Recent Trinity College Dublin environmental-geotechnics research and collaborations, with focus on greener economy by sustainable technologies

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integrated natural and engineered systems
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Online Workshop organised by Emerging Geohazards Research Group,
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Overview

• Natural polymers (biopolymers) for grouting
• Microbial-induced carbonate precipitation (MICP) for grouting/spraying
• Nanomaterials: nanosilica (NS) and nanoclay (NC) for soil mixing/grouting
• Overview of other novel ground improvement/remediation for:
  o Expansive soil
  o Soil remediation/adsorption of contaminants
  o Liquefaction resistance
  o Microplastics in soil/groundwater (our latest research area)

To finish with vacuum consolidation and granular anchors research
**1, Biopolymers**: environmentally friendly, sustainable grouting materials

Our early work (Khatami and O’Kelly, 2013)

- *Guidelines for selecting potentially useful biopolymers for soil improvement*

Plus, investigated compatibility of Fontainebleau sand with 1–4% agar and **6 modified starches** (0.5–1%)

**Starpols 600 & 136** at same agar concentration (1%) significantly increase cohesion/stiffness

Biopolymers (ctd.) Recent contribution (Khatami and O’Kelly, 2018)

Goal: **find additives that keep solids in suspension for reasonable period demanded by grouting application** (=> increase zeta potential of fine grout particles)

- **Superfine GGBS cement** at 2:1 & 5:1 water/binder ratio; various biopolymers investigated

<table>
<thead>
<tr>
<th>Biopolymer</th>
<th>Concentration (percentage by mass of water)</th>
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<tr>
<td>Diutan gum (DG)</td>
<td>0.25%</td>
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<td>Carboxymethylcellulose (CMC)</td>
<td>0.25% (for 2:1 w/b)–1.0% (for 5:1 w/b)</td>
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<td>Xanthan gum (XG)</td>
<td>0.25% (for 2:1 w/b)–1.0% (for 5:1 w/b)</td>
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<td>Guar gum (GG)</td>
<td>0.25% (for 2:1 w/b)–1.0% (for 5:1 w/b)</td>
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<td>Acacia gum (AG)</td>
<td>1.0% and 2.0% (for 2:1 w/b)</td>
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<td>Starch</td>
<td>0.5% (for 2:1 w/b)</td>
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<td>Xanthan gum and CMC</td>
<td>0.25% XG and 0.25% CMC (for 5:1 w/b)</td>
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Below: bleeding tests on GGBS–biopolymer grouts (acceptable bleeding considered <5%)

**Diutan gum** & **xanthan gum** gave highest performance in bleeding prevention at 0.25–1.0 wt%; **xanthan gum** provided synergy with both guar gum & CMC.

2, MICP (with Dr. S.M.A. Zomorodian, Shiraz University)

Goal: \textit{For loose sand, improve strength \& stiffness, without significant permeability (k) reduction}

- Achieve homogeneous calcite deposition throughout treated soil mass

Two loose medium quartz sands, different concentrations of bacterial cell (\textit{S. pasteurii}) and urea–\textit{CaCl$_3$} solutions, investigated various injection protocols

- Measured strength, stiffness and permeability coefficient (k), plus SEM, for treated specimens (Shahrokhi-Shahraki et al., 2015)

\textit{Staged injection including retention periods, with pressure head applied during injection of bacterial solution, proved most effective}

\textit{k} values reduced by up to one order of magnitude => method tailored, so as to not significantly affect drainage capacity of treated sand media

MICP (ctd.): *Reducing the hydraulic erosion of sand* (Amin et al., 2017)

- Erodibility parameters of dense, medium quartz sand, treated with different injection strategies, investigated using erosion-function apparatus (EFA) and SEM

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<td>Aeration during injections</td>
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More effective treatment – in terms of greater and more uniform calcite precipitation over test-specimen length – **achieved by aeration during solution injections and incorporating drained stage between the two injection cycles**
Achieved 95% reduction in erodibility and 5-fold increase in critical shear stress, relative to untreated sand

Calcite precipitate distribution recorded over specimen length (A–H: refer to Table 1)

2 injection cycles (each with aeration during injections and 24-h solution retention periods), with 6 d drained stage between cycles, and for 0.5 M cementation solution, produced 6.1 wt% calcite precipitate

Calcite precipitated as larger crystals, accumulating extensively over grain surfaces and formed integrated in pore voids

**MICP (ctd.):**

*Stabilisation of crustal layer to mitigate wind erosion* (Zomorodian et al., 2019)

**Spray treat sand** surface layer with cementation and bacterial solutions mixture, ...

  Goal, provide necessary bond strength (cohesion) at grain contacts

  • Investigated loose medium silica sand, and fine and medium carbonate sands

Determine optimal reagent concentrations for Torvane strength development of crustal sand layer after single- and double-MICP spray treatments (latter applied 6 d after first spray application)

  • **Effect of dew formation** on strength development, and **outdoor experiments**, testing efficiency of MICP treatment over 3.5 month curing; strong **temperature-dependence** of MICP process

  • Also, **wind tunnel experiments** => 28-d cured singly-MICP-spray-treated crustal sand layer (using optimum reagent concentrations) found stable to simulated 20 m/s winds measured at 20 cm above layer surface.

3. **Nanomaterials** (with Dr. Zomordian, Shiraz Univ.)

*Improving hydraulic erosion resistance of sand using nano-silica* (NS) additive (Zomorodian et al., 2019)

- Compacted medium silica sand mixed with 1–4% NS (11–13 nm particle size range) investigated using erosion-function apparatus

- **1·5% NS optimum** amount in terms of greatest erosion resistance; i.e., 92% reduction in erodibility coefficient and 6-fold increase in critical shear stress, also achieved within significantly shorter period compared to traditional cement/lime additives

NS viscous gel property allows mobilisation of effective cohesion (surface bond strength)

Improving seepage-induced erosion resistance of silty sand using nanoclay (NC) additive (Zomorodian et al., 2020)

Highly erodible SP-compacted very silty sand, mixed with 0.5–6 wt% montmorillonite K10 (MK10), and investigated using hole-erosion test (HET); compared with 0.25–3% cement

Effect of MK10 on erodibility of 1-d-cured compacted very silty sand at 13% water content ($i = 7.2$) => 1% MK10–soil mixture, results in moderately slow erosion

Compared to cement, MK10 additive equally effective at similar wt%; advantage of substantially lower embodied carbon

Zomorodian et al. (2017) investigated strength/stiffness improvement for clean and kerosene-contaminated compacted sandy lean clay (CL) soil mixed with 0.5–2.5% NC (montmorillonite) and NS: particle size ranges of 1–2 and 11–13 nm, respectively.

Contamination of soils with oil products can occur during refining, transportation & operation processes.

Influence of wt% kerosene on compression strength for CL soil

1 wt% NC additive more efficient in improving strength/stiffness

Other collaborations ... *Investigating colloidal NS hydrosols for use as alternative low-viscose grouting material* (medium-dense fine silica sand)


Effects of *sulfonated oil (SO) stabiliser* on swell–shrink properties of expansive soil investigated via cyclic wetting–drying tests: 0.75% SO identified as optimum (with PI Dr. Soltani, Federation University, VIC, Australia)


Inspired by chemically-assisted sedimentation for potable water production at municipal works, investigated effects of *dilute aluminum sulfate and polyelectrolyte solutions* on geotechnical properties of organic clay/silt


Using *Polyhydroxybutrate (PHB) as a method of soil remediation*.... PHB can be degraded aerobically/anaerobically, at rate between up to 1–20 µm/d, adsorbing organic compounds, which are co-metabolized as it degrades.


*Microplastics* in soil/groundwater (our newest research area)
• Up to 10% **tire-derived aggregate** (TDA) content reduced swelling potential of **high-expansivity clay soil** to moderate expansivity, while improving strength-related features (TDA gradations = medium/coarse sands)


• Combining **ground rubber** (GR) and **polyacrylamide** (PAM), the binder, for improving **expansive clay**; maximum GR of 20%, with 0.2 g/L PAM deemed optimum


• **Pulverized waste tires** (PWT: 0, 5, 10, 15, 25 and 100 wt%) with well graded sand for adsorption of contaminants (BTEX components and heavy metal ions (Pb$^{2+}$ and Cu$^{2+}$))

  => **Compacted soil and 5–25% PWT mixture** adequate shear capacity for many load bearing field applications, used as adsorptive fill material


• **Cyclic undrained triaxial-compression** to investigate **cyclic behaviour of saturated loose sand–silt–GR mixtures**; damping effect of GR improves liquefaction resistance


*PIs indicated with underlining*
**Vacuum consolidation**: 10 x 10m area field trial, 4m deep peat layer; demonstrate method in road construction (widening of existing roads) over peat deposits; 1.1-m settlement at end of 11 month pumping period (27.5% strain)

Vacuum lines, PVDs, instrumentation in place; awaiting sealing membrane cover.

Cross-section of Ballydermot vacuum consolidation field trial

• **Granular anchors under pullout loading**
  
  *(with Dr. V. Sivakumar, QUB)*

![Diagram of anchoring systems](image)

- (a) shaft capacity failure ($L < 6D$);
- (b) small force resisted in shaft resistance over lower section of long column;
- (c) shaft resistance mobilizing upwards along column to resist increasing load;
- (d) failure in localized end bulging ($L > 6D$);
- (e) encasement of lower section of gravel column to impose failure in shaft capacity.


.... plenty of scope for research collaborations

Thank you for your attention!