Lightweight aggregate fill has gained popularity over the past ten years in transportation markets. The increase in popularity stems from the benefits related to performance and ease of use of lightweight aggregate fill. The applications that lightweight fill has been used in includes slope stabilization, subgrade improvement, thermal insulation, fill behind bulkheads and retaining walls, and fill over poor soils and marshlands.

Lightweight aggregate fill has many performance benefits, which makes it a cost effective solution to many problems. The unit weight of the aggregate is half that of normal weight aggregates. It is very durable, chemically inert, free draining, acid insoluble, pH neutral and has a high internal angle of friction.

With all the benefits of lightweight aggregate fill, it appears that the primary factor in the increase in popularity is how easy lightweight aggregate fill is to use. Lightweight aggregate fill can be placed without the use of any special job site equipment and is readily available in most areas. It does not require forms, protection prior to placement or leachate control measures. Most importantly it does not require a specialty contractor to perform the work. The general contractor can remain in control of the construction schedule and does not have to pay mobilization charges on start-up, when switching from area to area and after long delays.

It is easy for contractors because lightweight aggregate fill is open graded coarse aggregate that weighs less than normal weight stone. It acts like normal weight open graded coarse aggregate and it is compacted and tested in the same manner. It really is just rock that weighs less.

Some of the advantages of lightweight aggregate fill are:

- Reduced In-Place Density (55 to 60 pcf compacted)
- High Internal Stability/Shear Strength (40° to 46°)
- High Permeability/Controlled Grading (2.4 cm/sec)
- High Thermal Resistance (~1.3 BTU/hr ft² °F/in)
- Reduced Dead Weight, Lateral Forces and Overturning Moments
The in-place density of lightweight aggregate fill ranges from 50 to 60 pcf depending on the material and compaction effort. The aggregate is typically tested using ASTM D4253 and D4254 to determine its relative density. The in-place density is typically specified as 65% relative density as outlined in these ASTMs. The minimum index density test (ASTM D4254) 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 cf 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. This test method is applicable to soils in which 100% of soil particles pass a 3 inch sieve and up to 30% by dry mass are retained on a 1.5 inch sieve.

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 vibrrated at a specified frequency and for a specified time using an electromagnetic or eccentric/cam-driven vertically vibrating table.

The minimum relative density, \( D_d \), is calculated using the following equation:

\[
D_d (\%) = \left( \frac{\gamma_d \max - \gamma_d \min}{\gamma_d \max - \gamma_d \min} \right) \times 100
\]

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 with all open graded coarse aggregates, field measurement of density is a little harder to measure than it is with soils. 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. The aim is to not compact lightweight aggregate to a maximum in-place density but to compact the material to the optimum density to achieve a high stability while avoiding increasing the in-place density due to aggregate breakage. Since lightweight aggregate fill is not soil, the typical density tests used on soil and ABC stone do not work very well. The in-place material has been tested by nuclear density gauge, volumetric (balloon) method, the ring/sleeve test and various other hybrid tests. All of the test methods are susceptible to error and interpretation of the results by a qualified engineer is required.
The method for density control most often used is a combination of prescriptive compaction requirements and a modified ASTM D698 test developed by the Expanded Shale Clay and Slate Institute (ESCSI). In the modified D698 the lightweight aggregate is placed in a 0.5 cf bucket in three layers, with each layer compacted by 25 blows of a 5.5 lb rammer dropped 12 inches. This modified D698 test has been shown to give a good approximation of the in-place density of lightweight aggregate fill compacted using typical prescriptive requirements.

The typical prescriptive construction recommendations are to place the material in approximately uniform horizontal layers and avoid operating 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 weight no more than 12 ton static weight and should make a minimum of two passes in the area to be compacted. In areas where access does not allow the use of vibratory rollers and portable vibratory plate compactors must be used it is recommended that the maximum lift thickness be 6 inches and minimum of 2 passes be made across the area. 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.

The physical properties other than unit weight that make lightweight aggregate fill suitable for use in geotechnical applications are:

- High internal angle of friction
- Low soundness loss
- pH Neutral
- Low LA Abrasion loss
- Low chlorides
- High permeability
- Controlled Gradation
- Acid Insoluble
- High Resistivity
- Low Sulfates

Lightweight aggregates provide an essentially cohesionless, granular fill that develops stability from inter-particle friction. Extensive testing on large 250 x 600 mm (10 x 24 in. high) specimens has confirmed angles of internal friction of more than 40 degrees\(^1\). Testing of expanded slate lightweight aggregate in triaxial and direct shear shows angles of internal friction of 40 to 46 degrees. When tested in direct shear in accordance with ASTM, the internal angle of friction is between 42 and 44 degrees.

### Soundness Test

Test results from NCDOT Approved Coarse Aggregate list - 3/8” results are shown

- Average all sources 0.91%
- Stalite - Gold Hill 0.90%
- Stalite - Aquadale 0.40%

NCDOT requirements - Std Specs 1014-2 (B)

- General requirement 15%
- for \(f'_c > 6\) ksi 8%
- For LWA 10%
Lightweight aggregate also has a relatively low Los Angeles Abrasion loss value. It is slightly lower than the average of the quarries on the NCDOT Approved Coarse Aggregate List. Some specifications call for an amended Los Angeles abrasion test to be run on lightweight aggregate fill. The amended test reduces the volume of lightweight aggregate in the abrasion machine to avoid overcrowding during the test. The results of the amended test method can vary depending on the aggregate, but for lightweight aggregate fill discussed in this paper the values for the two test methods are essentially the same.

Expanded Slate lightweight aggregate with a gradation conforming to ASTM C-330 AASHTO M-195 (¾” to #4) has a coefficient of permeability of greater than 2.4 cm/sec when tested in accordance with ASTM D 2434. This is typical of normal weight clean gravel. The free draining nature of the lightweight aggregate fill minimizes hydrostatic potential and allows exfiltration systems to work effectively.

The pH, sulfates, chlorides and resistivity of lightweight fill meet the FHWA requirements for MSE wall backfill. Below are the results of the testing recently completed on the 11th Street Bridge Project.

<table>
<thead>
<tr>
<th>Test</th>
<th>FHWA Specification</th>
<th>11th St. Test Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>5.0 – 10.0</td>
<td>8.3</td>
</tr>
<tr>
<td>Chlorides</td>
<td>&lt; 100 ppm</td>
<td>&lt; 1 ppm</td>
</tr>
<tr>
<td>Sulfates</td>
<td>&lt; 200 ppm</td>
<td>32.1 ppm</td>
</tr>
<tr>
<td>Resistivity</td>
<td>&gt;3,000 ohm-cm</td>
<td>35,209 ohm-cm</td>
</tr>
<tr>
<td>Organic Content</td>
<td>1% Maximum</td>
<td>0 %</td>
</tr>
</tbody>
</table>

The other questions we often get about lightweight aggregate fill are related to the aggregates compressibility and how it interacts with geotextiles. As far as compressibility, in large-scale compressibility tests completed on lightweight aggregate fills it was demonstrated that the curvature and slope of the LWA fill stress-strain curves in confined compression were similar to those developed for companion limestone samples. These tests were completed at UNB by Tom Holm and Alexander Valsangkar. Additional cyclic plate-bearing tests on LWA fills indicated vertical subgrade reaction responses that were essentially similar for the lightweight and normal weight aggregate samples tested.

The interaction between lightweight aggregate fills and geotextiles was tested by Valsangkar and Holm, the variables of differing aggregate types and densities, thickness of aggregate layer, and geotextile types were used in their studies.
The results indicated that the overall roadbed stiffness is unaffected when LWA is used instead of normal weight aggregate for small deflections and initial load applications. These tests were followed by a large-scale test\(^2\), which reported that the comparison of the friction angles between the LWA or the normal weight aggregate and the geotextiles indicate that interface friction characteristics are, in general, better for LWA than normal weight aggregates.

In summary, lightweight aggregate fills are cost effective, readily available and easy to use. They provide proven performance and durability in a wide range of geotechnical applications.

References:


The following pages contain brief summaries of projects that are in progress or have been completed utilizing expanded shale, clay or slate lightweight aggregate.
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 the existing embankment, raising the elevation one foot and lengthening the bridge 120 feet. The 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 about 9 feet to 16 feet thick and generally showed 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 2 feet and covered with an embankment stabilization fabric and backfilled to subgrade level with lightweight aggregate fill. About 3600 cubic yards of lightweight aggregate fill was used for the project.
The $390 million 11th Street Bridge Project is critical to improving travel and achieving the larger vision of the Anacostia Waterfront Initiative. The project is replacing two bridges built in the 1960s with three new bridges that separate local and freeway traffic.

Winner of the Road and Bridge 2012 Bridge Project of the Year, the 11th Street Bridge Design-Build Project in Washington DC is a great example of how innovative ideas lead to advances in construction. One of the many innovative things done on the project was the extensive use of lightweight aggregate fill to speed the construction, reduce settlement under the roadway, protect historic structures and 2800 cubic yards of lightweight aggregate concrete to reduce load on the new bridge decks.

The project area contained storm water drainage outfall structures that were constructed in the 1850’s. The historic structures had up to 20 feet of new fill going on them. In order to minimize the new load placed on the structures lightweight fill was placed over the structures and normal weight fill was used in the areas not overtop of the structures. In the pictures below you can see two of the areas where the lightweight aggregate fill was used 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.

<table>
<thead>
<tr>
<th>Test</th>
<th>Specification</th>
<th>Test Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.0 – 9.0</td>
<td>8.3</td>
</tr>
<tr>
<td>Chlorides</td>
<td>&lt; 100 ppm</td>
<td>&lt; 1 ppm</td>
</tr>
<tr>
<td>Sulfates</td>
<td>Not specified</td>
<td>32.1 ppm</td>
</tr>
<tr>
<td>Resistivity</td>
<td>30,000 – 40,000 ohm-cm</td>
<td>35,209 ohm-cm</td>
</tr>
<tr>
<td>LA Abrasion</td>
<td>&lt; 40 percent loss</td>
<td>27.2 percent loss</td>
</tr>
</tbody>
</table>

As shown in the picture below on the left, lightweight aggregate fill was used under the roadway to minimize settlement and speed construction in some areas on the south side of the project.

The specifications required the following testing to be performed on all the lightweight aggregate for the project. “During the initial placement of the lightweight aggregate fill, the density will be determined at the point of placement by the contractor….The contractor shall determine the in-place moist density (unit weight) of a given aggregate using the procedure as follows:

a) Lightweight aggregate producer shall submit documentation of a compacted wet density of less than 65 lb/ft³ determined from a one point proctor test conducted in accordance with a modified version of ASTM D698 “Standard Test Methods for Laboratory Compaction ‘Characteristics of Soil Using Standard Effort’. Due to the cohesionless nature of coarse lightweight aggregate, the standard shall be modified as follows: The aggregate sample shall be placed in a 0.5 cubic foot bucket at the moisture content that the aggregate is delivered to the jobsite. The sample shall be placed in three equal layers with each layer compacted 25 times using a 5.5 pound rammer by dropping from a distance of 12 inches (AASHTO T-99 modified as above)
b) Material shall be compacted to a minimum of 65% relative density in accordance with ASTM D4253 and D4254. The maximum index density and unit weight shall be determined using a vibratory table when tested in accordance with ASTM D4253 and the minimum index density and unit weight is determined when tested in accordance with D4254.”

The modified D698 proctor test is easy to run and was run on the materials shipped to the project. The determination of the in-place compacted density was harder due to the nature of coarse aggregate. Since most of the normal in-place density tests do not work on normal weight or lightweight coarse aggregate, test method were developed to determine the density from various compaction efforts. Two different size steel boxes were placed in the fill area and lightweight aggregate 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 weighted. The results of the testing indicated that the in-place density was lower than the project maximum density and greater than the 65% relative density required by the project specifications. The testing also showed that the in-place testing generated compacted densities very similar to the modified D698 proctor test.
Emergency Bridge Repair
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 bridge abutments which resulted in cracking and the subsequent failure of one abutment. The Bridge was closed in January 2012 and Lane Construction of Chantilly VA completed the repairs and the bridge reopened in August of 2012.

The Bridge abutments are on drilled shafts, as part of the repair the new bridge has a deeper foundation and a larger waterway opening which increased the load 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.

¾ inch lightweight aggregate was used on the project for the repair. The lightweight aggregate had an average damp loose unit weight of about 50 pcf. The initial specification released by VDOT for the project specified pumice or expanded clay with a ½ inch gradation. After discussions with the DOT, designer and contractor the decision was made to allow the use of expanded slate lightweight aggregate having a ¾ inch gradation.

The specification required the use of a D6 LGP or lighter equipment to place the 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.
Rapid Embankment Construction of US 17 Bypass Interchange over Soft Compressible Soils

Location: Myrtle Beach, SC
Owner: Horry County
Designers: STV Group, Inc.
Geotechnical Engineer of Record: Ed Tavera, PE, Owner and Founder of GeoStellar Engineering, LLC
Contractors: Balfour Beatty

Geotechnical Engineer of Record Ed Tavera, P.E., faced many challenges in the design of the US 17 Interchange known as Backgate. The project had a tight time schedule of 3.5 years and the geotechnical challenges of the site included:

- 30’ to 60’ Soft to Firm Clay
- 5’ to 10’ Loose Sands
- Intermediate Medium Sands (253+00 to 256+00)
- Pee Dee Hard Clay Formation Elevation -70’msl
- Poor Site Subgrade (Bridging Required)
- Excessive Settlement – (Total & Differential)
- Short & Long-Term Embankment Instability
- Seismic Slope Instability (Liquefaction)

The bridge was locally funded using a one cent capital project sales tax in Horry County. The local funding led to higher expectations for project completion. The heavy traffic volumes in the area also necessitated accelerated construction.

The Fantasy Harbour Bridge project located about 2 miles north of the site on similar soils utilized staged vertical construction. The embankment construction fill sequence for the Fantasy Harbour project was:
- 15 feet; anticipated settlement 21 inches; waiting period ~6months
- Additional 10 feet; anticipated incremental settlement 22 inches, total settlement 43 inches; waiting period ~6months
- Final Grade achieved; anticipated incremental settlement 24 inches, total settlement 67 inches; inches; final waiting period ~ 6months

For the US 17 Bypass project, settlement estimates were up to 75 inches utilizing normal weight fills materials. A staged vertical construction approach similar to that on Fantasy Bent 2.
Harbour would not allow for completion in the allotted time. Because of the need to eliminate the long settlement waiting periods, the geotechnical engineer envisioned an approach using lightweight aggregate fill to reduce the magnitude of settlement in conjunction with:

- Prefabricated Vertical Drain (PVD) / Granular Surcharges to Increase Rate of Settlement and Facilitate Rapid Construction
- Deep Soil Mixing to Improve Seismic Slope Stability and Bridge Abutment Foundation Performance
- Mechanically Stabilized Earth (MSE) Walls with 2-Stage and 3-Stage Wall Construction and Vertical Slip Joints

The lightweight aggregate fill reduced the predicted settlement at Bent 2 from about 75 inches down to about 20 inches. It reduced the predicted settlement at Bent 1 from about 27 inches down to about 12 inches.

The unique geotechnical design approach for the project is speeding construction. The estimated completion of the project is fall 2014.

Acknowledgements: The information in the above section was received from Ed Tavera, P.E., Owner and Founder of GeoStellar Engineering LLC. For more detailed information on the project: www.geostellareng.com
CATS South Boulevard Project

Location: Charlotte, NC
Owner: City of Charlotte
Structural Engineer: King Guinn and Associates.
Geotechnical Engineer: F&R
Contractors: Crowder Construction Company

A new parking deck at Interstate 485 and South Boulevard in Charlotte, NC provides parking for local commuters to access the south end of the present Charlotte Area Transit System (CATS) light rail line. 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 STALITE Geotechnical backfill material the pressures on the wall were greatly reduced. Because STALITE 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.

Crowder Construction Co., who was the contractor on the project, placed the approximately 13,000 tons of STALITE with relative ease and required minimum effort to consolidate it.

The top few feet of the backfill area was filled with topsoil and seeded with grass giving the potential to serve as art of the playground for the school next door.