IGS TC-Soil Reinforcement Workshop in Barcelona

20 – 21 January 2020 | BarcelonaTech | Barcelona, Spain

TC-R WORKSHOP

Topics

A) Reliability based design and analysis of geosynthetic reinforced structures
   – *Session Chair: Richard Bathurst, Canada*

B) Geosynthetic encased columns
   – *Session Chair: Erol Güler, Turkey*

C) Serviceability Limit States: analyses, design, specification
   – *Session Chair: Pietro Rimoldi, Italy*

D) Advancements, Developments and State of the Practice for International Codes of Geosynthetics in Reinforced Soil Structures
   – *Session Chair: Robert Lozano, USA*

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Social Event
Monday 20 January 2020, 7:00 pm
Venue: tbd

Organisation

Chair: *Gerhard Bräu (Germany)*

Co-chair: *Richard Bathurst (Canada), Fumio Tatsuoka (Japan), Yoshihisa Miyata (Japan)*

Secretary: *Lars Vollmert (Germany)*

Treasurer: *Jürgen Gruber (Austria)*

Local Contact: *Ivan P. Damians (Spain), Raquel Ribera (Spain)*

Venue

Workshop Location: Universitat Politècnica de Catalunya – BarcelonaTech (UPC, School of Civil Engineering), Spain

Technical Mission

The intention of the workshop is to stimulate the discussion and the formation of a group of experts to encourage the preparation of a guideline or a white paper on the very specific and defined topics shown below.

The responsible session chair organizes a half day event each by inviting speakers and main discussion participants. Proceedings are not planned, but the presentations will be available to the participants only.

IGS TC-Soil Reinforcement Workshop*, Universitat Politècnica de Catalunya-BarcelonaTech (UPC), Barcelona (Spain), 20 – 21 January 2020.

** All presentations reported/summarized below are available on IGS website*

A) RELIABILITY SESSION REPORT

20 January 2020, UPC, Barcelona, Spain

Chair: **Professor Richard J. Bathurst**

A call for session themes for the IGS TC-Soil Reinforcement workshop in Barcelona resulted in a session titled: **RELIABILITY-BASED ANALYSIS AND DESIGN OF GEOSYNTHETIC REINFORCED STRUCTURES**. This is a timely topic because the probabilistic approach (reliability-based design) for geotechnical foundations is gaining traction in Canada, the Netherlands, Japan and the USA. The case for reliability-based design has also been made in ISO2394:2015. Annex D: General principles on reliability for structures. International Organization for Standardization, Geneva, Switzerland. In the opening remarks to the session by the chair, Professor Bathurst, he explained that reliability-based design (RBD) can be fully probabilistic or simplified (semi-probabilistic). An example of the simplified approach used in the USA and Canada is calibration of load and resistance factor design (LRFD) limit states to a target probability of failure. RBD provides an alternative probabilistic appreciation of margins of safety and the accuracy of the load and resistance models that appear in simple limit state equations including those used for internal and external stability design of mechanically stabilized earth (MSE) walls. However, the session chair cautioned that reliability-based design should be viewed as a complementary approach to traditional (deterministic) working stress methods and LRFD approaches. He concluded by noting that the development and use of RBD for MSE walls is relatively new and it is for this reason that this session was developed.

Four presentations were given by the following IGS members: **R.J. Bathurst, P. Rimoldi, Y. Miyata** and **P. Pezzano**. A brief summary of each talk is reproduced below.

A simple approach for probabilistic internal stability analysis and design of reinforced soil walls

Dr. Richard J. Bathurst, GeoEngineering Centre at Queen's-RMC, Kingston, Ontario, Canada

The lecture explained the basics of probabilistic analysis and design for internal stability limit states for mechanically stabilized earth (MSE) walls using the example of geogrid reinforced soil walls. The general approach uses a closed-form solution for reliability index which is easily implemented in a spreadsheet and thus eliminates the need for Monte Carlo simulation. A novel feature of the formulation is that it includes uncertainty in the choice of nominal values [which is consistent with the notion of level of understanding that appears in the Canadian Highway Bridge Design Code] and the underlying accuracy of the load and resistance models that appear in each limit state equation using bias statistics. The lecture demonstrated how bias statistics for tensile load and pullout model accuracy can be gathered from load measurements recorded from instrumented walls and found in laboratory pullout box test databases. The concepts are general and can be applied to any soil-structure interaction problem which can be expressed by a simple linear limit state performance function and for which bias statistics are available. The lecture concluded with an example of the calculation of the probabilistic margin of safety against failure of the reinforcement tensile strength limit state for all reinforcement layers in a wall using the AASHTO Simplified Method and the recently adopted AASHTO Stiffness Method in the USA. The calculations were performed for an actual instrumented and monitored production MSE wall constructed in the USA.

Reliability analysis of external stability of geosynthetic reinforced soil retaining walls

Pietro Rimoldi, Consultant, Milano, Italy

This lecture was complementary to the previous lecture because it focused on reliability analysis and design for external stability limit states of MSE walls. The external limit states considered in the lecture were sliding, overturning, and bearing capacity. The lecture reviewed the link between probability of failure and reliability index (⍰) and linked these concepts to Eurocode 0 (EN 1990:2002) Annex C. Closed-form solutions for the three external limit states were first presented and then soil friction angle and unit weight parameters identified as stochastic variables with normal (Gaussian) distributions and statistical characteristics defined by mean and standard deviation (or COV). Monte Carlo simulation was explained in which multiple calculations for each limit state are performed with each calculation using randomly sampled values from the distributions above. The probability of failure is computed as the fraction of the total number of calculations that fail to satisfy the limit state function. These calculations can be performed using an EXCEL spreadsheet. The influence of the COV of soil parameters and different deterministic reinforcement lengths on the probability that a limit state is not satisfied was illustrated. The lecture showed that reducing the COV of soil parameters through better project investigation can lead to cost savings.

Reliability analysis of geogrid pullout capacity

Dr. Yoshihisa Miyata, National Defense Academy, Japan

The first speaker introduced the notion of model error as a contribution to probability of failure (or reliability index) in reliability analyses. This talk expanded on this idea by focusing on the calculation of model error (bias) for geogrid pullout capacity in the pullout limit state for internal limit states for MSE walls. The talk covered current pullout design models used in Japan, the collection of pullout test data used to quantify pullout model error, the interpretation of pullout load tests in Japan, the accuracy of current pullout models used in Japan, and a proposal for an improved pullout model. The paper shows that the current pullout model used in Japan is excessively conservative by a factor of 1.35 *on average* and COV of bias values of 38%. The proposed new model is much better with mean bias of 1 and COV of bias values of 26%. Furthermore, there is no statistically significant correlation between model error (bias) and predicted pullout capacity. While the lecture focused on reliability of geogrid pullout models using physical test measurements, the general approach to quantify model error is applicable to other limit states where physical measurements are available for both load and resistance parameters.

First order reliability method for reinforced soil walls

Pietro Pezzano, Officine Maccaferri, Italy

In this lecture, internal and external limit states for MSE walls were examined within a probabilistic framework. The margin of safety was expressed as reliability index (▯) and its calculation demonstrated using the well-known first-order reliability method (FORM) approximation. The probability of failure for five different limit states for a typical reinforced soil wall and expressed using formulations found in BS8009 was demonstrated. The calculations were easily carried out using an EXCEL spreadsheet application that is freely available.

Following the four presentations there was a lively collegial discussion between the speakers and the audience.

Prepared by
Prof. Richard J. Bathurst
IGS Past-President

B) GEOSYNTHETIC ENCASED COLUMNS (GEC) REPORT

One of the four sessions was on "**Geosynthetic Encased Columns (GEC)**". The session was held between 14:00-18:00 on the 20th of January 2020. The session was organized and chaired by Erol Güler, George Mason University

Basic design principles of GECs

by **Dr. Dimiter Alexiew**, independent consultant.

He summarized the design procedure using analytical and finite element methods and also addressed the global stability issue. He mentioned that the design suggested by EBGEO is a combination of Ultimate Limit State design and Serviceability Limit State design. He emphasized the importance of the encasement stiffness in the success of GECs.

Materials of GECs and some important case studies

by **Dr. Oliver Detert**, Huesker Synthetic GmbH.

He reported on the materials used as encasement of GECs and also emphasized the effect of the stiffness of the material on the end design. He stated that it is rather beneficial to use an encasement with higher elastic modulus and a smaller replacement ratio, rather than using a weak encasement and a higher replacement ratio. Because using a weak encasement geosynthetic will cause much more geosynthetic to be used and also increases the installation time and cost significantly. He also gave some examples of successfully completed projects.

Installation Issues of GECs

by **Steffen Taetz**, Züblin AG.

He mentioned the details of displacement and replacement installation methods. He also showed several examples and the machinery typically used in installation.

Alternative Installation Issues and their effect on design

by **Björn Böhle**, Keller Grundbau GmbH.

He mentioned Boundary conditions in terms of soil, installation technique and also mentioned the exclusion criteria. He further highlighted the influence of installation on the behavior of GECs. He also reported on tests sites and reported the results achieved from real projects.

Alternative design methods

by **Dr. Boštjan Pulko**, University of Ljubljana.

He presented an extension of a recently developed fully coupled elastoplastic method for the analysis of a poroelastic thick-walled soil cylinder around an elastoplastic end-bearing stone column to account for the influence of an elastic geosynthetic encasement. Analytical closed-form expressions for excess pore pressures, stresses, strains, displacements and encasement forces can be derived in the Laplace domain using this approach. The validity of the solution was checked against finite element analyses and compared with previously developed analytical methods.

Earthquake behavior of GEC improved foundations

by Dr. Erol Güler, George Mason University.

He presented a study showing the behavior of ordinary stone columns and GECs under earthquake loading conditions. It was shown that the geosynthetic encasement proves to be important in the stone columns keeping their integrity during earthquakes.

There was also lively discussion during all presentations. However since the subject were relatively new to the audience, they were most questions for better understanding the system. The only detailed discussion was related to whether GECs can be used as floating elements. The opinion of Dr. Detert was that they do not recommend it. However there were comments who stated that it is possible. No conclusion could be reached.

Prepared by
Prof. Erol Güler

C) SERVICEABILITY LIMIT STATES (SLS) REPORT

21 January 2020, UPC, Barcelona, Spain

The third session of the GeoReinforcement Workshop took place in the morning of 21 January 2020, for discussing the topic "**Serviceability Limit States: Analyses, Design, Specification**".

The session was chaired by **Pietro Rimoldi** and co-chaired by **John Sankey**, who introduced all lecturers and has driven all the discussions.

SLS in Eurocodes and Numerical models for SLS

by **Dr. Ivan Puig Damians**, Universitat Politècnica de Catalunya – BarcelonaTech, Spain.

- concept and requirements for Serviceability Limit States (SLS) analyses in the recent new draft of Eurocode (EN 1997-3. Chapter 9: Reinforced Ground) were introduced;
- the requirements for SLS in other existing codes (BS8006-1:2010+A1:2016 in UK, NF P 94-270 in Fraance, AASHTO LRFD in USA) were presented;
- the numerical methods and Numerical Modelling Specifications in Eurocodes (EN 1990 and EN 1997-1), including the requirements for the calibration and verification process of the model used and the different approaches suitable for numerical methods (namely the Effect Factors Approach EFA and the Material Factors approach MFA), were illustrated;
- a Case Study was used to show the practical application of Numerical Models for SLS: a complete analysis of a reinforced soil wall as bridge abutment, with bridge deck loading, was presented, with the comparison of results when performing calculations according to Eurocodes and BS8006 requirements.

Semi-dynamic models for SLS in seismic conditions. Post-seismic serviceability of earth-reinforced walls: evidences and predictions

by **Dr. Giovanni Biondi**, University of Messina, Italy.

- GRS walls: seismic behavior and earthquake-induced SLS permanent deformations and displacements of different types of reinforced soil walls (RSW) threshold values and/or code prescribed SLS limits post-seismic serviceability is often compromised
- field and lab data: governing mechanisms to be considered deformation patterns energy dissipation mechanisms in RSW seismic safety and post-seismic serviceability
- proposed numerical model with concentrated mass:
- theoretical background example of prediction (SLS check)

SLS in BS8006 and real case studies/problems under SLS criteria

by **Patricia Guerra Escobar**, Geosynthetics Ltd, UK.

- BS8006-1-2010+A1-2016: Description and range of applications
- Concepts and fundamental principles Ultimate Limit State Serviceability Limit State

- Design Process Load Combinations Partial Factors Design Principles
- Case Study: RSW, 14 m high and 160 m long, for the construction of level/horizontal working platform for the Elan Valley Aqueduct, Bleddfa, Wales, UK
- Case Study: RSW for The Fitz Residential development, , Cockermouth, Cumbria, UK.

SLS in EBGEO, taking care of the strength-strain characteristic of reinforcements

by Dr.-Ing. Lars Vollmert, NAUE GmbH & Co. KG, Germany.

- Applications of reinforcement in Ebgeo
- Use of Isochronous curves
- SLS requirements in Ebgeo Combined failure modes Deformation of reinforced walls at post construction stage Influence of tensile stiffness and reinforcement-soil interaction
- Mechanical Model of Reinforced Soil
- Differentiation of the facing stiffness
- Calculation of connection strength between facing and geogrid
- Results of large scale testing for impact loading on RSW and for fire on the facing
- Soil-Structure interaction for basal reinforcement of embankments on piles

SLS in the African contest

by Edoardo Zannoni, Maccaferri SA (Pty) Ltd, South Africa.

- in the African contest SLS is mainly based on ultimate limit state for checking maximum deformations that have been specified in the construction methodology (i.e. mining tip wall distance from crusher or staged construction);
- SLS is mostly used to confirm the safety of the structure following an occurred deformation.
- The most critical deformation is usually the horizontal deformation, for which several formulas are available based on the strain developed along the reinforcement
- Finite elements methods can be considered for complex analysis, which require a careful evaluation of soil stiffness, soil – geosynthetics interface parameters, and geosynthetics tensile modulus.
- Three examples of SLS analyses with post-construction displacements calculation were presented: An18 m high wall designed with 2 different reinforcements and length of 70 % of wall height A RSW which exhibited post construction movements of 48 mm over a period of 10 months A 5.6 m high RSW with concrete panel facing, built for a ramp with accelerated construction
- The final remarks highlighted the need for accurate information on the final construction (t = 0 data for post construction deformations), the need to enforce the quality of construction, for which the QC/QA is vital, and the design of drainage for ensuring optimal moisture conditions and compaction.

Serviceability limit state (SLS) in the Asia Pacific context

by **Mike Dobie**, Tensar International Limited, Indonesia.

- introduction to AS 4689-2002 (Australian Code for retaining walls), which requires for SLS:
    - a) limit Mode S1 - Rotation of the structure
    - b) Limit Mode S2 - Translation or bulging of the retaining structure
    - c) limit Mode S3 - Settlement of he structure
- Creep extension of synthetic soil reinforcement
- Method of calculation of horizontal displacements using 3-part wedge and comparison with measured performance of Japanese trial wall
- Examine some of the additional advice given in the Asia Pacific region, including BS8006 and R57 specification in NSW (Australia), which require specific limits on the post-construction strain in reinforcement; AASHTO; Geoguide 6 (Hong Kong).

The presentations were followed by a long and interesting discussion, where the presenters and all the audience debated about several specific topics related to Serviceability Limit State analyses. The interest and attention gained by this topic at the GeoReinforcement Workshop has shown that problems associated with displacements and deformations of reinforced soil structures, in both static and seismic conditions, deserves research and developments by the geosynthetics technical community.

Prepared by
Pietro Rimoldi

D) ADVANCEMENTS, DEVELOPMENTS AND STATE OF THE PRACTICE FOR INTERNATIONAL CODES FOR DESIGN OF REINFORCED SOIL STRUCTURES REPORT

21 January 2020, UPC, Barcelona, Spain

Session Chair: Robert Lozano, Geosynthetic product specialist, USA

AASHTO Migration from the Simplified Method to the Stiffness Method
by Dr.Richard J. Bathurst, GeoEngineering Centre at Queen's-RMC, Kingston, Ontario, Canada
Tony M. Allen, State Geotechnical Engineer. Olympia, Washington State, USA

Recent updates to AASHTO LRFD for Reinforced Soil Structures
by Keith Brabant, P.E., Vice President, Engineering Reinforced Earth Company.

Japanese technical standards on geo-structures for road applications and technical manual on geosynthetic-reinforced walls
by Dr. Yoshi Miyata, National Defense Academy of Japan

Examples of the strength, weakness and scope of the Chinese, Hong Kong and United Kingdom Codes of Practice for reinforced soil.
by Dr. Colin J F P Jones, Director of Electrokinetic Limited, UK

Australian experience on codes and guidelines for soil reinforcement
by Amir Shahkolahi, Global Synthetics Pty Ltd

Reinforced Fills Covered by The Future Eurocode 7 - Concepts and Limitations
by Nicolas Fritang, Terre Armée group

The effects of the new Eurocode 7 reinforced ground chapters on the German EBGEO
by Gerhard Bräu, Technical University of Munich – Zentrum Geotechnik

ISSMGE TC218 and Outcome of Review Addressing 12 Current Codes on Reinforced Fill Structures
by John Sankey, Chairman of the ISSMGE TC218 Committee on MSE Structures and Reinforced Soil Slopes

Round table and Open discussion

(No report available for this D-Session)

1st Session discussion:

Speakers of the 1st Session (A):

Speakers of the 2nd Session (B):

TC-R attendants:

Social event - 1st day dinner at Alba Granados:

Speakers of the 3rd Session (C):

Speakers of the 4th Session (D):

Last day beer-time at Garage Beer Co.