

Beneficial Reuse of Dredged Soil – Transferring Portland-Limestone Cement and Geosynthetics Technology Toward Sustainable Solutions to Dredged Material Management

Summary of a Technology Transfer Event Conducted By:

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16. Abstract This report summarizes a technology transfer event held on May 24, 2016 on MSU's campus. LafargeHolcim and TenCate™ supported this event and provided technical presentations from subject matter experts. This report contains the presentation slides used by presenters with very slight non-technical modifications to facilitate presentation in this report. Also, an executive summary of the event from the perspective of the presenters is also provided.			
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Disclaimer

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Acknowledgements

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MSU students and alumni supported the content presented in numerous ways. The data presented has been collected over several years, and there have been several individuals involved in that process. Also, MSU students volunteered their time to help work the registration desk on May 24. Individuals deserving special thanks include Walaa Badran, Melanie A. Barksdale, Mohammed Bazne, Will Carruth, Heather Craft (Clark), Corbin Coker, Will Crawley, Brian Jordan, Drew Moore, Dr. Jay Shannon, Braden Smith, and Griffin Sullivan.

MSU faculty and staff also provided a variety of support for this activity. Those deserving special thanks include Merri Kilpatrick, Dr. William H. McAnally (retired), Sandra Ortega, Dr. Dennis Truax, and Dr. Farshid Vahedifard.

Some of the content used in this technology transfer event was taken from NCITEC Project Number 2013-05 – Sustainably Enhancing Intermodal Freight Operation of Ports Using Geotextile Tubes. Everyone acknowledged in that report is, as such, a part of the success of this technology transfer event. The US Army Corps of Engineers (USACE) supported NCITEC Project Number 2013-05 in a variety of manners.

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Overview and Program Description

Program Establishment

From mid-March through mid-April, this event was conceptualized, a proposal was written, funding acceptance was granted, a plan was developed, a flyer was generated related to registration, and this flyer was sent to several groups in mid-April. The announcement flyer was circulated via email to several groups in Mississippi and surrounding states. For example, the ASCE MS Section sent the conference announcement to all their members. From mid-April to mid-May, registration proceeded, content was developed, and logistics were handled with the venue. From mid-May to the end of May, content was finalized, venue logistics were finalized, presentations were finalized, the event was held, and this report was generated.

Venue

The event was held on the Mississippi State University (MSU) campus in the Colvard Student Union. Figure 1 has photographs of the event. On May 24, signs were posted at the entrances of the Colvard Student Union directing attendees to Ballroom U, which had a registration table out front that was easily visible.

Registration and Attendance

The flyer used for announcement and registration purposes can be seen in Figure 2. Total attendance was estimated at 53 people. Before the day of the program, 59 people registered, and one person registered on site (60 total registrants). At the end of the program, there were 7 name badges remaining at the registration desk, which is how the attendance was estimated at 53 people. Attendees represented nine groups: consultants, dredging contractors, material suppliers/manufacturers, Mississippi Department of Transportation, MSU faculty/staff, MSU students, power generation, port authorities, US Army Corps of Engineers.

Technical Content and Presentations

The tentative schedule shown in Figure 2 was generally followed, though there was no formal panel discussion. Questions and comments from the audience were taken throughout the day, and as such the last presentation did not conclude until just after 2:30 PM, and all audience questions and comments had been addressed so the program concluded. When questions and discussion were considered, each presentation given lasted just over 1 hour, except for the opening remarks, which were only a few minutes.

There were 4 presentations given, and the slides used for each presentation are provided in the order they were presented. These slides have identical technical content relative to the actual slides used by the speakers, but there have been a few non-technical modifications for efficiency and ease of use. For example, all acknowledgements slides were removed and consolidated into a single section presented earlier in the document.

With regard to technical content, the audience seemed to be engaged with the speakers, and several questions were asked. Several of the attendees were not familiar with geotextile tubes and/or portland-limestone cement, which supports the notion that technology transfer events of this nature are useful. There were several attendees that were familiar with geotextile tubes and/or portland-limestone cement, but even some of them informally commented to the organizer that their attendance was good use of their time.

There were a few recurring themes of the technical content that are briefly described below. It was repeatedly emphasized in the opening remarks that responsible management of dredged materials is a multi-disciplinary problem where collaboration from groups with all sorts of expertise is needed. The triple bottom line philosophy of economics, environment, and social well-being was used to encompass the opening remarks challenging participants to view dredged material management in this context. Participants were encouraged to utilize solutions that did not overly favor one aspect of the triple bottom line at the detrimental expense of other aspects.

One theme related to geosynthetics was how the technology has improved over the past several years. Improved resistance to UV as the industry transitioned toward polypropylene and away from polyester is one example. This point was also made in other materials, but in all cases the intent was to encourage a progressive look at materials and processes, and not to take one snapshot in time (often from several years ago) and assume that it represents the progression of an industry and the state-of-the-art in present day. With regard to PLC, parallels could be drawn to use in Europe where grinding practices can differ with respect to total fineness of the as supplied cement.

A theme focused on mostly with PLC was how successful implementation has been of PLC into the regional concrete market over the past couple of years because of PLC's superior performance (in particular in conjunction with supplementary cementitious materials). In that the concrete market is by far the largest user of cement, other users such as dredged soil stabilization are going to, generally speaking, have readily available the products being heavily used for ready mixed concrete production. If the readily available products can perform needed tasks in an effective manner, they are the logical choice. It was also pointed out that some of the reasons for PLC's successful interactions with some supplementary cementitious materials may also be beneficial in some soils.

With regard to dredged material stabilization with cement, it was repeatedly stated that several useful applications of dredged materials at very high moisture contents could be feasible with relatively low cement dosages. The point was made that very high strength and quickly achieved early strength is not required for every project, and that construction tendencies in the US that favor high early strength may be unintentionally biasing the views of engineers for engineering with nature applications where high strength is not always needed. Participants were encouraged to think about applications within their working environments where dredged materials stabilized with modest amounts of cement would be worthwhile. One attendee mentioned the possibility of using non-contaminated lightly cemented dredged soil as a capping layer for rivers to isolate contaminated sediment while having more erosion resistance than non-stabilized soil.

Overall, there were many possible manners presented in which participants could effectively utilize PLC and/or geosynthetics such as geotextile tubes. The presentation slides provided later in this report show the specific details that were presented. The information presented was described in a context of providing sustainable solutions that were economically competitive.



a) Registration Desk



b) Opening Remarks



c) V. Tim Cost Introduced as Speaker



d) Overall View of Audience During PLC Presentation by V. Tim Cost



e) Chris Timpson Introduced as a Speaker



f) Geosynthetics Presentation

Figure 1. Photos From the May 24 Technology Transfer Event

**Figure 2 – Announcement
Flyer (page 10)**

*Beneficial Reuse of Dredged Soil-Transferring Portland-Limestone
Cement and Geosynthetics Technology Toward Sustainable Solutions to
Dredged Material Management*

WHEN: May 24, 2016

WHERE: Mississippi State University – Colvard Student Union – Ballroom U

FREE REGISTRATION: There are no registration fees, but to attend you must register by sending an email to Isaac L. Howard at ilhoward@cee.msstate.edu that contains the following information for each individual being registered: name, affiliation, phone number, and email address. If you are registering multiple people with one email, please make it clear who is being registered and provide the information for each registrant separately. Each registrant will receive a registrant number via email, and you are not registered until you receive this number. Total attendance for this event is limited to 100, and registration is first come, first serve. Please do not register for a seat at the conference unless you have every intention of attending as that might prevent someone else from being able to attend.

PARKING AND DIRECTIONS: Parking passes are required for all vehicles on campus, and attendees may go to the link below and obtain a parking pass that can be printed prior to arrival to campus. All attendees are responsible for obtaining their own parking pass and for any associated citations for not having a parking pass. Also provided below is a link to a campus map to help attendees locate suitable parking lots and the Colvard Student Union. It is recommended that attendees arrive on campus 30 minutes prior to the start of the event to allow ample time to park, locate Ballroom U in the Colvard Student Union, get registered, and find a seat in the ballroom.

Parking Pass - https://msstateparking.t2hosted.com/cmn/auth_guest.aspx

MSU Campus Map - <http://map.msstate.edu/map/?id=233#!ct/6665,7602,2396,2398,2399,2401,2400,7257,2397,7090,7088,2402,5465,8935>

REASONS TO ATTEND: Earn up to 3.5 professional development hours (PDHs). This one day conference focuses on sustainable use of material dredged from ports and harbors where portland-limestone cement (PLC) and geosynthetics are featured. Ports and harbors are a key component to any intermodal freight system, and in some senses, they define the true nature of intermodal activities as they are the transfer point for ships, barges, rail cars, and trucks. An ever present challenge faced by ports and harbors is dredging and subsequent handling of dredged soils (especially contaminated or very high moisture content fine grained materials), and this event aims to provide information to assist in this regard.



TENTATIVE SCHEDULE

9:45 AM to 10:05 AM:	Opening remarks (Isaac L. Howard)
10:05 AM to 11:00 AM:	PLC Properties, Sustainability Features, Marketplace Acceptance, and Implications for Dredged Material Stabilization (Tim Cost)
11:00 AM to 11:05 AM:	Break
11:05 AM to 12:00 PM:	Geosynthetics Properties, Sustainability Features, Marketplace Acceptance, and Implications for Dredged Materials (Chris Timpson)
12:00 PM to 1:00 PM:	Lunch - Provided and Served in Meeting Room
1:00 PM to 1:55 PM:	Engineering Properties of Stabilized Dredged Soils with Comparisons of ASTM C150 Type I Cement to ASTM C595/1157 PLC Cement (Isaac L. Howard)
1:55 PM to 2:00 PM:	Break
2:00 PM to 2:30 PM:	Panel Discussion – Questions/Comments Taken From Attendees



ABOUT THE SPONSOR

The National Center for Intermodal Transportation for Economic Competiveness (NCITEC) is sponsored by the US Department of Transportation (USDOT) <http://www.ncitec.msstate.edu/>

ABOUT THE ORGANIZER AND PRESENTERS

Organizer-Presenter: Isaac L. Howard, PhD, is the Construction Materials Research Center (CMRC) Director. CMRC is part of the Civil and Environmental Engineering (CEE) Department at Mississippi State Univ. (MSU). ilhoward@cee.msstate.edu 662-325-7193 <http://www.cee.msstate.edu/cmrc/>

Presenter: Tim Cost, PE, FACI, is a Senior Technical Service Engineer for LafargeHolcim, one of the world's largest construction materials companies and a leading supplier of PLC in the US. tim.cost@lafargeholcim.com 601-955-1622 <http://www.holcim.us/>

Presenter: Chris Timpson is a Technical Services Manager for TenCate™'s Water and Environment Group, which is a leading supplier of geosynthetics (including geotextile tubes) worldwide.

C.Timpson@TENCATE.COM 706-693-1833 www.tencate.com



Mississippi State University



Construction Materials
Research Center

An Industry, Agency
& University Partnership



Opening Remarks for:
**Beneficial Reuse of Dredged Soil-Transferring
Portland-Limestone Cement and
Geosynthetics Technology Toward Sustainable
Solutions to Dredged Material Management**

May 24, 2016, Starkville, MS

Organizer:

Isaac L. Howard, PhD, PE

Materials and Construction Industries Chair

Civil and Environmental Engineering Dept.

Mississippi State University

662-325-7193, ilhoward@cee.msstate.edu

Construction Materials Research Center (CMRC) Overview

- Housed within Civil and Environmental Engineering (CEE) department.
- 31 entities have contributed to CMRC's endowment.
- Two meetings per year. A variety of issues associated with construction materials are discussed at general meetings, PDH presentations are given at some meetings, and anyone is welcome to attend.
- Emails are sent around periodically, and anyone who is interested in getting on this email distribution list can send an email to ilhoward@cee.msstate.edu indicating you want to be added to the list.

http://www.cee.msstate.edu/cmrc/



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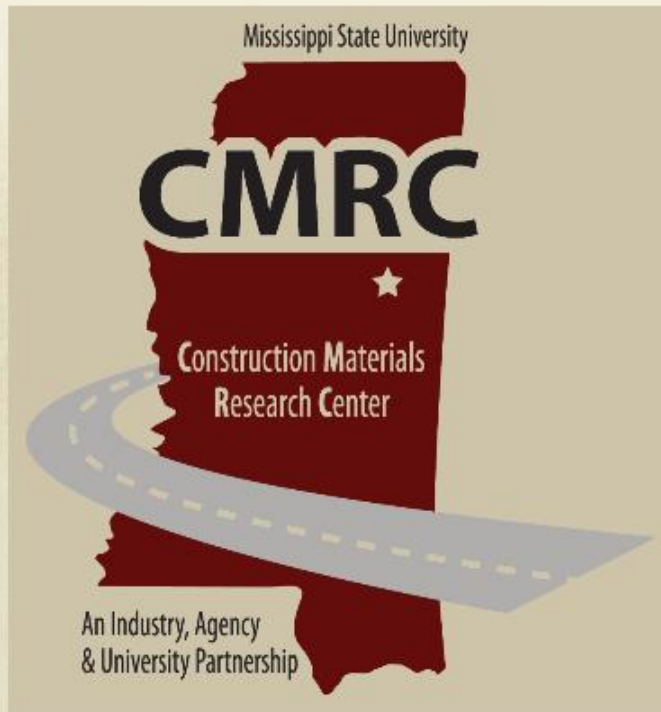
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GIVING

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- Charter and Board of Advisors
- Contributors
- Technical Documents
- Event Gallery
- Students & Alumni
- Student Gifts

↑
Tabs Within
CMRC Site

Today's Goals

1. **Emphasize** the importance of sustainable and economically competitive solutions to dredging (or any large scale process) within the context of an intermodal freight system
2. **Explain** techniques and materials that might help with dredged material management
3. **Facilitate** conversations between attendees (to be successful, this needs to be a two way event)

Dredging is Multidisciplinary & Global

- Photo is Port of Oakland last week at around 3:30 AM while I rode down the road – go ahead and scratch this off your bucket list!



- Whose problem is dredging? geotechnical, materials, water resources, environment operations, maintenance, policy makers....?
- **Yes to all these groups and more**

When Thinking Dredging Think Triple Bottom Line

- Economics, Environment, Social Well Being
 - Aka: People, Planet, Profit
- The triple bottom line is at the heart of today's event, which also considers sustainability and economic competitiveness
- If one item is emphasized to the severe detriment of one or two of the other facets of the triple bottom line, the solution is likely not optimal for the big picture

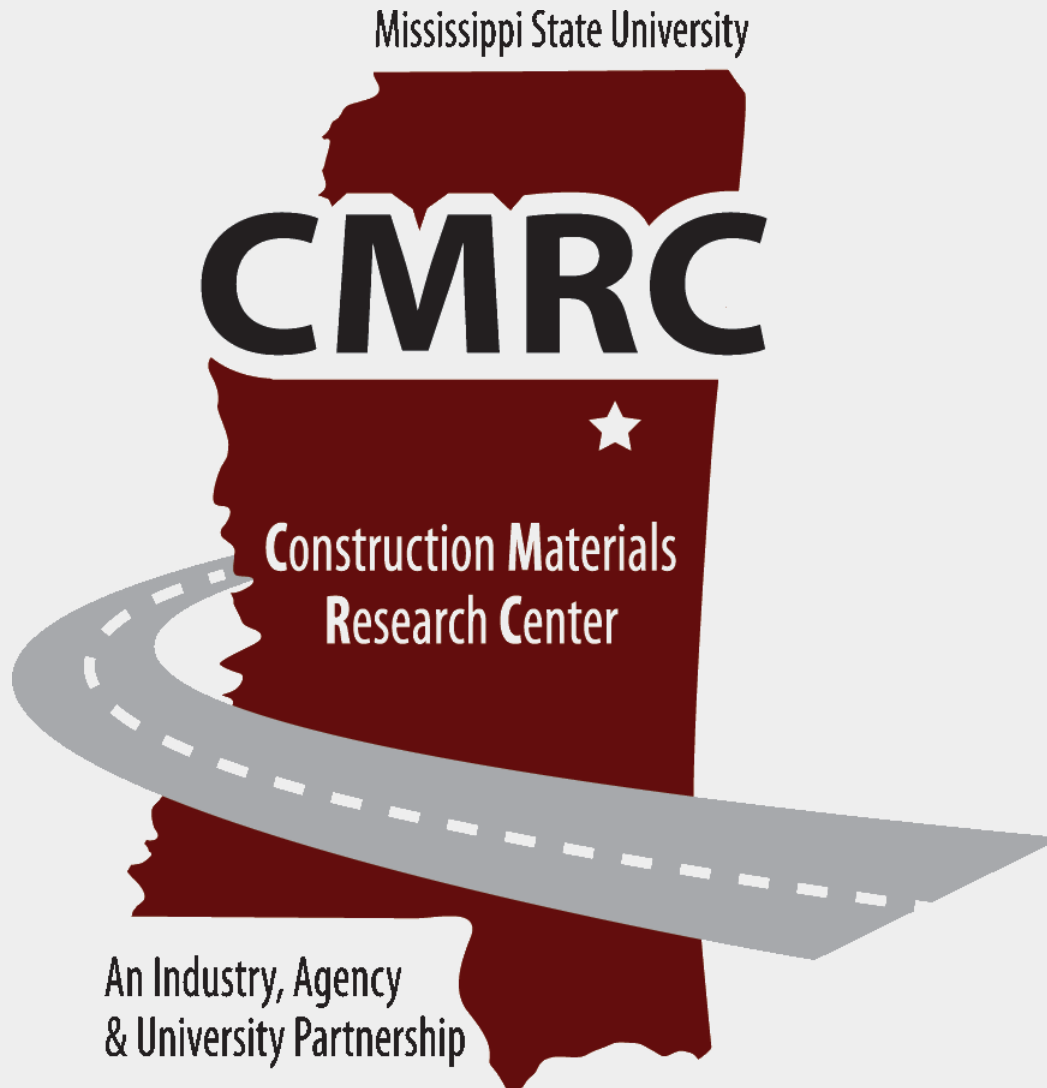
A Visual Assessment of Today's Key Materials

1. There are some small scale geotextile tubes (informally referred to as pillows to be passed around), and there are some available to take back to your office if you would like one.
2. There are two containers of cement being passed around. One container has Type I and the other has PLC. See if you can tell which is which.

Logistics and Reminders

1. Please remember to silence phones
2. Restrooms located just outside meeting room
3. PDH certificates are available at the front desk
4. Photos are being taken throughout the event
5. Check CMRC website a few weeks after event for downloadable content posted from today (<http://www.cee.msstate.edu/cmrc/>)

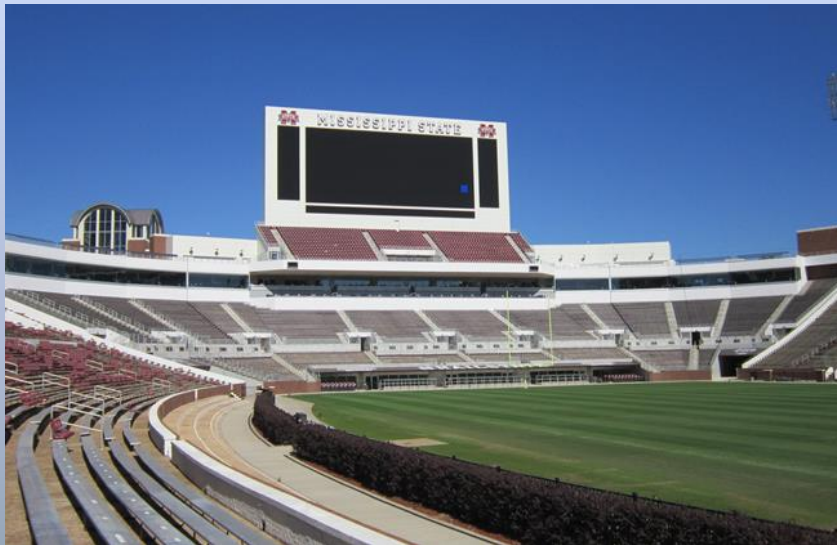
Thanks for Coming!





Portland-Limestone Cement – Introduction and Background

Properties, Sustainability Features, Marketplace Acceptance,
Implications for Dredged Material Stabilization



Tim Cost, PE, FACI
Sr. Technical Service Engineer
LafargeHolcim



Cement specifications and limestone content

Traditional, ordinary portland cement (OPC):

- ▶ ASTM C150 / AASHTO M85, Type I or II
Up to 5% limestone is allowed

Portland-limestone cement (PLC):

- ▶ ASTM C1157, Type GU or MS
- ▶ ASTM C595 / AASHTO M240, Type IL*

*Designation includes % limestone, i.e. Type IL(10)
– 5% to 15% limestone content

PLC production

- Made with less clinker, replaced by finely ground limestone (5% to 15%), which contributes to performance via both physical and chemical hydration influences
- Crushed, dried limestone is fed to the finish grinding mill along with clinker and gypsum
- Limestone is more easily ground than the clinker (which is harder) and becomes concentrated in the finest particles
- For equivalent performance, PLC fineness must be incrementally higher than that of OPC as a function of total limestone content
 - ▶ Production rate is slowed
 - ▶ Some additional grinding energy is required but increased costs are offset by lower clinker content and related kiln fuel savings

Why do this?

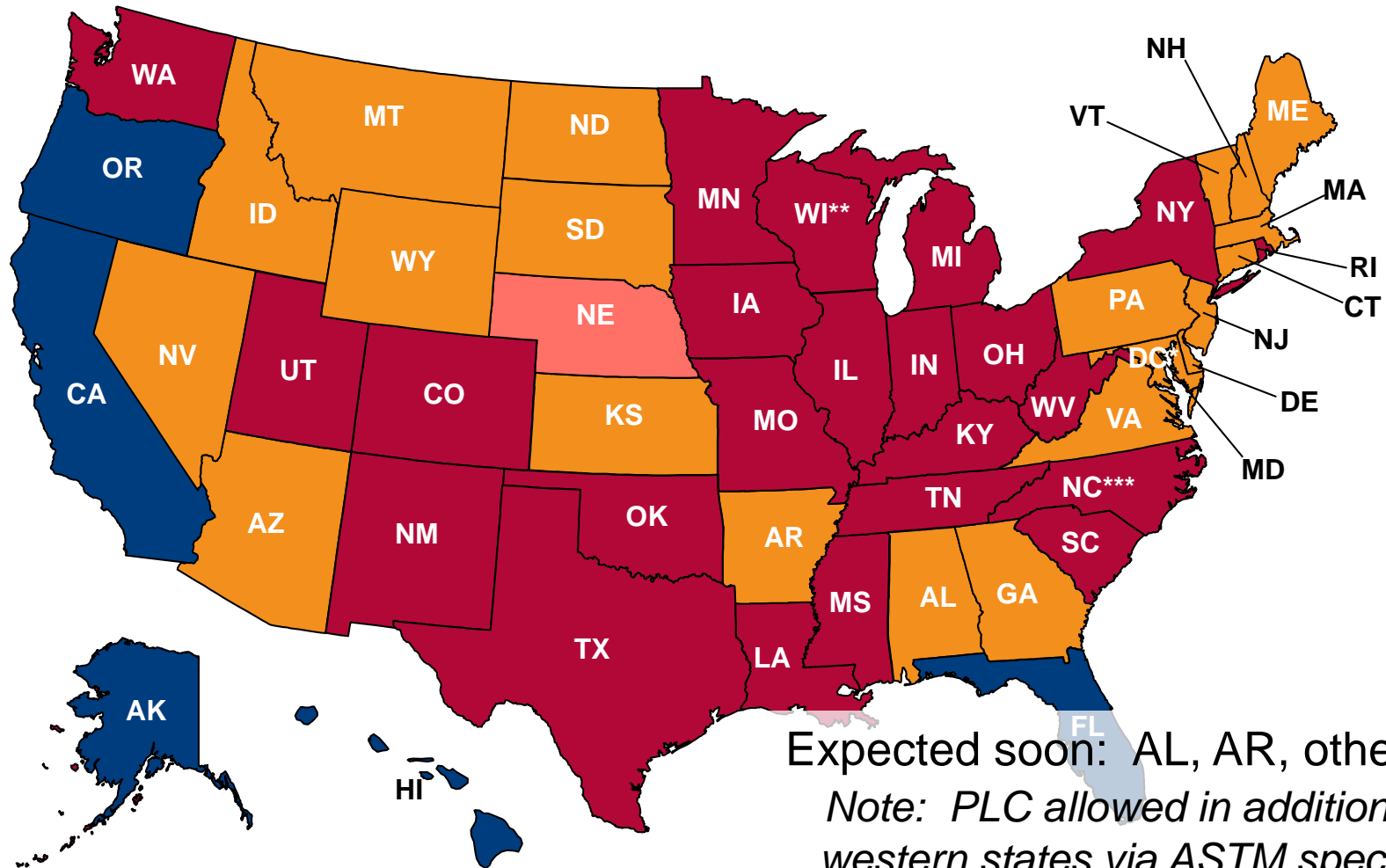
Initially, this was all about concrete sustainability, i.e. reduction of CO₂ footprint & embodied energy.



Cement is around 10% to 17% of concrete's mass but 80% or more of the embodied energy & CO₂ footprint (due to clinker production)



State DOTs now allowing Type IL in concrete



** Limestone percent (%) not to exceed 10% nominal
 *** Limestone percent (%) not to exceed 12%

Approved
 Not approved
 Unknown

State DOT approvals, PLC markets and availability

State approval is a requirement for market development

- Broad market presence will naturally lag DOT approvals
- Logistics and storage developments may be needed
- Market for PLC in soil stabilization and local experience should tend to track with concrete experience
- Already good availability in MS, LA, TX, OK, TN

Role of limestone in greater hydration efficiency

So how can PLC perform the same with less clinker?

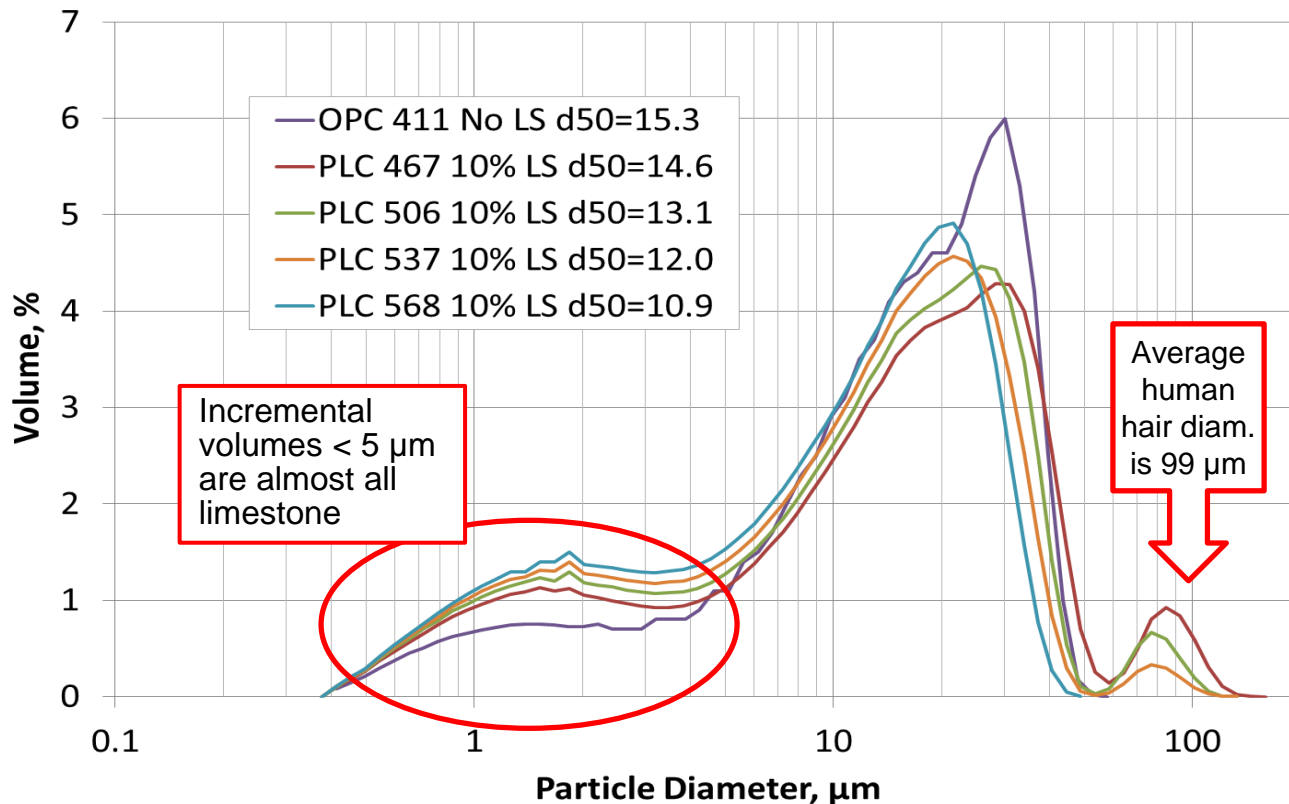
- Limestone is not inert, but contributes to hydration
 - ▶ Physically: enhanced particle packing (better PSD), nucleation sites
 - ▶ Chemically: calcium carbonate reacts with aluminates to form a new class of durable, strength-contributing crystals (carboaluminates)
- Chemical hydration contributions can be augmented in concrete when SCMs provide additional aluminates
 - ▶ The extent of this is governed by fineness of the limestone, which is controlled by overall fineness

PLC performance relative to OPC

- PLC production typically (at first) focused on basic performance equivalent to that of OPC, using fineness as a function of limestone % to control strength
 - ▶ ***Promoted as a more sustainable cement, with equivalent performance...***
 - ▶ Are there other incentives for producers to use it?
- CMRC study has shown that there are opportunities to use PLC for improved concrete performance
 - ▶ It's all about certain PLC properties and combining it (liberally) with the right SCMs

...which further enhances concrete sustainability as well!

Effects of higher PLC fineness, limestone vs. clinker



- Ref: $1 \mu\text{m}$ (micron) = 1 millionth of a meter = 0.001 mm (avg. hair is $99 \mu\text{m}$ \varnothing)
- Limestone is concentrated in finest particles (mostly $< 5 \mu\text{m}$) and volume of the very small sizes increases rapidly with additional grinding
- Limestone surface area (fineness) key to producing useful synergies with SCMs

How does PLC effect concrete operations?

- Existing mix designs can be used unchanged
- Efficiency of fly ash and slag may even be improved
- No special admixtures or dosage changes needed
- No differences in entrained air management
- No operational distinctions needed for OPC-similar performance

... but slight mix modifications may enable improved concrete performance (strength, setting, durability) and even lower mix costs.

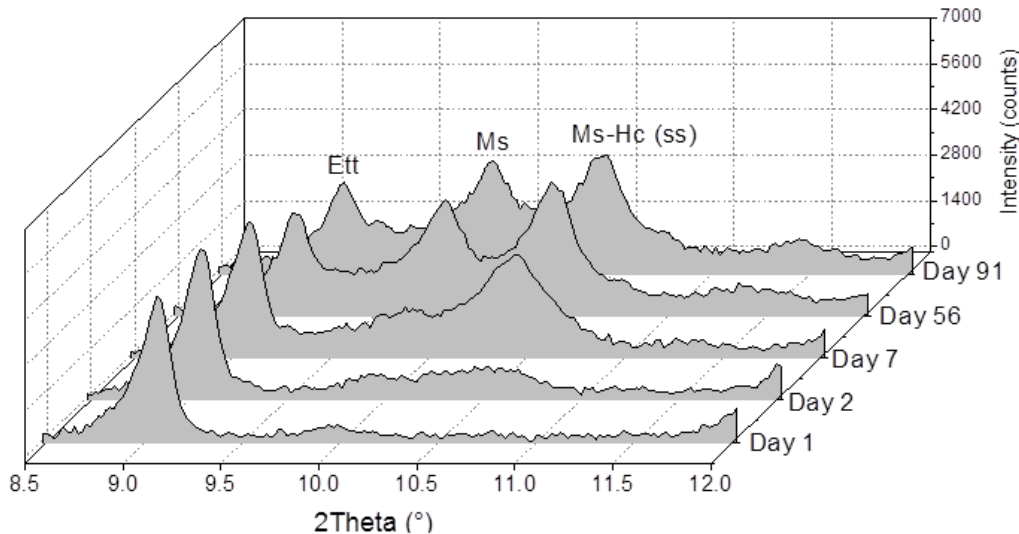
How does PLC effect stabilization applications?

- No differences generally apparent
- Early strength development may be slightly accelerated
- Experiences have been favorable

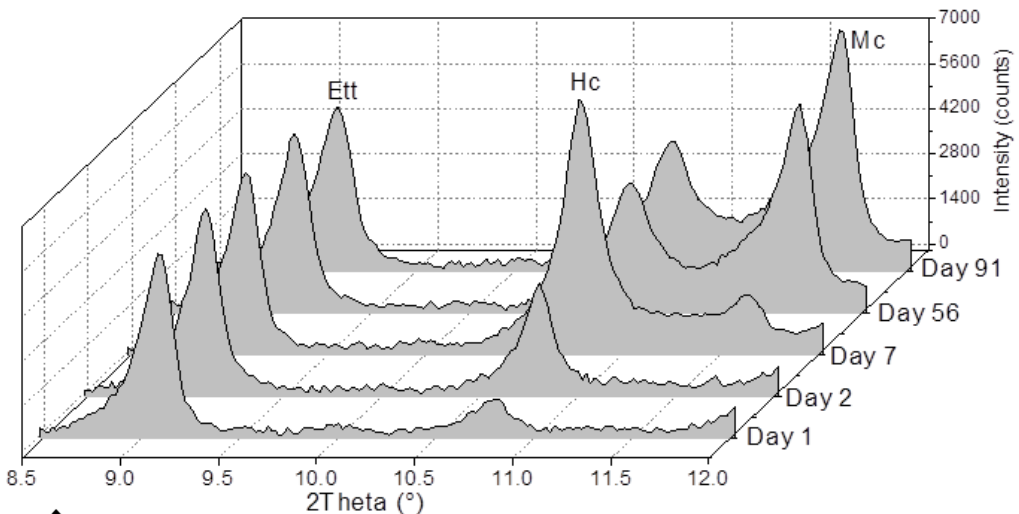
Discoveries from experiences with Holcim Theodore PLC

- Production began in 2004 (C1157, 10% limestone)
 - ▶ Limited market acceptance until CMRC study and subsequent MDOT approval, 2014
- Routine concrete testing consistently showed improved strength with ash and slag, using local materials
 - ▶ Always better with ash (sometimes significantly)
 - ▶ Generally similar, at best, in straight cement mixes
- Less set retardation with SCMs
- These observed benefits inspired research

Understanding limestone-aluminate chemical interaction



60% OPC-2a and 40% Class C fly ash



60% PLC-2a and 40% Class C fly ash

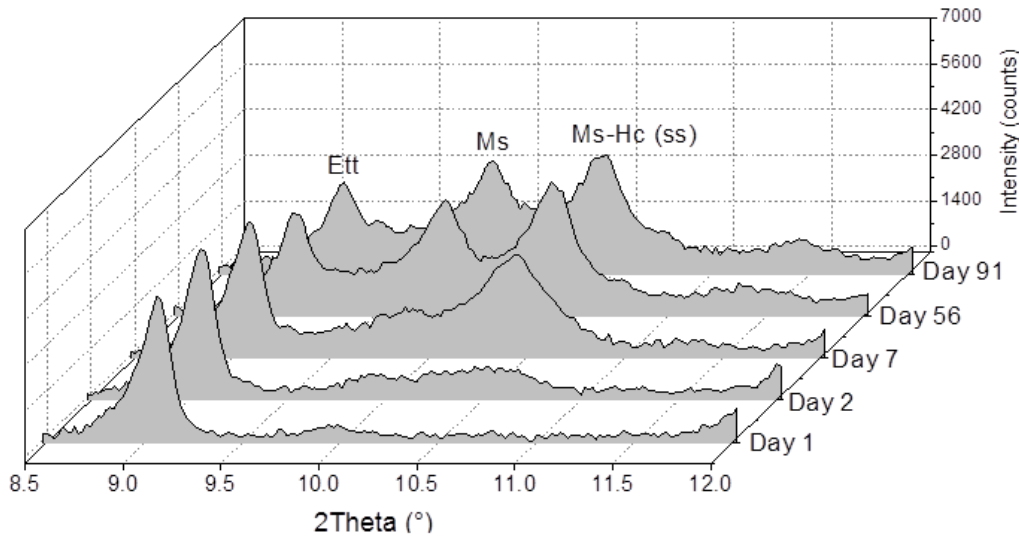
XRD Diffractograms: evolving mineralogy differences, OPC and PLC mixtures with 40% Class C fly ash

Legend:

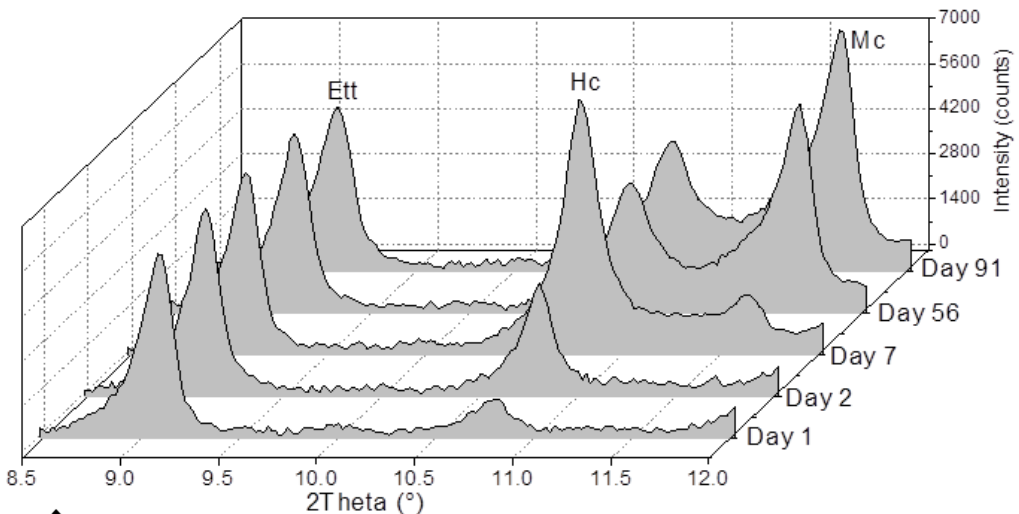
- ▶ Ett – Ettringite
- ▶ Ms – Monosulfoaluminate
- ▶ Hc – Hemicarboaluminate
- ▶ Mc – Monocarboaluminate
- ▶ Ms-Hc(ss) – Monosulfoaluminate-Hemicarboaluminate solid solution

Synergistic strength benefits are, in large part, the result of documented CaCO_3 interaction w/ aluminates and formation of carboaluminate crystals

Understanding limestone-aluminate chemical interaction



60% OPC-2a and 40% Class C fly ash



60% PLC-2a and 40% Class C fly ash

- Synergistic strength benefits occur with concrete SCMs rich in calcium aluminates
- It follows that the same trends are possible in combination with some fine-grained soil chemistries
- Afternoon presentation will discuss this!

CMRC study focusing on PLC synergies

- Work began late 2012
 - ▶ Funded initially by Holcim, with additional support from 3 other cement companies, substantial in-kind support from MMC Materials
- Justification for the project:

Reported performance trends not previously studied or widely observed

 - Cements in Europe and other continents not typically ground fine enough
 - SCMs in other countries not as rich in aluminates of interest
 - Most limestone-containing cements complex blends of multiple binders
 - ▶ Considerable new interest in extending concrete sustainability
 - ▶ Cement industry under pressure to reduce carbon footprint
 - ▶ Most approaches to more sustainable concrete detract from performance
 - ▶ Economic potential of implementation quite favorable
 - ▶ A potential win-win-win (cement producers, users, specifiers & agencies)

CMRC study details

- Over 200 laboratory concrete mixtures, various supporting tests, analytical evaluation, petrography, field trial
- Some of the topics investigated:
 - ▶ Optimal SCMs and proportions in concrete
 - ▶ Special benefits – concrete with smooth gravel aggregates
 - ▶ Extending the boundaries on SCM use & replacement rates
 - ▶ Field trial: MSU Davis Wade Stadium project, high cement replacement mixtures & OPC vs. PLC comparisons

Cements compared in MSU research

- OPCs and PLCs from 4 sources
- Each of 8 cement samples used in groups of identical concrete mixtures with and without aggressive SCM replacement, 2 different coarse aggregate types (limestone, gravel)

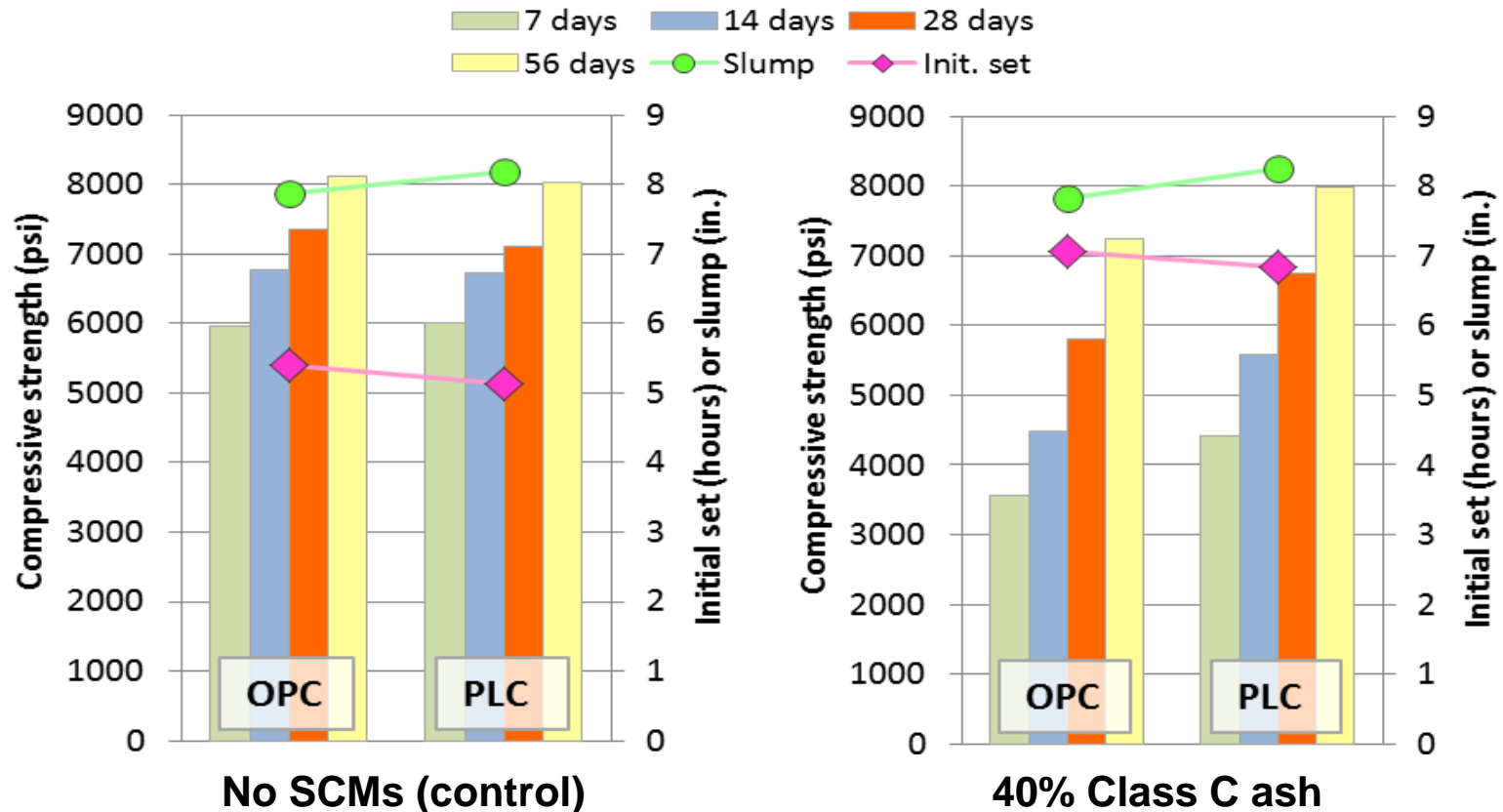
OPC, ASTM C150 Type I or II, or PLC, ASTM C595 Type IL								
Property	OPC-1	PLC-1	OPC-2a	PLC-2a	OPC-3	PLC-3	OPC-4	PLC-4
C ₃ S (%)	60.2	---	59.4	---	59.1	---	59.0	---
C ₃ A (%)	8.8	---	7.4	---	5.9	---	6.8	---
SO ₃ (%)	3.2	3.9	3.1	3.2	3.2	3.4	3.3	3.3
Na ₂ O eq. (%)	0.56	0.52	0.41	0.44	0.52	0.54	0.41	0.36
LOI (%)	2.4	4.7	1.2	4.2	1.5	7.0	2.6	7.3
Blaine (m ² /kg)	422	522	403	549	421	556	407	681
Limestone (%)*	2.6	8.8	0.1	8.5	0.3	14.0	4.1	15.7

* calculated

Example data from MSU study

Performance synergies w/ C ash – limestone aggregates

Each bar group shows the average of 4 mixes – 1 with each cement source

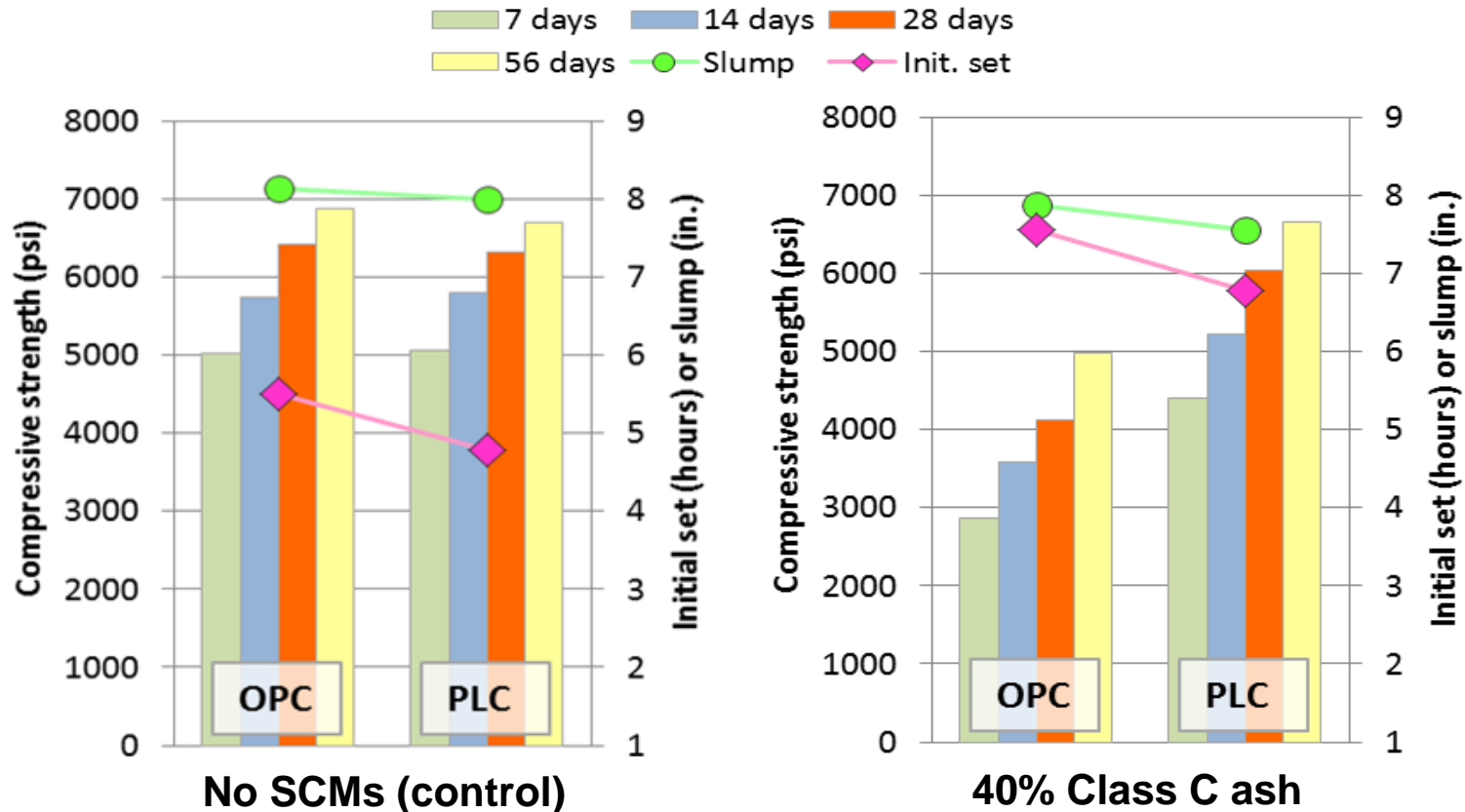


Otherwise identical concrete batches using limestone coarse aggregate, 540 lb/ft³ total cementitious content, w/cm = 0.43. The PLC strength advantage at 28 days in 40% fly ash mixtures ranged from 13% to 22%, averaging 16%.

Example data from MSU study

Performance synergies w/ C ash – gravel aggregates

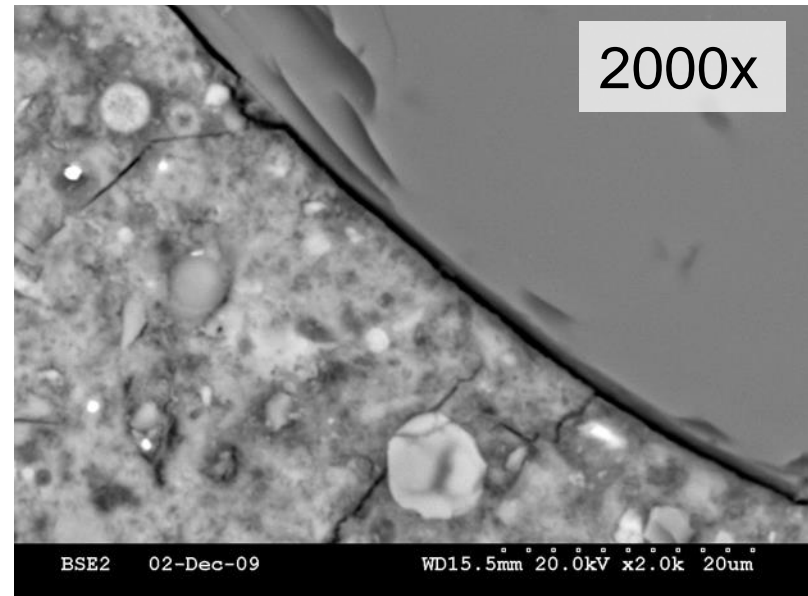
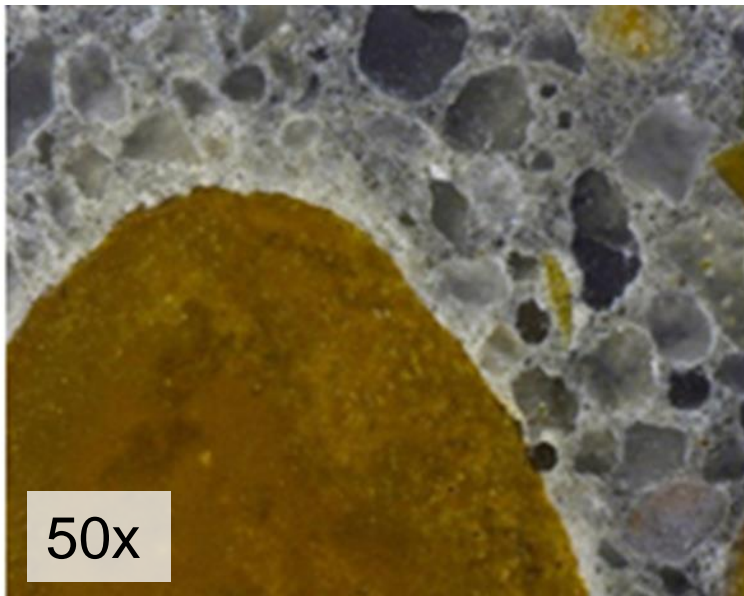
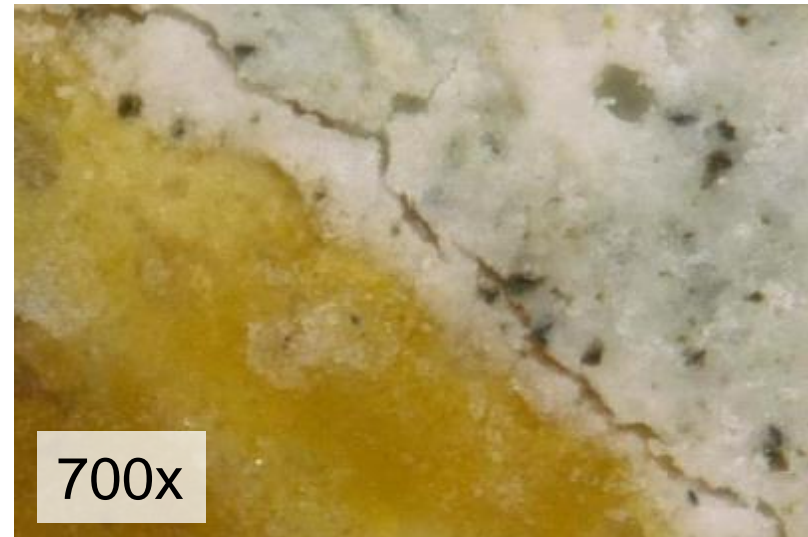
Each bar group shows the average of 4 mixes – 1 with each cement source



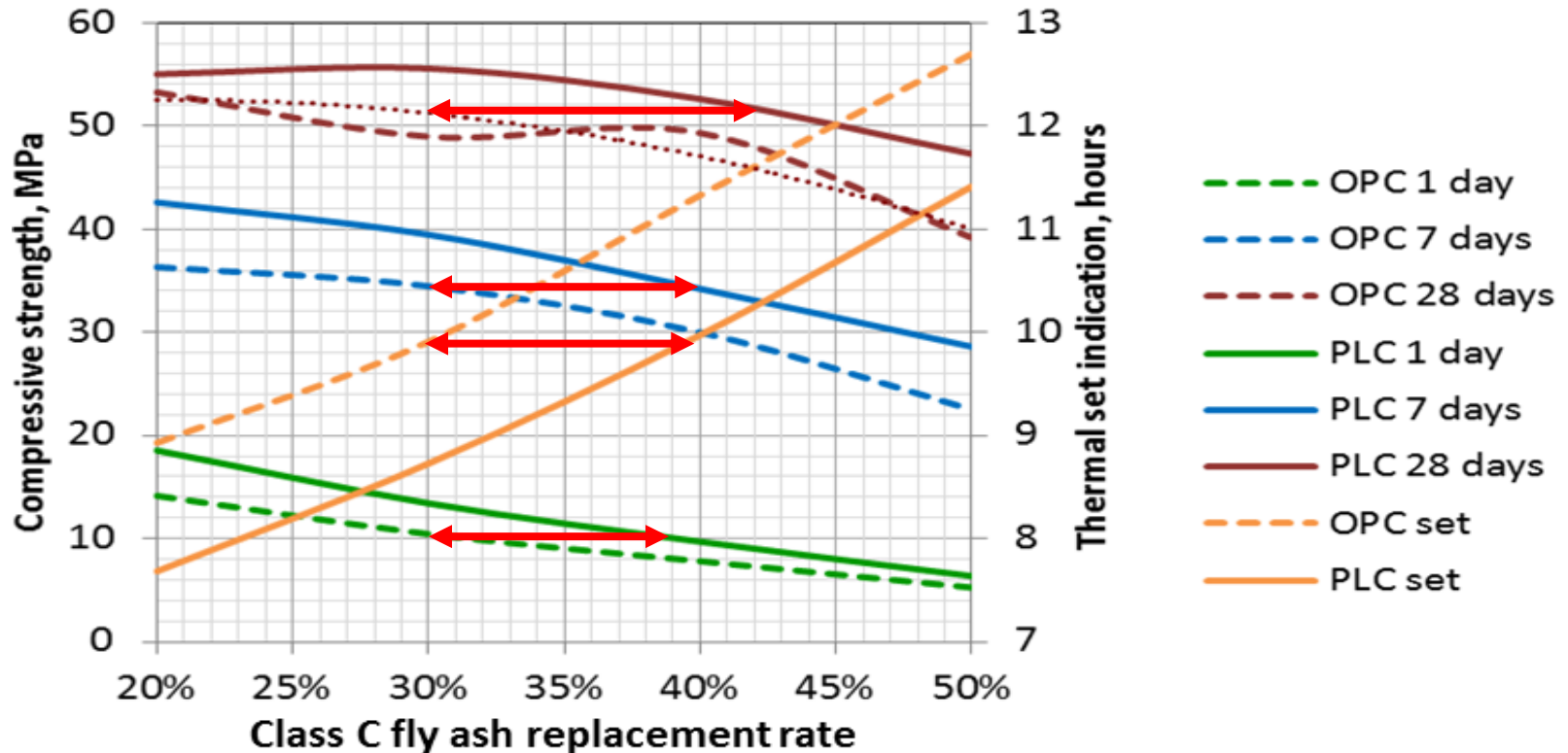
Otherwise identical concrete batches using gravel coarse aggregate, 540 lb/ft³ total cementitious content, w/cm = 0.43. The PLC strength advantage at 28 days in 40% fly ash mixtures ranged from 38% to 60%, averaging 46%.

Petrography micrographs of paste near agg surfaces

- Micrographs show that there tends to be distinguishing paste character near the ITZ in smooth gravel agg mixes
 - ▶ Higher w/cm
 - ▶ Some microcracks
 - ▶ Frequent failure zone near aggregate surface



OPC and PLC strength and setting vs. % fly ash (paste)



Observed trends suggest that equivalent performance should be possible with at least 10% higher fly ash replacement, using PLC.

907-701.02.1.1--Types of Portland Cement. Portland cement (cement) shall be either Type I or Type II conforming to AASHTO Designation: M85. Type III cement conforming to AASHTO Designation: M85 or Type III(MS), as defined by the description below Table 1, may be used for the production of precast or precast-prestressed concrete members.

907-701.02.1.2--Alkali Content. All cement types in this Subsection shall meet the Equivalent alkali content requirement for low-alkali cements listed in AASHTO Designation: M85, Table 2.

907-701.02.2--Replacement by Other Cement cement by weight is 25% for fly ash or 50% for GGBFS. The minimum tolerance for replacement shall be given any special consideration. Replacement contents below this minimum shall not be given any special consideration. portland cement concrete containing pozzolans. replacement of cement by fly ash or GGBFS

Maximum fly ash replacement rate increased from 25% (Type I or II) to 35% (Type IL)

MDOT Specs – recent Special Provision

- Type IS – Portland blast-furnace slag cement
- Type IP – Portland-pozzolan cement
- Type IL – Portland-limestone cement

Blended cement Types IS and IP for use in portland cement concrete or soil stabilization exposed to the moderate soluble sulfate condition or exposure to seawater as defined in Table 1 shall meet the Sulfate resistance requirement listed in AASHTO Designation: M 240, Table 4 and the “(MS)” suffix shall be added to the type designation.

907-701.04.1.2--Alkali Content. All blended cement shall be made with clinker that would result in cement meeting the requirements of Subsection 907-701.02.1.2 when used in the production of AASHTO Designation: M 85, Type I or Type II cement.

907-701.04.2--Replacement by Other Cementitious Materials. Fly ash and GGBFS shall not be used as replacements of cement for blended cement Types IS and IP.

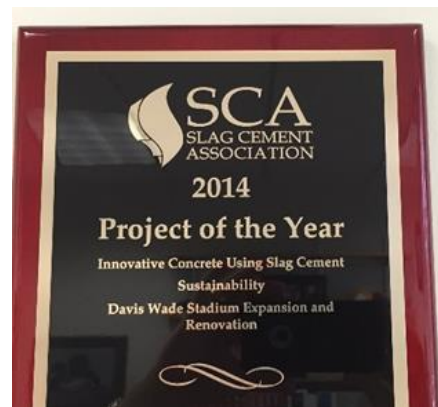
The maximum replacement of blended cement Type IL by weight is 35% for fly ash or 50% for GGBFS. Replacement contents below 20% fly ash or 45% GGBFS may be used, but shall not be given any special considerations, like the maximum acceptance temperature for portland cement concrete containing pozzolans. Special considerations shall only apply for replacement of blended cement by fly ash or GGBFS. No additional cementitious materials (such as Portland cement, performance hydraulic cement, fly ash, GGBFS, metakaolin, or others) shall be added to or as a replacement for blended cement types IS and IP.

1st major project in MS to use PLC

MSU Davis Wade Stadium expansion and renovation



- \$75 million investment, late 2012
- Increase seating by 6255 to 61,337, 22 suites, elevators, restrooms, west-side concession concourse
- Construction planning:
 - ▶ Sustainability & innovation focus
 - ▶ Most concrete using 50% replacement of cement with SCMs, much flatwork
- MSU CMRC involvement: mix designs, QC testing & performance monitoring, data evaluation, publications



Davis Wade Stadium Expansion and Renovation: Performance of Concrete Produced with Portland-Limestone Cement, Fly Ash, and Slag Cement

Isaac L. Howard, M.ASCE¹; Jay Shannon, S.M.ASCE²; V. Tim Cost, M.ASCE³; and Mark Stovall⁴

Abstract: This paper documents successful use of portland-limestone cement (PLC) with 50% replacement of cement using supplementary cementitious materials (SCMs) during expansion and renovation of a college football stadium. Concrete becomes more sustainable as clinker content is reduced, and use of PLC in place of ordinary portland cement (OPC), e.g., such as per a common U.S. national standard, has considerable appeal, especially if performance tradeoffs that are often associated with more sustainable concrete can be addressed. Higher replacement of cement in concrete with SCMs may also be possible by incorporating PLC, further adding value to projects from performance and sustainability perspectives. Concrete containing PLC was successfully used in approximately 1,900 m³ of on-grade and structural concrete flatwork. The cementitious system contained 50% PLC, 30% slag cement, and 20% Class C fly ash. This paper provides information related to properties of the PLC supplied to the stadium project as they are not necessarily typical of PLCs used worldwide over the past several years. One especially beneficial performance trend was that early-age strength gain of concrete containing 50% PLC, 30% slag cement, and 20% Class C fly ash was noticeably better than that of otherwise comparable concrete containing OPC. Additionally, use of PLC did not result in finishing problems, reduced slump by approximately 20 mm, reduced set time by approximately 1 h, and improved chloride ion resistance. DOI: [10.1061/\(ASCE\)MT.1943-5533.0001305](https://doi.org/10.1061/(ASCE)MT.1943-5533.0001305). © 2015 American Society of Civil Engineers.

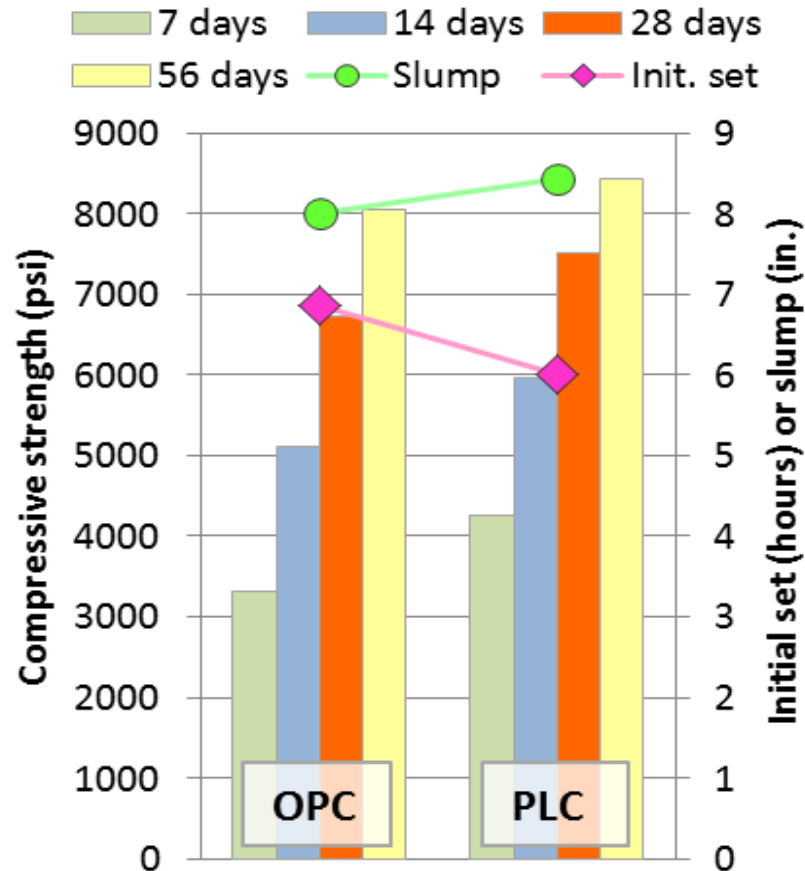
Author keywords: Stadiums; Sustainable development; Portland cement; Limestone construction materials; Concrete construction; Concrete fly ash slag cement.

Introduction and Background

The ASCE has recently referred to a triple bottom line relating to

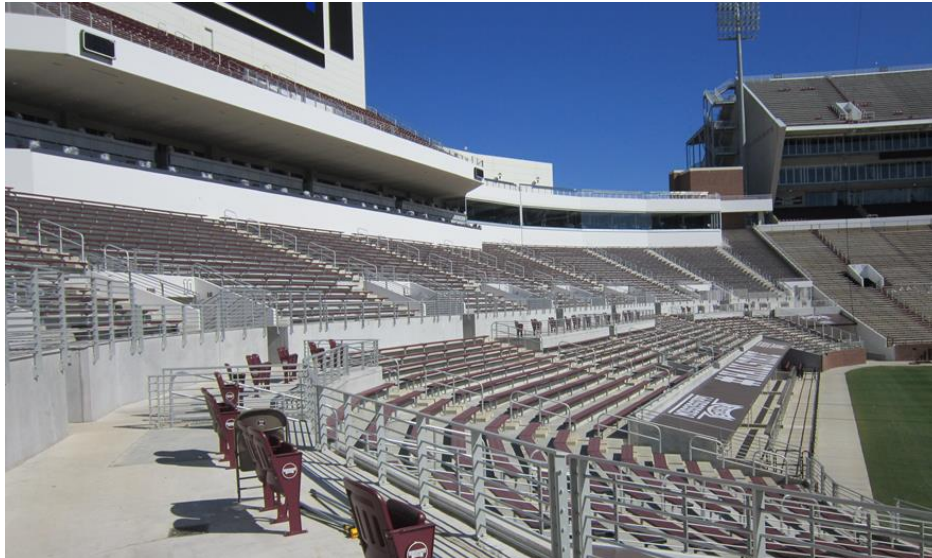
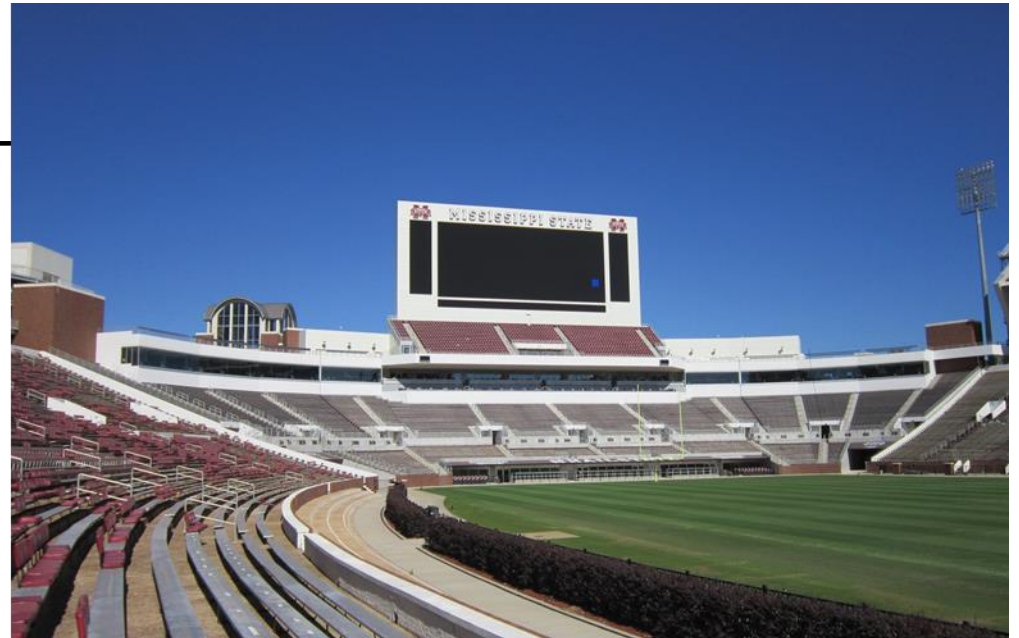
(Hawkins et al. 2003; Van Dam et al. 2010; Tennis et al. 2011; Schneider et al. 2011; Goguen 2014; Bushi and Meil 2014). Ordinary portland cement (OPC) as specified in ASTM C150

Laboratory concrete data, DWS flatwork mix (50/30/20C) comparing OPC and PLC, trend averages of 4 sources



Otherwise identical concrete batches using limestone coarse aggregate, 540 lb/ft³ total cementitious content, w/cm = 0.43. The PLC strength advantage at 28 days ranged up to 27% among the sources, averaging 12%.

Completed DWS views



Major findings of the MSU CMRC concrete research

- Performance trends were similar among all 4 sources, with some variability that could be associated with fineness / limestone % ratio.
- Strength benefits of PLC in limestone aggregate concrete were significant with C ash and with slag, lesser so and variable with F ash but mostly according to the ash calcium level.
- When smooth gravel aggregates were used, these benefits (relative to Type I) increased by as much as 3x.
- Setting was always faster with PLC, most noticeably with higher SCM replacement (mitigation of ash-related retardation).
- OPC – equivalent performance was possible with higher SCM replacement rates in PLC mixtures.
- In the field project, finishing properties were noticeably improved.
- Sustainability benefits can be compounded with PLC: lower CO₂ footprint and embodied energy (pound for pound), greater SCM replacement of cement, and improved cementitious efficiency, allowing reduced total cementitious content.

Papers and journal articles

- Cost, V. T., and Bohme, P., “Synergies of Portland-Limestone Cements and Their Potential for Concrete Performance Enhancement,” 2012 International Concrete Sustainability Conference, Seattle, WA, May 7-10, 2012, 14 pp.
- Cost, V. T., Howard, I. L., and Shannon, J., “Improving Concrete Sustainability and Performance with Use of Portland-Limestone Cement Synergies,” *Transportation Research Record: Journal of the Transportation Research Board*, No. 2342, Washington, D.C., 2013, pp 26-34.
- Cost, V. T., Matschei, T., Shannon, J., and Howard, I. L., “Extending the Use of Fly Ash and Slag Cement in Concrete Through the Use of Portland-Limestone Cement,” 2014 International Concrete Sustainability Conference, Boston, MA, May 12-14, 2014, 15 pp.
- Shannon, J., Howard, I. L., Cost, V. T., and Wilson, W., “Benefits of Portland-Limestone Cement for Concrete with Rounded Gravel Aggregates and Higher Fly Ash Replacement Rates,” presented at the Transportation Research Board 94th Annual Meeting (paper no. 15-4049).
- Howard, I.L., Shannon, J., Cost, V.T., Stovall, M. (2015). “Davis Wade Stadium Expansion and Renovation: Performance of Concrete Produced with Portland-Limestone Cement, Fly Ash, and Slag Cement, *Journal of Materials in Civil Engineering*, 27(12), 04015044.
- Cost, V. T., Wilson, W., Shannon, J., and Howard, I. L., “Unexpected Concrete Performance Benefits of Sustainable Binder Combinations Using Portland-Limestone Cement,” Fifth International Conference on Construction Materials: Performance, Innovations and Structural Implications, Whistler, BC, August 18-20, 2015, pp 1430-1441.
- Shannon, J., Howard, I.L., Cost, V.T. (2017). “Potential of Portland-Limestone Cement to Improve Performance of Concrete Made with High Slag Cement and Fly Ash Replacement Rates,” *Journal of Testing and Evaluation*, 45(3), 1-17, In Press, 10.1520/JTE20150306.

Further implementation (Holcim Theodore) in Mississippi

- MMC Materials – exclusive use in central MS since April 2015, expanding to other markets
- Very favorable market acceptance
- Higher fly ash replacement levels used in most cases
- MDOT projects underway, using new ash limits
- Slightly reduced cementitious content in many cases
- Realized benefits: improved cementitious efficiency, higher rates of fly ash replacement, excellent placing and finishing properties, formed & slipped surface quality, consistent with sustainability focus
- Changing the market place, rapidly greater availability
- All kinds of stabilization will quickly become PLC-possible (and potentially preferred)

Example projects

*Residential uses –
significant finishing
advantages*



Example projects



Entergy (electric power company) transmission operations center, all concrete building



Example projects



MDOT I-55 south of Jackson, MS: several miles of median barriers, bridge widening, incidental concrete

Example projects

*Wastewater
treatment plant,
Florence, MS*



Example projects

University of MS Medical Center classrooms & labs, parking garage, Jackson MS



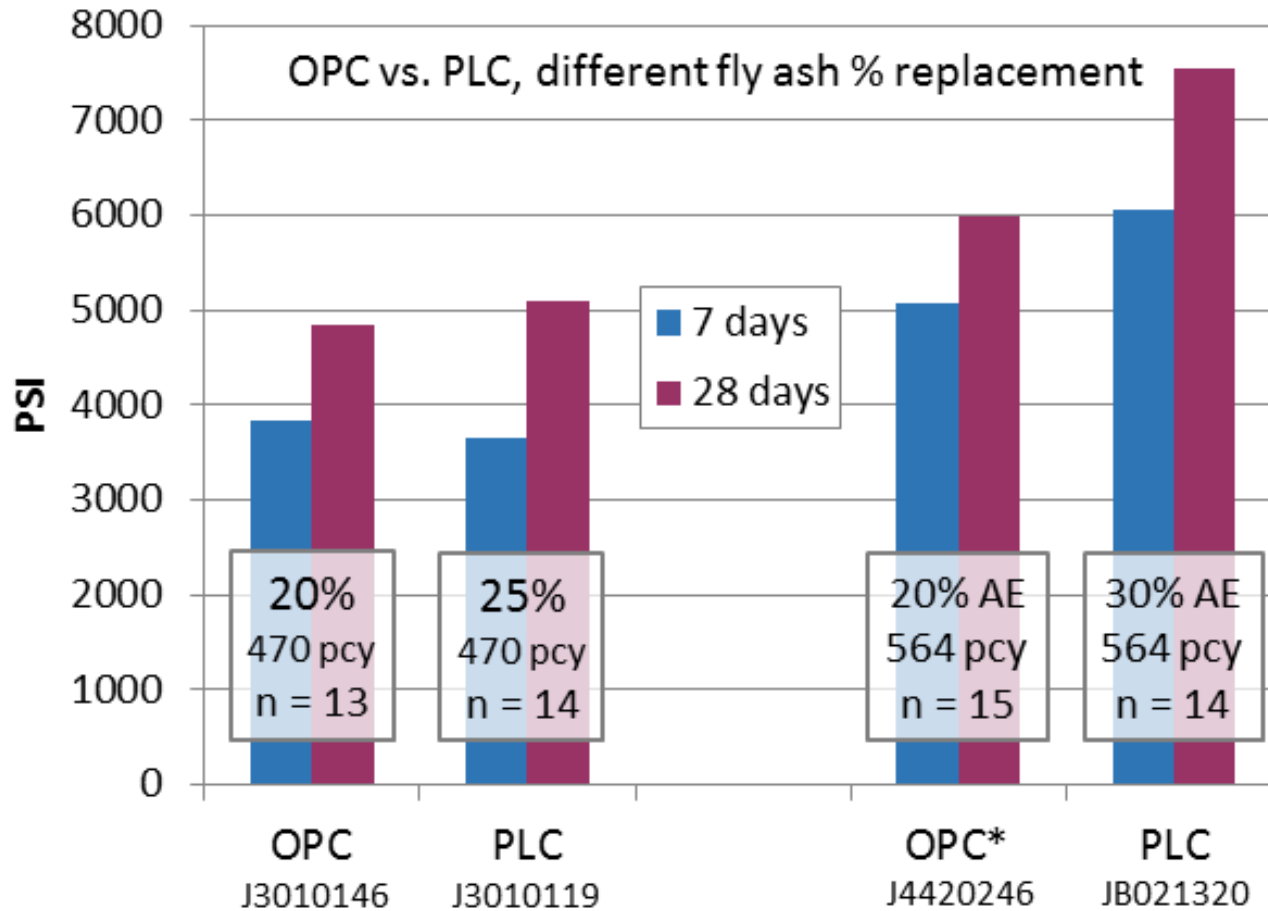
Example projects



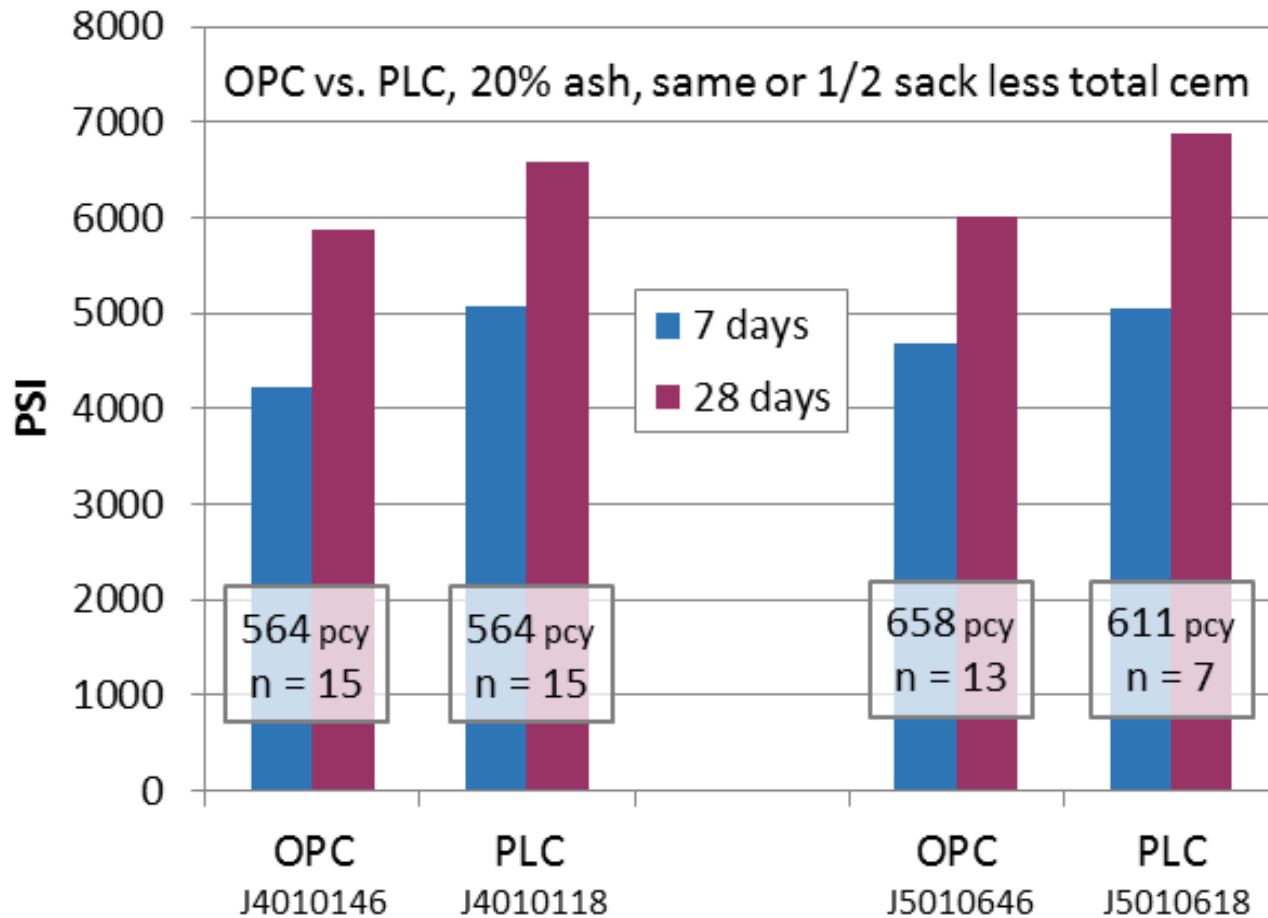
*Westin Hotel,
downtown
Jackson*



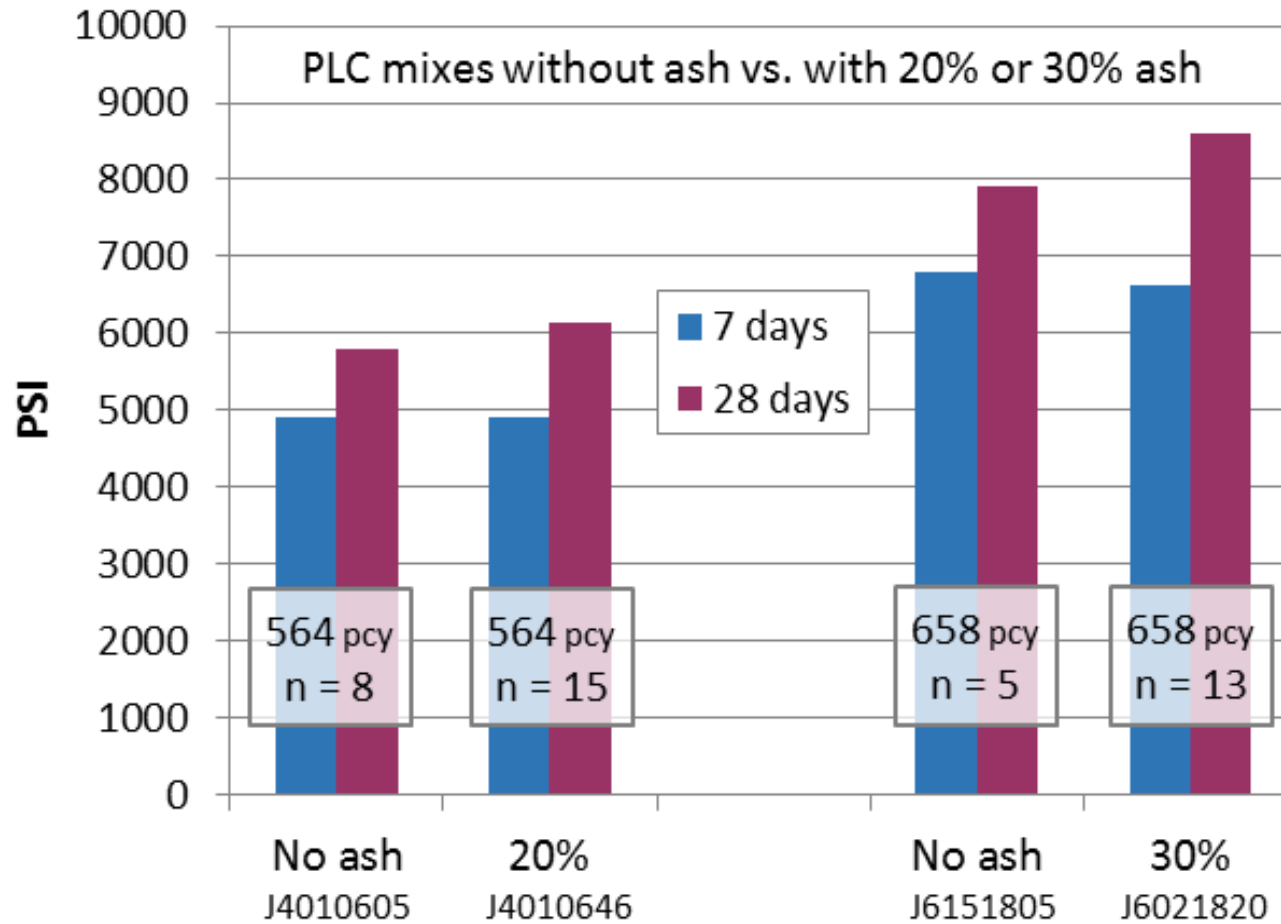
Project data – strength trends, OPC vs. PLC



Project data – strength trends, OPC vs. PLC



Project data – strength trends, PLC w/ and w/o ash



Potential concrete sustainability benefits quantified

- Comparing the 50/30/20C PLC mixture used at the Davis Wade stadium with a traditional 80/0/20C OPC mixture designed for similar 28-day strength performance:
 - 50/30/20C PLC mix → 14.8 psi/lb total cementitious (8000 psi)
 - 80/0/20C OPC mix → 11.7 psi/lb total cementitious
- Needed for 20% ash OPC mix: $8000/11.7 = 680$ pcy total cementitious
 - Comparing total cementitious required: 540 vs. 680 pcy
 - Comparing portland cement required: 270 vs. 544 pcy
 - Comparing clinker content: 233 vs. 501 pcy
- The DWS mix has about 47% of the clinker factor of a 20% C ash traditional mix designed for the same 28-day strength.

(about half of the CO₂ footprint and embodied energy)
- No difference in construction waste, materials transport, virgin aggregates use, most other sustainability metrics

Implications for stabilization of low-quality soil materials

- Synergy benefits of PLC in concrete depend on SCM chemistries
- Some soil types, when stabilized with cementitious binders, may have chemistry contributions similar to these SCMs
 - ▶ Related: clay is sometimes used in cement making as a source of aluminates
- It follows that synergistic PLC interaction with soil chemistries could enhance stabilization mix performance, relative to OPC
 - ▶ Potential for greater cementitious efficiency
 - ▶ Compound sustainability benefits, as in concrete
- Slightly more robust early strength performance is also usually characteristic of PLC and may be beneficial

Portland-Limestone Cement – Introduction and Background

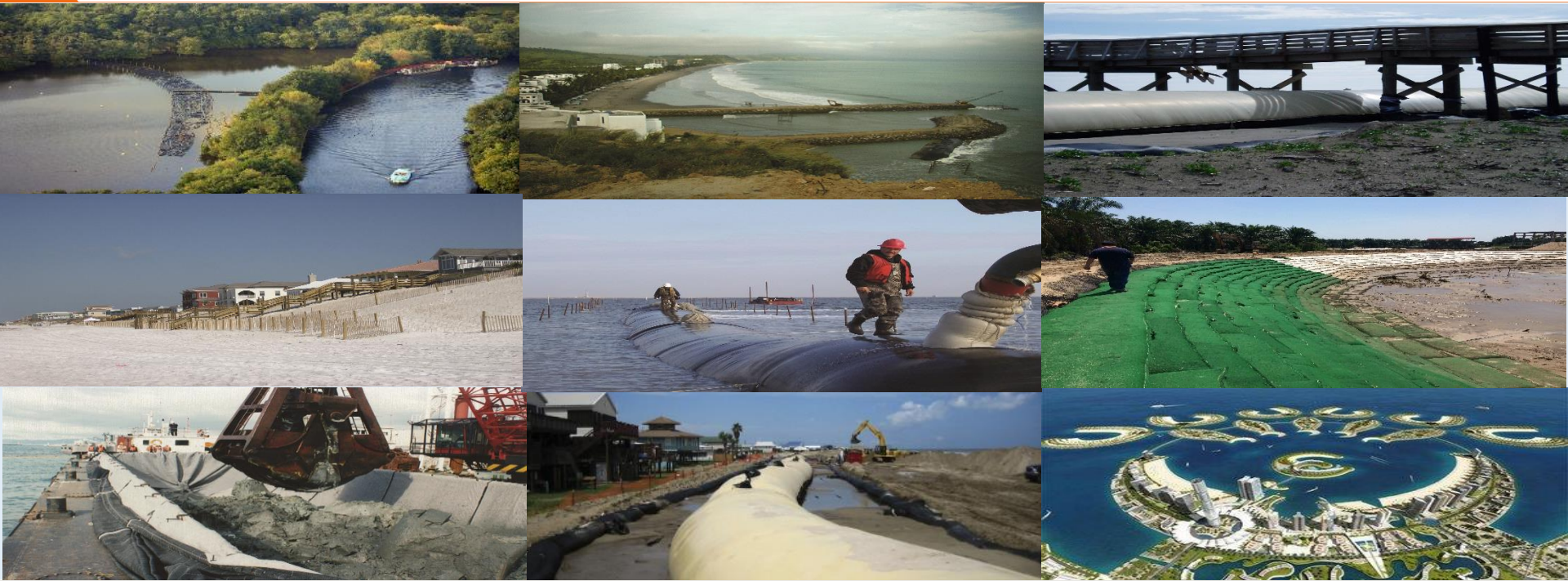
Questions?



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Geosynthetic Properties, Sustainability Features, Marketplace Acceptance, and Implications for Dredged Materials

Presented by: Chris Timpson



MSU Dredged Material Workshop
Starkville, MS
May 24, 2016

MSU Dredged Material Workshop

Agenda

- Background
- Geosynthetic Properties
- Sustainability
- Marketplace Acceptance
- Implications for Dredged Materials
- Summary

MSU Dredged Material Workshop

Background

Courtesy of Dredging International



Sand is an economical building material.

It can be obtained in large quantities, is reusable, and easy to process.

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Background

Courtesy of coastalcare.org of Topsail Beach, NC



Sand is mechanically & volumetrically stable, and has predictable engineering properties.

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Background



Sand lacks cohesion and erodes easily under the influence of current and waves.

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Background



- Geosynthetics can encapsulate sand to form containment structures to protect against erosion, build waterfront structures, and reclaim land.
- There has been an evolution of the technology over time.

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Background



Geotextile mattresses placed over prepared slope.

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Background



Flexible to conform to smooth curvatures



Can handle sharp angular changes

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Background



Smaller Units



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Background



Smaller Units

MSU Dredged Material Workshop

Background



Larger Units

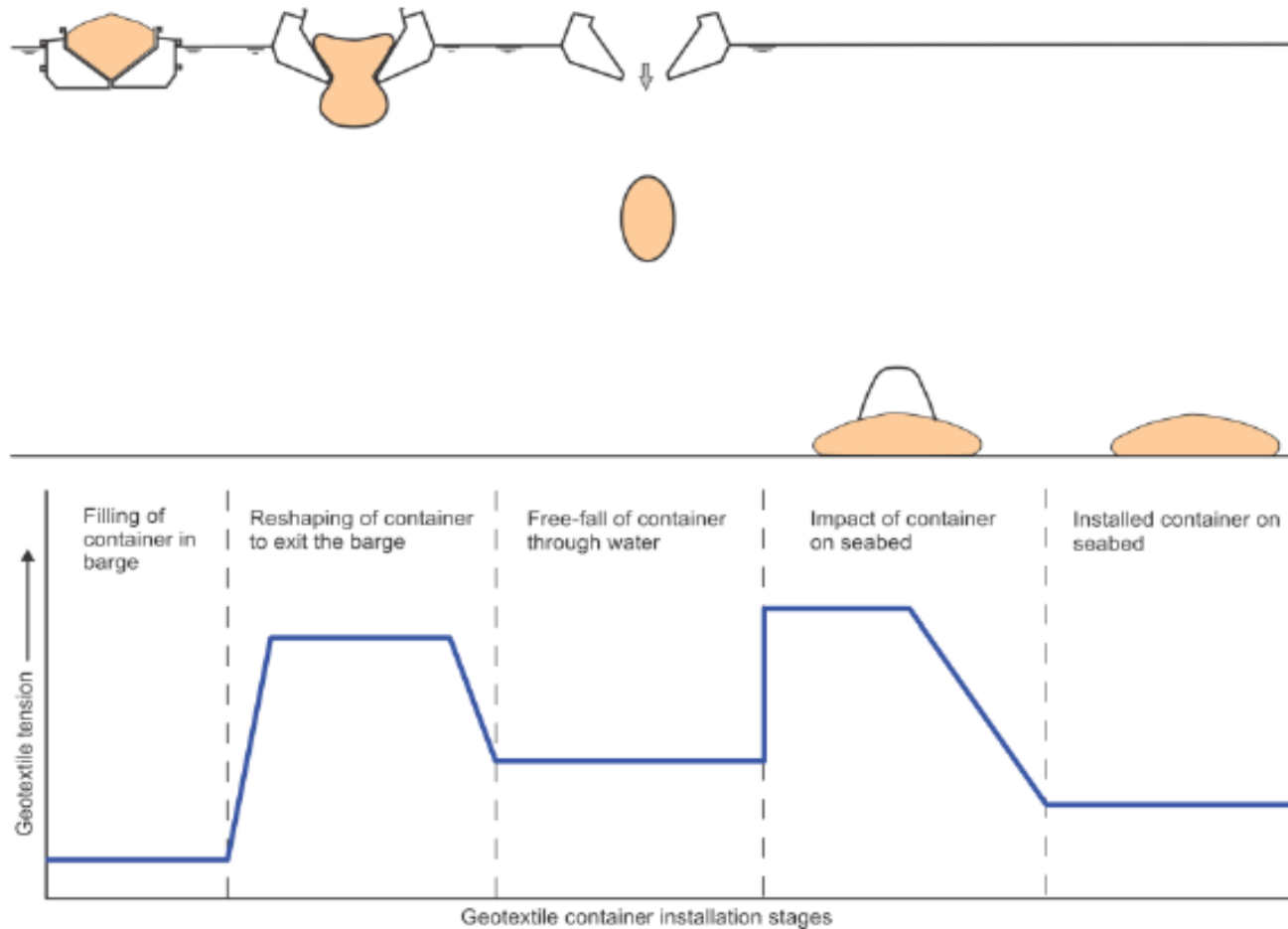
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Background

Deployment of Geocontainer[®] Unit from Work Barge



Analysis of Deployment of Geocontainer[®] Unit from Split Bottom Barge



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Background

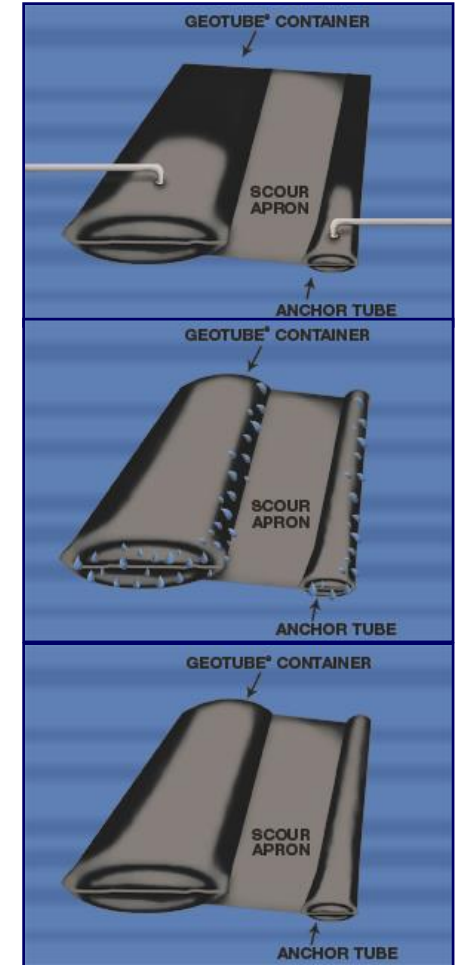
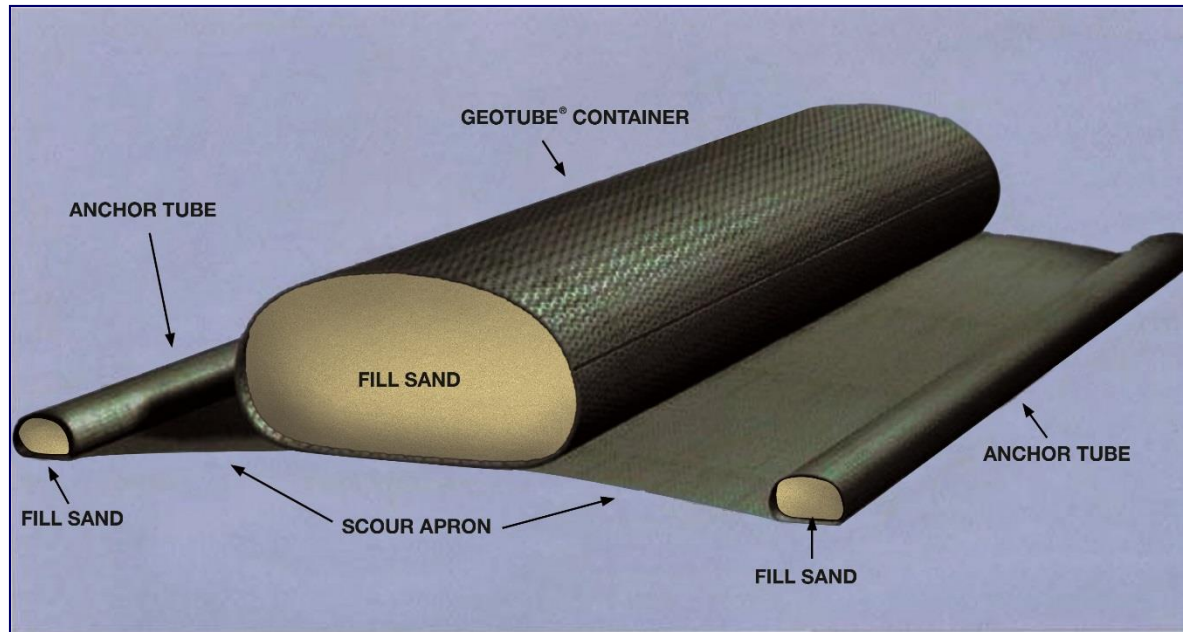
Lifting & Placement of Large Units



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Background

3 Step Process:



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Background



- Polyester tubes evolved in early 1990's.
- Required polypropylene shrouds for added UV resistance.

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Background



- High strength polypropylene tubes evolved in mid-1990's.
- Provided superior UV resistance over polyester tubes.

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Background



New materials have emerged to provide higher performance & additional protection.

Hydraulic & Marine Structures

Background



Composite materials can provide increased impact resistance against water-carried debris.

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Background



Impact Testing A

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Background



Impact Testing B

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Background



Composite materials are not only used to provide an additional protective layer, but marine containment systems can be fabricated as well.

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Background



Polyurea coated geosynthetics provide additional protection against the marine environment and vandalism.

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Background

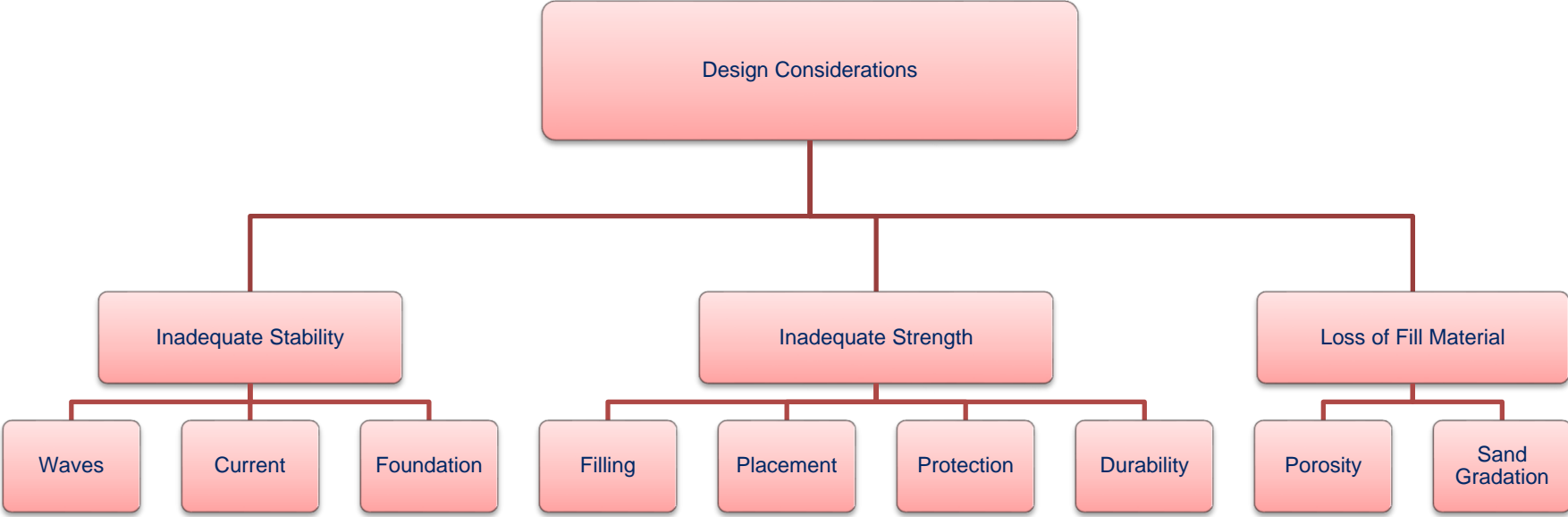


Benefits:

- Minimum impact on the environment
- Beneficial use for dredged material
- Custom site specific fabrication
- Low maintenance
- Cost effective

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Geosynthetic Properties



MSU Dredged Material Workshop

Geosynthetic Properties



Engineered Textile Design Criteria

- Raw Materials
- Yarn Formation
- Fabric Formation
- Finishing
- Fabrication

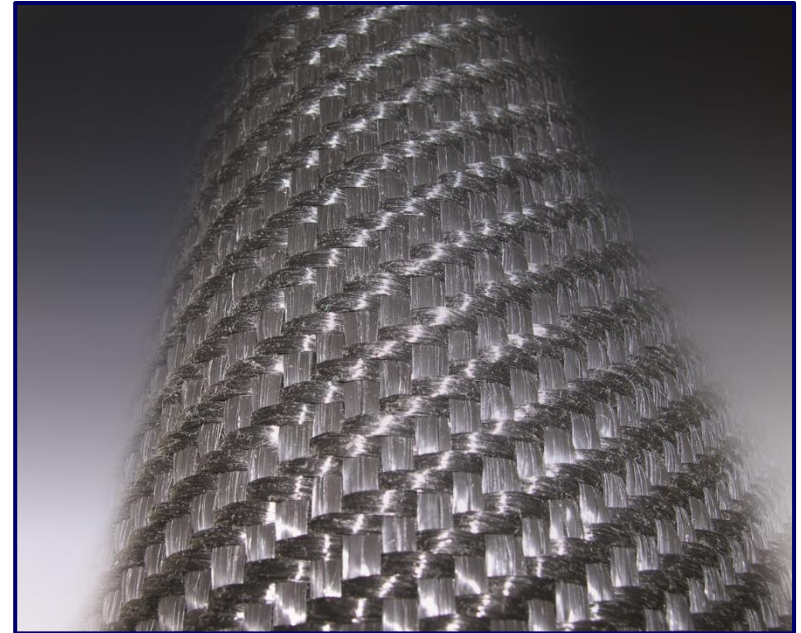
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Geosynthetic Properties



Internal design

- Fabric must be strong enough
 - Wide width
 - CBR
 - Seam strength
 - Port strength
- Geotube[®] containers are designed to withstand stresses generated during hydraulic filling.
- Stresses are a function of the circumference of tube and maximum designed pump height.

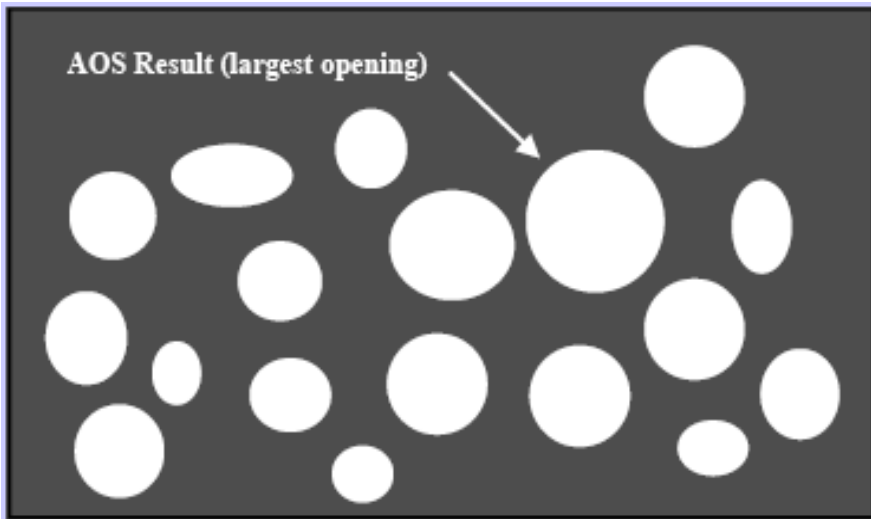


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Geosynthetic Properties

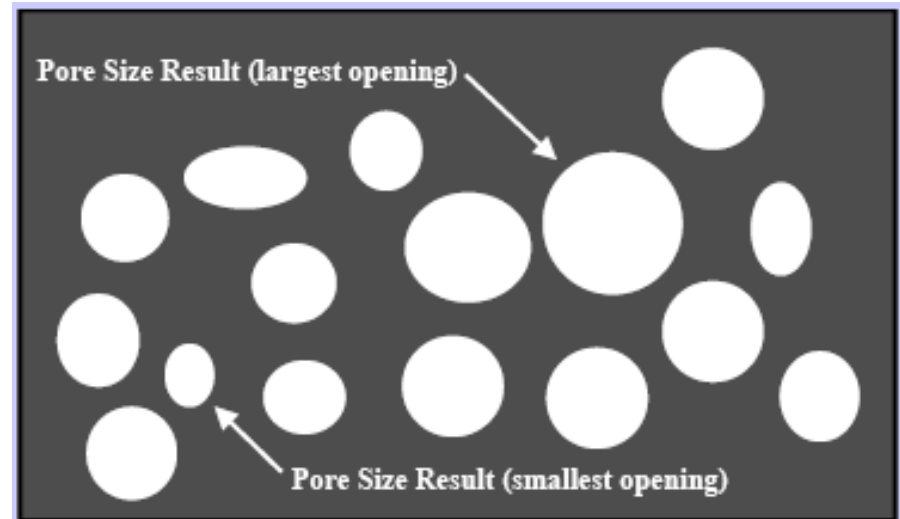
Internal design

- Fabric must be sand tight but sufficiently permeable.
 - AOS and porosity
 - Grain size distribution



Apparent Opening Size (AOS) result

Relative Measurement
Largest Opening
Static Test

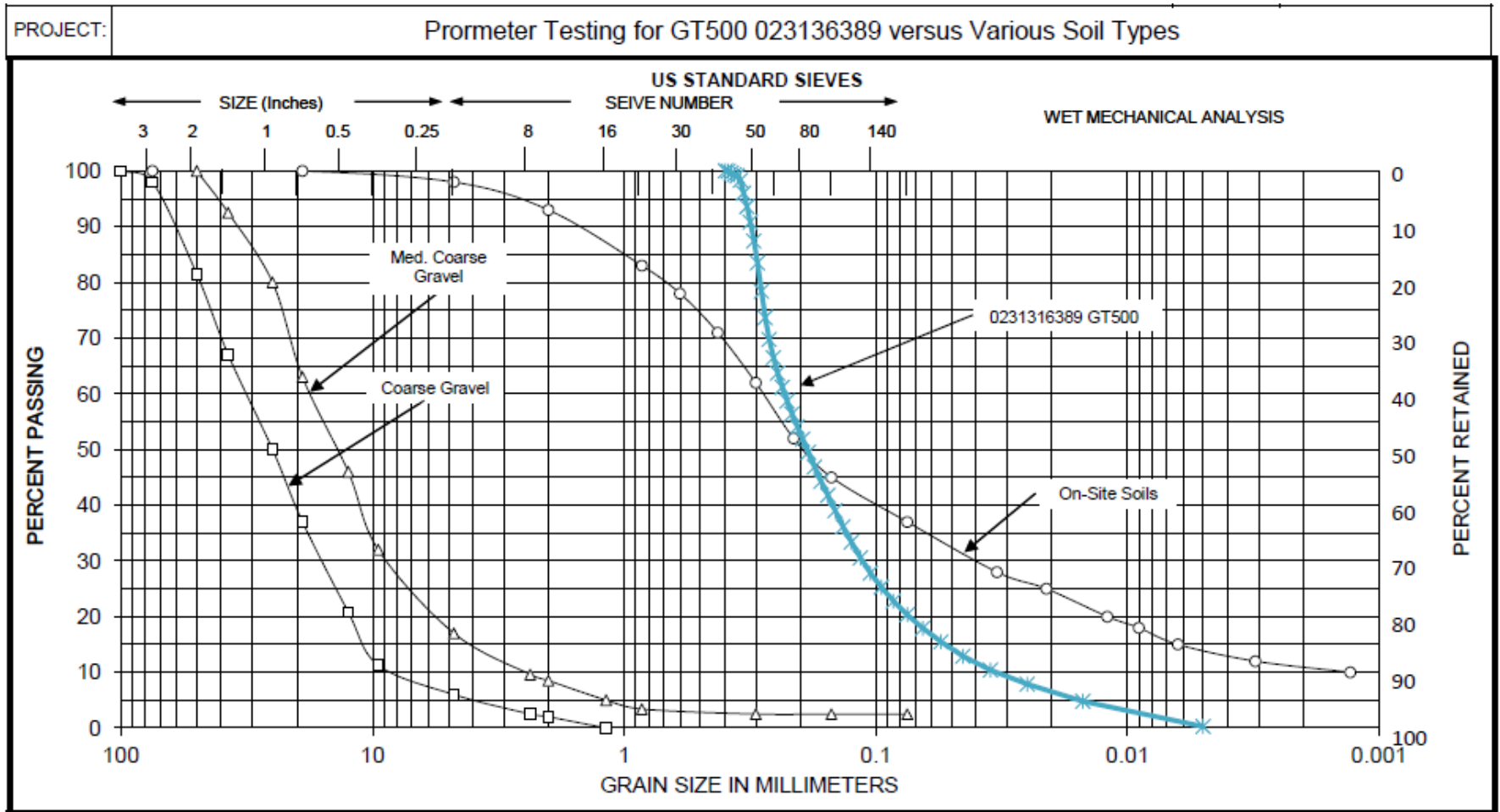


Pore Size Distribution result

Exact Measurement
Largest Opening
Smallest Opening
Average Distribution of all Openings
Dynamic Test

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Geosynthetic Properties

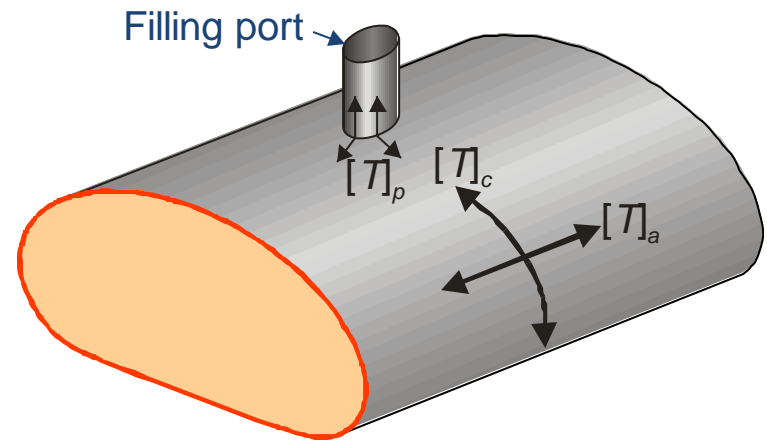


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Geosynthetic Properties

Internal design

- Typical sizes are available in a variety of circumferences.
- Tubes are constructed to achieve a specific design height.
- Innovative fabrication techniques to reduce stresses:
 - Variation of seam types
 - Circumferential vs. longitudinal seaming
 - Rigid mechanical ports vs. textile sleeves
 - Flat ends vs. tapered ends

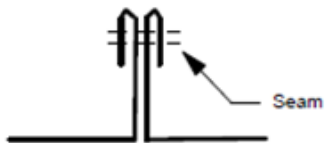


T_c – circumferential tension
 T_a – axial tension
 T_p – filling port tension

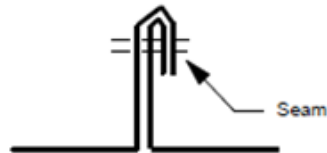
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Geosynthetic Properties

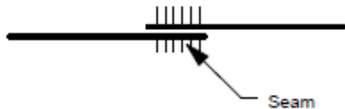
Butterfly Seam Detail



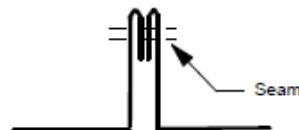
"J" Seam Detail



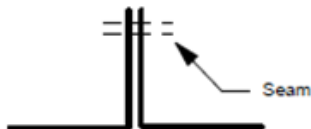
Lap Seam Detail



Inverted Butterfly Seam Detail



Prayer Seam Detail



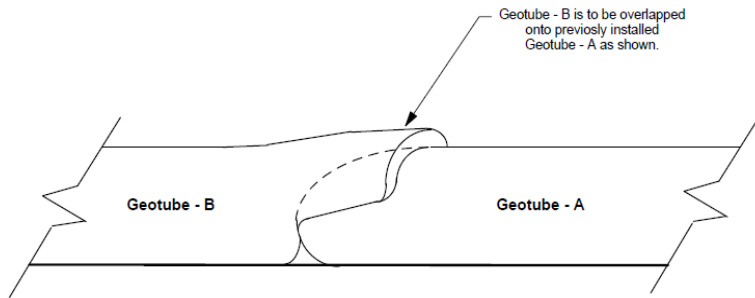
- Highest stress is concentrated at seams.
- Typical seam strengths are 50 – 65% of fabric strength.
- Innovative seaming techniques can achieve >80% of fabric strength, reducing risk of rupture.
- Higher seam strengths will increase safety factors for pumping heights.

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Geosynthetic Properties

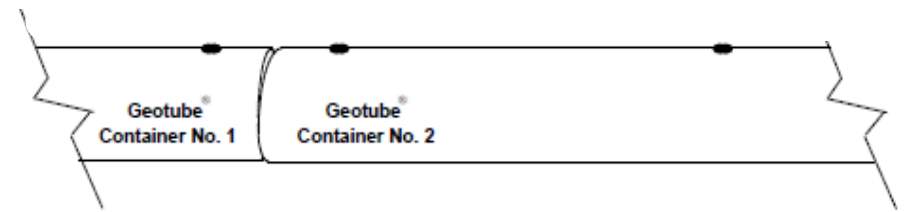
Tapered end junctions

Standard overlap of 10-ft



Flat end junctions

No overlap required

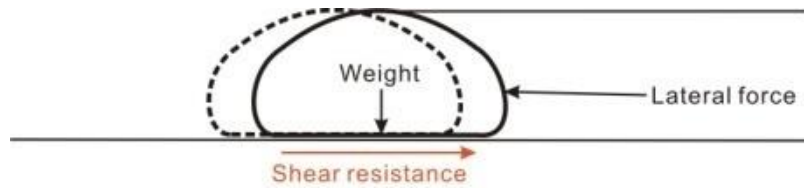
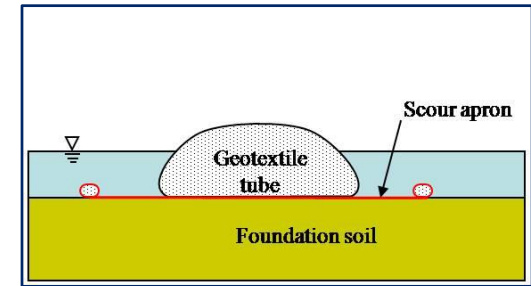


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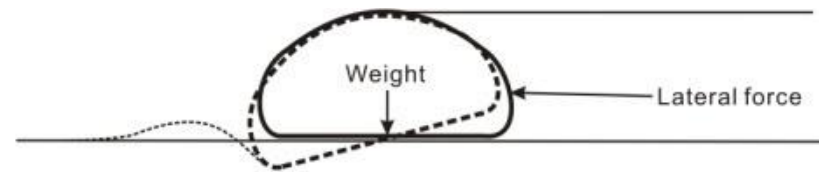
Geosynthetic Properties

External design

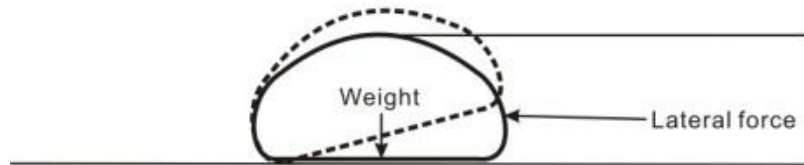
- Tube must resist wave attack.
- Tube must be geotechnically stable.



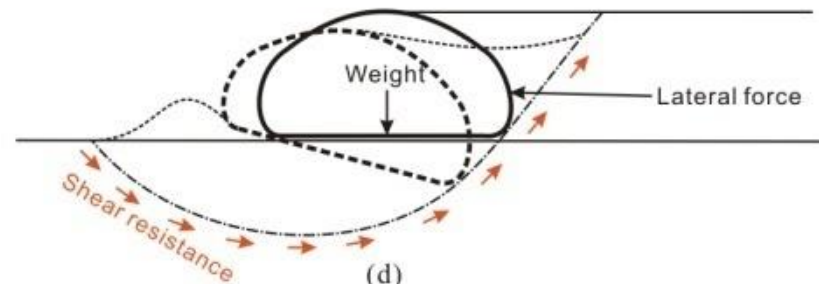
(a)



(b)



(c)



(d)

MSU Dredged Material Workshop

Geosynthetic Properties



- The objective of the scour apron is to protect the foundation of the Geotube[®] unit from erosion caused by currents or wave attack.
- For most applications, the scour apron should extend from the face of the Geotube[®] unit a minimum of 1 times the height of the unit.

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Geosynthetic Properties



In severe erosion conditions, the width of the apron may be extended or circumference of anchor tube increased.

MSU Dredged Material Workshop

Geosynthetic Properties



With unique conditions, the anchor tube can protect the entire perimeter of the scour apron.

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Geosynthetic Properties



Other geosynthetics can be incorporated into the design to provide additional reinforcement in less than suitable soil conditions.

Various Degradation Mechanisms

Mechanism	PE/PP	PET	PVC	EPDM	PS
ultraviolet	←———— major to all GSs only when exposed —————→				
oxidation	←———— concern to all GSs but to varying degrees —————→				
hydrolysis	←———— water is of nominal concern to all GSs except to PET —————→				
chemical	←———— concern over hydrocarbons to all GSs —————→				
biological	←———— no concern from bacteria or fungi —————→				
radioactive	←———— only concern with respect to high level waste —————→				
temperature	←———— heat accelerates all of above mechanisms —————→				

*Courtesy of Geosynthetic Institute webinar “GSI W8-LT Predictions of Exposed and Nonexposed Geosynthetics.

MSU Dredged Material Workshop

Geosynthetic Properties

Polypropylene is a derivative of olefin, which has excellent resistance to most acids and alkalis with exception of elevated temperature exposure to chlorosulfonic acid, concentrated nitric acid and certain oxidizing agents.

GENERAL PROPERTIES	
Average tenacity range of 4 - 7 grams per denier.	
Ultimate Elongation of 14 – 30%	
Specific Gravity is 0.90 – 0.91, polypropylene floats	
The degree of stiffness can be modified by additives and production techniques.	
Polypropylene is mildew and insect resistant	
Excellent resistance to most acids alkalis with the exception of chlorosulfonic acid and oxidizing agents.	
Generally good resistance to bleaches and solvents	
THERMAL PROPERTIES	
OPERATING TEMPERATURE	Maximum 180° F
SOFTENING TEMPERATURE	300° F - 310° F
MELTING TEMPERATURE	325° F - 335° F
SHRINKAGE	Shrinkage at boil, 3 – 9% Shrinkage at 250° F, 5 – 12.5%
BURNING CHARACTERISTICS	Melts: Burns slowly, curls and melts, shrinks rapidly in a flame. Smells: Faint smell of burning asphalt. After Burn: Hard, round, light tan

Thermal Oxidation Testing

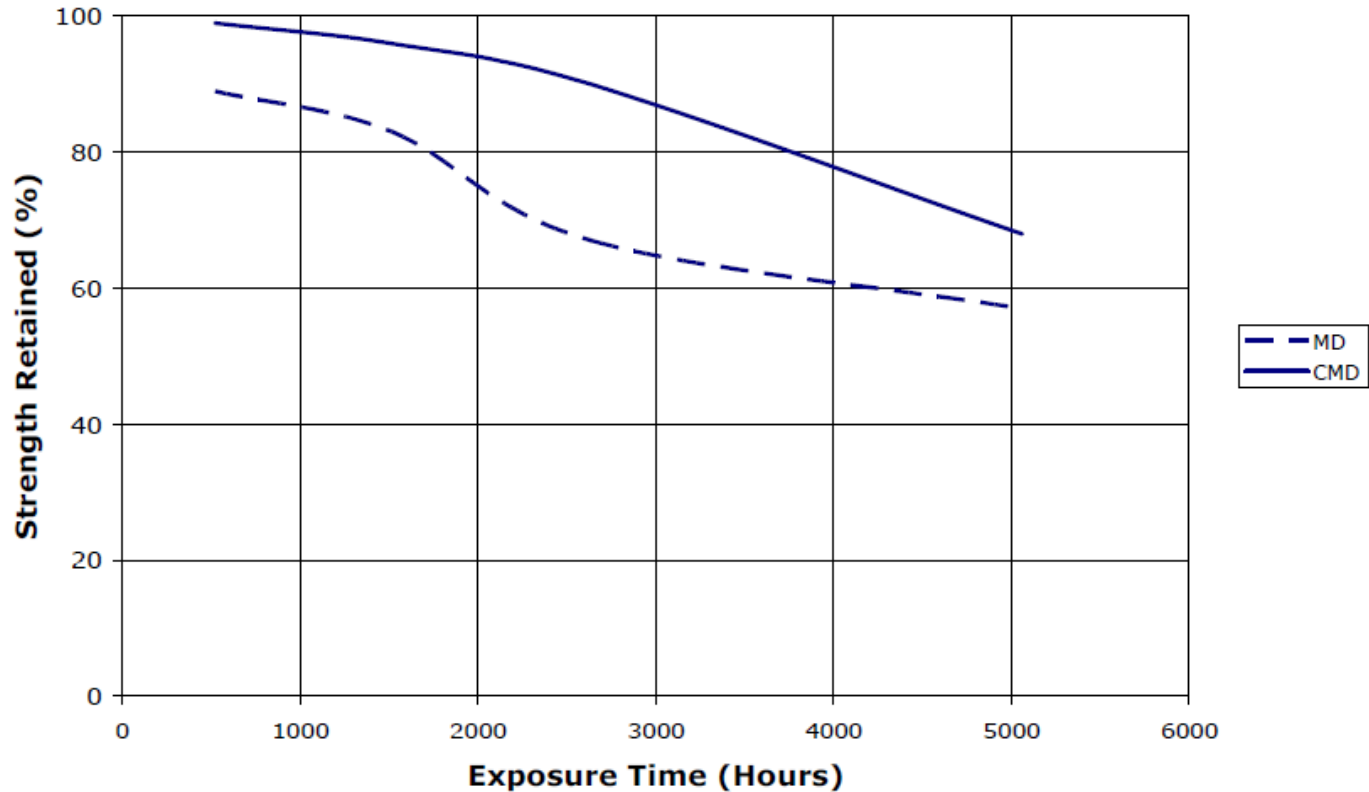
- The test determines leaching potential of additives into the water environment and no UV exposure is considered. Phase 1 is immersion in water at 90°C for 14 days. Phase 2 is oven testing for embrittleness at 150°C for 6 days.
- This test uses NEN5132 to predict long term exposure in a marine environment and classes fabric as:
 - Type A: normal life expectancy ~30 years
 - Type B: >30 years with respect to UV resistance
- Historical testing shows the thermo-oxidative resistance of TenCate yarns meets the requirements of Type B.

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Geosynthetic Properties



High UV Resistance Polypropylene Geotextile Degradation



Example of UV Degradation Strength Loss Over Time for Woven PP

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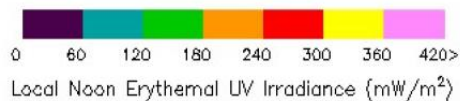
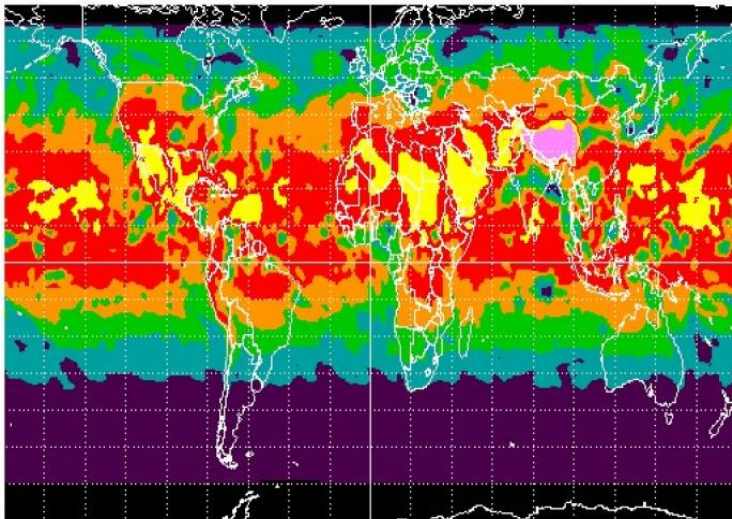
Geosynthetic Properties

- ASTM D4355 uses a xenon arc light source to provide UV spectrum wavelengths and also uses cycles of heat and moisture to simulate natural weathering cycles.
- ASTM D7238 utilizes condensation and a fluorescent UV light source (QUV) to simulate weathering cycles.
- While these test methods are accepted within the geosynthetics industry to be useful measures of UV durability, correlating them to real world exposure degradation rates is awkward and has been hit-or-miss at best.

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Geosynthetic Properties

Earth Probe TOMS Version 8 Local Noon Erythemal UV Irradiance on July 01, 2005

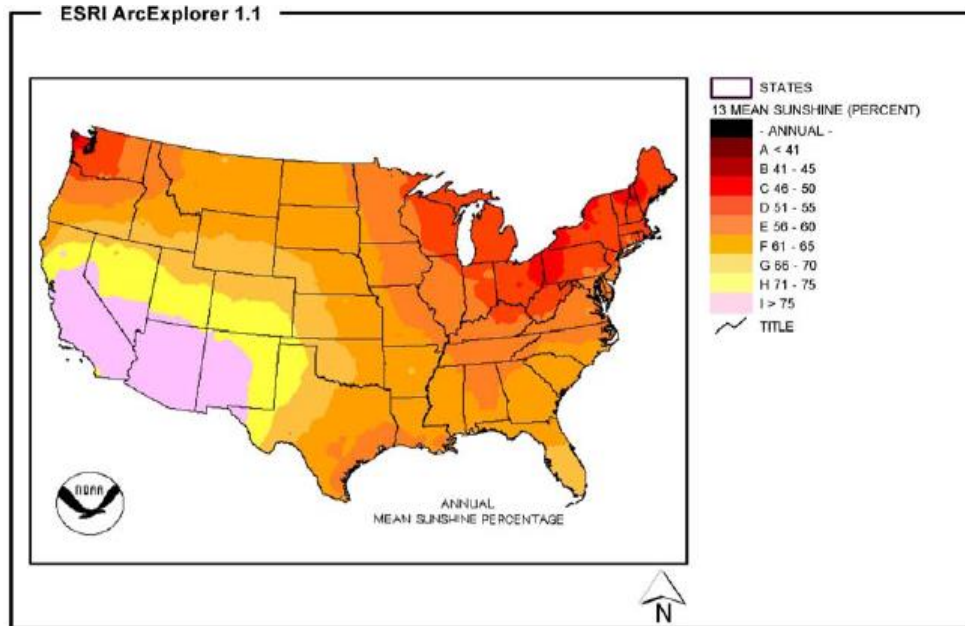


Goddard Space Flight Center

- Xenon arc light source 350 mW/m².
- QUV fluorescent UV light source 710 mW/m².
- Variables to consider include:
 - 1) Erythemal UV irradiance
 - 2) Diurnal sunlight variations

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Geosynthetic Properties



- Variables to consider include (cont):
 - 3) Mean sunshine percentage factoring cloud cover and rainfall.

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Geosynthetic Properties

Continental US City	Peak Erythemat UV Irradiance (mW/m ²)	Annual Mean Sunshine Normalized to 24 Hour Day (decimal)	Daily Average Solar Irradiance Level (decimal)	Annual Average Erythemat UV Irradiance (mW/m ²)	Equivalent Time of Exposure: 500 Hour ASTM D4355 (Years)	Equivalent Time of Exposure: 500 Hour ASTM D7238 (Years)
Atlanta, GA	300	0.34	0.24	213,701	0.8	1.7
Billings, MT	180	0.34	0.24	128,220	1.4	2.8
Chicago, IL	240	0.28	0.24	143,607	1.2	2.5
Hartford, CT	240	0.28	0.24	143,607	1.2	2.5
Orlando, FL	300	0.37	0.24	230,797	0.8	1.5
Phoenix, AZ	360	0.42	0.24	317,986	0.6	1.1
San Antonio, TX	360	0.34	0.24	256,441	0.7	1.4
San Diego, CA	300	0.39	0.24	247,893	0.7	1.4
Seattle, WA	180	0.20	0.24	76,932	2.3	4.6
Washington, D.C.	240	0.31	0.24	157,284	1.1	2.3
Wichita, KS	300	0.34	0.24	213,701	0.8	1.7

Equivalent Outdoor UV Irradiance Exposure for 500 hour Laboratory Testing for ASTM D4355 and D7238.

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Geosynthetic Properties



- A sand cover is the most traditional protection when the Geotube[®] structure is placed near the shoreline and is only subjected to occasional wave attack during storm events.
- If the sand cover is lost due to wave attack, it should be replaced as soon as possible.

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Geosynthetic Properties



- Rock is a typical material to cover the Geotube[®] structure if it is subject to extreme wave attack during storm activity.
- Before placing the rock, the Geotube[®] surface should be protected with a heavy weight non-woven geotextile.

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Geosynthetic Properties



- A protective fabric (shroud) cover will shield Geotube® containers from the sun's damaging UV rays.
- Composite systems offer increased benefits such as sediment entrapment.

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Geosynthetic Properties



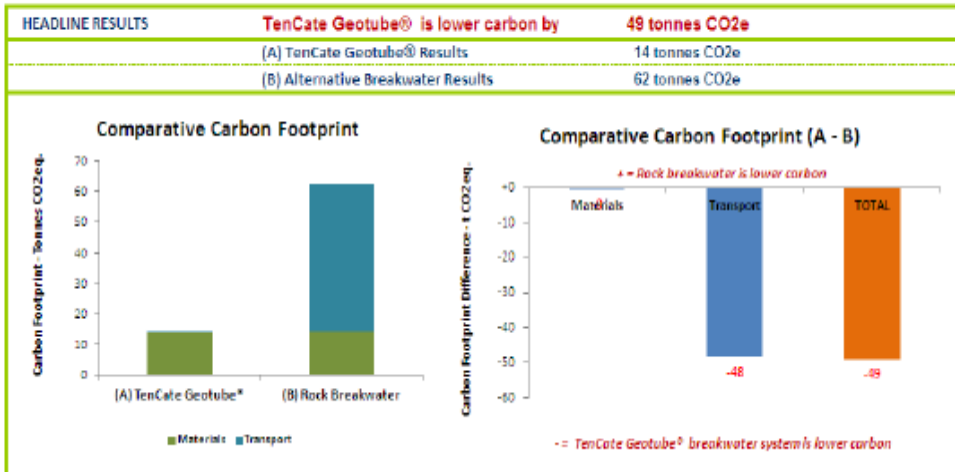
Polyurea spray on coatings are durable, attractive, and are available in many colors to match the surrounding environment.

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Sustainability

Breakwater Carbon Calculator Results

1. Summary Results - TenCate Geotube® System V Rock Breakwater



Geotube® Carbon Footprint Calculator:

- Comparison of Geotube® technology vs. traditional methods.
- Database was developed by Sustain, an independent environmental accounting agency.
- Carbon footprint methodology is in accordance with Publically Available Specification (PAS) 2050.

Geotube[®] Data needed:

- Tube dimensions for structure
- Scour protection
- Transportation
- Onsite or purchased sand
- Rock armor
- Sand cover layer

Marine Structure Data Needed:

- Type/weight of rock
- Transportation
- Sand cover
- Construction with concrete

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Marketplace Acceptance



Dredging is the most common method of filling tubes.

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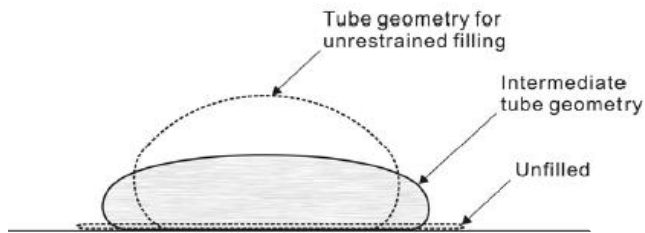
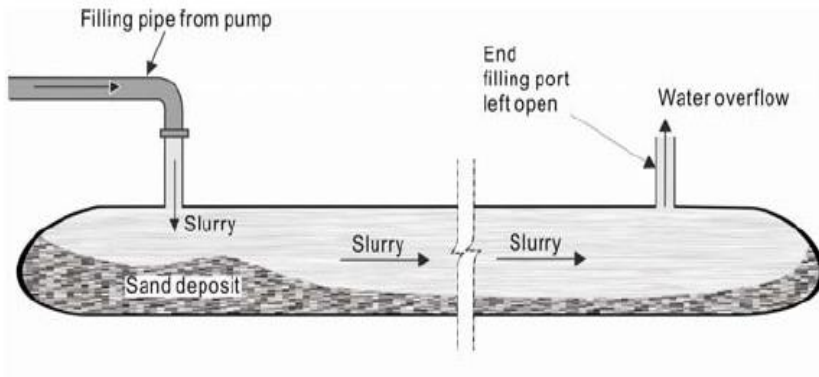
Marketplace Acceptance



Pumping methods can be modified to comply with local permits or site limitations using local or imported sand.

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Marketplace Acceptance

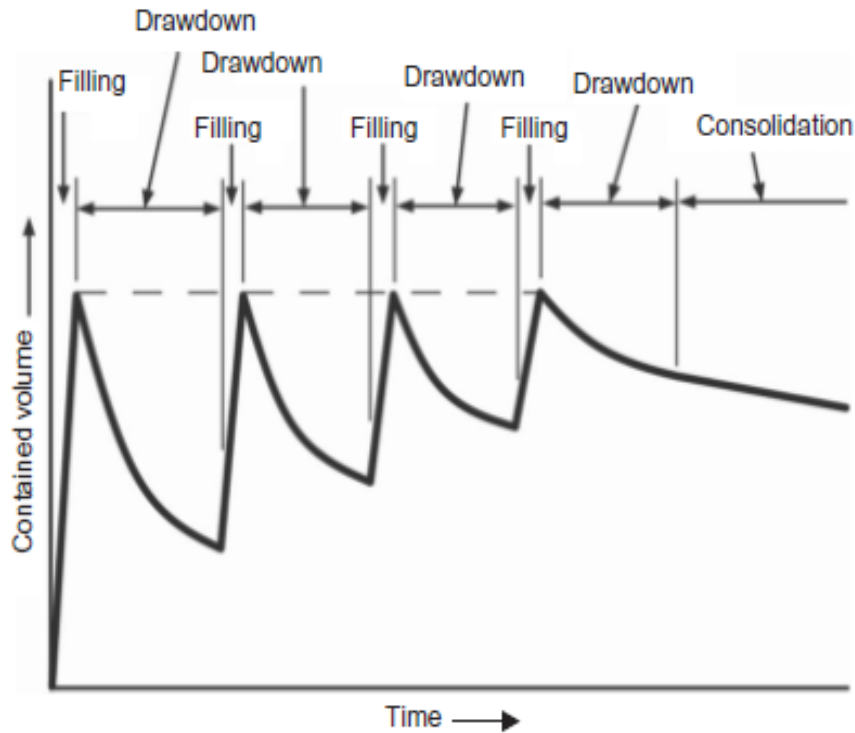


- A complex environment exists consisting of suspension, settling and settled zones within the structure; with the extent of these zones changing according to the nature of the dewatering phase and the time over which the dewatering process occurs.

Yee, T.W., Lawson, C. Modeling the Geotextile Tube Dewatering Process. Geosynthetics International, 19, No. 5. pp. 339 – 353.

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Marketplace Acceptance



Typical Geotube® Dewatering Process

- The dewatering process consists of multiple cycles of filling and drawdown to achieve a desired final volume reduction and solids concentration increase.

Yee, T.W., Lawson, C. Modeling the Geotextile Tube Dewatering Process. Geosynthetics International, 19, No. 5. pp. 339 – 353.

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Marketplace Acceptance



Unconditioned vs Conditioned

- The right chemistry is critical.
- This should be the first step of the process.
- Professional counsel is strongly recommended to enhance performance.



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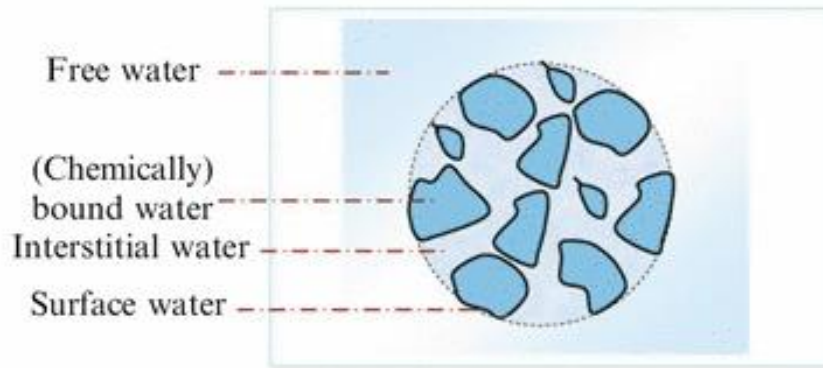


Fig 1 - Mahmoud, A., Olivier, J., Vaxelaire, J., Hoadley, A. (2012). Advances in Mechanical Dewatering of Wastewater Sludge Treatment. pp. 253 – 303.



Proper chemical conditioning improves:

- Rate of dewatering.
- Retention of suspended solids & contaminants .
- Clarity of effluent.
- Percentage of dry solids.
- Overall utility of the Geotube[®] container.

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Marketplace Acceptance



Cone Test



Rapid Dewatering Test (RDT)



Hanging Bag Test



Geotube® Dewatering Test (GDT)

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Marketplace Acceptance

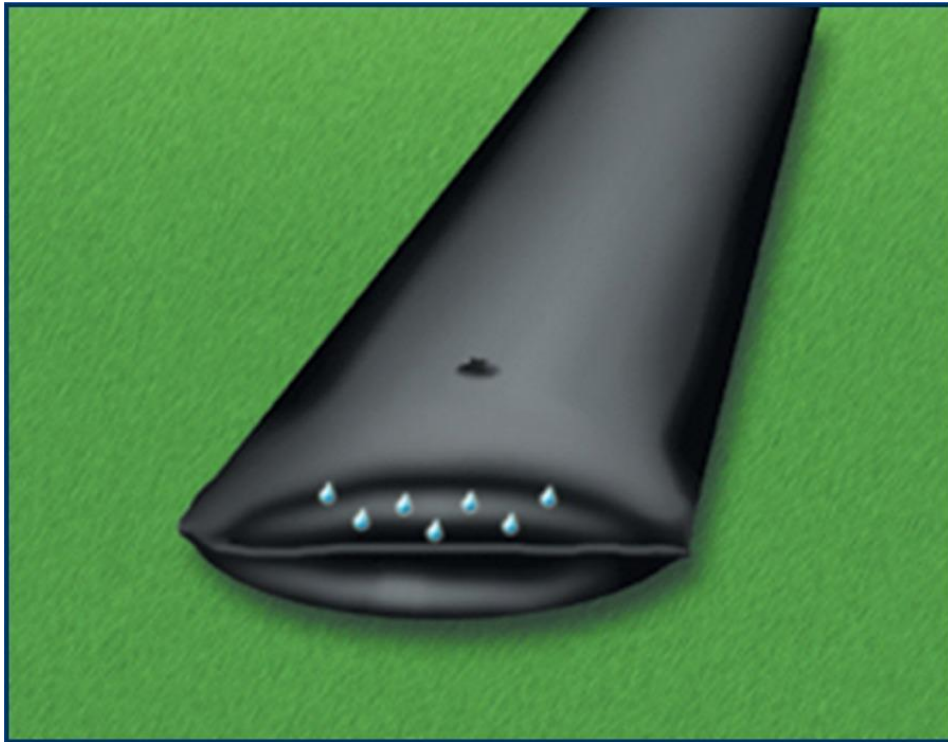


Advantages of GDT:

- Visualization of dewatering process.
- Analyze clarity of filtrate.
- Predict achievable percent solids of dewatered cake over time.
- Values obtained from GDT are used in development of project.

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Marketplace Acceptance



Wastewater residuals are captured, liquid escapes.
Filling & dewatering process is repeated.

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Marketplace Acceptance



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Marketplace Acceptance



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Marketplace Acceptance



Mechanical to hydraulic filling methods

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Marketplace Acceptance



Positive Displacement Pumps

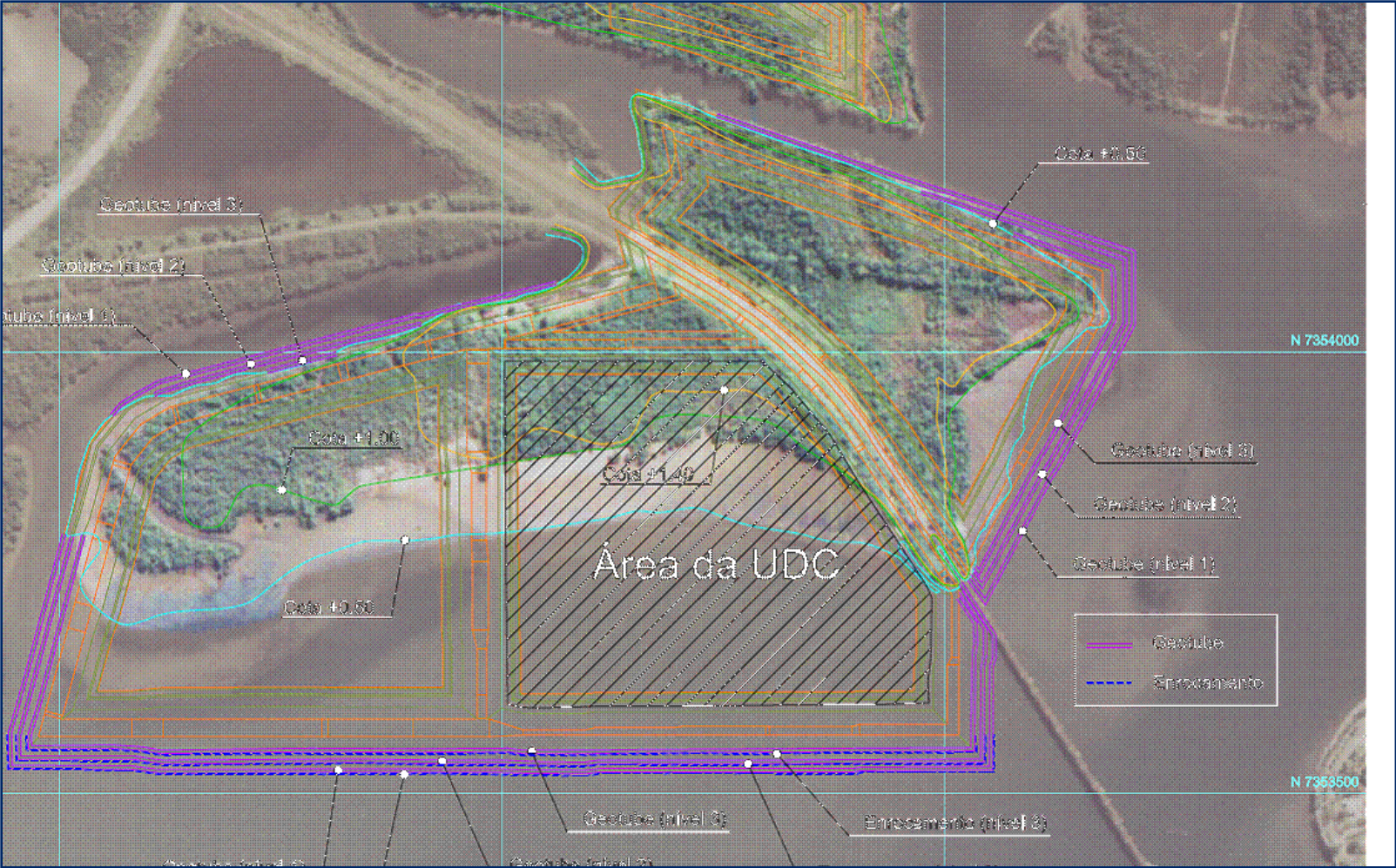
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Implications for Dredged Materials

- Over 600 miles of Geotube[®] containers produced for hydraulic and marine structures around the world which have contained several million cubic yards of dredged material.
- Dredging technology has advanced over time and geotextile tube technology has evolved into dewatering applications. Over 2,000 dewatering projects have been installed globally.
- Combining these technologies can offer opportunities to dredge locally available soils to construct geosynthetic containment structures.

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Port of Santos, Brazil



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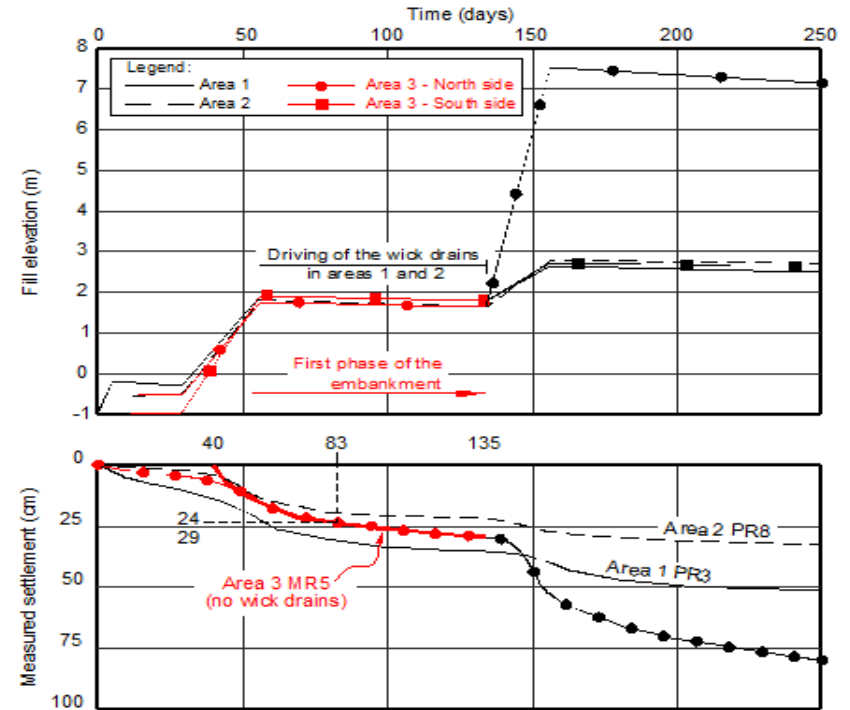
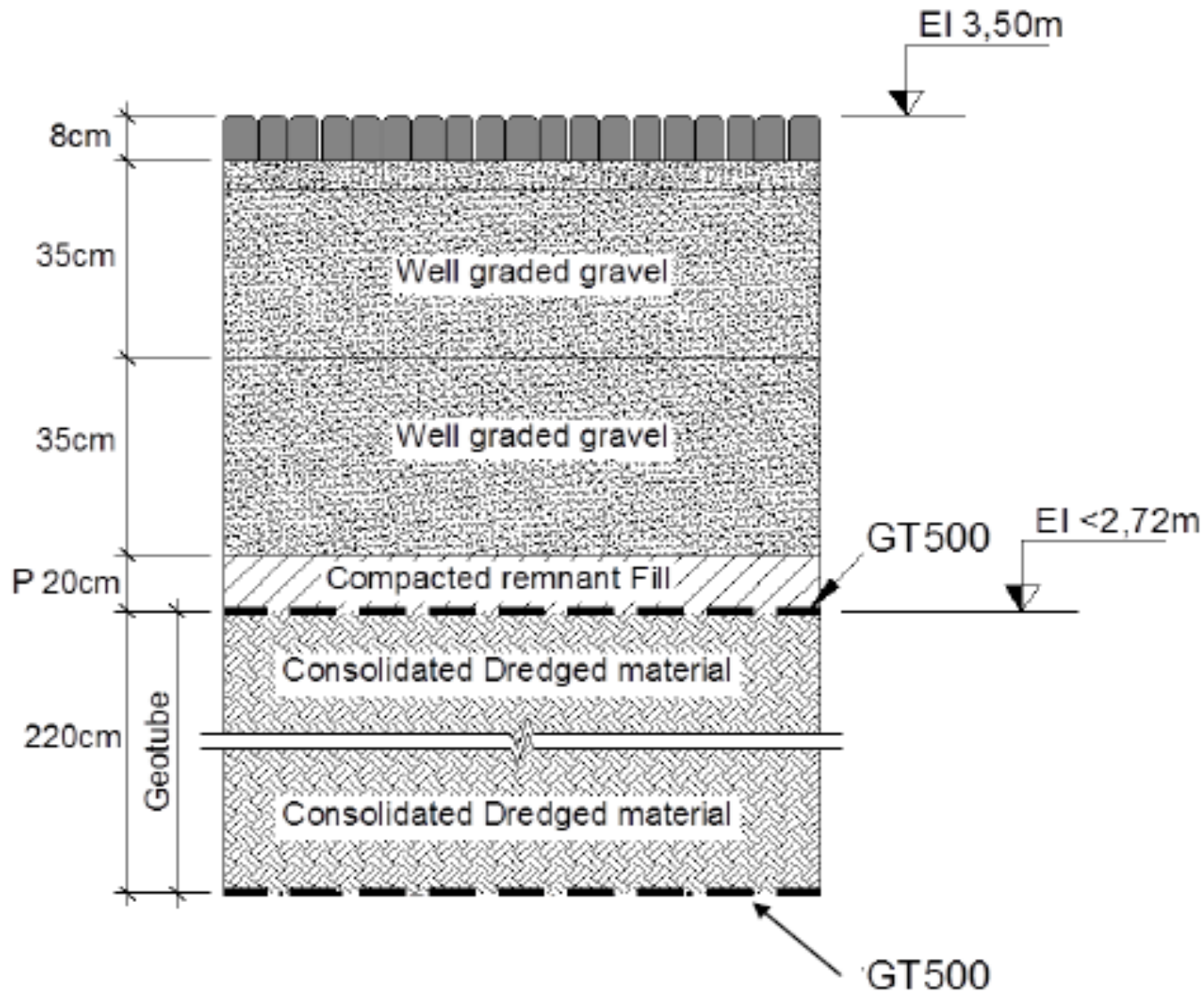


Figure 1

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Port of Santos, Brazil



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Port of Santos, Brazil



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Zutphen, Netherlands



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Zutphen, Netherlands



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Zutphen, Netherlands



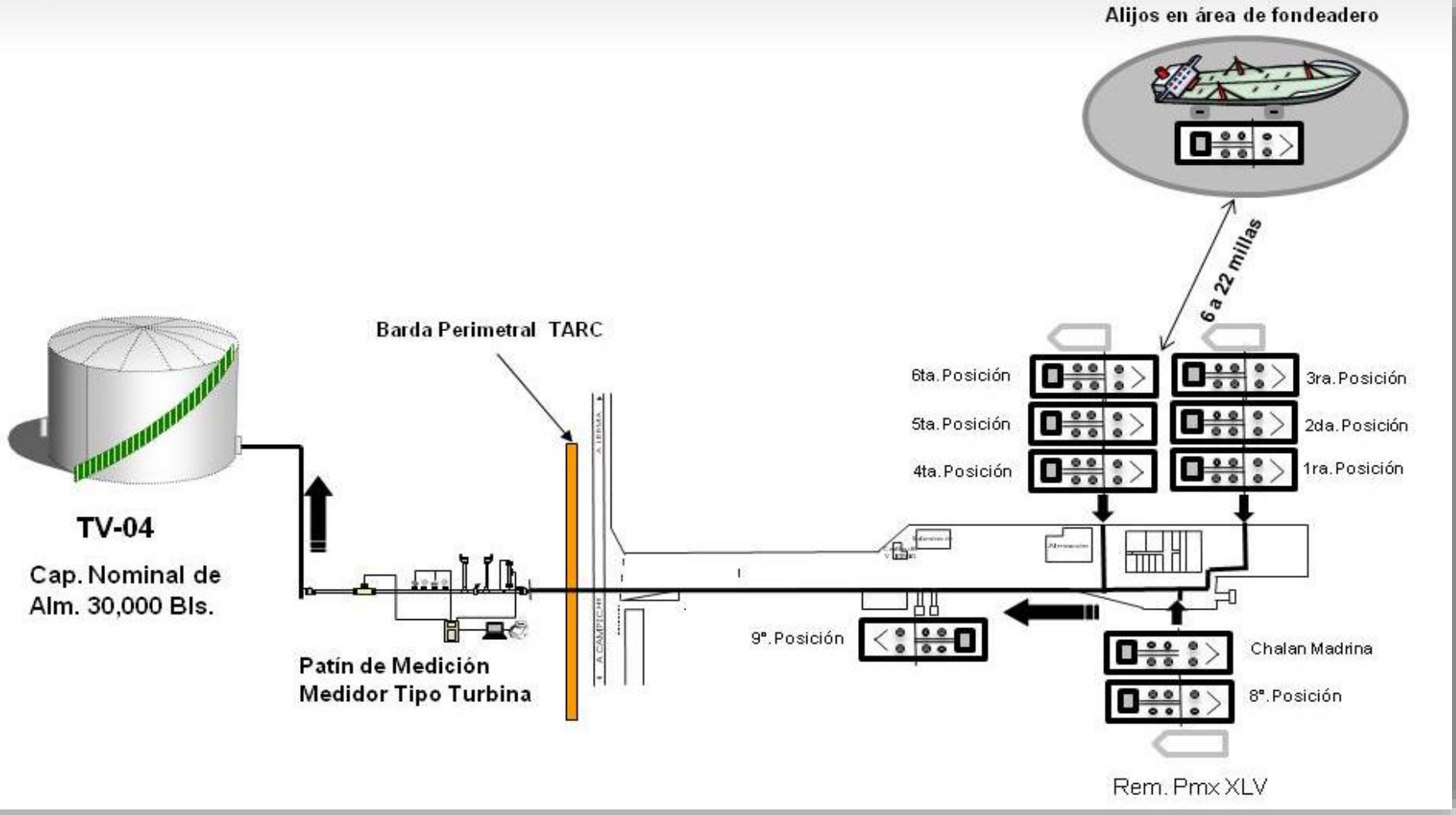
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Campeche, Mexico

ROMP Lerma, Camp.

TAR Campeche



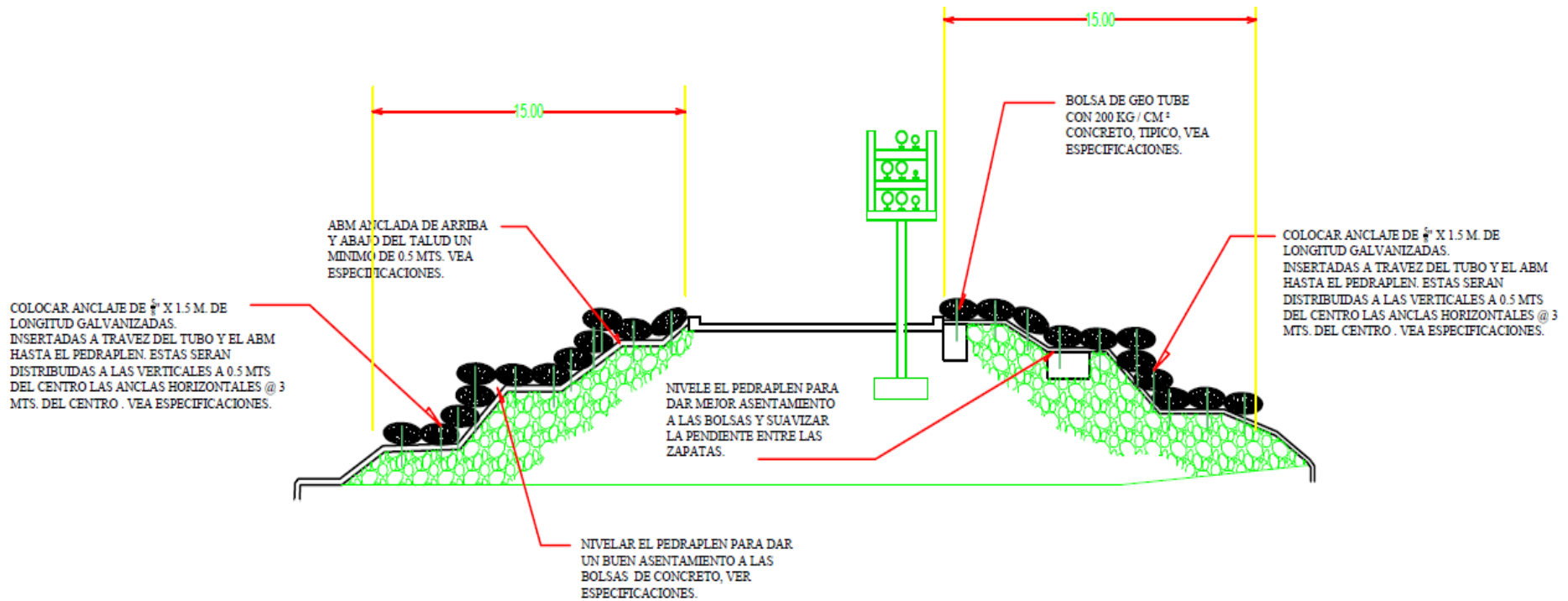
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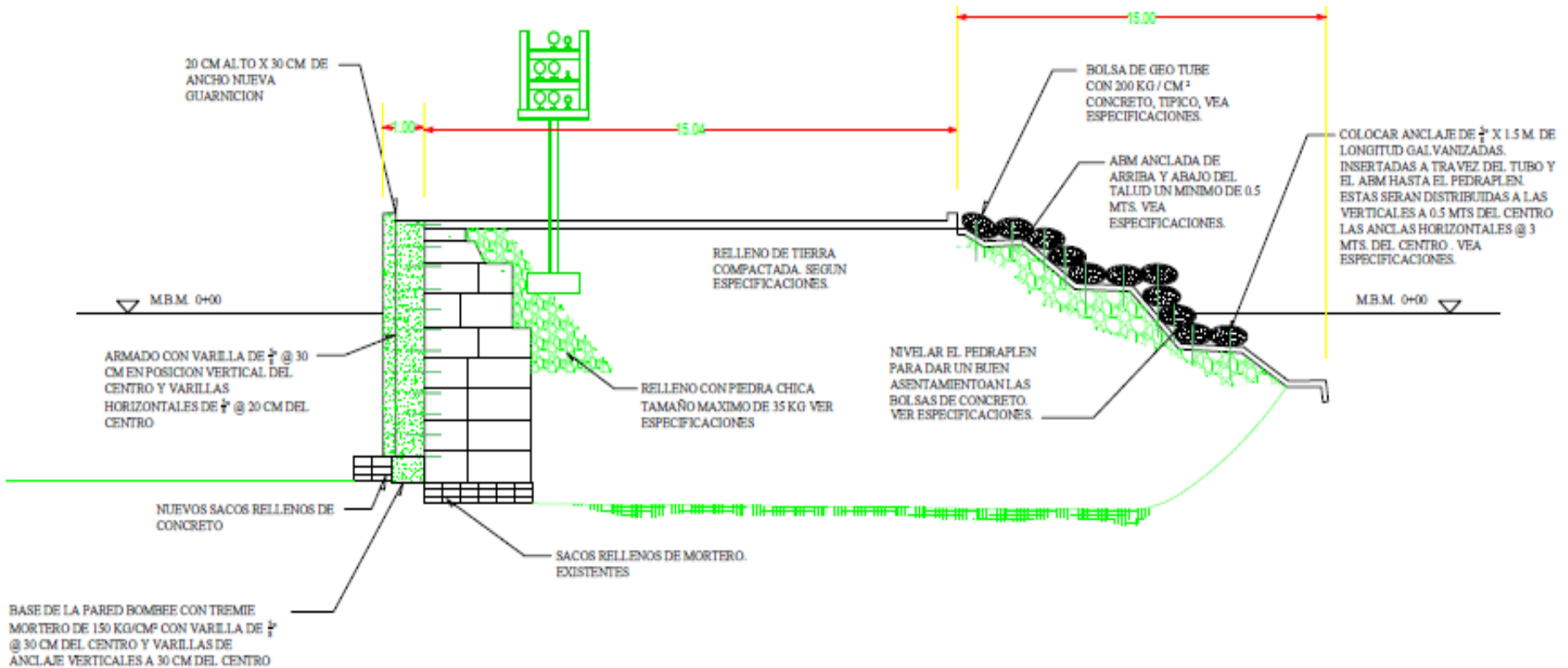
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Campeche, Mexico

	CLASSIFICATION	CHARACTERISTICS	APPLICATIONS
TYPE I	General purpose	Fairly high C ₃ S content for good early strength development	General construction, most buildings, bridges, pavements, precast units, etc.
TYPE II	Moderate sulfate resistance	Low C ₃ A content (<8%)	Structures exposed to soil or water containing sulfate ions.
TYPE III	High early strength	Ground more finely, may have slightly more C ₃ S	Rapid construction, cold weather concreting.
TYPE IV	Low heat of hydration (slow reacting)	Low content of C ₃ S (<50%) and C ₃ A	Massive structures such as dams. Now rare.
TYPE V	High sulfate resistance	Very low C₃A content (<5%)	Structures exposed to high levels of sulfate ions.
WHITE	White color	No C ₄ AF, low MgO	Decorative (otherwise has properties similar to Type I).

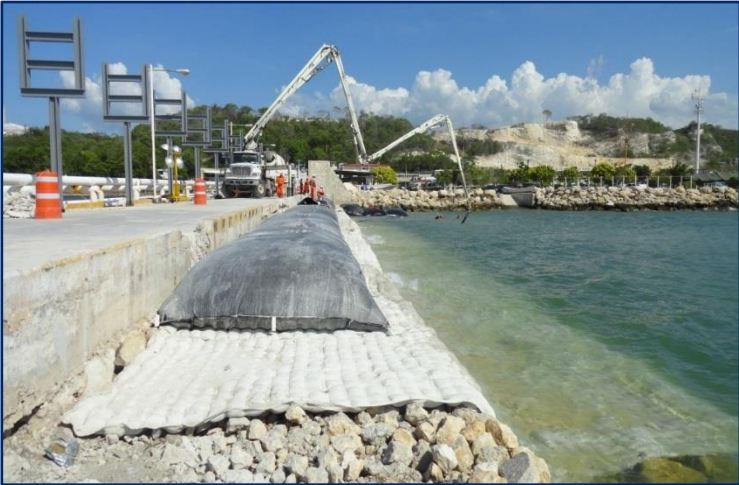
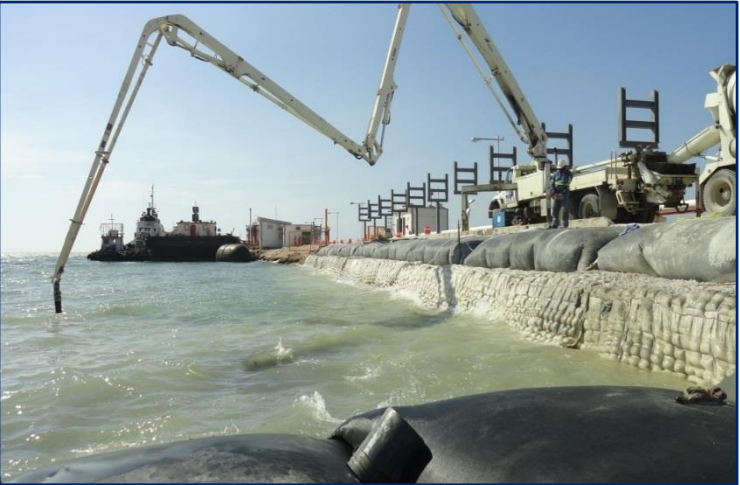
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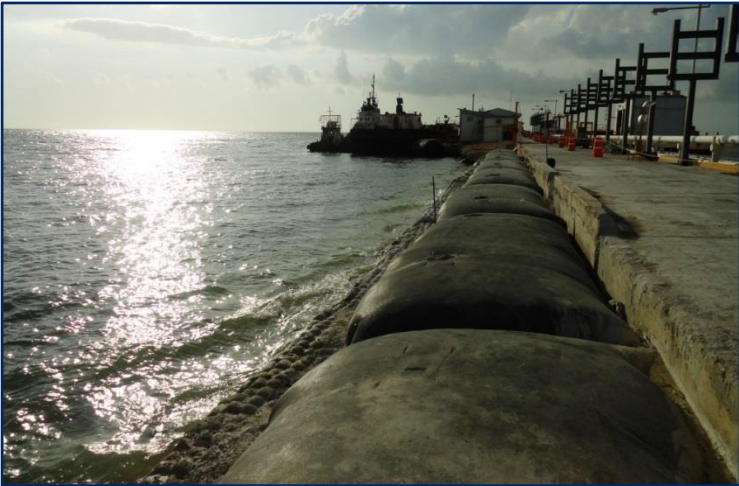
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THE SOLUTION - EXECUTION

Campeche, Mexico



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Campeche, Mexico



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Summary

- Geosynthetics are available in various forms as containment structures for temporary and long term design needs considered dredged material management. These solutions not only work with sand, but with local soils which may be considered less than suitable.
- Traditional systems can be compared against geosynthetic alternatives to evaluate environmental stewardship and sustainability.
- Geosynthetic solutions can provide opportunities to beneficially use dredged materials to potentially eliminate need to import construction materials.
- Case studies, technical papers, and continuing research demonstrate the viability of using high moisture content soils in geosynthetic structures.

Questions & Comments

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Engineering Properties of Stabilized Dredged Soils with Comparisons of ASTM C150 Type I Cement to ASTM C595/1157 PLC Cement

May 24, 2016, Starkville, MS

Presenter:

Isaac L. Howard, PhD, PE

Materials and Construction Industries Chair

Civil and Environmental Engineering Dept.

Mississippi State University

662-325-7193, ilhoward@cee.msstate.edu

Sponsor Report

- Some of the content in this presentation can also be found in the NCITEC report below.
 - Vahedifard, F., Howard, I.L., Bazne, M., Smith, B.T., Barksdale, M.A. (2015). *Sustainably Enhancing Intermodal Freight Operation of Ports using Geotextile Tubes*. Report NCITEC 2013-05, National Center for Intermodal Transportation for Economic Competitiveness – US Department of Transportation, pp. 122.
 - http://www.cee.msstate.edu/publications/2015_NCITEC_2013-05_Dredged_Soil-Geotextile_Tubes.pdf

Dredged Soil

- You could just about pick anything you want, and somebody dredges it
 - Clean beach or river sand
 - Contaminated sediment
 - Sapropel
 - Silt
 - Very high moisture content fine grained soil with varying amounts of clay and organic matter
 - Other....
- Some dredged materials don't need any of the content presented today, some are circumstance dependent, but some almost always need something
- Dredging & subsequent handling is ongoing challenge

Contaminated Sediments

(Not specifically addressed today, but cement is viable method in some cases)

- One reference in sponsor report stated there are over a billion yd^3 of contaminated sediments in rivers, lakes, and oceans
- The sponsor report has a section of literature review showing successful handling of some types of contaminated sediments with portland cement stabilization
- Calcium sulfoaluminate (CSA) cements can be good for handling contaminants, but aren't really part of today's presentation

Terminology

(Presentation deals with dredged soil in these categories that is fine grained and may or may not be contaminated)

- Very High Moisture Soil (VHMS) – soil at or above it's liquid limit
- Cemented (C) VHMS (C-VHMS) – VHMS dosed with 5% or more cement on a slurry mass (soil plus water) basis
- Lightly Cemented [LC] VHMS (LC-VHMS) – VHMS dosed with 5% or less cement on a slurry mass basis
- Ordinary Portland Cement (OPC) – ASTM C150
- Portland-Limestone Cement (PLC) – ASTM C595/1157

Overall C-VHMS and LC-VHMS Content Within CMRC

- CMRC has published several documents on these subjects that are not covered today in any detail, though they might be useful for attendees in future works.
- A list of citations follows on the next two slides, where most or all of the content in several of these papers is not covered today.
- A fair amount of today's content has not been published, but work is underway to get this work published in citable and archived form.

Journal Articles

1. Carruth, W.D., Howard, I.L. (2013). "Use of Portland Cement and Polymer Fibers to Stabilize Very High Moisture Content Fine-Grained Soils," *Advances in Civil Engineering Materials*, 2(1), 1-24.
2. Howard, I.L., Carruth, W.D. (2014). "Dewatering and Stabilizing Fine-Grained Soils with Very High Moisture Content," *Advances in Civil Engineering Materials*, 3(1), 220-237.
3. Howard, I.L., Carruth, W.D. (2015). "Chemical Stabilization of VHMS for Disaster Recovery Applications," *Journal of Materials in Civil Engineering*, 27(7), 04014200.
4. Howard, I.L., Carruth, W.D., Cost, V.T. (2015). "Improving Early Age Strength of Very High Moisture Content Fine Grained Soil via Specialty Ground Portland Cement," *Advances in Civil Engineering Materials*, 4(1), 218-236.
5. Vahedifard, F., Howard, I.L., Badran, W.H., Carruth, W.D., Hamlehdari, M., Jordan, B.D. (Print Year Forthcoming). "Strength Indices of High-moisture Soils using Handheld Gages," *Proceedings of the Institution of Civil Engineers-Ground Improvement*, Ahead of Print, Published Online October 30, 2015, doi: 10.1680/jgrim.14.00033.

Conference Proceedings

1. Carruth, W.D., Howard, I.L. (2011). "Evaluation of Unconfined Compression Area Correction Methods for Cementitious and Fiber Stabilized Fine Grained Soils," *Proc. of Geo-Frontiers 2011 (GSP 211)*, Mar 13-16, Dallas, TX, pp. 2564-2573.
2. Howard, I.L., Badran, W.H. (2011). "Comparison of Hand Held Gage and Unconfined Compression Results in Low Strength Cementitious Stabilized Materials," *Proc. of Geo-Frontiers 2011 (GSP 211)*, Mar 13-16, Dallas, TX, pp. 2574-2583.
3. Sullivan, W.G., Cost, T., Howard, I.L. (2012). "Measurement of Cementitiously Stabilized Soil Slurry Thermal Profiles," *Proc. of GeoCongress 2012 (GSP 225)*, Mar 25-29, Oakland, CA, pp. 958-967.
4. Howard, I.L., Trainer, E, Yee, T.W. (2012). "Alternative Geotextile Tube Fill Materials for Marine Applications," *Proc. of GeoCongress 2012 (GSP 225)*, Mar 25-29, Oakland, CA, pp. 3891-3900.
5. Howard, I.L., Cost, T. (2014). "Curing Temperature Effects on Soils Stabilized With Portland Cement Having Different Sulfate Contents," *Proc. of GeoCongress 2014 (GSP 234)*, Feb 23-26, Atlanta, GA, pp. 2159-2168.
6. Carruth, W.D., Howard, I.L., Sullivan, W.G. (2014). "Effects of Brackish, Salt, and Fresh Water on Very High Moisture Content Cement Stabilized Fine Grained Soil," *Proc. of GeoCongress 2014 (GSP 234)*, Feb 23-26, Atlanta, GA, pp. 2169-2178.
7. Sullivan, W.G., Howard, I.L., Carruth, W.D. (2014). "Effects of Soil Processing on Cementitiously Stabilized Soil Slurries," *Proc. of GeoCongress 2014 (GSP 234)*, Feb 23-26, Atlanta, GA, pp. 2179-2188.
8. Bazne, M.O.A., Vahedifard, F., Howard, I.L. (2015). "Beneficial Reuse of Fine Grained Soils for Port, River, and Shoreline Applications," *Proc. of the International Foundations Congress and Equipment Expo 2015 (GSP 256)*, Mar 17-21, San Antonio, TX, pp. 2717-2727.

Dredged Soil Properties

- The work presented interfaces with other practices that are fairly common, at least in some sectors of industry
 - Dewatering with polymers
 - Pumping
 - Rapid strength estimation
 - Vegetation establishment
- Cement hydration and soil interaction is presented first, followed by general properties of cement stabilized dredged soil, then by comparisons of OPC to PLC

Portland Cement

Oxide	Portland Cement	Class C Fly Ash	Class F Fly Ash
CaO	65	23	5
Fe₂O₃	5	20	19
Al₂O₃	3	5	17
SiO₂	20	37	50

Values shown are representative, but do vary with time and source

-- Hydration reactions are complicated-information shown is simplified to highlight key processes, especially in relation to interaction with other materials

Portland Cement Hydration

- $\text{CaO} + \text{Fe}_2\text{O}_3 + \text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{SO}_3 \Rightarrow \text{C}_3\text{S} + \text{C}_2\text{S} + \text{C}_3\text{A} + \text{C}_4\text{AF}$
[Portland Cement] Reaction is Exothermic
- **Portland Cement + $\text{H}_2\text{O} \Rightarrow \text{CSH} + \text{COH}$**
 - i.e. two families of products are of most interest
 - 1. CSH = calcium silicate hydrate, a cementitious gel, a desirable product (or group of products) with durable bonds
 - 2. COH = calcium hydroxide (hydrated lime), undesirable product (or group of products), water soluble (could be viewed as frelime that is needed for other materials for pozzolanic reactions)

Lime Treatment of Soil

- We aren't covering lime as sold separately, but one should understand the mechanism of the COH family of products and that of hydrated or quicklime are not too different

Lime:

Take CaCO_3 (e.g. limestone) and add heat $\Rightarrow \text{CaO} + \text{CO}_2$

CaO , or calcium oxide is referred to as quicklime

$\text{CaO} + \text{H}_2\text{O} \Rightarrow \text{Ca}(\text{OH})_2$, or calcium hydroxide; aka. hydrated lime

The term "lime" can refer to CaO or $\text{Ca}(\text{OH})_2$

Pozzolans (e.g. fly ash)

- Provide silica to react with lime (COH) and H₂O to form non-soluble calcium silicate hydrates (CSH).
- This same concept may happen in soil depending on the characteristics and reactivity of their mineralogy.
- If cement content is not reduced (as is typical when fly ash is used in concrete), these pozzolanic reactions don't replace hydraulic reactions that lead to earlier strength gain. In other words, constructability should not be affected when using dredged soil stabilized with PLC if pozzolanic reactions are contributing more to longer term strength gain.

Pozzolanic Reactions

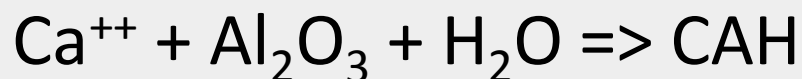
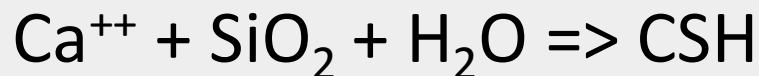
Hydrated Lime + Silica \Rightarrow CSH

Hydrated Lime + Alumina \Rightarrow CAH

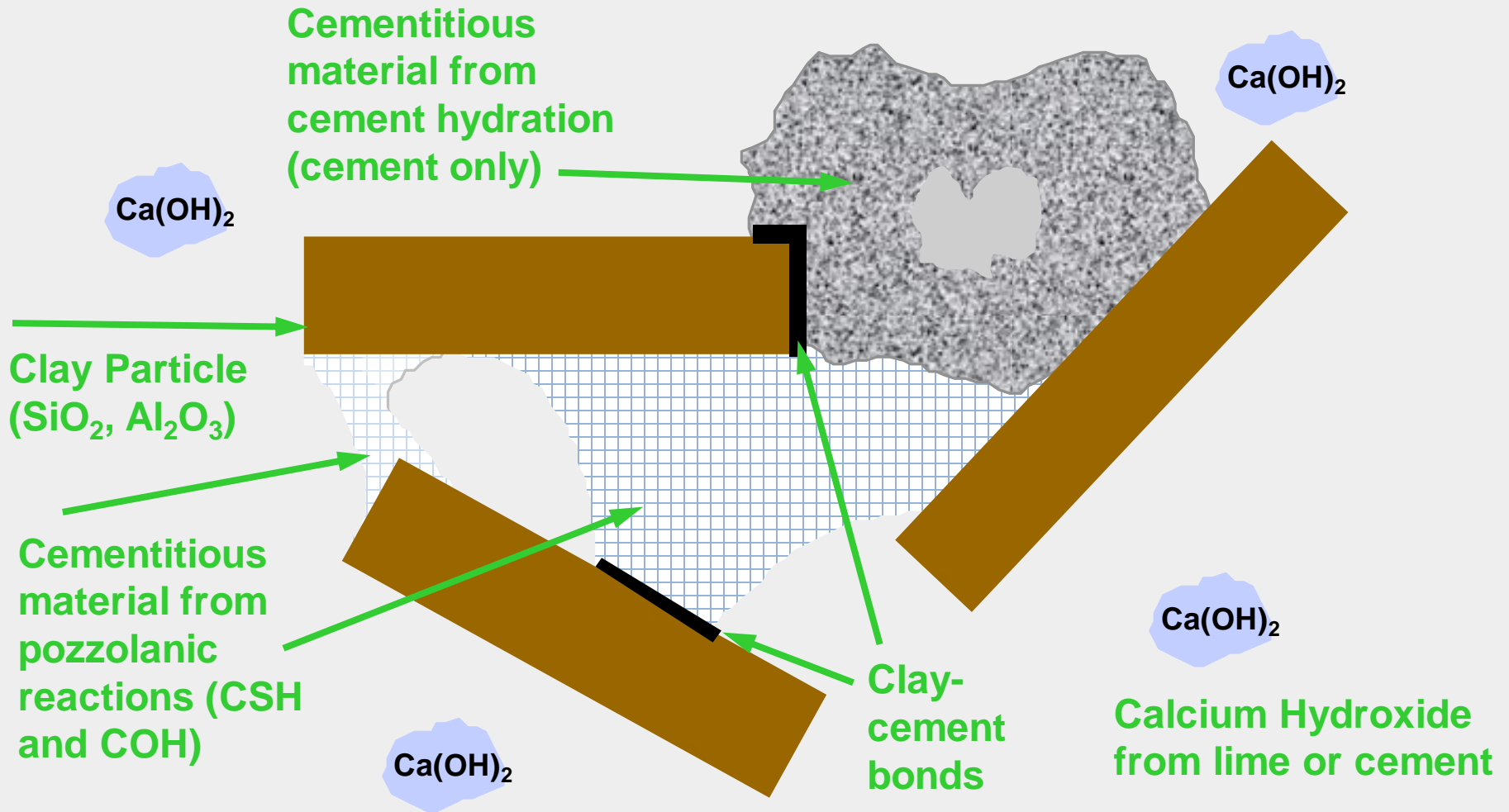
- Hydrated Lime can be supplied by lime or cement
- Silica and/or alumina can be supplied by clay minerals under proper conditions (note not all soil has or can provide silica or alumina)
- CAH (Calcium-aluminate-hydrate) and CSH are desired cementing products

Pozzolanic Reaction (more detail)

- A high pH environment (>12 and ideally 12.4) occurs when water is added to CaO. Some references state a pH above 10.5, but above 12 is more common. A pH of 12.4 is that of saturated lime water.
- Clay's composition is usually different than its parent materials (e.g. quartz, SiO₂, or calcite CaSO₃) and are classified as secondary minerals (usually leads to more reactivity potential of the silica and alumina)
- When pH is >12, some clay particles break down and SiO₂ and Al₂O₃ become soluble and are released and can then react with calcium

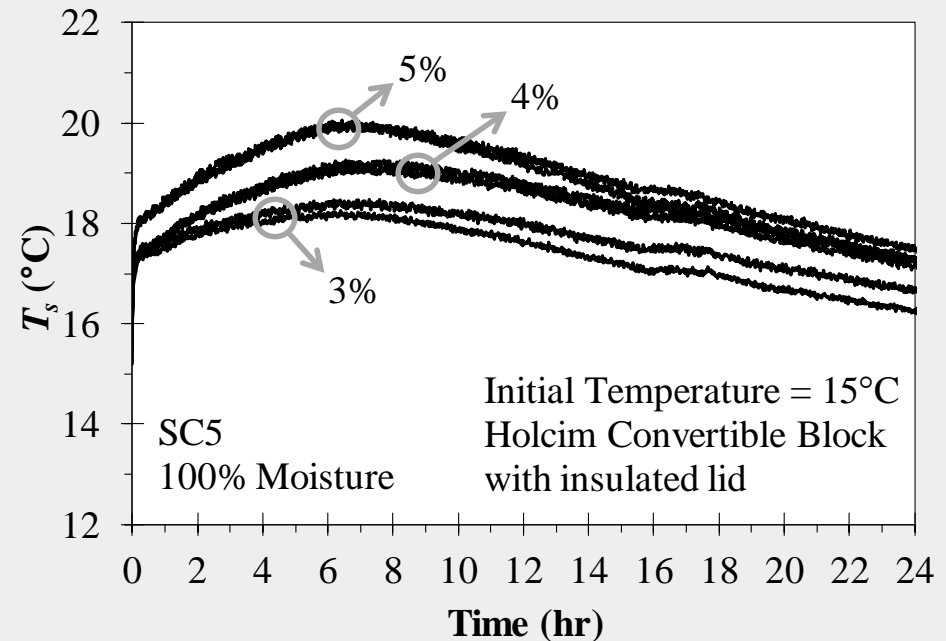
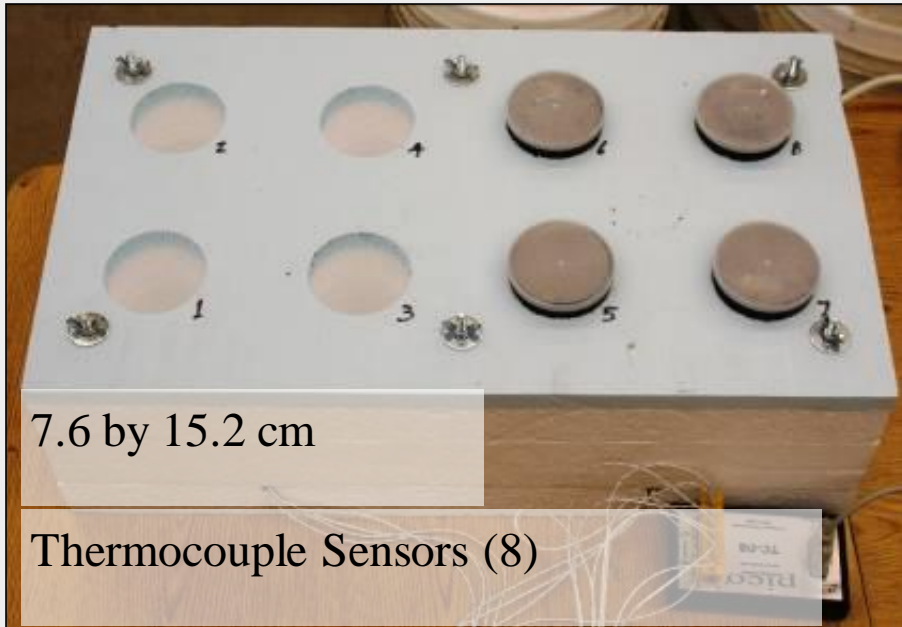


Pozzolan Reaction in Soil



There are several soil properties that influence lime reactivity with soil - some soils inhibit pozzolanic reactions.

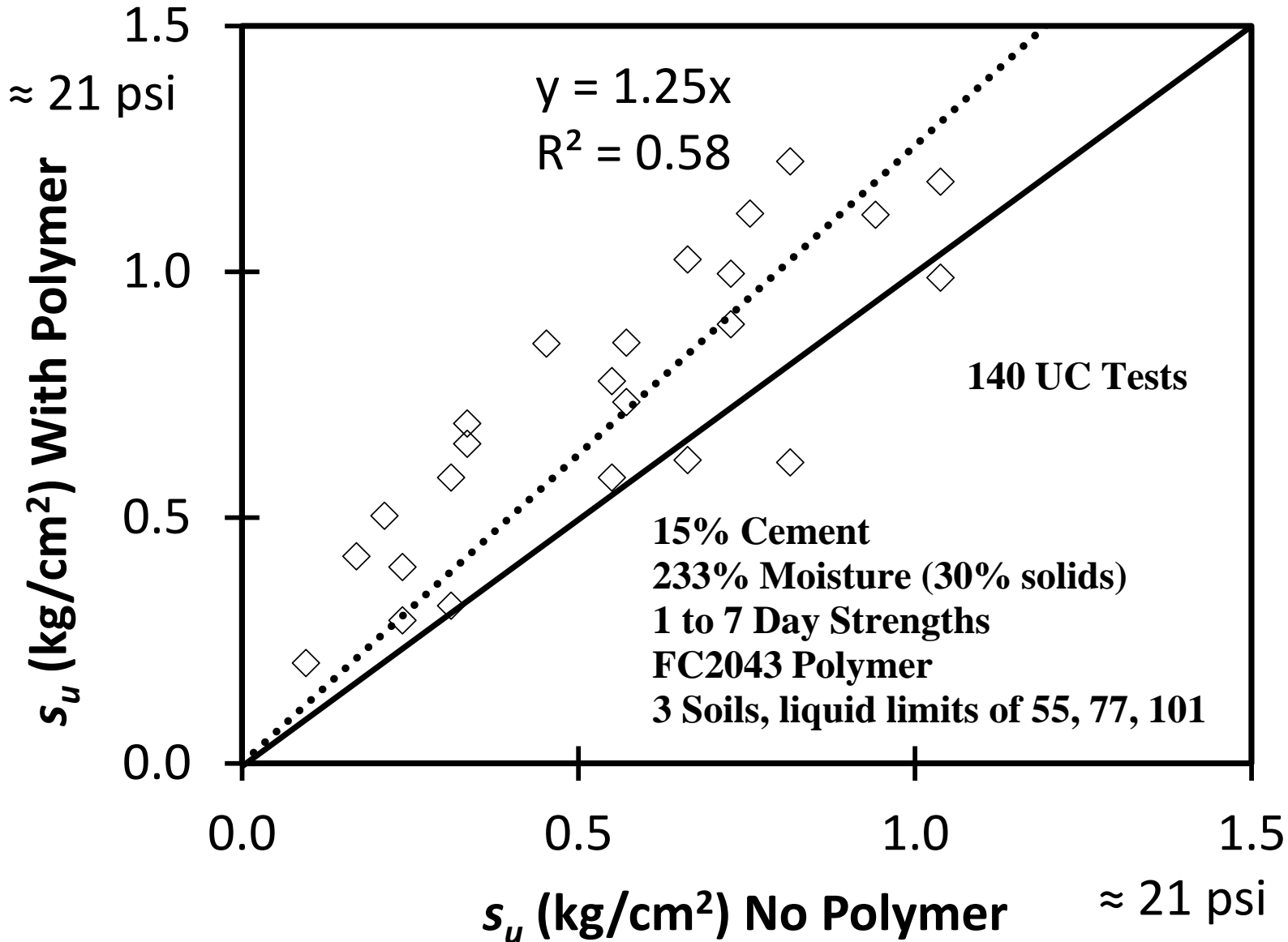
LC-VHMS Thermal Profiles



- Data shows cements exothermic signature can be detected even in VHMS at LC dosages, which demonstrates feasibility of thermal measurements for a variety of activities (e.g. mixing effectiveness), but also that cement can work effectively in dredged soil.

Dewater With Polymers, Then Stabilize (C-VHMS)

[Values plotted are shear strengths]



Relevant Construction Properties (Pumping)

- Positive displacement pumps are viable. Successful use of concrete pumps for moving VHMS are documented in multiple countries.



Dredging with Less Water

(Different types of equipment are available)



Dredge

Photo courtesy of
Dr. John C. Marlin
University of Illinois



Photo courtesy of Wayne Keene

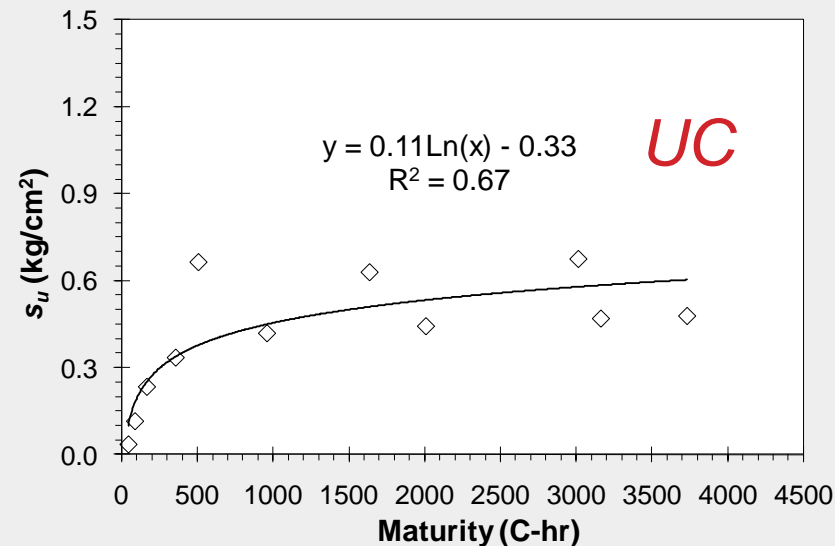
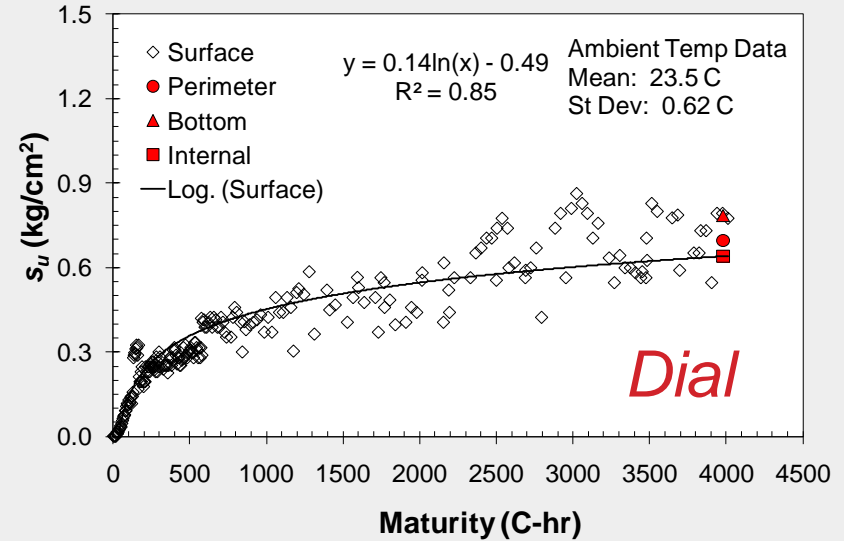


Hydraulic outlet (much more water)

Outlet pipe of same dredge
depositing material – dry
dredge material relative to
hydraulic approach

Rapid Property Measurement

- A few thousand readings were taken with hand held gages to assess their usefulness with C-VHMS, and to develop correlations to unconfined compressive (UC) strength



Rapid Property Measurement

- Data was assembled and used to create Gage to UC ratios (1.0 is desired; > 1.0 gage over predicts strength, < 1.0 gage under predicts strength). Ratios were 0.5 to 2.25 – so be careful.
- Hand held gage accuracy was a function of organic content, with strength over-prediction increasing with organic content.
- *Shear* gage, in general, predicted lowest strength of gages and was the least affected by organic content. It was the most accurate, yet the least precise.
- Accuracy of *Dial* and *Ring* gages were similar, *Dial* was more precise.
- Use hand held gage shear strength of high moisture content fine grained soils that have been chemically stabilized with caution- recommend *UC* calibration with same material until further data is available unless general trends is all you are looking for.

Geotextile Tubes and Ecosystem Restoration (or vegetation establishment)



LC-VHMS coupled with bio-degradable geotextile tubes is a possibly appealing combination

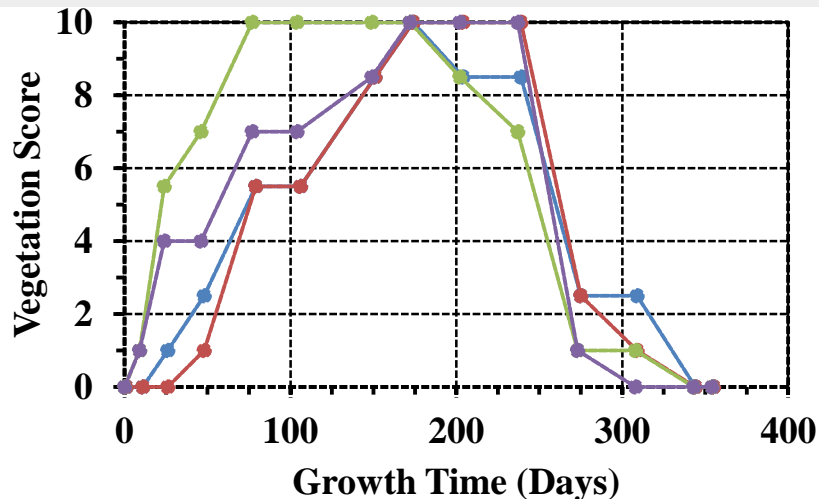
LC-VHMS with PLC was produced and monitored outside for vegetation establishment over time. Some experiments were inside geotextile, some were not



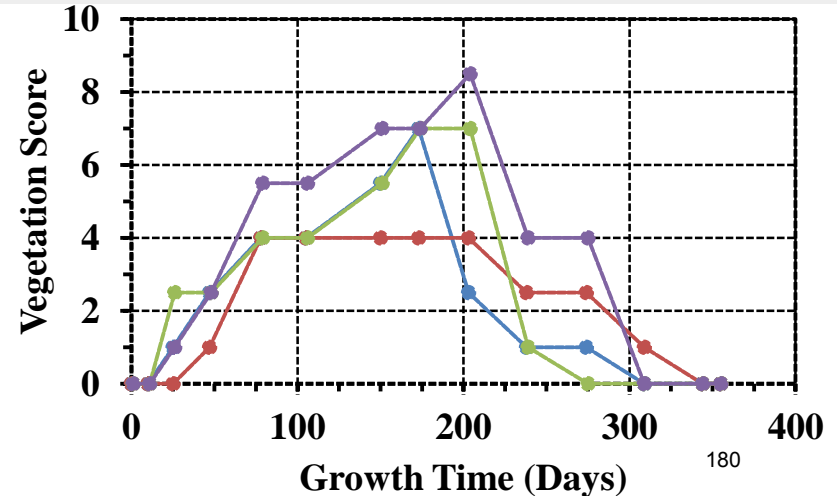
LC-VHMS Vegetation Establishment

- Sponsor report referenced earlier has several engineering with nature (EWN) references, and LC-VHMS seems to fit into the intersection of the natural and built environments
- Test results showed established vegetation, thus demonstrating viability of combining vegetation and portland-limestone cement. Geotextile encapsulation affected vegetation, but there was still some vegetation success.

Buckets

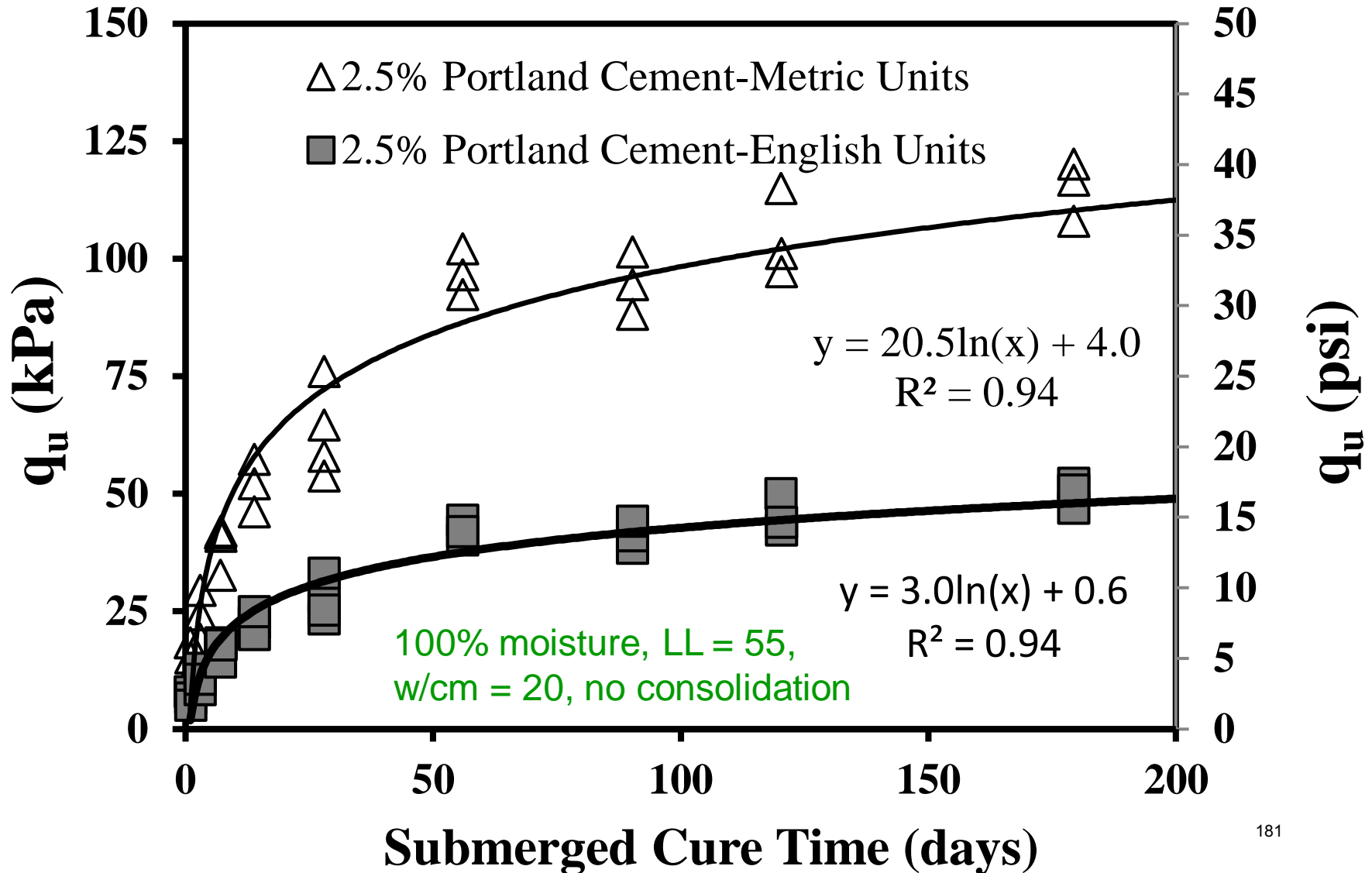


Geotextile



LC-VHMS Properties With Time

[Values plotted are unconfined compressive strengths]



PLC vs. OPC - Phase 1

- The next few slides use one OPC and one PLC from Holcim Theodore to perform property testing on soil from USACE dredge disposal facilities in Memphis and Mobile
- The OPC had a Blaine fineness of 405 m²/kg and 1.7% limestone
- The PLC had a Blaine fineness of 538 m²/kg and 12.8% limestone
- Bottom ash adjacent to disposal facility was also sampled for testing

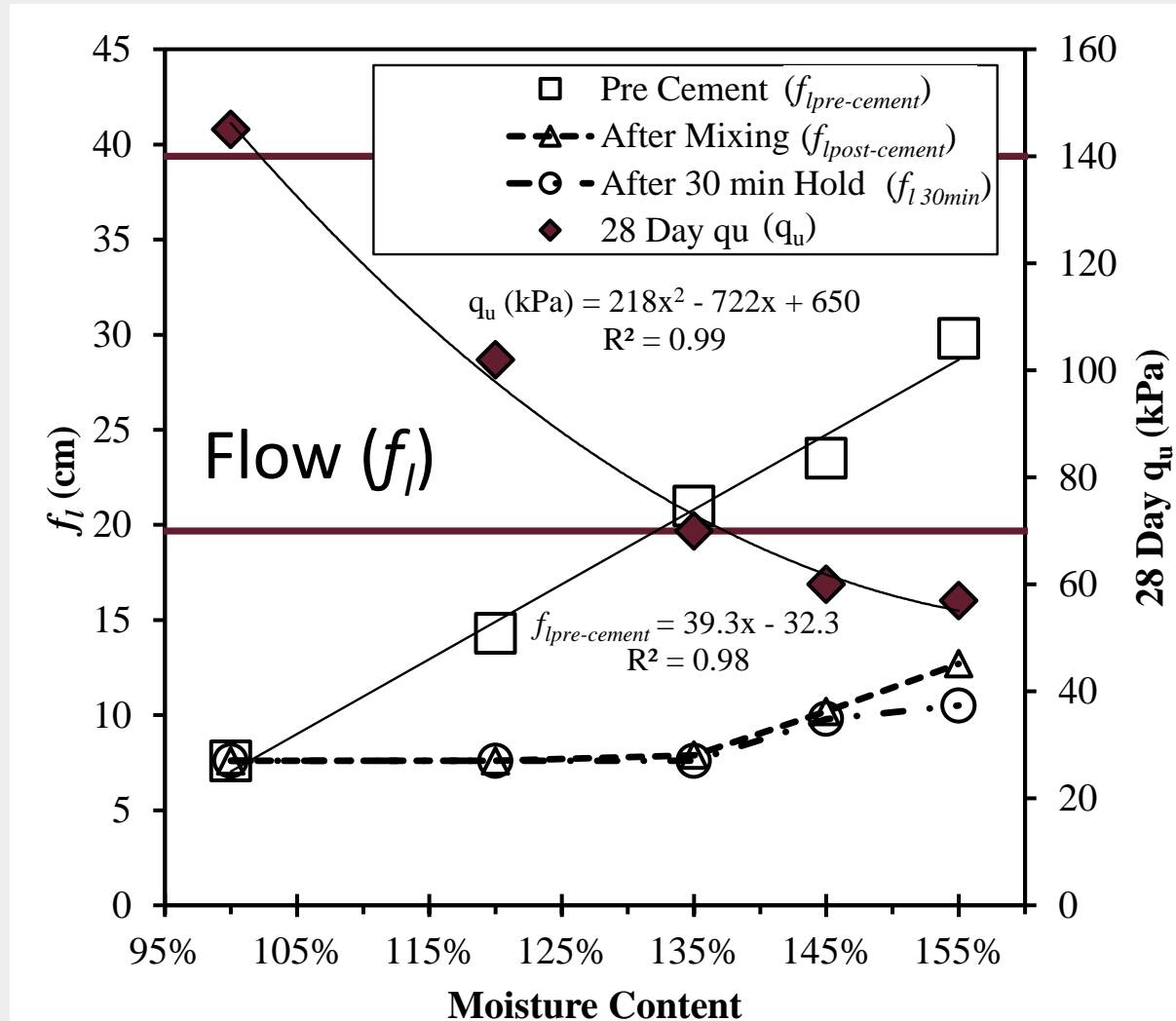
Engineering Properties When Stabilized With 5% PLC

Unconfined
Compressive
Strength (q_u)

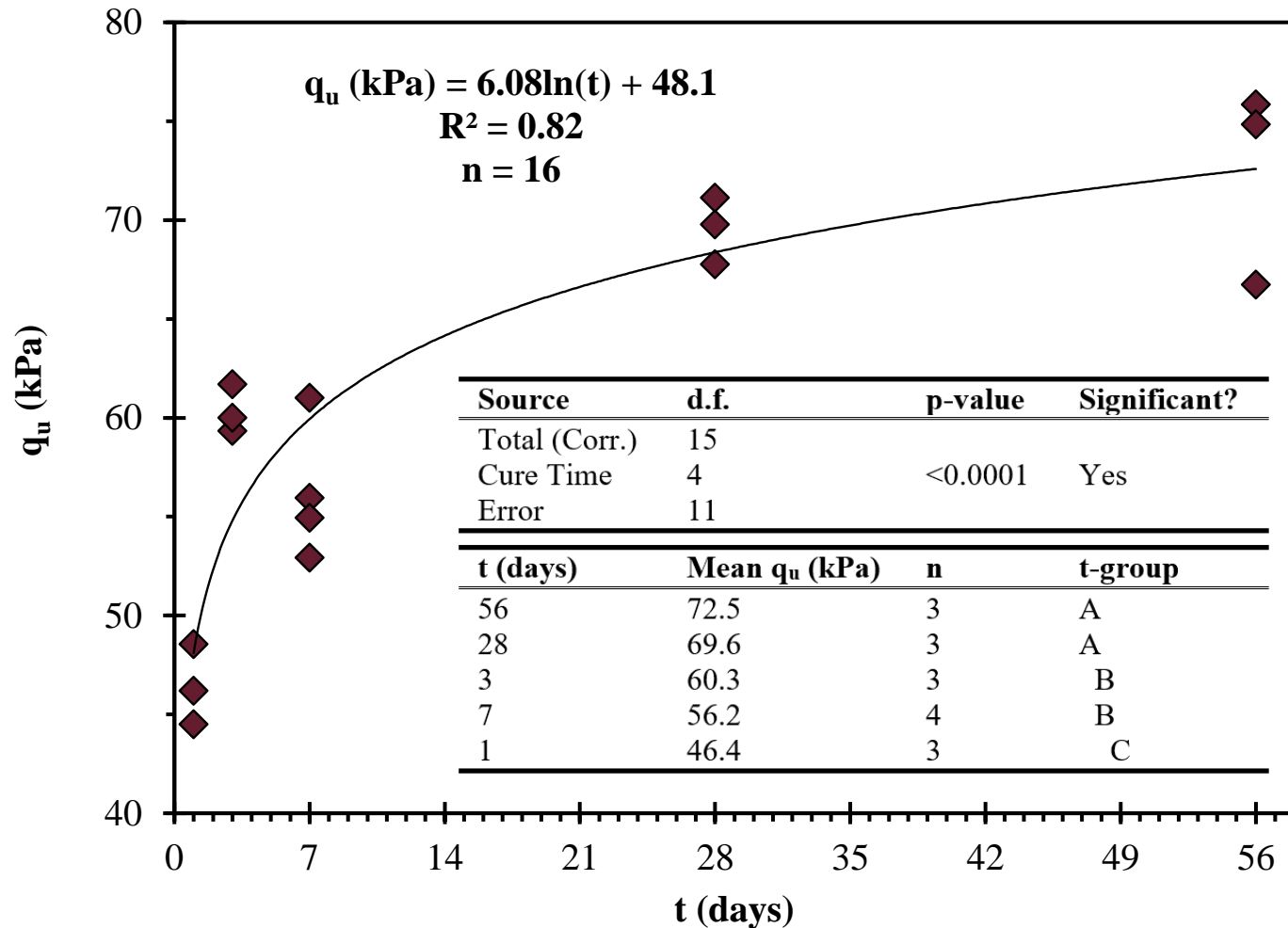
140 kPa \approx 20 psi

70 kPa \approx 10 psi

Raw Material
Atterberg Limits
LL = 90%, PL = 32%, PI
= 58%

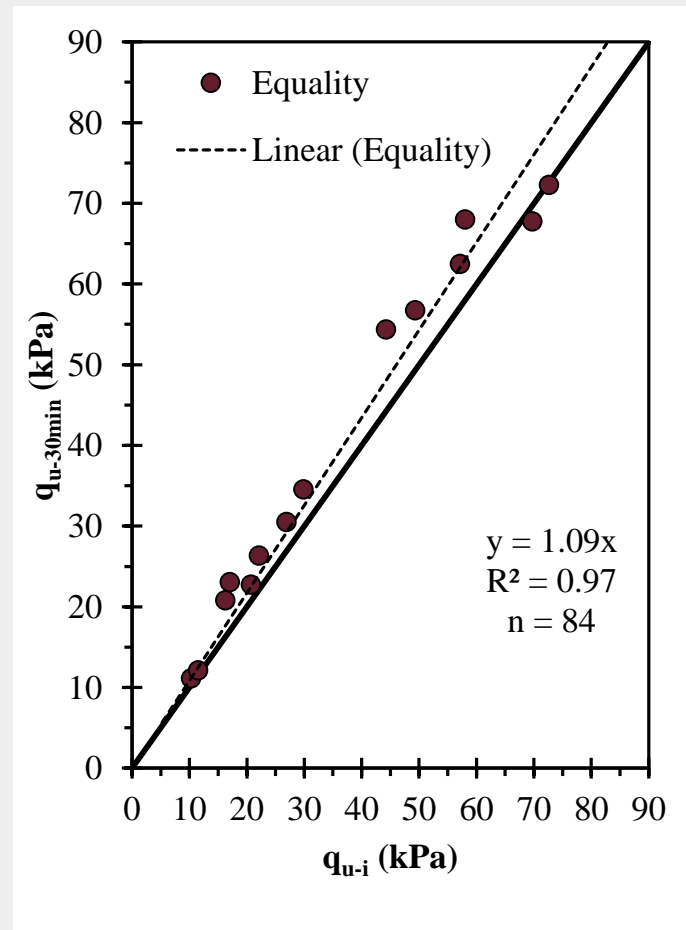


Engineering Properties When Stabilized With 5% PLC-Memphis at 135% Moisture



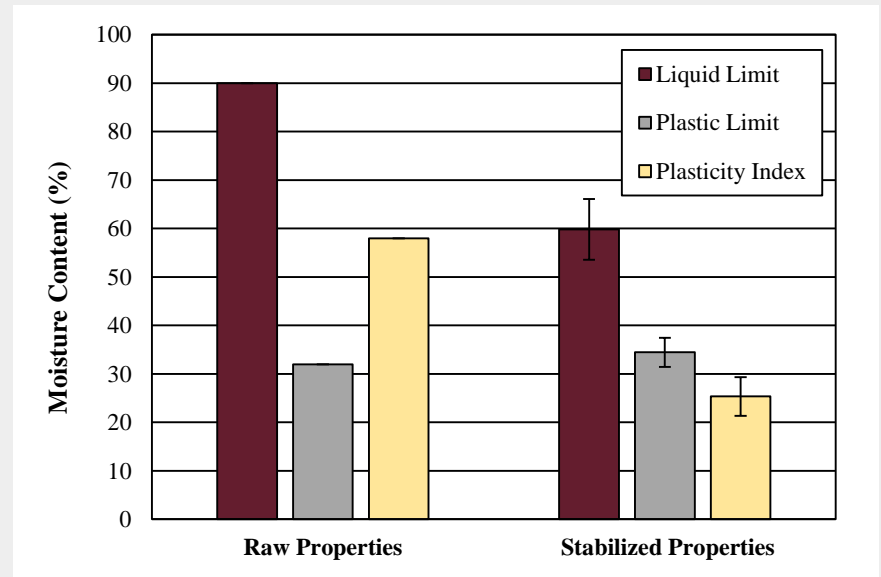
Effect of Molding Time on UC Strength (Memphis Soil)

- Mixtures were molded immediately or after a 30 minute holding period
- UC Strengths of specimens molded immediately vs specimens molded after waiting 30 minutes
- Marginal increase in strength if any change for specimens held for 30 minutes
- Mixture Variations:
 - Cement Content (2.5% or 5.0%)
 - Cement Type (OPC or PLC)
 - Cure Time (28 days or 56 days)
 - Initial Moisture Content (135% or 155%)



Effect of Cement Stabilization on Atterberg Limits-Memphis Soil

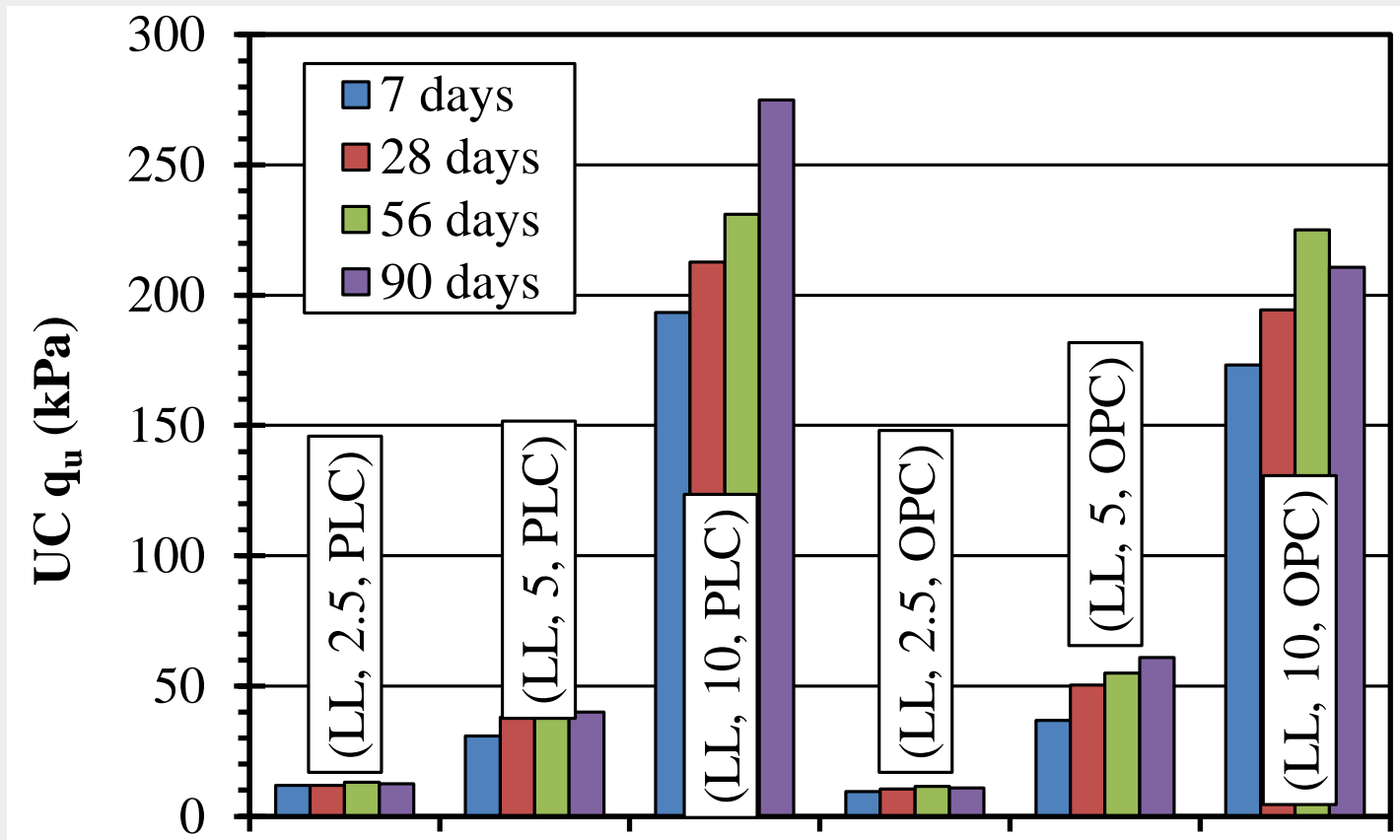
- Tested after 56 days of curing
- Average reduction in Plasticity Index (PI) of 33%.
- ANOVA analysis on stabilized PI indicated no significant difference between treatments.



LC-VHMS Cement Dosage Rate Effects

[unconfined compression, no consolidation]

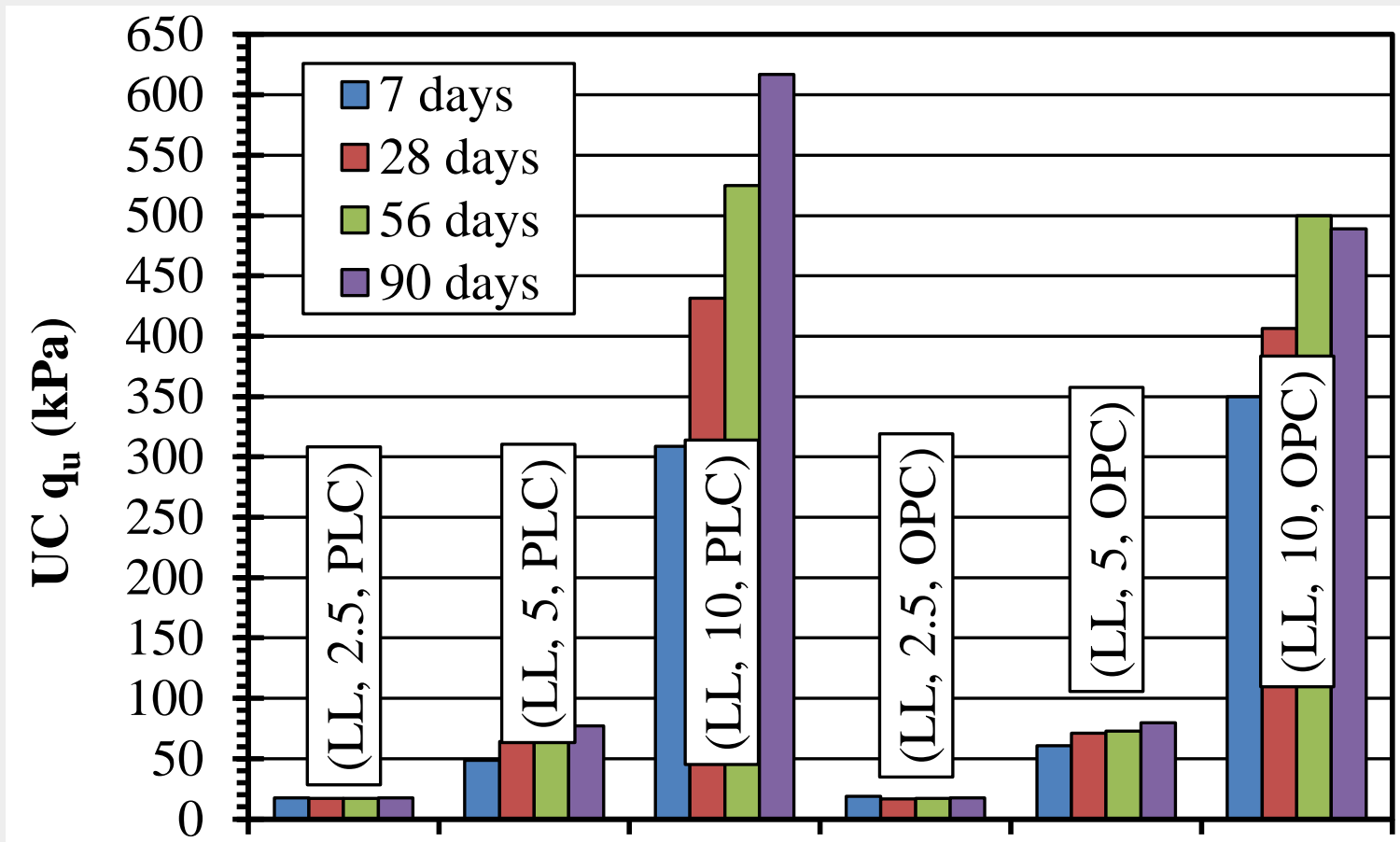
- None of these specimens had more than around 5% by slurry mass of cement-some had much less. All were molded at the lower bound of VHMS (i.e. LL of 90 – Memphis soil)



LC-VHMS Cement Dosage Rate Effects

[unconfined compression, no consolidation]

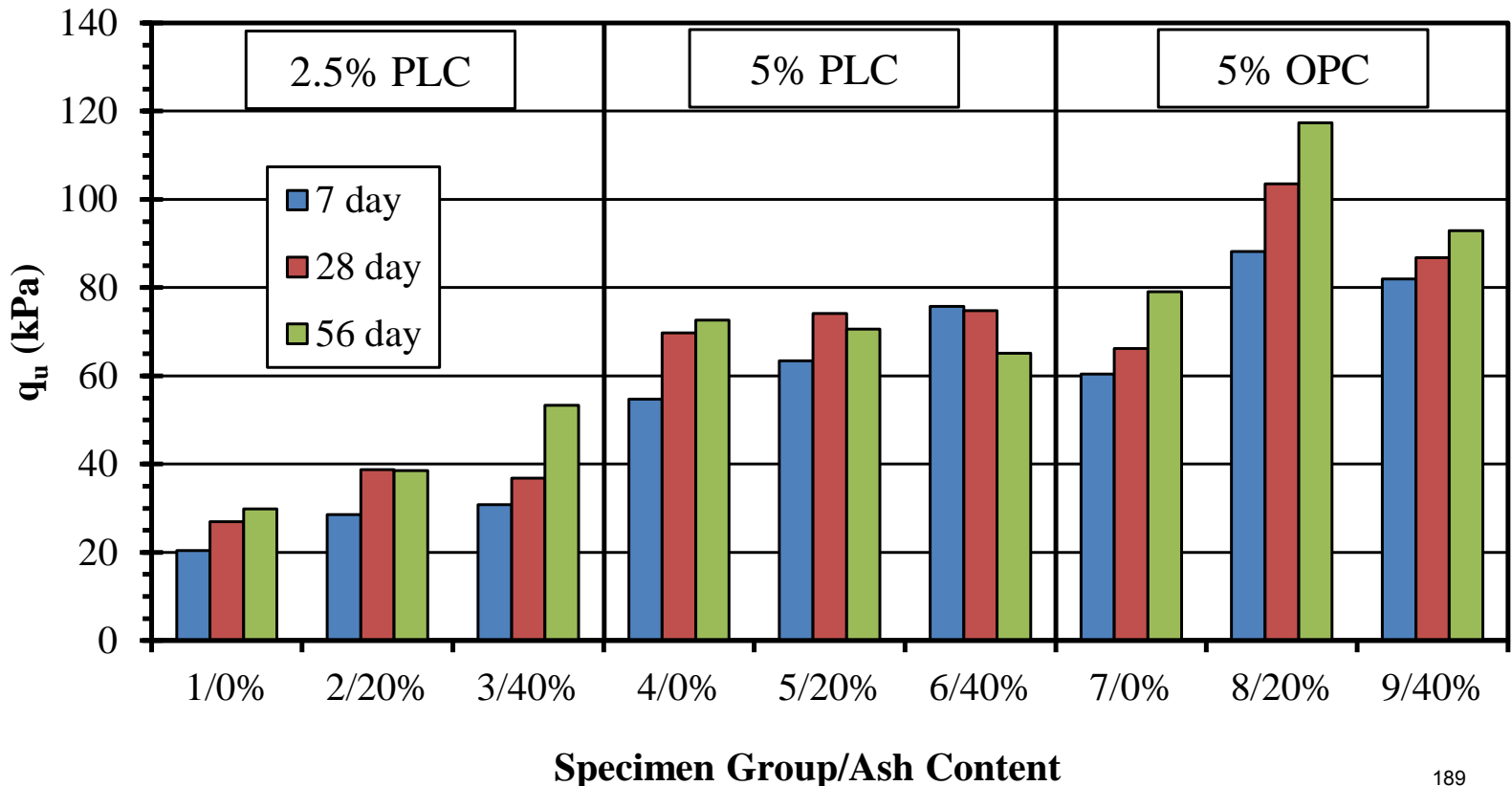
- None of these specimens had more than around 5% by slurry mass of cement-some had much less. All were molded at the lower bound of VHMS (i.e. LL of 70 – Mobile soil)



Mixing Cement and Bottom Ash

[unconfined compression, no consolidation]

- Dosages shown are on slurry mass basis, all mixes had equal ASTM D6103 flow of 7 in, the soil LL was 90 (Memphis soi) and moisture content was 100 to 135%



PLC vs. OPC - Phase 2

- The same two cements used in phase 1 were used, alongside four additional matched pairs, the same ones presented earlier by T. Cost that were used in the CMRC concrete work
- Mobile soil was used, moisture content was held to 100% for all cases. The cement dosage was 5% of slurry mass for all testing, which is the upper end LC-VHMS definition
- Oven curing at 60 °C (sealed containers to minimize moisture loss) was used to evaluate very long cure times to see what level of pozzolanic tendencies might occur OPC vs. PLC. Cure times were 3, 9, 27, and 95 days.

Cement Properties

Properties of Cements Utilized for Phase 2 Laboratory Experiments

Cement ID	OPC 1	PLC 1	OPC 2	PLC 2	OPC 3	PLC 3	OPC 4	PLC 4	OPC 5	PLC 5
Al ₂ O ₃ (%)	4.8	4.2	5.0	4.2	4.4	4.0	5.5	5.3	4.6	4.0
CaO (%)	64.1	64.3	64.2	64.9	63.1	63.1	63.9	63.4	63.1	63.9
SiO ₂ (%)	19.9	18.2	20.3	17.9	20.3	17.9	19.1	17.8	19.0	16.7
Limestone (%) ¹	1.7	12.8	0.1	13.0	0.3	14.0	2.2	8.8	4.1	15.7
Blaine (m ² /kg)	405	538	403	579	421	556	422	522	407	681
Vicat Initial (min)	90	135	115	95	140	100	95	95	105	90
Vicat Final (min)	170	190	190	155	250	225	170	160	205	175
fc-1 D (MPa) ²	16.6	20.4	18.0	18.7	15.2	17.1	18.2	19.9	15.0	20.1
fc-3 D (MPa)	28.6	31.0	25.9	29.5	27.0	27.4	29.7	31.8	25.8	29.2
fc-7 D (MPa)	35.2	39.2	31.6	34.1	30.2	32.3	34.6	38.0	31.8	35.6
fc-28 D (MPa)	44.7	45.6	44.0	42.8	39.3	39.7	41.4	42.8	42.1	41.2

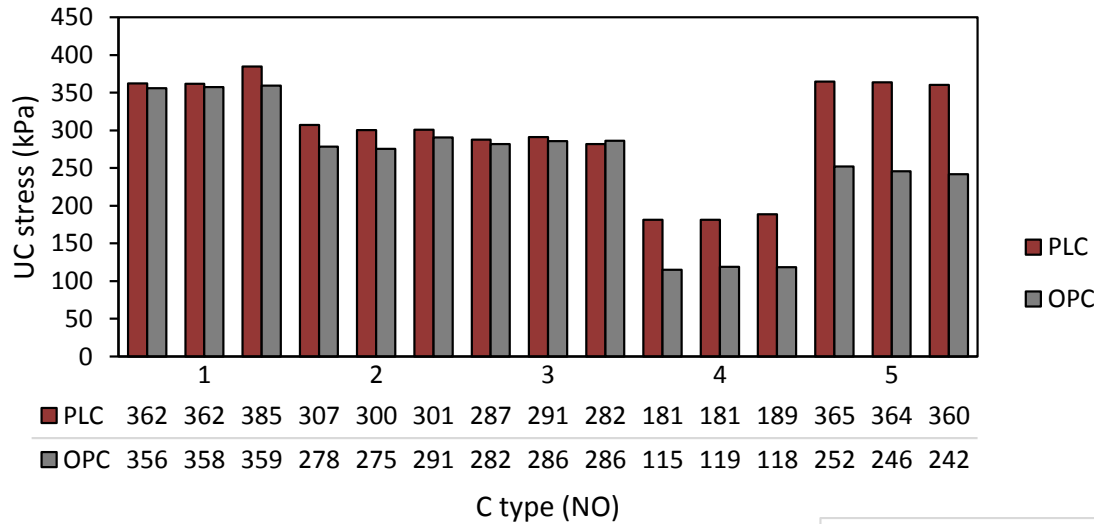
--OPC 1, PLC 1, OPC 2, and PLC 2 all came from the same plant, but were sampled several months apart. OPC 1 and PLC 1 are not a matched pair, rather were used during Vahedifard et al. (2015). OPC 2 and PLC 2 were also not a matched pair.

¹ Percent limestone reported for each cement sample was determined with split-loss type calculations as might be used in ASTM C150 reporting, though this is not a required method for reporting under ASTM C595. These values (and some chemical analysis results listed) are shown for comparative information only, and it should be noted that calculated values often slightly over-estimate actual limestone content due to trace amounts of carbon present in gypsum or other components. No samples exceeded Type IL specification limits for limestone content based on production data.

² fc = mortar cube compressive strength measured via ASTM C109 at test day (D) shown.

Unconfined Compression Results

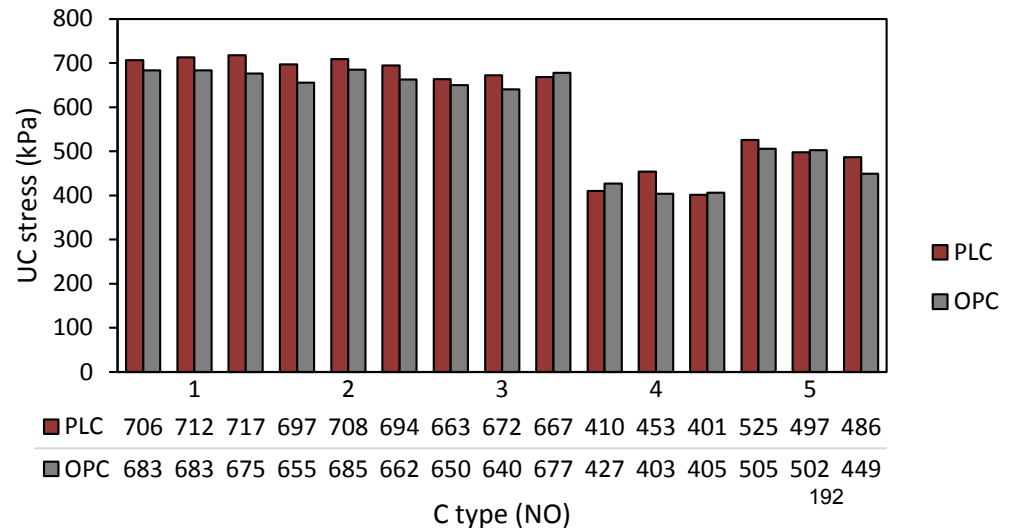
9 Days



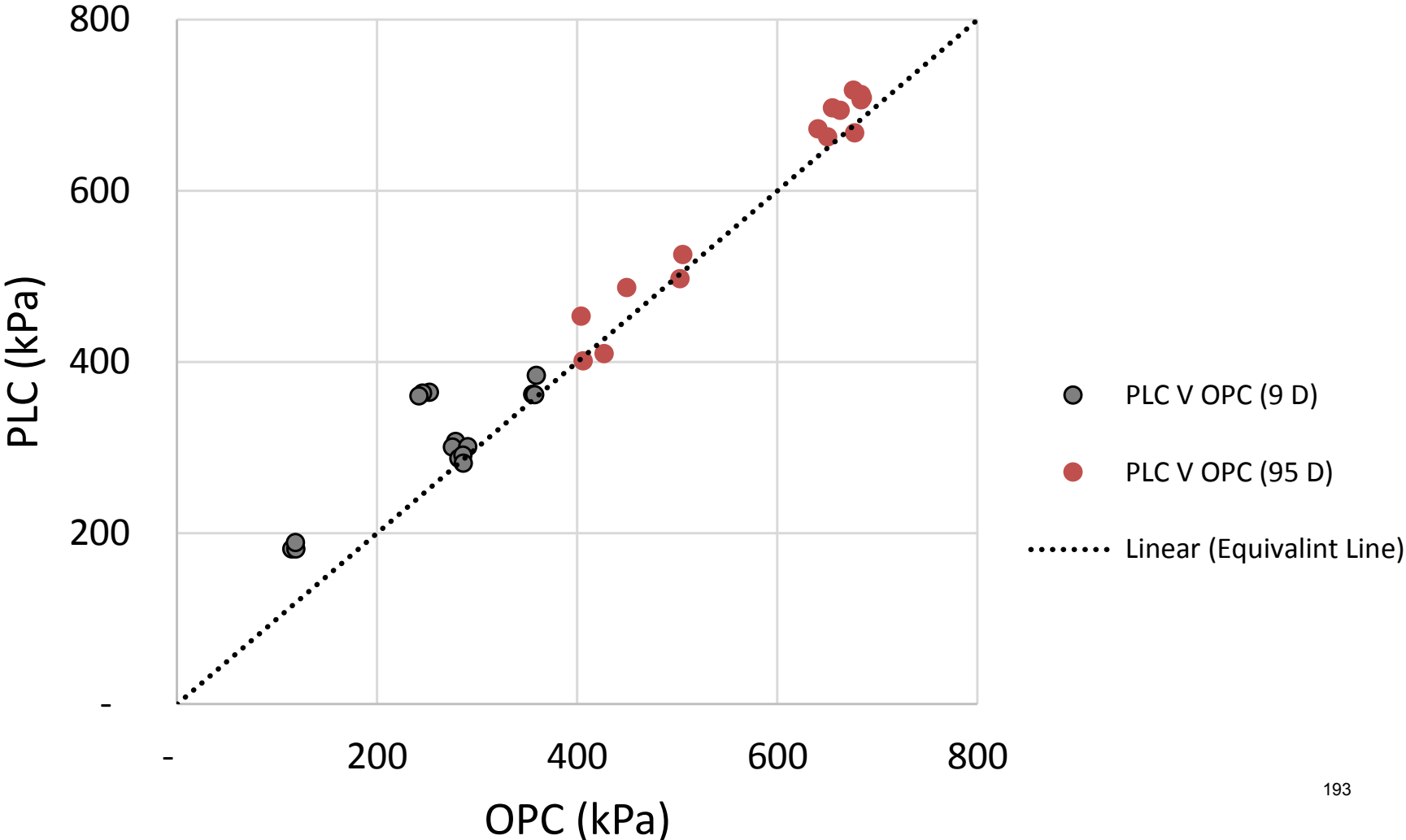
At 9 days in the oven, PLC was at to noticeably better than OPC

At 95 days in the oven, PLC was barely stronger in some cases, and practically the same in other cases

95 Days

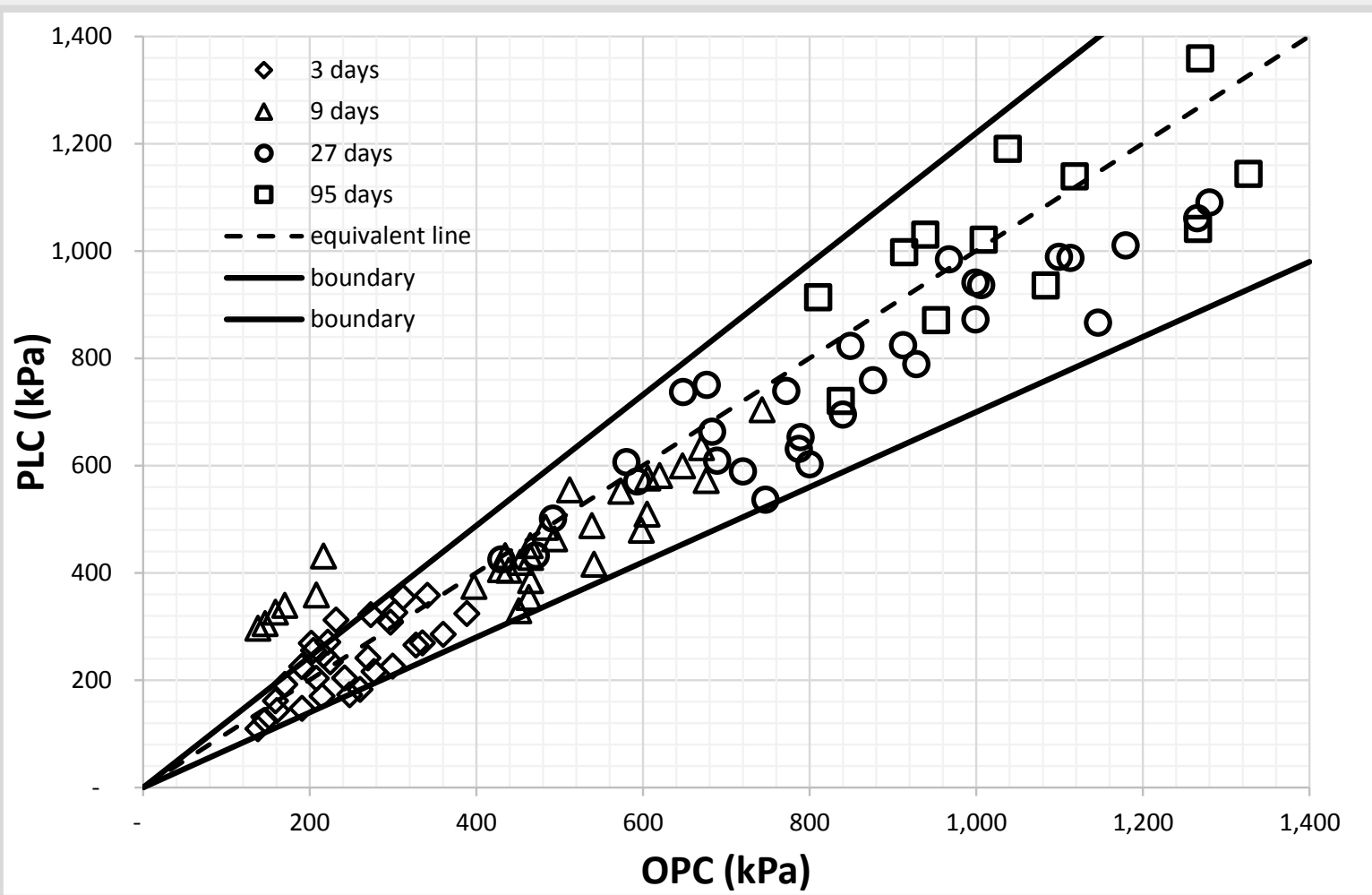


UC Equality Plot From Previous Slide Data



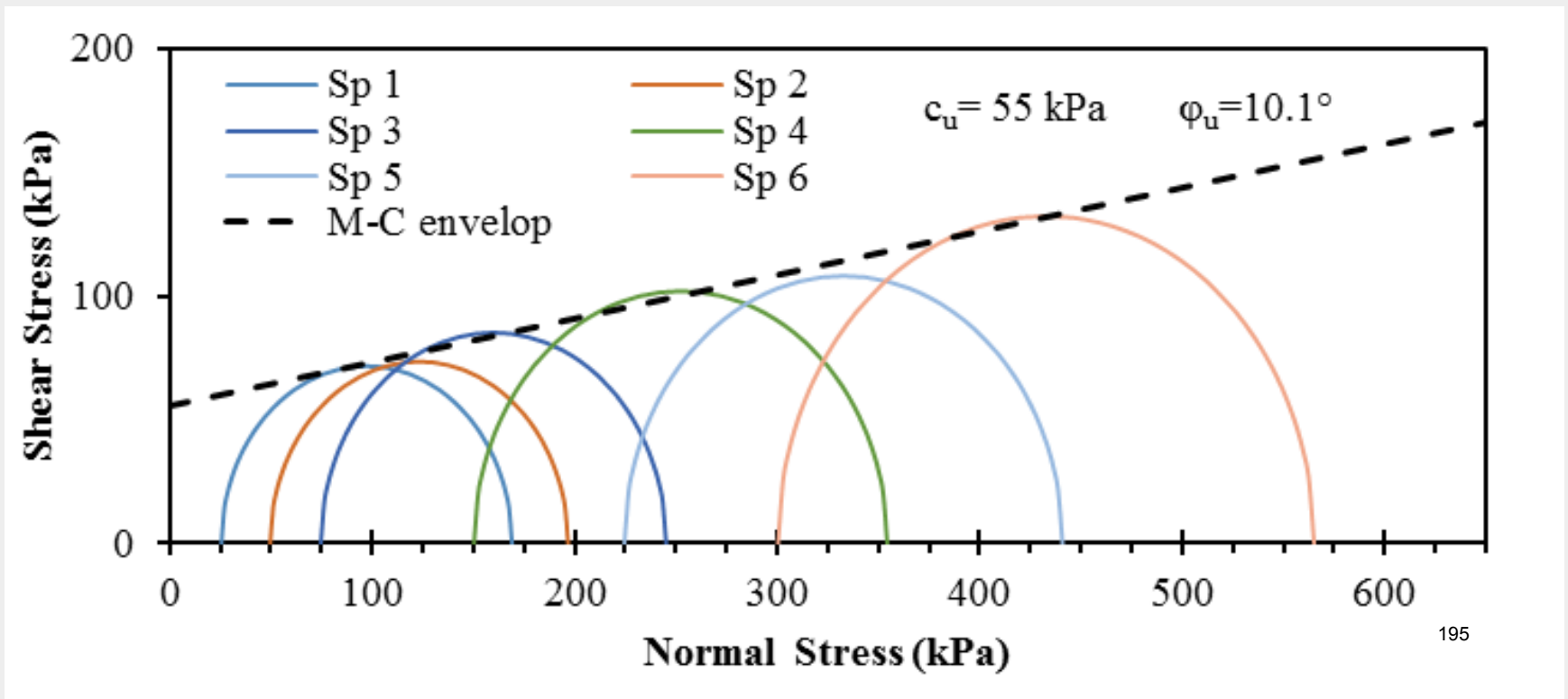
Unconsolidated-Undrained (UU) Triaxial Test Results

- UU data doesn't show the same trends as UC data-UU data analysis is ongoing



Example Mohr-Coulomb Envelope

- Failure envelopes are pretty clean, so there is a possibility that confining pressure is producing different responses OPC vs. PLC. More investigation is to be performed before any final statements are made on UU data.



Summary

- LC-VHMS can achieve properties that are suitable for some lower strength applications.
- C-VHMS has a much wider range of applications, which is intuitive, but these applications come with more embodied energy and materials expenses. LC-VHMS has not been widely studied, and more understanding is needed of this material.
- At a minimum, PLC is a viable cement for dredged soil stabilization from an engineering properties and sustainability standpoint.

Questions?

Mississippi State University

CMRC



Construction Materials
Research Center

An Industry, Agency
& University Partnership