Groundwater Technology

In Situ Soil Stabilization by Microbially Induced Calcite Precipitation

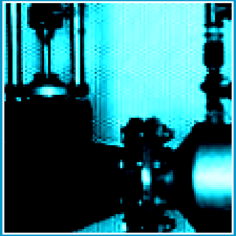
Using Biocementation to Stabilize unconsolidated soils

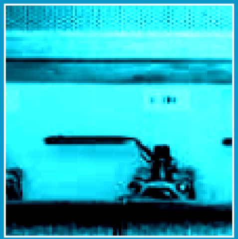
Solution Provider
Environmental Asset Management

Leading in soil and groundwater remediation

remediation technologies symposium

In Siu Biostabilisation



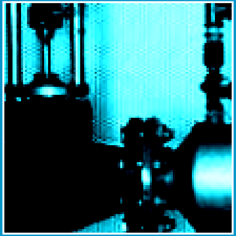


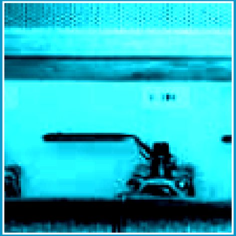
Unconsolidated loose soils often have poor physical properties:

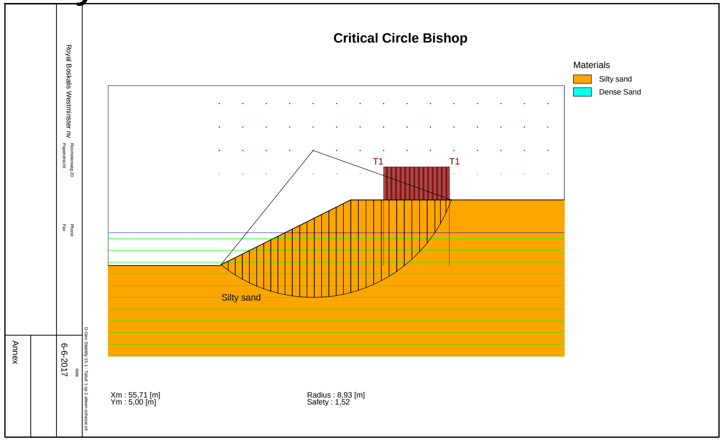
- Low natural slope angle
- Low load-bearing capacity
- Prone to subsidence / settlement
- Prone to erosion
- Prone to liquefaction

Examples

Theory:





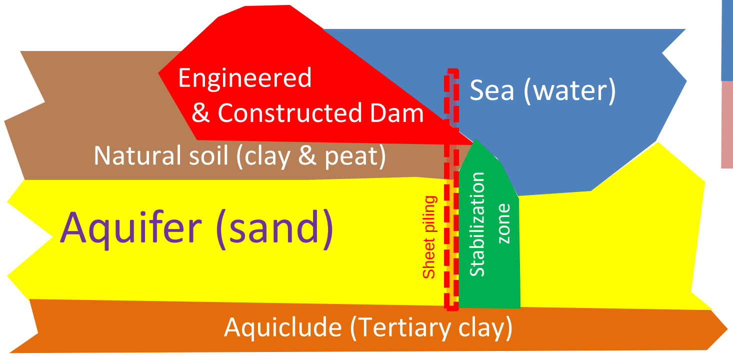


Slope stability:
Example calculation for project: a cohesion of **~16 kPa** is sufficient to provide stability against (static) failure for a 4 m high, 1 in 2 slope in extremely loose sand.
This is a <u>low strength</u> application

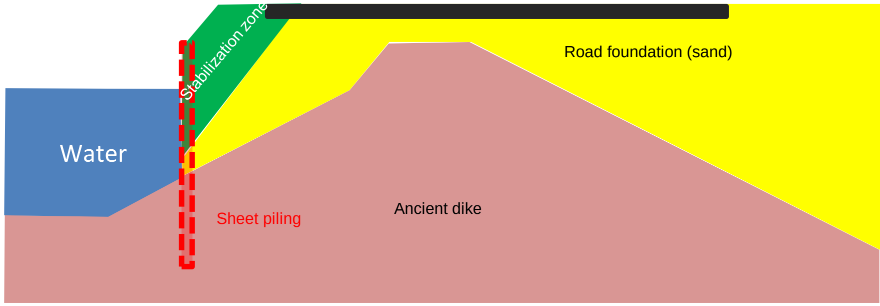
Erosion resistance:
< 5kPa required (<u>low strength</u> application)

Maximum strength achievable:
30.000 kPa UCS (concrete: 20.000 - 70.000 kPa)

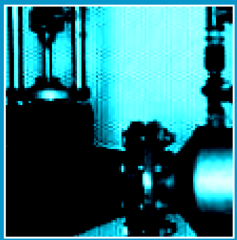
Example of application
Sea protection dam
Underlaying aquifer prone to liquefaction in case of earthquake

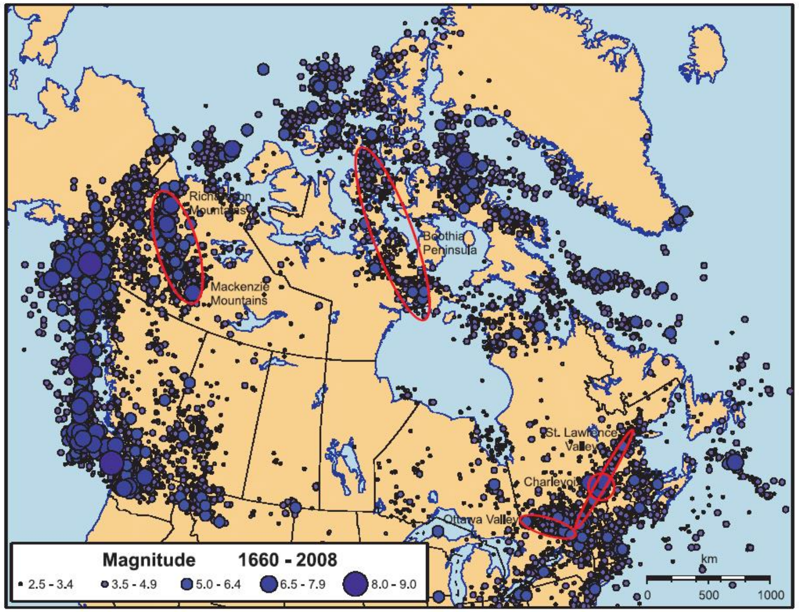


Example of application
Road bank along drainage canal



Liquefaction





Cassidy, J.F and others, Canada's Earthquakes:
'The Good, the Bad, and the Ugly': Geoscience Canada, Volume 37 Number 1

San Fernando earthquake, 1971.

Liquefaction in saturated loose soils
Pore water pressure in soil influences particle contacts: friction angle
Normally: static pore water pressure conditions
During earthquake: soil compacts -> rapid increase of excess pore water pressure -> particle contacts in soil reduced -> (complete) loss of strength: liquefaction

Japan: Kobe (1995) & Nigata (1964)

Port Lands Toronto

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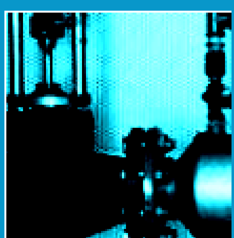

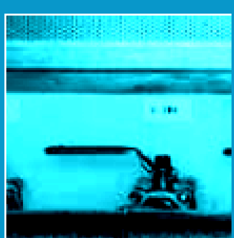

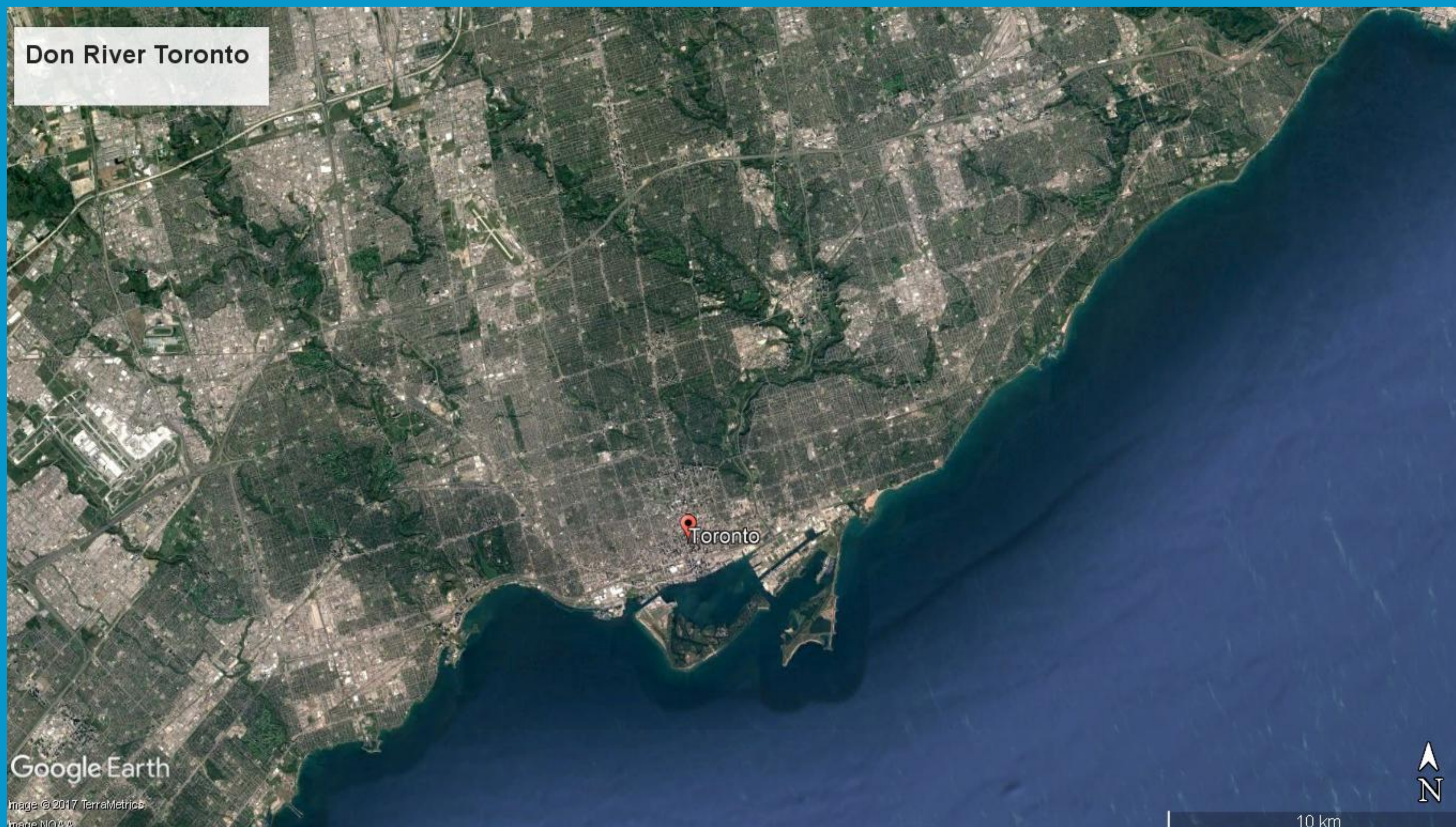

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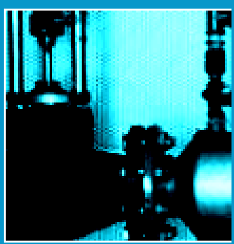

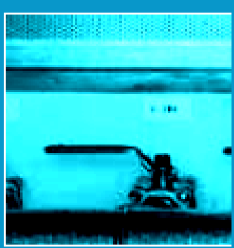

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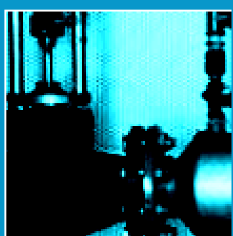
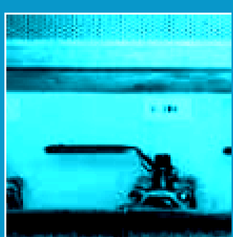


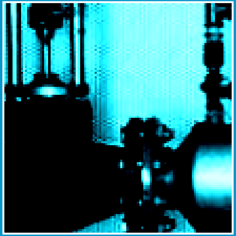


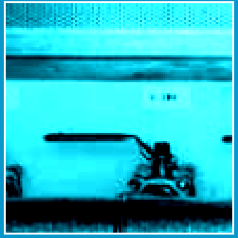
New Don River mouth into Lake Ontario

New developped (raised) land

New landscaped Don River Channel

Toronto Port Lands



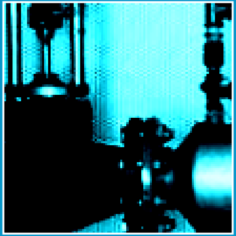


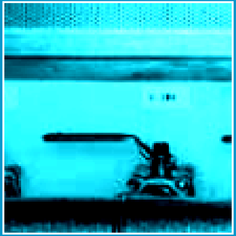
Issues:

- Unstable soils (“running sands”)
- Stable slope 1:8
- Prone to erosion
- Massive soil handling required for landcaping

(soil & groundwater contamination in specific area’s, but that is a different story . . .)

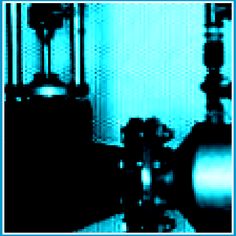
CLASSIC SOLUTIONS

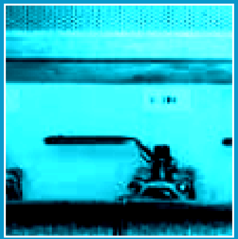




- Dewatering to improve settlement
- Pre Load for prolonged time to limit residual settlement
- Physical mixing with bonding agents
- Civil engineering solutions
  - Deep foundations
  - Sheet piling
  - Concrete piling

IN SITU BIOCEMENTATION



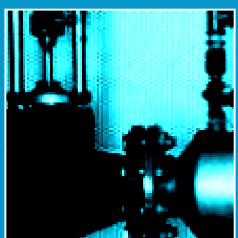


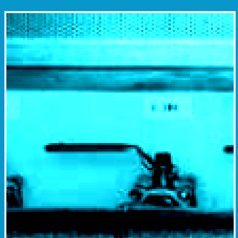
Increase bonding of soil particles:

- Utilizing soil natural biological characteristics;
- stimulating micro-organisms to catalyze chemical reactions;
- precipitation of calcium carbonate ($CaCO_3$) to bind soil particles

Conversion type	Catabolic reaction per mole $CaCO_3$	Solu-bility	Rate	Product Yield	By products
Urea hydrolysis	$1\ CO(NH_2)_2 + 2\ H_2O + 1\ Ca(Cl)_2 \rightarrow 1\ CaCO_3 + 2\ NH_4Cl$	++	++	−	−
Aerobic Acetate oxidation	$1\ Ca(C_2H_3O_2)_2 + 4O_2 \rightarrow 1\ CaCO_3 + 3\ CO_2 + 3\ H_2O$	−−	+	−−	+
Nitrate reduction with Calcium	$0.385\ Ca(C_2H_3O_2)_2 + 0.615\ Ca(NO_3)_2 \rightarrow 1\ CaCO_3 + 0.615\ N_2 + 0{,}539\ CO_2 + 1.159\ H_2O$	+	+	+	+
Sulphate reduction	$1\ Ca(C_2H_3O_2)_2 + 2\ CaSO_4 \rightarrow 3\ CaCO_3 + 1\ CO_2 + 1\ H_2O + 2\ H_2S$	−	−	++	−−

BIOCEMENTATION PROVEN RESULTS



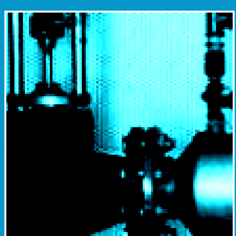


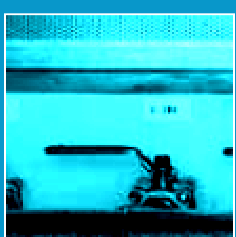
Process is lab-proven and field-demonstrated;

- Controlled bio-consolidation from 5kPa UCS (improved slope stability, less erodable) to high strength, 30MPa UCS (concrete: 20 - 70 Mpa)) by adapting the concentration and the number of treatments applied.
- Application uses standard in situ remediation technologies

Pilot to Demonstrate Soil Stabilization

Groundwater Technology

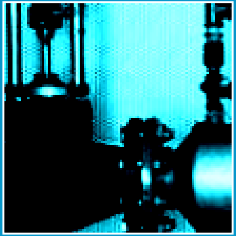


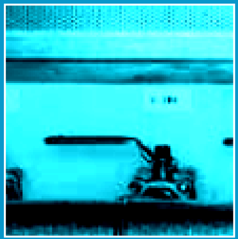


Two-step pilot commissioned by Waterfront Toronto:

1. Bench-top test to demonstate ‘proof of principle’;
2. Demonstration of technology on site in Port Lands: full scale on limited portion of the site

Bench top tests





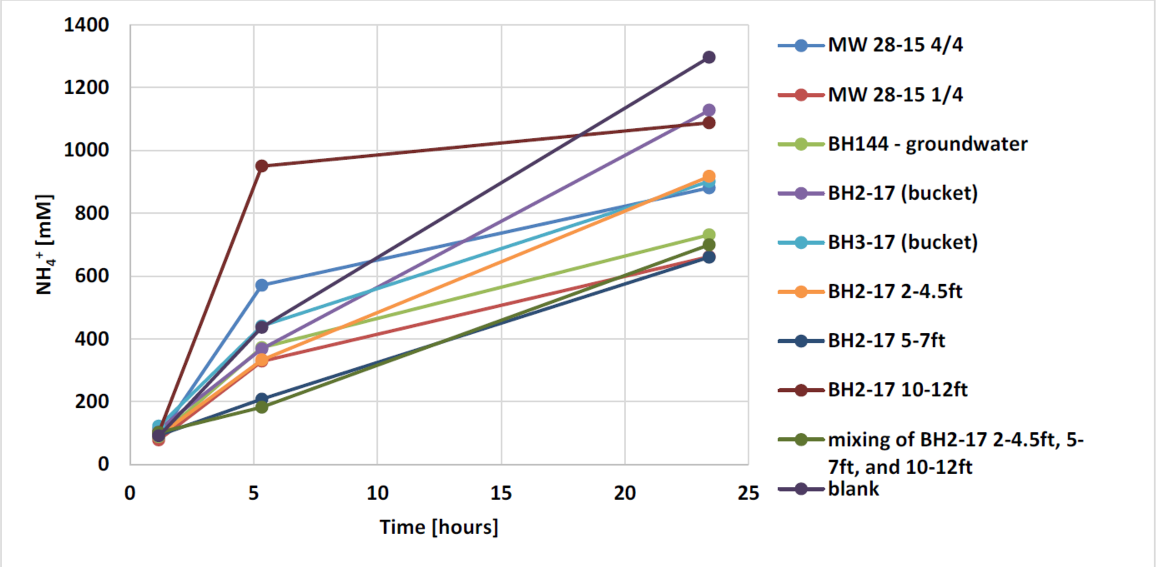
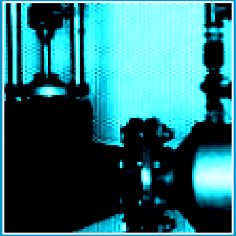
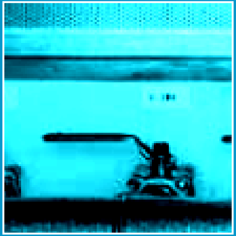
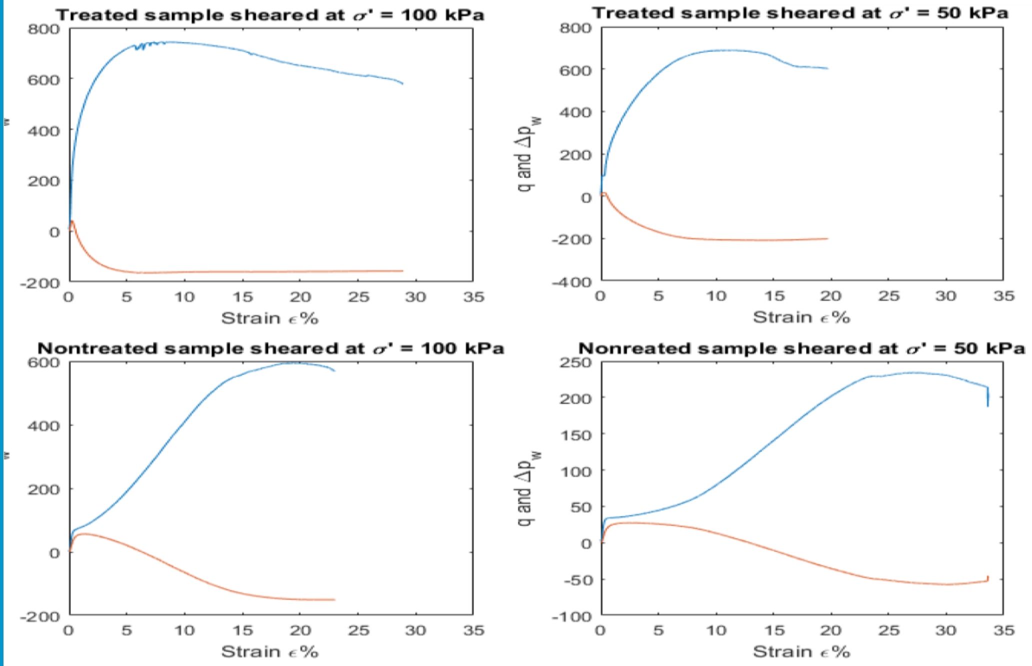


Figure 3. Conversion of urea when subjected to several groundwater and soil samples from Port Lands Toronto. [note: new figure!]

Bench Scale Results







The τ – σ diagram is shown in figure 2

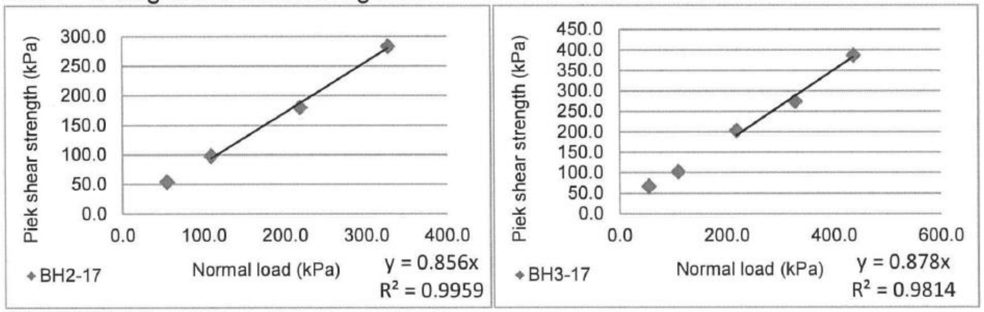


Figure 2: The τ – σ diagram BH2-17 and BH3-17

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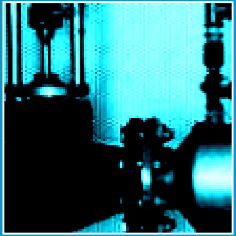
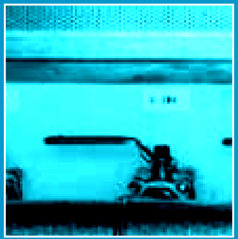
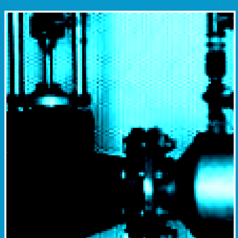
Bench Test Results

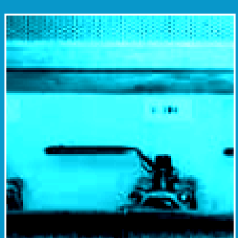




- Soil Shear Strength increased to 300-400 kPa
- Soil cohesion increased to 7 – 19 kPa
- Geotechnical analyses and calculations:
  - For slope stability, 1:2 gradient, cohesion of 5kPa of better is sufficient;
  - For erosion resistance in river bed under normal flow conditions: cohesion of 3kPa or better is sufficient;

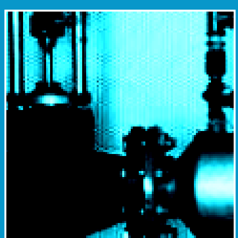
Next steps

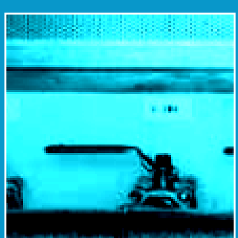




- On site pilot to demonstrate efficacy at full scale commissioned by WT
- On Site pilot will be implemented in spring 2018
- WT will evaluate spring/summer 2018.

BIOCEMENTATION PROCES

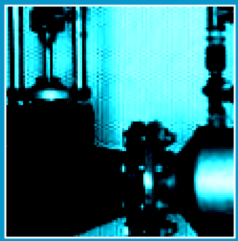




Steps:

1. Analyze soils for suitability (pH, macro parameters, contaminants, toxicity)
   (optionally: do lab test)
2. Enrich local naturally occuring bacteria
3. Apply cultivated bacteria & amendments in treatment zone
4. Process takes between 1 week & 3 months

Biostabilization Applications



- reinforce embankments
- prevent liquefaction and its damage
- reduce building settlement and increase bearing capacity for foundations
- stabilize the soil prior to trenching or underground constuction (eliminate over-excavation)
- increase resistance to erosive forces of water flow (piping or surface erosion)

Biostabilization Applications

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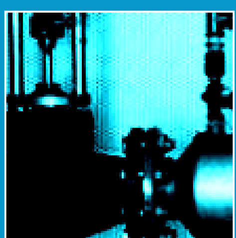

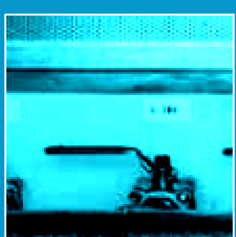

- provide additional stability needed to stabilize slopes
- reduce sand production in oil or water wells (sand control)
- create barriers that treat/clean groundwater as it flows
- immobilize materials in the soil and prevent contamination of aquifers
- create subsurface facilities for storage of liquefied natural gas or CO_2
- stabilization of gravel formation

Thank you
for
Your Attention

Groundwater Technology

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