforced flyash subbase course yielded results that showed less improvement than the waste plastic reinforced gravel subbase. The paper illustrates a pavement improvement technique that can be implemented at low cost using what is usually considered waste materials (plastic and flyash).

Paper #7.69a by Ken Ivanetich and Lisheng Shao describes using jet grout columns and constructing a 1.8 m thick engineered fill pad to improve the subsurface conditions for support of a gravel storage building and distribution facility. The paper includes a good description of the subsurface conditions that included 1.5 m to 3 m of uncontrolled fill consisting mostly of clay with sand and lenses of silt underlain by soft clays to depths of about 10 m. Jet grout columns were selected as a cost-effective alternative to piles to minimize settlements in the soft clay layer. A field trial program was conducted to verify jet grout column diameters and strength prior to production installation. The paper concludes that the engineered fill pad and jet grout columns perform very well and meet design criteria. However, no settlement monitoring results are presented to substantiate these conclusions.

Paper #7.01b by Sanjay Das and Indra Prakash describes groundwater hazards in a coastal district of Gujarat, India. The authors believe that these hazards are caused mostly by the inherent salinity of rocks, sea water ingress, and chemical pollution. An increase in sea water ingress has been observed for as far as 7.5 km distance landward within the past 20 years. High values of lead, nickel, nitrate, and sulfate have been observed in and around industrial areas. Higher values of lead and nickel were observed in the area occupied by picrite basalt. Higher concentrations of sulfate and nitrate were noted along the boundary of brackish and fresh water.

Paper #7.03b by R. Jeffrey Dunn describes lessons learned from the successful closure of three major sanitary and hazardous waste landfill sites. The first site described contained four adjacent hazardous waste landfills containing pesticides/solvents (P/S), heavy metals/sludges, caustics/cyanides, and acids. Initial analyses using published information to characterize engineering properties of the hazardous waste materials were rejected by the regulators. After performing field and laboratory investigations and analyses mandated by the regulators, a cover design was adopted for the P/S landfill. Construction of this cover proved difficult and slow, and cover design changes were introduced for the remaining landfills. These design changes required additional regulatory reviews and approvals, with associated schedule impacts. The second site contained a municipal landfill that was eventually classified as a hazardous waste landfill because of groundwater contamination, primarily by volatile organics, and migration of landfill gas to surrounding areas. One issue was the awkward design review and approval submittal schedule that result in a 3-year cycle to reach an acceptable design. Another issue involved using dried stabilized sewage sludge (biosolids). Field testing of biosolids indicated compaction characteristics quite different from what was expected based on laboratory test results. The third site contained a municipal landfill. The main issue was related to the fact that the firm that designed the cover was not hired to provide services during construction. This resulted in construction documents being narrowly interpreted because the original designer was not available to consider suggested field request changes. This, in turn, resulted in unnecessary additional costs.

Paper #7.09b by B.N. Moolchandani describes a case study of environmental improvement through recharge of surface water. The scheme described in the paper consists of collecting surface runoff from rainfall and channeling this runoff into recharge wells. Prior to recharging, the runoff water is filtered to remove sand and silt through a silting chamber. After filtration, the water is then recharged into an aquifer layer located at a depth of 50 m below grade. Besides filtration, there are no descriptions of the other measures taken, such as testing and further processing, to ensure that the runoff water being recharged is not contaminated. However, the paper discusses the results of testing aquifer samples to determine that levels of fluoride, nitrate, and total dissolved solids meet acceptable standards.

Paper #7.10b by Derrick A. Shelton, David A. Schoenwolf, and Nisha P. Mohanan describes an excellent case history of urban land development in an area consisting of three closed landfills. Landfill materials included construction debris, municipal solid waste (MSW), flyash, and white goods. Landfill thickness ranged from about 20 m to 60 m in the development area and posed significant challenges for site grading and foundation construction. An extensive field and laboratory investigation was performed to assess subsurface conditions and establish strength and compressibility properties for natural soils and rock, as well as for landfill materials. Site grading included cuts and fills; some of the cuts reached the MSW. Regulations required that these materials be reused on site. To achieve the desired grade in fill areas, vegetated reinforced steep slopes (VRSS) were used throughout the site. These structures were supported by different materials, including MSW. Ground improvement, which included excavation and replacement of materials, deep dynamic compaction, and heavy rolling, helped stabilize the VRSS structures. Special attention was given to protecting underground utilities and installing a landfill gas control system. Field instrumentation of the VRSS structures includes settlement plates, horizontal inclinometers, and vertical inclinometers. Settlement of one of the VRSS structures underlain by about 60 m of MSW has reached more than 1.6 m. Onsite construction is still under way, and additional monitoring is planned. Hopefully the authors will have additional data to present at a future ICCHGE.

FINAL REMARKS AND TOPICS FOR DISCUSSION

The papers presented in this session cover a wide range of important topics in the application of ground improvement techniques to geotechnical design, construction, and monitoring. They illustrate many successful practical applications of these techniques and reflect advances that have been made in these areas. Some applications originating in less developed countries, where resources are sometimes severely limited, offer excellent insight into the creative power of engineers to develop homegrown solutions. Several papers described initial/incomplete stages of ongoing case histories that will result in very useful data, which should then be disseminated. Space constraints most likely resulted in useful information being omitted from some case histories.

The purpose of the discussion topics that follow is to establish a communication venue between the authors and the delegates of this Conference to foster what we expect to be a lively and vigorous dialogue. However, any topic relevant to Sessions 7a and 7b not listed below should also be discussed.

SUGGESTED LIST OF SESSION 7a DISCUSSION TOPICS

1) Analytical procedures (closed form and numerical) for bearing capacity and settlement estimates
2) Advances in installation monitoring technology
3) Construction specifications
4) The role of geotechnical engineers and specialty contractors
5) Adaptation of existing technologies to local labor conditions and equipment availability
6) Emerging technologies
7) Field performance monitoring (what to monitor, etc.)
8) Presentation of field monitoring obtained after paper preparation
9) Presentation of information not included in the paper owing to space limitation

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