Landmarks in Earth Reinforcement, - Ochiai et al (eds),
© 2003 Swets & Zeitlinger, Lisse, ISBN 90 265 1863 3

Technical report – Foundations session

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ABSTRACT: This report summarises and discusses the papers presented in the technical session on Foundations of the International Symposium on Earth Reinforcement-IS Kyushu 2001. A wide variety of subjects were approached by the Authors, such as soil improvement by injections, use of granular columns, reinforced granular and cohesive fill layers and slopes and soil reinforcement solutions for pile foundations. The main findings in these works are presented and discussed and points for further research are identified.

1 INTRODUCTION

Soil reinforcement has been consolidated as a technical and economical solution in geotechnical engineering. From the early uses of the technique in ancient times to the present days, the application of reinforced soil has increased in number, variety and sophistication. The application of the technique has been extended to larger structures, to more severe situations and to ingenious and increasingly daring projects. The use of reinforcement to increase bearing capacity of foundation soils is one of the fields of application of soil reinforcement. However, the development and actual use of reinforcement in foundations has taken place at a slower rate of increase than that of other applications of soil reinforcement. One of the reasons is the responsibility involved in works of this nature for designers and contractors. The complexity of the theoretical study of the problem also limits the use of simple and accurate design solutions in routine works.

The Kyushu international symposia have been key references on soil reinforcement development, where this technique has been discussed in all its variety of applications. This is also certainly the case of foundations reinforcement and improvement. The high quality of the contributions presented in previous and at the present edition of the symposium has increased markedly the knowledge on the use of reinforcement in foundations. This report summarises and discusses the papers presented at the technical session on Foundations of the IS Kyushu'2001.

2 OVERVIEW ON THE SUBJECTS OF THE PAPERS

Twenty four papers addressing the use of reinforcement in foundations are published in the proceedings of IS Kyush'2001. These papers cover a wide range of subjects, from shallow to deep foundation problems. Figures 1 and 2 show schematically the type of problems investigated. With respect to the last IS Kyushu symposium, it can be observed a slight decrease in the percentage of papers on reinforced granular layers on soft soil, but this subject still responds for approximately a quarter of the total number of papers. The use of reinforcement in granular foundation soils also showed a small decrease in the number of papers, but works on this subject and on the use of reinforced granular layers represents approximately 42% of the papers. A slight increase on the number of papers on bearing capacity of reinforced slopes can be identified with respect to the previous edition of the symposium. In addition, it can also be noted a more significant increase on the number of papers on the use of reinforcement in conjunction with pile foundations.

Figure 1(a) to (f) shows that the use of reinforcement in shallow foundation and slopes involved the use of single or multi-layers of reinforcement (mainly geosynthetics), geocells and geosynthetic bags filled with granular material as a load transfer element. The studies related to the application of soil reinforcement in piled foundations and ground improvement/protection are

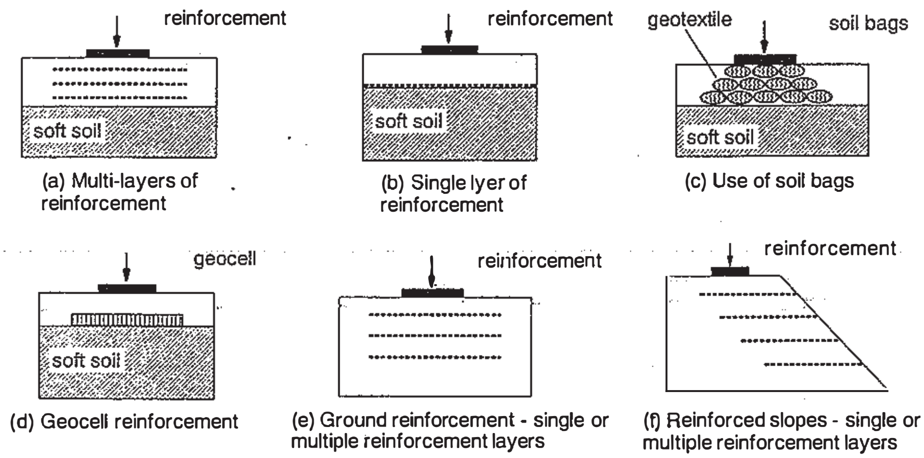

Figure 1. Cases approached by the papers of the session related to shallow foundations on reinforced soil.

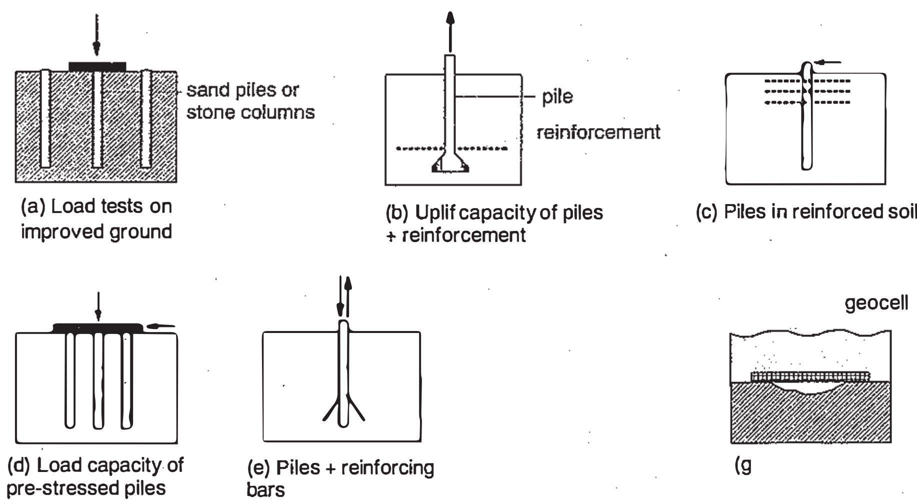

Figure 2. Cases approached by the papers of the session related to deep foundations and ground improvement.

summarised in Figure 2 (a) to (g). These applications involved the use of granular piles to improve foundation ground, pre-stressed piles, piles with reinforcing bars, ground improvement and the use of reinforcement layers to increase pile load capacity.

In the next sections the contributions published in the proceedings on the several applications listed above are summarised and discussed.

3 FOUNDATIONS OF REINFORCED SOILS

3.1 *Shallow foundations on reinforced or improved ground*

Adamczyk and Adamczyk presented a study on the settlement of continuous foundation footings on geogrid reinforced sand layers (Fig. 1a). The Authors performed numerical analyses on different arrangements of reinforced sand fill. The reinforcement tensile stiffness is not provided in their paper. The results obtained showed that the presence of the reinforcement reduced settlements and that insufficient fill compaction exerts less influence in reinforced than in unreinforced fills.

The bearing capacity of a clay foundation reinforced by a sandwiched geogrid sand system is investigated in Ghiassian and Jahannia. The Authors performed model tests and some of these tests were conducted having the anchorage of the geogrid increased with the use of nails along the reinforcement edges (for cases of clay foundation and reinforcement only). The reinforced sand layer, when present, increased the bearing capacity and reduced the settlements of the system. The Authors also observed that theoretical methods underpredicted experimental results. Quantitative extrapolation of the results to prototype conditions may be limited, because of reinforcement scaling.

Gosh et al. conducted a theoretical study on the behaviour of multi-layered reinforced granular soil resting on soft foundation (Fig. 1a). Winkler's spring hypothesis was assumed for the soft soil foundation. The study investigated the influence of several parameters, but the Authors do not comment on possible limitations of Winkler's hypothesis in this type of analysis.

Haque et al. investigated the performance of 4 stores high buildings with footing foundations resting on a geotextile-reinforced granular fill on a soft foundation (Fig. 1b) in Bangladesh. Settlements of the footings varied between 50 and 600 mm, but no significant differential settlements or cracks were observed. Unfortunately, the Authors do not provide information on soft foundation soil properties.

The analysis of two layer soil systems beneath rigid footings (Figs. 1a or 1b) is approached by Sridharan et al. The Authors employed analytical and finite element methods to predict the bearing capacity of two layered systems. Good comparisons between predictions and experimental results were observed. It is important to note that not all the data from back-analysed case histories were available to the Authors, so some of the input parameters had to be adopted. The difficulty that may be associated to this method is the choice of parameters to be adopted to the composite material formed by the granular fill reinforced by inclusions.

Matsuoka et al. investigated the mechanical properties of soil bags and their applications to earth reinforcement (Fig. 1c). Small and large scale laboratory tests were carried out and the performance of case-histories are presented. The Authors emphasise the potentials of the solution and also observed a reduction of traffic induced vibrations due to the use of the soil bags system. The long-term performance of the solution when creep susceptible reinforcement materials are used is still to be assessed.

A study on the reinforcement of soft subgrade for high speed railroads with the use of geocells (Fig. 1d) is presented in Cho et al. Field plate load tests and laboratory dynamic loading tests were performed by the Authors. They observed that the geocell reinforcement can significantly save fill thickness. The Authors also observed that the presence of a geotextile below the geocell reduced the bearing capacity of the system, but that should not happen under field conditions.

Ogisako and Ryokai studied the use of geogrids to reinforce cohesive soils (Fig. 1e). Pull-out test results were combined to finite element analyses. The Authors found good comparison between predicted and observed results from plate load tests.

Akai et al. studied the bearing capacity of reinforced foundations (Fig. 1e). Numerical analyses were conducted taking into account the presence of shear bands in the fill. The results obtained by the Authors compared well with those from conventional solutions. No comparison between predictions and observed experimental results is presented in the paper.

The effects of reinforcement tensile and bending stiffness on the behaviour of reinforced soil is investigated in Kotake et al. (Fig. 1e). Predictions from finite element analyses and model tests results are compared and the influence of factors such as reinforcement bending stiffness and length are investigated. The Authors concluded that bending stiffness is important for longer reinforcements.

Michalowski and Xin studied collapse loads on reinforced foundation soils (Fig. 1e). A theoretical analysis is presented as well as a simple equation for the estimate of the bearing capacity of a foundation soil reinforced by a single layer of reinforcement. Predictions by the solution proposed is consistent with other results in the literature. In their paper the Authors do not present comparisons between predictions and results from experiments.

The bearing capacity of reinforced granular foundation soil is investigated in Wang and Wang (Fig. 1e) . Limit equilibrium analysis was employed and the performance of a case-history is also described. The Authors observed good comparison between theoretical predictions and model test results.

Choudhary and Verma presented a study on the behaviour of footings on reinforced sloped fills (Fig. 1f). Large scale laboratory tests on grid reinforced slopes were performed using fly ash as fill material. The theoretical predictons underestimated the experimental results and no comments are presented on possible influences of boundary conditions on the test results.

Gnanendran investigated the behaviour of slopes reinforced by a single reinforcement layer subjected to footing loads (Fig. 1f). Comparisons between results from numerical analyses and model tests are made and the influence of soil compaction was also taken into account in their analyses. Poor comparison can be observed between predictions and observations of distributions of tensile loads in the reinforcement. The Author do not comment on the long term effect of compaction on horizontal stresses. It would be expected that the initially larger horizontal stresses caused by compaction would decrease in time due to reinforcement creep deformation.

3.2 *Pile foundations in reinforced ground and ground improvement or protection techniques*

Alamgir and Zaher present results on the behaviour of soft ground reinforced by granular piles in Bangladesh (Fig. 2a). Field plate loading tests o fine grained foundation soil improved by sand and stone columns were carried out. The Authors comment on the beneficial effects of ground improvement and that pile group effect was obtained for pile spacing ratios smaller than 2.5.

The use of deep geotextile coated sand columns for the improvement of very soft foundation soils is studied in Gedhun et al. (Fig. 2a). Model scale, with careful considerations on scaling, and full scale tests were performed and soft soil heave between piles was investigated. The Authors observed significant reductions of settlements and increases in soft soil undrained strength caused by the presence of the piles. The cost-effectiveness of the solution compared to alternatives and the range of required geotextile properties are not addressed in the paper.

Zhigang et al. analysed the use of geosynthetic wrapped stone columns to improve foundation ground (Fig. 2a). The Authors observed that the use of geotextile wrapping the columns improved filtration performance and increased soft ground bearing capacity. No comments are provided on additional costs or construction difficulties associated with column wrapping.

Dembicki and Duzinski presented a study on the bearing capacity of reinforced subsoil loaded by uplifted foundations (Fig. 2b). Model tests on mushroom foundations subjected to uplift forces and with the use of different types of geosynthetics were performed. It was observed that the case where a geocomposite was used as reinforcement showed the best performance. The Authors do not address possible limitations in reinforcement scaling in model tests.

The performance of laterally loaded piles in foundation ground reinforced by multi-layers of reinforcement (Fig. 2c) is investigated in Yamada et al. Model tests and theoretical analyses using the p-y concept were carried out. The Authors observed greater lateral displacement reductions for stiffer piles. Limit equilibrium analyses under-predicted the reinforcement forces.

The effectiveness of the use of pre-stressed micropiles under footings is studied in Miura et al. (Fig. 2d). Model tests were performed to investigate the effects of horizontal loads applied to the footing. The main conclusion of the paper was that pre-stressed piles yielded bearing capacity increases up to 100%. The Authors comment on the applicability of this type of solution to earthquake loading conditions, but no information on the performance of footings on pre-stressed piles under these conditions is provided.

Otani et al. also investigated the effects of horizontal loads on footings on pre-stressed piles by field tests (Fig. 2d). This is a complementary research to the one on model tests reported above. The Authors also observed that the use of pre-stressed piles yielded bearing capacity increases and reductions of footing lateral displacements.

The behaviour of reinforced foundations under uplift and push-in loads is approached in Nakai et al. (Fig. 2e). Reinforcing bars were used close to the pile tip. Numerical analyses and model tests were performed to investigate the influence of bar orientation and bending stiffness. The Authors concluded that the bars protruded diagonally downwards were the most effective against pile uplift regardless of the bar stiffness. Some deviations between predicted and observed results were observed, which may be in part attributed to the complexity of the problem under study.

Sfar and Bouassida presented a paper on jet grouting application for a quay restoration in Tunisia (Fig. 2f). Problems in a road bed in the quay were caused by lack of proper filter design. The use of jet grouting caused significant reductions on soil hydraulic conductivity and the solution chosen did not disrupt harbour activities during execution.

Spector at al. presented a paper on the use of geocell for the protection of buried pipelines against river bed erosion (Fig. 2g). The effectiveness of the solution is shown in the paper, which seems more directed towards mitigating solutions against erosion induced problems.

CONCLUSIONS

The technical session on foundations can be considered a great success. High quality papers on a wide range of applications of soil reinforcement were presented. Innovative design methods and construction solutions were also introduced.

Some matters for concern and subjects for additional researches are: modelling difficulties or limitations in model tests and numerical analyses, cost-effectiveness and construction difficulties associated with some techniques proposed, need for a better and more comprehensive assessment of the accuracy of design methods and need for a greater number of well instrumented case histories.

The study of reinforced foundations is a complex task. Therefore, much research will still be required in the coming years for a better understanding on the mechanisms of foundation reinforcement, development of accurate and comprehensive design methods and consolidation of the soil reinforcement technique to foundation problems for its use as a safe and reliable engineering solution.

REFERENCES

Complete references of the papers cited in the text can be found in the proceedings of the International Symposium on Earth Reinforcement–IS Kyushu' 2001, Technical Session on Foundations, Volume 1, pages 513 to 638.