ARCOSA
LIGHTWEIGHT

Geotechnical Applications for Expanded Clay and Shale Lightweight Aggregate

Jack Moore

Geotechnical Market Manager

MOVING
INFRASTRUCTURE
FORWARD

Agenda

Arcosa Lightweight – Who we are

Expanded Shale and Clay History

Traditional Markets and Applications

Load Reduction and Lightweight Fill Options

Relevant Physical Properties

Project Profiles

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Select Albuquerque History

- 1912
  - New Mexico was admitted to the U.S. as the 47th state.
- 1928
  - Airport Opens
- 1972
  - Balloon Fiesta Founded
- 1975
  - Bill Gates and Paul Allen Complete BASIC

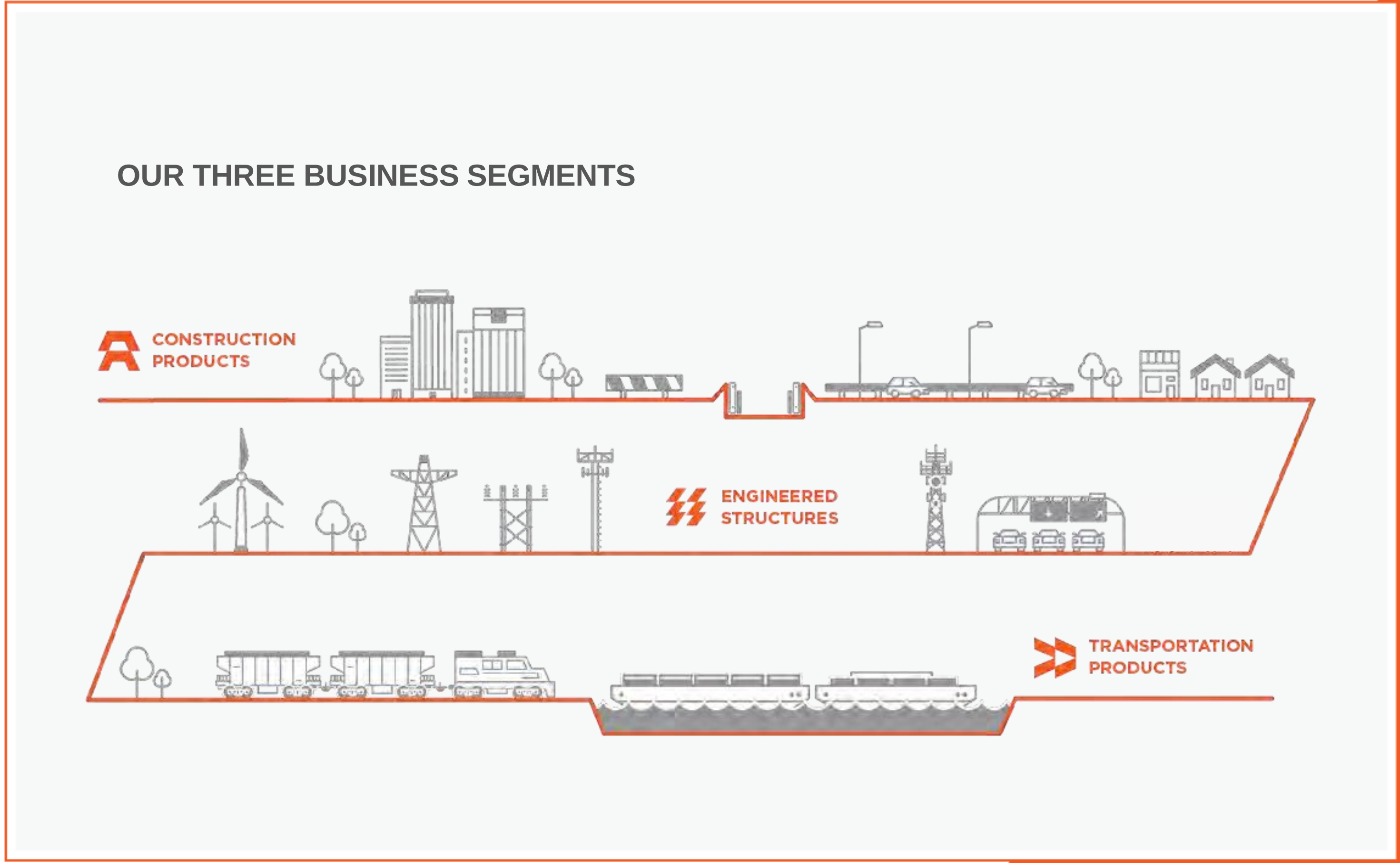
Albuquerque History

- 1983
  - April 4, University Arena aka The Pit
  - NC State won the national title with a 54-52 victory over Houston
  - Ending of the game is one of the most famous in college basketball history
  - A buzzer beating dunk by the late Lorenzo Charles

NCAA Tournament Flashback

NCAA Tournament Flashback

ARCOSA AT A GLANCE



$2.3B	Revenues
$159M	Net Income
$368M	Adjusted EBITDA
~6,075	Employees
85+	Years of Operating History
3	Infrastructure-related Segments

Revenue, net income, and Adjusted EBITDA are for the year ended 12/31/2023. See Adjusted EBITDA reconciliation in Appendix

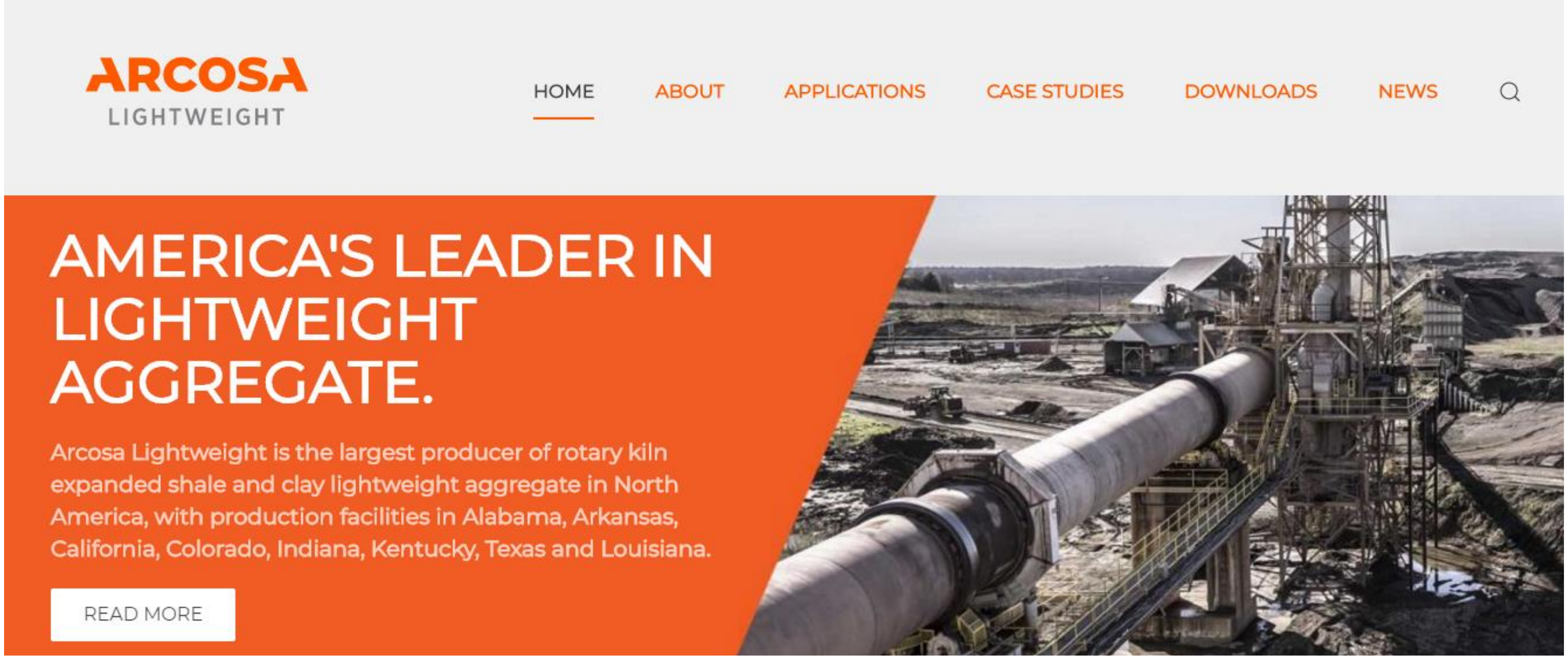
BUSINESS OVERVIEW

Arcosa's three segments are made up of leading businesses that serve critical infrastructure markets

CONSTRUCTION PRODUCTS	ENGINEERED STRUCTURES	TRANSPORTATION PRODUCTS
$1,001M REVENUES	$874M REVENUES	$434M REVENUES
$245M 25% ADJ. SEGMENT EBITDA & MARGIN	$116M 13% ADJ. SEGMENT EBITDA & MARGIN	$62M 14% ADJ. SEGMENT EBITDA & MARGIN

Revenues and Adjusted Segment EBITDA and margin for the year ended 12/31/2023. See Adjusted Segment EBITDA reconciliation in Appendix.

Arcosa Lightweight

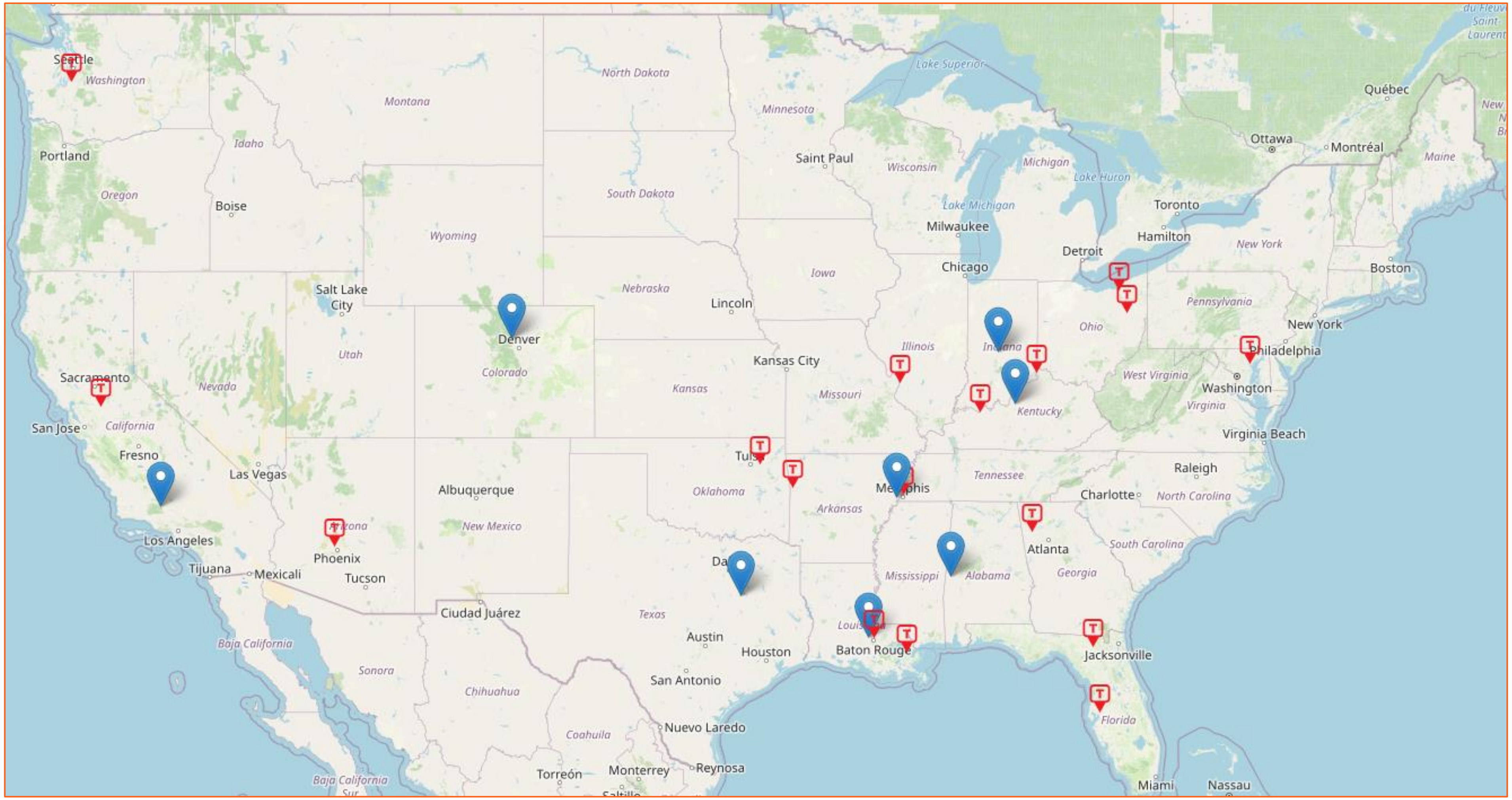


ARCOSA LIGHTWEIGHT:

THE NEW NAME FOR AMERICA'S LEADER IN LIGHTWEIGHT AGGREGATE

Arcosa Lightweight

Arcosa Lightweight Facilities and Terminal Footprint



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Arcosa Lightweight

Boulder, Colorado

11728 Highway 93
Boulder, CO 80303

Frazier Park, California

17410 E Lockwood Valley Rd
Frazier Park, CA 93225

Phone (661) 245-3736

View on Google Maps

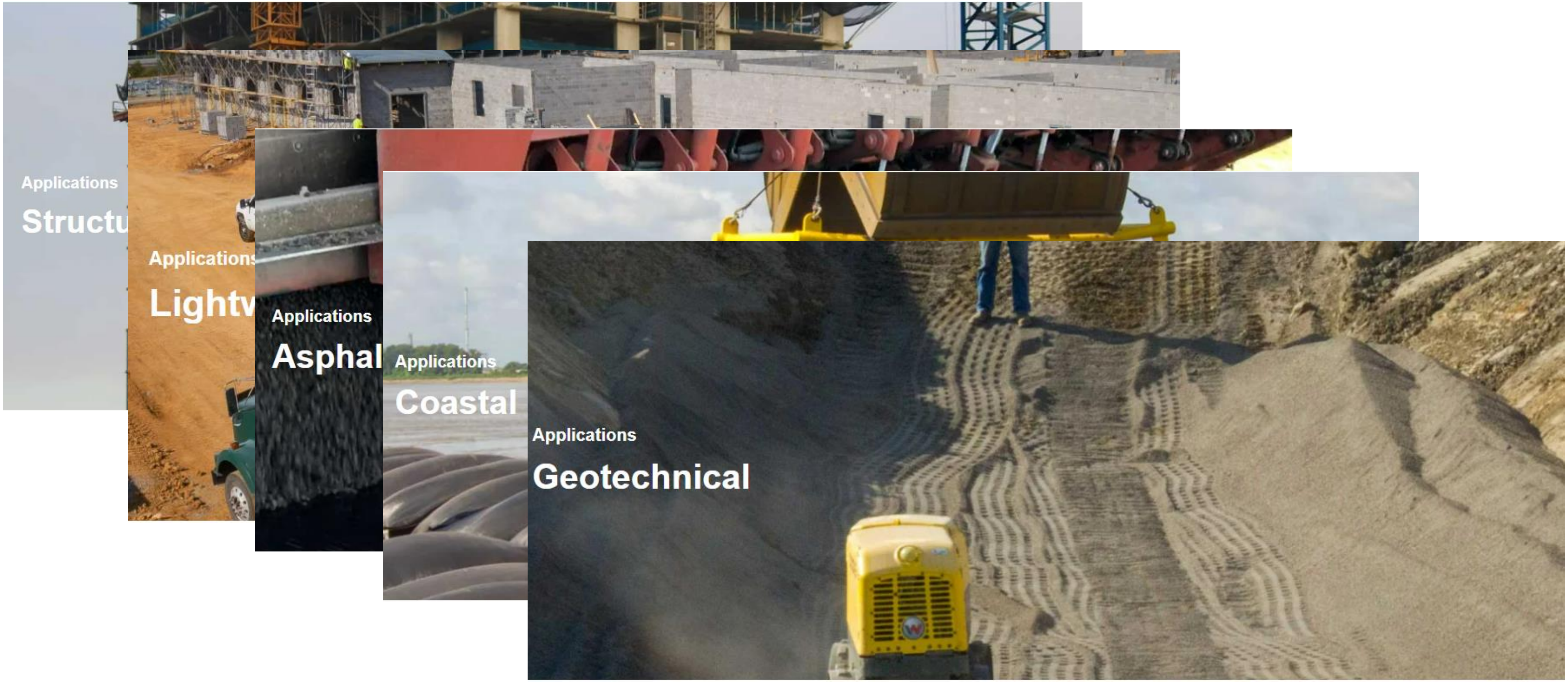
Streetman, Texas

14885 South Interstate 45
Streetman, Texas 75859

Phone (800) 870-3397

View on Google Maps

Arcosa Lightweight Markets



History Of Rotary Kiln Produced Lightweight Aggregate

Brick Industry Roots

"Bee hive" brick kilns

Invention of Stephen Hayde

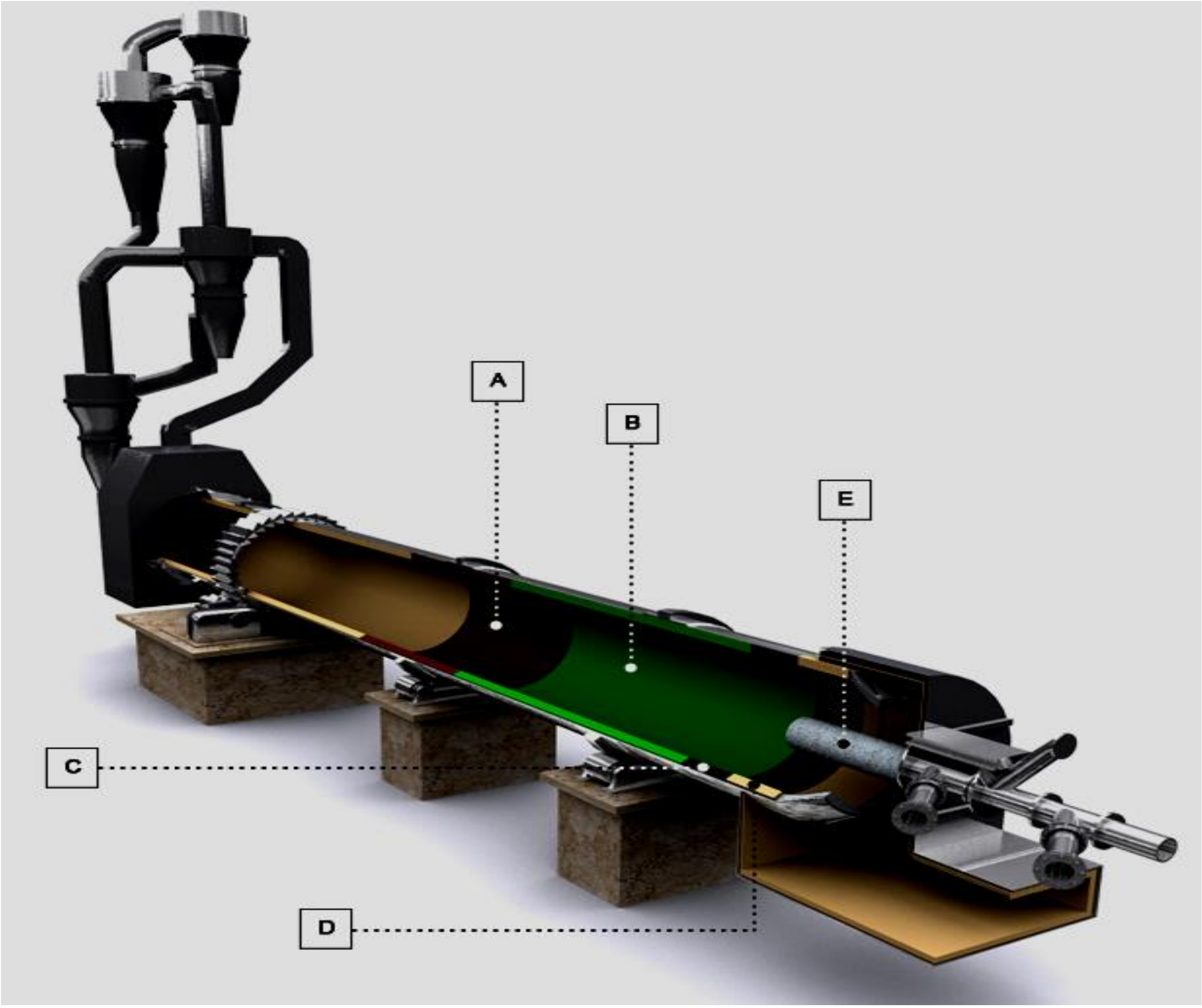
- Certain clays bloated with heat
- Bloated brick were culls
- Given lemons, make lemonade
- Patent issued in 1918

History Of Rotary Kiln Produced Lightweight Aggregate

Rotary Kiln Method

Study of Time-Temperature Relationship

- Stationary Material Not Important
- Rotary Kiln – Time & Temperature Control
- Proved to be the Most Efficient Method



History Of Rotary Kiln LWA – Expanded Shale, Clay, & Slate

Process Patented by Stephen Hayde in 1918

During World War I, Hayde gave patent rights to U.S. Government

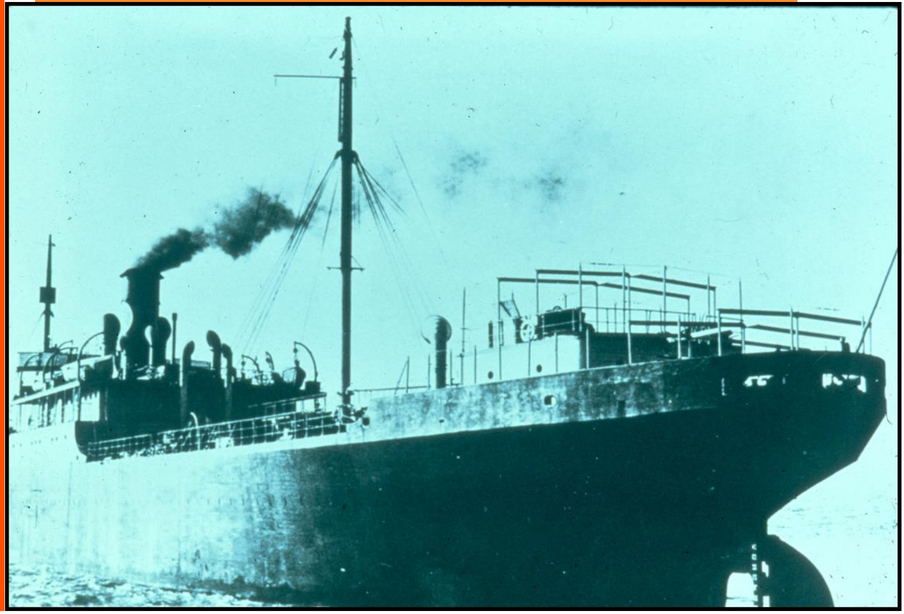
U.S. Government developed lightweight concrete and built LWC ships

USS Selma was the first LWC ship to be commissioned

Story repeated in WW II
- At least 9 WW II ships remain today
- Powell River - Canada

USS Selma

Commissioned 1919



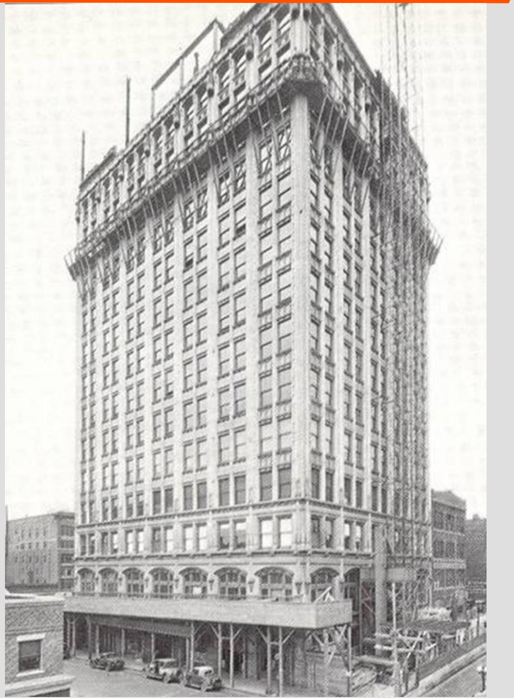
History Of Rotary Kiln LWA – Expanded Shale, Clay, & Slate

Other structural uses emerged

Bridges – S.F. Bay Bridge, circa 1930

LWC ship passing under LWC Bridge - 1944

Buildings – Floors and frames



Parking structures – Prestressed and cast-in-place

150 ft. LWC Double Tee

Manufacturing Process

Ground Improvement/Modification

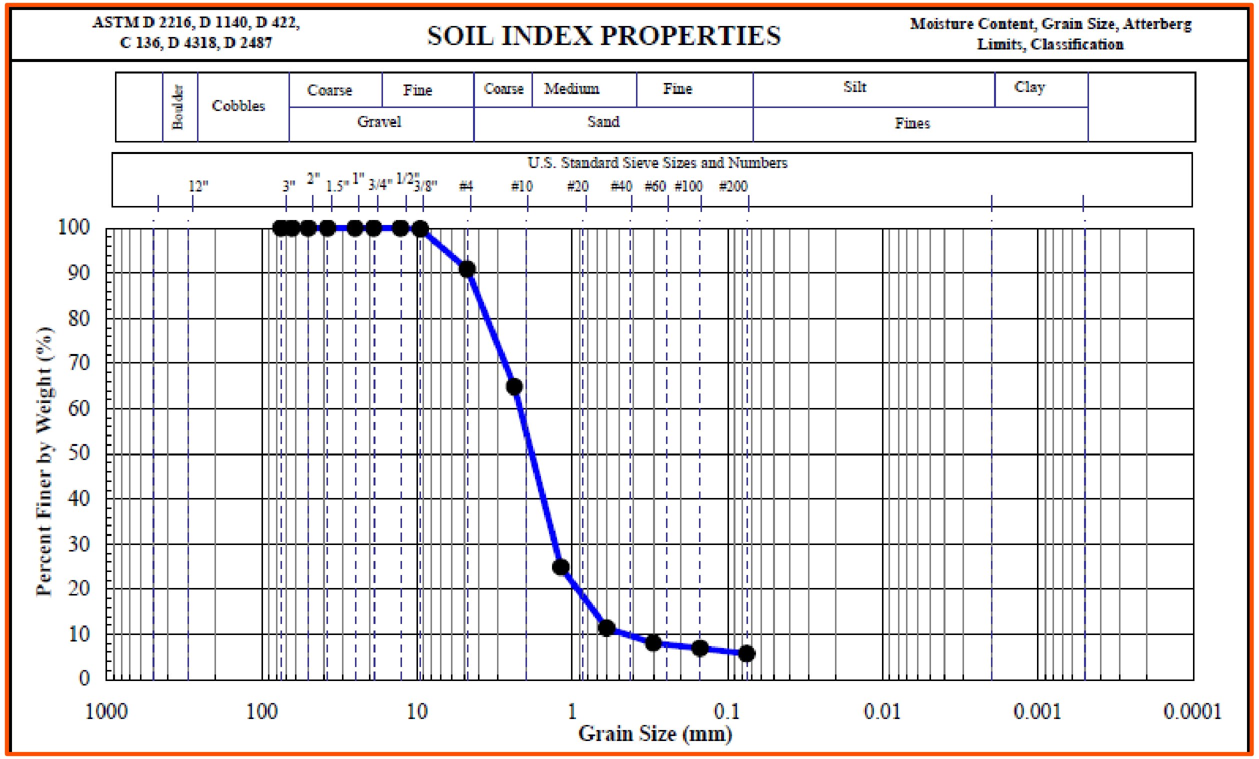
Method	Technology
Vertical Drains and Accelerated Consolidation	Prefabricated Vertical Drains (PVDs)
Deep Compaction	Deep Dynamic Compaction, Vibro-Compaction
Aggregate Columns	Stone Columns, Rammed Aggregate Piers
Soil Mixing	Deep Mixing, Mass Mixing
Grouting	Chemical Grouting, Jet Grouting, etc.
Reinforced Soil Structures	Reinforced Embankments, Walls, and Slopes
Load Reduction	Lightweight Fill Materials: Expanded Shale, Clay, and Slate (Lightweight Aggregates), Expanded Polystyrene, (EPS) Foamed Glass Aggregate (FGA), Low Density Cellular Concrete (LDCC)

Lightweight Fill Materials

Fill Material	Unit Weight (lb./ft^3)
ESCS	40 – 65
Low Density Cellular Concrete (LDCC)	20 – 60
Waste Tires	24 – 33
Wood Chips	20 – 35
Expanded Polystyrene (EPS)	0.75 – 2
Foamed Glass Aggregate (FGA)	10 - 25
For Reference: Quarried Select Fill and Aggregates	95 - 135

Applicable Physical Properties

Physical Properties – Grading and Specific Gravity



- Manufactured to meet grading requirements in ASTM C330
- Specific Gravity 2.1

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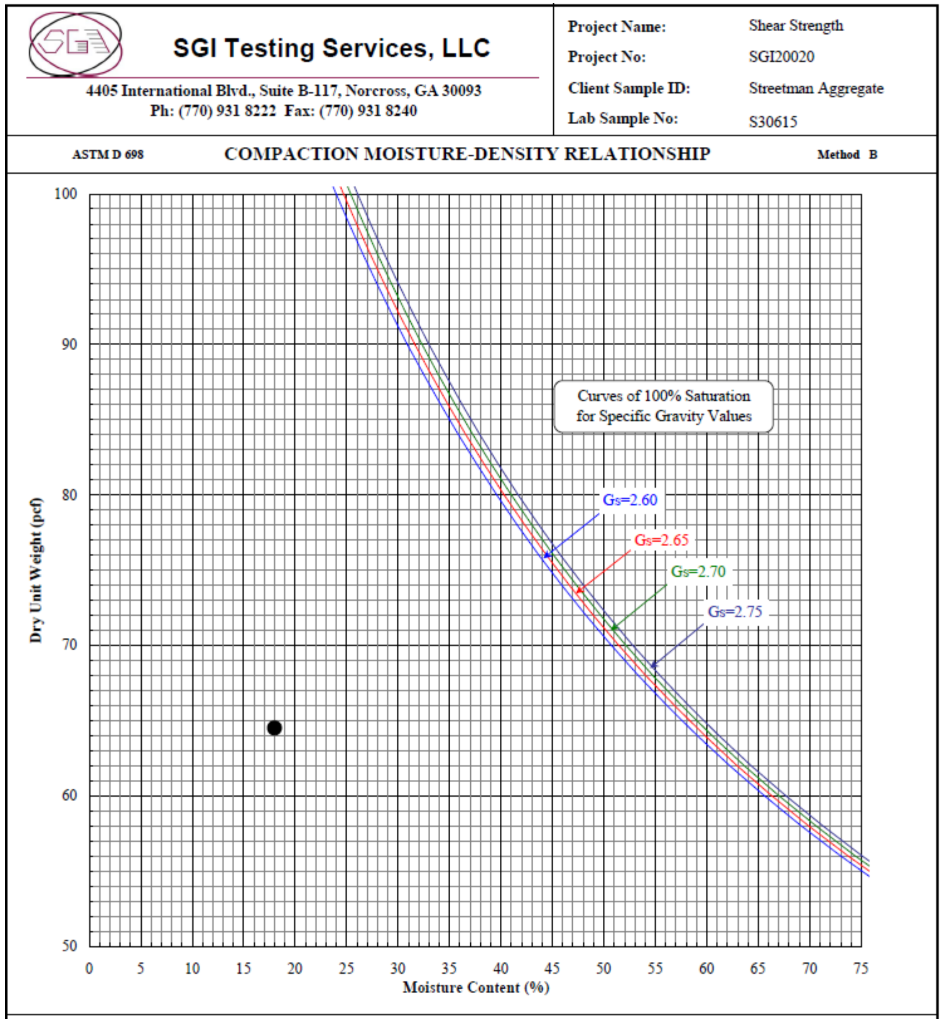
Physical Properties – Loose Bulk Density and Proctor



- ASTM C29 Loose Bulk Density
  - 62 pcf
- ASTM D698 (modified) one-point proctor results
  - 65 pcf wetted, surface dry

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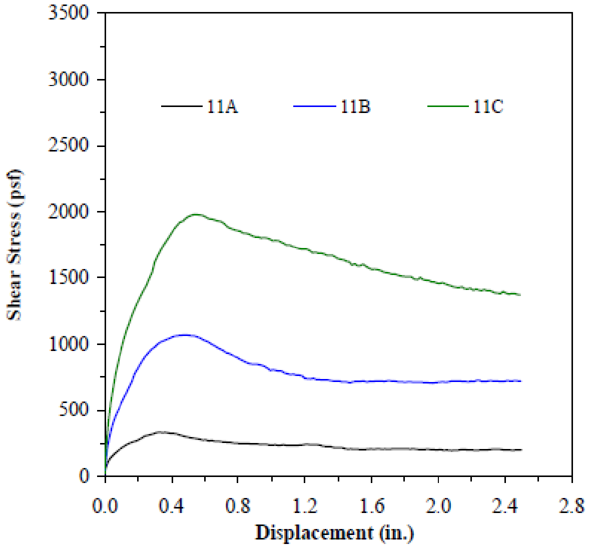
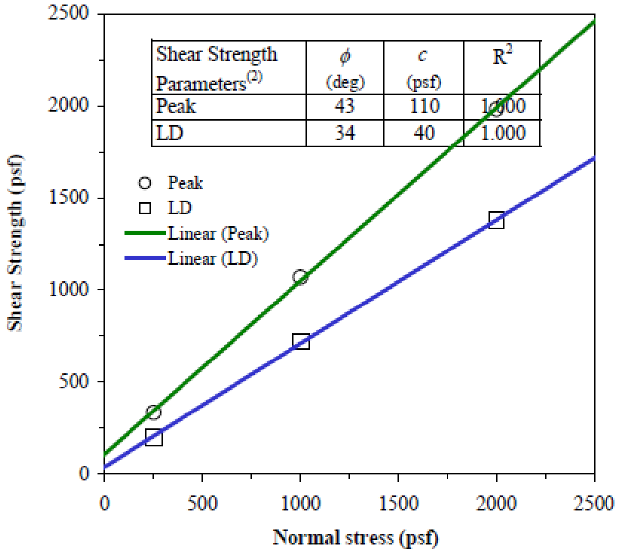
Physical Properties – Internal Friction Angle

ARCOSA LIGHTWEIGHT
DIRECT SHEAR TESTING (ASTM D 3080)

Test Series No. 11: Streetman TX Plant lightweight aggregate nominally compacted under as-received moisture conditions



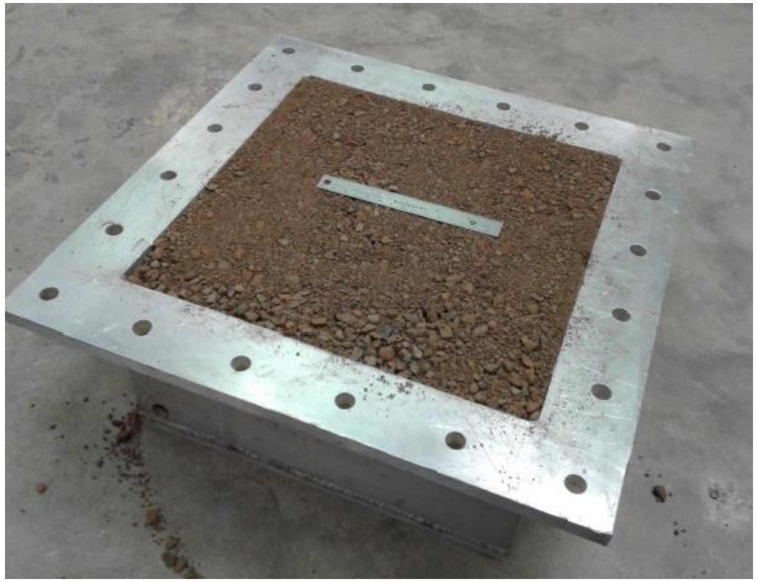


Test No.	Shear Box Size (in x in)	Normal Stress (psf)	Shear Rate (in/min)	Soaking Stress (psf)	Soaking Time (hour)	Consolidation Stress (psf)	Consolidation Time (hour)	Soil Compaction Moist Density (pcf)	Soil Compaction Moist Content (%)	Soil Compaction Moist Density (pcf)	Soil Compaction Moist Content (%)	Shear Strength τ_p (psf)	Shear Strength τ_r (psf)	Secant Angle ϕ_p (deg)	Secant Angle ϕ_r (deg)	Failure Mode
11A	12 x 12	250	0.04	-	-	250	0.5	65.0	5.7			335	201	53	39	(1)
11B	12 x 12	1000	0.04	-	-	1000	0.5					1069	721	47	36	(1)
11C	12 x 12	2000	0.04	-	-	2000	0.5					1981	1375	45	35	(1)

NOTES:
(1) Sliding (i.e., shear failure) was forced to occur along the shear plane between the upper and lower shear box.
(2) The reported total-stress parameters of friction angle and adhesion were determined from a best-fit line drawn through the test data. Caution should be exercised in using these strength parameters for applications involving normal stresses outside the range of the stresses covered by the test series. The large-displacement (LD) shear strength was calculated using the shear force measured at the end of the test.

SGI TESTING SERVICES, LLC

DATE OF REPORT:	5/6/2024
FIGURE NO.	1
PROJECT NO.	SGI20020
DOCUMENT NO.	
FILE NO.	



Physical Properties – Durability and Soundness

Table 3 – LA Abrasion (C Grading)

Passing	Retained on	Grading C Requirements (g)	Test Sample Size (g)
9.50 mm (3/8 in)	6.3 mm (1/4 in)	2,500 ± 10	2,500.0
6.3 mm (1/4 in)	4.75 mm (No. 4)	2,500 ± 10	2,500.0
	Total	5,000 ± 10	5,000.0
		Retained on #8 after Test	3,846.5
		Percent Loss	**23**

Table 4 - Magnesium Sulfate Soundness

Sieve Size	Grading of Original Sample *(% Retained)*	Mass of Test Fractions Before Test (g)	% Passing Designated Sieve After Test	Weighted % Loss
9.5 to 4.75 mm (⅜ to #4)	67.5	300.0	7.0	4.7
			Percent Loss	**4.7**

Table 5 - Sodium Sulfate Soundness

Sieve Size	Grading of Original Sample *(% Retained)*	Mass of Test Fractions Before Test (g)	% Passing Designated Sieve After Test	Weighted % Loss
9.5 to 4.75 mm (⅜ to #4)	67.5	300.0	1.7	1.1
			Percent Loss	**1.1**

- Durability and Soundness Data
  - LA Abrasion 23% loss
  - Magnesium Sulfate 4.7% loss
  - Sodium Sulfate 1.1% loss

Physical Properties - Electrochemical

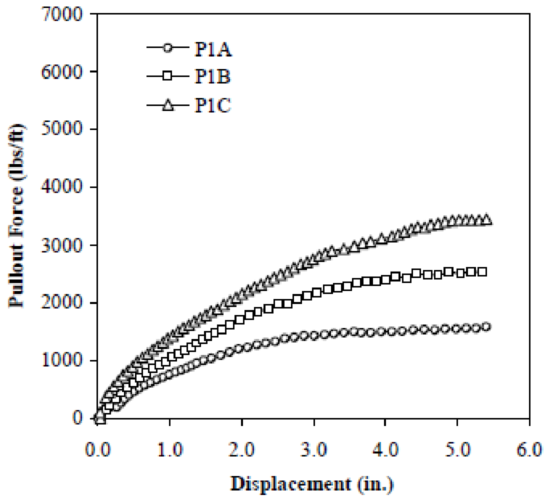
Chemical Composition	Test Results	Requirements
AASHTO T290 Soluble Sulfate Ion - (ppm)	186*	< 200 ppm
AASHTO T291 Water Soluble Chloride Ion - (ppm)	60	< 100 ppm
AASHTO T288 - (Modified Resistivity) – As Received	5,690*	>3000 ohms-cm
AASHTO T289 - (Ph)	9.57*	5 – 10

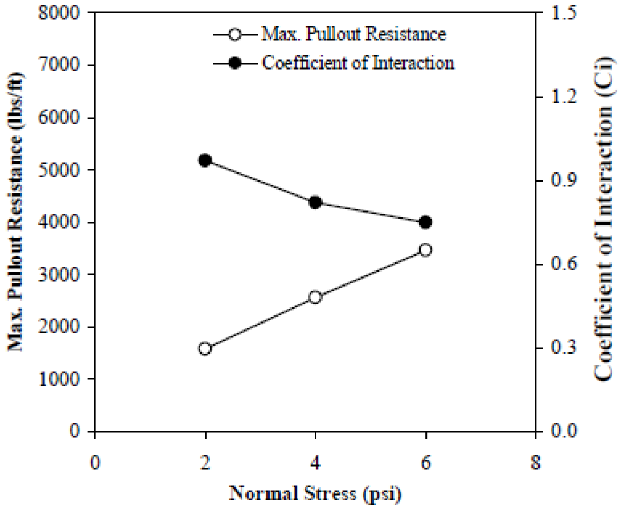
- Electrochemical Data
  - Soluble Sulfate Ion – 186 ppm
  - Soluble Chloride Ion – 60 ppm
  - Resistivity – 5,690 ohm-cm
  - pH – 9.57

Physical Properties – Geosynthetic Pullout Resistance

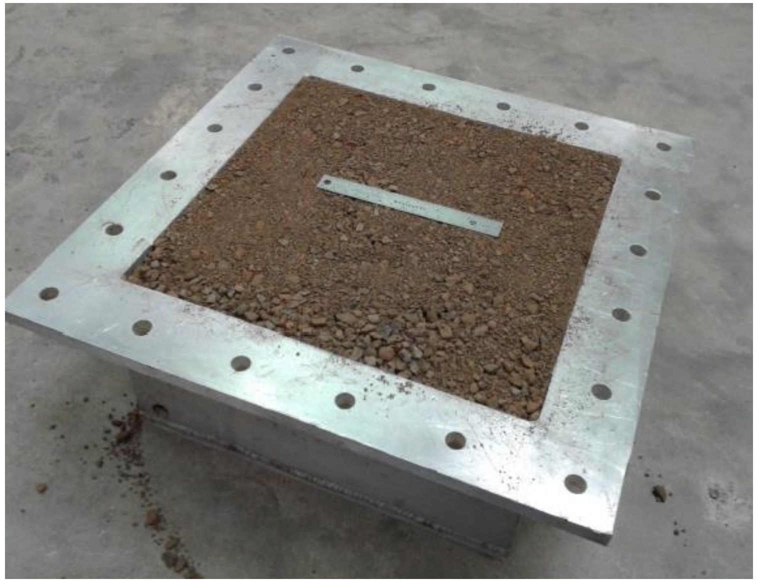
GEOSYNTHETIC PULLOUT TESTING (ASTM D 6706)

TEST SERIES NO. P1: Tensar UXMESA 3 (Quint) geogrid in machine direction within compacted Big River expanded clay lightweight aggregate materia under as-received moisture condition





Test No.	Test Specimen Width (in.)	Test Specimen Length (in.)	Normal Stress (psi)	Pullout Rate (in./min)	Residual Soil Shear Strength		Maximum Pullout Resistance (lb/ft)	Coefficient of Interaction	Failure Mode
					ϕ (degree)	c (psf)			
P1A	17.0	50.0	2.0	0.04	32	15	1578	0.97	Pullout
P1B	17.0	50.0	4.0	0.04	32	15	2563	0.82	Pullout
P1C	17.0	50.0	6.0	0.04	32	15	3464	0.75	Pullout



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Lateral Earth Pressure

Lateral Earth Pressure is defined by the following formula:

$$F = 1/2\ \alpha H^2 K_a$$

α is the density in lbs./ft^3

H is the wall height in feet

K is the active earth pressure coefficient and is calculated by the following:

$$K_a = \frac{1 - \sin \varphi}{1 + \sin \varphi}$$

φ is the internal friction angle

Lateral Earth Pressure – Wall Height of 15 Feet

Select Fill

α of 115.0 lbs./ft^3

φ of 30 degrees

K_a is 0.33

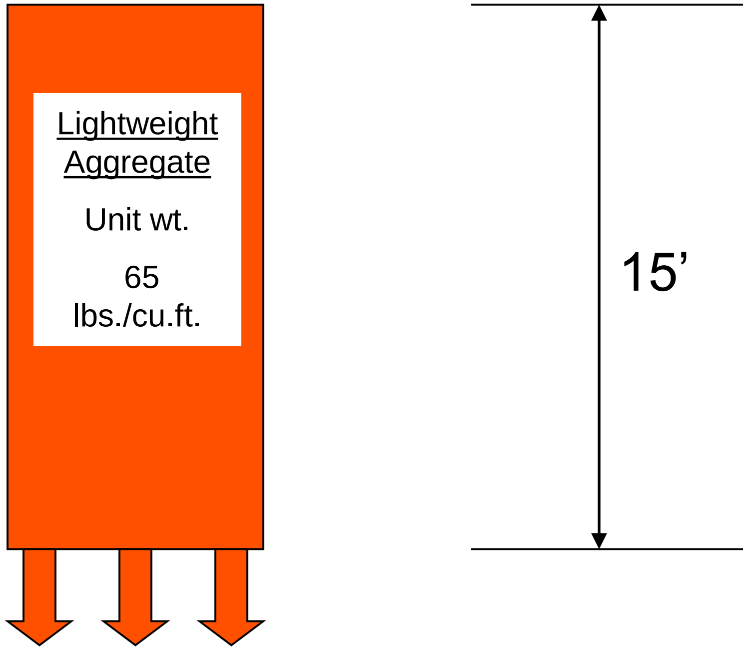
F = ½ (115)(15)^2 (0.33) = **4, 270 pounds per foot** of lateral earth pressure

Expanded Shale Lightweight Aggregate

α of 65 lbs./ft^3
φ of 43 degrees
K_a is 0.19
F = ½ (65)(15)^2 (0.19) = **1,176 pounds per foot** of lateral earth pressure

30% of the lateral earth pressure compared to quarried backfill

Vertical Pressure – Wall Height of 15 Feet



σ_v = 65 x 15 = **975 lbs./sf**.

σ_v = 115 x 15 = **1,725 lbs./sf**

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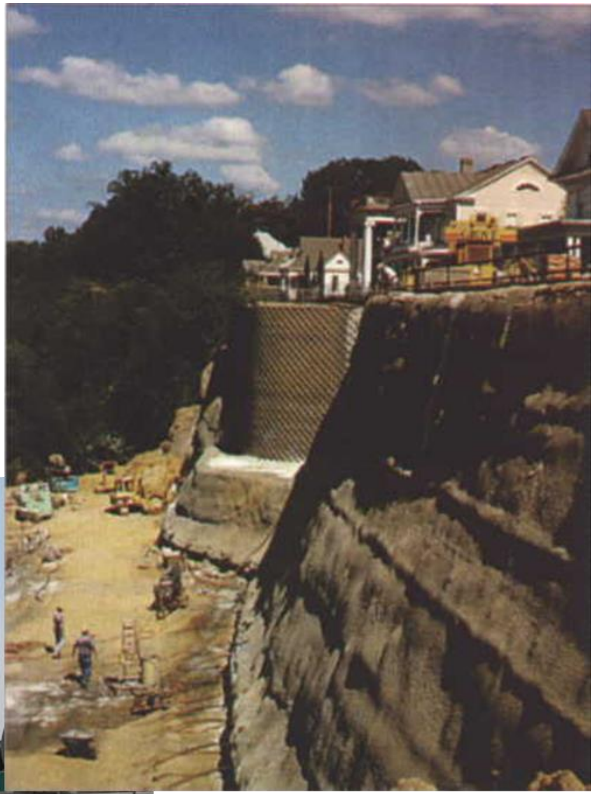
Lightweight Fill Project Profiles



Lightweight Fill Project Profile

US 17 Bypass at SC 707/Farrow Parkway Interchange Project - SCDOT

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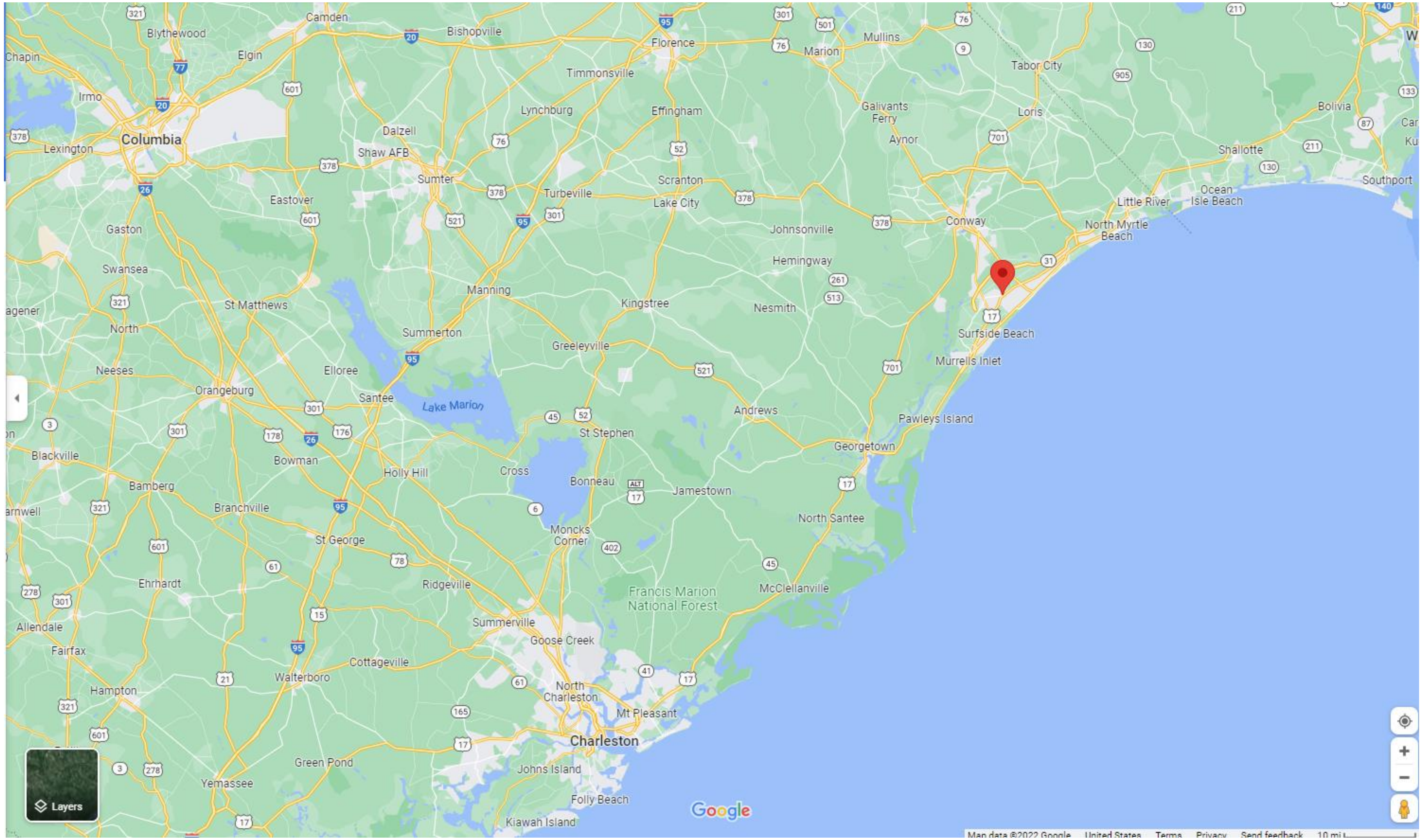
Lightweight Fill Project Profile

US 17 Bypass at SC 707/Farrow Parkway Interchange Project - SCDOT



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Lightweight Fill Project Profile

US 17 Bypass at SC 707/Farrow Parkway Interchange Project - SCDOT

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Lightweight Fill Project Profile

US 17 Bypass at SC 707/Farrow Parkway Interchange Project - SCDOT

- $120 million redesign of an at-grade intersection by STV
- Dual 1,250’ long bridges and associated ramps
- Coastal SC project with poor-bearing soils that required geotechnical modifications to support the structure, roadway, walls and drainage features
- Located near one of the most active earthquake zones on the East Coast

Lightweight Fill Project Profile

US 17 Bypass at SC 707/Farrow Parkway Interchange Project - SCDOT

Project Constraints

- High existing traffic volume
- No lane closure during summer
- Maintain access to numerous businesses
- 3.5 year construction requirement

Complex Construction Traffic Control

- 8 stages of construction
- Multiple traffic shifts
- Temporary alignments
- Detour routes

Lightweight Fill Project Profile

US 17 Bypass at SC 707/Farrow Parkway Interchange Project - SCDOT

Geotechnical Challenges

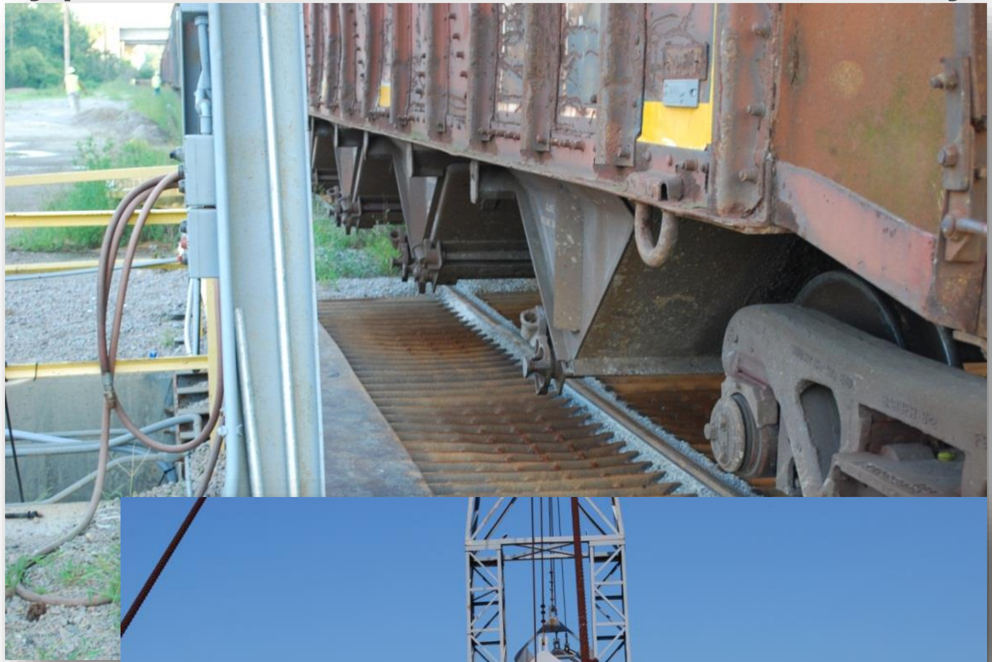
- Poor Subgrade conditions
  - 2' – 3' Bridge lift Required
- Settlement concerns – Total & Differential
- Slope Embankment stability – bearing and seismic

Geotechnical Design Approach

- Lightweight Aggregate Borrow
  - Reduce Magnitude of Settlement
- Prefabricated Vertical Drain (PVD) / Granular Surcharges
  - Increase Rate of Settlement and Facilitate Rapid Construction
- Deep Soil Mixing
  - Improve Seismic Slope Stability and Bridge Abutment Foundation Performance
- Mechanically Stabilized Earth (MSE) Walls
  - 2-Stage MSE Wall Construction with Vertical Slip Joints

Lightweight Fill Project Profile

US 17 Bypass at SC 707/Farrow Parkway Interchange Project - SCDOT



Lightweight Fill Project Profile

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Lightweight Fill Project Profile

US 17 Bypass at SC 707/Farrow Parkway Interchange Project - SCDOT

Project Recognition

NATIONAL RECOGNITION AWARD
2016 Engineering Excellence Award
American Council of Engineering Companies

STATE FINALIST AWARD
2016 Engineering Excellence Award - Transportation
American Council of Engineering Companies of South Carolina

Lightweight Fill Project Profile

Cruise Terminal 3 (CT-3) Marine Works Port Canaveral, Florida

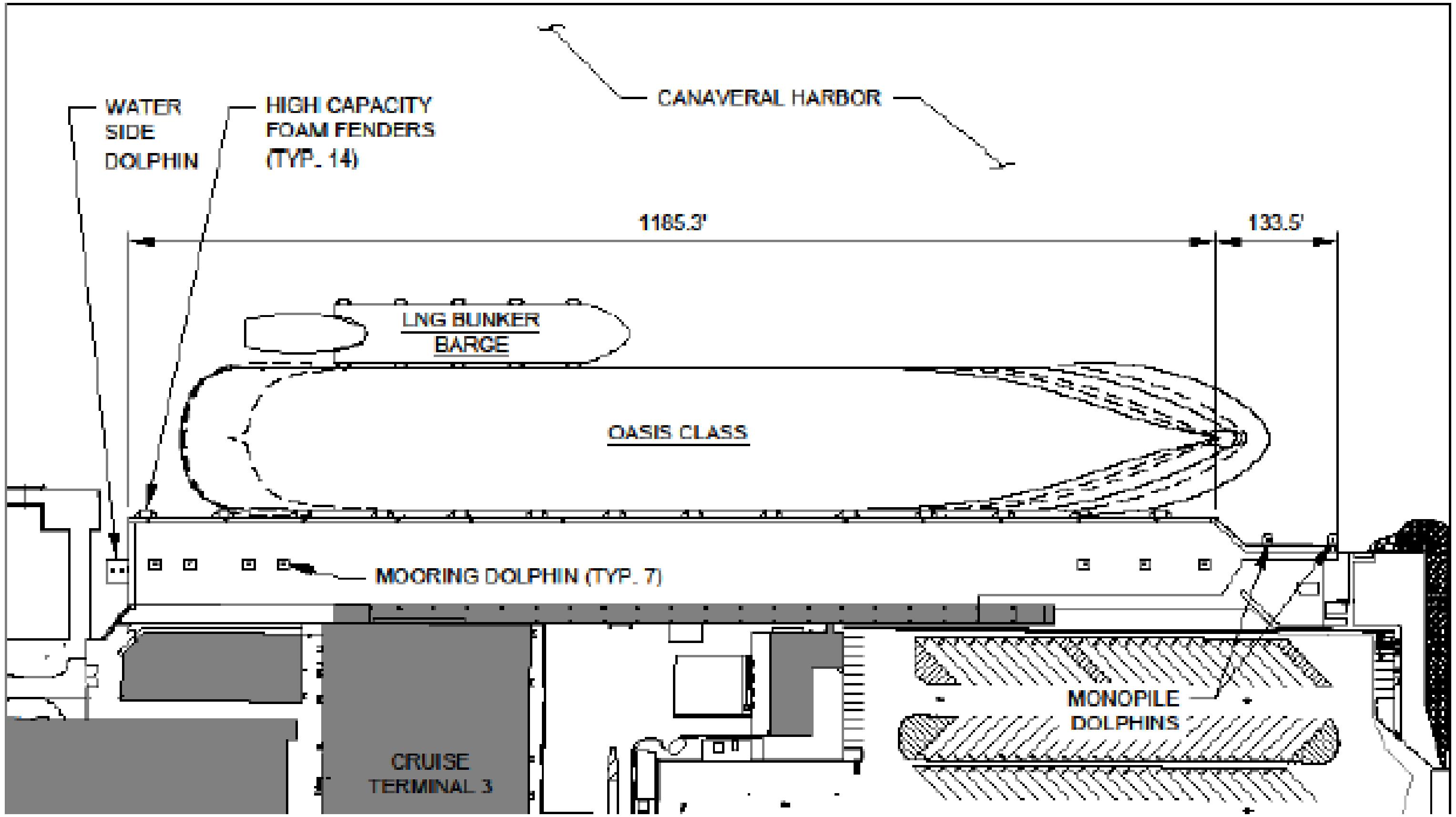


Figure 1. CT3 Site Plan

***Port Canaveral Cruise Terminal 3 Wharf Design and Construction** Gary D. Ledford, P.E., M. ASCE, Bill Crowe, P.E., M. ASCE Ports19 Paper and Presentation

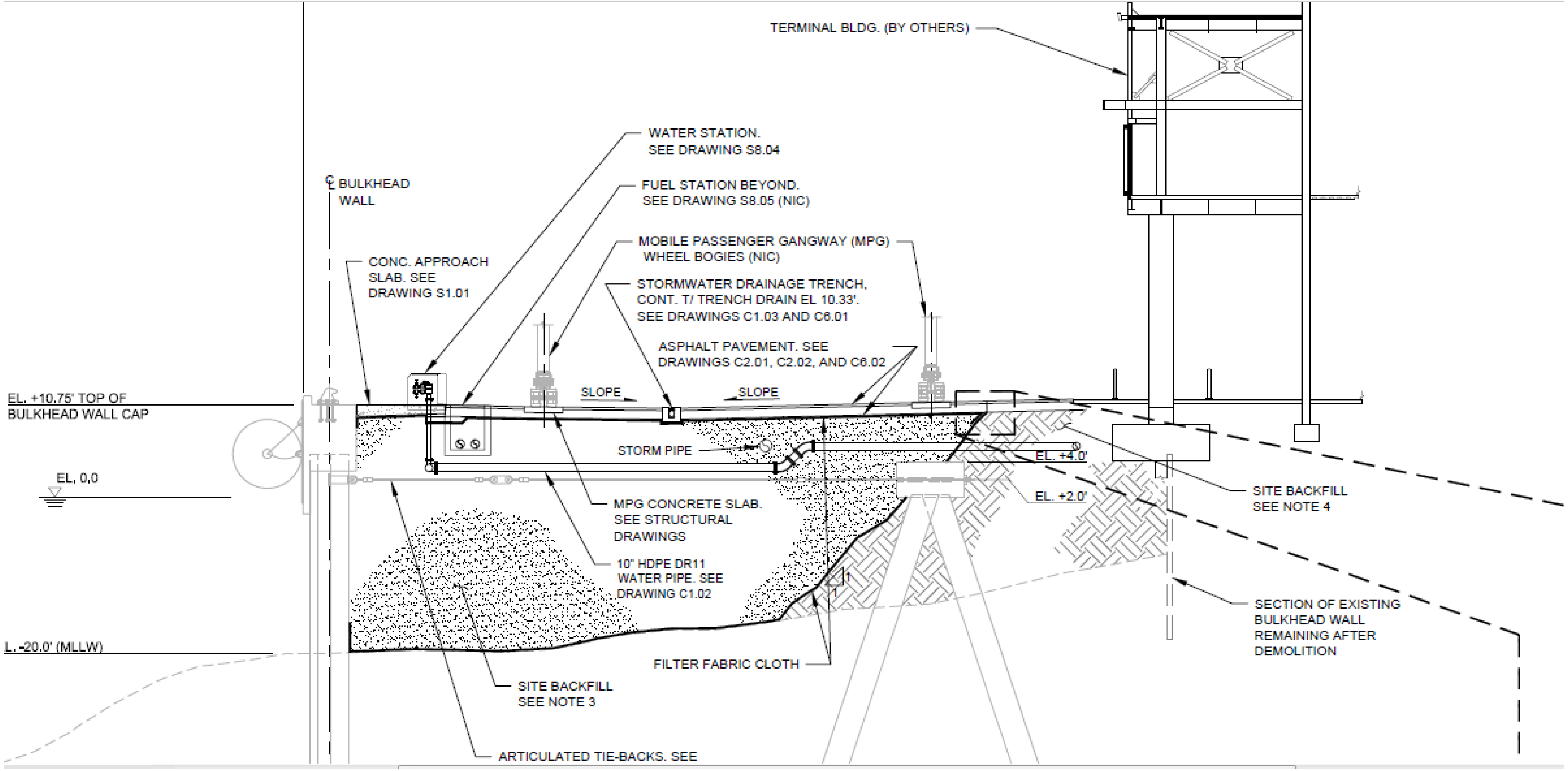
Lightweight Fill Project Profile

Cruise Terminal 3 (CT-3) Marine Works Port Canaveral, Florida

- Rebuild of Cruise Terminal 3 to accommodate the increasing size of cruise vessels (Oasis Class)
- Constructed in 1983, the existing open pile wharf was functionally obsolete
- Berth construction and new terminal building were constructed simultaneously
- Lightweight aggregate fill was used to lower the demand on the bulkhead to facilitate reducing the steel pipe-pile section
- The creative lightweight aggregate fill solution provided considerable cost savings in the steel Combiwall section, the depth required, and reduction in the expected long-term settlement of the site.

Lightweight Fill Project Profile

Cruise Terminal 3 (CT-3) Marine Works Port Canaveral, Florida



Lightweight Fill Project Profile

Cruise Terminal 3 (CT-3) Marine Works Port Canaveral, Florida

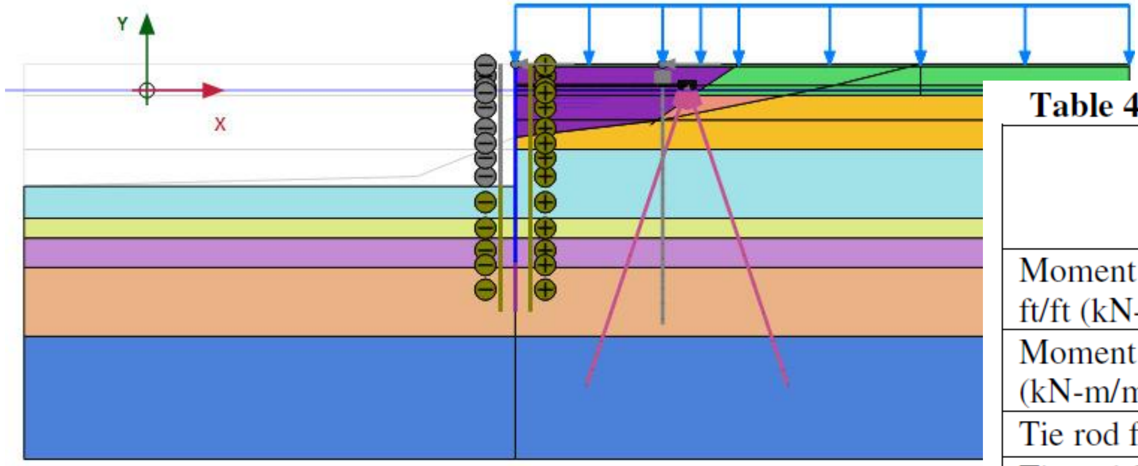


Table 4. Main Bulkhead Plaxis Analysis Results

Description	West Side Bulkhead		East Side Bulkhead (Note 1)
	Regular Fill	LWF	LWF
Moment (Extreme Condition) kip-ft/ft (kN-m/m)	841 (3741)	501 (2229)	395 (176)
Moment (Normal Condition) kip-ft/ft (kN-m/m)	684 (3043)	407 (1811)	301 (1339)
Tie rod force (Extreme) kip/ft (kN/m)	52.5 (766)	37 (540)	34 (496)
Tie rod force (normal) kip/ft (kN/m)	45.4 (663)	29.2 (426)	26.6 (388)
Notes: (1) Regular fill case was not analyzed for east side bulkhead.			

Table 4 indicates that based on west side bulkhead analysis results, bulkhead bending moment would decrease by 40% by using lightweight fill, and the tie rod force would decrease by 30% to 35%. Based on a cost comparison, the savings resulting from the reduction of bulkhead and anchor size would outweigh the lightweight fill cost by approximately $3 million US. The final bulkhead was designed based on the lightweight fill (LWF) case.

***Port Canaveral Cruise Terminal 3 Wharf Design and Construction** Gary D. Ledford, P.E., M. ASCE, Bill Crowe, P.E., M. ASCE Ports19 Paper and Presentation

Lightweight Fill Project Profile

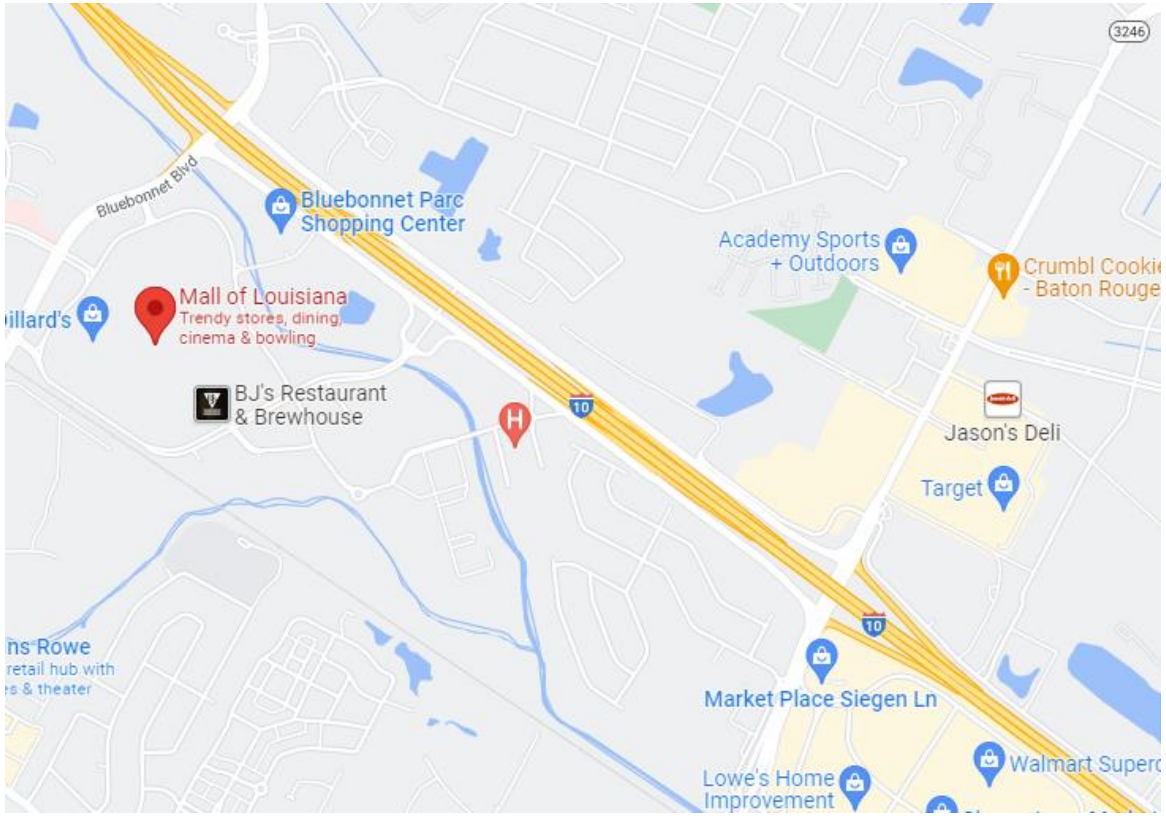
Cruise Terminal 3 (CT-3) Marine Works Port Canaveral, Florida

Lightweight Fill Project Profile

Cruise Terminal 3 (CT-3) Marine Works Port Canaveral, Florida

Lightweight Fill Project Profile

LaDOTD Picardy Avenue Interchange at I-10 Baton Rouge, LA



- Need to reduce traffic congestion at I-10 at Bluebonnet Road and Siegen Lane
- Project added a new overpass above I-10
- Provided access to the Mall of Louisiana via the new Picardy Avenue extension
- Created two one-way eastbound and westbound frontage roads connecting Siegen Lane and Bluebonnet Blvd.

Lightweight Fill Project Profile

LaDOTD Picardy Avenue Interchange at I-10 Baton Rouge, LA

- Geotechnical Challenges
  - Low bearing capacity soils at retaining wall locations
  - Site geometry required MSE wall heights of 30 – 40 feet
  - Critical wall height was 22 feet using natural select fill
  - Transitioned to lightweight aggregate fill at 22 feet up to the maximum wall height
- Using LWA fill reduced the applied pressure on the low bearing capacity soils

Lightweight Fill Project Profile

LaDOTD Picardy Avenue Interchange at I-10 Baton Rouge, LA

Lightweight Fill Project Profile

LaDOTD Picardy Avenue Interchange at I-10 Baton Rouge, LA

Lightweight Fill Project Profile

LaDOTD Picardy Avenue Interchange at I-10 Baton Rouge, LA

Lightweight Fill Project Profile

LaDOTD Picardy Avenue Interchange at I-10 Baton Rouge, LA

- 214,000 ft^2 of modular block retaining walls
- 120,000 $yards^3$ of lightweight aggregate
- $50.6 million project was completed November 2006

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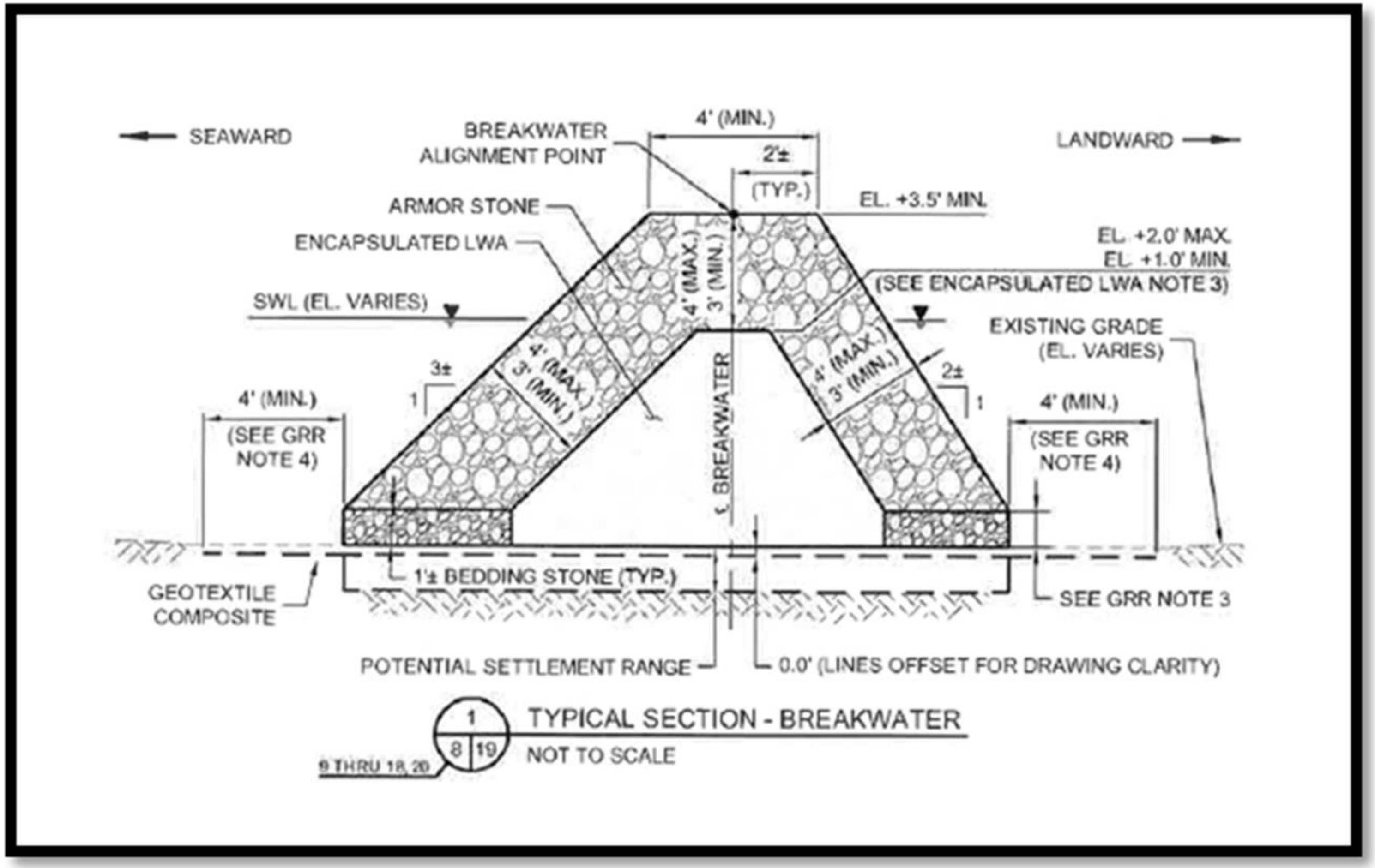
Coastal Restoration

In an aerial view provided by Pontchartrain Partners, crews are seen placing rip-rip atop bags of lightweight aggregate along the Barataria Landbridge shoreline.

Coastal Restoration Project Utilizes Lightweight Aggregate Encapsulated in Geotextile Bags

Louisiana is shrinking. By some estimates, the state loses roughly 16-square miles of coastline every year. Bays and bayous marked on nautical maps for centuries have vanished, washed away by decades of erosion and storm surge. A series of projects hopes to change that.

Lightweight Aggregate Core for Breakwater Structures



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Lightweight Aggregate Core for Breakwater Structures

Rockefeller Refuge Shoreline Stabilization

Rockefeller Refuge Shoreline Stabilization

Geotechnical Properties

Summary

Loose Bulk Density **42 - 62 pcf**	High Internal Friction Angle **40º - 43º**	pH **8.5 - 9.6**
Granular and Free Draining Aggregate **> 300 in/hour**	Durable (LA Abrasion) **17 - 30% loss**	Specific Gravity **1.4 – 2.1**

Questions

MOVING
INFRASTRUCTURE
FORWARD