1 INTRODUCTION

Earth reinforcement techniques have developed significantly over the last three decades and are now used worldwide. 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 Columns” 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 columns 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.
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 mat-
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 pines 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 relative 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.


