

# **EXPANDED SHALE CLAY AND SLATE LIGHTWEIGHT AGGREGATE GEOTECHNICAL FILL**

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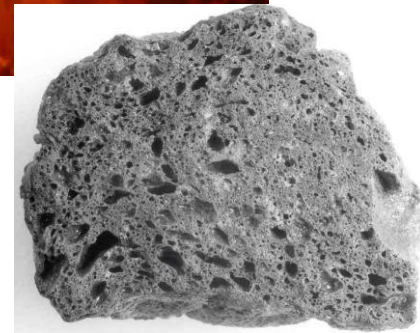
# Structural Lightweight Aggregate

LWA is a manufactured aggregate

- Raw material is shale, clay or slate
- Expanded in a kiln at 1900-2200 deg. F



- Gas bubbles formed in softened material are trapped when cooled



# Relative Density of Lightweight vs. Normal Weight Aggregate

Relative density for rotary kiln expanded lightweight aggregates

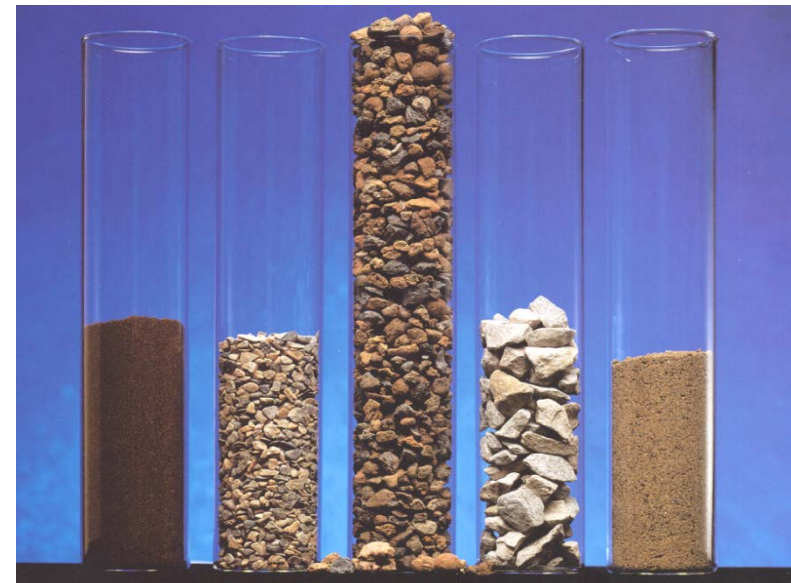
- Range from 1.3 to 1.6

Relative density for normal weight aggregates

- Range from 2.6 to 3.0

Twice the volume for same mass

Half the mass for the same volume



Soil  
Gravel  
ESCS Agg.  
Limestone  
Sand

**1 lb. of each aggregate**

# Physical Properties of LWA

Vitrified ceramic material

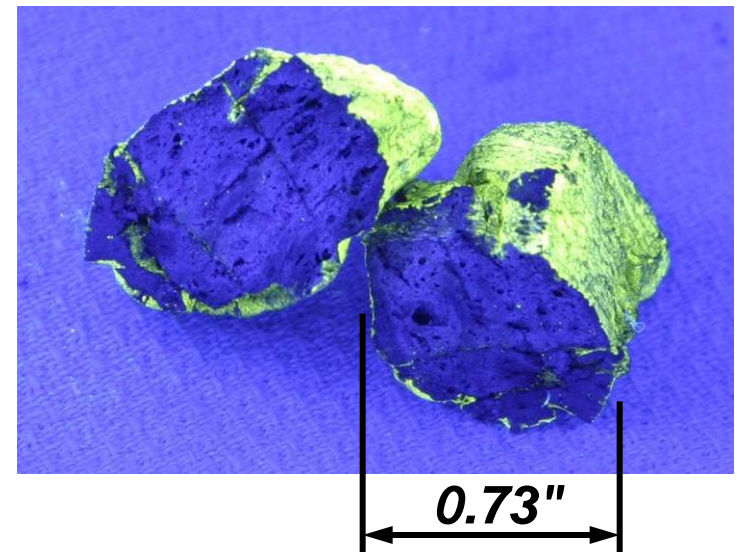
- Hardness equivalent to quartz

Pores with limited connectivity reduce density

- Results in increased absorption
- But does not act like a sponge

An expanded slate LWA particle soaked in water with fluorescent yellow dye for 180 days, then split open.

Absorption at the time of testing was 8% by mass.





# Aggregate Gradations

- After crushing and screening, lightweight aggregate (LWA) fractions are blended for
  - Uniformity of specific gravity
  - Optimal gradation
- LWA conforms to AASHTO M 195 gradations & other properties
  - Coarse sizes shown
  - Several gradations of aggregate (sand) available



# $\frac{3}{4}$ inch Lightweight Aggregate

- 50 to 60 pcf in-place density
- Internal angle of friction ( $\phi$ ) above  $40^\circ$
- Soundness loss less than 1%
- LA Abrasion 25 to 31%
- Chlorides, sulfates, pH and resistivity meet FHWA MSE wall requirements
- Free draining

# Physical Properties of LWA

## Soundness Test Results for ¾" Gradations

- Average all sources 0.62%
- Carolina Stalite – Gold Hill 0.90% (2011)
- Carolina Stalite – Aquadale 0%

## NCDOT requirements – Std Specs 1014-2 (B)

- General requirement 15%
- For  $f'_c > 6$  ksi 8%
- For lightweight aggregate 10%

# Physical Properties of LWA

## LA Abrasion Test Results for $\frac{3}{4}$ " Gradations (A)

- Average all sources 31.3%
- Carolina Stalite – Gold Hill 31%
- Carolina Stalite – Aquadale 27%

## NCDOT requirements – Std Specs 1014-2 (D)

- General requirement 55%
- For  $f'_c > 6$  ksi 40%
- For lightweight aggregate None



Test	FHWA Specification	11 <sup>th</sup> St. Test Results
pH	5.0 – 10.0	8.3
Chlorides	< 100 ppm	< 1 ppm
Sulfates	< 200 ppm	32.1 ppm
Resistivity	>3,000 ohm-cm	35,209 ohm-cm
Organic Content	1% Maximum	0 %

Date	Testing Agency	Direct/ Triaxial	Sample Size	Material Size	Angle of Internal Friction
11-14-11	Geotesting Exp.	(COE1110)	3x6	3/4"	47°
11-11-11	Geotesting Exp.	Triaxial	3x6	3/4"	43°
9-06-05	S&ME	Direct	12x12	3/4"	45°
8-22-05	ECS	Triaxial	2.8 x 5.5	5/16"	42°
1-10-03	Mactec	Triaxial	6 x 12	3/4"	43°
8-12-91	Law	Triaxial	6 x 12	3/4"	43°
8-12-91	Law	Triaxial	6 x 12	3/4"	45°
8-12-91	Law	Triaxial	6 x 12	3/4"	44°
8-12-91	Law	Triaxial	6 x 12	3/4"	46°
8-12-91	Law	Triaxial	6 x 12	3/4"	43°
8-12-91	Law	Triaxial	6 x 12	3/4"	40°
8-12-91	Law	Triaxial	6 x 12	3/4"	46°
8-12-91	Law	Triaxial	6 x 12	3/4"	41°
8-12-91	GA Tech	Triaxial	12 x 24	3/4"	44°
8-12-91	GA Tech	Triaxial	12 x 24	3/4"	45°

# Permeability

Typical values of coefficient of permeability or hydraulic conductivity

Soil Type	k cm/sec	k ft/min.
Clean Gravel	1.0 to 100	2.0 to 200
Coarse Sand	0.01 to 1.0	0.02 to 2.0
Fine Sand	0.001 to 0.01	0.002 to 0.02
Silty Clay	0.00001 to 0.001	0.00002 to 0.002
Clay	< 0.000001	< 0.000002

$\frac{3}{4}$ " x #4 – 2.3 cm/sec

# General Engineering Properties of ¾” to #4 Gradation

Aggregate Property	Measuring Method	Test Method	Commonly Used Specifications of ESCS* Aggregate	STALITE Expanded Slate Lightweight Aggregate	Typical Design Values for Ordinary Fills
Soundness Loss	Magnesium Sulfate	AASHTO T 104	< 30%	< 1%	< 6%
Abrasion Resistance	Los Angeles Abrasion	ASTM C 131	< 40%	25 - 28%	10 - 45%
Chloride Content	Chloride Content of Soils	AASHTO T 291	< 100 ppm	< 40 ppm	
Grading	Sieve Analysis	ASTM C 136	¾" x #4	¾" x #4	
Compacted Density	Density Test	ASTM D 698	< 70 lb/ft <sup>3</sup>	60 lb/ft <sup>3</sup> wet 55 lb/ft <sup>3</sup> dry	100 - 130 lb/ft <sup>3</sup>
Stability (Phi Angle, Φ)	Direct Shear Consolidated Drained	ASTM D 3080	35° - 45° +	40° - 46°	26° - 38°
	Triaxial Test Consolidated Drained	ASTM D 4767			
Loose Bulk Density (Unit Weight)	Loose	ASTM C 29	Dry 50 lb/ft <sup>3</sup> Saturated < 65 lb/ft <sup>3</sup>	Dry 48 lb/ft <sup>3</sup> Saturated 50 lb/ft <sup>3</sup>	89 - 105 lb/ft <sup>3</sup>
pH	pH Meter	AASHTO T 289	5 - 10	7 - 9	5 - 10



# Compaction and Density Control of ESCS Fill

## Specification Methods

### One Point Proctor

- ASTM D698 Modified
- Tested at Received MC
- Maximum density specified
- Can be run in Field or Lab

### Relative Density

- ASTM D4253 and D4254
- Typically 65% minimum Relative Density
- Lab Test Only

# ESCSI Recommended Compaction Procedure for LW Coarse Aggregate

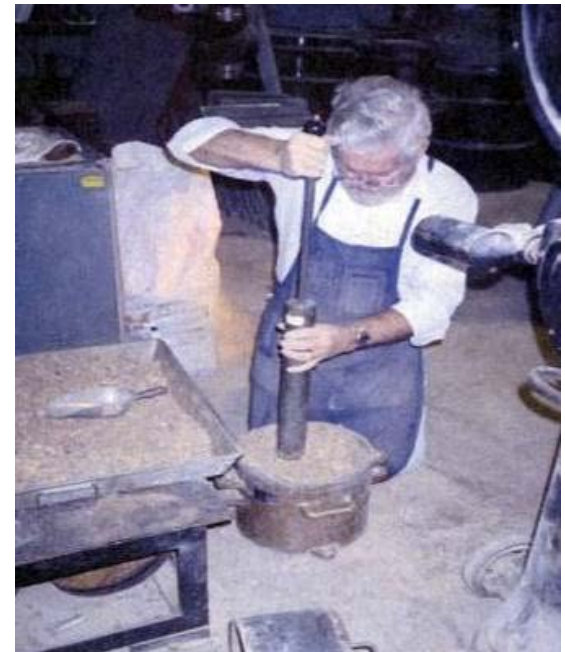
*Based upon the results of laboratory tests as well as the experience gained in field testing on major lightweight [coarse] aggregate geotechnical projects, ESCSI recommends the following procedure:*

Compacted moist density shall be determined by a modification of ASTM D 698 (AASHTO T 99) “*Standard Test Methods For Laboratory Compaction Characteristics For Soil Using Standard Effort.*” The aggregate shall be placed in three layers in a standard 0.5 cubic foot bucket, with each layer compacted by 25 blows of a 5.5 pound hammer dropped from a distance of 12 inches. The aggregate is compacted only once at the received moisture content.

This procedure is referred to as the One Point Proctor (OPP).

# One Point Proctor Test (Modified ASTM D 698)

- The LWA is placed in a 0.5 cf bucket in 3 layers, with each layer compacted by 25 blows of a 5.5 lb rammer dropped 12" per ASTM D 698 procedures
- LWA sample tested only once at the as received moisture content



# Two Examples From ESCSI Laboratory Compacted Density Program

Specimen	Relative Density Max D 4254 Min D 4253 Difference	One Point Proctor Min D 4253 Difference	<u>OPP</u> RD	Densification
“U” 3/8-#8 SA	57.4 <u>50.2</u> 7.2	57.3 <u>50.2</u> 7.1	1.00	1.14
“V” 3/4-#4 SR	41.6 <u>36.8</u> 4.7	39.4 <u>36.8</u> 2.6	0.95	1.07



# One Point Proctor (OPP) Test

## Average of 6 Tests

Tested at “as delivered” moisture content

Ratio of OPP to Maximum Relative Density

- $OPP / \text{Max RD} = 1.0$

Densification due to compaction

- Average            1.08
- Range             1.05 to 1.14

Increase in density due to compaction

- Average            3.8 pcf
- Range             1.7 to 7.2 pcf

# Dry Loose Density – ASTM D 4254 or “Minimum Index Density”

This test is used to determine the minimum index dry density of oven-dried cohesionless, free-draining soils that contain up to 15%, by dry mass, of particles passing a #200 sieve. There are three acceptable methods, but only the most common, Method A, is shown here:

The sample is placed in either a 0.100 or 0.500 ft<sup>3</sup> mold using a funnel or a hand scoop to place material in the mold. If a funnel is used, its height above the material should be adjusted continuously to maintain a soil free fall of ~ 0.5 inch.

# Minimum Index Density

After filling the mold, excess soil is carefully screed off. The volume of this mold is  $0.1 \text{ ft}^3$ .

Knowing the weight of soil in the mold, the dry density is easily computed



# Dry Compacted Density – ASTM D 4253 or “Maximum Index Density”

This method is used to determine the maximum-index dry density of cohesionless, free-draining soils that contain up to 15%, by dry mass, of particles passing a #200 sieve and 100% passing a 3-in. sieve. This method requires that oven-dried soil be placed in a mold of known volume and compacted by a 2 psi force. The mold is then vibrated at a specified frequency and for a specified time using an electromagnetic or eccentric/cam-driven vertically vibrating table.

The maximum dry density can be calculated from the equation:

$$\gamma = m/v$$

Where:  
m = mass of the sample  
v = volume of the sample

# Maximum Index Density



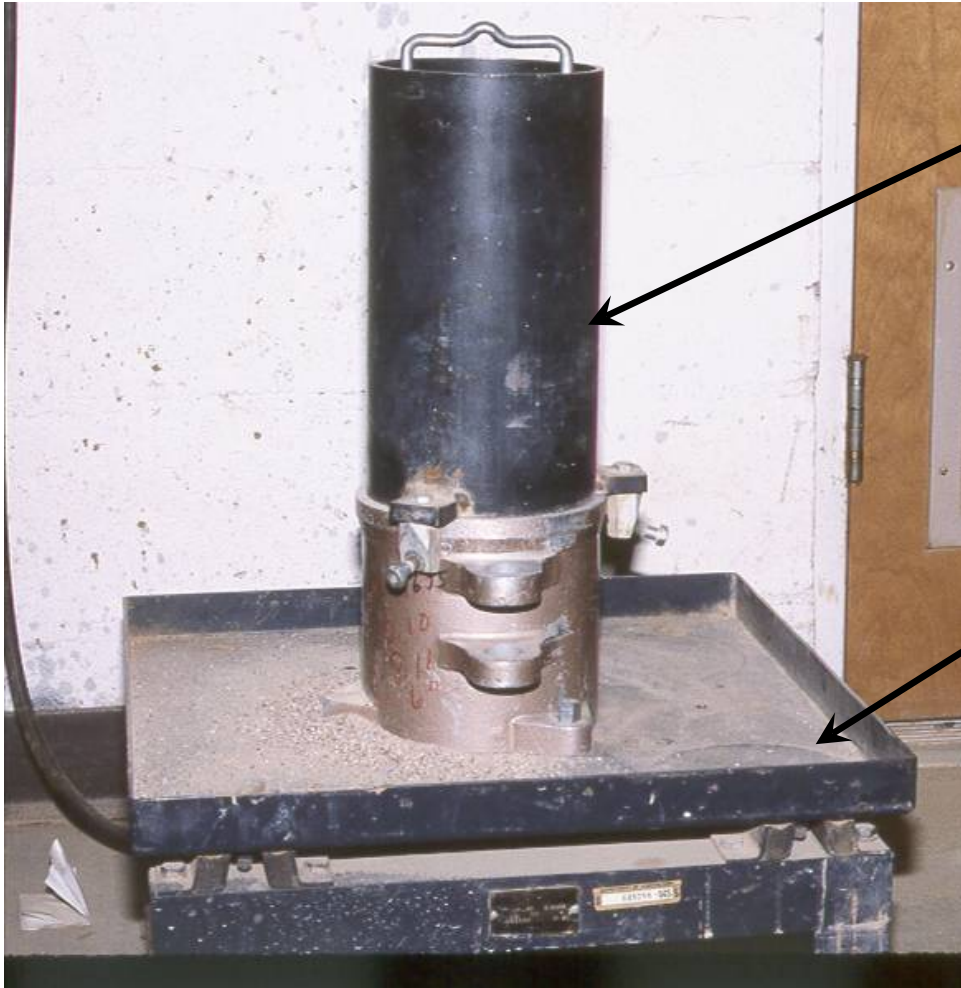
Weight on  
sample

Sleeve

Vibratory  
table



# Maximum Index Density

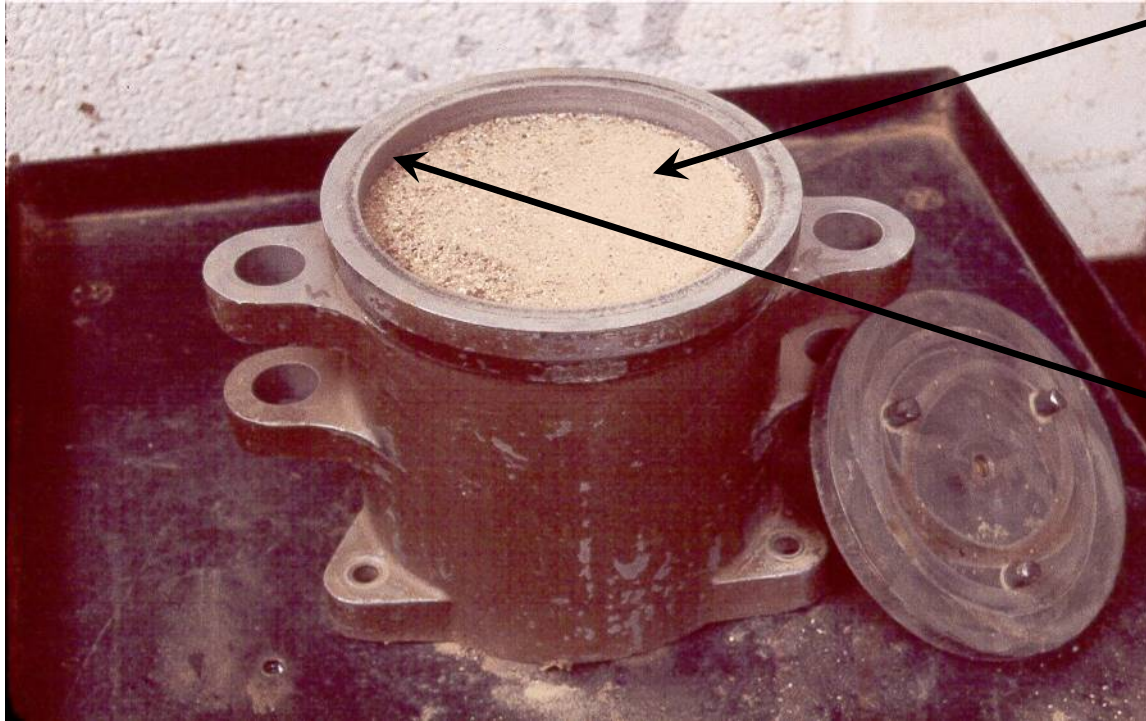


Weight on  
sample inside  
sleeve

Vibratory  
table



# Maximum Index Density



Sample  
densified by  
vibration

Measure D  
height to  
determine  
new  $\gamma_d$

# Minimum Relative Density

The minimum relative density,  $D_d$ , is calculated using the following equation:

$$D_d (\%) = \frac{\gamma_{d \max} (\gamma_d - \gamma_{d \min})}{\gamma_d (\gamma_{d \max} - \gamma_{d \min})} \times 100$$

where:

$\gamma_{d \max}$  = maximum index density as determined by ASTM D 4253

$\gamma_{d \min}$  = minimum index density as determined by ASTM D 4254

$\gamma_d$  = measured in-place density as determined by ASTM D 1556 *“Standard Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method”* or other appropriate method approved by the engineer.

Material is typically required to be compacted to a minimum 65% relative density as determined by ASTM D 4254.

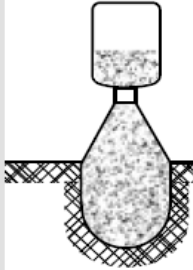
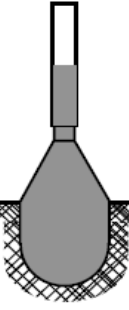

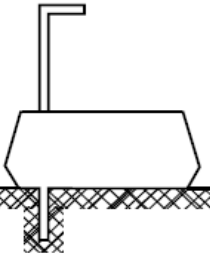


# Field Density Control

While open graded coarse aggregate is often thought of as self-compacting, this is not really the case.

All open graded coarse aggregates, lightweight included, require some level of compaction to give the maximum stability and minimize settlement of the aggregate.

# Field Density Testing Methods

	Sand Cone	Balloon Densometer	Shelby Tube	Nuclear Gauge
				
<b>Advantages</b>	<ul style="list-style-type: none"> <li>• Large sample</li> <li>• Accurate</li> </ul>	<ul style="list-style-type: none"> <li>• Large sample</li> <li>• Direct reading obtained</li> <li>• Open graded material</li> </ul>	<ul style="list-style-type: none"> <li>• Fast</li> <li>• Deep sample</li> <li>• Under pipe haunches</li> </ul>	<ul style="list-style-type: none"> <li>• Fast</li> <li>• Easy to redo</li> <li>• More tests (statistical reliability)</li> </ul>
<b>Disadvantages</b>	<ul style="list-style-type: none"> <li>• Many steps</li> <li>• Large area required</li> <li>• Slow</li> <li>• Halt equipment</li> <li>• Tempting to accept flukes</li> </ul>	<ul style="list-style-type: none"> <li>• Slow</li> <li>• Balloon breakage</li> <li>• Awkward</li> </ul>	<ul style="list-style-type: none"> <li>• Small sample</li> <li>• No gravel</li> <li>• Sample not always retained</li> </ul>	<ul style="list-style-type: none"> <li>• No sample</li> <li>• Radiation</li> <li>• Moisture suspect</li> <li>• Encourages amateurs</li> </ul>
<b>Errors</b>	<ul style="list-style-type: none"> <li>• Void under plate</li> <li>• Sand bulking</li> <li>• Sand compacted</li> <li>• Soil pumping</li> </ul>	<ul style="list-style-type: none"> <li>• Surface not level</li> <li>• Soil pumping</li> <li>• Void under plate</li> </ul>	<ul style="list-style-type: none"> <li>• Overdrive</li> <li>• Rocks in path</li> <li>• Plastic soil</li> </ul>	<ul style="list-style-type: none"> <li>• Miscalibrated</li> <li>• Rocks in path</li> <li>• Surface prep required</li> <li>• Backscatter</li> </ul>
<b>Cost</b>	• Low	• Moderate	• Low	• High

None of these methods work well for coarse LWA

- Not necessary – just dump and compact like 57 or 67 stone

The method most often used for density control of lightweight aggregate is a combination of prescriptive compaction requirements and the modified ASTM D 698 test.

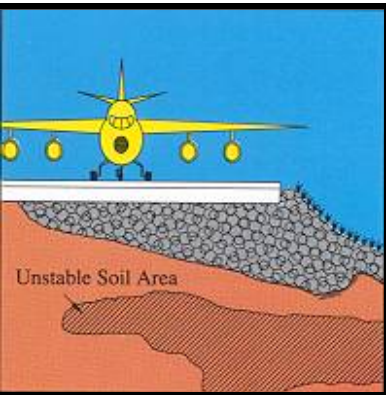
Typical prescriptive construction recommendations include:

- placing the material in approximately uniform horizontal layers and avoiding the operation of construction equipment other than compaction equipment on exposed lightweight aggregate.
- The thickness of the layers should not exceed 12 inches loose thickness when using a vibratory roller.
- The vibratory roller should have a static weight of no more than 12 tons and a minimum of two passes should be required in the area to be compacted.

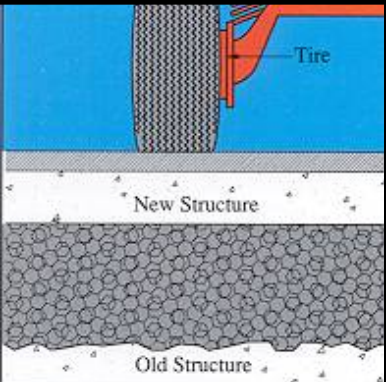
## Prescriptive Requirements Cont.

- In areas where portable vibratory plate compactors must be used because access does not allow the use of vibratory rollers, it is recommended that the maximum lift thickness be 6 inches and a minimum of 2 passes be made across the area.
- In this case, a pass is considered to be vibration of the area covered by the vibratory plate compactor for at least 10 seconds before moving to an adjacent location.

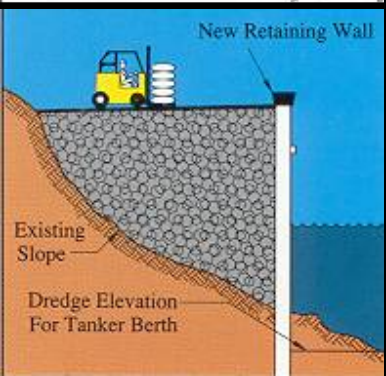
# Successful LWA Geotechnical Applications



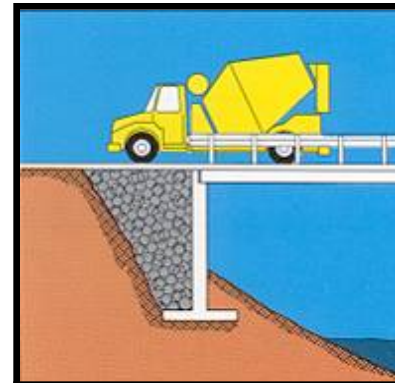
Fill Over Poor Soils  
& Marsh Lands



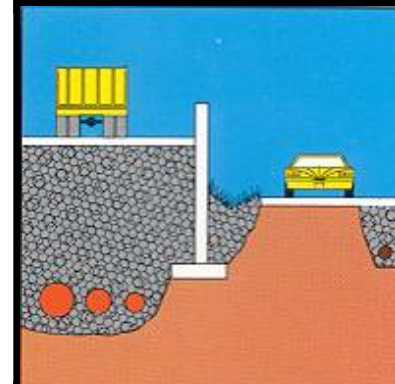
Structure Repair  
& Rehabilitation



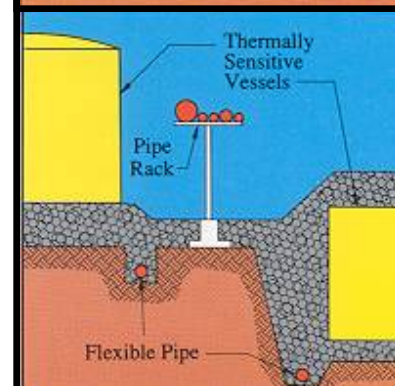
Waterfront  
Structures



Bulkheads &  
Retaining Walls

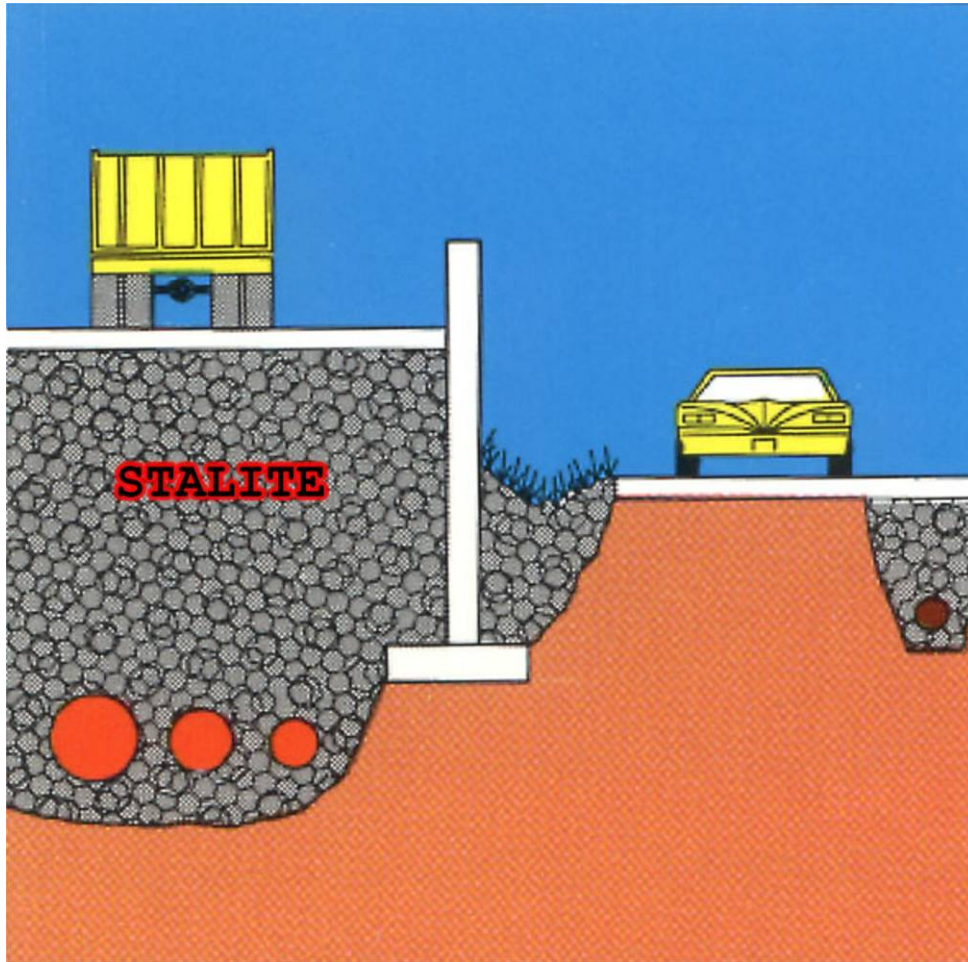


Underground  
Conduit &  
Pipelines



Insulating  
Backfill

# Underground Conduit and Pipelines



- Reduces dead load on buried pipes and structures
- Allows for higher fill construction over buried pipes and structures
- Minimizes hydrostatic potential
- Provides thermal insulation to underground pipes and structures
- Economical alternative to flowable fill

# **11<sup>TH</sup> ST. BRIDGE REPLACEMENT DESIGN-BUILD PROJECT**

Location: Washington, D.C.

Owner: District DOT

Designers: URS, HNTB Corp.

Geotechnical Engineer: JMT

Contractor: Skanska/Facchina JV

Winner of the Road and Bridge 2012 Bridge Project of the Year, the 11<sup>th</sup> Street Bridge Design-Build Project in Washington, D.C., is a great example of how innovative ideas lead to advances in construction.





One of the many innovative concepts used on the project was the extensive use of lightweight aggregate fill to speed the construction, reduce settlement under the roadway, and protect historic structures.

The project area contained storm water drainage outfall structures that were constructed in the 1850s.

- The historic structures had up to 20 feet of new fill being placed over them.
- In order to minimize the new load placed on the structures, lightweight aggregate fill was placed over the structures.
- Normal weight fill was used in areas not above the structures.

In the pictures, below you can see two of the areas where the lightweight aggregate fill was used. These locations were separated by normal weight fill in the non-load critical areas.



Lightweight aggregate was also used as backfill for MSE walls on the project. The project specifications for lightweight aggregate included specific limits on pH, chlorides, and resistivity along with the other requirements.

Test	Specification	Test Result
pH	7.0 – 9.0	8.3
Chlorides	< 100 ppm	< 1 ppm
Sulfates	Not specified	32.1 ppm
Resistivity	30,000 – 40,000 ohm-cm	35,209 ohm-cm
LA Abrasion	< 40 % loss	27.2 % loss

# Construction Testing of ESCS Fill

- A) Lightweight aggregate producer shall submit documentation of a compacted wet density of less than 65 lb/ft<sup>3</sup> determined from a one point proctor test conducted in accordance with a modified version of ASTM D 698
  
- B) Material shall be compacted to a minimum of 65% relative density in accordance with ASTM D 4253 and D 4254.

The modified ASTM D 698 proctor test is easy to run and was run on the materials as they were shipped to the project.

However, the determination of the in-place compacted density was more challenging because most in-place density tests cannot be used for any type of normal or lightweight coarse aggregate.

Two different sizes of steel boxes were placed in the fill area; the lightweight aggregate was then placed over the entire area and compacted.

The boxes were 1 cubic foot and 3 cubic feet in size, and three of each size box was used in the testing





After the compaction, the boxes were dug out of the fill by hand and weighed.

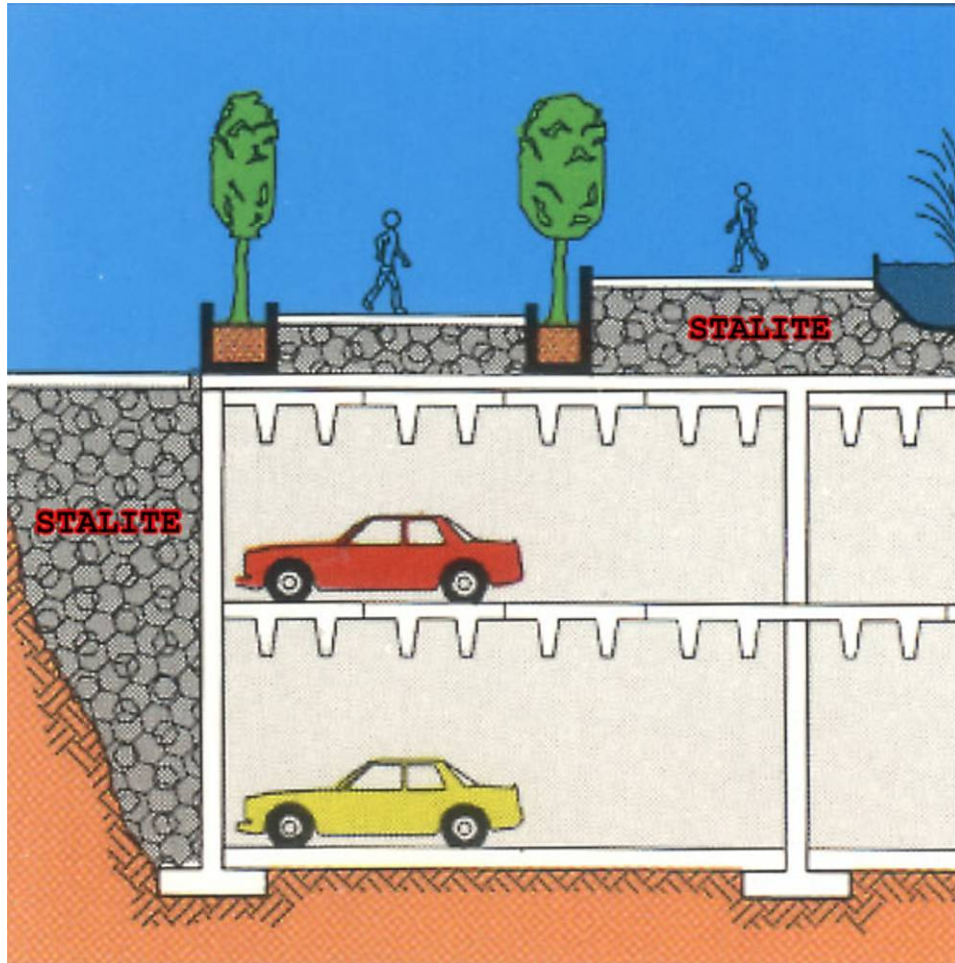


The tests indicated that

- The in-place density was lower than the specified maximum density
- The in-place density was greater than the 65% relative density required by the project specifications.
- The measured in-place densities were very similar to the modified D 698 proctor test results.



# Landscape and Plaza Fills



- Minimizes dead loads
- Free draining which helps minimize hydrostatic potential
- Due to reduced mass of fill, more planters and levels can be added
- Easy to transport and to install

# LYNX Light Rail Station

Location: Charlotte, NC

Owner: City of Charlotte

Structural Engineer: King Guinn and Associates

Geotechnical Engineer: F&R

Contractor: Crowder Construction Company

This three story parking deck is adjacent to a local elementary school. In order to keep the embankment level with the school yard, it was necessary to backfill behind the parking deck. To backfill against a wall of this height with ordinary soil would result in high pressures on the wall.

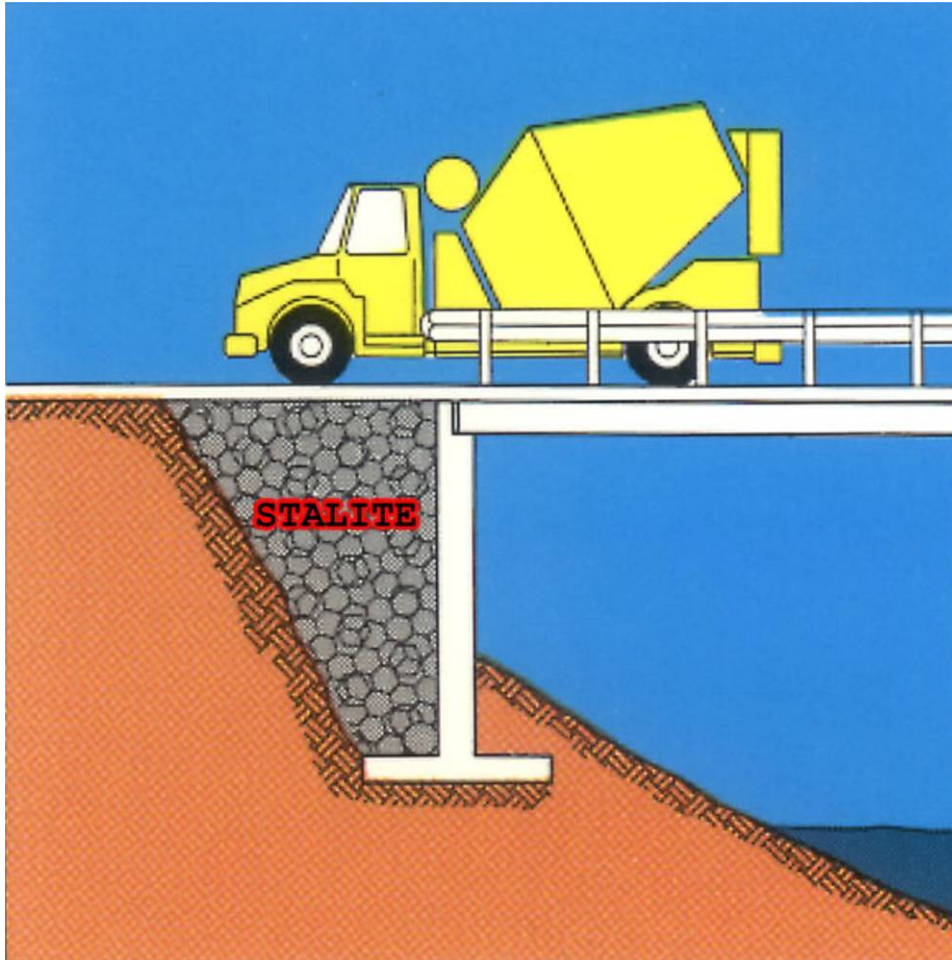


King Guinn and Associates of Charlotte designed a solution. By using ESCS lightweight aggregate fill material, the pressures on the wall were greatly reduced. Because ESCS lightweight aggregate is inert, it will never degrade or lose its strength. It is also self-draining, which keeps the moisture from accumulating behind the wall and causing more pressure to build against the wall.





# Bulkheads and Retaining Walls



- Reduces soil thrust and bending moments
- Reduces pressures against both the abutment and the end slope
- Allows for free drainage
- Improves embankment stability

# **EMERGENCY BRIDGE REPLACEMENT BLACKBURN ROAD OVER NEABSCO CREEK**

Location: Woodbridge, VA

Owner: Virginia Department of Transportation

Designer: Parsons Binckerhoff

Geotechnical Engineer: Burgess and Niple

Contractor: Lane Construction of Chantilly, VA

The remnants of Tropical Storm Lee and other heavy rain in late 2011 caused scour at the abutments for this bridge which resulted in cracking and the subsequent failure of one abutment. The bridge was closed in January 2012. Lane Construction of Chantilly, VA, constructed the new bridge which was opened in August 2012.





The new bridge abutments are founded on drilled shafts. The deeper foundation and a larger waterway opening resulted in high loads on the drilled shafts. The designers decided to use lightweight aggregate behind the abutments to decrease the lateral earth pressure on the abutment walls and hence decrease the lateral loads on the drilled shafts.

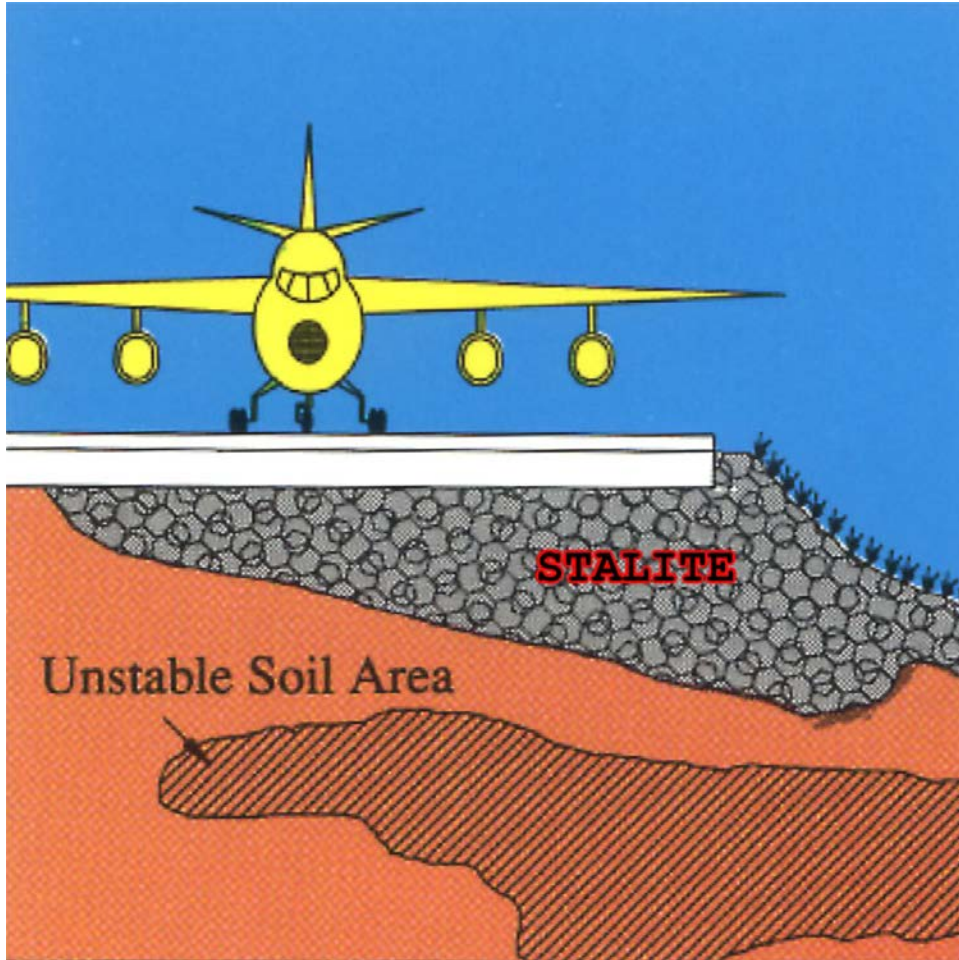


The specification required the use of a D6 LGP or lighter equipment to place the lightweight aggregate. A D6 LGP typically weighs between 18 and 20 tons.

- The specification allowed the use of a “light” steel drum roller with no amplitude to perform any additional required compaction.
- The specifications did not require a minimum in-place density for the materials.

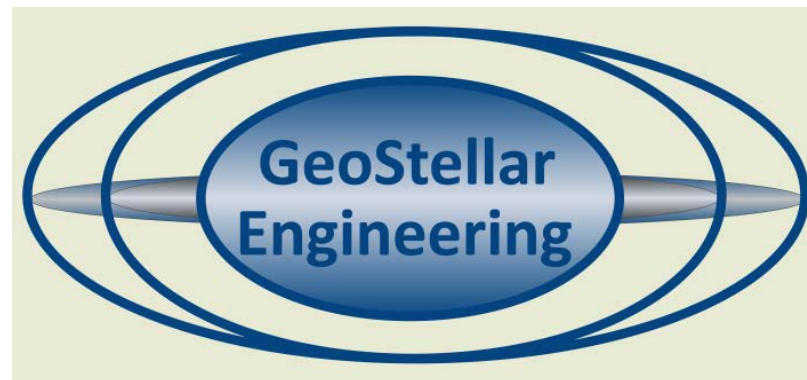
But typically placing with an 18 ton loader will compact the material to a density in excess of the 65% relative density typically required in specifications.

# Fill Over Poor Soils and Marsh Lands



- Poor construction sites can be reclaimed and developed
- Design elevations can be achieved with much lower fill weights than when using conventional fill
- Long term settlement is controlled and reduced
- Controlled fill allows uniform load distribution

# **Rapid Embankment Construction of US 17 Bypass Interchange Over Soft Compressible Soils Using Lightweight Aggregate Myrtle Beach, SC**

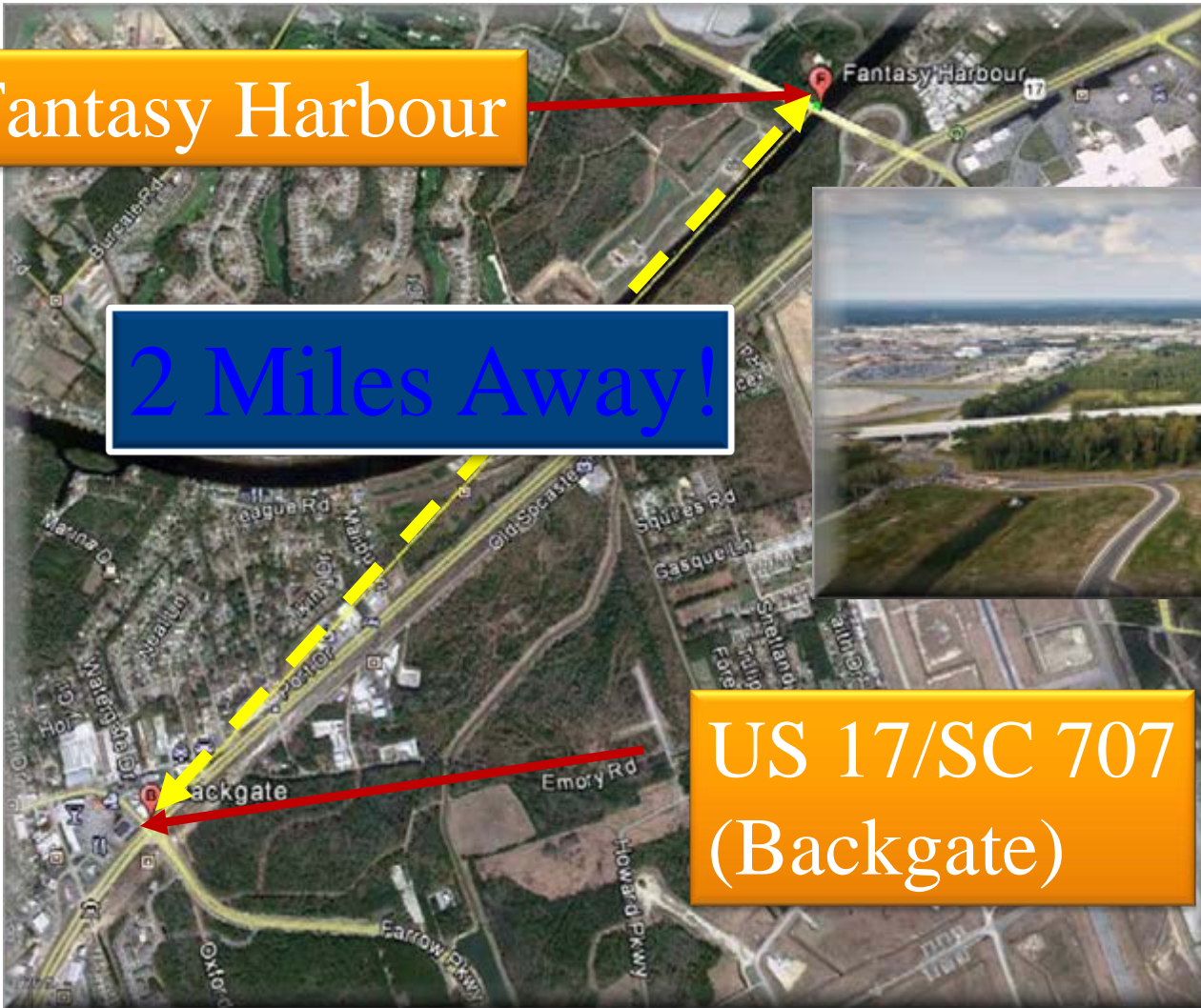


# Myrtle Beach, SC Regional Experience

Fantasy Harbour

2 Miles Away!

US 17/SC 707  
(Backgate)

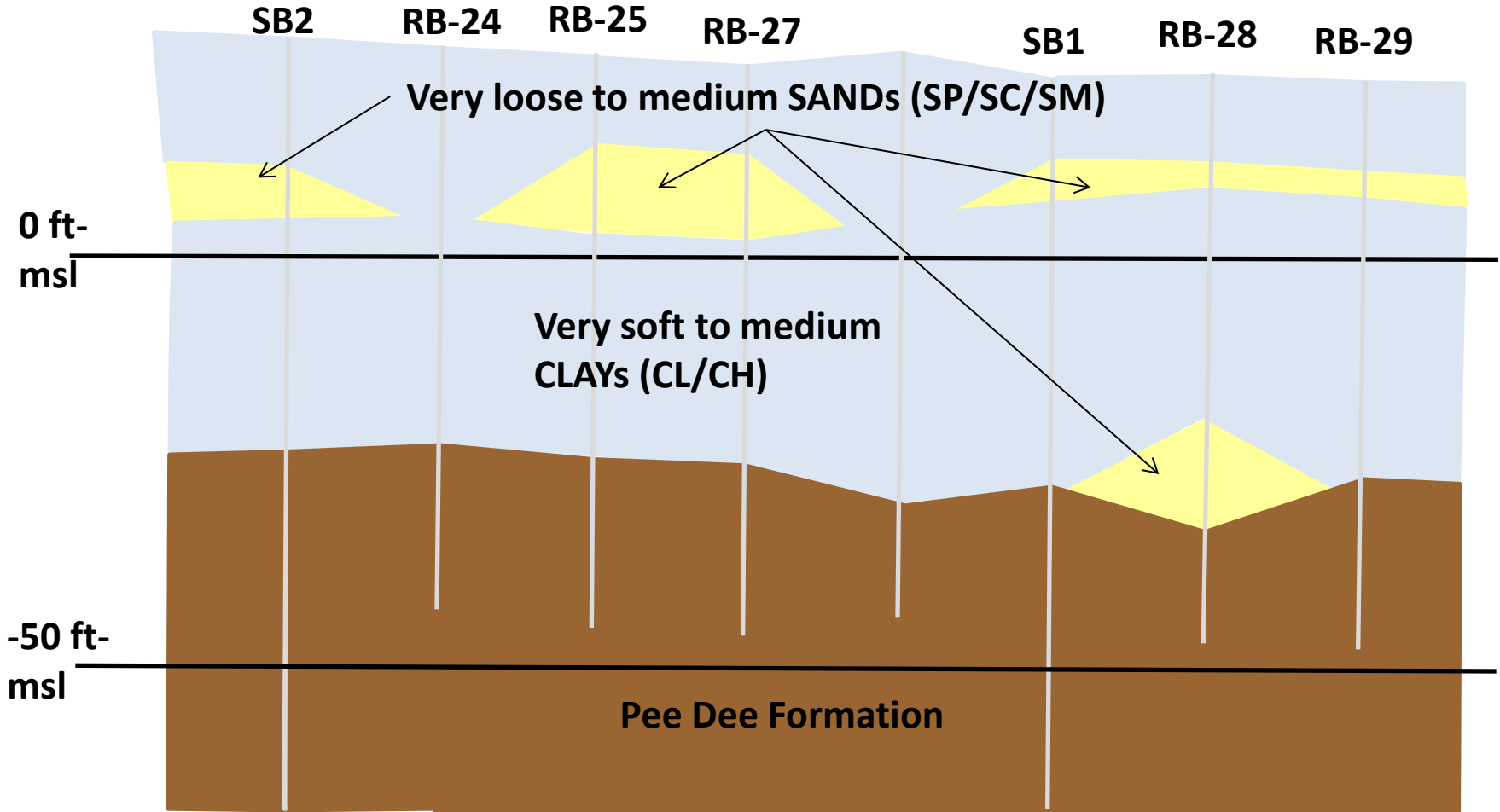


# Fantasy Harbour



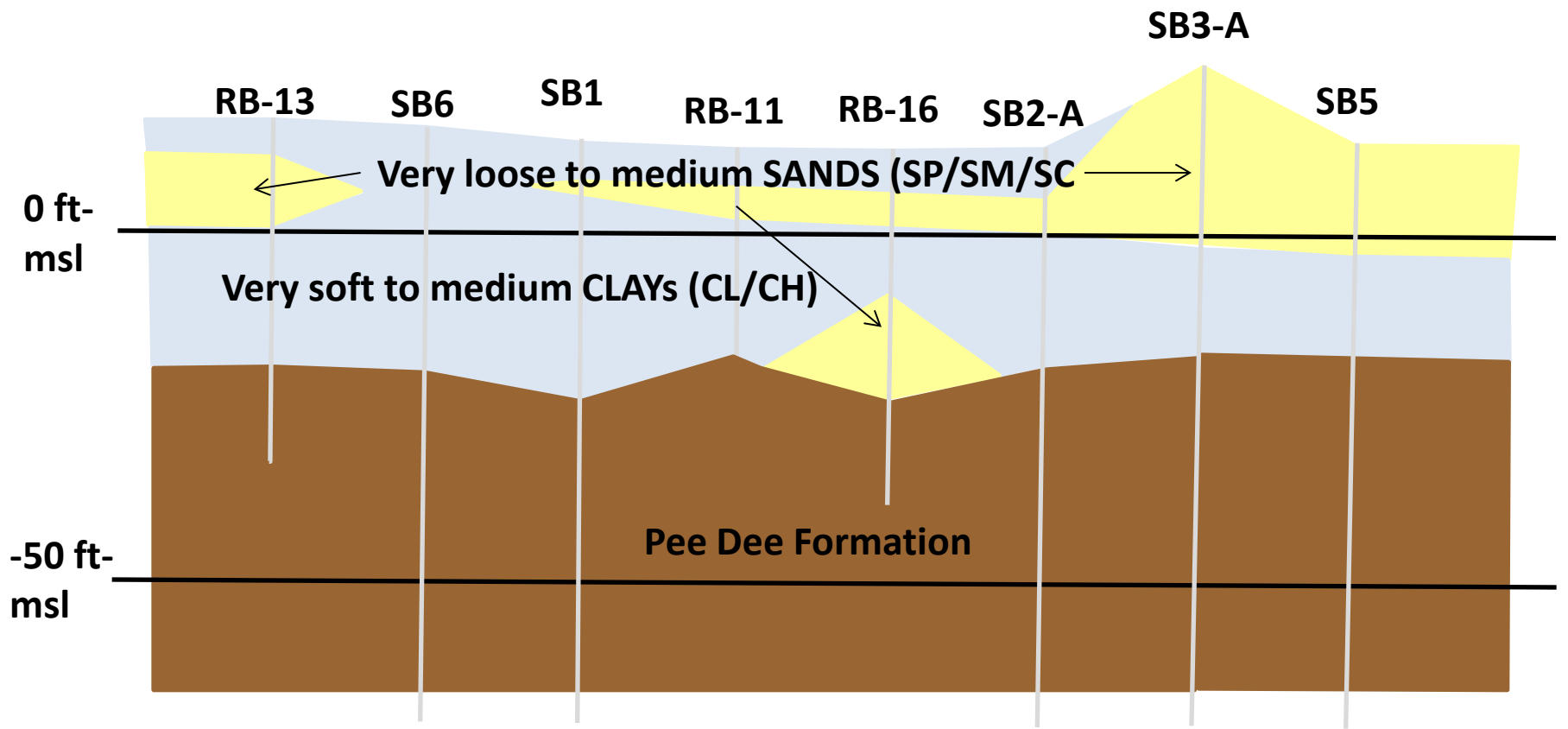
- 2 Miles North of US 17 /SC 707 Interchange
- New Alignment
- Bridge Over the Atlantic Intracoastal Waterway
- 3.1 Miles Roadway Approaches and Bridge

# Fantasy Harbour West Abutment Subsurface Soils





# Fantasy Harbour East Abutment Subsurface Soils





# Fantasy Harbour Geotechnical Experience

- 10' – 42' Embankment,  
Settlement 9" to 67"
  - Liquefaction – Loose Sands
  - Embankment Slope Instability  
(Static/Seismic)
- 
- Ground Improvement!!!
  - 2 Year Embankment Construction Contract
  - 2-3 Year Bridge Construction Contract



# US 17/ SC707 Interchange (Backgate)

South Bridge  
Approach

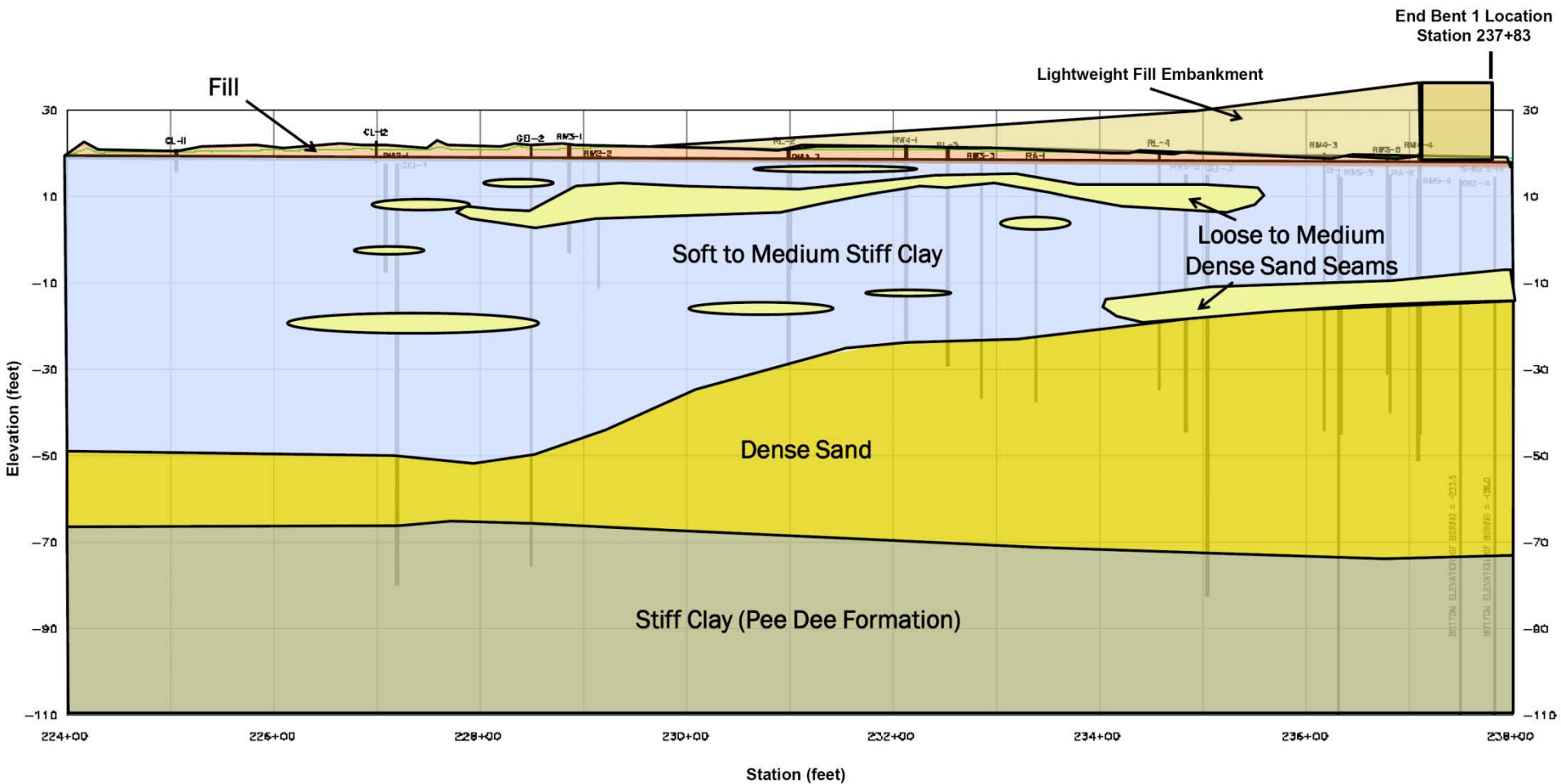
North Bridge  
Approach



US 17 Bypass at SC 707/Farrow Parkway  
Myrtle Beach, SC

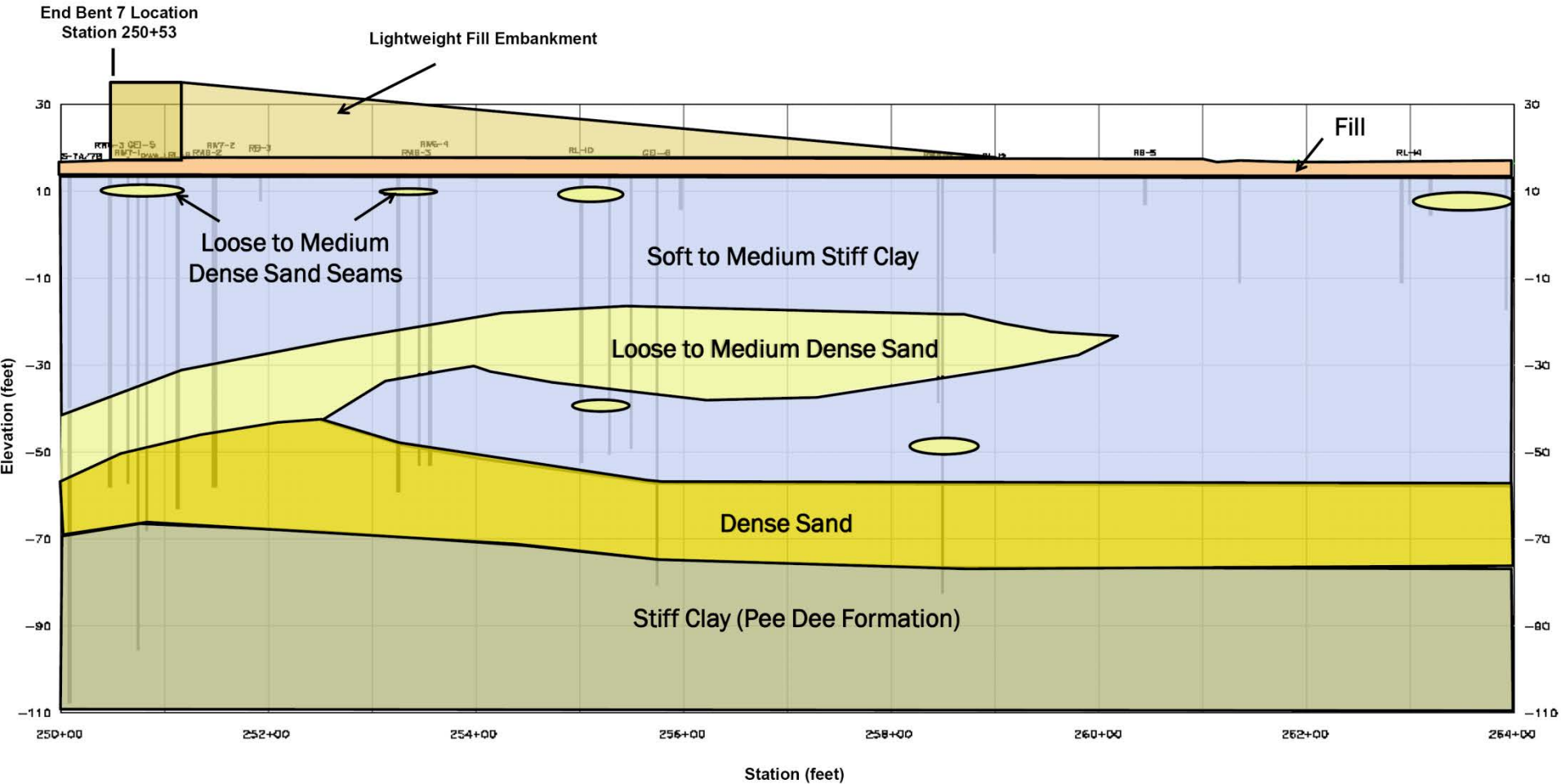
Concept Rendering

# South Bridge Approach Subsurface General Profile





# North Bridge Approach Subsurface General Profile

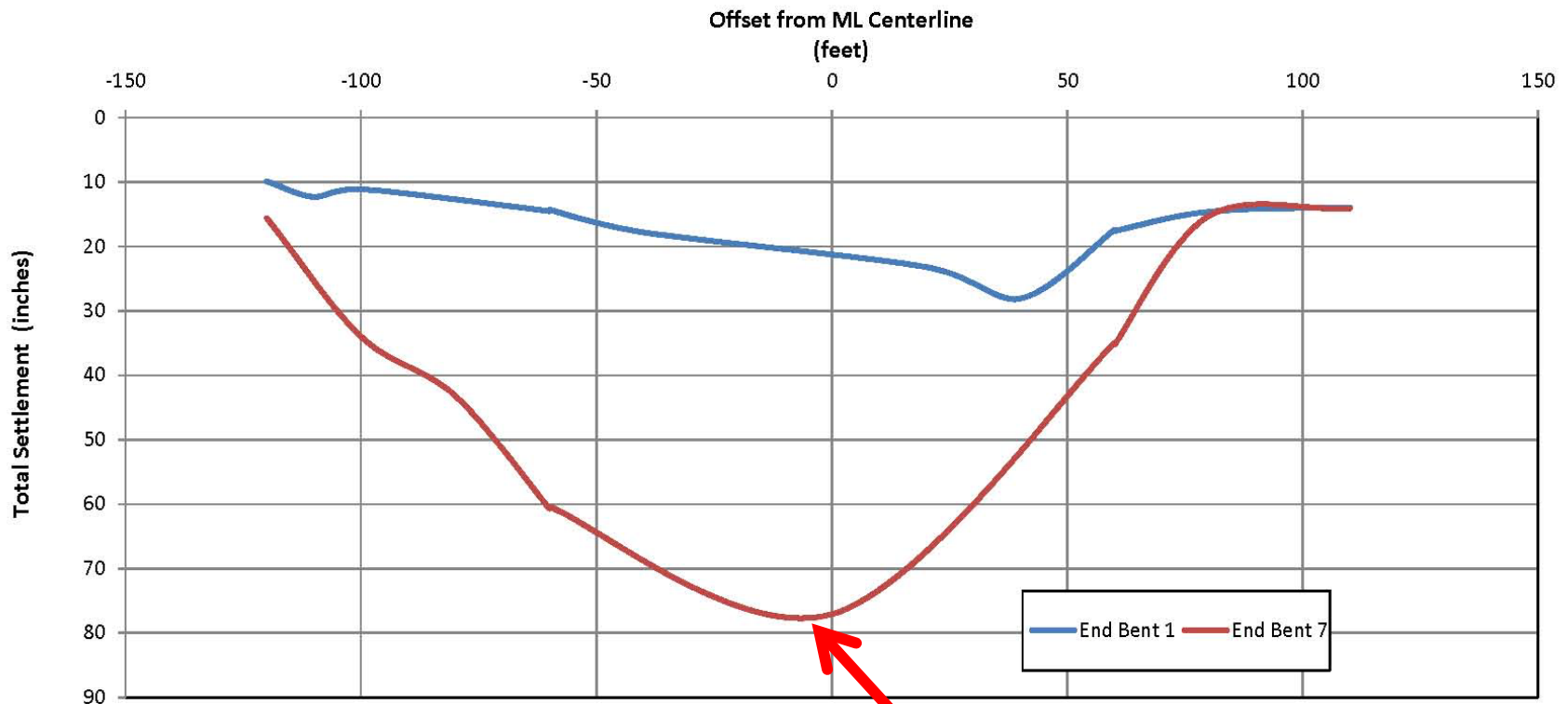




# Geotechnical Challenges

- 30' to 60' - Soft to Firm Clay
- Pockets of Loose Sands in upper 10'
- Intermediate Medium Sands (253+00 to 256+00)
- Loose Sands above Dense Sands (Liquefiable)
- Pee Dee Formation

# Bridge Abutment Settlement (Normal Weight Fill $\approx 120$ pcf)



78" of settlement!!



# Geotechnical Challenges

- Poor Site Subgrade (2' – 3' Bridging Required)
- Excessive Settlement – (Total & Differential)
- Static Slope Embankment Instability/Bearing
- Seismic Slope Embankment Instability (Liquefaction)



# **RAPID EMBANKMENT CONSTRUCTION**

# Geotechnical Key Design Issues

- **Settlement** – Total & Differential
- Embankment Slope Instability / Bearing (Static/Seismic)
- Bridge Abutment Foundation Performance - Extreme Event I and II Limit States
- MSE Wall Construction Over Soft Soils

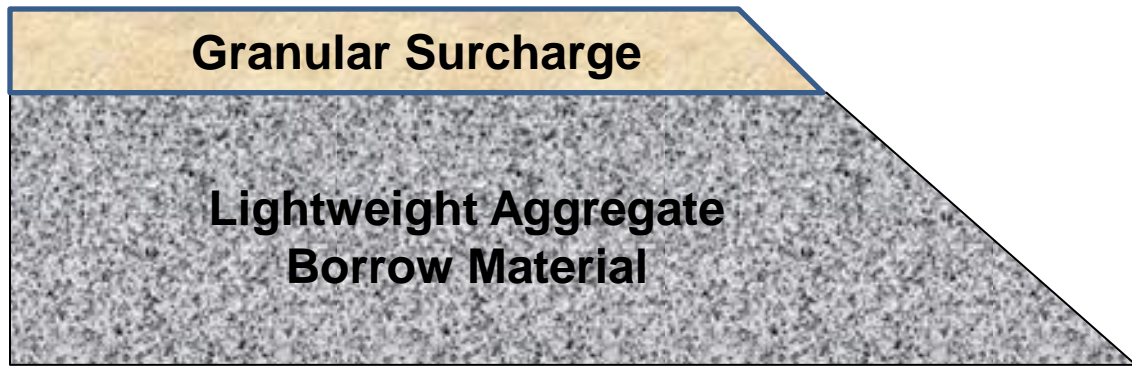
# Geotechnical Design Approach

- **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 and 3-Stage MSE Wall Construction
  - Vertical Slip Joints

# Granular Surcharge & Lightweight Aggregate Borrow

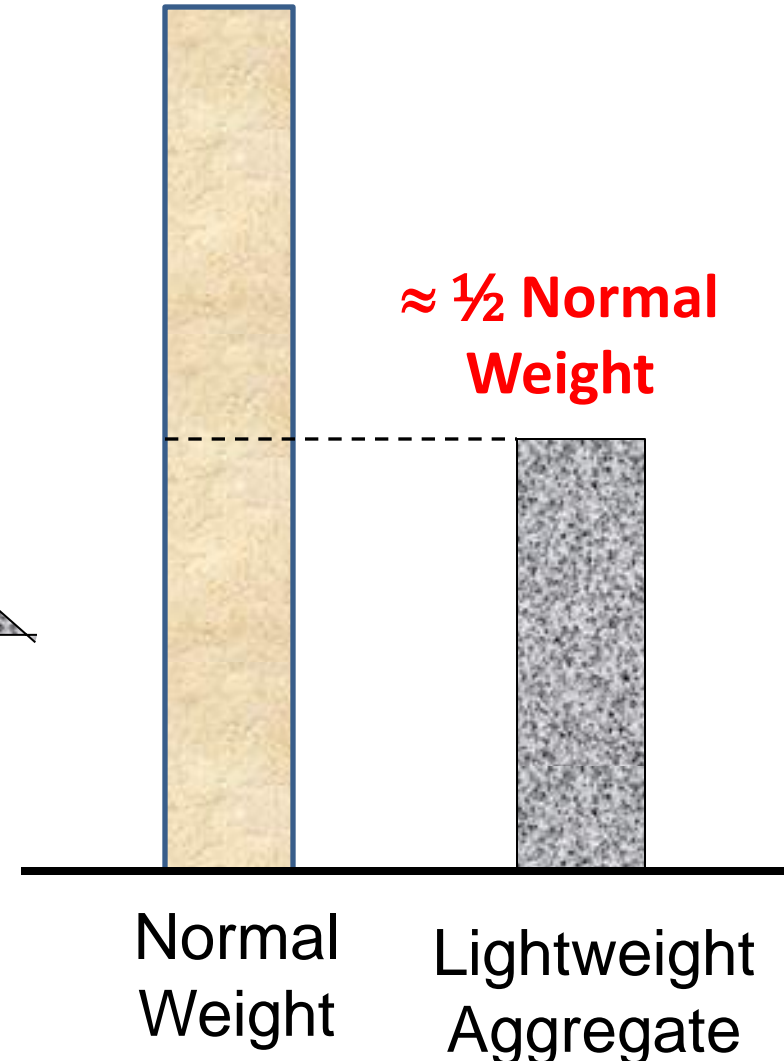
## Granular Surcharge Properties:

- $\phi = 32$  degrees
- Unit Weight: 125 pcf



## Lightweight Aggregate Properties:

- $\phi = 40$  degrees
- Short Term Unit Weight: 60 pcf
- Long Term Unit Weight: 70 pcf
- MSE Wall Backfill Properties



# Lightweight Aggregate Borrow (Rotary Kiln Produced)

**226,000 CY**



# PVD Installation

**3 Million LF**





# MSE Walls

## Permanent MSE Walls

**30,500 SF**

- Two-Stage Construction
- Three-Stage Construction (w/Drainage Structures)

## Temporary MSE Walls

(Welded Wire Mesh Facing)

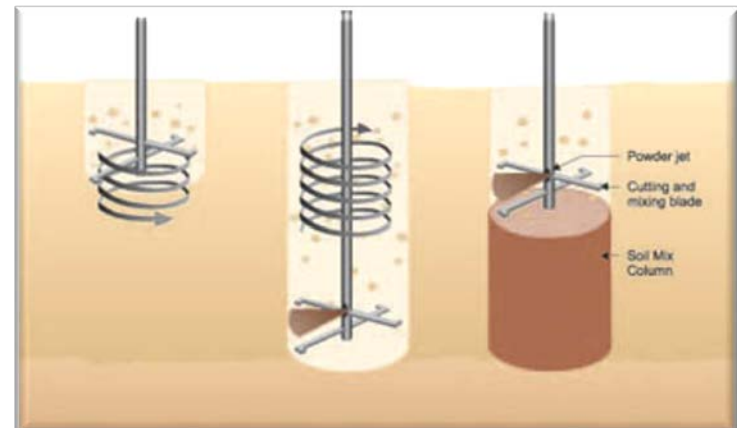
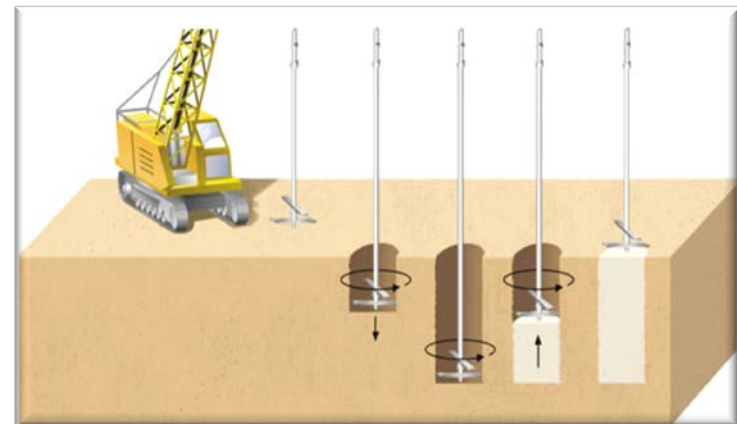
**51,500 SF**





# Deep Soil Mixing Columns (Overlap – Block Pattern)

- Seismic Slope Stabilization – Shear Key **35,600 CY**
- Improved Performance of Bridge Abutment Foundations
- 2013

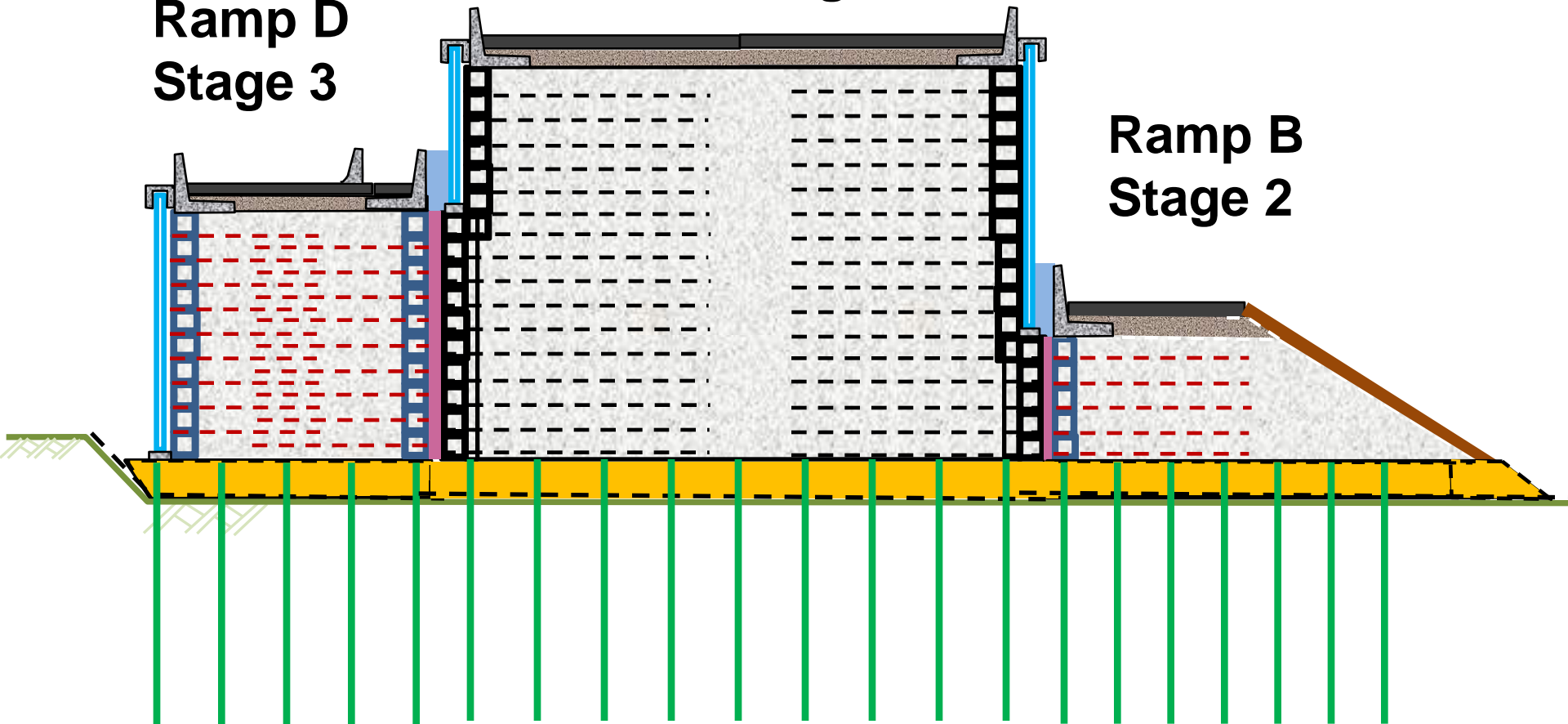


# Project Construction Stages (North Abutment 252+01)

## Bridge Approach Embankment Stage 4

Ramp D  
Stage 3

Ramp B  
Stage 2



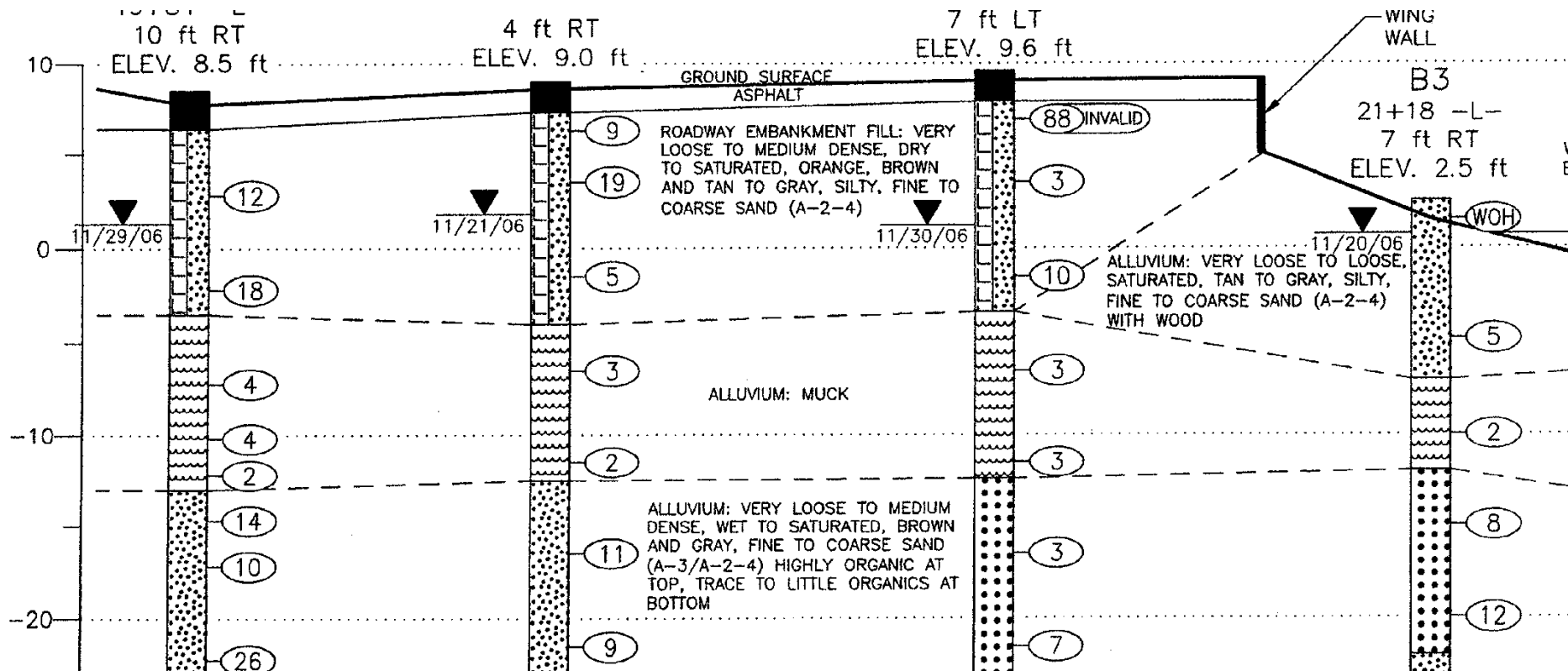
# TRANTERS CREEK BRIDGE APPROACH

- Location: Washington, NC
- Owner: North Carolina Department of Transportation
- Geotechnical Engineer: NCDOT Geotechnical Unit / Mactec
- Contractor: Atwell Construction

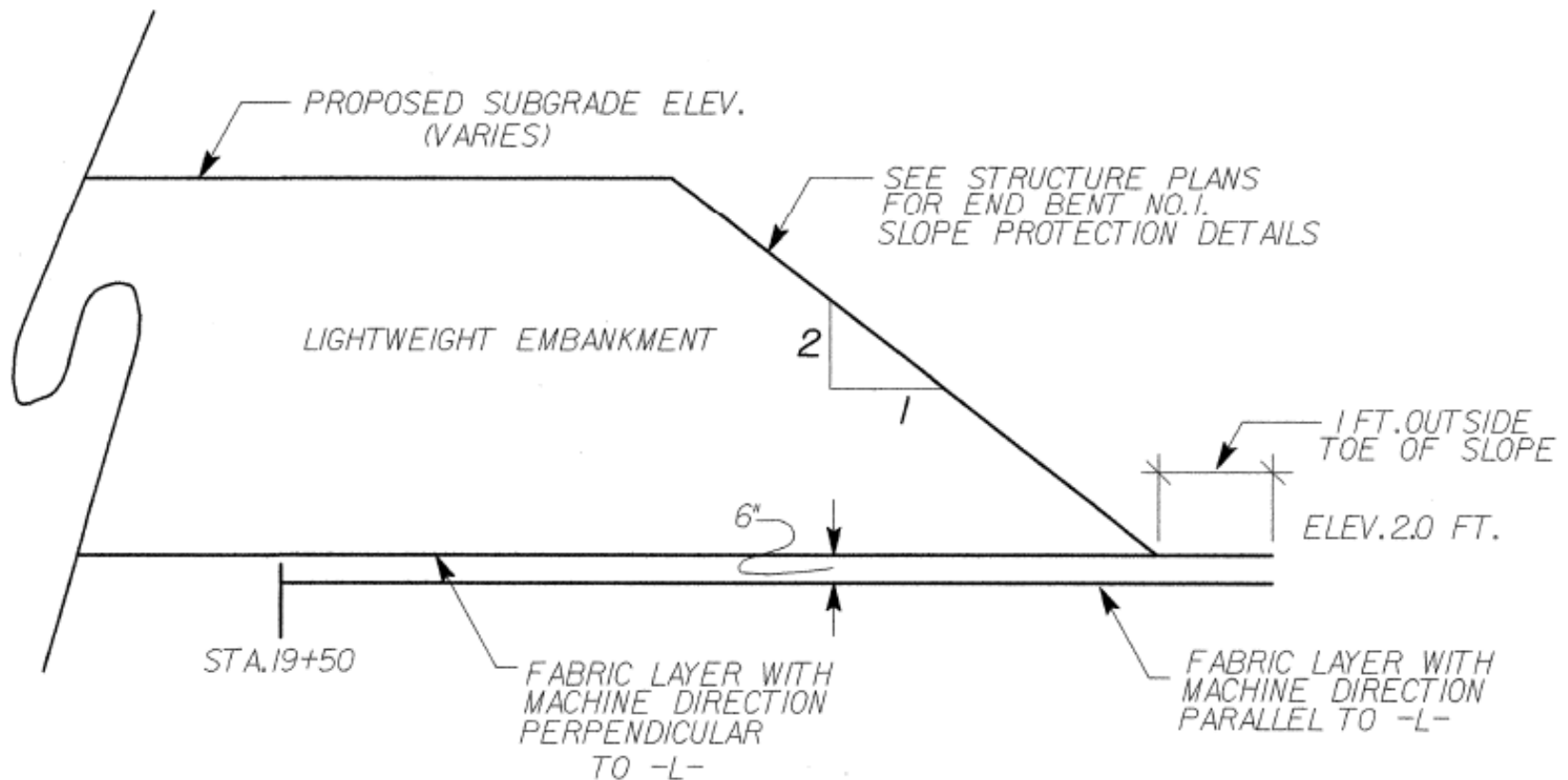
The project consisted of widening and raising an existing bridge approach embankment as part of a bridge replacement project.

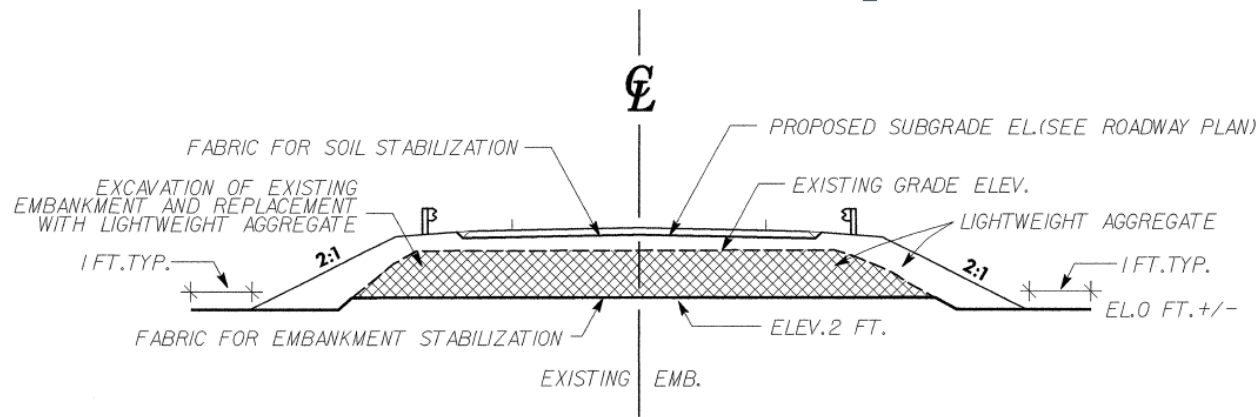


The existing soils consisted of roadway embankment fill underlain by alluvial muck. The embankment fill was very loose to loose, silty fine to coarse sand. The alluvial muck was 9 feet to 16 feet thick and generally had SPT values of 2 to 4 blows per foot.



The area from station 16+25 to 19+98 on the west side of the bridge was undercut to the elevation of 2 feet and covered with an embankment stabilization fabric and backfilled to subgrade level with lightweight aggregate fill.





LIGHTWEIGHT AGGREGATE EMBANKMENT (TYP. SECTION A-A)

N.T.S

NOTES:

1. EXCAVATE EXISTING EMBANKMENT FROM -L- STA. 16+25 +/- TO STA. 19+98 +/- TO THE ELEVATION 2 FT. AS SHOWN IN PLAN OR AS DIRECTED BY THE ENGINEER.
2. PLACE FABRIC FOR EMBANKMENT STABILIZATION FROM -L- STA. 16+25 +/- TO STA. 19+98 +/- AS SHOWN IN THE PLAN OR AS DIRECTED BY THE ENGINEER.
3. AT FABRIC LOCATIONS, ALL STUMPS SHALL BE CUT CLOSE TO THE GROUND AND/OR WATER SURFACE. GRUBBING IS NOT TO BE PERFORMED IN THE FABRIC PLACEMENT AREAS.
4. REPLACE EXISTING EMBANKMENT AND BUILD PROPOSED EMBANKMENT WITH LIGHTWEIGHT AGGREGATE UP TO THE SUBGRADE ELEVATION SHOWN IN THE ROADWAY PLAN OR AS DIRECTED BY THE ENGINEER.
5. FABRIC FOR SOIL STABILIZATION (SEPARATION) FABRIC BETWEEN THE SUBGRADE (LIGHTWEIGHT FILL EMBANKMENT) AND PAVEMENT STRUCTURE AS SHOWN IN THE PLAN OR AS DIRECTED BY THE ENGINEER.





**I-40 WESTERN LOOP  
GREENSBORO, NC**





**PENTAGON SECURED ENTRANCE  
FROM I-395  
WASHINGTON, DC**





**COUNTY LINE ROAD  
MIAMI, FL**



# NC 133 BRIDGE WILMINGTON, NC



10/20/2005



# FP&L MANATEE PLANT INTAKE STRUCTURE CONSTRUCTION PARRISH, FL





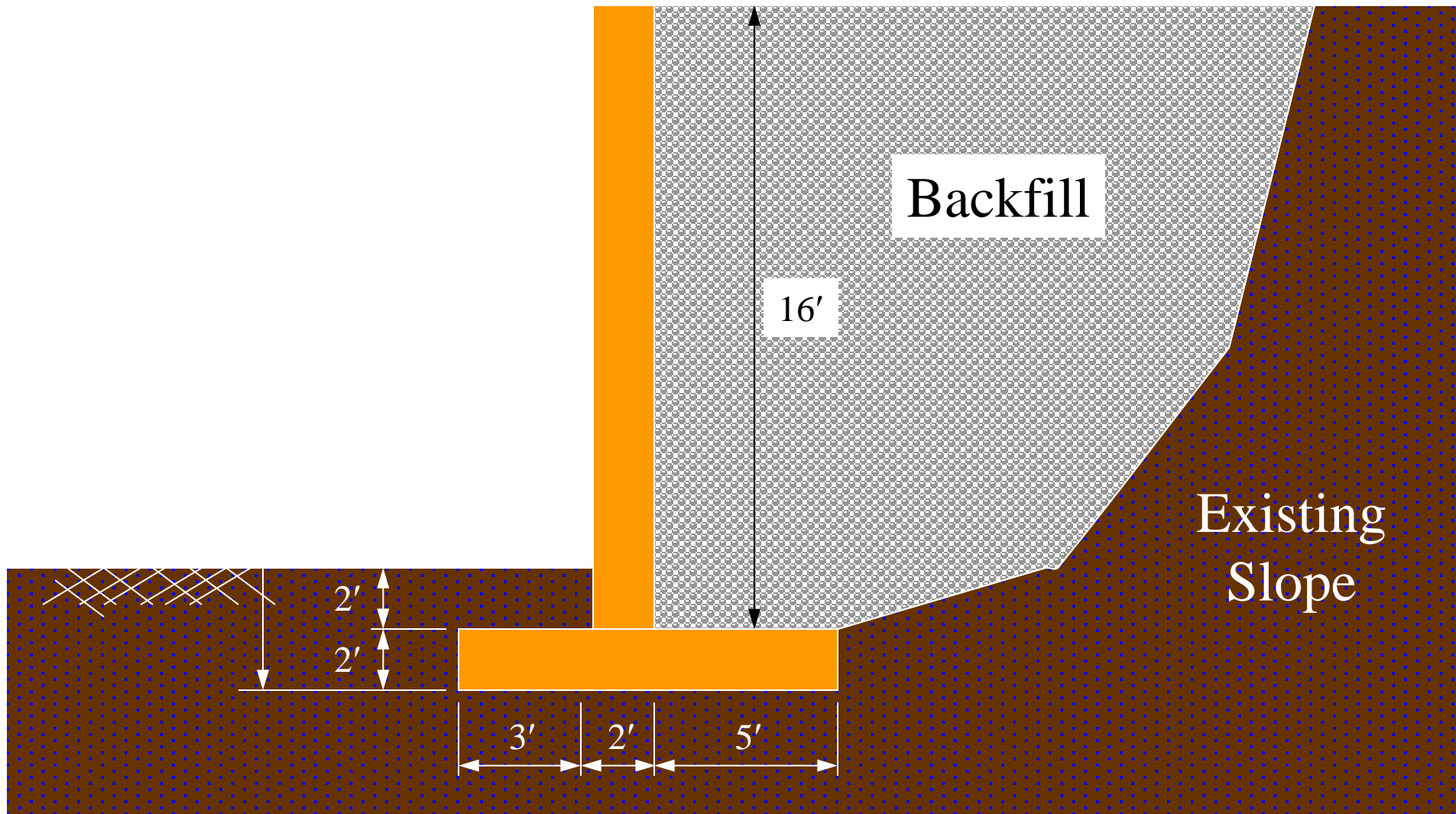
**FILL OVER PIPE  
MIAMI, FL**

2009-09-22



# DESIGN EXAMPLES

# Retaining Wall Example

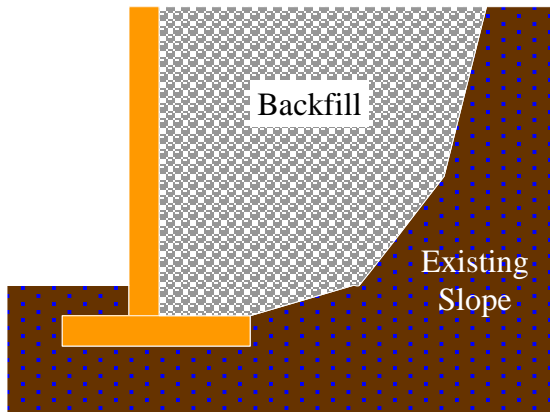


Compare effect of using NW and LW backfill on wall design

# Retaining Wall Example

Design a reinforced concrete retaining wall to support 16 feet of backfill

- Unit weight of the concrete is 150 pcf



## Normal Soil Design – Sand Backfill

Properties of the cohesionless sand

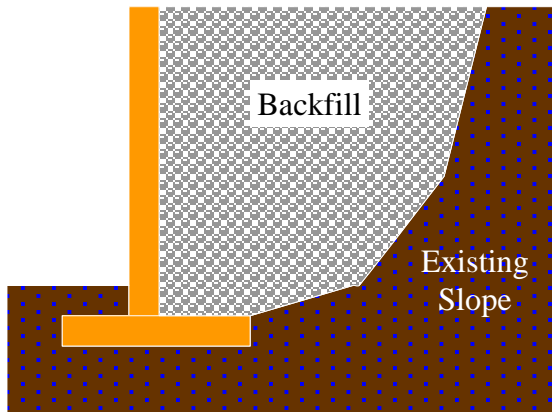
- Total unit weight = 120 pcf
- Angle of internal friction =  $30^\circ$

## Lightweight Aggregate Design

Properties of the coarse LWA fill

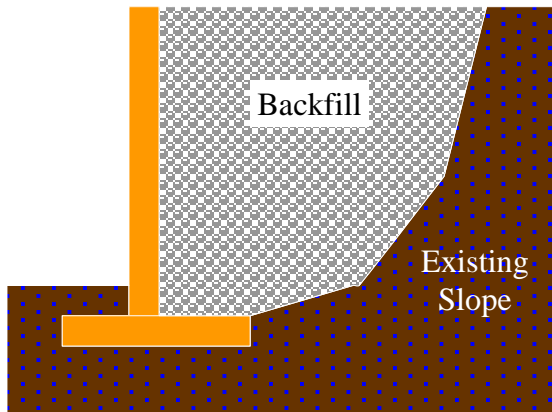
- Total unit weight = 60 pcf
- Angle of internal friction =  $42^\circ$

# Retaining Wall Example



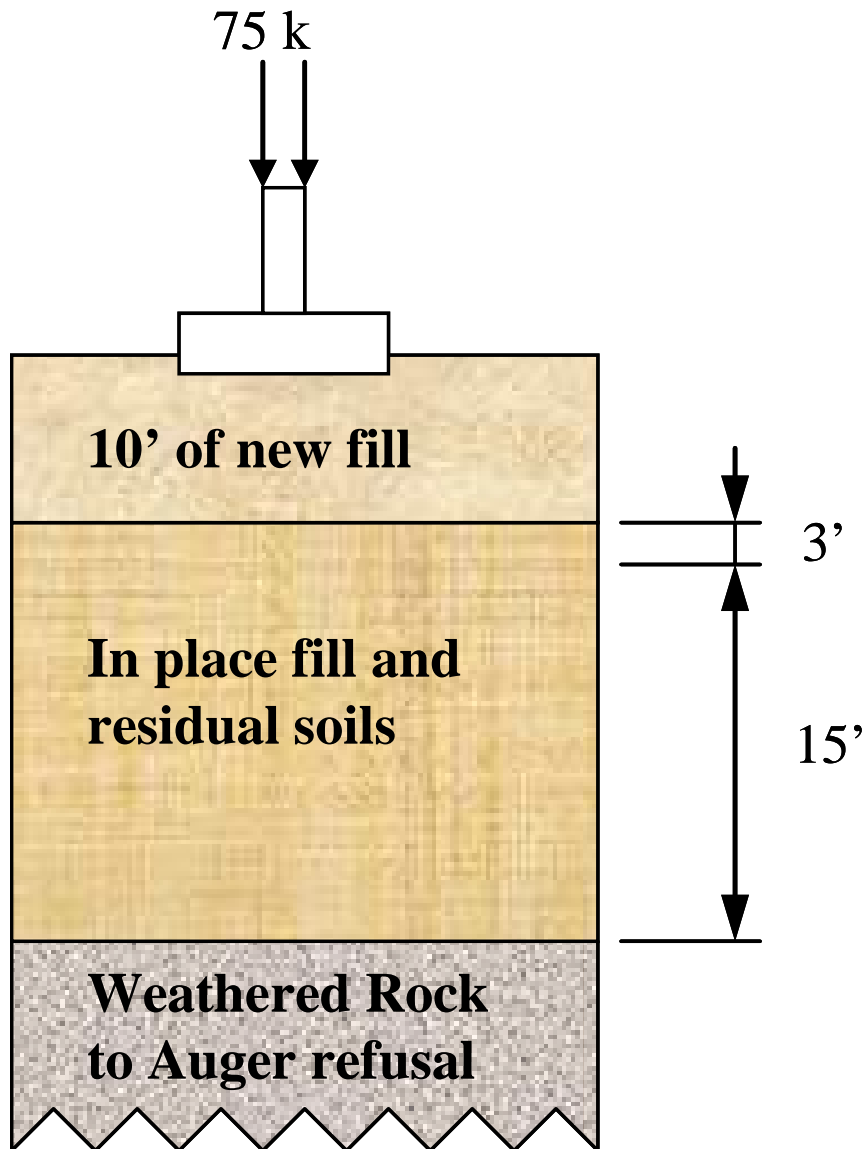
	Normal Soil Design	LW Aggregate Design	<i>Ratio LWA / Normal</i>
Active lateral earth pressure coefficient, $K_a$	0.33	0.198	<i>0.60</i>
The total active force per foot of wall, $P_a$	6.4k	1.92k	<i>0.30</i>
The overturning moment per foot of wall, $M_o$	38.4 ft-k	11.52 ft-k	<i>0.30</i>
Resisting moment per foot of wall, $M_r$	107.3 ft-k	71.3 ft-k	<i>0.66</i>

# Retaining Wall Example



Factor of safety against ...	Normal Soil Design	LW Aggregate Design	<i>Ratio LWA / Normal</i>
Overturning, $FS_o$	2.8	6.2	2.2
Sliding, $FS_s$	1.6	6.2	3.9
Bearing capacity failure, $FS_b$	2.6	6.3	2.4

# Foundation Settlement Example

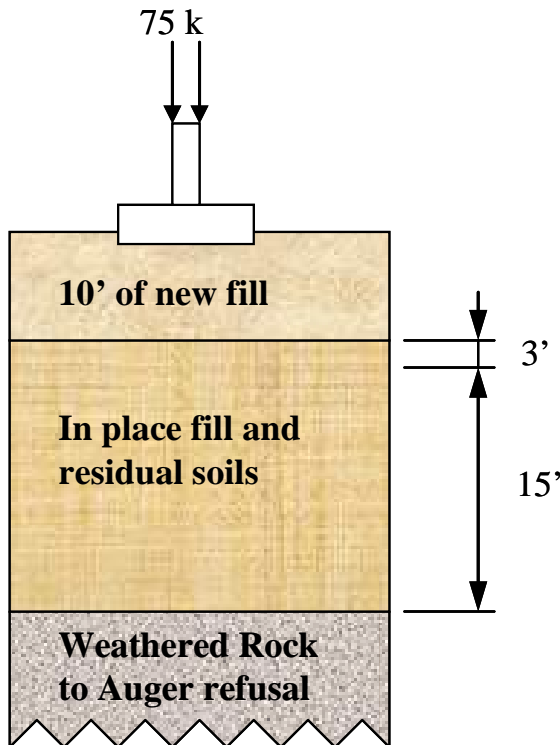


Add 10 ft of new fill and new footing load on two layers of existing fill and residual soils

Compare effect of using NW and LW fill on the expected settlement



# Foundation Settlement Example



Unit weight of in place fill (3 ft) = 120 pcf

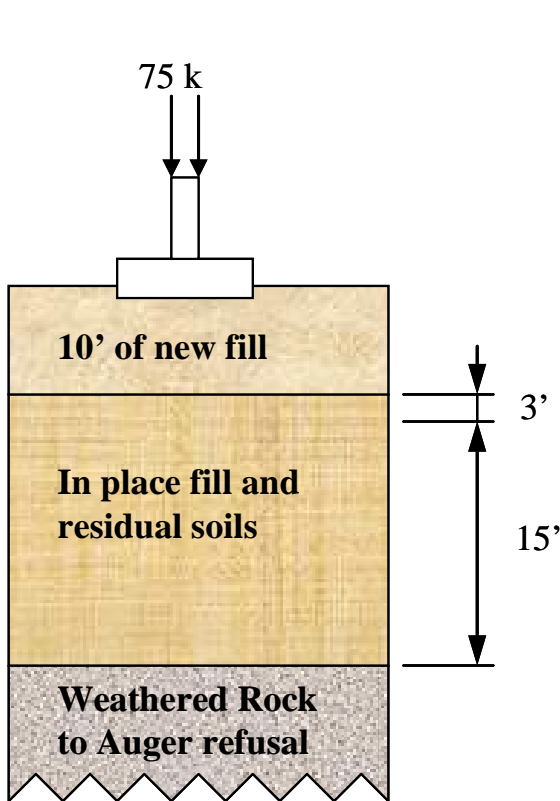
Unit weight of residual soils (15 ft) = 100 pcf

The in place fill and residual soils have an average SPT blow count,  $N$ , of 14

The corrected  $N$  value with 1110 psf overburden is 15.4

Most of settlement will occur in the 15 ft thick layer of residual soil. Settlement will be computed at center of this layer

# Foundation Settlement Example



$$\text{Settlement, } \Delta H = H \frac{1}{C'} * \log \frac{p_o + \Delta p}{p_o}$$

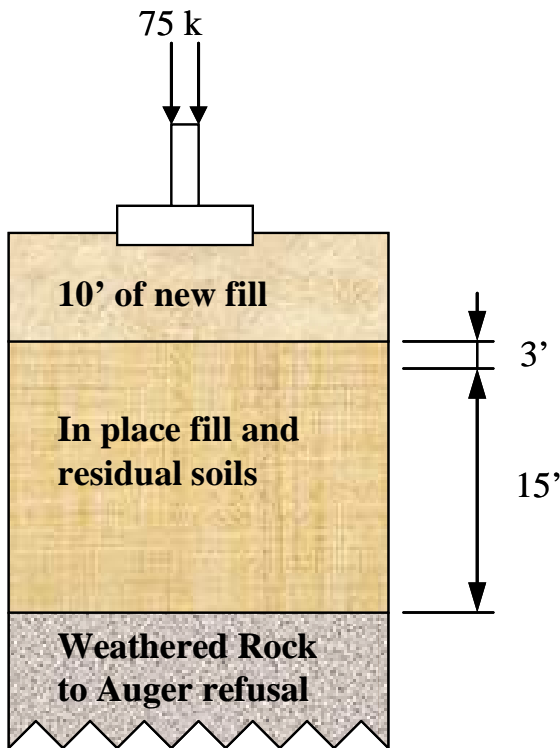
H = thickness of layer

C' = bearing capacity index from chart

$p_o$  = existing overburden pressure at center of residual soil layer

$\Delta p$  = load applied by fill and structure at center of residual soil layer using Boussinesq curve factor

# Foundation Settlement Example



Initial weight of existing soils,  $p_o$ , at center of residual soil layer

$$p_o = 3 \text{ ft} \times 120 \text{ pcf} + 7.5 \text{ ft} \times 100 \text{ pcf} \\ = 1110 \text{ psf}$$

Applied load from 5 ft x 5 ft footing

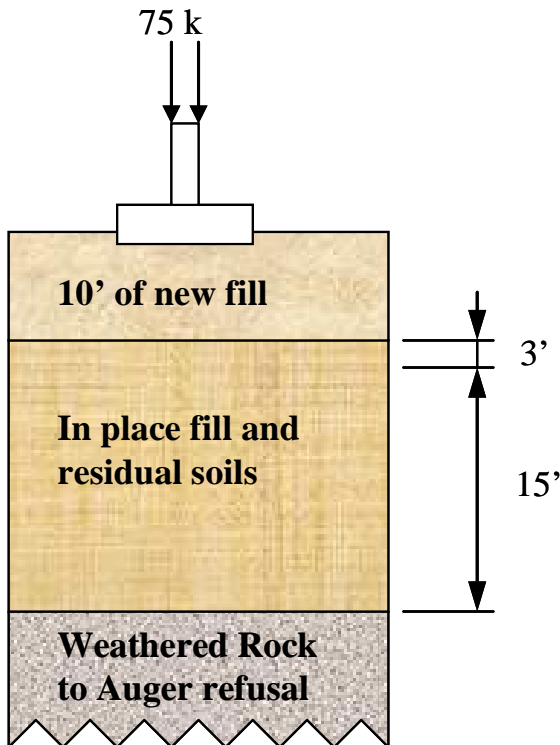
$$p = 75 \text{ k} / (5 \text{ ft} \times 5 \text{ ft}) = 3000 \text{ psf}$$

Applied load from footing at center of residual soil layer

$$\Delta_p = 3000 \times 0.03 = 90 \text{ psf}$$

where the factor 0.03 is obtained from the Boussinesq curve for a depth of 4B

# Foundation Settlement Example



Applied load from 10 ft of new fill

$$\text{NW fill: } \Delta_p = 10 \text{ ft} \times 120 \text{ pcf} = 1200 \text{ psf}$$

$$\text{LW fill: } \Delta_p = 10 \text{ ft} \times 60 \text{ pcf} = 600 \text{ psf}$$

$$\text{Using } \Delta H = H \frac{1}{C'} * \log \frac{p_o + \Delta p}{p_o}$$

Settlement with load of footing and new fill

$$\text{NW fill: } 15(1/40) * \log (1110+1290)/1110$$

$$\Delta H = 0.126' \text{ or } 1.512'' > 1'' \text{ N.G.}$$

$$\text{LW fill: } 15(1/40) * \log (1110+690)/1110$$

$$\Delta H = 0.078' \text{ or } 0.940'' < 1'' \text{ OK}$$

$$\text{Ratio of settlements (LW/NW)} = 0.62$$

# Questions ?

