REINHOLD ENVIRONMENTAL Ltd.

2014 Wastewater-Ash Round Table & Expo Presentation

September 22, 2014, in Birmingham, AL / Hosted by Southern Company

Binder Stabilization Technologies for Closure and Corrective Actions at CCR Impoundments

Waste Water-Ash/PCUG Conference 09.22.2014

Vito Schifano, PhD, PE

Golder Associates

Binder Stabilization Technologies at CCR Impoundments

RCRA, ELG, SDWA will set a framework for management and disposal of CCR

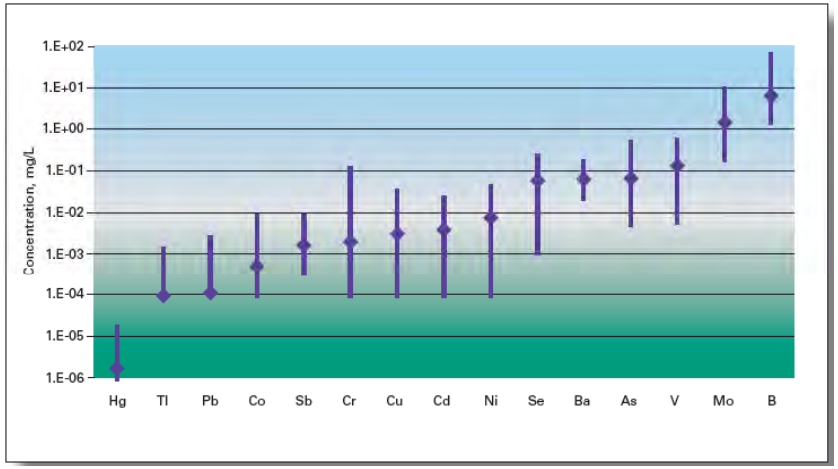
- Future Management
  - Wastewater management
  - Ash management: dry management ; new approaches (BAT, BADCT…)
- Existing Facilities
  - **Closure** of all wet CCR handling facilities (Subtitle C) or several facilities (Subtitle D)
  - Legacy groundwater impacts → **Corrective Actions**: Soil and groundwater remediation and monitoring
  - Structural stability requirements

Binder Stabilization Technologies at CCR Impoundments

- Technical Challenges
  - CCR materials may exhibit geotechnical properties which are challenges for rapid closure
    - Liquefaction
    - High compressibility and low strength of fine, wet ash
    - Long term stability of cap / differential settlements
    - Stability of embankments (foundations, erosion, frost susceptibility etc.)
  - Timescale for closure are quite aggressive

Binder Stabilization Technologies at CCR Impoundments

- Challenges Corrective Actions
  - Technology Limitations: much of the knowledge on remediation technologies centers on organics, while the suite of chemicals unique to CCR consists largely of inorganic chemicals such as boron, sulfate, arsenic, selenium, chromium, thallium, antimony, molybdenum, and vanadium
  - Timescales



EPRI CP-Info Database

Binder Stabilization Technologies at CCR Impoundments

Impoundment Closure

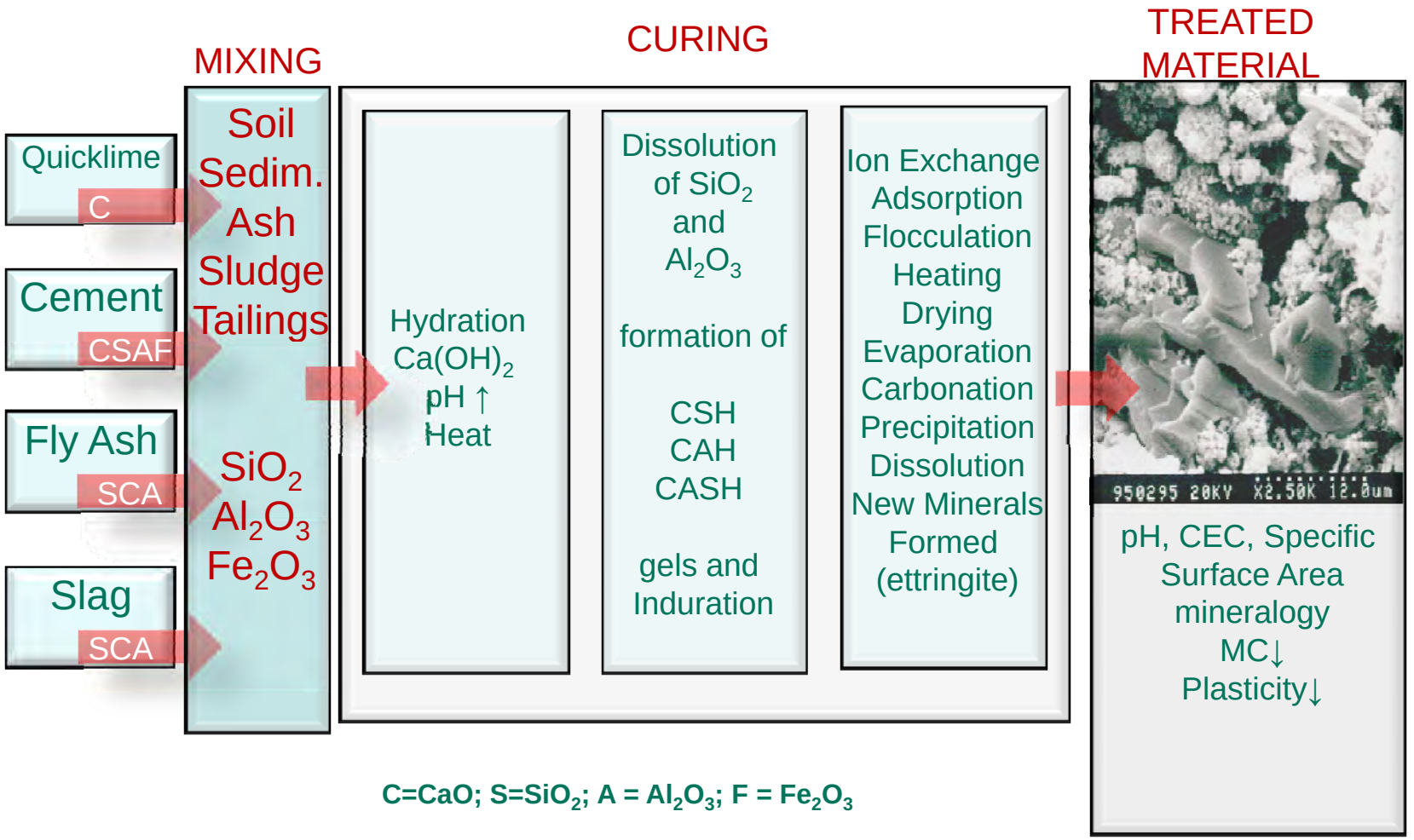
- Capping
  - Compacted clays
  - Geosyntetics
  - Evapotranspiration caps
  - In-situ solidified caps
- Subsurface Barriers
  - Sheetpiles
  - Soil/bentonite
  - Soil/cement/bentonite
- Dewatering
  - Gravity
  - Geotubes
  - Chemical amendments
- Stabilization of impoundment berms
  - Drainage
  - Grouting
  - Reprofiling
  - Binder Stabilization

Corrective Actions

- Groundwater
  - PRB
  - P&T
  - Engineering containment (cap and barriers)
  - Source Treatment
    - Geochemical Fixation
    - In-situ Solidification/Stabilization
  - Phyto
  - Bio
  - Electrokinetics
  - MNA
- Soil
  - Source Removal / Excavation
  - Ex-situ soil washing
  - Soil Flushing
  - In-situ or ex-situ Solidification/Stabilization

Golder Associates

Binder Stabilization

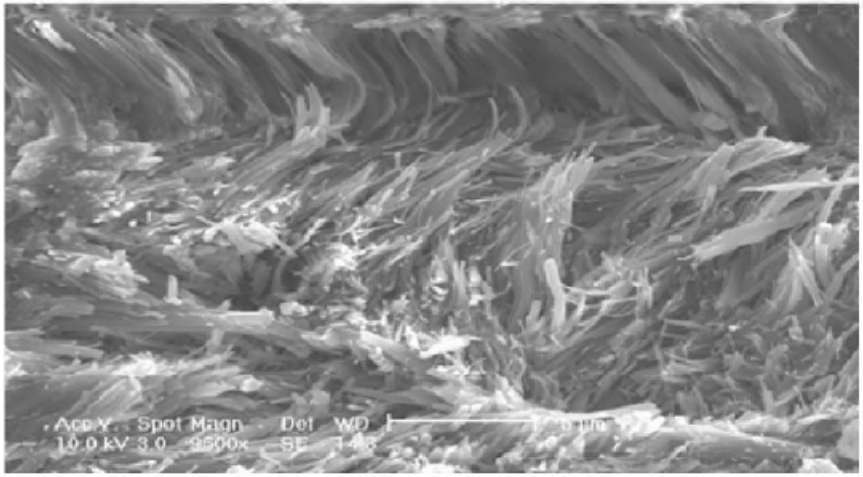


C=CaO; S=SiO_2; A = Al_2O_3; F = Fe_2O_3

Golder Associates

Binder Stabilization

A. End Product of Cement Hydration Showing Elements of Crystalline Structure Formed



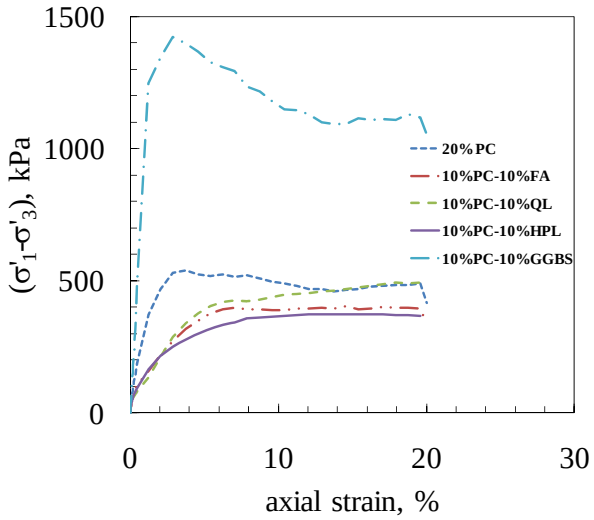
B. End Product of Cement + RoadCem Hydration Showing Extended and More Pronounced Crystalline Structure Formation and "Wrapping" Effect

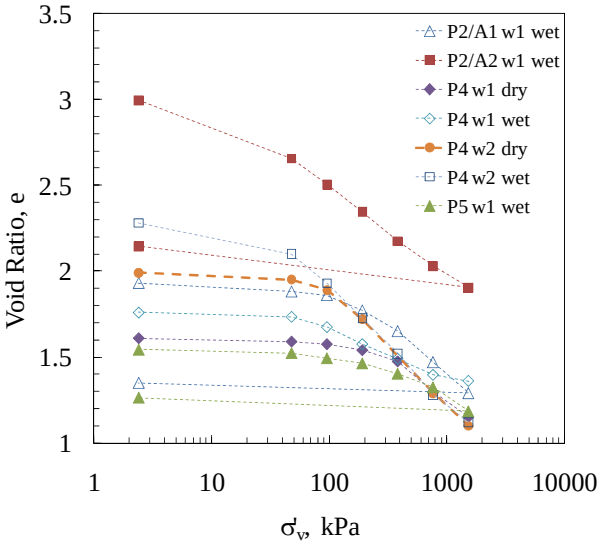
Microscopic Structure

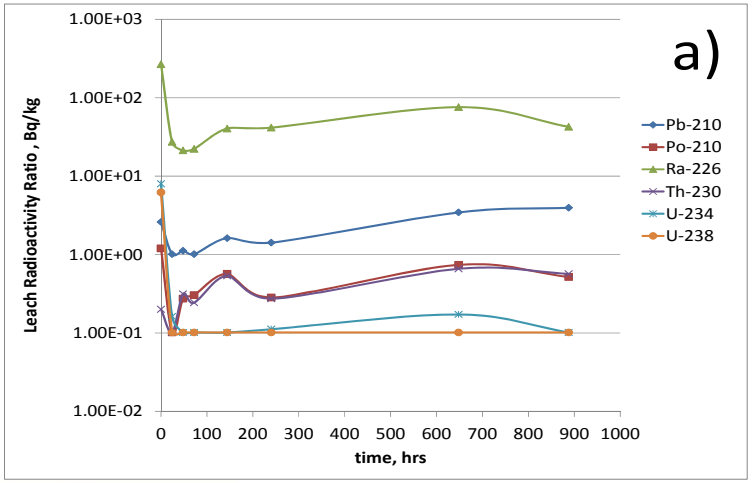
Macroscopic Structure

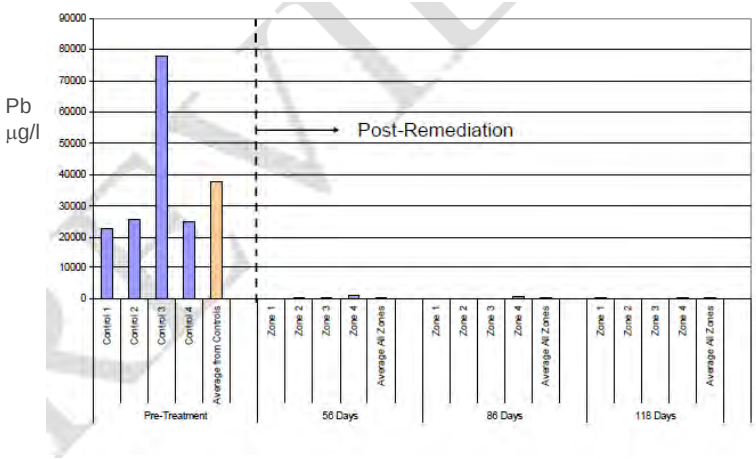
Golder Associates

Binder Stabilization







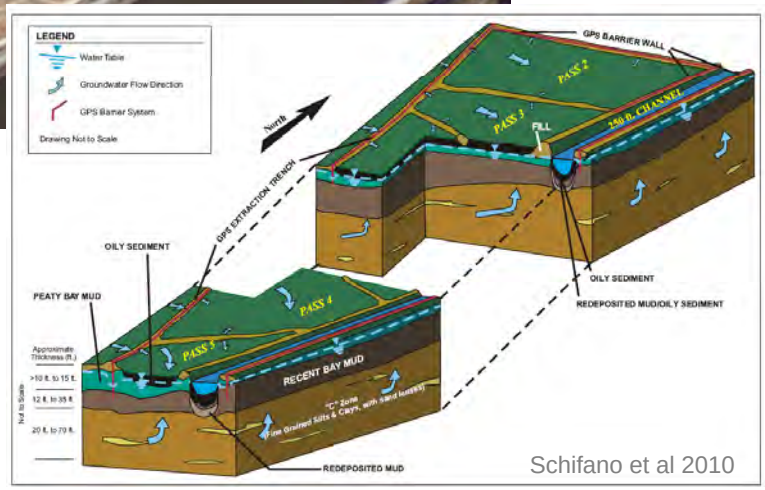


Binder Stabilization Technologies

Applications

1. Engineering Containment for Impoundment Closure
   a. Cover Systems
   b. Subsurface Barriers
2. Remediation Treatment
   a. Solidification / Stabilization
3. Geotechnical Stabilization
   a. Foundation soils improvement
   b. Slope stabilization
   c. Seismic stabilization

Impoundment Closure



Schifano et al 2010

- 64 acres
- 400,000CY sludge
- 80,000 CY dredged sediments

- Regulatory obligation to close the sludge impoundment

- Owner intent of reclaiming the land

Golder Associates

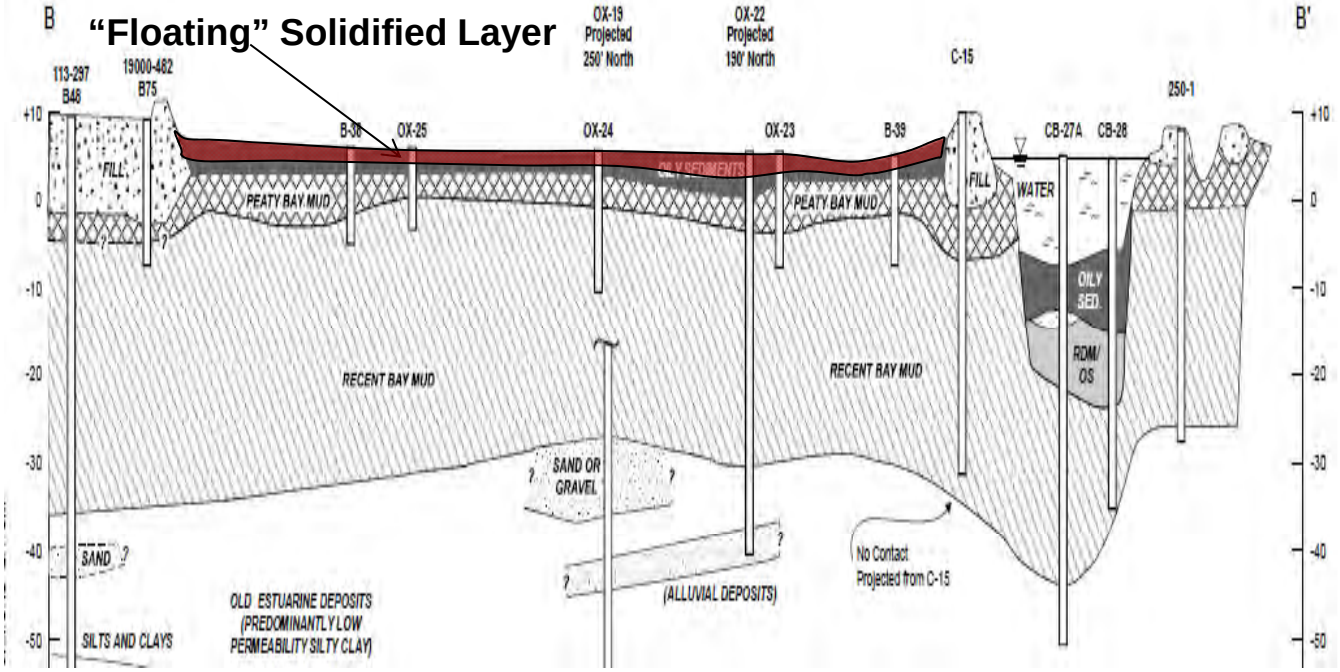
Impoundment Closure

- Soft sludge and dredged sediments render the site unusable without geotechnical improvements
- Binder Stabilization of the upper few feet of materials was selected to provide a work platform which then became the foundation layer to cover system

Golder Associates

Impoundment Closure

- Solidification Performance:
  - Multi-layer bearing capacity (t=3 to 6ft; s_u=1000 to 1500psf)
  - Hydraulic conductivity < 1 x 10^{-6} cm/sec
  - Minimize shrinkage cracking and cracks resulting from differential settlements



Golder Associates

Phased Approach Design

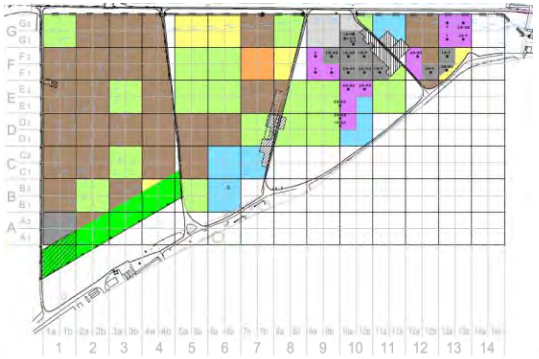
CSM → Design Analyses → Site Investigation → Laboratory Treatability → Pilot Test → Full-scale Implementation

Geotechnical Performance

- Bearing capacity
- Slope stability analyses
- Deformations/settlements

Hydrologic Performance

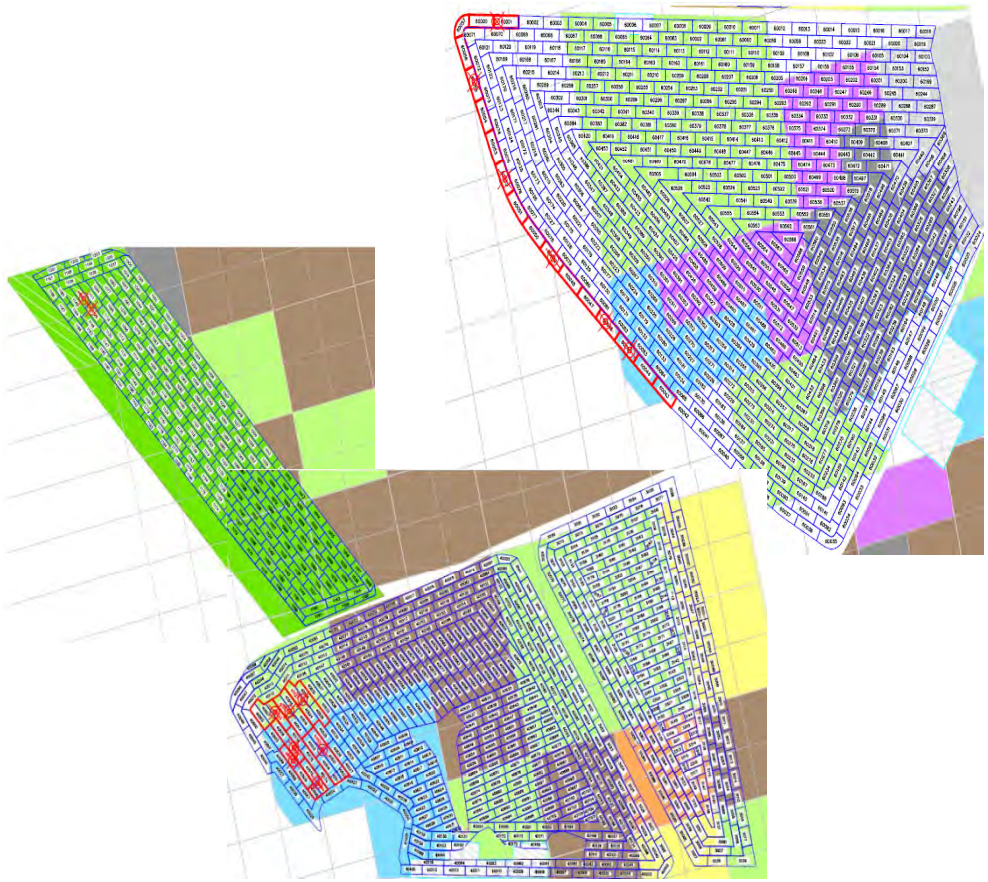
- HELP



Schifano et al 2010

Golder Associates

Heterogeneities and Observational Approach



Schifano et al 2010

Golder Associates

Mass Mixing Technology






- Max Depth to 10 to 15 feet bgs
- Low plasticity and granular soils, sludges, sediments, tailings
- Production rates 300-800 CY / day

Schifano et al 2010

Golder Associates

Full Scale Implementation

Schifano et al 2011

Binder Stabilization Technologies

Applications

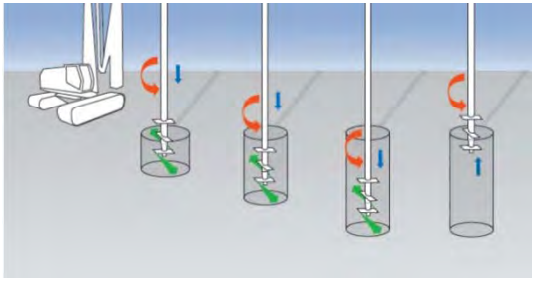
1. Engineering Containment for Impoundment Closure
   a. Cover Systems
   b. Subsurface Barriers
2. Remediation Treatment
   a. Solidification / Stabilization
3. Geotechnical Stabilization
   a. Foundation soils improvement
   b. Slope stabilization
   c. Seismic stabilization / liquefaction mitigation

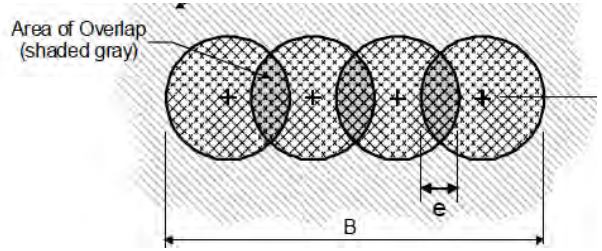
Slurry Wall Soil/Bentonite Barrier

- Site: TCE Plume in Hospital Center, QC
- Services: QC testing review.
- Technology: Slurry Wall / Cement Bentonite Barrier with Permeable Carbon Windows to control TCE migration.
- Up to 70 ft typical, some to 90 feet depth, 2 to 3 feet wide
- Production: *c*. 25 to 50 LF per day

Golder Associates

DSM Technology



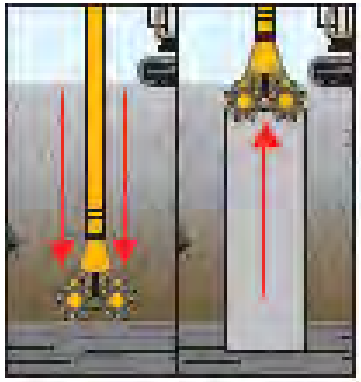


- Low plasticity cohesive and granular soils, sludges, sediments, tailings
- Depth over 200 ft, 3 to 12 ft wide
- Production rates few hundreds of CY / day

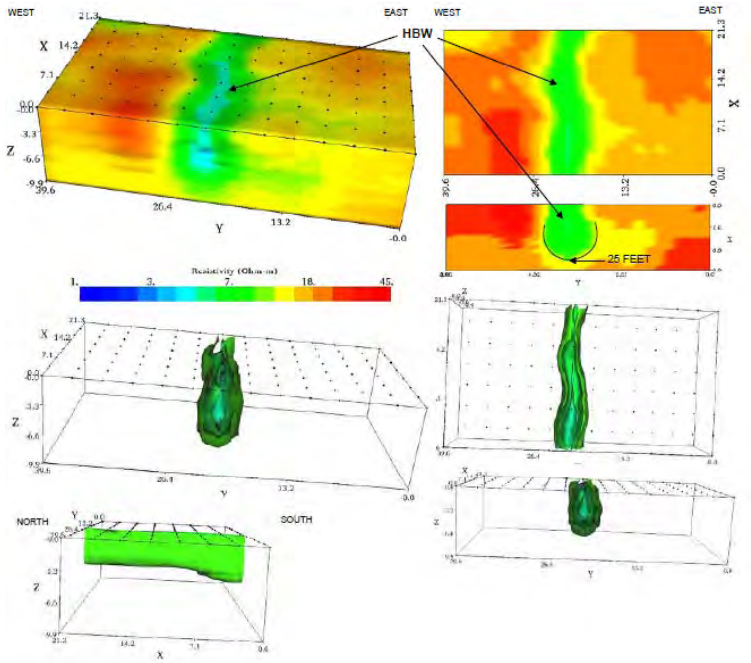
Golder Associates

Cutter Soil Mixer (CSM) Technology

- Site: Wood Preserving Site Brunswick, GA
- Services: D/B of barrier cut off wall
- Technology: Cutter Soil Mixing. Cement/bentonite soil mix wall with $k < 1 \times 10^{-6}$ cm/sec
- Performance 1,520 linear feet, 3-foot thick, average depth of 53 feet.



Mass Mixing Technology



- Site: Chemical Manufacturing Plant, CT
- Services: independent QA/QC
- Technology: In-Situ Soil / Cement/ Bentonite Mixing.
- Goals: 5000 ft long; 25 ft deep barrier. Pilot test inclusive of geophysical survey (3D resistivity) and CPT testing to assess identify potential discontinuities or anomalies within the barrier.

Binder Stabilization Technologies

Applications

1. Engineering Containment for Impoundment Closure
   a. Cover Systems
   b. Subsurface Barriers
2. Remediation Treatment
   a. Solidification / Stabilization
3. Geotechnical Stabilization
   a. Foundation soils improvement
   b. Slope stabilization
   c. Seismic stabilization / liquefaction mitigation

Solidification / Stabilization

Solidification = chemical agent(s) introduced in waste (contaminated soil) to physically bound or encapsulate the contaminants within a stabilized mass

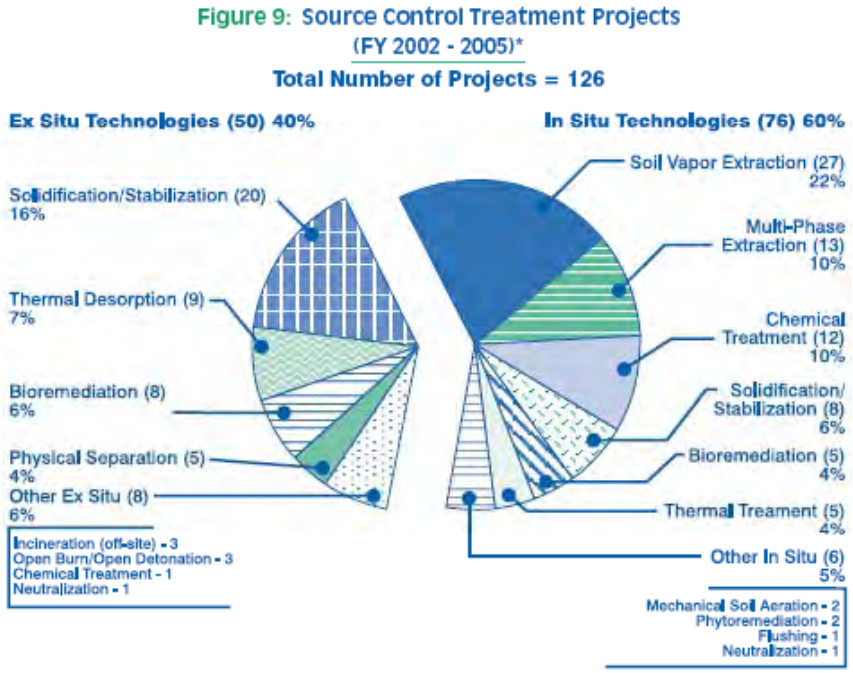
Stabilization = chemical agent(s) introduced in waste to promote chemical reactions with contaminants and to reduce their mobility

Golder Associates

Solidification / Stabilization

The U.S. Environmental Protection Agency

- Considers S/S an established treatment technology for the management of industrial hazardous wastes.
- Identified S/S treatment as Best Demonstrated Available Technology (BDAT) for many RCRA - Listed hazardous wastes
- Historically, S/S has been one of the top five source control treatment technologies used in Superfund sites (USEPA, 2005)



Golder Associates

Acceptance: Past Applications

- Manufactured Gas Plants
- Wood Preserving Sites
- Oil Refinery Sludge Lagoons
- Coal Tar Lagoons
- Dredged Sediments Confined Disposal Facilities
- Mine waste and tailings impoundments including low level radioactive sites
- Chemical, Pharmaceutical Waste Sites
- Paper Mill Sludge Ponds
- Metal Refining, Smelting, Plating, Recycling
- Residual Ash
- Industrial, commercial, recreational, residential redevelopments

Golder Associates

Acceptance: Past Applications

Table 2-1. Documented effectiveness of S/S treatment for chemical groups

Chemical groups	Citations for treatment effectiveness[a]		
	EPA 1993a[b]	EPA 2009b[b]	Other references[c]
Organic chemicals			
HVOCs[d]	N	N	D, with pretreatment (Paria and Yuet 2006)
N-HVOCs[d]	N	N	D, with pretreatment (Paria and Yuet 2006)
HSVOCs[d]	D	D	
N-HSVOCs, N-VOCs[d]	D	D	
PCBs	P	D	
Pesticides	P	D	
Dioxins/furans	P	P	D (Bates, Akindele, and Sprinkle 2002, PASSiFy Project 2010)
Organic cyanides	P	P*	D (Wilk 2007)
Organic corrosives	P	P*	D (Wilk 2007)
Pentachlorophenol	–	–	D (Bates, Akindele, and Sprinkle 2002, Wilk 2007)
Creosotes, coal tar	–	–	D (Bates, Akindele, and Sprinkle 2002,Wilk 2007)
Heavy oils	–	–	D (Wilk 2003)
Inorganic chemicals			
Volatile metals	D	D*	
Nonvolatile metals	D	D	
Asbestos	D	D*	
Radioactive materials	D	D	
Inorganic corrosives[d]	D	D*	
Inorganic cyanides[d]	D	D*	
Mercury	D	D*	EPA 2007b
Reactive chemicals			
Oxidizers	D	D*	
Reducers	D	D*	

[a] Key:
- N = no expected effectiveness, P = potential effectiveness, D = demonstrated effectiveness.

ITRC (2011)

Golder Associates

Phased Approach Design

CSM → Design Analyses → Site Investigation → Laboratory Treatability → Pilot Test → Full-scale Implementation

Environmental Performance

- **Leaching**
- **Hydraulic conductivity**
- **Durability**

Geotechnical Performance

- Bearing capacity
- Slope stability analyses
- Deformations/settlements

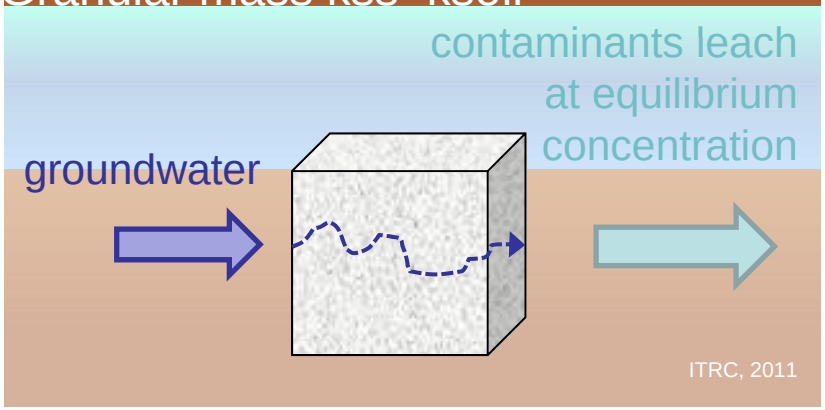
Hydrologic Performance

Golder Associates

Performance Criteria

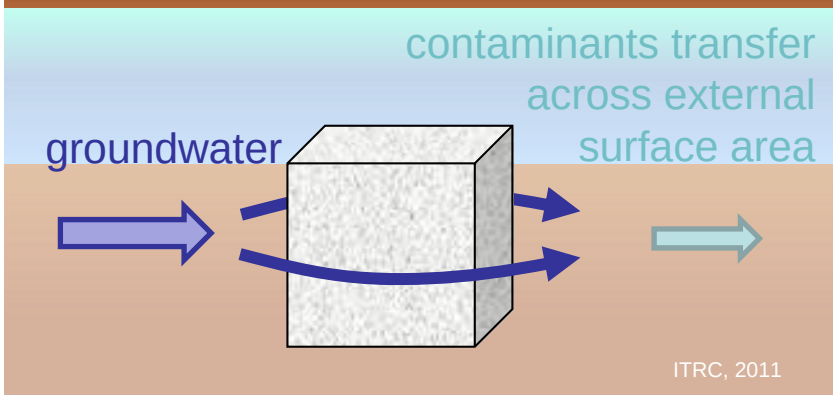
Leaching= process of release of a constituent from a solid into a contacting liquid

Granular mass kss=ksoil



- Water permeating the mass
- All effective pore area is exposed to leaching
- Contaminant mass transport governed by **liquid-solid partitioning**
- Lab leaching tests: TCLP, SPLP, EPA LEAF tests (1313; 1316).

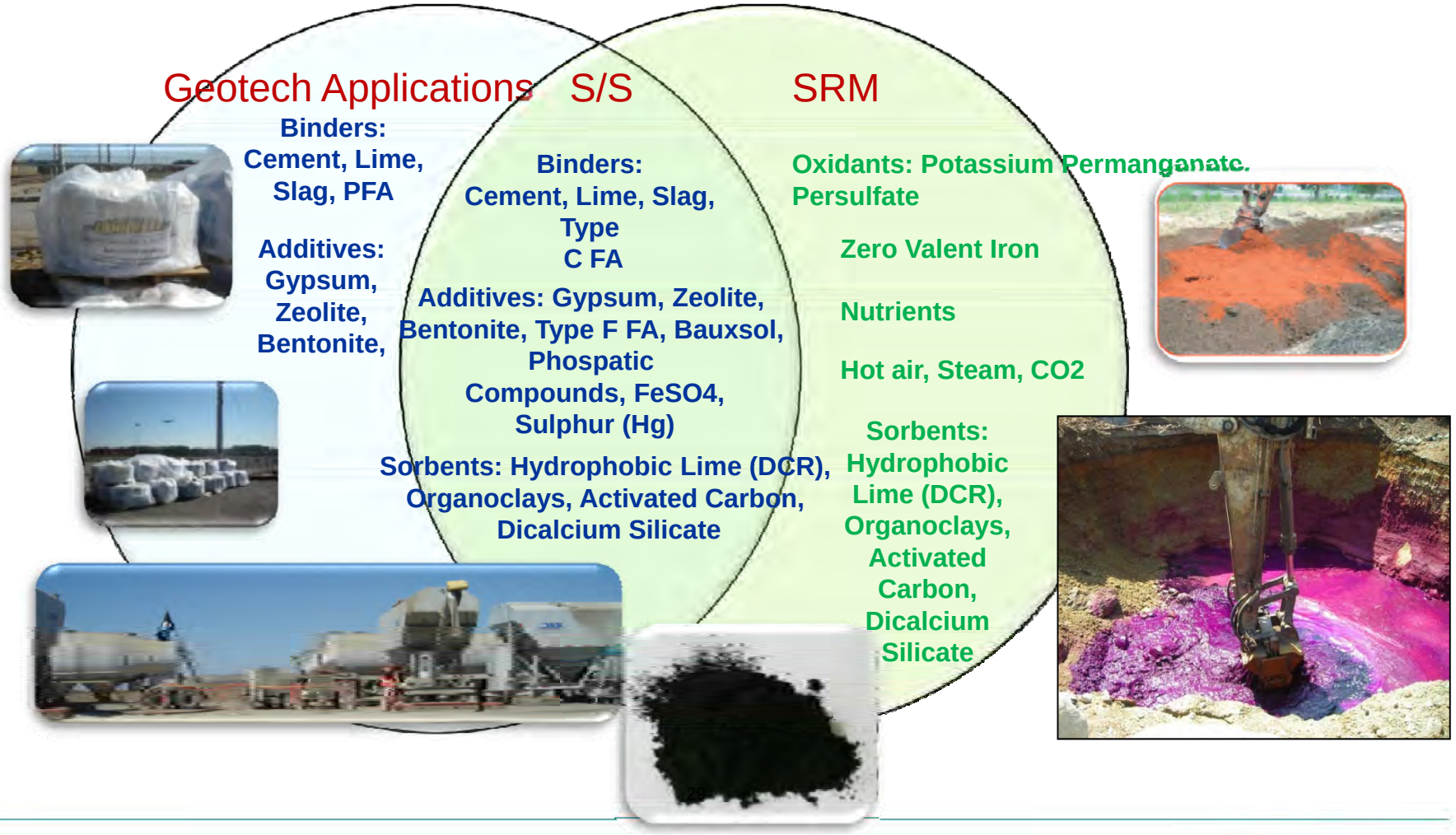
Monolithic mass kss<ksoil



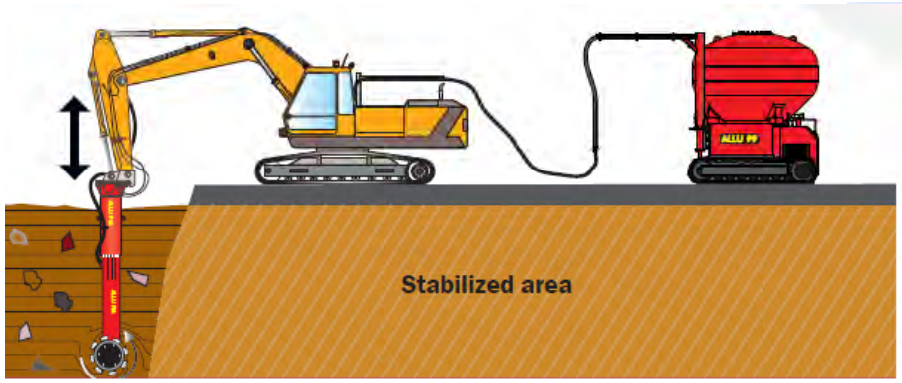
- water diverted from treated zone
- Only outer surface area is exposed to leaching
- Contaminant mass transport governed by **diffusion plus associated physical and chemical retention**
- Lab leaching tests: ANS/ANSI 16.1, ASTM C1308, EPA LEAF 1315 test.

Golder Associates

Binder Stabilization Technologies



Binder Stabilization Technologies

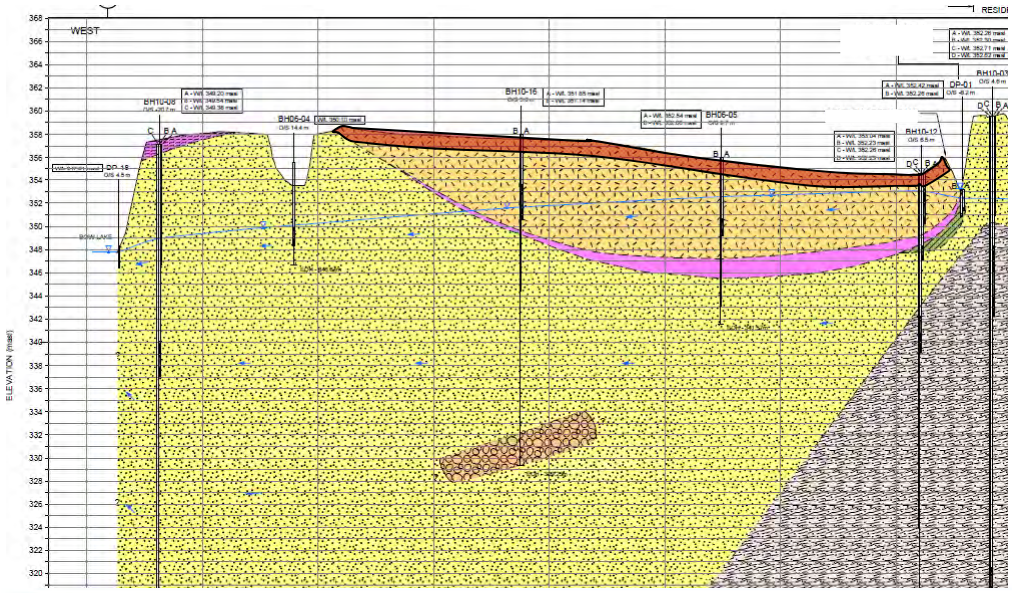


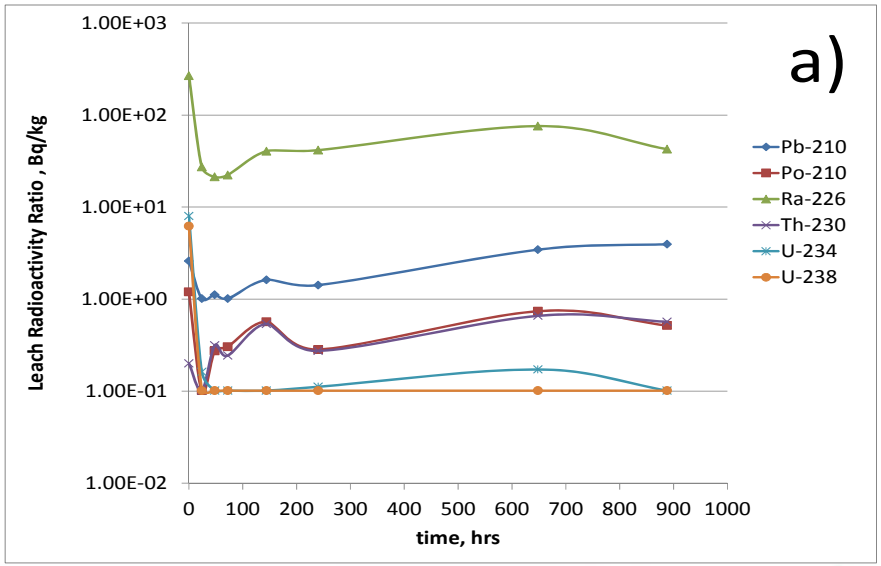
ALLU PMX700 / PF7
- max depth 7m (requires 1m excavation)
- PR 300-500 m^3/day
- Dry Reagent
- Slurry Reagent

Golder Associates

Rehabilitation of Radioactive Tailings Pond

- Site: Uranium Tailings Facility
- Technology: Binder Solidification and Stabilization
- Objectives:
  - Create a solidified cap
  - Minimize Radon Emission
  - Immobilize Radionuclides and Metals





Golder Associates

Rotovator Technology

- Applicable to in-situ soils to a depth of up to 2 feet bgs
- Low plasticity and granular soils, sediments, tailings
- Max production rates 4000 CY / day

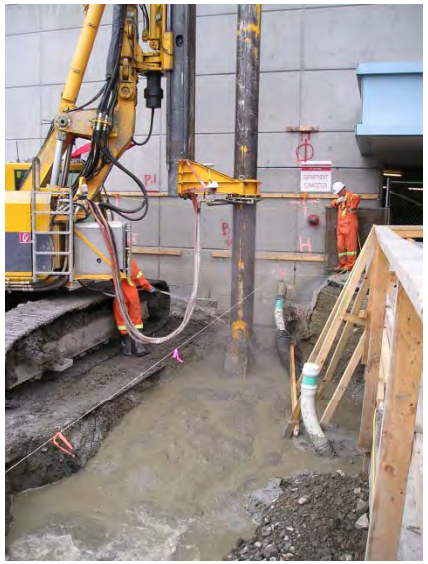
Golder Associates

Applications

1. Engineering Containment for Impoundment Closure
   a. Cover Systems
   b. Subsurface Barriers
2. Remediation Treatment
   a. Solidification / Stabilization
   b. Soil Reagent Mixing
3. Geotechnical Stabilization
   a. Foundation soils improvement
   b. Slope stabilization
   c. Seismic stabilization / liquefaction mitigation

Applications: Foundations

- Site: City of Nanaimo, BC
- Project: Design-Build foundation soil stabilization
- Technology: Cutter Soil Mixer



Golder Associates

Applications: Embankments

Courtesy of LC Technology

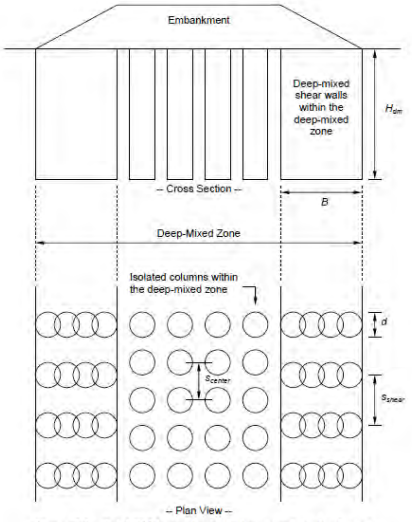


Figure 7-2 . Trial DM layout beneath the example embankment.

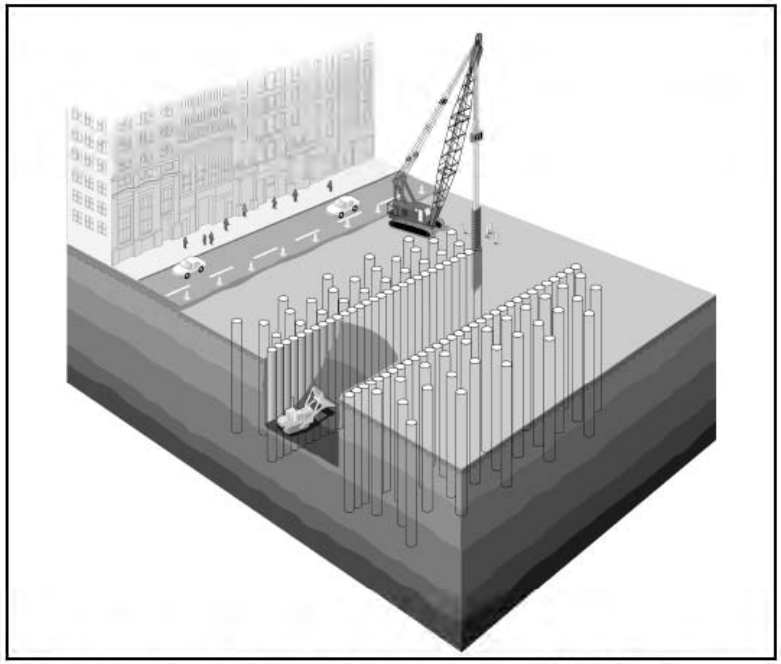


Figure 1. Oblique view of the Geo-Con VERT Wall (Note: Relieving platform not shown)

Conclusions

- CCR are suitable for binder stabilization (rich in SiO_2, Al_2O_3 and Fe_2O_3)
- S/S addresses the fundamental mechanism of release of COCs (leaching)
- S/S has demonstrated effectiveness in CCR constituents of concern (As, Cd, Cr, Pb, Hg etc).
- S/S can be integrated with components of closure actions
  - S/S remedial treatment can be extended beyond source zone to treat liquefiable foundation soils or sluiced ash.
  - Thickness of solidified caps can be varied to address differential settlements.
  - Low permeability of treated mass may minimize requirements for a cover system or subsurface barrier

Conclusions

- In large impoundment sites costs are driven by:
  - Mixing technology costs (production rates)
    - Costs for deep soil mixing applications $100 to $200 per CY
    - Mass mixing technologies $40 - $100 per CY
    - Rotovator mixing $20 - $60 per CY
    - Large scale application may further reduce costs of 30% to 40%
    - Mob / demob costs usually negligible
  - Binder Reagent costs
    - PC $100 per ton; lime $150 per ton
    - Application of CKD instead of Portland Cement or LKD instead of lime may significantly reduce costs for binders
    - Type C fly ash may be used as primary binder agent
    - Type F fly ash may be used as a pozzolanic additive. FGD may also be used as additive to improve S/S performance.
- Innovative applications include accelerated carbonation technology with blending of binder and injection of CO_2.

Questions?

Golder Associates

Thank You

Contacts: Vito Schifano, PhD, PE. vschifano@golder.com

Archie Filshill, PhD (Construction) afilshill@golder.com

Manitia Moultrie, (Golder U. S. Power Sector Leader) mmoultrie@golder.com

Golder Associates