Technical Session 4a: Ground Improvement/Grouting/Dredging
Séances techniques 4A: Amélioration des sols/ Injections / Remblaiement hydraulique

Buddhima Indraratna

Professor and Head, School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong City, NSW 2522, Australia.
Email: indra@uow.edu.au

1 INTRODUCTION

Due to the rapid increase in population, industrial and construction boom especially in the urban as well as coastal regions of many countries have considerably intensified the inevitable need for infrastructure development on problematic soils including soft compressible clays, deposits with low bearing capacities, soils prone to erosion and collapse upon wetting, highly fractured and jointed rock mass among other geological deposits. Good quality geologic materials for construction are also becoming scarce, exacerbated by numerous environmental constraints in various countries. Due to these reasons and environmental restrictions on certain public works, ground improvement has now become an integrated and essential component of infrastructure development. Consequently, civil engineers are forced to utilize even the softest and weakest of natural deposits for foundations, and therefore, the application of ground improvement techniques including preloading and consolidation, static and dynamic compaction, grouting and chemical treatment, subsurface drainage and dewatering, vacuum consolidation, among other methods have now become common practice in heavy construction.

As summarized at the end of this Report (Annexe-Table3), there are 64 papers formally allocated to this Technical Session 4A, composed of 187 authors and co-authors from more than 32 countries. The papers can be grouped in to the following key sub-themes:

(a) Soft Clay Consolidation with vertical drains with or without vacuum preloading
(b) Sand and gravel piles, stone columns and rigid inclusions
(c) Geosynthetics reinforcement
(d) Compaction (static and dynamic) and Vibroflotation
(e) Grouting and Chemical stabilization
(f) Other methods including: Electro-kinetic, Electro-osmotic, Thermal, Root-Osmosis and Explosion-Based techniques.

This General Report has attempted to offer a review of the majority of papers that have made significant contributions. However, due to the imposed brevity of the report, not all papers could be reviewed and commented upon in detail. Nevertheless, brief comments on all papers have been provided as warranted to provide a balanced overview of the entire Technical Session. Bulk of the papers elucidates already established technologies, but providing greater insight to the processes supplemented with well compiled field and laboratory data. While a few papers have drawn on modified theoretical concepts (e.g. Basu et al.; Indraratna et al.), most papers have presented field studies including comparisons between predictions and observations, as warranted.

The following part of the Report describes the contributions to this session in relation to the relevant ground improvement categories.

2 SOFT CLAY CONSOLIDATION WITH VERTICAL DRAINS (WITH OR WITHOUT VACUUM PRELOADING)

There are 7 articles in this section of which vacuum consolidation is discussed by Liausu and Scache; Kim et al.; Karunawardena and Nithiwana; and Indraratna et al. This category of papers describes the consolidation process with time with very useful information on the field data, laboratory testing, analytical formulations and numerical modeling, with some reference to comparison of observed data with consolidation predictions.

Liausu and Scache describe the field study of Kwang Yang Port reclamation works in South Korea, with considerable volumes of dredged fill (up to 10m high) placed over relatively thick soft marine clay up to 15m deep below the original ground surface. The paper presents the role of secondary consolidation and extensive site monitoring. The settlement prediction is based on the Asaoka (1978) method, and the pore water pressure dissipation and settlement plots give reasonable agreement with what one expects from the consolidation theory.

Kim et al. describes what they introduce as the "Suction Drain Method", which is still effectively a slightly modified version of vacuum pressure application via the prefabricated vertical drains. The main difference is the absence of any surcharge fills in the suction drain method (Fig.1), which is most useful in mitigating lateral displacements that are inevitable under surcharge fill embankments. Also, this technique adopted both platy and circular drain shapes in two different sections of the site. In the absence of total stress (surface surcharge fill), the suction drain method optimizes the effective stress increase directly through maximum suction effect, and is recommended as a better approach for curtailing shear failure, differential settlement and lateral yield. Finite element analysis provides an acceptable comparison between the field observations and calculated values at various soil depths.

Burgos et al. describe the improvement of dredged mud in the Port of Valencia (Spain), by combining radial drainage (15m deep vertical drains) with a soil-cement surface crust for added base stiffness supporting almost 10m of high surcharge fill as preload. It is shown that more than one year is taken for the mud to consolidate to a good degree of consolidation (@ 95%) and to obtain an acceptable increase in shear strength approaching or exceeding the design value as shown in Fig. 2. It seems that compared to the sites where vacuum preloading can

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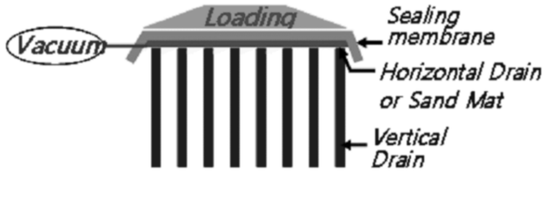
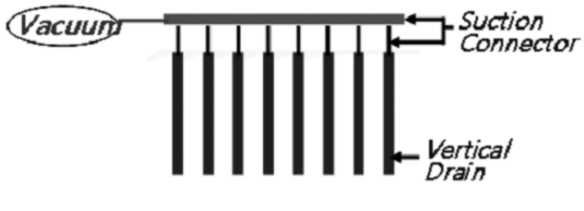
significantly cut down on the height of surcharge fill and consolidation period (e.g. Indraratna et al. 2005), this approach may not be the most effective if the challenge is to reduce lateral movements that are unfortunately not given by the Authors.



(a) vacuum consolidation method



(b) suction vertlcal drain method

Figure 1. Comparison between vacuum consolidation method and suction vertical drain method (Source: Fig.1, Kim et al., 2009)

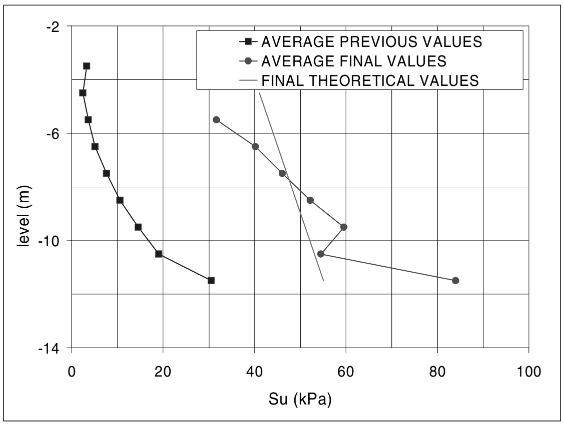


Figure 2. Undrained shear strength of the mud (Source: Fig. 7, Burgos, 2009)

Karunawardena and Nithiwana present a trial embankment stabilized by vertical drains and vacuum consolidation on a very soft and compressible peaty soil in Sri Lanka. A most comprehensive instrument layout has been implemented as shown in Fig. 3. The embankment was constructed multi-stage and raised to a maximum height of 11m to achieve a very high degree of consolidation with primary consolidation fully completed after one year of loading. The settlement and pore pressure plots are shown in Fig 4. which clearly shows that the settlements gradually occur even at retarded excess pore water pressure dissipation, and it is interesting to note that a considerable decrease in pore pressure is plotted between 230 and 300 days (relatively small increase of suction noted), but no significant increase in settlement is observed given the increase of effective stress by at least 25 kPa. Noting the very high embankment fill height almost reaching 12m (at 230 days), the small value of vacuum pressure (not more than -20 kPa at most times) seems to be sufficient for this project. Irrespective of cost implications, an increased vacuum pressure up to say -50 kPa could have substantially decreased the required surcharge fill height as well as giving a better control of lateral movements (not plotted in the paper).

Basu et al. discusses an analytical solution for radial consolidation capturing soil disturbance, for a series of different hydraulic profile. They have also introduced a transition zone between the smear zone and the undisturbed zone to make these hydraulic conductivity distributions smoother and more realistic, and follow some improvement of the original hydraulic conductivity profiles of the smear zone proposed by Indraratna and Redana (1998).

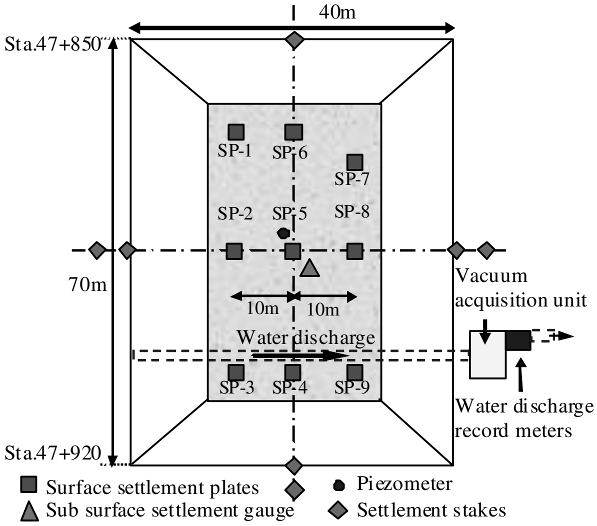


Figure 3. Plan of the embankment and instrumentation layout (Source: Fig. 1, Karunawardena and Nithiwana, 2009)

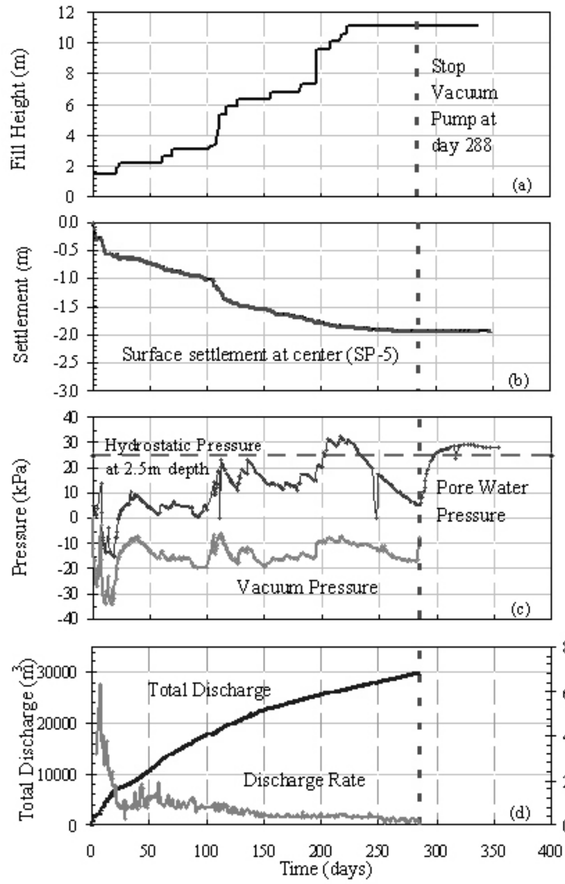


Figure 4. Loading curve and monitoring data during construction period (Source: Fig. 1, Karunawardena and Nithiwana, 2009)

Smith and Rollins investigated the effect of soil disturbance or smear effects using six test areas with a range of PVD spacing varying from 0.9m to 2m. As expected the rate of consolidation increased as the spacing decreased, but when the spacing was reduced below a critical value, the soil disturbance caused was significant that the associated increase in consolidation was marginal. They have proposed on the basis of good field data, that the consolidation effectiveness will be insignificant if the drain spacing to effective mandrel diameter is decreased to a value less than 8. The relationship between T95 and drain spacing is shown in Fig. 5.

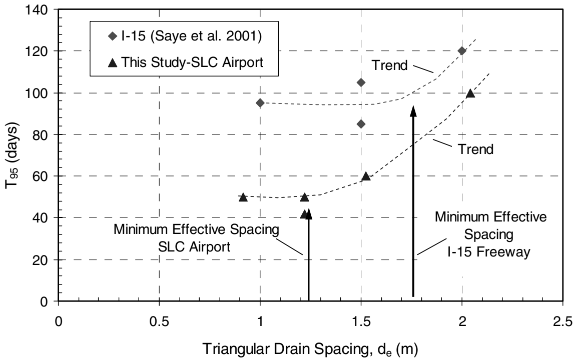


Figure 5. Variation of t95 with PV drain spacing for this study and previous study for I-15 in Salt Lake Valley, Utah (Source, Fig.4, Smith and Rollins adopted from Saye et al. 2001).

Indraratna et al. analyse case histories from China and Australia employing combined PVD and vacuum preloading schemes. The theory of equivalent 2D consolidation gives almost the same settlement-time curves as the true 3-D analysis as shown in Fig. 6. It is also shown that a relative high vacuum pressure of up to -70 kPa can significantly decrease the required fill height for achieving a desirable degree of consolidation exceeding 95%. They also show that for these normally consolidated soft clays, the modified Cam-clay parameters are sufficient to predict with acceptable accuracy, the settlements, pore pressures and lateral displacements. In addition, Chai et al. (2009) shows that the drainage condition also influences the vacuum system applied to the multi-layer soil.

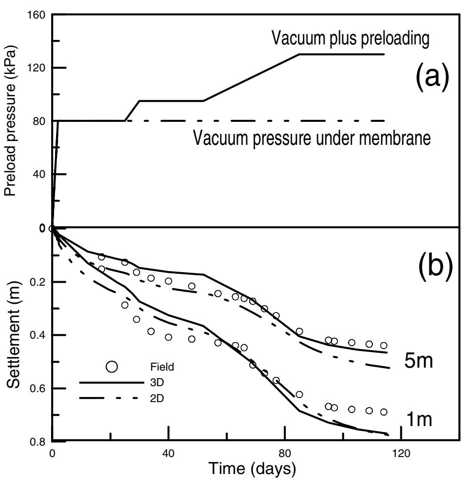


Figure 6. (a) Loading history and (b) Consolidation settlements (Source Fig. 9, Indraratna et al. **, 2009**)

3 SAND AND GRAVEL PILES, STONE COLUMNS AND RIGID INCLUSIONS

A total of 14 articles are categorized in the area of sand piles/stone column and other rigid inclusions. There are 4 papers investigating the behavior of stone columns (Murugesan & Rajapagal; Wegner et al.; Castro & Sagseta; Foray et al.). The performance and numerical modeling of sand compaction piles (SCP) to improve the soft ground under static conditions are well covered in a number of papers (Kurka and Zavoral; Ranjan et al.; Takahashi et al.; Kasper et al.), while Hatanaka & Masuda used SCP to control liquefaction, plus a couple of contributions address the use of deep mixing columns (Ameratunga et al.; Ishikura et al.). Green et al. present the advantages of auger piles based on field observations. Chirica et al. have employed a physical model to simulate micropiles, while numerical modeling of rigid inclusions complements this technique (Martin & Olgun).

Murugesan & Rajapagal conducted load tests on a single geosynthetics encased stone column (Fig. 7). They found that the geosynthetics encased stone columns become stiffer when the diameter of the stone columns increases, and then the spacing of the stone columns can be increased. Wagner et al. installed the stone columns to improve the soft clay foundation under an ore storage yard. During design, a numerical analysis was executed to simulate time-dependent shear strength for the optimization of stone column spacing (Fig. 8). Subsequently, the design concept was confirmed by the execution of an in-situ test combined with a comprehensive instrumentation program. It was observed that the measured settlements decrease after 4 months. Castro & Sagseta employed the same technique to reduce settlement and increase stability of a 10m high embankment on a marshy area. A 3D numerical analysis for stone columns presented by Foray et al. show that the lateral expansion of the columns can influence the ratio between the modulus of column and soil (Fig. 9). Shahu et al. (2000) also showed that granular mat can reduce the stress concentration factor on top of the granular pile by the same percentage of relative stiffness.

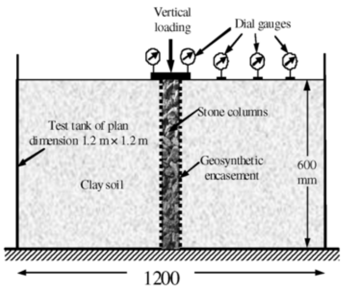


Figure 7. Schematic of Load test on single stone column (Source: Fig.1, Murugesan and Rajapagal, 2009)

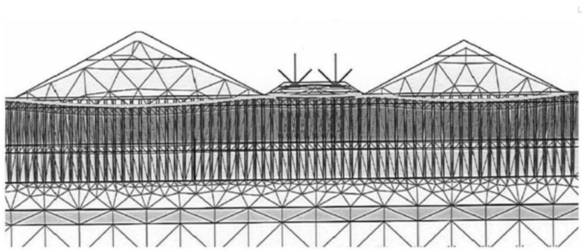


Figure 8. Deformation prediction at runway corridor by FE-analysis. (Source: Fig. 6, Wagner et al., 2009)

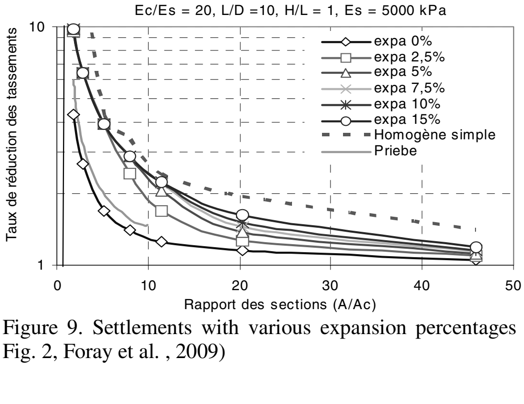


Figure 9. Settlements with various expansion percentages (Source: Fig. 2, Foray et al. , 2009)

Kurka & Zavoral present a comprehensive analytical method to calculate stresses and strains in compressible ground improved by a group of vibrated or rammed gravel-sand columns, while Takahashi et al. employed a centrifuge model to investigate the deformation and failure patterns of the foundation improved by sand compaction piles (SCP) (Fig. 10). They conclude that the displacement of the improved ground increased nonlinearly with an increased backfill loading. To verify the performance of granular piles installed under an oil storage tank, Ranjan et al. conducted the in-situ load tests to assess the load bearing capacity of a granular pile group. They observe that the ratio of settlement between soil and piles is not in the same ratio as the increase in the pile cap size. Indraratna et al. (1997) showed that the benefits of installing sand compaction piles, geogrids and vertical pre-fabricated drains are obvious in controlling lateral displacement and increasing embankment stability.

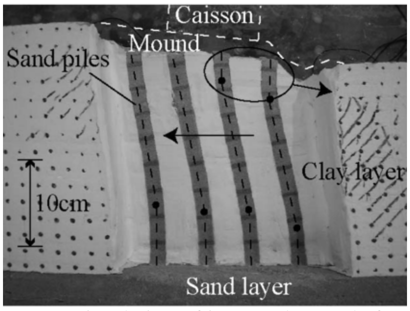


Figure 10. Cross-sectional view of improved ground after loading test (Source Fig. 4, Takahashi et al, 2009.)

Kasper et al. combined cement deep mixing and sand compaction piles to minimize the settlement of a marine clay. The usefulness of the SCP is elucidated to accelerate excess pore pressure dissipation thereby achieving quick strength gain of the marine clay, whereas the cement deep mixing method was used to increase the stiffness of the foundation in the short term. To study the effect of degree of saturation on liquefaction strength of SCP, Hatanaka & Masuda conducted cyclic triaxial testing. They show that injected air into SCP is an effective method to increase the liquefaction strength (Fig. 11).

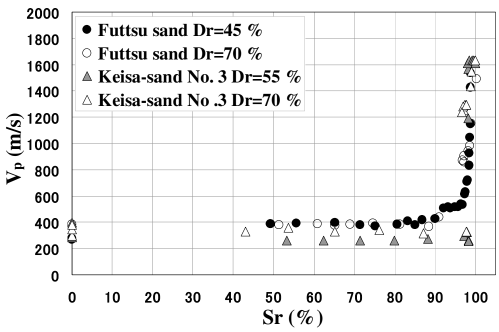


Figure 11. Effect of relative density on the Sr–Vp relationship (Source, Fig.7, Hatanaka and Masuda, 2009)

Ameratunga et al. present a case study of deep soil mixing using the Cutter Soil Mixing technique under a storage tank (Fig. 12). They designed the pile cap to facilitate the load distribution and limit the differential settlements across the foundation. Ishikura et al. based on the deep mixing column, studied the concept of homogenized composite ground to predict the settlement accurately (Fig. 13). Green et al. proposed a range of integrated quality control of auger piles to eliminate uncertainty regarding the stress transfer between the pile base and bedrock. A number of 100mm diameter steel tubes were placed in a circular arrangement into the augered hole along with the steel reinforcing to check for voids or anomalies in the concrete. Van Impe et al. (2006) investigated the behaviour of a cement-stabilised dredged material in the laboratory and field testing.

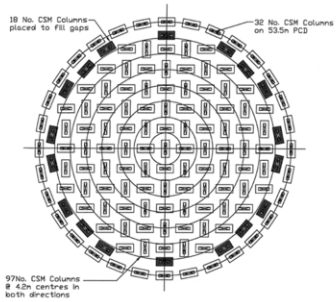


Figure 12. Layout of CSM columns (Source Fig. 1, Ameratunga et al., 2009)

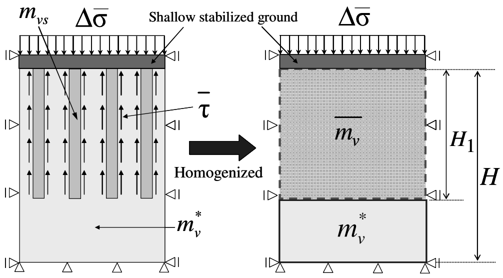


Figure 13. Concept of the homogenized composite ground (Source, Fig.3, Ishikura et al. , 2009)

To study the drainage condition and strength of micropiles, Chirica et al. employed a scaled physical model in the laboratory to study the performance of micropiles (Fig. 14). The test results imply that the micropiles can induce radial consolidation, and also reduce total settlement by increased diameter. Martin & Olgun employed a 3-D dynamic FEM to investigate a possible reduction in seismic ground motions in various ground improvement techniques including stone columns, jet grouting, and soil mixing. Their results show that stiff ground reinforcements arranged in lattice-type soil-mix panels may significantly reduce ground movements.

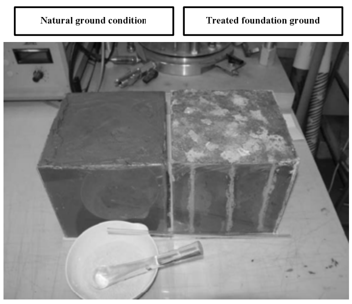


Figure 14. Layout of scale model – natural and treated soil (Source, Fig.7, Chirica et al. , 2009)

Table 1. Effect of ground improvement on normalized deformation factors (adopted from Indraratna et al. 1997)

Ground improvement scheme	α	β_1	β_2
Sand compaction piles for pile/soil stiffness ratio 5 (h = 9.8 m, including 1 m sand layer	0.18	0.02	0.09
Geogrids + vertical band drains in square pattern at 2.0 m spacing (h=8.7 m)	0.14	0.02	0.14
Vertical band drains in triangular pattern at 1.3 m spacing (h = 4.75 m)	0.12	0.03	0.27
Embankment rapidly constructed to failure on untreated foundation (h=5.5m)	0.63	0.10	0.16

α = ratio of maximum lateral displacement at the toe to the maximum settlement at centre line

β_1 = ratio of maximum lateral displacement to the corresponding height

β_2 = ratio of maximum settlement to the corresponding height

4 GEOSYNTHETICS REINFORCEMENT

There are 6 articles in this section. The majority of papers discuss general issues of geosynthetic reinforcement (Heerten et al.; Alexiew et al.; Okamoto et al. and Yang et al.), while one article examines the elastic modulus of granular soil-geogrid composite (Atalar et al.) and another draws on the African experience of mechanically stabilized earth (Smith & Dison). Overall a good number of well monitored case histories are covered, and a few studies also refer to large scale plate loading tests.

Heerten et al. present an overview of the current state-of-the-art using geogrid/non-woven composite materials to increase the bearing capacity of the base course at ports in Turkey, and in the Sultanate of Oman. At the Mersin port of Turkey, a rehabilitation work was taken up due to large rut depths formed at the pavement surface under large traffic volumes. A Combigrid® geocomposite made of a non-woven needle-punched geotextile and a high modulus laid and welded geogrid have been installed on the soft subgrade (Fig. 15). At Oman Polypropylene LLC plant in Sultanate of Oman, the geo-composite reinforcement has been installed to improve the bearing capacity of the weak subgrade (very loose sand and organic silt). These field experiences highlight that the use of geocomposite reinforcement requires less installation time, improves load distribution capacity and decreases the base course thickness. It also reduces the transport costs and the consequential environmental impact.

Figure 15. Installation of composite base course reinforcement (Source: Fig. 7, Heerten et al.)

Alexiew et al. discuss the improvement of soft subgrade soil (15 to 20 m thick saturated soft clay layer underlain by sands and rock.) using geotextile encased columns (GEC) and horizontal geosynthetic reinforcement. The project site is a steel plant inclusive of a stockyard for coal/coke at the Brazilian seashore near Sepetiba. Authors state that the main objective of GEC as building a vertical pile-similar element composed of compacted sand and a confining high-strength high-modular geotextile encasement. The high-strength horizontal geosynthetic reinforcement is reported to increase the overall stability of the system and to reduce the lateral pressures and horizontal displacements of the runways. Authors have described the important design concepts of GEC technique and a typical solution is presented in Fig. 16.

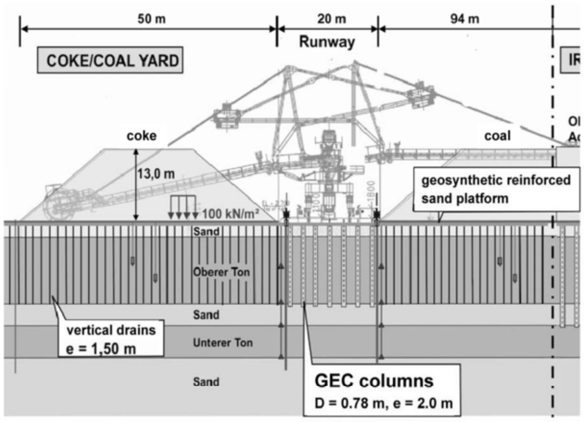


Figure 16. Typical solution in the coal/coke stockpile area. (Source: Fig. 5, Alexiew et al.)

Okamoto et al. present a new subgrade stabilization technique using the lattice-frame-reinforced (LFR) sheet, which consists of a textile sheet and mortar-injected fabric hoses (Fig. 17). A series of plate loading tests have been carried out on soft subgrade (1m thick clayey sand underlain by a 2.35m thick stiff layer) to examine the performance of this technique. A significant increase was observed in the coefficient of vertical subgrade reaction K_{30} of base course, and a typical arrangement of test points for plate load tests is shown in Fig. 18. Authors report on a few temporary road works where this technique has been successfully implemented.

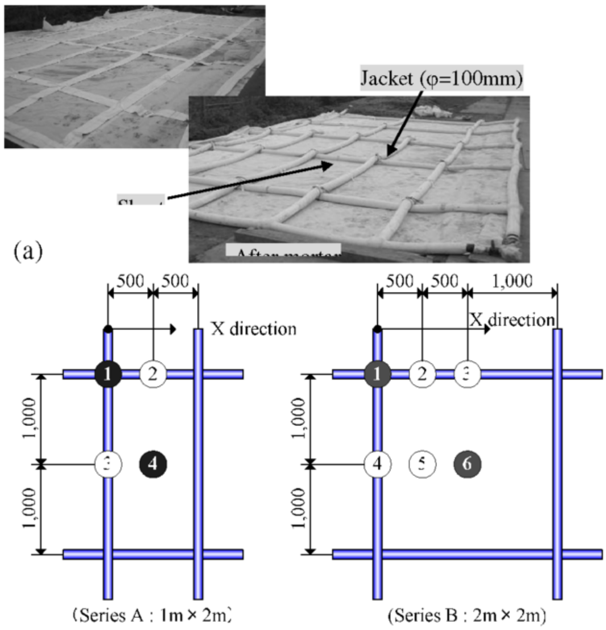


Figure 17 (a) Structuring of lattice frame by mortar injection (b) Integrated arrangement of test points (Unit: mm) (Source: Fig. 5, Okamoto et al.)

Atalar et al. describes the evaluation of modulus of elasticity of the granular soil-geogrid composite at the site of the Incheon International Airport, South Korea. They report the results of four cyclic plate load tests on a granular soil pad both with and without geogrid reinforcement layers. Details of field load tests are shown in Fig. 19. A summary of test results (Table 2) highlights that geogrid reinforcement increases the overall stiffness and therefore, the modulus of soil elasticity.

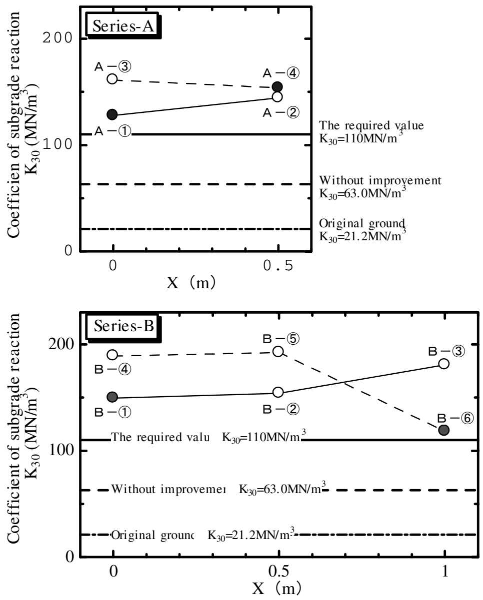


Figure 18. Effect of offset distance on K30 (Source: Fig. 6, Okamoto et al.)

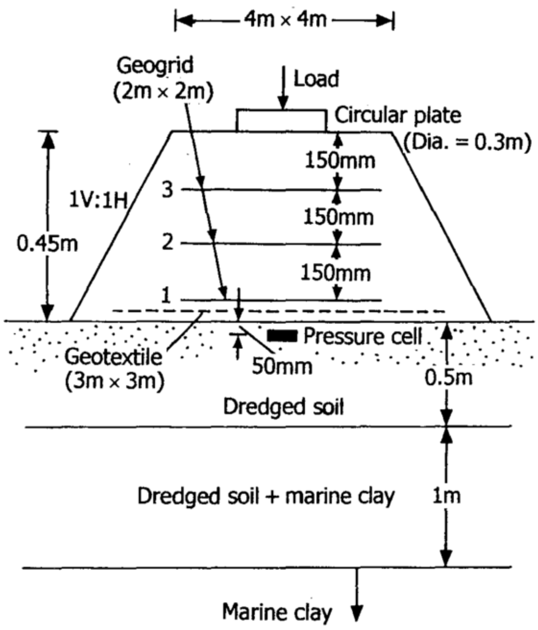


Figure 19. A comparison of measured and calculated settlement (Source, Fig.4, Atalar et al.).

Yang et al. report the results of large scale plate loading tests conducted to investigate the load bearing capacity of very soft ground reinforced with bamboo net. They showed that the bearing capacity ratio (BCR) of the bamboo net is more than that of geosynthetics by a factor of about 1.5 (Fig 20). It is suggested that further studies should be conducted to check the economical and practical feasibility of using bamboo net as reinforcing material.

Table 2. Summary of test results with geogrid reinforcement ($\mu_s = 0.3$) (Table 3, Atalar et al.)

Test No.	C_z (kN/m^2)	E_{sg} (kN/m^2)	E_{sg}/E_s
2	33.1×10^4	70,830	1.094
3	39.1×10^4	83,670	1.292
4	46.7×10^4	99,940	1.543

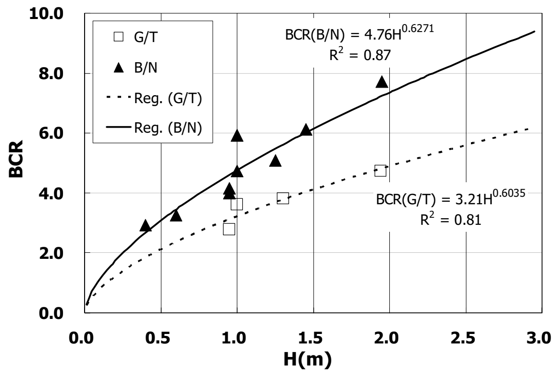


Figure 20. BCR with reinforcement materials. (Source Fig. 2, Yang et al.)

Smith and Dison review various case studies in South Africa where mechanically stabilized earth (MSE) structures are used. They report that the backfill is usually the costliest component of MSE structures and usually encounters problems, this necessitating careful selection of the backfill. They discuss the possibility of formulating a revised range of specifications of backfill for MSE structures.

5 COMPACTION (STATIC AND DYNAMIC) AND VIBROFLOTATION

There are 8 articles in this section of which the majority of the articles discuss the techniques of dynamic compaction (Adam and Brandl; Avalle et al.; Varaksin and Racinais; Wittke et al.; Pooley et al.), on article on the quality control of compaction for optimizing water storage (Mavlyanov and Abdullaev) and a couple of papers address some salient aspects of vibro-compaction of granular soils (Arnold and Herle; Ouni et al.). Useful practical information on the interpretation of field data plus effective site applications are presented and discussed, while the assessment of compaction efficiency based on centrifuge tests (Pooley et al.) and the numerical modeling of vibrocompaction using hypo-plasticity (Arnorld and Herle) add further variety to the contributions included in this category.

Adam and Brandl provide a general overview of the compaction technologies and detailed account of the soil properties and their integrated measurement before and after ground improvement, with special reference to dynamic rollers and heavy tamping including rapid impact compaction. A practical approach to derive two key soil parameters for any given soil subjected to compaction, namely, Young's modulus and Poisson's ratio is described in Fig. 21. The effective control of seepage by quality assurance of compaction processes in a dam site for gravelley and loamy soils (filling and rolling). Use of field densitometer and seismic wave profiling has been effective to ensure sufficient densification upstream of the dam and beneath the upstream shell and central core.

Based on the research conducted on a test site of estuarine deposits in South Australia, Avalle et al. describe the dynamic compaction achieved by square impact rollers of mass 8 and 12 tonnes, with detailed determination of the imparted impact energy and the measurement of associated surface and sub-surface soil compression. Figure 22 shows the impact rolling in process. The measurements are effected by a transmitter and accelerometer devices attached to the impact module, and the embedded load cell in the ground in the centerline of the path of the impact module.

Varaksin and Racinais look at dynamic compaction applied to a large shipyard elucidating the need for optimizing soil parameters such as bearing capacity in terms of cone penetration resistance. A salient finding is the ability to define the depth of influence as a function of the unit impact energy as well as total impact energy, and useful practical equations are derived for this purpose.

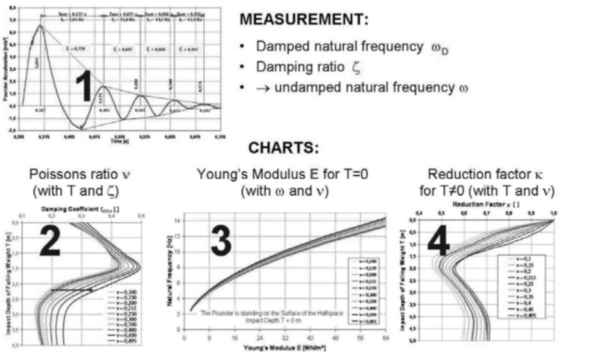
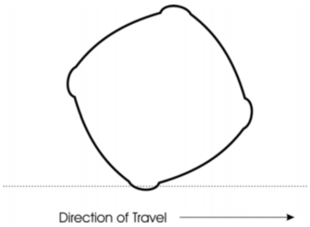
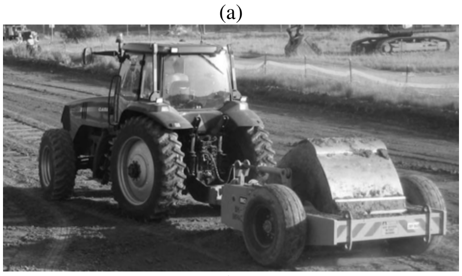


Figure 21. Practical approach to derive unambiguously two soil parameters (E-modulus and Poisson's ratio ν) from two vibration parameters (frequency and damping coefficient) within 4 steps. (Source: Fig.6, Adam and Brandl, 2009)



(a)



(b)

Figure 22 (a) Cross-section of the "square" impact module.(b) Impact rolling in progress.(Source: Figs. 1&2, Avalle et al, 2009)

An interesting exercise using dynamic compaction with falling weights combined with geosynthetic reinforcement for the construction of a highway above abandoned lignite mines in Eastern Germany is described by W. Wittke and M. Wittke. As the mines are not appropriately backfilled, it was imperative to prevent the instability due to the occurrence of sinkholes or sudden collapse during highway operation. The design concept involved the initial dynamic compaction to demolish any near-surface cavities and then reduce the risk of subsequent collapse by the use of geosynthetics (Fig 23). An elegant 3D FEM numerical model could be used to predict the displacements and the tension generated in the geosynthetic placed above to a simulated cavity (Fig. 24).

An elegant laboratory centrifuge study was conducted by Pooley et al. on a clay landfill that is highly inhomogeneous. These clay lumps are double porosity by definition due to the inter-particle voids within the over-consolidated single clay lumps, and the intra-particle voids between the lumps. Scale down clay lumps (from 50cm to 10mm) were used in the drum centrifuge and dynamic compaction was carried out in flight to model the stress in the soil, using a previously developed compaction tool (Chikatamarla et al., 2006). The pore pressure response due to impact is well monitored (Fig 25) over the impact area (Fig. 26). In general, the test results provided a good correlation between compaction energy and the associated soil stiffness, hence the net soil pressure-displacement relationships. However, a limitation of the study could be the actual transfer of the energy levels to the field, given the different boundary conditions of the centrifuge.

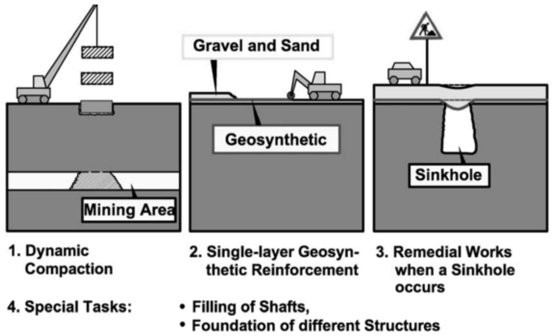


Figure 23. Plan of the embankment and instrumentation layout (Source: Fig. 2, Wittke &Wittke, 2009)

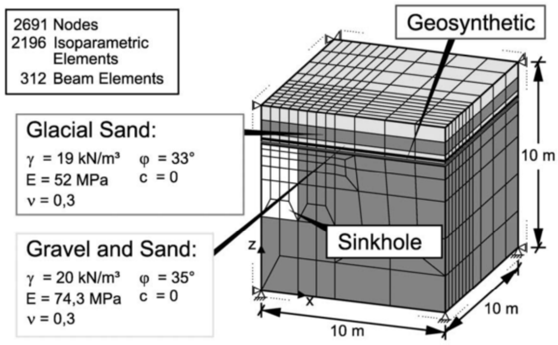


Figure 24. 3D-FE-Mesh (Source: Fig. 5, Wittke & Wittke, 2009)

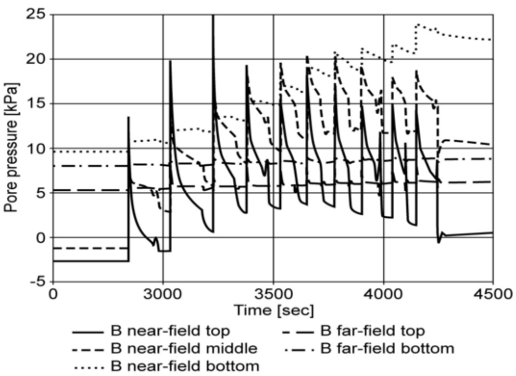


Figure 25. Pore pressure variations during 10 impact events for 3.2_dtv model B, with nominal 2.7 kJ impact energy (Source, Fig.7, Pooley et al., 2009).

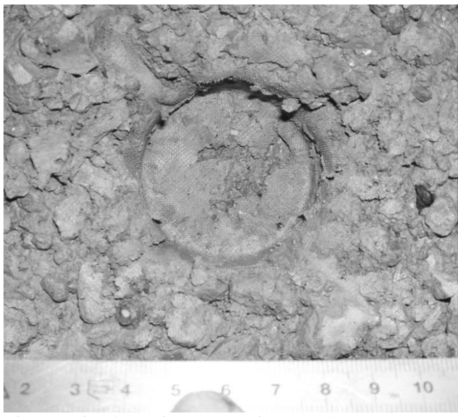
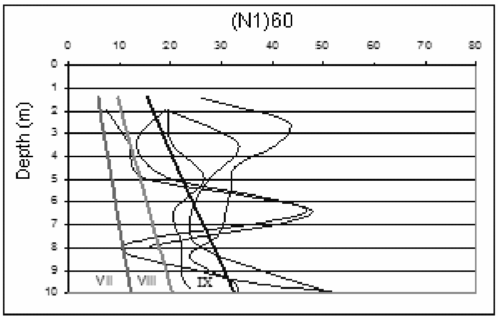
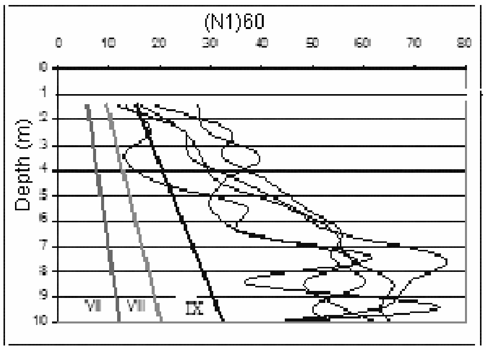


Figure 26. Close view on the impacted area (Source Fig. 6, Pooley et al., 2009)

Two papers address sandy soil improvement by vibroflotation. Ouni et al. describe the application of this technique for improving the liquefaction potential of Tunisian sand, with both SPT and CPT results before and after densification for an earth dam foundation (Sidi El Barrak) mainly consisting of alluvial sands and dunes. The improved soils are found to minimize potential damage from earthquakes at 0.15-0.20g. Typical improved SPT values are shown in Fig. 27. Arnold and Herle provide an impressive Finite Element dynamic analysis using a 3D disk-shaped model (15m radius and 0.5m height), employing a hypo-plastic constitutive model (Niemunis and Herle, 1997), characterized by loose sands (e.g. e_o @ 0.85). The model is able to reproduce a correct degradation history of the strain dependent shear stiffness with increasing number of cycles. The decrease in void ratio or cyclic densification of the sand along the radial distance from the axis of vibroflotation is shown in Fig. 28.. The Authors further imply that their model can capture the improved model of secant shear modulus and shear strain relationship suggested by Hardin and Kalinski (2005).



(a)



(b)

Figure 27. (a) Pre treatment corrected Ñ values in zone D2. Post treatment corrected SPT values in zone D2 ((Source, Figs. 5&6, Ouni et al., 2009).

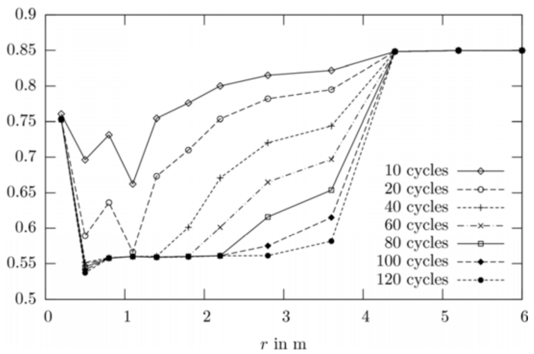


Figure 28. Evolution of void ratio along radial distance from the vibrator (Source Fig. 6, Arnold and Herle, 2009)

6 GROUTING & CHEMICAL STABILIZATION

There are 27 papers allocated to this session representing 15 countries. These articles are mostly related to ground improvement using Jet grouting, chemical stabilization, deep mixing and bi-mediated soils. Almost half of the contributions are in the Jet grouting area (Dupla et al; Kouby et al; Stelte & Pablick; Pinto et al; Mulabdic and Minazek; Christodoulou et al; Farcus et al; Chang et al; Correia et al; Arroyo and Gens; Ali & Woods; Karim et al). While the remaining papers are predominantly in chemical stabilization and deep mixing,(Marzano et al;Lee & Hwang; Fratalocchi et al; Lemanza and Lesmana; Kitazume & Takahashi; Kasama & Zen; Passalacqua; Borgne et al; Leivo and Ravaska; Chittoori et al; Davoudi et al), and four articles (De Jong et al.; Van Paassen et al; Den Hamer et al; Molendijk) addresses the bio- mediated method. Most of the papers in jet grouting are based on case studies, while a couple of papers detail the basic behaviour of grout under different initial conditions based on laboratory work and numerical simulations. Farcus et al. presents a spatial physical-mathematical model to describe the injection fluid progression in unsaturated non-cohesive ground, particularly for the permeation grouting. It gives a detailed view on the relation between injection pressure, injection debit and periphery advance fluid velocity for one dimensional, axi-symmetric and spatial symmetric penetration. The model results have been validated with laboratory data. Chang et al. highlighted that major uncertainties in grouting appears to be the actual mechanism of injection and the performance of grouted ground. In the above context, authors have made an attempt to study the injection mechanism, through an in-situ grouting program and subsequent excavation. Various types of grout have been introduced into different soil layers with controlled injection pressure and volume. Based on the preliminary experimental results authors have concluded that hydro-fracturing would be more significant in clayey soils when injected with suspension grouts. For solution grouts in sandy layers, permeation mechanism is predominant Fig. 29. Muabdic & Minazek and Pinto et al. presented the design and execution of the criteria for jet grouting in relation to case studies. Fig. 30 presents a typical plot showing the efficiency of the foundation remediation using Jet grouting (Muabdic & Minazek).

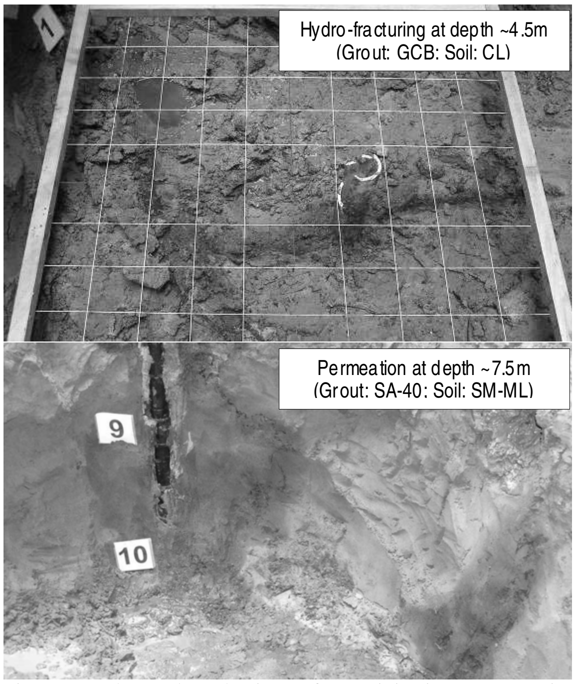


Figure 29. Observed mechanisms of grout injection (Source: Fig. 3, Chang et al. , 2009)

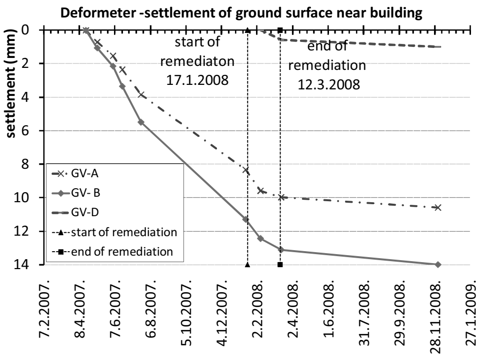


Figure 30 (Deformeter measured settlements of ground surface close to building (Source: Figs. 10, Muabdic & Minazek, 2009)

Deep mixing method was developed in Japan and Scandinavian countries in early 1970's. Since then a lot of research have been carried out on the in this area of ground improvement. Lemanza and Lesmana have presented deep mixing with jet grouting method as a relatively new technique. Authors believe that the integration of the two methods can combine the advantages of both techniques and reduce the limitations technically and economically. Based on the case study results, both mechanical mixing part and jet grouting part are able to produce reasonable treatment similarities in terms of density, strength and stiffness (Fig. 31).

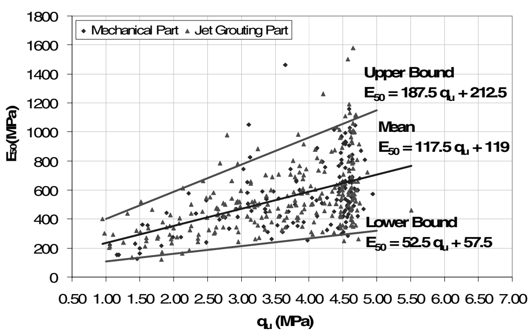


Figure 31 Correlation of qu and E50 of all DMJG core samples (Source: Fig. 7, Lemanza and Lesmana, 2009)

Kasama and Zen have presented a reliability based design on the bearing capacity of cement-treated ground considering the spatial variability of shear strength. The statistical interpretation of the bearing capacity is based on Monte Carlo simulations using the Random Field numerical limit analyses. A relationship between resistance factoring in Load and Resistance Factor Design (LRFD) code for the bearing capacity of cement treated ground and target reliability index has been proposed, as shown in Fig. 32. Chittoori et al. carried out a series of tests related to durability studies to address the permanency of the lime treatment. The Authors claim that the dominating clay mineral present in the soil has a significant influence on the long term durability of the lime stabilized soil

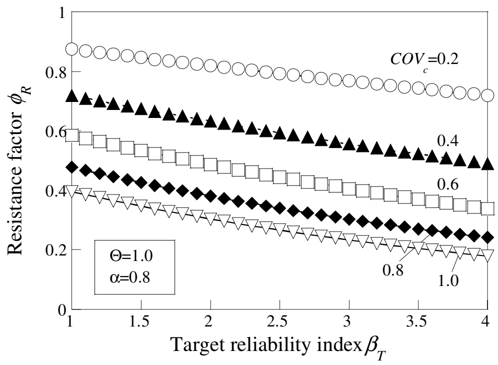


Figure 32. The tolerance of percent defect PD (Source: Fig. 9, Kasama and Zen, 2009)

DeJong et al. have demonstrated the potential of bio-mediated soil improvement for geotechnical application. Bio-mediated soil improvement relies on the geotechnical processes that are facilitated by significant biological activity as shown in Fig. 33. Authors have presented the results of their preliminary investigation carried out on large scale laboratory equipments, non destructive geophysical measurements and modeling to develop an optimized ad predictable bio-mediated treatment method. Authors also highlight the on going research in this area and have pointed out the need for more environmental friendly methods in the area of soil improvement. Molendijk et al and Van Paassen et al have presented the soil improvement method based on microbiologically induced precipitation of calcium carbonate. The precipitated calcium carbonate crystals form bridges between the sand grains, which increases the strength of sand mass and named this new technique as BioGrout/smart soils. Recently, Indraratna and co-workers have shown the potential benefit of lignosulfonate for soft soil improvement. Lignosulfonate belongs to a family of lignin based organic polymers derived as a waste by-product from wood and paper processing industry. It is an environmental friendly, non-corrosive and non-toxic chemical that does not alter the soil pH upon treatment. Since this by-product can be obtained cheaply and only a very small quantity is required for soil treatment (compared to other admixtures) lignin based treatment is sustainable over a much longer period of time. Indraratna et al (2008) studied the internal erosional behavior of lignosulfonate treated erodible soils using the Process Simulation Apparatus for Internal Crack Erosion (PSAICE) designed and built at University of Wollongong (UoW). The findings of this study indicate that lignosulfonate stabiliser increased the resistance to erosion, and some salient findings are shown in Fig. 34.

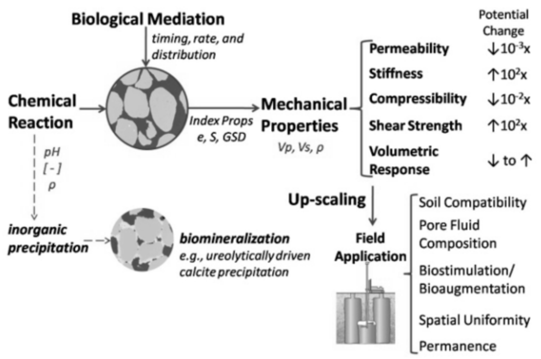


Figure 33. Variation of t95 with PV drain spacing for this study and previous study for I-15 in Salt Lake Valley, Utah (Source, Fig.1 DeJong et al. , 2009)

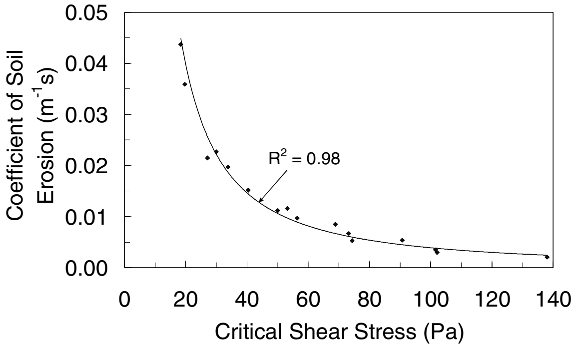


Figure 34. Variation of coefficient of erosion with critical hydraulic shear stress for all cement and lignosulfonate treated soils (Indraratna et al, 2008)

7 ELECTRO-KINETIC, THERMAL, ROOT-OSMOSIS AND EXPLOSION-BASED TECHNIQUES

In this category, there are 4 articles representing 4 countries. Omine and Kobayashi investigated the electro-kinetic method for decomposition of persistent organic matter, with respect to the stabilisation of bottom ash from the incineration of waste disposal landfill and municipal solid waste (MSW). In order to study the effect of hypochlorous acid and the effect of pH on the decomposition of organic matter (leachate), the electrolytic test under different pH conditions was performed. It is shown that circular system of electrolytic water is capable of stabilising the MSW incineration ash (Fig. 35; Source Fig.12).

Kulathilaka presents the results of the electro-osmotic consolidation of soft peaty soil. The laboratory experiments were carried out using electrodes made of non-corroding geosynthetic (Fig. 36, Source fig 5). Based on the laboratory experiments it has been concluded that the new non-corroding geosynthetics electrode is capable of improving the strength and stiffness of the soft peaty clay.

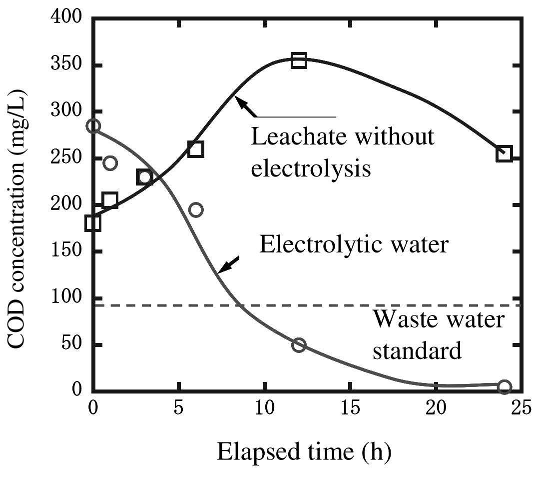


Figure 35. Relationship between COD concentration and elapsed time. (Source: Fig. 12, Omine and Kobayashi, 2009)

Khasanov et al. analysed (i) the reasons of base deformation of structures and (ii) different methods of strengthening foundation for different historical monuments. Authors claim that the main reasons for base deformations may be due to ageing of the materials and non-uniform sagging of structures. In addition, based on the case studies the Authors recommend the use of spurting technology for strengthening soils on the foundations of the monuments. Noorzad et al, have presented the improvement of fine grained soild by electokinetic unjection of silicate grouts. Author's shown that silicate precipitate into the soil pores and increases the cementation of soil.

Although no explosion-based techniques have been discussed in the current proceedings, this method has also been successful in the past. For instance, Yan and Chu (2005) describe the principles and applications of an explosion-based method to compress soft clay for a highway project in Jiangxi, China, as shown in Fig. 37.

The use of root-osmosis (native vegetation) in the stabilization of silty clays has been described by Indraratna et al. (2005). Figure 38 shows the influence of root suction in the stabilization of subgrade soils in the vicinity of a rail track. Abuel-Naga et al. (2008) presents the laboratory results on the thermal conductivity of soft saturated clay to enhance the consolidation process of soft soils (Fig. 39).

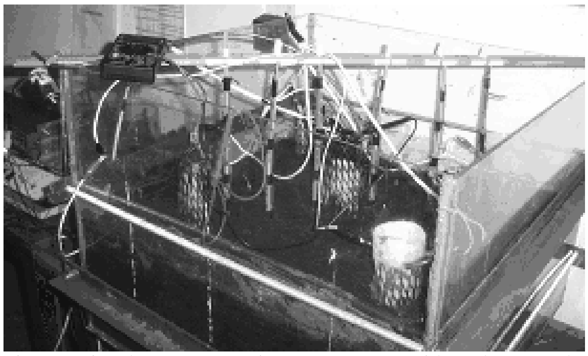


Figure 36. Electro Oosmotic arrangement with voltage probes (Source: Fig. 5, Kulathilaka., 2009)

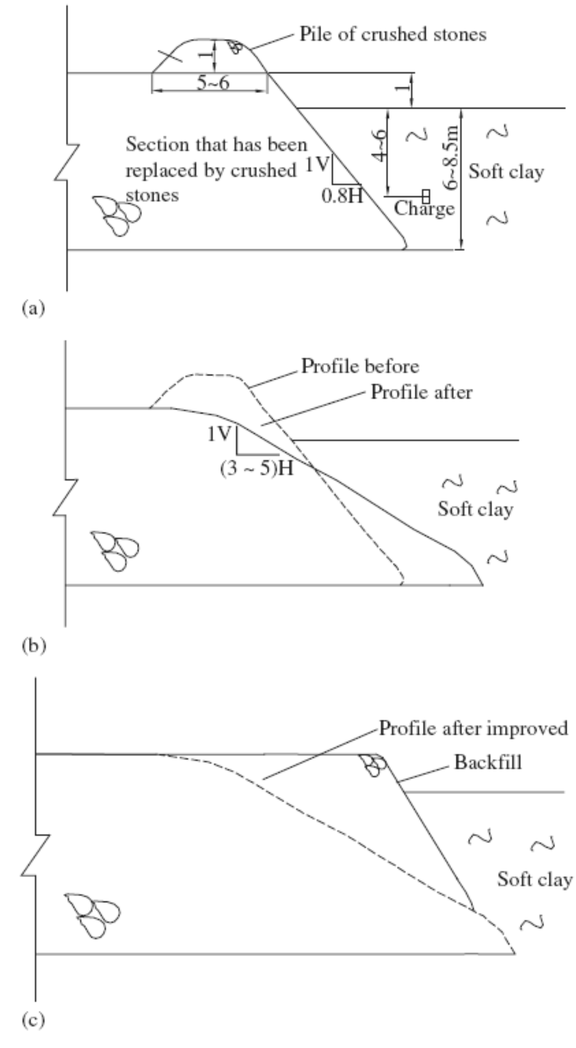


Figure 37. Explosive displacement procedure: (a) before explosion; (b) after explosion; (c) after backfill. (Yan and Chu., 2005)

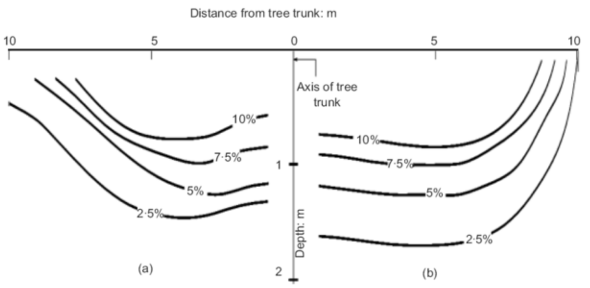


Figure 38. Contours of volumetric soil moisture content reduction (%) close to a lime tree (Indraratna et al. 2006)

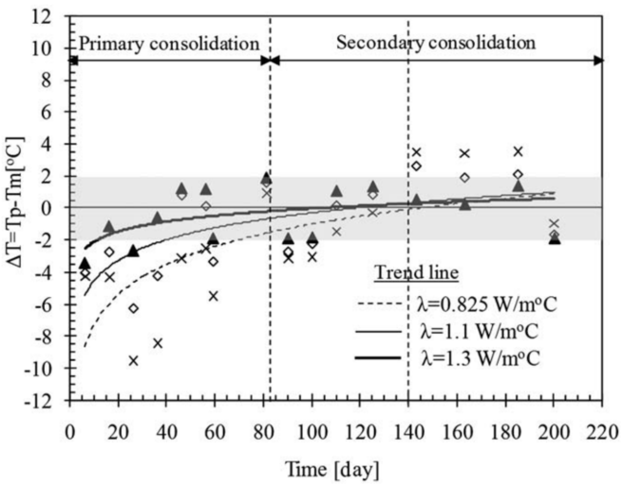


Figure 39. Comparison between full-scale and numerical simulation results at different thermal conductivity values (Abuel-Naga et al. 2008)

8 CONCLUSIONS

The Technical Session 4A consisted of about 60 papers (more than 240 pages) describing numerous efforts on field monitoring and data interpretation, experimental research, analytical methods and numerical modelling in six distinct ground improvement categories as stated below.

(a) Soft Clay Consolidation with vertical drains with or without vacuum preloading
(b) Sand and gravel piles, stone columns and rigid inclusions
(c) Geosynthetics reinforcement
(d) Compaction (static and dynamic) and Vibroflotation
(e) Grouting and Chemical stabilization
(f) Electro-kinetic, Electro-Osmotic, Thermal, Root-Osmosis and Explosion-based techniques

This General Report has attempted to offer a critical review of the majority of papers that have made significant contributions, and the salient aspects of all papers have been summarised in the Annex-Table 3. Considering the extensive worldwide efforts put in by practitioners, academics and research students (187 contributors from more than 30 countries), there is no doubt that this Technical Session 4A offers one of the most comprehensive Ground Improvement compilations, representing the current state-of-the-art of the commonly used or traditionally established techniques. However, it is noted that only a limited number of evolving techniques have been presented to any significant extent, and these include electro-thermal, electro-osmotic, electro-kinetic, cation exchange-based chemical treatments, combined thermal and vacuum, explosion-based methods and root-osmosis (native vegetation) among others. More details of some of these evolving techniques from the recent past have been presented by Indraratna and Chu (2005).

9 ACKNOWLEDGEMENT:

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ANNEX - Table 3: Summary of All Contributions in Technical Session 4A

Table 3A Soft Clay Consolidation with vertical drains and/or vacuum preloading

No	Title of Paper	Authors	Country	Summary of Main contribution
1.	Treatment of soft marine clays by vacuum consolidation	Liausu, P. and Scache, H.	France	• The design of the solution, with the predictable settlements during the consolidation for a peripheral cut off wall carried out by soil /cement bentonite soil mixing down to 10 metres depth. • Reported a very comprehensive geotechnical monitoring during and after the works.
2.	Field Application and Numerical Analysis of Suction Vertical Drain Method	Kim, S.S., Kim, Y.Y.; Han, S.J., Kim, K.N. and Kang, B.Y.	Korea	• Exclusive use for suction drain method, FE Program (SFEP) which can apply suction pressure effectively to the ground were developed. • The result of SFEP were compared with the results of field test for verifying the program.
3.	Very soft dredged mud improvement in the Port of Valencia	Burgos, M., Samper, F., and Alonso, J J	Spain	• A complete monitoring system has been installed to control the process of mud consolidation with some kinds of ground improvement methods, like the vertical darin method etc.
4.	Construction of a trial embankment on peaty ground using vacuum consolidation method a highway construction project in Sri Lanka	Karunawardena, W.A, Nithwana, W.	Sri Lanka	• Numerical assessment of the consolidation behavior of an embankment constructed on Sri Lankan peaty clay was simulated using an Elastio-viscoplastic model. • FE analysis was carried out by considering the finite deformation theory based on updated Lagrangian method and permeability was varied with the void ratio in order to simulate the peat consolidation process.
5.	Analytical Solutions for Vertical Drains Considering Soil Disturbance	Basu; D., Basu, P., and Prezzi,M.	USA	• Based on data available in the literature, four possible profiles of hydraulic conductivity versus radial distance from the vertical drain were identified. Analytical solutions were developed for the rate of consolidation considering these hydraulic conductivity profiles.
6.	Minimum Effective PV Drain Spacing from Embankment Field Testing in Soft Clay	Smith, A. and Rollins, K.M.	USA	• In consolidation with vertical drains, critical drain spacing is related to soil sensitivity as well as the geometry of the anchor and mandrel. • Field tests were carried out using a mandrel/anchor geometry with a smaller area and diameter for Interstate 15 project to verify the theory .
7.	Modeling of Combined Vacuum and Surcharge Preloading with Vertical Drains and Associated Design Charts	Indraratna, B., Rujikiatkamjorn, C. and Kelly, R.	Australia	• The application of vacuum pressure can reduce the need for high surcharge embankments, thereby providing increased soil stability apart from reducing substantially. • The conventional and often cumbersome trial and error methods could be avoided by the proposed use of design charts.

Table 3B Sand piles, gravel piles, stone columns and other rigid inclusions

No	Title of Paper	Authors	Country	Summary of Main contribution
1.	New approach to calculation of stresses and strains in compressible ground improved with vibrated gravel-sand columns and model verification	Kurka, J., Zavoral, J.	Czech Slovak	• An analytic method deals with the calculation of stresses and strains in compressible ground improved with the group of vibrated or rammed gravel-sand columns
2.	Foundation of an immersed tunnel with CDM and SCP soil improvement of soft marine clay	Kasper, T., Jackson, P.G., Heijmans, R., & Meinhardt, G.	Denmark and Netherlands	• Cement Deep Mixing (CDM) and Sand Compaction Piles (SCP) soil improvement of soft marine clay
3.	Soft soils improvement solution. Design based on laboratory test results on scale model	Chirica, A., Olteanu, A., Serbula, M.S., Boti, I.	USA	• The proper selection of type and concentration of the stabilization of a soil should consider the complex interaction between the mineralogy of the materials and additives, the presence or absence of moisture in soils and the long-term durability of the stabilization process.
4.	3D Modeling of stone columns and application	Foray, P., Flavigny, E., Nguyen, N.T.	France	• 3D numerical modelling of the behaviour of reinforcements by stone columns in very soft clay. Installation of the columns is taken into account in the simulation.

5.	Soil Improvement by Stone Columns for the Ore Storage Yard t the Rio de Janeiro Steel Plant on Soft, Alluvial Deposits	Rainer Wegner, N.N., Moormann, C., Jud, H., Glockne, H.	Germany	• Using stone columns to support a steel plant; full-scale load test on a group of 4 x 4 stone columns.
6.	Investigations on the behaviour of geosynthetic encased stone columns	Murugesan, S., Rajagopal, K.	India	• The qualitative and quantitative improvement in the load capacity of stone column by encasement through laboratory model experiments. • The performance of single as well as group of stone columns with and without encasement was investigated.
7.	Performance of a Large Diameter Tank on Improved Clay Deposit	Ranjan, G., Sundaram, R. Gupta, S.	India	• A case study of a large diameter tank founded on marine clay deposit treated by granular piles. Load tests were performed on single granular pile as well as a group
8.	Mechanical performance of different stabilised soils for application in stratified ground	Marzano, I.P., Osman, A., Grisolia, M., Al-Tabbaa, A.	Italy	• A large laboratory investigation of the binder content influence on the mechanical properties of cement-stabilised soils as used in deep soil mix applications
9.	Estimation of settlement of in-situ improved ground with a combined technology of shallow stabilization and floating type columns	Ishikura, R. Ochiai, H. Matsui, H.	Japan	• FEM analysis using Cam-clay model to investigate combined effectiveness of shallow stabilization and floating type columns; discussion on field observation results; a composite spring model for predicting the total settlement of this type improved ground
10.	Deformation behaviour of SCP improved ground to limit state	Takahashi, H. Kitazume, M. and Maruyama, K.	Japan	• Centrifuge model tests and finite element analysis of sand compaction pile improved ground
11.	Field instrumentation of an embankment on stone columns	Castro, J., Sagaseta, C.	Spain	• The construction of a 10-metre-height embankment on a marsh area is presented. The soft soil is treated by stone columns. Field instrumentation was used to study stone column behaviour.
12.	Numerical modeling of the seismic response of soil-mixed reinforced ground	Martin, J.R., and Olgun, C.G.	USA	• Parametric 3-D dynamic finite element modeling of the Seismic Response of Columnar-Reinforced Ground
13.	Ground improvement for a large above ground storage tank using cutter soil mix columns	Ameratunga, J., Brown, D. Ramachandran, M. & Denny, R.	Australia	• A case study where deep soil mixing was carried out using Cutter Soil Mixing (CSM) equipment ; Both analytical and numerical analyses are conducted.
14.	Integration of Quality control and base improvement in auger piles	Green, T.A.L., Parrock, A.L., Laughton M.	South Africa	• A range of integrated quality control of auger piles to eliminate uncertainty regarding the stress transfer between the pile base and bedrock. • A number of 100mm diameter steel tubes placed in a circular arrangement into the augered hole along with the steel reinforcing to check for voids or anomalies in the concrete.

Table 3C Geosynthetics Reinforcement

N	Title of Paper	Authors	Country	Summary of Main contribution
1.	Improvement of subgrade strength and serviceability for new container terminals using geogrid reinforcement	Heerten, G., Klompmaker, J., Partridge, A.	Germany	• A state-of-the-art report about the successful use of laid and welded geogrids to improve the subgrade strength in international port projects like e.g. in Germany, Turkey, Romania, the Sultanate of Oman and Egypt.
2.	Foundation of a Coal/Coke Stock Yard on Soft Soil with Geotextile Encased Columns and Horizontal Reinforcement	Alexiew, D., Moormann, C., Jud, H.	Germany	• Project-specific conditions in terms of geotechnical situation, loads, geometries and specific requirements to be met are described. • The general philosophy of the Geotextile Encased Column (GEC) solution in this case is explained together with the pros and contras

3.	Subgrade stabilization with lattice-frame-reinforced sheet	Okamoto, M., Yoshida, T., Kitamoto, Y.,	Japan	• Roadbed stabilization technique with newly developed geotextile called 'lattice-frame-reinforced sheet (LFR sheet). Plate loading test showed that loading intensity of base-coarse constructed upon the conventional sheet was smaller than that of base-coarse upon LFR sheet.
4.	Elastic Modulus of granular soil-geogrid composite from cyclic plate load tests	Atatlar, C., Shin, E.C., Das., B. M.	Turkey	• The prediction of improvement in the ultimate bearing capacity of eccentrically loaded strip foundation supported by multi-layered geogrid-reinforced sand.
5.	A Bearing Capacity Characteristics of Dredged and Reclaimed Ground Reinforced by Bamboo Net	Yang, K.S., Lee, S.	Korea	• Large scale plate loading tests on the bearing power characteristics of the dredged and reclaimed soft ground strengthened by the bamboo net. • A relationship between sand mat thickness(H), bamboo net space(S), and bearing capacity ratio(BCR) was proposed.
6.	Backfill Materials for Mechanically Stabilized Earth (MSE): African Experience	Andrew, C.S., Smith, L.D.	South Africa	• Methods of locating sources of suitable material and the possibility of formulating a revised and wider range of backfill specifications for MSE structures.

Table 3D Compaction (static and dynamic) and Vibroflotation

No	Title of Paper	Authors	Country	Summary of Main contribution
1.	Innovative dynamic compaction techniques and integrated compaction control methods	Adam, D., Brandl, H.	Austria	• Recent advances in the field of innovative compaction techniques and integrated compaction control methods. • Guidelines were provided for sophisticated quality management and quality assurance systems.
2.	Ground energy and impact of rolling dynamic compaction – results from research test site	Avalle, D., Scott, B., Jaksa, M.	Australia	• The "square" impact roller tests at in field provide physical data on energy input, dissipation and ground response that will be utilised to develop a numerical model, and to examine the effects on other sites of differing sub-surface conditions.
3.	Study parameters for the application of dynamic consolidation and associated techniques	Varaksin, S., Racinais, J.	France	• Dynamic Replacement techniques are described as well as tested by pressuremeter techniques and verified by full scale loading. • An alternative called "dynamic surcharge" reducing the required static surcharge intensity is theorically analysed and verified for heavy structures
4.	Modelling of vibrocompaction using hypoplasticity with intergranular strains	Arnold, M. & Herle, I.	Germany	• To model vibrocompaction methods using dynamic FE analysis and to compare results with practical experience.
5.	Design and Construction of Highway A143 above abandoned Lignite Mines	Walter E., Wittke, H. Wittke, M.	Germany	• Dynamic compaction by falling weights was carried out in the area of the new highway to destroy the existing cavities which on the short- or medium-term would have lead to sinkholes.
6.	Assessment of the use of dynamic compaction on double porosity clay landfill	Pooley, E. Laue, J. Springman, S.	Switzerland	• Model tests on scaled double porosity clay landfills were carried out in the ETH Zurich drum centrifuge. • In-flight displacement-controlled rigid foundation tests were carried out on the centrifuge models.
7.	Vibro compaction improvement of Tunisian liquefiable sands	Ridha, M., Ouni, EL Bouassida, M., Das, B.	Tunisia	• SPT and CPT control tests show significant improvement related to densification of subsoil after vibrocompaction
8.	Monitoring of building the dam of Razaksay water storage from the point of view of engineering geology	Mavlyganov, N.G., Abdullaev, S, K.	Uzbekistan	• Monitoring carried out by implementation during stacking and compactions of the ground in a body of the dam the audit engineering-geological tryouts, lab tests and seismic measuring using modern express methods.

Table 3E Grouting & Chemical stabilization

No	Title of Paper	Authors	Country	Summary of Main contribution
1.	Foundation improvement for a building on loess soil	Mensur, M. and Krunoslav, M.	Croatia	• An investigation of 200 years old high school building revealed that jet-grouting formed columns in soil helped directly to stabilization of foundation.

2.	Mechanical performance of different stabilized soils for application in stratified ground	Marzani, I P; Osaman, A; Grisolia, M & Al-Tabba, A	Italy	• A large laboratory investigation of the binder content influence on the mechanical properties of cement-stabilised soils as used in deep soil mix applications
3.	Permeability and workability of clay stabilized with small amount of cement	Leivo, A. and Ravaska, O.	Finland	• Reported use of cement for soft clay stabilization and described practical needs for workability and compaction.
4.	Injectability of a loess by reinforcement grouts	Dupla, J.-C., Canou, J., Terpereau, J. –M., and Marchadier, G.	France	• Studied the injectability of specific loess of northern France, carried out with the objective of stabilizing this soil with respect to possible risk of liquefaction under high speed train loading. • The results of injection tests obtained with different products such as micro cement suspensions, silicates and nanosilica suspensions are presented.
5.	Effects of deleterious chemical compounds on soil stabilisation	Borgne, T. Le, Cuisinier, O., Deneele, D., and Masrouri, F.	France	• Chemical compounds may alter silt stabilization process. However, the presence of a given chemical compound at a given concentration in the soil is not sufficient enough to determine the suitability of the soil for a treatment
6.	Soil reinforcement beneath existing rail tracks with soil cement columns	Kouby, A., Bourgeois, E. and Frédéric R.L.	France	• The soil reinforcement technique based on soil-cement columns was studied and results showed that the deflections were reduced.
7.	Protection of structures with the Soilfrac ® method in the course of the two greatest inner-city tunnel building measures in Germany	Stelte, M. Paßlick, T. and Grundbau, K.	Germany	• Advantage of Soilfrac ® technology in tunneling and in a difficult foundation with very far-reaching requirements on uplifts precision as well as its control.
8.	Groutability and effectiveness of microfine cement grouts	Christodoulou, D.N., Droudakis, A.I., Pantazopoulos, I.A., Markou, I.N., and Atmatzidis, D.K.	Greece	• Groutability of cement suspensions increases with increasing cement fineness and water to cement ratio and is affected by suspension viscosity.
9.	Mix-design, construction and controls of lime stabilised embankments	Fratalocchi, E., Bellezza, I. Pasqualini, E., and Di Sante, M.	Italy	• The case history points out the importance of a detailed and careful construction quality control to assure the desired overall performance of lime-stabilised embankments
10.	27 Years' Investigation on Property of In-situ Quicklime Treated Clay	Kitazume, M. and Takahashi, H.	Japan	• The wet density of the treated soil has been almost constant during 27 years' curing. • And the treated soil strength was increased about threefold during the early 11 years, but became almost constant after then.
11.	Reliability-based Design on the Bearing Capacity of Cement-treated Ground Considering the Spatial Variability of Shear Strength	Kasama, K. Zen, K.	Japan	• Presented a reliability-based design on the bearing capacity for cement-treated ground using numerical limit analyses with random field theory and Monte Carlo simulation
12.	Ground Improvement Solutions at Sana Vasco da Gama Royal Hotel	Pinto, A., Pereira, A. Cardoso, D. Sá, J.	Portugal	• Presented main design and execution criteria related with ground improvement solutions, using jet grouting columns.
13.	Evaluation of mechanical properties of jet-grouting columns using different test methods	Gomes Correia; A., Valente, T.; Tinoco, J. Falcão, ,J. Barata, J., Cebola, D. and Coelho, S.	Portugal	• It was shown the importance of local sample strain measurements for evaluating modulus of the treated material in unconfined compression tests.
14.	Variation of the parameters of injection for the ground in different regimes	Farcas, V.S., Popa, A.,& Ilies, N.M.	Romania	• Presentation of an experimental model for grouting, on natural scale and comparison with the mathematical model.
15.	Deep soil improvement technique using combined deep mixing and jet grouting method	Lemanza, W. & Lesmana, A.	Singapore	• Discussed 'Deep Soil Mixing or Jet Grouting (DMJG)' technique.

16.	Engineering assessment of jet-grouted structures	Arroyo, M. and Gens, A.	Spain	• The strength and stiffness of the jet-grouted slab were deemed adequate
17.	Upscaling of bio-mediated soil improvement	DeJong J.T.,, Mortensen, B., Martinez, B. and Nelson, D.	USA	• This paper explores the two primary modes of treatment possible, bio-mineralization and bio-film formation.
18.	Flow of Foamed Grout in Granular Soil	Ali, L. and Woods, R.D.	USA	• Foam-displacement is an efficient and cost-effective means of aquifer decontamination
19.	Durability Studies of Lime Stabilized Clayey Soils	Chittoori, S. Puppala, A.J., and Nazarian, S.	USA	• Though soils contain similar plasticity characteristics, they exhibited different strength losses at similar number of wetting and drying cycles, owing to difference in the clay mineralogy characteristics.
20.	Effects of an angle of mixing paddles on deep mixing in soft clays	Lee, K.Y. and Hwang, J.H.	USA	• To investigate the efficiency of deep mixing method for ground improvement on a soft clay ground, experimental studies are performed
21.	Investigation on the mechanism of field low-pressure grouting and the engineering characteristics of grouted soils	Chang. M., Chen, C.C., Huang, R.C., Chang, J., Yang, P J	USA	• The study shows the penetration resistance of the ground increased as the result of grouting.
22.	Ground improvement under historical buildings: a case history	Passalacqua, R	Italy	• Recent experience, regarding the soil improvement technique which was used in order to deepen safely a large excavation in adherence to an historical building, sited into a well urbanized area. • An FEM simulation which take into consideration all it's executive sequences and the soil improvement phase.
23.	Stabilization of peat by silica based solidification	Den Hamer, D.A.; Venmans, AAM; van der Zon W.H., and Olie, J J	Netherlands	• Peat solidification is a promising technique for cost-effective and efficient soft soil improvement with a wide range of potential applications
24.	Scale up of BioGrout: a biological ground reinforcement method	Van Paassen, L.A., Harkes, M.P., van Zwieten, G.A., W.H. Van der Zon, G.A.M. Van Meurs, and M.C.M. Van Loosdrecht	Netherlands	• BioGrout is a new soil improvement method based on microbiologically induced precipitation of calcium carbonate • Showed that it is possible to improve soil mechanical properties using BioGrout under conditions and techniques as used in practice
25.	SmartSoils, Adaptation of soil properties on demand	W.O. Molendijk, W.H. van der Zon and G.A.M. van Meurs	Netherlands	• Describes the novel use of SmartSoils and other microbial and geochemical applications in geo-engineering
26.	Soft soil strengtheining by calcium cation permeation	Davoudi, M. H.; Astaneh F., Alvandkoohi, H.	Iran	• A new method is proposed in which lime is intruded into the soil mass via permeating a lime saturated solution of water. • Results demonstrate an increase in shear strength of the soil after permeation.
27.	Large consolidation and experimental ageing of cement-based grouts	Karim, U F A; Bangoyina, P. and Van der Stoel, A E C	Netherlands	• Grout bleeding behavior and interaction with boundary soils can be numerically simulated and fitted to experimental results to obtain an efficient grout mix design for the different conditions.

Table 3F Miscellaneous Topics including electro-kinetic, electro-osmotic, waterproofing etc.

No	Title of Paper	Authors	Country	Summary of Main contribution
1.	Decomposition of organic matter of MSW incineration ash by electrolytic method	Omine, K. and Kobayashi, T.	Japan	• Electrolytic method for decomposition of persistent organic matter is applied to municipal solid waste (MSW) incineration bottom ash. • Stabilization of MSW incineration ash progresses by using circular system of electrolytic water

2.	Improvement of soft peaty clays with different configurations of geosynthetic electrodes	Kulathilaka, S A S	Sri Lanka	• The Electro-kinetic consolidation process could be used economically to enhance the strength and stiffness characteristics of soft peaty clays to some level.
3.	Long-term Technologies of Bases and Foundations for Strengthening of Monuments in Conformably with Ground of Central Asia	Khasanov, A Z, Khasanov, Z A., Ikramov, F A.,	Uzbekistan.	• The problems of engineering-geological analysis of historical cities, territories, traditional methods of erection and materials of the foundations of historical monuments of architectures. • The main reasons of deformations of structures and methods of foundations and bases strengthening including waterproofing devices are analysed.
4.	Fine-grained soil improvement by electrokinetic injection	Ali Noorzad, Amin Falamaki, and Nader Shariatmadari	Iran	• The sodium silicate solution are injected from the anode compartment across a silty specimen for a week with 10% acid phosphoric solution as catholyte to control pH. • It is shown that silicate precipitate into the soil pores and increases the cementation of soil.