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Technical session 2b: Reinforcement and stone columns

Séances techniques 2b: Renforcement et colonne de pierre

H. Ochiai
Department of Civil Engineering, Kyushu University, Japan
R. Bathurst
GeoEngineering Centre at Queen's-RMC, Royal Military College of Canada, Canada
J. Otani
Department of Civil and Environmental Engineering, Kumamoto University, Japan

1 INTRODUCTION

Earth reinforcement techniques have developed significantly over the last three decades and are now used world wide. To promote earth reinforcement techniques internationally, Technical Committee No.9 (TC9) was formed by the ISSMGE (International Society for Soil Mechanics and Geotechnical Engineering). The most recent Chairman of TC9 is Prof. Ochiai of Japan (for the two terms from 1997 to 2005). The committee has been supported during this period by the Japanese Geotechnical Society (JGS) which formed the Japanese Supporting Committee for TC9 for this purpose. The objective of TC9 for the term from 2001 to 2005 was to focus on the full range of current and new/novel techniques including geosynthetics, soil nailing, and other methods for ground reinforcement using artificial materials placed in the soil. The terms of reference of TC9 are as follows:

1) To disseminate experience and knowledge on earth reinforcement practice;
2) To promote research and development of earth reinforcement technologies;
3) To promote publication of education materials on earth reinforcement practice for engineers and students;
4) To promote international symposia/conferences related to earth reinforcement technologies; and
5) To collaborate with TC17 (Ground Improvement).

The Organizing Committee of the 16th ICSMGE Osaka Conference asked TC9 to organize "Session 2b: Reinforcement and Stone Column" with the chairman of TC9, with Prof. Ochiai as session chair. The Organizing Committee of the Osaka Conference invited Prof. Bathurst of Canada, past-president of the IGS (International Geosynthetics Society) to be the General Reporter of the session and Prof. Otani, Secretary of TC9, to be Secretary of the session.

After discussing the theme of Session 2b as mandated by the Organizing Committee, these key persons established the following session objectives:

1) To discuss current issues on practice and research around the world;
2) To discuss relatively new topics; and
3) To include in the session all technical papers submitted to Osaka Conference, falling within the theme areas of soil reinforcement and stone columns.

To meet these objectives, four distinguished panelists were invited to give special presentations. The following schedule was finalized:

1) Date: 10:30-12:30, Thursday, 15 September 2005
2) Place: Rm 1001-1002 (10F)
3) Key persons:
   Chairman: Hidetoshi Ochiai (Japan, Chairman of TC9)
   Session Secretary: Jun Otani (Japan, Secretary of TC9)
   General Reporter: Richard J. Bathurst (Canada)
4) Panelists and their topics:
   B. Simon (France): Non-geosynthetic reinforcement;
   M. Madhav (India): Stone columns;
   P. Sharle (Hungary): Structural failures and lessons learned; and
   D. Cazzuffi (Italy): Reinforcement using vegetation.

The session was started with an opening address by Prof. Ochiai (Chairman). Then, the General Reporter, Prof. Bathurst gave a presentation that was a summary review of all 28 technical papers in the session. Next, the four panelists gave their presentations. Following these presentations, a floor discussion was opened on all topics including both the presentations and related issues. At the end of the session, the Secretary of the session, Prof. Otani gave his closing remarks including his vision of future TC9 activities related to the topic of earth reinforcement.

In the following sections, the content of the General Report, the four panel presentations, and the session discussion are summarized.

2 GENERAL REPORT

The General Report noted the following session statistics:

1) Total number of papers: 28
   Number of countries represented: 16;
2) Reinforcement papers: 20
   Number of countries represented: 13; and
3) Stone column papers: 8
   Number of countries represented: 8.

The papers on the topics of reinforcement and stone column were reviewed separately with summary tables made by the General Reporter. The application field, reinforcement type (reinforcement topic only) and their investigations were categorized in these tables. After reviewing all the papers, selected papers were singled out for special mention by the General Reporter and key points identified.

3 PANEL PRESENTATIONS

3.1 *Soil reinforcement combining vertical stiff inclusions and a transfer granular layer under floor slabs and rafts by B. Simon(France)*

Pile supported earth platforms have gained increasing use in France over the last 15 years as a cost effective foundation solution for industrial and commercial floor slabs and tank rafts on poor soils. These systems combine a granular mattress and vertical piles (stiff inclusions) to form a composite structure that transfers loading from the slab to a deep bearing stratum. Load transfer is due to shear mechanisms that develop within the mattress and around the pile shafts. Geosynthetic-reinforced piled embankments have also received much interest and research effort in other countries. For example, outside of France, geosynthetic reinforcement is often used with piled embankments (BS8806, EBGEO). However, geosynthetic base-reinforcement is seldom used in France for pile-supported earth platforms supporting floor slabs and rafts.

A review of national and foreign practice (Briançon 2002) pinpointed a few differences between both approaches. Mattress thickness is generally kept between 0.4 m and 0.9 m under non-geosynthetic reinforced slabs while higher values are reported under piled embankments. A displacement method is generally adopted for pile design under such foundations in France. Due to a lack of a sufficient number of well-instrumented cases, no single design approach exists despite the many applications for this technology. Design approaches are either step-by-step incremenal or global. In the former approach, load transfer within the mattress is analyzed first. While soil arching theory (Hewlett et al. 1988, Zaeske et al. 2002) has proved effective for piled embankments where the mattress is thick, it appears of limited use for geosynthetic reinforcement applications. In an alternative approach by Combarieu (1988), shear mechanisms within the granular fill are modeled as downdrag stresses along an imaginary upwards pile extension. Next, load transfer along the pile shaft is analyzed using a downdrag model and introducing strain compatibility between the soil and pile (Simon 2001). The latter approach relies on Finite Element or Finite Difference 2D- or 3D- modeling. Nevertheless, there are a few limitations. Most 2D models are axisymmetric and hence are only accurate close to centre of the embankment where with uniform loading prevails. Plane strain models can deal only with “wall”-supported earth platforms where shear mechanisms are different. 3D models have the disadvantage of being time- and memory-intensive and are quite often restricted to a central unit cell of the numerical grid. Yet some promising improvements in 3D model efficiency are possible using biphasic models (Sudret et al. 2001) or the development of special pile elements (Sadek et al. 2004))

The correct choice of constitutive models for soils and interfaces is important for all numerical models. For example, granular fill properties are strongly stress dependent and soil disturbance around piles should be taken into account as well as consolidation and creep in the soft soil.

Some other points are still being debated: Can shear effects be partly destroyed by vibrations due to surface transient loads? What is the minimum quality requirement for the mattress bearing in mind the cost of high quality granular fill in many urban areas? How do we include fill compaction effects in design? While the Rion-Antirion bridge foundation design is an outstanding example of the application of a pile-reinforced granular embankment in a highly seismic region (Pecker et al. 1998), seismic behavior needs to be considered for all projects.

A 4-year national research project has been started in France (ASIRI project) with state and industry funding. This project will draw on full-scale experiments (2 x 5 pile test embankments), centrifuge testing, physical modeling and numerical analyses. Current design methods will be checked against the experimental data and the results of numerical modes. The final objective of the project will be recommendations for the use and design of pile-supported earth platforms. Efficient and easy to use design methods will be developed to evaluate stresses, displacements and factors of safety of these cost-effective foundation solutions.

3.2 *Granular Piles/Stone Columns – An Overview of Recent Developments- by M. Madhav (India)*

Granular piles/stone columns continue to draw the attention of geotechnical practitioners. They offer versatility and utility for improving a variety of ground conditions ranging from soft soils to loose granular deposits to waste fill sites and for improving bearing capacity, reducing settlements, accelerating consolidation and increasing liquefaction resistance of the ground in which they are installed. The primary functions of granular piles are reinforcement of soft deposits, densification of loose sands and improved drainage of low permeability soils.

Of the twenty-seven papers included in this session, seven papers deal with granular piles/stone columns. This attests to their relevance in present day geotechnical practice and research. The General Report presents some interesting studies of: (i) visualization of granular pile deformations using a transparent material; (ii) identification of various deformation and failure modes of groups of granular piles loaded through a raft or a rigid footing; and (iii) a new innovation, the granular pile anchor (GPA).

With the exception of the classical study of Hughes and Withers (1974) on visualization of deformations of a single stone column including identification of the bulging phenomenon, very little work has been reported on the response of granular piles, especially pile groups. Work at Queen’s University, Belfast, demonstrates the importance of the location of the granular pile in a group on its response. Rigid rafts supported by stone columns can fail in a variety of ways, depending on the column spacing, relative length to diameter ratio, etc. The work carried out at Glasgow University identified classical failure modes identified as: wedge type failure, punching of short granular piles, compression of long granular piles and shear buckling due to lateral earth stresses.

Granular piles are typically used to carry compressive loads (related to increased bearing capacity and reduced settlements) and occasionally to increase the base shear capacity of embankments on soft ground. By placing a rigid pedestal of concrete, with a steel plate or a layer of geogrid reinforcement at the base and connecting a tie rod or cable to transfer pullout loads, granular piles can be made to resist uplift forces. Granular pile anchors are thus a new innovation that can be used to minimize the effects of swelling of expansive soils and to resist pullout loads. Other studies at J.N.T. University and IIT, Roorkeein India on GPA are also reported in the literature.

3.3 *Structural failures and lessons learned by P. Sharle(Hungary)*

Structural and geotechnical successes are common subjects of professional conferences. Failures and mistakes are less favored topics presented for discussion, even though they offer important lessons, particularly for many more experts than those involved directly in any particular case. There can be many good examples of lessons learned from failures as illustrated by Giroud (2005).

The classic system consisting of "reinforced concrete facing and soil reinforcing strip" has been modified and applied in different forms in several countries. Alternative facing geometries have been combined with innovative strip arrangements and materials, motivated either to avoid legal and financial conflicts or simply to prove engineering imagination. Some innovators prefer simplifications, others create sophisticated arrangements - both approaches may be risky.

Modification of the concrete facing element is plausible. Modifications using strip reinforcement (i.e. material type, spacing, connections, etc) may be more risky. Glass fibre reinforced resin strips, for instance, meet all conventional tests but may fail to work appropriately under in-service conditions (Szepeshazi and Scharle 2003).

Conventional crib wall arrangements consisting of wooden frameworks filled with broken stone or gravel may be considered as gravity walls. However, less traditional design, accompanied with careless construction and unexpected weather conditions may result in large strains (Nemeth et al. 2006).

The following are the major conclusions from this presentation:

1) Understanding the kinematic behavior of reinforced structures is a crucial requirement, when less traditional construction arrangements or technologies are applied. Use of advanced computational techniques does not remove this requirement.
2) Failures and observed damage prove that reinforced earth structures may have unexpected reserve load capacities, but requirements to keep strains, displacements and local stability under working loads to acceptable levels requires more attention.
3) Robust structural arrangements, even if they are not (or cannot be) computed with elegant numerical methods, seem to maintain their justification until the design methods involve crude approximations and during the construction the precise implementation requirements might be neglected.

3.4 *Reinforcement by vegetation -An overview of experimental studies carried out on different types of plants- by D. Cazzuffi (Italy)*

The stability of a slope depends on a delicate balance between forces. In general, slopes fail when the shear stress on a potential failure surface exceeds the shear strength. It is customary to express this balance of forces in terms of a factor of safety. Possible ways in which vegetation might affect the balance of forces are: mechanical reinforcement from the root system; slope surcharge from the weight of the trees; wind-induced leverage forces and root wedging; modification of the soil moisture distribution and pore water pressures and lateral restraint by buttressing and soil arching (Coppin and Richards 1990).

With the exception of wind forces and root wedging, each of these factors generally enhances stability (Bache and MacAskill 1984). At first inspection, surcharge loads would appear to increase shear stresses, but this effect is largely negated by an accompanying increase in shear strength. Evaporation and transpiration as modes of water loss each contribute to the reduction of soil moisture. Moisture depletion not only reduces the unit weight of soil, but also enhances cohesion due to the surface tension forces in partially saturated soils. Buttressing and arching refer to the lateral restraint on soil movement from the trunks and the roots. For example, arching in slopes occurs when soil attempts to move through and around a row of piles firmly embedded or anchored in an unyielding layer.

Wind leverage or wind forces can represent a serious problem caused by the overturning moment of wind on trees, or excessive vibrations which cause loosening of the roots. Root wedging has been proposed as a mechanism in which roots penetrate the soil, thereby loosening it or opening cracks.

As mentioned earlier, the most obvious way in which plants stabilize soils is by root reinforcement, the roots tending to bind the soil together and to increase its shear strength. The use of vegetation for soil slope reinforcement in civil and landscape applications has grown in importance, but specific design standards are still under development. In fact, while the effects related to the presence of roots are very well known from a theoretical point of view, more research is required to arrive at a general approach.

The work described in this paper was part of a research program aimed at evaluating quantitatively the shear strength increase in soil due to plant roots. In order to quantify the contribution of roots to soil shear strength, direct shear tests both on soil and on root-reinforced soil, were carried out. These tests were performed on undisturbed samples collected from a site in southern Italy, as described below. The sampling activities and the results of the direct shear tests represent the main subjects of the present paper.

The research presented in this paper quantified the influence of the root systems of four “gramineae” species, commonly used in bio-engineering works, on the shear strength of a cohesive soil. One objective of the study was to develop an experimental method to quantify the contribution of the roots to the soil mechanical properties. Large undisturbed soil samples, with roots and without roots, (diameter of 0.2 m and height of 1 m), were extracted on site to be tested in the laboratory using a direct shear test device. The tests were carried out using three different vertical pressures corresponding to three different relatively shallows depths (0.2 m; 0.4 m; 0.6 m).

The results allowed direct comparisons to made of the influence of roots by testing soil samples with roots and soil samples without roots. Following an approach found in the literature, it was observed that the increase in soil shear strength can be understood to be the result of an increase in soil cohesion. Moreover, this increase in cohesion was quantified to be in the range of 2 kPa and 15 kPa which is in agreement with other studies. In particular, it was noted that the increase in the soil shear strength depends on the considered plant species and that the increase is a function mainly of the tensile strength contributed by the root systems. This conclusion justifies the growing interest on the use of the “gramineae” species used in this study and in particular the Vetiver type. These species, in fact, are characterized by very resistant roots and the present study confirms how they, and all the other species with similar properties, can be successfully used to stabilizing soils in slopes prone to shallow landslides.

4 DISCUSSION

After all the panelist presentations, the floor discussion was opened by Prof. Bathurst as chair of this part of the session. First, he invited questions from the floor on each of the topics presented by the panelists. These questions allowed the panelists to provide qualifying information on points made in their formal presentations.

Next, a free discussion was started. An exciting exchange resulted involving the relative merits of 1g model testing and centrifuge testing of reinforced soil models. Both advantage and disadvantage were commented on by many members of the audience and the General Reporter.

Additional comments on stone columns were also made by members of the audience. These discussions were related to the observation that the number of counties or regions where this technology is used is restricted. Consequently, many engineers are not familiar with this technique. It was very active and worthwhile discussion.

5 CONCLUSIONS

The total number of participants was about 100 persons. These included researchers and practicing engineers. The papers that comprise this session of the conference will provide a valuable resource for many years to come in the areas of ground reinforcement and stone columns.

LIST OF PAPARS IN TECHNICAL SESSION 2B

Aoki, H., Yonezawa, T., Tateyama, M., Shinoda, M., Watanabe, K. 2005. Development of aseismic abutment with geogrid-reinforced cement-treated backfill.

Bellezza, I., Pasqualini, E. 2005. Parametric study of the stability of slopes reinforced with piles.

Benjamim, C.V.S., Bueno, B.S., Zornberg, J.G. 2005. Comparison between field monitoring and numerical results of a woven geotextile-reinforced soil retaining wall.

Clemente, J.L.M., Senapathy, H., Davie, J.R. 2005. Performance prediction of stone-column-supported foundations.

Consoli, N.C., Casagrande, M.D.T., Coop, M.R. 2005. Behavior of a fiber-reinforced sand under large shear strains.

Davies, M.C.R., Morgan, N. 2005. The influence of the variation of effective stress on the serviceability of soil nailed slopes.

Dittrich, J.P., Boone, S.J., Hutchinson, A.E. 2005. Ground improvement in a coralline deposit in Barbados, W.I..

Freitag, N., Morizot, J.-C., Berard, G., Silveira Fernandes, K. 2005. Innovative solution for reinforced earth walls – Frictional connection.

Gualco, D., Berardi, R. 2005. Effects of geosynthetics reinforcement on bearing capacity and settlement of shallow foundations.

Guetif Fessi, Z., Bouassida, M. 2005. Settlement estimation of soils reinforced by columns using a poroelastic model.

Heitz, C., Kempfert, H.-G., Alexiew, D. 2005. Embankment project on soft subsoil with grouted stone columns and geogrids.

Justo, J.L., Durand, P., Soriano, C., Saura, J., Marco, J.M. 2005. Ground improvement and reinforcement in four dikes on soft soil.

Kim, N.K., Park, J.S., Jang, H.J., Kim, M.Y., Han, M.Y., Kim, S.B. 2005. A new IPS earth retention system.

Li, C., Zornberg, J.G. 2005. Interface shear strength in fiber-reinforced soil.

Magnan, J.P., Droniuc, N., Canépa, Y., Dhouib, A. 2005. Some thoughts about the design of stone columns.

Matsuoka, H., Muramatsu, D., Liu, S.H. 2005. Reduction of traffic-induced vibration by soilbags (“donow”).

Maurya, R.R., Sharma, B.V.R., Naresh, D.N. 2005. Footing load tests on single and group of stone columns.

Moraci, N., Recalcati, P. 2005. Pullout resistance of extruded geogrids embedded in a compacted granular soil.

Mulabdic, M., Minazek, K., Mrackovski, D. 2005. Influence of reinforcing grids on soil properties.

Patra, C.R., Mandal, J.N., Das, B.M. 2005. Ultimate bearing capacity of shallow foundation on geogrid-reinforced sand.

Pulko, B., Majes, B. 2005. Simple and accurate prediction of settlements of stone column reinforced soil.

Saramago, R.P., Ehrlich, M. 2005. Physical 1:1 scale model studies on geogrid reinforced soil walls.

Sayão, A.S.F.J., Lima, A.P., Springer, F.O, Nunes, A.L.L.S., Dias, P.H.V., Gerscovich, D.M.S. 2005. Design and instrumentation aspects of a 40m high nailed slope.

Shroff, A.V., Patel, B.R. 2005. Study on composite stone column in soft kaolinitic clay.

Stanic, B., Kovacevic, M.S., Szavits-Nossan, A. 2005. Parametric study of reinforced earth walls deformations.

Steenbergen-Kajabová, J., Steenbrink, R., Habib, H.A.A. 2005. Innovative restoration of medieval city walls of ‘s-Hertogenbosch by soil nailing.

Tan, S.A., Oo, K.K. 2005. Finite element modeling of stone columns - A case history.

Uchimura, T., Mizuhashi, M. 2005. Effects of reinforcement stiffness on deformation of reinforced soil structures under small cyclic loading.