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Milestone in earth reinforcement - TC9 activities (2001-2005) -

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ABSTRACT
The general objective of TC-9 in the period 2001-2005 was to focus on the use of full range of developed and new/novel techniques including geosynthetics, nailing, and other methods for ground reinforcement using artificial material placed in the soil. And co-operation with TC-17 whose topic was ground improvements was required. Under these guidelines, not only TC-9 meetings but also the organizing sessions have been done whenever the related international symposia/conferences were held. The joint activities with TC-17 were also examined. A beginning of the activity was the International Symposium on Earth Reinforcement (IS Kyushu 2001), which was held on November 14-16, 2001 in Fukuoka, Japan under the joint-auspices of the Japanese Geotechnical Society and the TC-9. Here in this report, the activities by TC-9 during this period are summarized. On the basis of these activities, the future prospects of TC-9 including theme and activities were also presented.

1 INTRODUCTION

TC-9 covers the professional area of the subjects on any kinds of earth reinforcement technique. The title of TC-9 had been called “Geotextiles and Geosynthetics” during the period 1994-1997. But the name of TC-9 was changed to “Geosynthetics and Earth Reinforcement” in order to match their activities in the next period 1997-2001. This was based on the great success of IS Kyushu (International Symposium on Earth Reinforcement) which were held in Fukuoka, Japan in 1988, 1992 and 1996. For this reason, the Japanese Geotechnical Society (JGS) had supported the activities of TC-9 as a Host Member Society, and a supporting committee had been established in the framework of JGS. The President of ISSMGE for the period 2001-2005 presented the new general objective for TC-9 and decided that JGS continues to support TC-9 as a Host Member Society.

This is a report on TC-9/ISSMGE activities for the period 2001-2005. First of all, the objective and terms of reference, and the members of TC-9 including those of Japanese supporting committee are introduced. Then, the activities by TC-9 during this period are summarized. Finally, the future prospects for TC-9 including their topics and activities are presented.

2 OBJECTIVE AND TERMS OF REFERENCE

The general objective of TC-9 is to focus on the use of full range of developed and new/novel techniques including geosynthetics, nailing, and other methods for ground reinforcement using artificial material placed in the soil. And co-operation with TC-17 is required. Terms of reference for the TC-9 are shown as follows:

1) To continue enhancement in developing and spreading the experiences and knowledge on earth reinforcement practice, along the lines of the objectives stipulated for this TC;
2) To promote research and development, along the lines of objectives stipulated for this TC;
3) To promote publication of education materials on earth reinforcement practice for engineers and students;
4) To contribute international symposia/conferences related to earth reinforcement; and
5) To collaborate with TC-17.

3 MEMBERS AND SUPPORTING COMMITTEE

A well-selected international group of experts were appointed as responsible members of this committee based on the candidates recommended by ISSMGE member’s societies, presided by Prof. H.Ochiai from 2001 to 2005 as a chairman and Prof. J.Otani as a secretary as well. These were finalized by the ISSMGE President. List of members are shown in the Table 1. TC-9 has also set up the supporting committee in the framework of the Japanese Geotechnical Society (JGS) in order to enhance the activities of TC-9. The members of Japanese Supporting Committee are also listed in Table 2.

4 REVIEW OF ACTIVITIES

4.1 *Basic concepts of our activities*

First of all, TC-9 has put deeply attention to the mutual communication among all the members. This communication was done under the information technology. Thus, our own website and mailing list on the e-mail were successfully established at the beginning of this term. Secondly, the Japanese Supporting Committee under Japanese Geotechnical Society was organized in order to enhance TC-9 activities.

Thirdly, TC-9 offered strong supports, which were not only technical but also of amicable, to the related conferences and regional conferences in ISSMGE. Fourthly, we tried to organize our meeting as much as we could where the related and regional conferences were held. Lastly, collaboration with TC-17 was highly concerned. Table 3 shows a brief summary of our activities with their purposes under the terms of reference. In this chapter, details of our activities are summarized. In order to complete all the terms of reference shown in Chapter 2, we set up the activity plan.

Table 1. Member List of TC9 of ISSMFE.

CHAIRMAN: Ochiai, H., Japan
SECRETARY: Otani, J., Japan
CORE MEMBERS:

Gassler, G., Germany	Gourc, J.P., France
Madhav, M., India	Oden, K., Sweden
Palmeira, E.M., Brazil	Tan, S.A., Singapore
Zornberg, J., U.S.A.	

MEMBERS:

Abramento, M., Brazil	Bouassida, M., Tunisia
Bekenov, T.N., Kazakhstan	Bathurst, R.J., Canada
Bergado, D., Thailand	Cazzuffi, D.A., Italy
Chang, D.T.T, Taiwan	Ehrlich, M., Brazil
Garcia-Mina, J., Spain	Guler, E.F., Turkey
Kvasnicka, P., Croatia	Herle, V., Czech Rep.
Heerten, G., Germany	Jones, C.J.F.P., UK
Kitazume, M., Japan	Lafleur, J., Canda
Lam, A, Hong Kong	Lawson, C.R., Malaysia
Liausu,Ph., France	Lopes, M.D.G.A., Portugal
Leshchinsky, D., U.S.A.	Lo, R., Australia
Matys, M., Slovak Rep.	Moraci, N., Italy
Rajagopal, K., India	Rathmayer, H., Finland
Rowe, R.K., Canada	Scharle, P., Hungary
Timofeeva, L.M.,Russia	Uriel, S., Spain
Voskamp, W., Netherlands	Yeo, K.C., Hong Kong
Yoo, C., Korea	

Table 2. Member List of Japanese Supporting Committee for TC9 of JGS

CHAIRMAN: Ochiai, H., Japan
SECRETARY GENERAL Otani,J., Japan
SECRETARY
Katagiri, M., Japan
Hirai, T., Japan
Miyata, Y., Japan
MEMBERS:
Aoki, M., Japan
Fukuda, N., Japan
Iizuka, A., Japan
Kitazume, M., Japan
Kojima, K., Japan
Konami, T., Japan
Kotake, N., Japan
Kumagai, K., Japan
Kuwano, J., Japan
Nagao, K., Japan
Nozu, M., Japan
Ogata, K., Japan
Otani,Y., Japan
Tsukamoto, Y., Japan
Uchimura, T., Japan
Yokota,Y., Japan
Wada, H., Japan

Table 3. Relationship between terms of reference and activity

Activity \ Terms of reference		To continue enhancement in developing and spreading the experiences and knowledge	To promote research and development	To promote publication of education materials	To contribute international symposia/ conferences	To collaborate with TC-17
TC9 web site		X	X			
IS Kyushu		X	X		X	
Organizing Sessions in the Regional Conferences and Related Conferences	12th Asia Conf. of ISSMGE (Singapore, 2003)	X	X		X	
	13th Africa Conf. of ISSMGE (Marrakech, 2003)	X	X		X	X
	3rd Asian Conf of IGS (Seoul, 2004)	X	X		X	
	Seminar on Ground Treatment (Hong Kong, 2004)	X	X	X	X	X
	Geo Frontiers (ASCE, IFAI) (Austin, 2005)	X	X		X	
Publications		X	X	X		
TC9 meeting	1st (Nice, 2002), 2nd (Boston, 2003), 3rd (Prague, 2003), 4th (Seoul, 2004), 5th (Austin, 2005), 6th (Osaka, 2005)	X	X	X	X	
Case Histories of Combined Technology		X	X	X		

These were the management of TC-9 web site, organizing IS-Kyushu, organizing sessions and TC-9 meeting in the regional and related conferences, and compiling the case histories of combined earth reinforcement technique. Relationship between the terms of reference and each activity are shown in Table 3. List of all the papers and presentation materials by TC-9 members and Japanese TC9 supporting committee member are shown in APPENDIX I.

4.2 *TC-9 Website*

TC-9 home page has been successfully used and all the formal information and the activities have been updated in this website. (TC-9 home page: http://www.nda.ac.jp/cc/users/miyamiya/tc9/) And TC9 mailing list was also used in order to discuss our activities. (TC9 mailing list: TC9GER@nda.ac.jp) In this mailing list, the non-TC9 members who have been interested in earth reinforcement technique were also added. To make full use of web site and mailing list was effective for our activities.

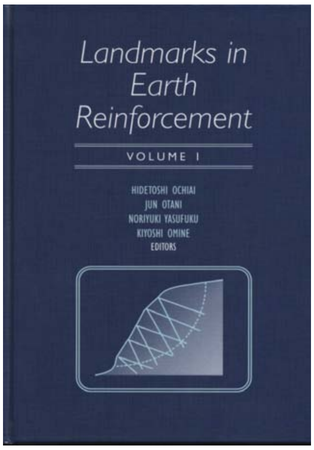


Figure 1. Proceeding of IS Kyushu 2001

4.3 *IS Kyushu 2001*

The International Symposium on Earth Reinforcement, IS Kyushu 2001, was held at Garden Palace Hotel in Fukuoka, Japan on November 14-16, 2001 under the joint-auspices of the Japanese Geotechnical Society (JGS) and TC-9. This symposium was a continuation of the three previous international symposia, IS Kyushu '88, '92, and '96 which have provided successful contributions to the development of earth reinforcement practice in geotechnical engineering.

The aim of those symposia was to discuss various problems and topics on earth reinforcement for the benefit of collecting and exchanging knowledge concerning recent developed techniques and to shear the knowledge with all the countries around the world for further development. From over the world, 212 abstracts were submitted, and finally 137 papers were accepted. These papers were published in the proceeding from BALKEMA publishers (see Fig.1). All the papers were classified into 5 categories such as 1) testing and materials, 2) embankments, 3) wall structures, 4) foundations, and 5) slopes and excavations. All the categories and countries of the accepted papers are shown in Figs. 2 and 3. It can be understood that both subjects and regions of the papers were well balanced. Total number of participants was 471.

A brief summary of the technical program was as follows: ("* ":TC9 members)

(1) Day 1(November 14)
(a) Special Lecture
1) Recent full-scale testing of reinforced soil walls and implications to design: R.J. Bathurst* (Canada)
(b) Keynote Lectures
1) Earth reinforcement practice for natural slopes: M. Hirano (Japan)
2) Issues facing reinforced soil structures: C. Lawson* (Malaysia)
(c) Technical Sessions and Poster Sessions

(2) Day 2(November 15)
(a) Keynote Lectures
1) An outlook on recent research and development concerning long-term performance and extreme loading: O. Murata (Japan)

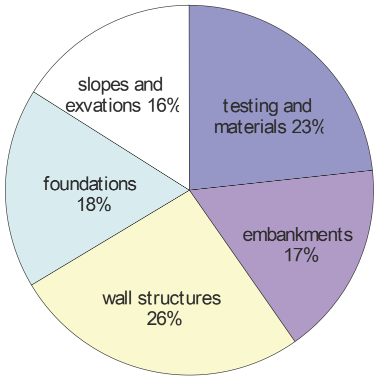


Figure 2. Accepted paper in IS Kyushu 2001 (Category)

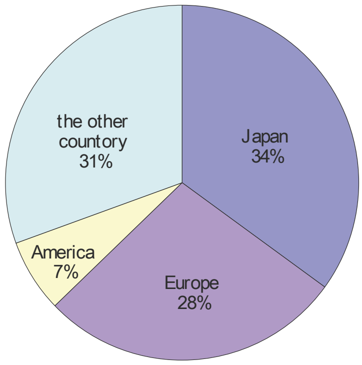


Figure 3. Accepted paper in IS Kyushu 2001 (Country)

2) Insights from consideration of case histories involving reinforced embankments, slopes and walls: Prof. R.K. Rowe* (Canada)
(b) Technical Sessions and Poster Sessions

(3) Day 3(November 16)
(a) Keynote Lecture
1) Application of geosynthetics for retaining walls and slopes for long term performance: Mr. G.R.A.Watts (U.K.)
(b) Special Session on "Soil Nailing" chaired by Dr. R. Jewell (Belgium)
(c) Summary Discussion Session on "Design Procedure" chaired by D. Leshchinsky* (U.S.A.) and J.G. Zornberg* (U.S.A.)

It is noted that many of the TC9 members played an important role such being lecturers and chairpersons, and discussion readers in some of the sessions. Japanese supporting committee members also played very important role on the scientific management of this symposium. The outcomes of TC-9 activities were also published in the second volume of the symposium proceedings. Total number of pages for this report was over 140.

Recently, a global standardization became a key issue for the testing and designs around the world and new design concepts such as limit state design and performance-based design were discussed. This symposium also offered an excellent opportunity to discuss such issues.

Photo 1. Chairmen and Panelists in 12th Asian Regional Conference 2003

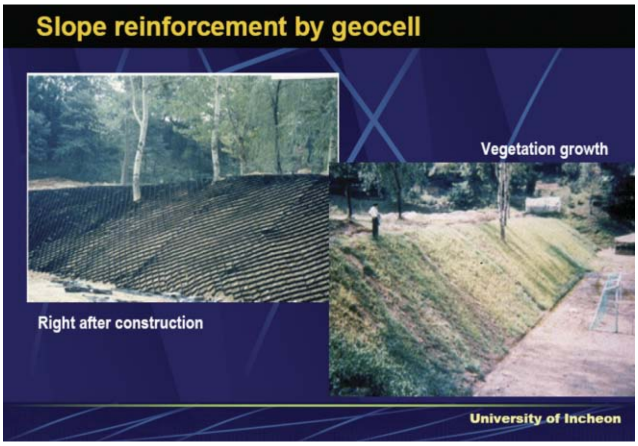


Figure 4. Combining techniques with geocell (from presentation by Prof Shin)

4.4 *Organizing Sessions in the Regional Conferences and Related Conferences*

(1) TC-9 session during 12th Asian Regional Conference

THEME: Combined technology in earth reinforcement
DATE & PLACE: August 7, 2003 / Singapore
PROGRAM:

1) Opening address: H. Ochiai (Japan)
2) General report on the accepted papers: S.A. Tan (Singapore)
3) Discussion on future development of earth reinforcement
   a) Panelists presentations: E.C. Shin (Korea), D.T. Bergado (Thailand), C. Lawson (Malaysia), and Y. Miyata (Japan)
   b) Discussion: Chaired by: J. Otani (Japan) and Y.C. Yeo (Hong Kong)

CONTENTS:

A summary of the contents of the presentations such as general report, 4 panelist presentations and session report are shown as follows. These papers are found in the Vol.2 of the proceeding of this conference.

General Report: S.A. Tan (Singapore)
In this paper, accepted paper will be briefly reviewed. Key points of discussion in this session are shown as follows.

1) The use of environment-friendly earth reinforcement system has received attention from the industry and research institute.
2) The use of composite (combined) reinforcement technique may further enhance the reinforcement effect, appears as an alternative to the design of critical reinforcement system.
3) Back analysis of case history is essential for better understanding of the behavior of earth reinforcement system, and for better deign in the future.
4) The main working mechanism of earth reinforcement system is to enhance the shear strength of soil, either globally or locally.

Korean Practice of Earth Reinforcement in Combination with Other Methods: E.C. Shin (Korea) (see Figure 4)
This paper presents a brief review of the development of reinforced earth technology and recent applications of geosynthetic reinforced earth wall and slope systems in Korea. The first part of this paper describes about construction of traditional castle wall and house, and old temple with utilizing the reinforced earth techniques which is mud mixed with the chopped rice straw and timber.

The latter part of this paper presents a brief overlook of various modern reinforced earth walls technology. Finally, three reinforced earth slope systems, which called environmentally sustainable technology, are presented.

Behavior of Reinforced Embankment on Soft Ground with and without Jet Grouted Soil-Cement Piles: D.T. Bergado (Thailand)) (see Figure.5)
Two full scale reinforced test embankments were constructed on soft Bangkok clay. Test Embankment 1 (TE1), 5.8 m height and reinforced with steel wire grids, was constructed over an unimproved soft ground. Test Embankment 2 (TE2), 6.0 m height and reinforced with hexagonal wire mesh, was constructed over a jet grouted soil-cement piles improved ground. After their construction, the maximum lateral movements in the foundation soils were 130 mm and 5 mm under TE1 and TE2, respectively. After one year of full embankment loading, the maximum settlement of TE1 was 1000 mm, while that of TE2 was only 325 mm; also, the maximum wall face lateral movements were 350 mm and 230 mm for TE1 and TE2, respectively. Moreover, the rate of consolidation settlement of TE2 is faster than TE1. Therefore, the installation of jet grouted soil-cement piles in the soft clay foundation has effected a suitable improvement in the engineering performances of the improved soft clay foundation and of the reinforced wall/embankment.

Southeast Asian Practice of Soil Reinforcement in Combination with Other Soil Improvement Methods: C. Lawson (Malaysia)) (see Figure 6)
Ground improvement techniques are increasingly applied in combination with reinforced soil structures. This paper reviews those ground improvement methods in use in Southeast Asia from the viewpoint of when they are applied, which may be during new reinforced soil construction or for (later) remedial works.

Recent Case Histories on Combined Technology with Earth Reinforcement in Japan: Y, Miyata (Japan))
Recent case histories on combined technology with earth reinforcement are summarized. The combining with the other geotechnical methods is able to spread the application field of earth reinforcement. In the present paper, thirteen current case histories are introduced and some future task is considered.

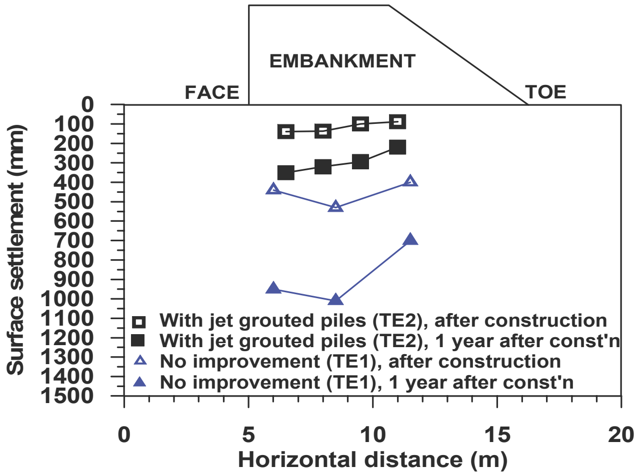


Figure 5. Combining effects with ground improvement (from presentation by Prof Bergado)

This result is an outcome of TC9 Supporting Committee setup in Japanese Geotechnical Society. Such activities will contribute for the future development of earth reinforcement technology.

Session Report: Y.C. Yeo (Hong Kong)
Discussions were held over four key points as outlined in the General Report and on the contents of the four panelist presentations. The contents of the discussions were summarized as follows.

1) On vertiver grass for vegetation:
   The grass has been used extensively in Thailand for erosion prevention and its cost is relatively inexpensive. The roots of the grass may penetrate few meters into the ground, thus reinforce the zone of soil. Hong Kong has used vertiver grass for greening slope and the cost is relatively expensive. In addition, the issue on maintenance of the grass remains to be resolved. It is noted that importing plants can be expensive as there are many additional costs to be considered, i.e. nursery, fertilizer, import license etc. It is important to use indigenous plants for developing these types of reinforcement systems to enable cost effectiveness.
2) On the case histories:
   Further efforts to promote the use of composite reinforcement technique are required for members to exchange experience on the detailing, cost, system compatibility and maintenance of the various techniques in combination. The experience of applications of composite reinforcement system outside Japan is limited.
3) On the back analysis:
   Substantial amounts of field monitoring data have been collected by the Korean Railways for earth reinforcement structures. Back analysis of these data to validate the development of finite element models will improve and enhance understanding of the behaviors of these structures. It is noted that the data will be published in due course.
4) On the earth reinforcing effects:
   It is noted that the main working mechanism of earth reinforcement systems is to create an integrated composite structure with (strain) compatibility ensured for various parts of their components. The use of slit system (metallic chain) for reinforced fill slope and geocell for slope erosion prevention in Korean was further discussed. Concern was raised over the corrosion protection of the chain over the designed life of the structure and also the economy of using geocell as an erosion mat.

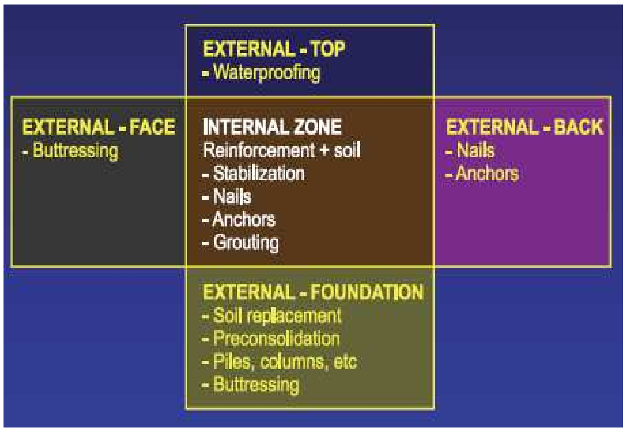


Figure 6. Classification of combine technology (from presentation by Mr. Lawason)

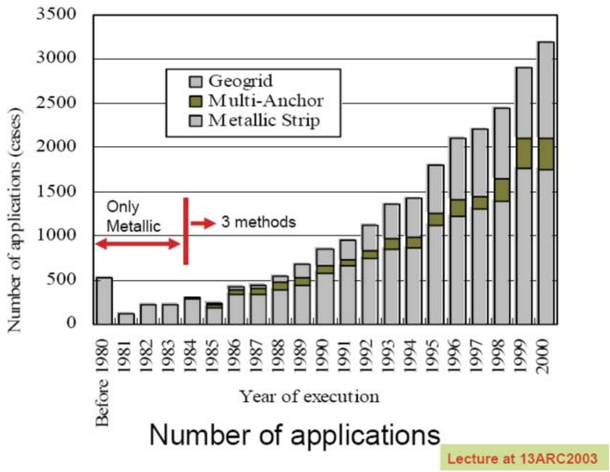

Photo 2. Session in 13th African Regional Conference 2003

5) On the soil improvement effects:
   On the use of jet grouted soil-cement piles, it was noted that mixing of cement with the Bangkok soft clay at the liquid limit produced the optimum design strength with the least percentage of cement used as compared to mixing it at the natural water content of the soft clay. In addition, the mixed material at 7-day old gave an improved permeability over the original clay. The improved ground yielded 70% less settlement than the unimproved ground. Further research on the fundamental behavior of the mixed material may be required.

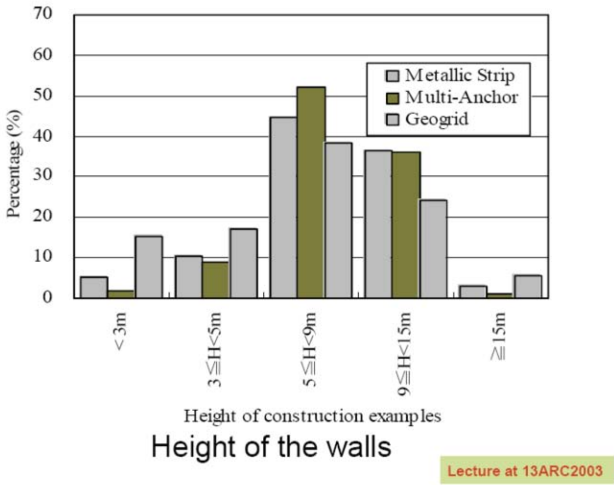
(2) TC-9 and TC-17 Jointed Special Session during 13th African Regional Conference

THEME: Reinforcement and Improvement of Soil
DATE & PLACE December 8-11,2003 / Marrakech, Morocco
PROGRAM:
1) Opening address: J.P. Grouc (France)
2) Introduce of TC-9 and TC-17: J. Otani (Japan)
3) Keynote lecture: J. Otani (Japan)
4) Presentation and Discussion
5) Conclusion and Remarks

CONTENTS:
   Abstract of keynote lecture and papers submitted by TC9 member are as follows.



(a) Number of application of reinforced soil wall



(b) Frequency of scale of constructed reinforced soil wall in Japan
Figure 7. Japanese statistical data for reinforced soil wall (from presentation by Prof J. Otani)

1) Keynote lecture:
Current case histories of reinforced soil retaining wall technique in Japan: J.Otani, H.Ochiai, Y.Miyata and T.Hirai (Japan)
Recently, earth reinforcement technique has been a powerful and economical solution to various geotechnical problems and the use of this technique has been drastically increased in Japan for this two decades. Thus, it is considered that the case histories of this technique from the beginning to up to now should be analyzed in order to discuss new trend of this technique.
In the meantime, there is a Technical Committee No.9 in ISSMGE (International Society for Soil Mechanics and Geotechnical Engineering) for the topic related to earth reinforcement and the group of Japanese Supporting Committee has investigated all the case histories of earth reinforcement techniques from 1980 to 2000. The purpose of this paper is to show the results of this investigation on behalf of TC9 Japanese Supporting Committee. Here, only the applications for the retaining wall structure will be on the discussion and the statistical changes of not only the number of various methods but also that of application type with its scale are reported. Some of the results of those analyses are summarized as follows:

1) Number of applications in 2000 is one hundred times as much as those in 1981.
2) The main application field was road construction.
3) The wall whose height from 5m to 15m is most frequently constructed.
4) On the type of foundation or used fill material for this technique, some combined technique such as piling or soil improvement may be necessary in order to use earth reinforcement technique, effectively.

Finally, the results of this paper will promise not only for Japan but also around the world the development of new earth reinforcement technique.

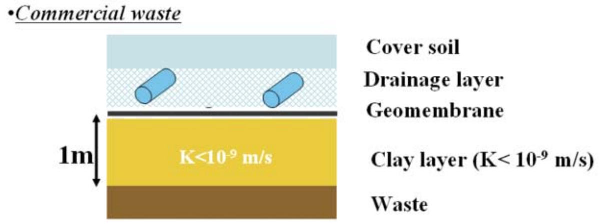
2) Technical Papers:
Constitutive parameters of compacted sandy soils: A.Iizuka, M. Hirata and H.Ohta (Japan)
The proposed paper is dedicated to the presentation of a new research program related both to the way of restricting differential settlement effect and of improving ability of a clay layer to sustain tensile strains (under low stress confinement) without cracking:

- strategy to mitigate the effects of waste settlement in landfill
- present specifications for cap barriers
- tests of characterization of the tensile behavior of fine soils in laboratory and in the field
- micro- reinforcement of fine soils by short fibers
- macro-reinforcement of a mineral layer by a geosynthetic .

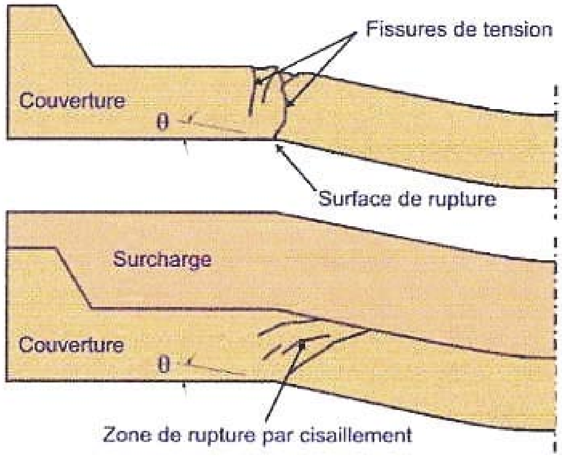
The geosynthetic-reinforced soil structures consist of two elements: one is compacted soil and the other is geosynthetics. The reinforcement effect should be understood as that soils and the geosynthetics are unified and show their fresh strength and rigidity as a composite material. The strength and rigidity of geosynthetic-reinforced soil structure come out as a result of mechanical interaction between soils and geosynthetics. Therefore, it is quite important to grasp the shear characteristics of soil itself. This paper describes the mechanical behavior of compacted soils and discusses the applicability of an elasto-plastic constitutive model to the compacted soils based on a series of laboratory test results obtained from shear box tests under the condition of constant volume. Particularly in this paper focused is on describability of the dilatancy characteristics of the compacted soils and to applicability of the elasto-plastic constitutive model proposed by Sekiguchi and Ohta. Despite that the Sekiguchi and Ohta's constitutive model has been originally proposed for saturated clayey materials, the similarity in the mechanical behavior between the compacted soils and over consolidated clays encourages the authors to apply the model for such essentially unsaturated compacted sandy soils. A key is how the compression and shear behaviors of the compacted soils can be characterized in terms of the effective stress.

In this paper, the equivalent pre-consolidation pressure is introduced to quantify the compaction degree of the compacted soils and thus a rational determination procedure of constitutive parameters needed in the analysis is proposed.

Soft soil improvement due to vivrocompacted columns installation: J.M. Debats, Z. Guetif and M. Bouassida (Tunisie)
Settlement estimation for soils reinforced by columns is currently done without taking into account improvement of the initial soil due to columns installation. Even though, as shown by in situ control tests, the use of vibrocompaction methods leads to an increase of resistance of the initial soil. The evaluation of this in



(a)



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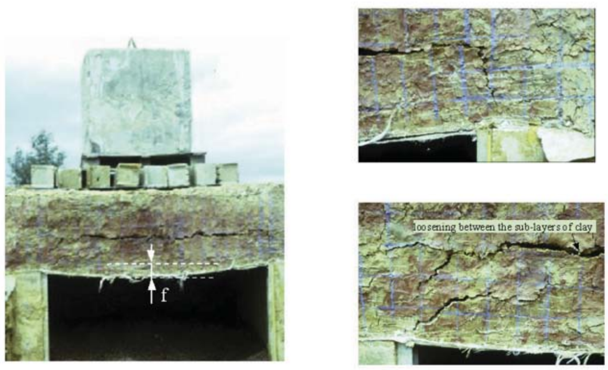


(c)

Figure 8. Improvement of the capability to sustain differential settlement with geosynthetics (from presentation by Prof Grouc)

situ soil improvement will be particularly interesting to evaluate when primary consolidation is accelerated by columns with high permeability material (clean sand, stone, etc..).

Considering a unit cell model with improvement ratio of 15 %, the present contribution illustrates the increase in deformation modulus of a soft clay after vibrocompacted column installation. Using the Plaxis software (version 8) calculation were conducted by considering two elasto-plastic behavior models (perfectly plastic, and hardening soil: HSM) for the soft clay. The column installation with final diameter of 1,1 m was simulated as lateral expansion due to a uniform cylindrical deformation in the soft clay. The influence of parameters such as improvement area ratio, drained Poisson's ratio, thickness of sand layer surcharge and radius of the soil body in which the expansion takes plade were studied through analysis of stress states in the clay surrounding the column. Comparison of states of stress before and after a consolidation period taken equal to 11 months in the soft clay leads to the following results.

Photo 3. TC9 members attending Session in Geo-Asia 2004

1) Through calculation of effective mean stresses ratio the improvement of the soft soil modulus is found equal to some 60% when using the perfect plastic behavior model while the prediction made by the hardening soil model (HSM) leads to an improvement of 100%.
2) The improvement of soft soil modulus still takes place even if the surcharge (due to a sand layer) is reduced.

From these results it can be inferred that taking into account the improvement of soft soil stiffness due to the installation of vibro-compacted stone columns could lead to substantial savings in the quantity of stones needed, as compared to the present design uses.

Landfill cap cover issue –Improvement of the capability to sustain differential settlement": J.P. Gourc, O. Ple and P. Villard (France)

From these results it can be inferred that taking into account the improvement of soft soil stiffness due to the installation of vibro-compacted stone columns could lead to substantial savings in the quantity of stones needed, as compared to the present design uses.

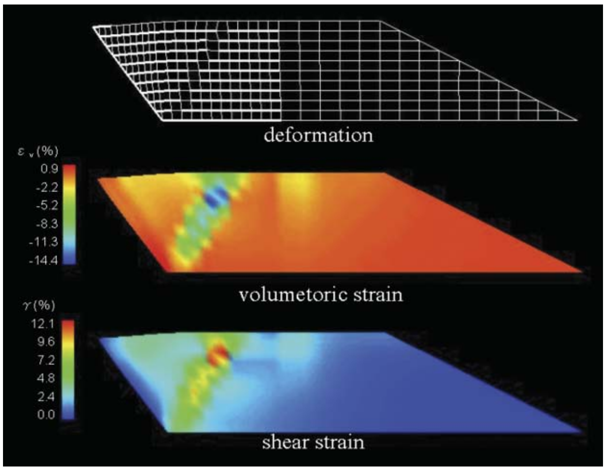
Confinement of domestic and industrial waste in controlled landfill is a very topical issue. Generally speaking, the cap liner topping the dome of the waste disposal should meet of several requirements related mainly to the tightness with regard to the external rainfall water (to prevent increasing uncontrolled leachate production) and simultaneously to the tightness with regard to the internal biogas (to increase their value following the bioreactor concept).

The cap barrier consists of a complex multi components system of mineral and geosynthetics layers following regulations varying from country to country, but supposed to satisfy the same requirements (tightness as indicated above and collection of fluids).

There is a major concern about preserving the barrier properties in spite of large deformations of the waste body: not only an average compression strain level of 20% is quite common, but also significative differential surface settlements could be expected, due to the heterogeneity of the nature and height of the refuse .It is well known that clayed soil used in isolation or in association with geosynthetics for cap liners is likely to crack under bending solicitation.

It is noted that the contents of TC-9 session during Asian Regional Conference in Singapore was also reported during this session.

(a) Field test



(b) Analysis
Figure 9. The role of numerical simulation for geosynthetic reinforced soil structures (From presentation byProf. Iizuka)

(3) Special Session at 3rd Asian Regional Conference on Geosynthetics
THEME: Role of numerical analysis on earth reinforcement
DATE: June 21-22, 2004
PLACE: Seoul, Korea
PROGRAM:
1) Opening address: H. Ochiai (France)
2) Keynote lecture: A. Iizuka (Japan)
3) Panelist presentations and Discussion
4) Conclusion and Remarks
CONTENTS:

Abstract of paper of general report, 4 panelist papers and session report are as follows. These paper are appeared in the proceeding of this conference.

1) Keynote Lecture:
The role of numerical simulation for geosynthetic reinforced soil structures - from laboratory tests to full scale structures – : A. Iizuka (Japan)
Ohta et al. carried out a series of field experiments of geosynthetic-reinforced soil structures for a period from 1992 to 1996 in Kanazawa, Japan, the soil bridge, the embankments having overhanging cliff and soil cantilevers. These trial soil structures showed amazingly higher levels of strength and rigidity as a unified composite material than expected. This strongly motivated the authors to investigate the mechanical interaction between compacted soil and geosynthetics. In this paper, the authors focus on the confining effect brought by geosynthetic-reinforcement. First, field experiments carried out by Ohta et al. are presented. These experiment results would be useful for calibration of not only numerical methods but also new design methods.

Next, the compression and shear properties of soil used in the experiments are described. Herein, a series of shear box tests under the condition of constant volume are performed. Furthermore, a consistent procedure to specify the constitutive parameters of the compacted soil is proposed, when the compacted soil is modeled as an elasto-plastic material, in which a key is estimate of equivalent pre-consolidation stress. After that, using the proposed method, finite element simulations of field experiments are carried out. The computed predictions are compared with the monitored results. However, the compacted soil is essentially unsaturated. Its mechanical properties are governed by suction remaining in the compacted soil. Then, finally, a simple idea to estimate the equivalent pre-consolidation stress considering the suction remaining in the compacted soils is presented in this paper.

2) Panelist Presentations:
Design of a Geosynthetics Reinforced Segmental Retaining Wall in a Tiered Arrangement -Use of Numerical Modeling as Design Aid: C. Yoo (Korea) :
This paper presents a case history illustrating the use of finite-element procedure as a design aid for construction of a 12-m high geosynthetic-reinforced segmental retaining wall (SRW) in a tiered configuration on a yielding foundation containing a layer of relative soft soil deposit. On account of the concerns raised by the owner with regard to the adequacy of the original design in terms of the reinforcement distribution, a verified finite-element model was employed to examine the effect of foundation yielding on the wall behavior and to find an optimum reinforcement distribution. The finite-element analysis provided relevant information on the mechanical behavior of the wall that was otherwise difficult to obtain from the limit equilibrium based current design approaches. Practical implications of the findings obtained from this study are highlighted in this paper along with the role of numerical modeling in the design of geosynthetic-reinforced retaining walls.

Finite Element Analysis of a Soil Nailed Slope -Some Recent Experience: S. A. Tan (Singapore)
This paper presents some recent experiences on the use of Finite Element Modeling in the back analysis of an instrumented soil nailed slope in Singapore. Geotechnical instrumentation consisted of sensors located within the reinforced mass and vibrating wire strain gages along selected soil nails. The mobilizations of soil nail forces at dimensional finite element analysis were performed to replicate field behavior. It is known that the analysis of soil nailed structures is essentially a three dimensional (3D) problem which requires huge computational resources. In engineering practices, it is ideal to simplify complex 3D problems into two-dimensional (2D) so that large parametric finite element analysis can be made reasonably well to verify and optimize soil nail design concepts. To do this, the simplification process has to be good and represent the insitu boundary conditions. In this paper, apart from assessing the legitimacy of 2-D Finite element analysis, it will be shown that higher order soil models and interface models and interface models should be used to capture adequacy the real behavior of soil nailed slopes. The assessment of factor of safety based on FEM will be shown and are compared to conventional methods.

Photo 4. Technical Seminar in Hong Kong 2004

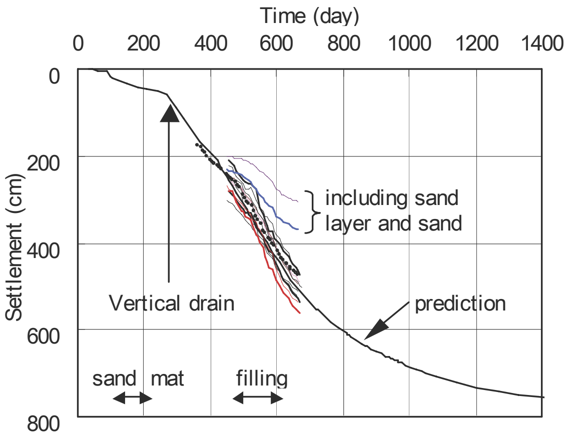


Figure 10. Evaluation of design of ground improvement by monitoring results (from presentation by Dr. Katagiri)

Application of Numerical Modeling to the Design of Reinforced Soil Walls for Infrastructure Projects -Some Australian Experiences: R. Lo (Australia)

The use of geosynthetic reinforcement encourages innovation in the design of reinforced soil walls. However, conventional design rules may no longer be adequate for these innovative wall configurations. Numerical analyses contribute to the design of these innovative walls even under severe project constraints. Two cases are reviewed, with the second one being studied in detailed.

(4) TC-9 and TC-17 Jointed Seminar in Hong Kong
THEME: One-Day Seminar on Ground Treatment
DATE: April 17, 2004
PLACE: Hong Kong
PROGRAM:
1) Opening address: President of Hong Kong Geotechnical Soc.
2) Introduction of technical committee TC-9 and TC-17: J. Otani (Japan)
3) Session about Soft ground treatment
4) Session about clay foundation
5) Session about foundation improvement

CONTENTS:

This seminar was made plan as a memorial event for the start of Hong Kong Geotechnical Society. 13 speakers gave lectures. Contents of lecture by TC9, TC17 and Japanese supporting committee members are as follows.

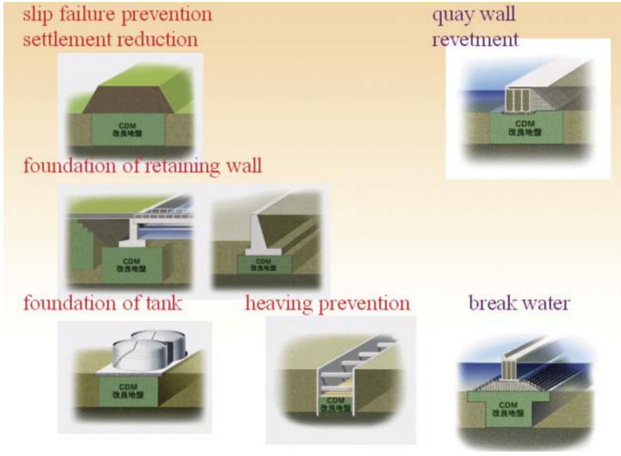


Figure11. Development of Pneumatic Flow Mixing Method and its Application (from presentation by Dr. Kitazume)

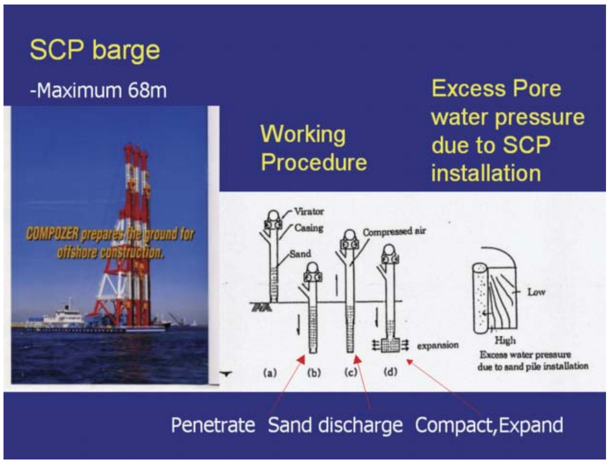


Figure 12. Sand Compaction Pile Method (from presentation by Dr. Nozu)

Soil sedimentation and vertical drain method: M. Katagiri (Japan)

<Main contents>
1) Problems in reclamation with dredged clay
2) Vertical drain for dredged clay foundation
3) Construction flow
4) Key issues in the construction
5) Design of ground improvement for rapid construction
6) Case Study

Development of Pneumatic Flow Mixing Method and its Application: M. Kitazume (Japan)

<Main contents >
1) Deep Mixing Method-historical review of R&D in Japan-
2) Classification of Deep Mixing Method
3) CDM method (machine & system)
4) DJM method (machine & system)
5) Comparison of wet and dry method
6) Jet And Churning System
7) Application
8) Execution procedure
9) Quality Control
10) Design procedure and past records

Photo.5. Technical Seminar in Geo-frontier 2005

Sand Compaction Pile Method: M. Nozu (Japan)
<Main Contents>
1) Outline of Sand Compaction Pile (SCP) Method
2) Design procedure for SCP to clayey ground
3) Applications of SCP in Japan
4) Strength increase of inter-pile clayey soil

(5) Co-sponsored session between TC-9 and ASCE during Geo-Frontiers
THEME: International Perspectives on Soil Reinforcement Applications
DATE: January 24, 2005
PLCAE: Austin, U.S.A.
CONTENTS:
In this session, 12 speakers gave presentation about Australian, Brazilian, European, Japanese and United State perspective for the geosynthetics reinforcement for pavement system, soft foundation, landfill, wall and slopes. Abstract of TC9 member's papers are as follows. These papers are appeared in the proceeding of this conference.

Geosynthetic Reinforcement for Soft Foundations: Brazilian Perspectives: E. Palmeira (Brazil)
Brazil has large regions of its territory covered with soft soil deposits. Some of these deposits can be over 40m deep with very low shear strength. These types of situations pose important challenges for designers and contractors in civil engineering works. In this context geosynthetics can be effectively employed as reinforcement and its use has increased markedly in the last decades in the country. The same applies to the use of prefabricated vertical drains for the acceleration of soft soil consolidation. This paper presents the Brazilian perspectives on the use of geosynthetics in such applications. A case-history is also presented and discussed.

Geosynthetic Reinforcement in Landfill Design: European Perspectives: J.P. Gourc (France)
Stability of Geosynthetic Lining Systems is, from a geotechnical standpoint, a complex matter. Two geotechnical questions are identified: sliding of the geosynthetic lining system on the slope and pull-out strength of the geosynthetic anchorage at the top of the slope. Research programs carried out in France on these topics, are presented and related to the two following topics: -Large scale experimentations on actual slopes are especially emphasized. The observations derived from the tests and their detailed interpretation are very fruitful, as they highlight specific local in-

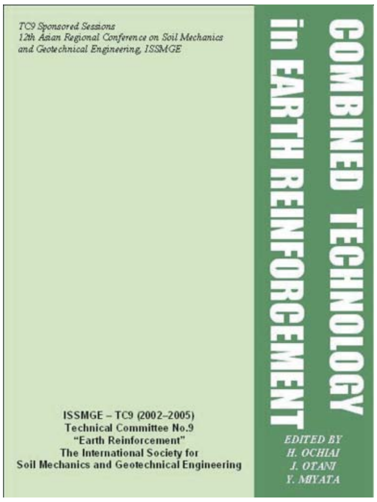


Figure 13. Special Publications "Combined Technology in Earth Reinforcement

teraction behavior between soil and geosynthetics. These aspects are not taken into account in design methods, in particular the effects of wrinkles and real relative displacements of the geosynthetics along the slope. The behavior of the anchorage of geosynthetics sheets at the top of a slope is a decisive factor when it comes to designing geosynthetic-lining systems on slopes. In order to optimize the geometry of the structures in question (to reduce the area taken up by the anchorage at the top of the slope), anchorage solutions using trenches of varying forms are sometimes used. Large scale experimentations and a theoretical approach of this problem were carried out and are presented in this paper.

Geosynthetic Reinforcement in Landfill Design: US Perspectives: J.G. Zornberg (U.S.A.)
Geosynthetic reinforcement in landfill applications in the US has involved conventional reinforced soil structures and veneer stabilization with reinforcements placed along the landfill slope and anchored at the crest. In addition, innovative approaches have been recently implemented in the US to reinforce landfill covers and base liners. This includes horizontally placed geosynthetic reinforcements, which are anchored into solid waste, and fiber reinforcement to enhance the shear strength of the soil liner material and the interface shear strength between the soil liner and texture geomembranes. This paper presents a framework for the design of steep reinforced liners. Recent case histories illustrating the use of the different geosynthetic reinforcement applications are also presented to document the different approaches in specific projects.

Geosynthetic-Reinforced Soil Walls and Slopes: Japanese Perspectives: J. Otani (Japan)
The objective of this paper is to present a state of the art report on geosynthetic-reinforced soil walls in Japan. From 1996 to 2005, Japanese Geotechnical Society (JGS) has been in charge of the Technical Committee No.9 on earth reinforcement set up by International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE). This paper summarizes the current activities of geosynthetic-reinforced soil walls in Japan including design procedures and case histories. It is noted that most of the contents in this paper was prepared by the members of the Japanese supporting committee.

Photo 6. 1st meeting in Nice 2002

Photo 7. 2nd meeting in Boston 2003

Geosynthetic-Reinforced Soil Walls and Slopes: European Perspectives: C.J.F.P. Jones (U.K)
This paper provides a brief review of developments and current perspectives of reinforced soil structures and slopes in Europe. A number of innovations and studies in reinforced soil technology have been introduced in recent years. Improved reinforcing materials have been introduced which include new forms of conventional geogrid reinforcements, composite materials providing combined drainage and reinforcement, and electrically conductive reinforcements. Research has resulted in a better understanding of the residual creep strength of geosynthetic materials and the influence of a seismic event on the long-term strength of geosynthetic reinforcement. Analytical methods continue to be developed and the use of reinforced soil in construction is being promoted by the introduction of new International and National Codes of Practice. This report provides details of these developments.

4.5 *Publications*

Following is the list of our publications:
(1) Proceedings of International Symposium on Earth Reinforcement (IS Kyushu), Vol.1 and 2, BALKEMA, November, 14-16,2001.
(2) Proceedings of 12th Asian Regional Conference Vol.2, pp.1303-1335, 2003.
(3) Proceedings of 13th African Regional Conference, pp.673-768, 2003.

Table 4. Compared design manual for reinforces soil wall (from the presentation by Zornberg)

Country	Agency	Reference
Australia	RTA, NSW DOT	RTA (1997)
	OMRD, QL DOT	QMRD (1997)
Brazil	GFSSCC	Geo Rio (1989)
Canada	CGS	CGS (1992)
Germany	GSMFE	EBGEO (1997)
Hong Kong	GEO	GEO (1989)
Italy	IMPW	IMPW (1988)
Japan	PWRC	PWRC (2000)
United Kingdom	BSI	BSI (1995)
United State	AASHTO/FHWA	FHWA (1997)
	NCMA	NCMA (1998)

Table 5. Considered item in the comparison of design manual (from the presentation by Zornberg)

Performance criteria	Sliding, Overturning, Eccentricity of base, Bearing capacity, Compound and deep seated stability, Seismic stability, Pullout resistance
Soil-reinforcement interaction	Default soil reinforcement interaction (static and dynamic)
Reinforced fill	Maximum cohesion, Default value ϕ, Peak or constant volume ϕ, Gradation requirements, Plasticity index, Soundness, PH
Geosynthetics reinforcements	Ultimate tensile strength, Material safety factors, Factor of safety in the design
Design methods/ considerations	External and internal stability, seismic stability, limitations for lay out of reinforcement etc.

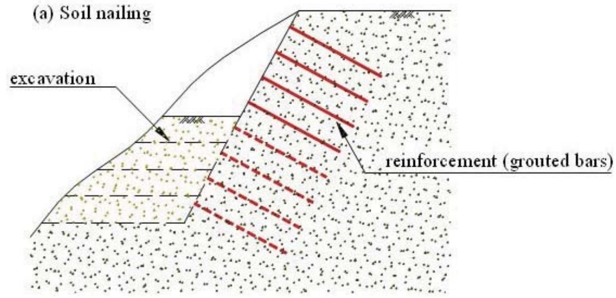
(4) Proceedings of 3rd Asian Regional Conference on Geosynthetics, pp. 153-203, 2004.
(5) Proceedings of Seminar on Ground Treatment, total number of pages:167, 2004.
(6) Proceedings of Geo-Frontiers, CD-ROM, 2005.
(7) Special Publications "Combined Technology in Earth Reinforcement, editors by H.Ochiai, J.Otani, and Y.Miyata, Total number of pages:30, 2004.

All list of papers and presentations by TC9 members and Japanese TC9 supporting committee member is shown in Reference.

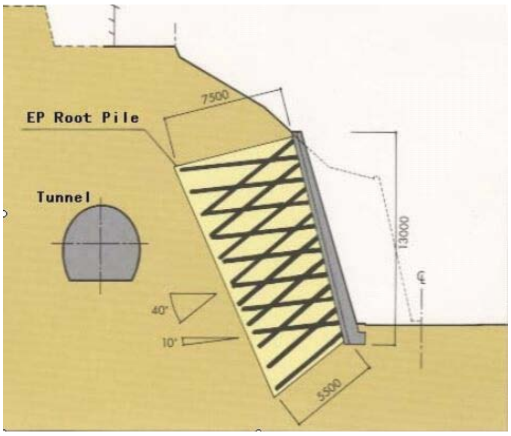
4.6 *TC-9 meetings*

TC-9 has set up mailing list which is issmge_tc9@cc.nda.ac.jp in order to discuss on e-mail. And meantime, the meetings during the conferences on the related topics with earth reinforcement were organized as much as possible. Followings are the contents of the meeting, in which we have done in the period 2001-2005.

(1) 1st meeting
DATE: September 23, 2002 from 16:30 to 18:00
PLACE: Nice, France during 7th International geosynthetics Conference
AGENDA:
/ Opening address by Chairman (Prof. Ochiai)
/ Introduction of new TC-9 (including the topics which are concerned by TC-9)



(a) Reinforcing soil for excavation technique



(b) Reinforcing soil for cutting slope

Figure 14. Reinforcing soil technique for slope and excavation (from presentation by J.Otani)

/ Introduction of members
/ Terms of reference and action plan
/ Possible our activities
/ Short presentations

Dr. Miyata(Japan) of Japanese Supporting Members introduced the case histories of the "Earth Reinforcement Technique Combined with Other Methods" such as pile foundation, soil improvement, some pre-stress and others.
PARTICIPANTS: 35

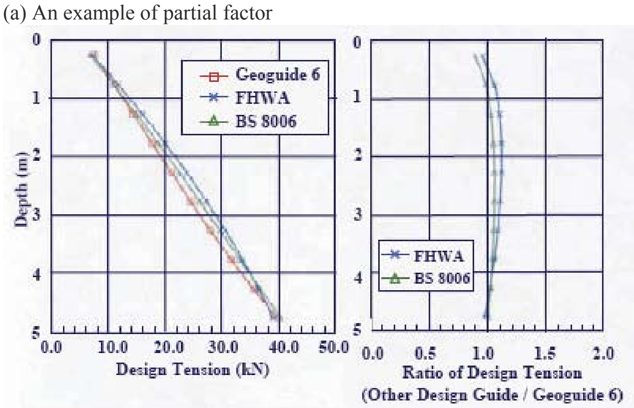
(2) 2nd Meeting
DATE: June 25, 2003 from 12:30 to 13:30
PLACE: MIT, Boston, U.S.A. during Pan American Conference
AGENDA:
/ Presentation 1: Comparison of International Design Criteria for Geosynthetic-Reinforced Soil Structures (by J.Zornberg)
/ Presentation 2: Summary of procedures/criteria/practice in Japan (by J.Otani)
/ Discussion - Future activities in this area to be organized by TC-9
PARTICIPANTS: 5

(3) 3rd Meeting
DATE: August 24, 2003 from 15:00-17:00
PLACE: Prague, Czech during European Regional Conference
AGENDA:
/ Introduction by Chairman of TC9 (by H.Ochiai)
/ Report on the TC9 session during Asian Regional Conference held in Singapore in August, 2003 (by J.Otani)
/ Presentations for some of the activities in Europe

Photo 8. 3rd meeting in Prague 2003

Loading	Partial Load Factor, γ_f Ultimate Limit State	Serviceability Limit State
Dead load due to weight of the reinforced fill	1.0	1.0
Dead load due to weight of the facing	1.0	1.0
External dead load (e.g. line or point loads)	1.5	1.0
External live load (e.g. traffic loading)	1.5	1.0
Seismic load	1.0	1.0
Water pressure	1.0	1.0

(a) An example of partial factor



(b) Comparison of three design codes

Figure 15. Geoguide 6 (from presentation by Prof. Jones)

Photo 9. Case study for failure of reinforced soil wall (from presentation by Prof. Sharle)

Photo 10. 4th meeting in Seoul 2004

Photo 11. 5th meeting in Austin 2005

/ Presentations by European members
Guide to reinforced fill structure and slope design (by Jones, UK)
Reconstruction of damaged earth walls in Hungary (by Scharle, Hungary)
A case history of large strain consolidation (by Kvasnicka, Croatia)
PARTICIPANTS: 10

(4) 4th Meeting
DATE: June 23, 2003 from 13:00-14:00
PLACE: Seoul, Korea during GeoAsia 2004
AGENDA:
/ Opening Address by Chairman of TC-9, Prof. Ochiai of Kyushu University, Japan
/ Brief summaries on our activities so far
/ Contents of final report by TC-9
/ Discussion on Chairmanship of next period of TC-9 (from 2005 to 2009)
PARTICIPANTS: 23

(5) 5th Meeting
DATE: January 25 from 17:00 to 19:00, 2005
PLACE: Austin, U.S.A. during Geo-Frontiers
AGENDA:
/ Summary of our activities

Photo 12. 6th meeting in Osaka 2005

/ About final reports
/ About session at Osaka conference
/ About next TC-9 host
/ About next IS Kyushu
/ Schedule of next (final) meeting
PARTICIPANTS: 15

(6) 6th Meeting
DATE: September 15, 2005 from 12:30-13:30
PLACE: Osaka, Japan during 16th ICSMGE
AGENDA:
/ Opening Address by Chairman of TC-9, Prof. Ochiai of Kyushu University, Japan
/ Summaries of our activities
/ Final report submitted to secretary of ISSMGE
/ Discussion on future activity of TC-9 (from 2005 to 2009)
/ Closing address by Secretary of TC-9, Prof. Otani of Kumamoto University, Japan
PARTICIPANTS: 16

4.7 *Meetings of Japanese Supporting Committee*

The meetings were held by Japanese Supporting Committee for three or four times in each year and the discussion by this supporting committee were a guideline for the whole activities by TC-9. Meetings were held as following schedule:

/ 1st meeting: June 5, 2002, Tokyo
/ 2nd meeting: September 2, 2002, Tokyo
/ 3rd meeting: December 4, 2002, Tokyo
/ 4th meeting: March 13, 2003, Tokyo
/ 5th meeting: July 3, 2003, Akita
/ 6th meeting: November 28, 2003, Tokyo
/ 7th meeting: March 17, 2004, Tokyo
/ 8th meeting: June 17, 2004, Tokyo
/ 9th meeting: September 30, 2004, Tokyo
/ 10th meeting: December 12, 2004, Tokyo
/ 11th meeting: March 17, 2005, Tokyo
/ 12th meeting: June 8, 2005, Tokyo

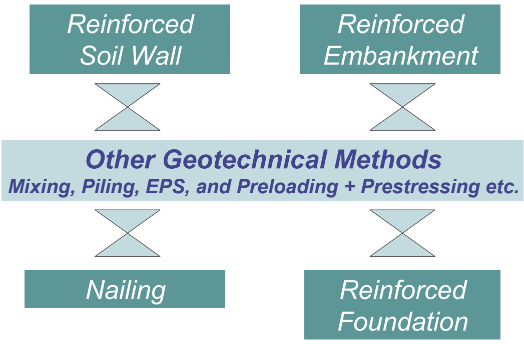


Figure16. Earth reinforcement combing other geotechnical methods.

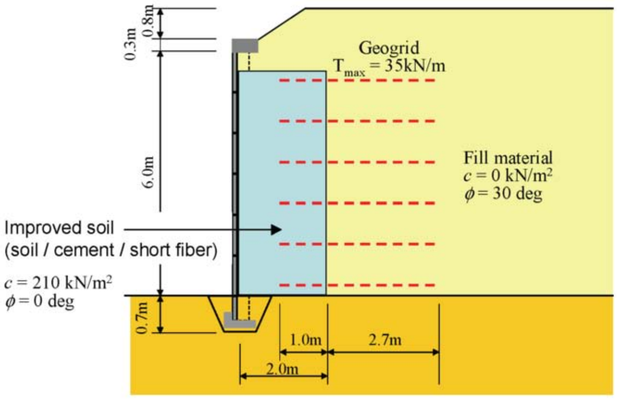


Figure 17. RSW combined with mixing of cement and short fiber.
(From Dr.Hirai, member of Japanese Supporting Committee)

4.8 *Case history of combined technology*

(1) Basic Concept of activity

Earth reinforcement has been a powerful and economical solution to various geotechnical problems. Reinforced soil wall, reinforced embankment, nailing and reinforced foundation are used in various geotechnical practices. Recently, the number of application of earth reinforcement combining with the other geotechnical methods is increased in Japan. In the background of this increasing, there are demands for public works shown as follows, i) reduction in construction costs, ii) realization of high mechanical performance, and iii) countermeasure for global or regional environment. Combined technology with earth reinforcement is mixing, piling, EPS, preloading and prestressing (PLPS) and others. Combination pattern is shown in Figure 16. TC9 Supporting Committee setup in Japanese Geotechnical Society summarized the recent case histories on combined technology with earth reinforcement. Trying to give overview on the combining methods may be effective for applying earth reinforcing methods more widely. In this paper, the thirteen case histories are introduced on four combination pattern as shown in Figure 16. Introduced case histories were given by the member of the Japanese Supporting Committee for TC9. Those are shown in APPENDIX II.

(2) Case Histories

(2.1) *Introduced Case Histories*

Earth reinforcement combining with other geotechnical methods can be classed with considering application of earth reinforcement and kind of combined method. The Classification is shown in Table 6. Application of earth reinforcement was divided into four patterns such as retaining wall, embankment, slope and foundation. The combined method was divided into three types such as improvement of soil properties, using of other member and PLPS (Preloading and Prestressing).

Ex. n in table 6 means example number for case history introduced in this paper. The combining method is rapidly advancing. There must be not only introduced method but also other combining method. However this classification is a first try to focus on combing method, it will be effective for future development of earth reinforcement.

(2.2) *Reinforced Soil Wall*

Reinforced soil wall (RSW) has been applied for important and permanent structure such as highway road, abutment, rail road and others. In these applications, high stiffness and stability are required in the life time. The other side, sandy soils are mainly used in the traditional construction of RSW. Making of good use of inferior quality soil such as high water contents cohesive soil is needed due to reduction of disposal area and preserving of environment. Combining with the other geotechnical methods is a solution for the above demand. In this paragraph, five case histories on RSW are introduced.

Ex.1 Combination with Mixing of Cement & Short Fiber

The section of RSW combined with mixing of cement and short fiber is shown in Figure 17. The Mixing of cement and short fiber is able to increase shear strength and stiffness of soil. Construction at near facing has been a task in reinforced soil wall method because it is difficult to compact fill material at there. The connection portion between facing and reinforcement has been pointed out as a structural weak point. In this case the mixed soil was used at the connection portion. This combining method is able to improve the stability of connection portion and achieve labor-saving.

Ex.2 Combination with Mixing of Foam Grass

The section of RSW combined with mixing of foam glass is shown in Figure 18. Photo. in the construction period is shown in APPENDIX II. Mixing of foam glass is a technology of light weight geo-material. It is able to improve shear strength and stiffness of soil and to be light weight. In this case the mixed soil is used as main fill material of RSW. Density of the mixed soil is about 1.1 (kN/m^3) and cohesion c or internal friction angle ϕ is 20 (kN/m^2) or 41 (degree) respectively. This combining method is able to achieve required stability by shorter reinforcing member.

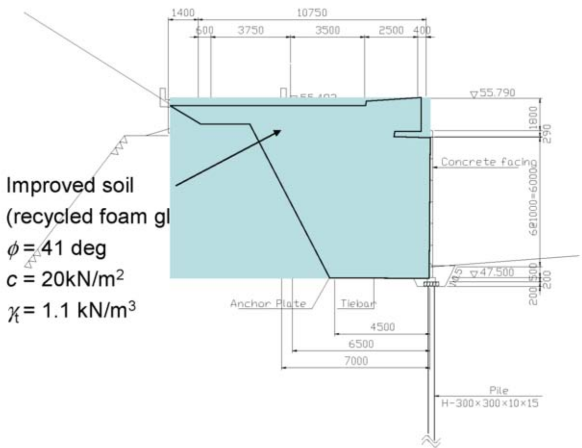


Figure 18. RSW combined with mixing of foam grass.
(From Mr.Konami, member of Japanese Supporting Committee)

Table 6. Earth reinforcement combing other methods introduced in this paper

Combined Method / Application of Reinforcement	Improvement of Soil Properties		Using of other member	PLPS
	Densification	Mixing & Grouting		
Retaining Wall	-----	Ex. 1, Ex. 2, Ex. 3	Ex. 4 (EPS)	Ex.5
Embankment	Ex.6, EX.7	-----	Ex. 8 (Impact Absorber)	Ex.7
Slope	-----	Ex. 9, Ex. 10	Ex. 11 (Ring Reinforcement)	-----
Foundation	-----	Ex. 13	Ex. 12 (Pile)	-----

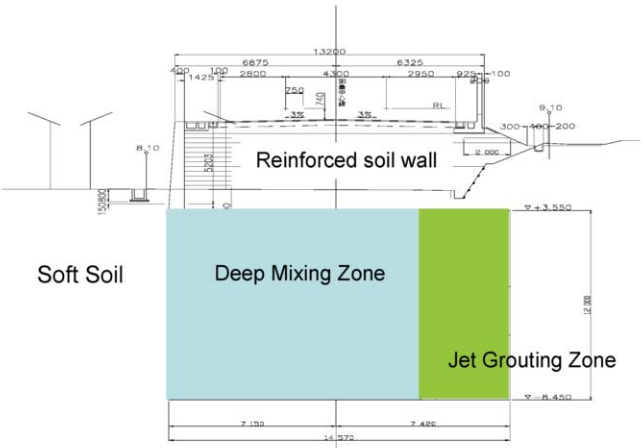


Figure 19. RSW with deep mixing and grouting.
(From Dr.Kotake, member of Japanese Supporting Committee)

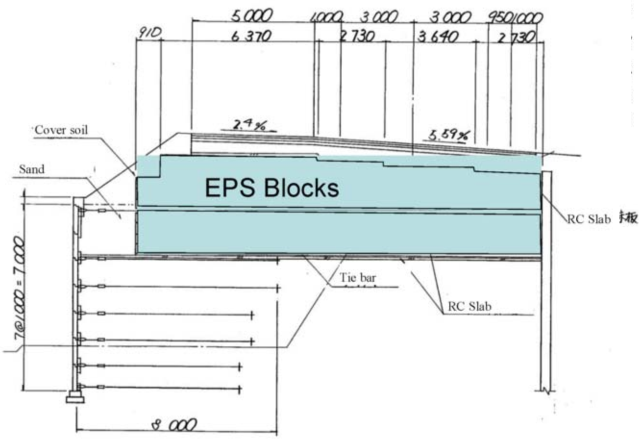


Figure 20. RSW combined with EPS Blocks.
(From Mr.Konami, member of Japanese Supporting Committee)

Ex.3 Combination with Deep Mixing and Grouting
The section of RSW combined with deep mixing and grouting is shown in Figure 19. RSW with rigid facing is often used for rail road. In the restoration or extending of rail road, construction work without stopping of train running is often demanded. In this case history, deep mixing and grouting were conducted before constructing of RSW with rigid facing.

By applying combining method, the undesirable deformation due to construction work of RSW can be prevented in neighboring construction.

Ex.4 Combination with EPS Blocks
The section of RSW combined with EPS block is shown in Figure 20. Photo. in the construction period is shown in APPENDIX II. EPS block is a light weight geo-material (its density = 0.9-1.2kN/ m^3) and has high stiffness. In this case the EPS blocks are

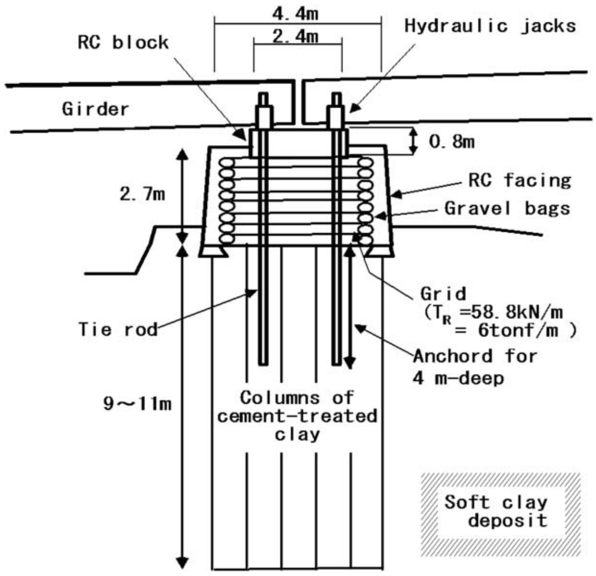


Figure 21. RSW combined with preloading and prestressing.
(From Dr.Uchimura, member of Japanese Supporting Committee)

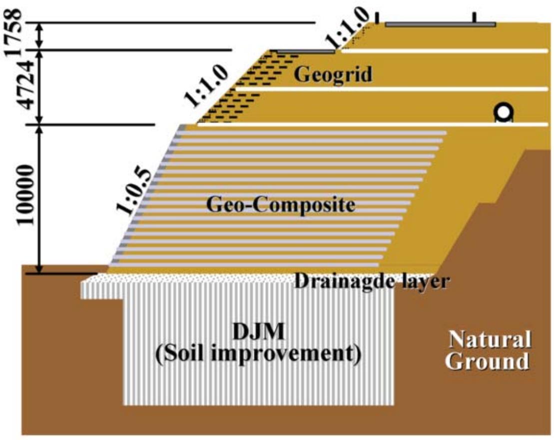


Figure 22. RE combed with drainage.
(From Dr.Hirai, member of Japanese Supporting Committee)

set on the RSW by using tie bar and RC slab. Overburden load is a main design load because it causes undesirable deformation at facing or foundation of RSW. This combining method is able to decreases the bad influence due to the overburden load.

Ex.5 Combination with PLPS
The section of RSW combined with preloading and prestressing (PLPS) is shown in Figure 21. Vertical stiffness of retaining wall is not improved effectively by reinforcement. For abutment or building foundation, allowable deformation is very small. PLPS is conducted to improve the vertical stiffness of RSW by using tie road, hydraulic jacks, RC block etc. Photo of first prototype of RSW bridge pier is shown in APPENDIX II. This pier has

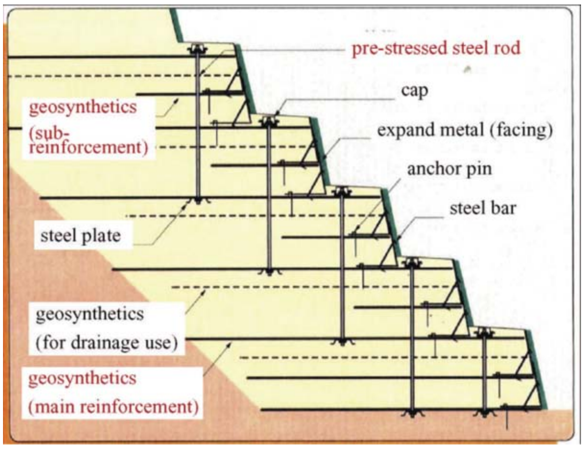


Figure 23. RE combined with drainage, preloading and prestressing.
(From Mr.Yokota, member of Japanese Supporting Committee)

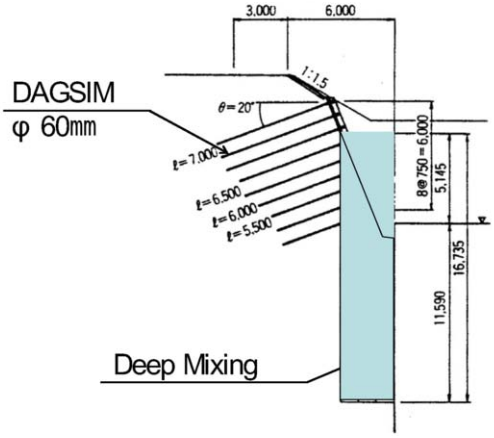


Figure 25. Nailing combined with deep mixing.
(From Dr.Kotake, member of Japanese Supporting Committee)

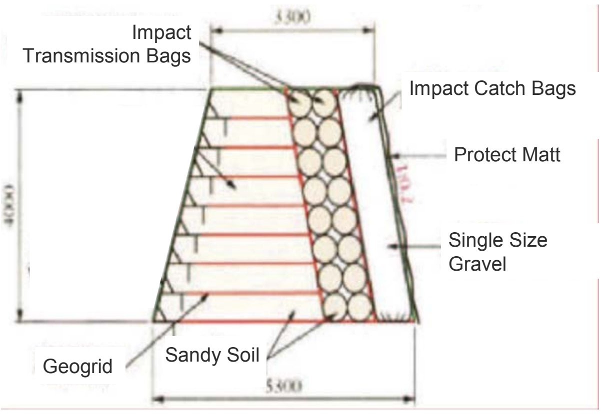


Figure 24. RE combed with impact absorber.
(From Mr.Yokota, member of Japanese Supporting Committee)

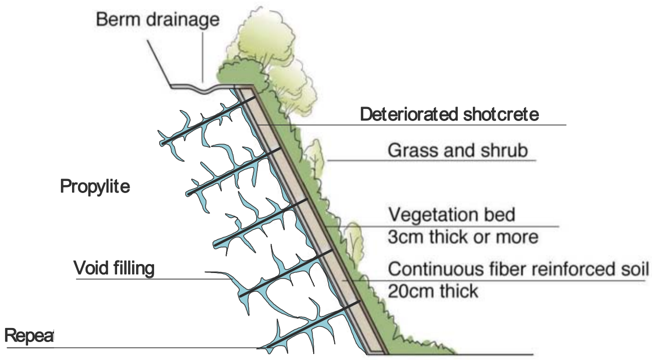


Figure 26. Nailing combined with fiber reinforced soil.
(From Dr.Wada, member of Japanese Supporting Committee)

been opened to service for more than three years and its effective were cleared.

(2.3) *Reinforced Embankment*
Reinforced embankment (RE) is constructed in various projects such as road, railway, airport, developing site for building, and others. Recently, scale of embankment has become larger and larger. Earth reinforcement has become an essential technology in the embankment work, it is used with replacing classical steel or RC structure as same as in the case of RSW. In this paragraph, three case histories are introduced.

Ex.6 Combination with Drainage
The section of RE which is combined with drainage is shown in Figure 22. Making good use of soft cohesive soil is often needed in embankment work. Acceleration of consolidation is a typical method to improve soil strength. Geosynthetics which has enough transmissivity is often placed in cohesive embankments. In this case study, geo-composite, that non-woven geotextile had been glued at both side of woven geotextile, was placed in the embankment.

It has both reinforcing and drainage functions. Layout of geo-composite was determined by considering increasing of soil strength induced by consolidation and reinforcement effect. This is effective for embankment work with cohesive soil.

Ex.7 Combination with PLPS and Drainage
The section of RE which is combined with PLPS (preloading and prestressing) and drainage, is shown in Figure 23. Photo. of vegetated slope is shown in APPENDIX II. PLPS was conducted with steel plate, steel plate, and steel rod. As drainage material, strip geo-composite, which has enough transmissivity, was used.

By combining with PLPS and drainage, the embankment whose height is over 40m was constructed with cohesive soil whose IP was about 20. Detailed field observation was also conducted in this site. It was reported that the embankment had been in high stability condition.

Ex.8 Combination with Impact Absorber
The section of RE combined with impact absorber is shown in Figure 24. Photo. in the construction period is shown in APPENDIX II. This was constructed to prevent rock fall which is a collapse mode of natural slope. Rock fall is caught by impact absorber attaching at back of reinforced soil wall.

Slope of the embankment can be vegetated. In the design of reinforced embankment, effect of impact load was considered. Many of traditional rock fall prevention work are steel or RC structures. They destruct more and less landscape. This combining method is better in ductility against rock fall and preserving of local environment.

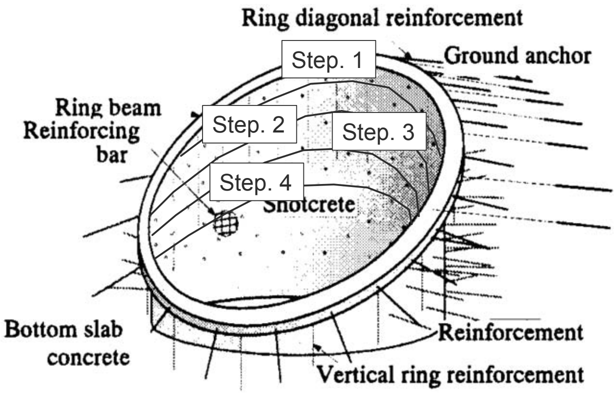


Figure 27. Nailing combined with ring reinforcement.
(From Mr.Ogata, member of Japanese Supporting Committee)

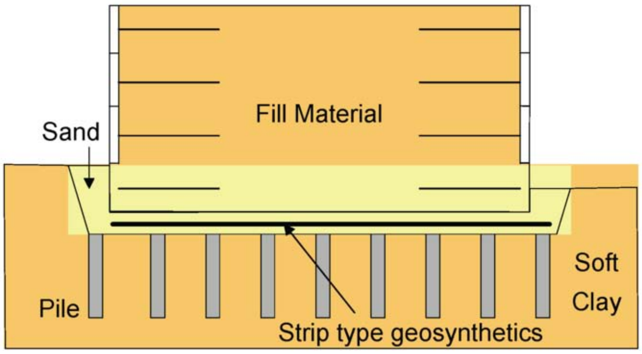


Figure 28. RF combined with piles
(From Mr.Konami, member of Japanese Supporting Committee)

(2.4) *Nailing*
Nailing is conducted in cutting slope, stabilizing of natural slope and others. Used reinforcement is deformed metallic bar or strip, prestressing steel bar and others. Slenderness ration of reinforcement is about from 30 to 140. In ordinary construction, grouting is conducted after installing of reinforcement. Slope is covered with PC panel, shotcrete, vegetation and others. In this paragraph, three case histories are introduced.

Ex.9 Combination with Deep Mixing
The section of slope, where Nailing combined with deep mixing was conducted, is shown in Figure 25. Photo. in the construction period is shown in APPENDIX II. This case study is in repairing of exciting rail road embankment. In this construction, slope deformation, which influence train running, was strictly restricted.

To meet this demand, nailing was conducted after soil stiffness had been improved by deep mixing. Slope deformation is a task in nailing. This is a good example to overcome the task. It should be noted that only deep mixing can not meet for the construction condition.

Ex.10 Combination with Fiber Reinforced Soil
The section of slope, where Nailing combined with fiber reinforced soil was conducted, is shown in Figure 26. Repairing of deteriorated shotcrete is a serious problem to keep slope stability. In this case study, shotcrete was repaired by conducting nailing and fiber reinforced soil. Additionally, vegetation bed was attached with improved slope with fiber reinforced soil. Nature conservation is an important task in civil engineering work. By applying this technique, both keeping of stability and preserving of regional environment was achieved.

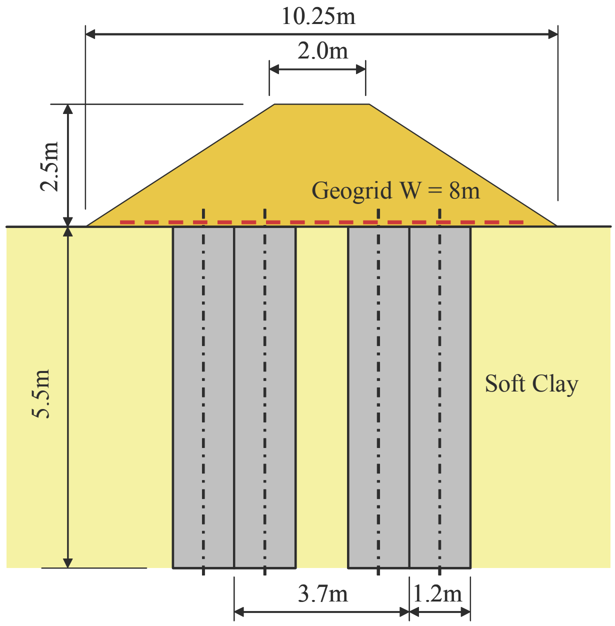


Figure 29. RF combined with deep mixing.
(From Dr.Hirai, member of Japanese Supporting Committee)

Ex.11 Combination with Ring Reinforcement
The section of foundation of pier on the steep slope, where Nailing combined with ring reinforcement was conducted, is shown in Figure 27. From the top layer, constructing of ring reinforcement with RC, installing of reinforcement and excavation were repeated. At the upper side of the slope, ground anchor was set. Pier was set inner the ring reinforcement. There are many methods to set the pie on steep slope.

They have a tendency to excavate too much. This method is able to decrease the excavation volume. Principle of this method looks like NATM method.

(2.5) *Reinforced Foundation*
Reinforced foundation is conducted in improvement of trafficability on the very soft soil foundation, embankment work on soft soil foundation. Recently, it is also applied for reinforcement of sub grade, base course and pavement. Used reinforcement is geosynthetics such as woven geotextile or geogrid, metallic material such as steel mesh or bar, and natural material such as bamboo net, palm rope. Load distribution is a key mechanism in reinforcement of foundation. In this paragraph, two case histories are introduced.

Ex.12 Combination with Pile
The section of reinforced foundation combined with pile is shown in Figure 28. After piles had been installed into soft ground, sand mat layer was formed. The sand mat was reinforced with singular or plural geosynthetics. This combing method was developed for constructing of embankment on the soft ground. Recently, this method is applied for the foundation of reinforced soil wall as shown in figure 13. Deformation of soft soil and sand mat are confined with piles and geotextile. This method is able to prevent differential settlement of surface ground and flow deformation of soft clay foundation.

Ex.13 Combination with Deep Mixing
The section of reinforced foundation combined with deep mixing is shown in figure 29. Photo. in the end of placing geogrid is shown in APPENDIX II. Principle of this method is as same as

one of *Rx. 12* that is combination with piles. Function of pile was replaced by cement mixing column. Improved area ratio ordinary is ordinary from 10 to 30%.

(3) Future task
Earth reinforcement combining with the other geotechnical methods has various possibilities to rationalize traditional geotechnical solutions. In order to develop this combining technology, reasonable method on design, site management and maintenance should be established. In order to achieve the above contents, i) research, ii) case study and iii) completion of technical system may be important.

On the point i), the combining effects should be investigated by conducting laboratory model test and numerical analysis. Research on needed material property for reinforcing material, construction process and dynamic behavior will be effective because we do not have enough experience on the combing method.

On the Next point ii), it is important to accumulate constructing information including material property of soil and reinforcement. Additionally, decision process on selecting a combining technology or field observation data is desirable.

The final point iii) may be accomplished by the activities on the points i) and ii). Organizing of technical course or sharing of information (for example on the web) will accelerate the completing speed of technical system.

5 CONCLUDING REMARKS

5.1 *Summary of Activities*

TC-9 activities in the period 2001 to 2005 are summarized:
(1) five organized sessions in the regional conferences and other conferences and symposia,
(2) five TC-9 meetings during the regional and the related conferences,
(3) more than ten meetings for the Japanese Supporting Committee, and
(4) seven publications

Those activities have also been done within the framework of following cooperation:
(1) TC-17/ISSMGE (Ground Improvement), and
(2) IGS (International Geosynthetics Society)

5.2 *Expected Activities from Now on*

Following activities have already assigned as TC-9 activities:
(1) To organize a technical session whose topic is earth reinforcement at Osaka Conference (16th ICSMGE) on September 15, 2005;
(2) To publish an educational textbook entitled "Earth Reinforcement Technique -New Horizon-" (in Japanese) by Japanese Supporting Committee of TC-9 in 2005;
(3) To organize a technical session at 8th ICG (International Conference on Geosynthetics) in Yokohama on September 18-22, 2006. This has been decided between ISSMGE and IGS presidents;
(4) To support 5th IS Kyushu (International Symposium on Earth Reinforcement) in Fukuoka, Japan in 2007. The IS Kyushu will be held as one of the activities by TC-9 according to the agreement of TC-9 members.

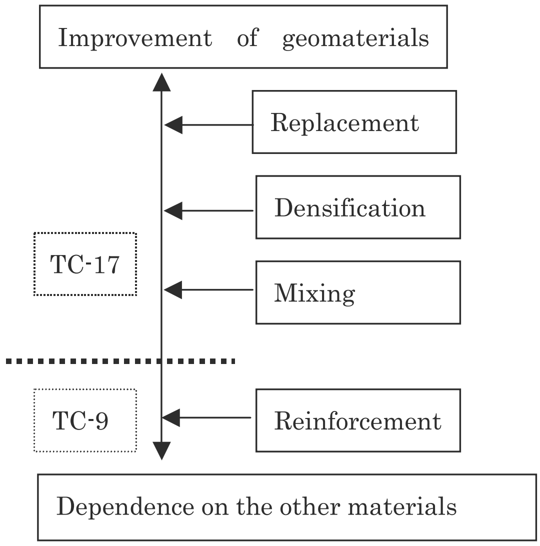


Figure 30. Classification of the topics by TC-9 and TC-17

5.3 *Topics under TC-9 and TC-17*

The title of TC-9 has been changed as follows:
(1) 1993-1997: Geotextiles and Geosynthetics,
(2) 1997-2001: Geosynthetics and Earth Reinforcement, and
(3) 2001-2005: Earth Reinforcement

For the period 2001-2005, the ISSMGE President presented the new general objective for TC-9, by which the topics under TC-9 became wide range of "earth reinforcement" including the topic of "ground improvement" which was originally covered by TC-17.

In order to enhance the activities by TC-17, it is advisable to distinguish the topics under TC-9 and TC-17 clearly based on the principle of ground improvement. We have suggested the topics, which have to be covered by TC-9, in the final report of previous term (1997-2001), as shown in Figure 30. We would like to propose this figure again in order to enhance mutual activities between TC-9 and TC-17. Of course, the education of earth reinforcement is very important issue, so that it should be continued both the system and material of education. Topics on the design and testing methods for earth reinforcement will be discussed in TC-9. To co-operate with TC-17 as well as the International Geosynthetics Society (IGS) should also be important activities of TC-9.

5.4 *Next Host Member Society of TC-9*

The TC-9 has obtained good results in this period 2001-2005, providing successful contributions towards the development of the earth reinforcement practice. It is believed that the fruitful outcomes of TC-9 activities are attributing to the great efforts of Japanese Supporting Committee established in the framework of Japanese Geotechnical Society. Thus, a large number of TC-9 members wish that the Japanese Geotechnical Society would be strongly expected to be a Host Member Society of TC-9 for the next term (2005-2009) again.

APPENDIX I

The followings are the list of papers and presentations by TC9 members during all the TC9 activities:

a. International conference and symposium

1) R.J. Bathurst, D.L. Walters, K. Hatami and T.M. Allen (2001): *Special lecture*, Recent full-scale testing of reinforced soil walls and implications to design, IS-Kyushu, 4th International symposium on earth reinforcement, Fukuoka, Japan, Vol.2, pp.777-802
2) R.K. Rowe and A.L. Li (2001): *Keynote lecture*, Insights from consideration of case histories involving reinforced embankments, slopes and walls, IS-Kyushu, 4th International symposium on earth reinforcement, Fukuoka, Japan, Vol.2, pp.803-830
3) C.R. Lawson (2001): *Keynote lecture*, Issues facing reinforced soil structures, IS-Kyushu, 4th International symposium on earth reinforcement, Fukuoka, Japan, Vol.2, pp.831-868
4) MR. Madhav and N.Fukuda (2001): *Technical report*, Embankments, 4th International symposium on earth reinforcement, Fukuoka, Japan, Vol.2, pp.957-962
5) E. M. Palmeira (2001): *Technical report*, Foundation, 4th International symposium on earth reinforcement, Fukuoka, Japan, Vol.2, pp.963-968
6) R.A. Jewell and N. Kotake (2001): *Technical report*, Soil nailing, 4th International symposium on earth reinforcement, Fukuoka, Japan, Vol.2, pp.969-974
7) D. Lechchinsky, J.G. Zornberg and Y.Miyata (2001): *Technical report*, Design procedure, 4th International symposium on earth reinforcement, Fukuoka, Japan, Vol.2, pp.975-982
8) S.A. Tan and P.H. Ooi (2003): *General report*, 12th Asia Conference on SMFE, Singapore, Vo.2, pp.2-5.
9) E.C. Shin (2003): *Panel presentation*, Korean Practice of Earth Reinforcement in Combination with Other Methods, 12th Asia Conference on SMFE, Singapore, Vo.2, pp.12-17.
10) D.T. Bergado and G.A. Lorenzo (2003): *Panel presentation*, Behavior of Reinforced Embankment on Soft Ground with and without Jet Grouted Soil-Cement Piles, 12th Asia Conference on SMFE, Singapore, Vo.2, pp.24-29.
11) C.R. Lawson (2003): *Panel presentation*, Southeast Asian Practice of Soil Reinforcement in Combination with Other Soil Improvement Methods, 12th Asia Conference on SMFE, Singapore, Vo.2, pp.18-23
12) Y. Miyata, H. Ochiai, and J. OTANI (2003): *Panel presentation*, Recent Case Histories on Combined Technology with Earth Reinforcement in Japan, 12th Asia Conference on SMFE, Singapore, Vo.2, pp.6-11
13) Y.C. Yeo (2003): *Discussion Summary*, 12th Asia Conference on SMFE, Singapore, Vo.2, pp.30.
14) J. Otani, H. Ochiai, Y. Miyata and T. Hirai (2003): *Keynote lecture*, Current case histories of reinforced soil retaining wall technique in Japan, 13th African Conference on SMFE, Marrakech, Morocco, pp. 673 - 679.
15) A.Iizuka, M. Hirata and H.Ohta (2003): Constitutive parameters of compacted sandy soils, 13th African Conference on SMFE, Marrakech, Morocco, pp. 713 - 719.
16) Z. Guetif, M. Bouassida and J.M. Debats (2003): Parametric study of the improvement due to vibro-compacted columns installation in soft soils, 13th African Conference on SMFE, Marrakech, Morocco, pp.463-466.
17) J.P. Gourc, O. Ple and P. Villard (2003): Landfill cap cover issue Improvement of the capability to sustain differential settlement, 13th African Conference on SMFE, Marrakech, Morocco, pp. 681 - 692.
18) M.R. Madhav, T.P. Manoj (2003): Response of sheet reinforcement to transverse downward force/displacement, 13th African Conference on SMFE, Marrakech, Morocco, pp.707-712.
19) A. Iizuka, M. Hirata, H. Ohta, K. Kawai and Y. Yokota (2004): *Keynote lecture,* The rule of numerical simulation for geosynthetics reinforced soil structure - from laboratory test to full scale structures-, GeoAsia 2004, 3rd Asian regional conference on geosynthetics, Seoul, Korea, pp.153-172
20) C. Yoo (2004): Design of geosynthetic reinforced segmental retaining wall in a tiered arrangement – use of numerical modeling as design aid, GeoAsia 2004, 3rd Asian regional conference on geosynthetics, Seoul, Korea, pp.173-182
21) S.A.Tan, C. William, P.H. Ooi and T. Derick: Finite element analysis of a soil nailed slope- some recent experience, GeoAsia 2004, 3rd Asian regional conference on geosynthetics, Seoul, Korea, pp.183-192
22) S.R. Lo: Application of numerical modeling to the design of reinforced soil walls for infrastructure projects –some Australian experiences, GeoAsia 2004, 3rd Asian regional conference on geosynthetics, Seoul, Korea, pp.193-203
23) E.M. Palmeira (2005): Geosynthetic Reinforcement for Soft Foundations: Brazilian Perspectives, Geo-Frontier 2005, Austin, USA, GPS 141, 19p
24) J.P. Gourc, R. Reyes-Ramirez, and P. Villard (2005): Geosynthetic Reinforcement in Landfill Design: European Perspectives, Geo-Frontier 2005, Austin, USA, GPS 141, 12p
25) J.G. Zornberg (2005): Geosynthetic Reinforcement in Landfill Design: US Perspectives, Geo-Frontier 2005, Austin, USA, GPS 141, 17p
26) J. Otani and H. Ochiai (2005): Geosynthetic-Reinforced Soil Walls and Slopes: Japanese Perspectives, Geo-Frontier 2005, Austin, USA, GPS 141, 15p
27) C.J.F.P. Jones (2005) Geosynthetic-Reinforced Soil Walls and Slopes: European Perspectives, Geo-Frontier 2005, Austin, USA, GPS 141, 13p
28) B.R. Christopher, D. Leshchinsky, and R. Stulgis (2005): Geosynthetic-Reinforced Soil Walls and Slopes: US Perspectives, Geo-Frontier 2005, GPS 141, Austin, USA, 12p

b. TC9 meetings and the others

1) Y. Miyata (2002): Earth Reinforcement Technique Combined with Other Methods, 1st TC-9 meeting, Nice, France.
2) J. Zornberg (2003): Comparison of International Design Criteria for Geosynthetic-Reinforced Soil Structures, 2nd TC-9 meeting, Boston, USA.
3) J. Otani (2003): Summary of procedures/criteria/practice in Japan, 2nd TC-9 meeting, Boston, USA.
4) P. Sharle (2003): Reconstruction of damaged earth wall in Hungary, 3rd TC-9 meeting, Prague, Czech.
5) C.J.F.P. Jones (2003): New guide to reinforced fill structure and slope design in Hong Kong, 3rd TC-9 meeting, Prague, Czech.
6) P. Kvansnicka (2003): A case history of large strain consolidation, 3rd TC-9 meeting, Prague, Czech.
7) M. Katagiri (2004): Soil sedimentation and vertical drain method, TC-9 and TC-17 Jointed Seminar on Ground Treatment, Hong Kong.
8) M. Kitazume (2004): Development of Pneumatic Flow Mixing Method and its Application, TC-9 and TC-17 Jointed Seminar on Ground Treatment, Hong Kong.
9) M. Nozu (2004): Sand Compaction Pile Method, TC-9 and TC-17 Jointed Seminar on Ground Treatment, Hong Kong.

APPENDIX II

Pictures of combined technology are shown in photo13 - 19. All of twelve case histories introduced in this paper are appeared in TC9 web site: http://www.nda.ac.jp/cc/ users/miyamiya/tc9/.

Photo 13. RSW combined with EPS blocks.

Photo 14. RSW combined with foam glass mixing.

Photo 15. RSW combined with PLPS.

Photo 16. RE combined with PLPS and drainage.

Photo 17. RE combined with impact absorber.

Photo 18. Nailing combined with deep mixing.

Photo 19. RF combined with deep mixing.