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Panel discussion on R&D challenges in soil reinforcement

Débat de spécialistes sur les défis de la recherche et des mises au point en renforcement des sols

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INTRODUCTION

In the field of soil reinforcement practice has traditionally preceded theoretical considerations and research. Technological innovations put forward by the construction industry and new construction materials made available by the manufacturing industry have continuously challenged the infrastructure agencies and the engineering community with the critical needs for establishing relevant engineering guidelines and quality control standards. Effective cooperation among the manufacturing industry, the construction industry, the infrastructure agencies and the research community has often been a major factor in the development of soil reinforcement technologies and engineering practices.

While a wide variety of questions are yet unresolved and raise major challenge to research and development, it is believed that soil reinforcement techniques have matured and became reliable and cost effective engineering tools for geotechnichal construction in difficult site and soil conditions. The increasing amount of full scale experiments and performance monitoring of actual structures has provided a significant database for the development and evaluation of design methods, and Engineering guide lines.

However, among the major issues to be addressed one can identify: (I) issues pertaining to the engineering use and quality control of innovative materials such as the engineering use of 3-D fiber reinforcement which gains significant interest regarding the potential use of recycling waste products as shredded tires in soil reinforcement. (ii) long term performance assessment of various reinforcement types and particularly goesynthetics,(i.e. chemical and mechanical durability and in soil confined creep). (iii) chemical compatibility of geosynthetics with contaminants for environmental applications. (iv) new fields of engineering applications and in particular the growing use of soil reinforcement systems for geotechnical construction in earthquake zones. (v) reinforcement of fine grain soils, and (vi) the potential use of innovative construction technologies, specifically for in-situ ground reinforcement.

It is anticipated that future developments in construction and installation technologies will continue to raise challenging R&D needs pertaining to their reliable engineering use in construction practice. This panel discussion will attempt to briefly highlight some of the R&D challenges in soil reinforcement. In order to comply with space limitation it will be limited to some comments on:

(i) *Durability of Reinforcements.*

(ii) *Seismic performance of reinforced soil systems.*

DURABILITY OF REINFORCEMENTS

Corrosion of metallic reinforcement under various site conditions has been extensively investigated and results incorporated in various engineering manuals and design codes. PTI '96 provides guide lines for corrosion protection with ground anchors, and AASHTO for metallic reinforcements. However, chemical and mechanical degradation of geosynthetics is still not clearly understood and no generally accepted testing protocols have yet been established. With this regard it is of interest to summarize at this point the main conclusions of a major 6 year study conducted by the FHWA on the development of testing protocols to measure the degradation of various types of polyesters by hydrolytic reaction and polyolefins by thermo-oxidation. Polytechnic University conducted the laboratory testing program for this study. (Salman et al, 1997)

For polyesters the laboratory studies illustrate that kinetics of hydrolysis in solutions of different pH, can be described with an Arrhenius model to estimate strength degradation rate at ambient temperature. However predicting degradation of polyolefins is still a major challenge since it is a function of the manufacturing process, antioxidants used and partial oxygen pressure.

Figure 1. illustrates the results of oven aging testing of polyolefins with controlled oxygen partial pressure. The results clearly suggest that it is quite difficult to extrapolate the degradation rate established under accelerated oven testing conditions to ambient conditions of temperature and oxygen partial pressure with regard to both, (i) the induction period (a period of no strength loss), and (ii) the degradation rate of the loss in strength.

Further, the test results indicate that coupled mechanisms intervene in the thermo oxidation process. Fig. 2 illustrates an initial increase in strength with time. SEM demonstrated that due to diffusion process under high temperatures, "self healing" of initial surface fissures may explain this initial gain in strength. In conclusion, oven aging changes the structure of a product with initial surface fissures typical of type products.

The main conclusions of the study for polyolefins degradation can be summarized as follows:

1. The use of oven aging and kinetic models for durability assessment requires a special precaution as the effect of the manufactured state of the product, initial cracks may significantly depend upon the oven testing conditions, particularly temperature.
2. Effective antioxidant increases induction time,

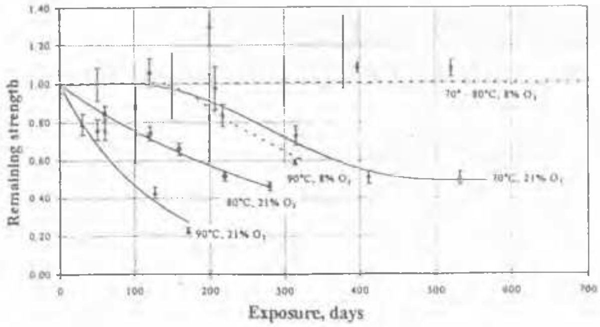

Figure1. Tensile strength for continuous filament geotextile. (Salman et al. 1997)

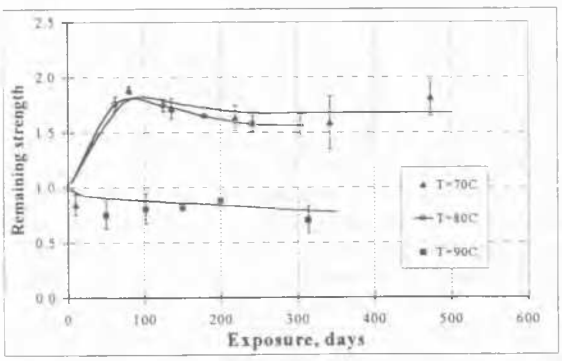

Figure 2. results of oven aging testing of polyolefin with controlled oxygen partial pressure. (Salman et al. 1997)

eventually in excess of the design service life. However, relevant testing protocols need to be developed to assess induction time under representative design service conditions.

3. SEM demonstrates the effect of manufacturing process such as cracks on fiber surface, which may significantly affect induction time and degradation rate.
4. For products with no initial cracking, kinetic models (Basic Auto-oxidation Scheme) can be useful to assess degradation rate. This is typical of monofilament products.
5. Oxygen partial pressure significantly affects the rate of the mechanical degradation. Note that in the ground, the oxygen content is significantly smaller than under atmospheric conditions. Alternative degradation testing method using high oxygen partial pressure could be investigated to address the limitations of the oven aging technique.

It is therefore anticipated that the degradation mechanics of polyolefins will continue to raise R&D needs in the years to come. Further research should focus not only on mechanical strength but also on other mechanical properties depending upon the specific use in civil and environmental applications. Of a particular interest should be an attempt to establish correlations between the degradation rate of mechanical properties and relevant chemical degradation indices. This research should also provide reliable testing protocols for long term performance assessment and quality control.

SEISMIC PERFORMANCE OF REINFORCED SOIL SYSTEMS

During the past decade post-earthquake observations on reinforced soil retaining structures consistently demonstrated that due to their composite behavior and energy absorption capacity these structures present high resistance to earthquake loading, the following comments will share some observations on (i) engineered fills, and (ii) in-situ ground reinforcement.

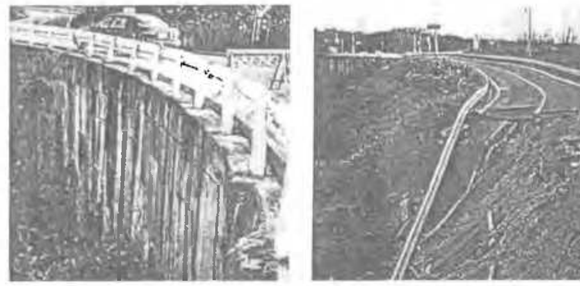
Figure 3. Reinforced earth structures after the Hanshin earthquake.

(i) Engineered Fills

Figure 3. illustrates a typical example of the seismic performance of reinforced earth structures. During the Hanshin earthquake, Japan, 27 km from the epicenter the reinforced earth structure has not suffered any damage whereas 200 meter away the road has completely collapsed.

For reinforced earth walls extensive research has been conducted on reduce scale models and full scale monitored structures to provide seismic design guide lines and predict structural displacements. The initial seismic design method proposed by Seed and Mitchell, (1981), was modified by Bastic and Segrestain, (1989) following finite element simulations and incorporated in design guide lines.

The seismic performance of Texsol was investigated in Japan by Fukuoka, (1990), on (i) a series of shaking table tests on models of earth dam with reinforced facing, and (ii) a ten meter high test wall instrumented for performance monitoring under earthquakes. During the February 19, 1989 earthquake, 5.7 on the Richter scale, measured acceleration at the ground surface reached 95 gal with frequency spectrum from 2 to 8 Hz. Site observations illustrated that while the static safety of the wall was already at the critical state no damage was observed. Figure 4. illustrates the instrumentation of the wall and measured earth-pressure due to the seismic load compared with predicted values obtained from the Mononobe-Okabe formula. These results as well as the results of the model scale shaking table tests demonstrated the effectiveness of Texsol for earthquake design.

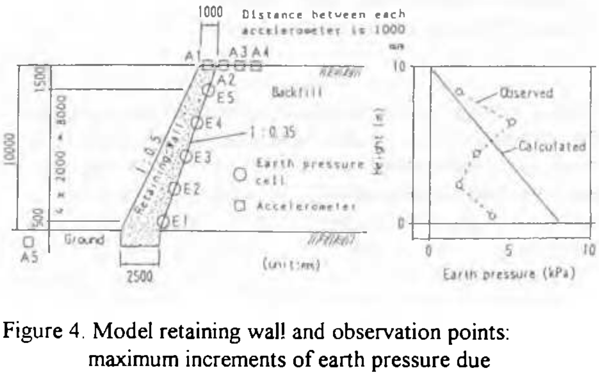

Figure 4. Model retaining wall and observation points: maximum increments of earth pressure due to earthquake. (Fukuoka, 1990)

It is of interest at this point to share few comments on the potential use of 3-D fiber reinforcement. Texsol represents an industrialization of the fiber reinforcement concept, where continuos polyester thread 0.1 % to 0.2 % by weight, is injected together with sand in order to create in situ composite material with a friction angle of the native sand and "cohesion" due to the sand encapsulation by the continuos filament. With 100 to 250 kilometers of continuous thread per cubic meter, Texsol yields a substantial cohesion to the composite material. Major issues concern: deformation response, long term performance and, QC. It is of interest to indicate that in Japan tests have been conducted to assess the feasibility of using low level cementation (up to 4%) for a better control of deformation response of Texsol.

3-D fiber reinforcement of both sand and clays have been reported in the literature as potentially effective tool for various civil engineering applications, including retaining structures, engineered fills, pavement design, volume change control of expensive clays, increasing liquefaction resistance of loose sands, and improving dynamic resistance and shear modules (Noorany et al, 1989, Mahar & Woods, 1990). However the mechanics of interaction between the fiber and soil particles is still a subject of research and no consensus has yet been reached with regard to the optimal aspect ratio in different types of soils. Furthermore the use of fibers to isotopically reinforce soils raises significant concerns with regard to the uniformity of compaction and quality control.

Fiber reinforcement has gained a significant interest with the current investigation and thrust on the potential use of recycled waste products such as shredded tires in high-way construction. It is believed that in the next decade the use of recycle products often mandated in different countries, will raise new R&D challenges in material design and quality control. The past experience with manufactured goesythetics that in the 80's has escalated to a billion dollar industry could set forth a relevant model for turning processed waste materials into economically viable resource for infrastructure construction materials. Numerous examples already attest to this end raising challenging R&D needs as the emerging industry of processed waste material continues to grow and faces new engineering applications.

(ii) In-situ Ground Reinforcement

For soil nailing the site observations by Fellio (1990) raised significant interest in the potential use of the technology for construction in earthquake zones. However only limited studies have todate been conducted to investigate the seismic response of soil nailed structures and evaluate the available pseudo-static limit equilibrium design methods. Of particular interest with this regard is the centrifugal model study conducted by Prof. Vucetic from U.C.L.A. (Vucetic et al, 1993). At this point it should be emphasized that while the centrifuge offers effective tools for modeling actual working load conditions it raises significant R&D challenges with regard to the difficulties involved in complying with scaling requirements, controlling the effect of boundary conditions for seismic loading, and simulating in flight construction processes and installation of reinforcements. Several papers to this session present innovative approaches to address such limitations. However, at this stage further centrifugal model studies on instrumented soil nailed walls as well as performance monitoring of full scale structures are required in order to establish a relevant database for the development and evaluation of reliable seismic design methods for soil nailed structures.

In particular the seismic loading effect on nail pull out resistance needs to be investigated. The potential use of innovative nail installation technologies in earthquake zones raises pertinent questions with this regard. Recent examples for such innovative construction technologies include Jet Nailing (Louis 1986) which combines vibro-purcussion driving with high pressure jet grouting, and Nail Launching (Ingold & Miles 1989). The use of such innovative technologies raises the need to investigate the effect of the installation process on soil nail interaction under both static and seismic loading in different types of soils. Further, the use of these technologies for the reinforcement of clayey soils, raises various questions regarding creep potential at the interface and the effect of bending stiffness on structural displacements.

Micropiles have been reported (Bruce and Juran 1997) to be successfully used for seismic retrofitting. However, the engineering use of micropile systems in earthquake zones requires better understanding of the seismic response of micropiles groups and networks as well as the development of relevant methods to predict the effect of seismic loading on structural displacements. A national research project "FOREVER" is presently being conducted in France in cooperation with the US Federal Highway Administration to investigate the behavior of the micropile groups and networks, and establish engineering guidelines for their use in civil engineering applications. Within the framework of this project a cooperative study is conducted to evaluate the seismic response of micropile systems involving cyclic and dynamic calibration chamber tests by the ENPC in Paris, 1-G shaking table model tests conducted by the University of Canterbury, New Zealand, and centrifugal model tests conducted by polytechnic Univ. in the USA. The prime objectives are to evaluate the seismic response of micropile groups and networks to earthquake loading.

It is anticipated that this cooperative research program will provide the necessary database for the development and evaluation of seismic design methods for micropile groups and networks for infrastructure applications.

Figure 5 shows the micropile model system tested by Polytechnic University in the centrifuge. The instrumentation involved accelerometers to measure the pile head and free field accelerations in order to characterize the structural response of soil-micropile system, transducers (LVDT's) to monitor soil surface settlements, vertical and lateral pile cap displacements, and strain gauges to monitor both axial forces and bending moments and to assess seismic loading and vibration effect on the soil-micropile interaction.

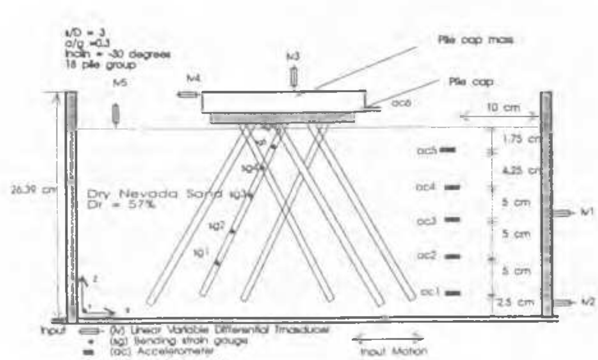

Figure 5. The micropile model system tested by Polytechnic University (From Juran et al., 1997)

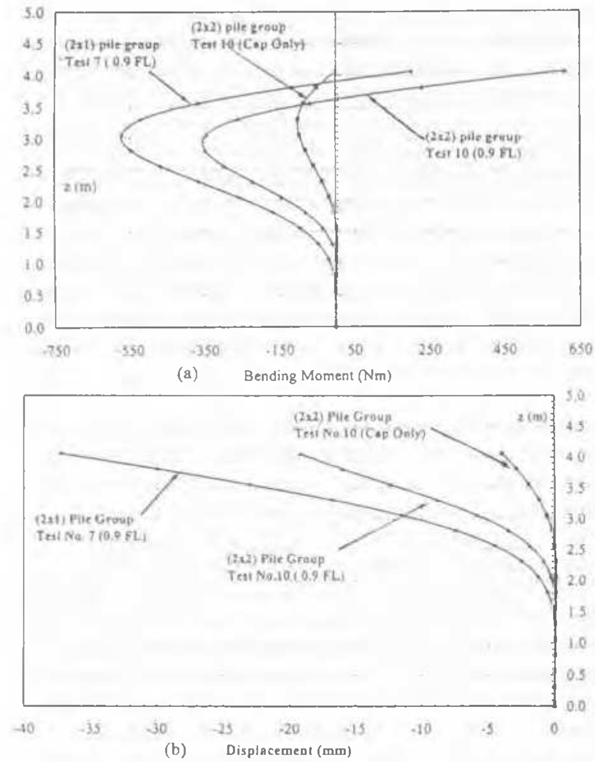

Figure 6. Comparison of: (a) Recorded Bending Moment Profiles for (2x1) and (2x2) Vertical Pile Groups During Steady State Shaking. (a/g =0.3 - s/D =3 - L/D =32) (b) Corresponding Displacement Profiles (From Juran et al., 1997)

Comparison between the acceleration time histories indicates an amplification of the base input acceleration towards the ground surface, which is similar to the behavior observed by other centrifuge investigators for cohesionless soils.

Based on the bending strain gauges recordings, bending moment profiles of the instrumented micropile in the various configurations for each event were derived and group and network effect investigated. A comparison of the distributions of the bending moment profiles and the associated pile displacements for 2x1 and 2x2 vertical pile groups subjected to different loading levels (i.e. cap alone and 0.9 Fl where Fl is the failure load derived from 1-g static loading test, is displayed on figure 6(a) and 6(b) respectively. For the case of a (2x2) pile group (cap only), the bending moment distribution shows a pile response which is similar to that for a single free-headed pile. For the case of static loading of 0.9 Fl on the pile cap, simulating the effect of a superstructure, the bending moment distributions and the associated displacement profiles illustrate the group effect. The apparent group effect appears to significantly affects the pile superstructure interaction and the associated restraint of the pile cap against rotation, the maximum bending moment generated in the pile and the maximum lateral pile displacements. However, the complex soil-pile-superstructure interaction under seismic loading for micropile groups and network systems needs to be further investigated in order to develop reliable design guidelines for micropile systems in earthquake zones.

CONCLUSIONS

The most significant contribution of the past ten years to the current state of practice has undoubtedly been the full scale experiments and monitoring of in-service structures that have demonstrated the performance of reinforced soil systems under a variety of static and seismic loading conditions.

It is anticipated that monitoring of the long-term performance of structures, development of reliable quality control procedures, testing of witness inclusions for degradation studies, and basic research on soil-inclusion and soil structure interactions under both static and seismic loading, will significantly contribute to further improving the state of design and practice. This may substantially enhance technological innovations and cost-effective use in more aggressive environments and in a wider range of fine-grained soils, providing effective means to address new engineering applications such as bridge abutments, structural retrofitting and geotechnical construction in earthquake zones.

In conclusion it should be emphasized that effective technology transfer tools are required in order to support world wide through information exchange and experience sharing the dissemination of research results and the incorporation of innovative technologies in construction practice. This is the main goal of TC-17, the ISSMFE technical committee for ground improvement reinforcement and grouting. During the past few years the committee has worked on the development of technology transfer tools including:

1. An international Knowledge Database on ground improvement technologies.
2. Ground improvement Journal with an editorial board which represents a blend of the major industries, the Infrastructures agencies and, the academia from different countries members of TC-17, and
3. Series of International Conferences on ground improvement geosystems co- organized with the national members societies with the next one being scheduled for 2000 in Finland.

These tools are designed to serve the international geotechnical community, not only in promoting technology transfer and knowledge exchange, but ultimately in fostering cooperative research and demonstration projects and facilitating the integration of innovative technologies through international standardization. The ISSMFE TC-17 looks forward to continue working with the International Geotechnical Community towards these goals.

REFERENCES

Bruce, D. A., and I. Juran, (1997). "Drilled and Grouted Micropiles: State-of-Practice Review". U.S. Federal Highway Administration, Publication No. FHWA-RD-96-017.

Fukuoka, M., et al. "Stability of Retaining Wall Reinforced by Continuous Fibers During Earthquakes". Proc., 4th International Congress on Geotextiles, the Hague, the Netherlands, 1990, pp. 546-558. 1990

Fillio, G.Y., Vucetic, M., Hudson, M., Barar, O., and Chapman, R. (1990). "Performance of Soil Nailed Walls during the October 17, 1989 Loma Prieta Earthquake". Proceedings, Forty-third Canadian Geotechnical Conference, Quebec, pp. 165-173.

French National Research Project CLOUTERRE, (1993). "Recommendations CLOUTERRE 1991-Soil Nailing Recommendations 1991". Presses de l'Ecole National des Ponts et Clausseess, English Translation.

Ingold, T.S. and Myles, B. (1996). "Ballistic soil nailing: Earth Reinforcement" H. Ochiai, N. Yasufuku, and K. Omine, eds., Proceeding of the International Symposium on Earth Reinforcement, Japan.

Juran, I., Benslimane, A., Hanna, S., and Perlo, S., (1997). "Seismic Behavior of Micropile Systems - Centrifuge Test Results " Preliminary Report - FHWA Contract No DTFH61-96-00021

Louis, C. (1986). "Theory and practice in soil nailing temporary or permanent works". ASCE Annual Conference, Boston.

Maher, M.H. and Woods, R.D. (1990). "Dynamic response of sand reinforced with randomly distributed fibers." J. Geotech. Engrg., ASCE, Vol. 116, No. 7, pp. 116-1131.

Salman, A.,, V. Elias, I. Juran, S. Lu, E. Pierce, (1997). "Durability of Geosynthetics Based on Accelerated Laboratory Testing". Proc. of the Geosynthetics Conference Long Beach, California USA.

Seed H. B. and Mitchell J.K. ,(1981) Earthquake resistant design of reinforced earth walls. Internal study for the Reinforced Earth company. Progress Report.
Berkely, California.

Segrestin P. and Bastick M.J. (1988) Seismic design of reinforced earth retaining walls: the contribution of finite element analysis. Proc. Int. Symp. On Theory and Practice of Earth Reinforcement, Kyushu, Japan, Oct.

Vucetic, M., Tufenkjian, M., and Doroudian, M. (1993). "Dynamic Centrifuge Testing of Soil-Nailed Excavations". ASTM Geotechnical Testing Journal, Vol. 16, No. 2: 172-187.