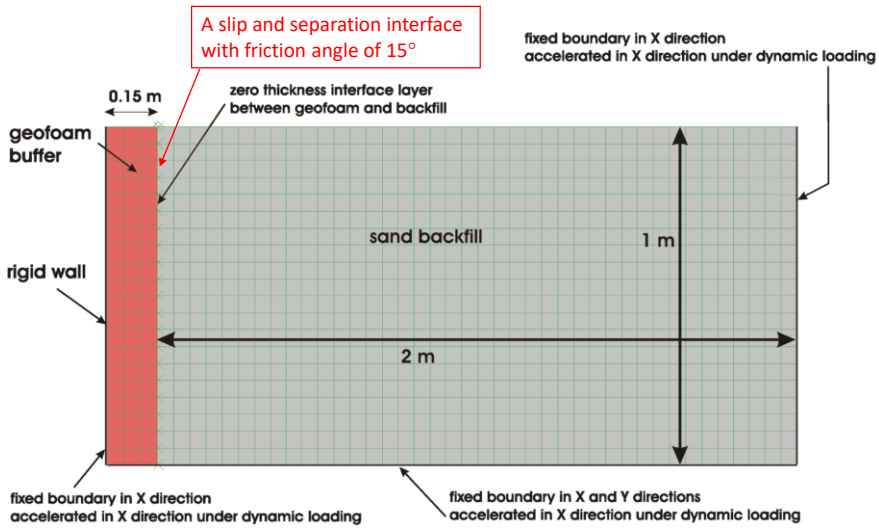
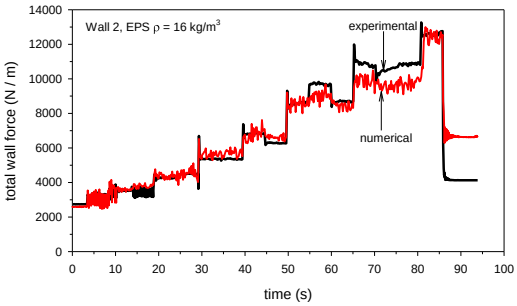
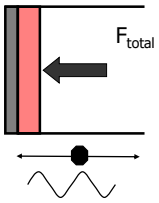
NUMERICAL MODEL VERIFICATION

Numerical study: FLAC Model

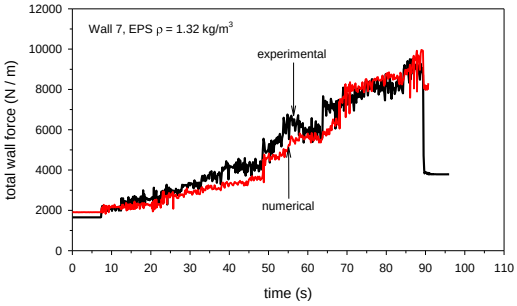


Numerical results - Forces





Wall 2, EPS ρ = 16 kg/m^3



Wall 7, EPS ρ = 1.3 kg/m^3

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PARAMETRIC NUMERICAL STUDY

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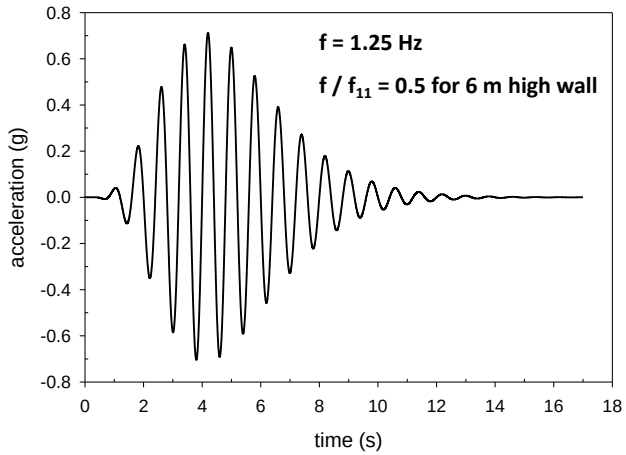
Model excitation

- Variable amplitude sinusoidal acceleration record:

$$\ddot{u}(t) = \sqrt{\beta e^{-\alpha t} t^{\gamma}} \sin(2\pi f t)$$



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Parametric numerical study: Design and performance parameters

$$\text{Buffer stiffness} = \text{K (MN/m}^3) = \frac{\text{E}}{\text{t}} = \frac{\text{Elastic modulus of geofoam}}{\text{geofoam thickness}}$$

$$\text{Isolation efficiency} = \frac{\text{peak force (rigid wall)} - \text{peak force (seismic buffer)}}{\text{peak force (rigid wall)}} \times 100\%$$

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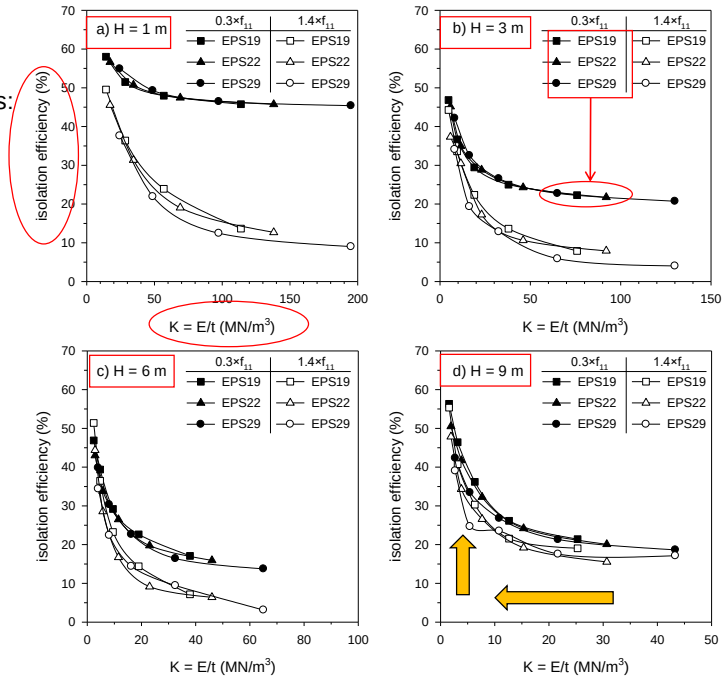
Design charts:



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Conclusions

- Experimental shaking table test results and numerical simulations demonstrated proof of concept for using EPS geofoam material as a seismic buffer to attenuate dynamic earth pressures against rigid retaining walls
- The practical quantity of interest to attenuate dynamic loads using a seismic buffer is the buffer stiffness defined as:

$$K = E / t$$

- For the range of parameters investigated in this study,

$$K < 50 \text{ MN/m}^3$$

was observed to be the practical range for the design of these systems to attenuate earthquake loads

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Zarnani, S. and Bathurst, R.J. 2009. Numerical parametric study of EPS geofoam seismic buffers, *Canadian Geotechnical Journal*, Vol. 46, No. 3, pp. 318-338.

Queen Elizabeth Water Reservoir - Vancouver

Protected with Elasticized EPS Seismic Buffer

Some useful references related to seismic analysis and design

- Bathurst, R.J., Hatami, K. and Alfaro, M.C. 2021. Geosynthetic-reinforced soil walls and slopes - seismic aspects, Chapter 19, Handbook of Geosynthetic Engineering, Third edition, Editor: S.K. Shukla, ICE Publishing, London, UK, 371-415.
- Bathurst, R.J. and Hatami, K. 1998. Seismic response analysis of a geosynthetic reinforced soil retaining wall. Geosynthetics International 5(1-2): 127-166.
- AASHTO. 2020. LRFD Bridge Design Specifications, 9th Ed., American Association of State Highway and Transportation Officials (AASHTO), Washington, DC, USA.
- Zarnani, S., El-Emam, M.M. and Bathurst, R.J. 2011. Comparison of numerical and analytical solutions for reinforced soil wall shaking table tests. Geomechanics and Engineering 3(4): 291-321.
- Bathurst, R.J. and Cai, Z. 1995. Pseudo-static seismic analysis of geosynthetic reinforced segmental retaining walls. Geosynthetics International 2(5): 789-832.
- Koseki, J., Bathurst, R.J., Güler, E., Kuwano, J. and Maugeri, M. Seismic stability of reinforced soil walls, Keynote paper, 8th International Conference on Geosynthetics, Yokohama, Japan, 18-22 September 2006.

http://www.geoeng.ca/members/Bathurst/Index.html#fndtn-publications

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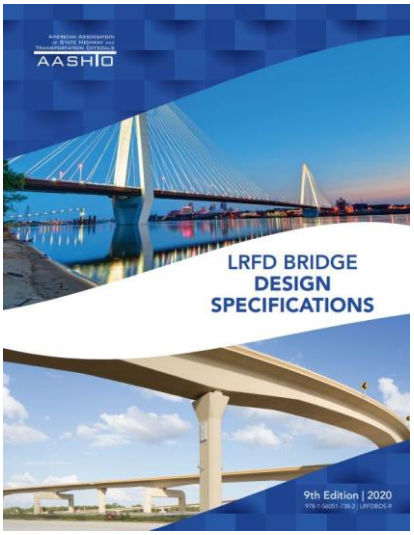
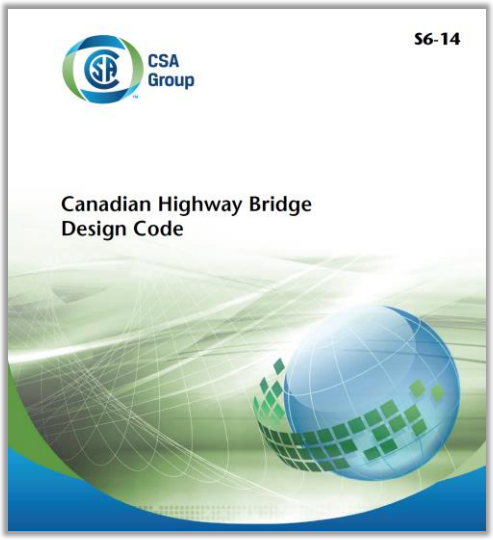
LRFD codes in North America



AASHTO 2020



CHBDC 2019

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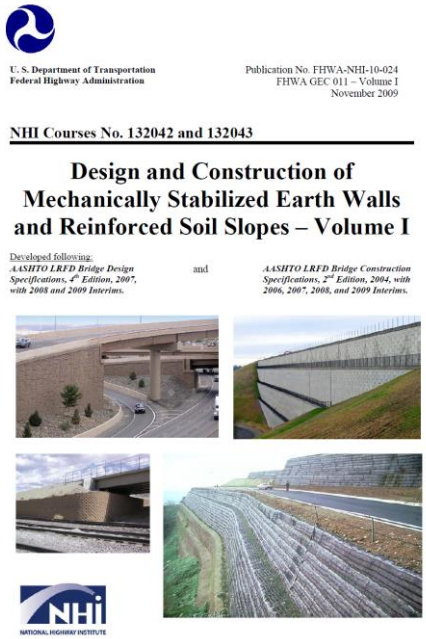
A useful reference

Example calculations can be found here


U. S. Department of Transportation
Federal Highway Administration

Publication No. FHWA-NHI-10-024
FHWA GEC 011 – Volume I
November 2009

NHI Courses No. 132042 and 132043

Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes – Volume I

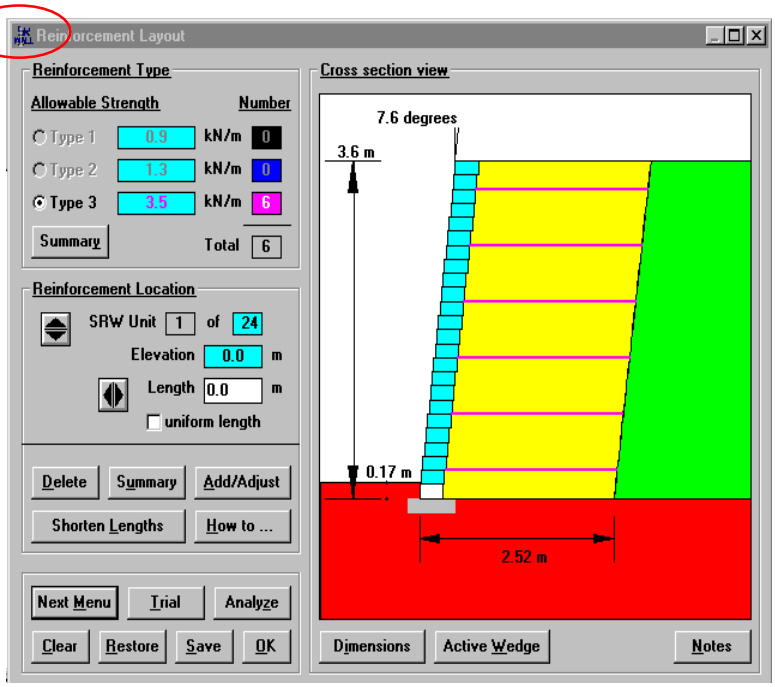
Developed following:
AASHTO LRFD Bridge Design Specifications, 4th Edition, 2007, with 2008 and 2009 Interims. and *AASHTO LRFD Bridge Construction Specifications, 2nd Edition, 2004, with 2006, 2007, 2008, and 2009 Interims.*

NHI
NATIONAL HIGHWAY INSTITUTE

https://www.fhwa.dot.gov/engineering/geotech/pubs/nhi10024/

Design Software Aids

- NCMA Segmental Retaining Wall Program
- ADAMA Engineering
- Vendors



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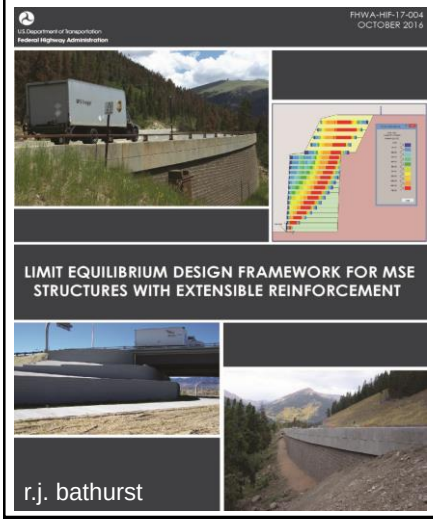
- *ReSSA+* (*Reinforced Slope Stability Analysis*) is a software package that analyzes:
  - Internal stability (pullout, connection loading, rupture, compound stability)
  - External Stability (sliding, overturning, bearing capacity, global failure, etc.)
- Details of method outlined in FHWA Document

https://www.fhwa.dot.gov/engineering/geotech/pubs/hif17004.pdf



Technical Report Documentation Page

1. Report No. FHWA-HIF-17-004	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle: Limit Equilibrium Design Framework for MSE Structures with Extensible Reinforcement		5. Report Date: October 2016 6. Performing Organization Code
7. Principal Investigator(s): See Acknowledgements for Authors and Contributors: Dov Leshchinsky, Ph.D.[1], Ora Leshchinsky, P.E.[1], Brian Zelenko, P.E., John Horne, Ph.D., P.E.		8. Performing Organization Report No.
9. Performing Organization Name and Address: Parsons Brinckerhoff, 1015 Half Street, SE, Suite 650, Washington, DC 20003; [1]ADAMA Engineering, Inc., 12042 SE Sunnyside Rd., Suite 711, Clackamas, OR 97015		10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFH6114D00047-5010
12. Sponsoring Agency Name and Address: Federal Highway Administration, HIBT-20, Office of Bridge Technology, 1200 New Jersey Avenue, SE, Washington, DC 20005		13. Type of Report and Period 14. Sponsoring Agency Code
15. Supplementary Notes: FHWA COR – Silas Nichols, P.E. FHWA Alt. COR – Khalid Mohamed, P.E.		
16. Abstract: Current design of reinforced soil structures in the U.S. distinguishes between slopes and walls using the batter angle as a criterion. Using a unified approach in limit state design of reinforced 'walls' and 'slopes' should diminish confusion while enabling a wide and consistent usage in solving geotechnical problems such as complex geometries and soil profiles. Limit equilibrium (LE) analysis has been used successfully in the design of complex and critical (e.g., tall dams) for many decades. Limit state analysis, including LE, assumes that the *design* strength of the soil is mobilized. Presented is a LE framework, limited to extensible reinforcement, which enables the designer to find the tensile force distribution in each layer required at a limit state. This approach is restricted to Allowable Stress Design (ASD). Three example problems are presented.		
17. Key Words: Mechanically Stabilized Earth Wall Design, MSE Wall Design, Limit Equilibrium, Geotechnical, Extensible reinforcement		18. Distribution Statement: No restrictions.
19. Security Classif. (of this report): UNCLASSIFIED	20. Security Classif. (of this page): UNCLASSIFIED	21. No. of Pages: 120 22. Price

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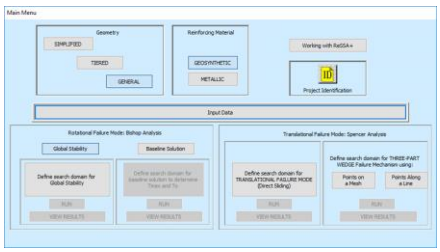
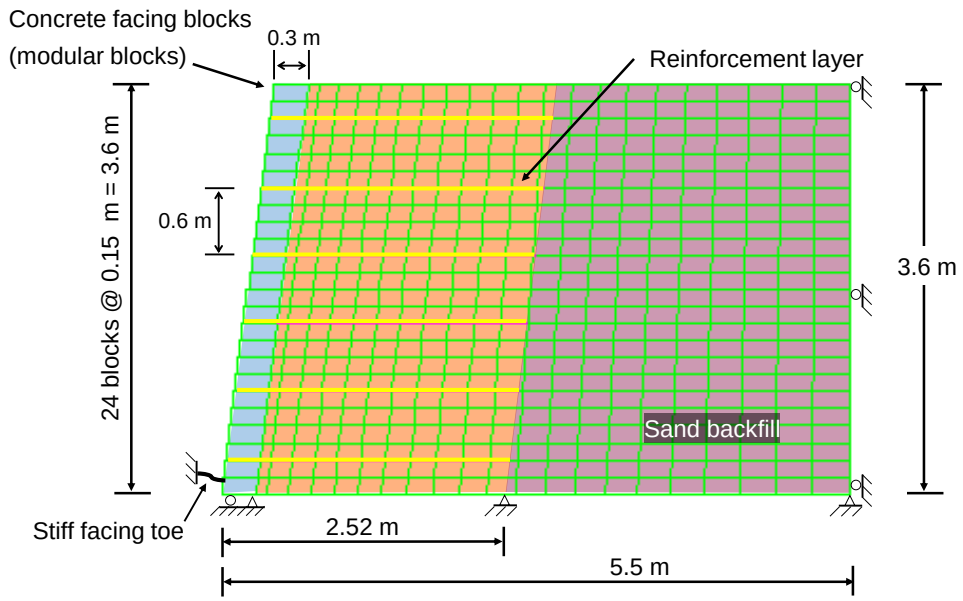
ReSSA+: Reinforced Slope Stability Analysis



Numerical modeling

- Finite element modeling
- Finite difference modeling (FLAC)

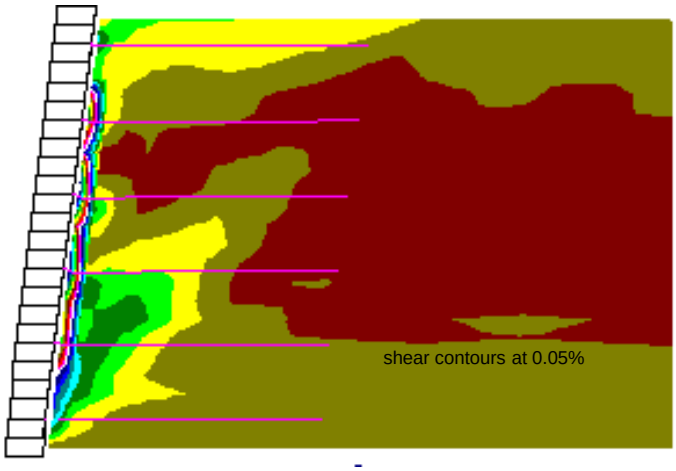
FLAC Numerical grid for RMC segmental retaining walls



FLAC Numerical Simulation

(Wall 5 - Segmental wall with polyester reinforcement)

Soil shear contours at end of construction



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12 ICG

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Geosynthetic Reinforced Structures including Seismic Aspects

Richard J. Bathurst

GeoEngineering Centre at Queen's-RMC

17 September 2023

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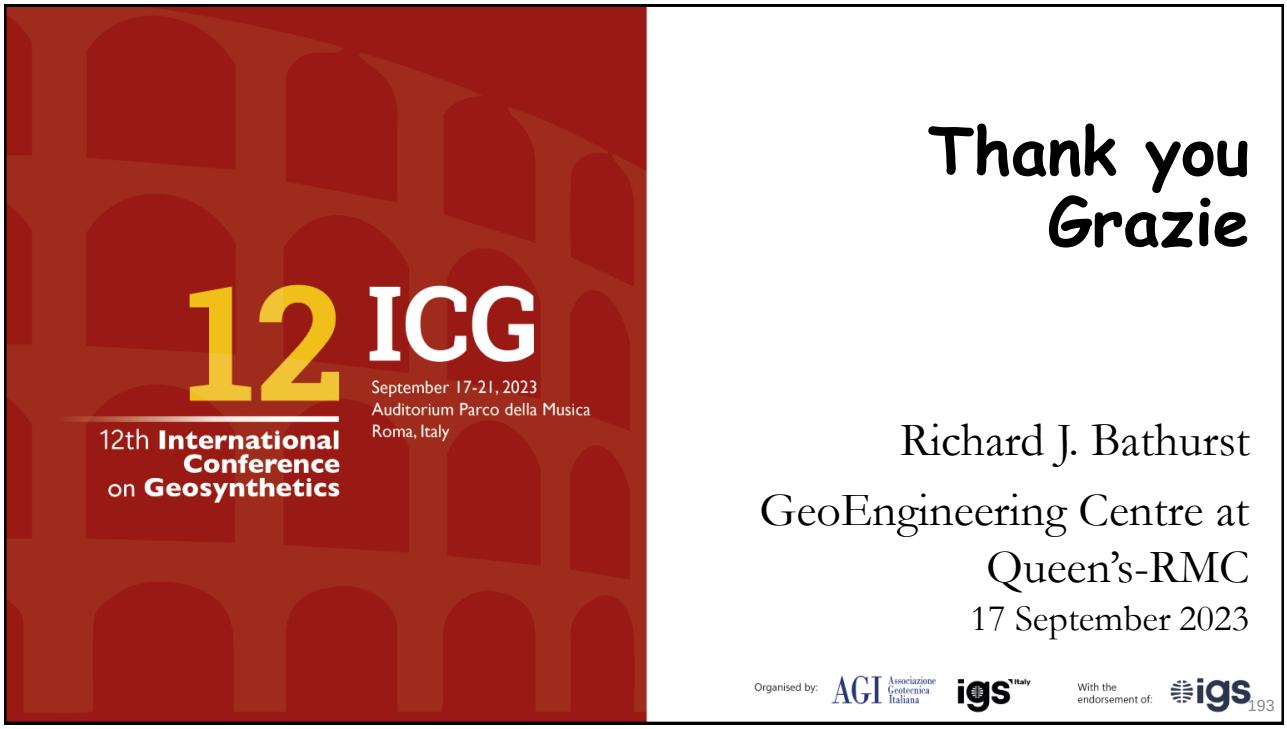
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Thank you
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