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Technical report – Design procedure

Dov Leshchinsky
University of Delaware, USA

Jorge G. Zornberg
University of Colorado at Boulder, USA

Yoshihisa Miyata
National Defense Academy, Yokosuka, Japan

1 INTRODUCTION

Summary Discussion Session –Design Procedure– was held on November 16th, 2001 from 14:00 to17:00 pm. The Chairmen of this session were D. Leshchinsky and J. G. Zornberg, and the secretary was Y. Miyata. The program of this session is shown in Table 1. After a brief introduction, five panelists presented topics on design procedure for reinforced soil structures. Abstracts of their presentations are presented in Section 2 of this report. After the presentations by the five panelists, two presentations from floor were performed. Finally, the contents of the presentations by the five panelists and two presenters were subject of open discussion. A significant number of written discussion sheets were collected. In addition, several participants from the audience expressed directly their questions and comments.

Table1 Program of the summary discussion session

1. Introduction / J.G. Zornberg, University of Colorado at Boulder, USA.
2. Technical Reports

(2.1) Residual or Peak Shear Strength in Design? / D. Leshchinsky, University of Delaware, USA.
(2.2) Comparison of International Design Criteria for Geosynthetic-Reinforced Soil Structures / J.G. Zornberg.
(2.3) Serviceability of MSE Structures / P. Segrestin, Freyssinet International, France.
(2.4) Material Properties for Design in Reinforcement Applications / C. S. Hoe, National University of Singapore, Singapore.
(2.5) Instrumentation to Ascertain Design Assumptions /H. Miki, Public Works Research Institute, Japan.

3. Presentations from floor

(3.1) Residual Strength and its Application to Design of Reinforced Soil in Seismic Areas / J. Greenwood, ERA Technology Ltd., UK.
(3.2) Role of Numerical Analysis on Design Procedure / A. Iizuka, Kobe University, Japan.

4. General Discussion
5. Concluding Remarks / D. Leshchinsky

2 ABSTRACTS OF TECHNICAL REPORT

2.1 *Residual or Peak Shear Strength in Design? / D. Leshchinsky*

Most design methods for geosynthetic reinforced soil structures are based on limit equilibrium analysis. The required strength and length of the reinforcement is calculated based on the shear strength of the soils through which potential slip surfaces are likely to develop. Many design guidelines require a free-draining compacted backfill. Such soil exhibits strain-softening behavior, a phenomenon that is related to deformations, the values of which cannot be calculated using limit equilibrium. As a result, there is a question whether peak or residual shear strength should be used in the limit equilibrium analysis. In fact, this selection may have significant economic consequences especially when the foundation soil is competent. This presentation recognizes the potential for the development of progressive failure, especially when the reinforcement material, upon which stability is hinging, exhibits time-dependent behavior. The straightforward approach of using residual strength would produce a safe structure, however, it might be overly conservative. To produce safe and economical structures, a hybrid approach is proposed for design, which preserves the simplicity of current limit equilibrium analysis. The trace of the critical slip surfaces is determined based on peak strength as observed in laboratory soil element testing as well as centrifugal models of reinforced slopes. Accounting for the possibility that soil strength along these surfaces will degrade to its residual plastic value, the limit equilibrium analysis is repeated, along the critical trace determined for the peak value, to determine the required long-term reinforcement strength. To demonstrate the effects of the proposed approach, a simplified analytical design methodology is presented. It can be used, however, with any rigorous limit equilibrium method. Parametric studies show that the hybrid approach allows for marginal reduction in strength of reinforcement as compared to the 'pure' residual strength approach; hence, in that respect the level of conservatism in the residual strength approach remains nearly the same. However, the required length using the hybrid approach may decrease significantly, depending on the slope angle and soil strength. Since the economics of geosynthetics is more sensitive to its area or length than to its strength in many instances, the presented approach may have significant design implications.

2.2 *Comparison of International Design Criteria for Geosynthetic-Reinforced Soil Structures/ J.G. Zornberg*

A summary of currently available criteria for the design of geosynthetic-reinforced walls, geosynthetic-reinforced slopes, and embankments founded on soft soils was compiled. The objective is to evaluate the consistency among different design criteria put forth by agencies worldwide, including evaluation of different performance criteria, backfill criteria, reduction factors for geosynthetics, and design methods. This compilation includes criteria established by Australia, Brazil, Canada, Germany, Hong Kong, Italy, Japan, the United Kingdom, and the United States.

2.3 *Uncertainty of Design Parameter Serviceability of MSE Structures / P. Segrestin*

What is serviceability design?

Checking that construction and post-construction movements remain within acceptable limits

- Construction movements: usually claimed to be under control (construction procedure, know how)
- Serviceability generally likened to post-construction creep, a concern with extensible polymeric reinforcement

Is post-construction creep-strain of extensible reinforcement really a problem?

No — for most reinforced slopes with soft facing, all the more so if vegetated

Maybe — for visual, aesthetic, rather than structural reasons for walls with concrete cladding

Yes — for structures adjacent or connected to sensitive structures or structures where large load is applied after construction, e.g. true supporting bridge abutment.

What do the main Codes specify?

France — Extensible (draft G 38064): true bridge abutments excluded. Assessment of post-construction strain required for other structures. Limits not specified. Inextensible (P 94220): no serviceability design.

UK — Extensible (BS 8006): post-construction strains (over total length) limited. Overlooked for reinforced slopes Limits: walls 1%, abutments 0.5% (could be therefore larger than 50mm at top of abutment?)

USA — AASHTO interim 98. Serviceability disregarded for extensible and inextensible, abutments as well as walls

How are creep strains calculated?

UK — Substantiate variation of tensile load along reinforcement, then average it out (or, consider maximum tension over entire length)

France — Maximum tensile loads derived from movements along slip circles which would restore stability, as a result of progressive mobilization of strain and interaction. However, strains and displacements then assessed from the tensile loads, forgetting the slip circles?

Does serviceability only relate to creep-strain of reinforcement?

No — Serviceability = limit state wherein the structure is checked to ensure that it fulfils its function throughout its life, without the needs for abnormal maintenance (BS). Concerns should also include consequences of movements such as:
- settlement and differential settlement
- shear deformation of fill
- consolidation of high embankment
- creep of fill with high fine content

So, serviceability is also an issue for inextensible reinforcement?

Of course. For everything else than creep-strain

How can detrimental differential settlements be dealt with in the design?

1 - Select a technology suitable to the application (illustration: differential settlement resulting in opening of horizontal joints between modular units)
2 - Select fill compatible with the technology, take care of placement and compaction (illustration: differential settlement between stiff facing and insufficiently compacted fill)
3 - Pay uppermost attention to conceptual design (illustration: damages due to differential settlement along segmental panel wall built on top of box culvert)

When is it necessary to assess the potential displacements of a MSE structure at the design stage?

A few examples (with illustrations)

1 - Building in front, close to the wall
2 - Superstructure connected to MSE wall
3 - High tiered walls and embankment. Predict movements which should be expected, and those which would be abnormal

How can the deformations of a MSE wall be assessed?

Creep-strain of reinforcement is only one part of the problem. FEM analysis is more likely to take everything into account, including environment, and represent actual behavior. However, modeling interaction between fill and reinforcement is still uneasy, especially with discrete reinforcements. New software available in the future, with homogenized anisotropic properties?

2.4 *Material Properties for Design in Reinforcement Applications / C. S. Hoe*

The following aspects will be covered:

1) Geosynthetics material

a. Testing of High Strength Geosynthetics: This has become quite important, as suitable grips without slippage should be engaged during testing.

b. Degradation under various environments will be discussed with exhumed geosynthetics from coastal structures

c. Installation damage during construction of coastal structures and walls/slopes will be discussed and the energy concept will be introduced in the assessment. Specifications to establish such damage in construction projects will be discussed.

2) Soil

a. It is not clear how to use residual soils in the tropics with reinforced material. There is great need to use such material, as they are abundant in the tropics, yet they pose some uncertainties in respect of strength and drainage properties. Some work done in the laboratory as well as field trials will be discussed. Measurement of pore pressure, settlement, total pressure, and movement will be presented from real slopes. The rate of dissipation of pore pressure in residual soils, as monitored in a wall built with residual soil and the behavior of the wall during load testing, in respect of movement and pore pressure, will be discussed.

3) Soil–Geosynthetics Interaction

a. It has been found to be quite important and critical to look at the interaction of the hydraulic conductivity, pore pressure and the overburden pressure in slopes and walls when residual soils are used.

b. Large scale of pullout box tests carried out will be presented in respect of the above properties.

c. Field pull out tests of a 12 m high slope and a 3 m high wall built with residual soil will be presented to elucidate the interaction behavior.

d. Filed test conducted on 3m high wall to monitor the lateral movement and pore pressure generation with permeable and high strength geosynthetics reinforcements will be presented.

2.5 *Instrumentation to Ascertain Design Assumptions/ H. MiKi*

My presentation deals with the hidden reinforcing mechanism not accounted for by usual practical design of reinforced embankment taking advantage of the reinforcing effects of geotextiles.

A full-size experiment was performed by using sand bags as slope protection work, which was then sandwiched between densely installed geotextile, gradually cutting off the geotextile installed inside the embankment. When this procedure was completed, the surface zone of the embankment where the sand bags had been placed between the densely installed geotextile, by then cut down to a final length of 70 cm, provided a counter-balance equivalent to an inclined retaining wall.

It is necessary to install geotextile at sufficient density and to integrate the reinforced zones to provide a apparent cohesion similar to that of stabilized soil. To clarify this point, large-scale triaxial compression tests were performed on the reinforced soil as the reinforcing material density was varied, which showed that the anisotropic apparent cohesion depends on the tensile strength of the reinforcing material and the spacing of the material.

If it is possible to obtain a suitable method of assessing the apparent cohesion in a pseudo retaining wall zone in which sand-bags or geotextiles are densely installed, it will also be possible to use rotational slip calculations to easily incorporate the effects of slope protection work into design.

Another solution to make use of the cohesion in a pseudo retaining wall zone is to use a real stabilized soil in the surface zone of the embankment, thus reducing the cost of reinforced embankment. A new design concept of reinforced embankment combined with stabilized soil in the surface zone of the embankment will be introduced, including the construction cases.

3 DISCUSSION

3.1 *Presentations from floor*

Two presentations were performed from floor. Their contents are as follows.

(1)*Residual strength and its application to design of reinforced soil in seismic areas/ J. Greenwood*

Dr. Greenwood's main point was as follows: At the last IS Kyushu it was suggested that, in spite of the appearance of the stress–rupture graph, the full strength of the geosynthetic is retained over the lifetime of the structure. This early suggestion was substantiated by a wide range of experimental results presented by Dr. Greenwood. Experimental simulation of seismic events also showed no effect on the tensile strength of geosynthetics. This has major consequences for seismic design. The strain response may be different: the modulus may increase with sustained load or after a seismic event. For seismic design it is argued that, in contrast to current design methodologies, design should be based upon factored lifetime rather than on factored load.

(2)*Role of numerical analysis on design procedure / A. Iizuka*

Prof. Iizuka discussed the usefulness of numerical computation in the design work. He emphasized the following concepts by validating some full-scale model tests against their numerical simulations.

a. Importance of proper modeling of (unsaturated and compacted) soils, rather than modeling of geosynthetics, in mechanical interaction between soils and reinforcement materials.
b. Necessity of objective procedure in specifying input parameters needed in the computation.
c. Proper understanding of reinforcement mechanism (that is, the reinforcement materials such as geosynthetics does not merely work so as to resist the extension force, but intrinsically, does work so as to restrict the volumetric (dilative) deformation of compacted soils).

3.2 *General Discussion*

Due to the limited time allocated to the discussion session and the numerous questions submitted on all presentations, only a fraction of the questions could be addressed during the discussion. Main discussed themes are as follows.

1) Parameter determination of fill material (particularly peak or residual shear strength, but also other parameters)

Dr. Leshchinsky addressed the questions on this topic. Judging by the number of questions related to peak and residual strength, the topic of progressive failure was of great interest. Dr. Leshchinsky indicated that proper response to all the comments relevant to his presentation are presented in his paper: Leshchinsky, D. , "Design dilemma: Use peak or residual strength of soil," *Geotextiles and Geomembranes*, 19(2001), 111-125. Therefore, in addition to his verbal response at the session, Dr. Leshchinsky referred all interested persons to an in-depth discussion of the topic as appear in the paper. He noted that his presentation was based on this paper, which contains additional facts and references.

2) International harmonization of design criteria

Dr. Zornberg addressed the questions on this topic. Also due to the number of questions, only a fraction of them could be addressed during the general discussion. Dr. Zornberg highlighted that the purpose of the comparison of different international design criteria was only to document similarities and differences among different agencies. For specific aspects of the comparison, the reader is referred to the paper published in the TC-9 report: Zornberg, J.G., and Leshchinsky, D. (2001). "Comparison of International Design Criteria for Geosynthetic-Reinforced Soil Structures." *Geosynthetics and Earth Reinforcement*, H. Ochiai, J. Otani, and Y. Miyata (Editors), ISSMGE-TC9, pp. 106-117. "

3) Life time and strength of geosynthetics

4) Numerical simulation and design

4 CONCLUDING REMARKS

To establish a perspective of the status of design and construction of MSE structures, one needs to set a timeline. Considering that the first IS-Kyushu conference was held in 1988, this year is selected as a benchmark.

The civil engineering discipline follows an evolutionary process. Typically, implementation of new technology takes decades. Using this perspective, the question is what has happened in soil reinforcing technology since 1988?

Metallic Reinforced Structures: By 1988 there were established design methods and established construction techniques. The technology was already well accepted. Since 1988, a few new configurations of MSE walls were introduced without major changes of the basic structure. There was, however, an increased use of soil nailing and anchors as those applications became more economical.

Geosynthetic Reinforced Structures: By 1988 it has been used in secondary applications, which were based on ad-hoc design procedures. There were limited testing standards. Construction techniques were inconsistent though innovative. Since 1988 geosynthetic reinforcement has been used in permanent and critical structures. There are many established national design codes around the globe. Material properties are based on full range of laboratory testing standards. Construction procedures are consistent and include quality control to insure proper performance. Furthermore, new types of structures have been accepted since 1988. One prime example is segmental block walls, a structure that is aesthetically pleasing and economically competitive with all other walls.

In retrospective, the developments in geosynthetic reinforced structures since 1988 is a revolution by civil engineering yardstick. In fact, undergraduate textbook can serve as evidence of acceptance of the discipline of soil reinforcement with manmade materials; most include chapter dedicated entirely to design using metallic and geosynthetic reinforcement as construction materials. This rapid acceptance is due to safe performance of reinforced structures, material characterization including insitu durability, economics and aesthetics.

Since 1988 there were a few major earthquakes around the globe. MSE structures performed much better than the equivalent non-reinforced structures. As is evidenced from new research, creep does not reduce the actual strength of geosynthetics before 'rupture at the end of the life of the structure' occurs. Hence, superimposed seismic loads do not affect creep, a fact that allows for further design refinement.

Finally, the question then is 'are we there yet?' Well, not yet. Design of tiered walls may or may not be overly conservative. Such structures are aesthetic and may reduce the stress in lower level reinforcement; however, there is no established design procedure for such structures. Field and laboratory data implies that SRW walls are extremely conservative under static loading; however, it may not be sufficiently conservative under seismic loading. Again, design refinement is needed. Furthermore, current designs need to be refined when using low grad soils that are not necessarily free draining (silts) or when the reinforcement is closely spaced (say, about 20 cm apart between continuous sheets). The distributions of tensile force in reinforcement layers along the height of the wall/slope needs to be better identified (i.e., is it uniform, triangular, or any other shape? Such knowledge will make limit state analysis more accurate). As the level of conservatism decreases, the amount of deformation will increase. Hence, assessing the serviceability of MSE structures becomes more important. Such assessment requires more refined material properties. It also requires higher-level type of analysis (e.g. FE) compared with that used in design. Such advanced numerical tools should be used in research. Experience shows that simple design processes facilitate acceptance and use of new technology. Therefore, after verifying the validity of the numerical predictions, parametric studies should be conducted so as to produce simple design procedures.

Dov Leshchinsky would like to acknowledge his co-chair, Jorge Zornberg, and the secretary Yoshihisa Miyata. The organizers of the 4th IS-Kyushu Conference are to be congratulated for a well-organized and technically rewarding conference. We are looking forward to the next Kyushu conference.