THE UNIVERSITY OF TENNESSEE KNOXVILLE

Shear Strength of #57 Aggregates (Aggregate #A13 – TDOT Region 2)

Institute of Geotechnology

Table 1. Aggregate basic properties.

Property	Value
Specific Gravity for particles coarser than sieve #4 (ASTM-C127)	2.661
Specific Gravity for particles finer than sieve #4 (ASTM-D854)	2.734
Average Specific Gravity of Solids	2.662
Maximum Dry unit weight, Ib/ft^3 (ASTM-D4253)	101.048
Minimum Dry unit weight, Ib/ft^3 (ASTM-D4254)	87.720
Maximum void ratio (ASTM-D4254)	0.894
Minimum void ratio (ASTM-D4253)	0.644
D_{85} (mm)	21.20
D_{60} (mm)	16.10
D_{30} (mm)	10.30
D_{10} (mm)	6.00
Coefficient of uniformity, C_u	2.68
Coefficient of curvature, C_c	1.10

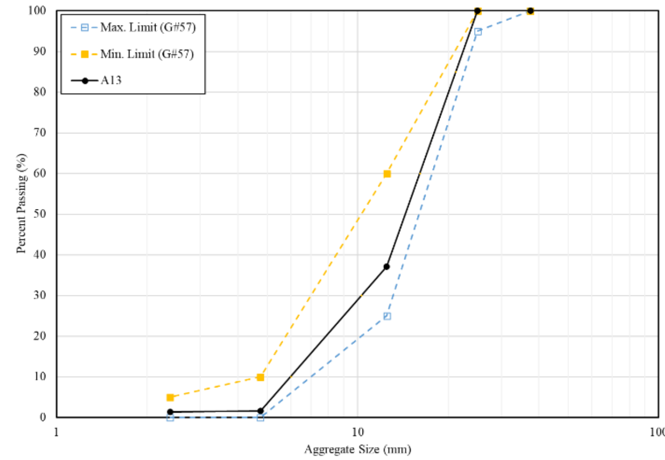

Figure 1. Gradation and size limits for A13 aggregate.

Table 2. Chemical composition of A13 aggregate.

Mineral	Percentage (%)
Calcium Carbonate ($CaCo_3$)	39.70
Calcium Magnesium Carbonate (Dolomite, $CaMg(Co_3)_2$)	57.2
Silicon Oxide (Quartz, SiO_2)	3.10
Others	0

Figure 1 shows the gradation of the aggregate and Table 1 summarizes its physical properties. The chemical composition of the tested aggregate was identified using powder X-ray diffraction (Table 2) where multiple aggregate particles were ground into powder to a size passing US sieve #200 (75 µm). The test was conducted at the Institute for Advanced Material and Manufacturing (IAMM), University of Tennessee-Knoxville (UTK).

The morphology of the aggregate was measured using 3D computed tomography (CT) images for a representative sample with a diameter of 2 in. and a height of 10 in. (Figure 2). Sphericity index (I_S) refers to particles' 3D general shape regardless of angularity characteristics of corners and edges. I_S is calculated as the value of the actual volume of a particle divided by the volume of the sphere inscribed within the particle. Roundness index (I_R) is defined as the ratio of the particle's actual surface area divided by the surface area of a sphere with a size equal to the average size of the particle using its three principal axes. Form (F = shortest particle axis/ longest axis) is another shape parameter to describe granular materials. The mean values for morphology indices are $I_S = 2.483$, $I_R = 0.911$, and $F = 0.512$. For more details, the reader is referred to https://alshibli.utk.edu/research/morphology-of-granular-materials/.

The shear strength of the aggregate was measured using a special large-scale direct shear (LSDS) apparatus at two relative densities (D_r = 80% to represent dense specimens and D_r = 30% for loose specimens). The aggregate was tested at normal stresses (σ) of 35, 70, 105, and 140 kPa (~ 5, 10, 15, and 20 psi) to represent typical stress ranges for fill aggregates behind a retaining wall. Figures 3 and 4 show the relationship between shear and normal displacements and the shear strain versus shear stress (τ) respectively. Figure 5 and Table 3 present a summary of peak state friction angles, critical state friction angles, and dilatancy angles in relation to normal stress. Figure 6 displays the same values with wall height. Table 4 lists the recommended Friction angle for the design of different wall heights.

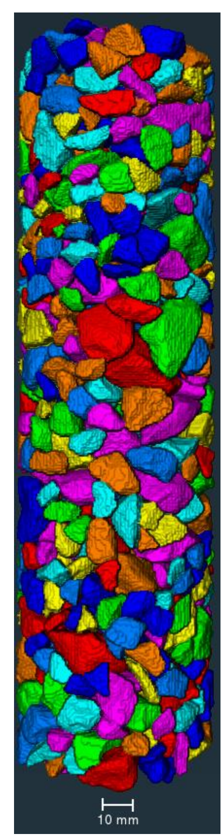

Figure 2. CT of aggregates.

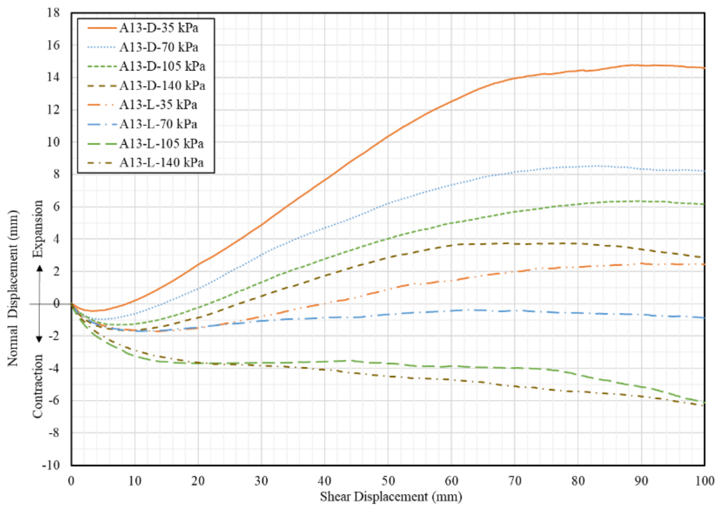

Figure 3. Shear displacement versus normal displacement.

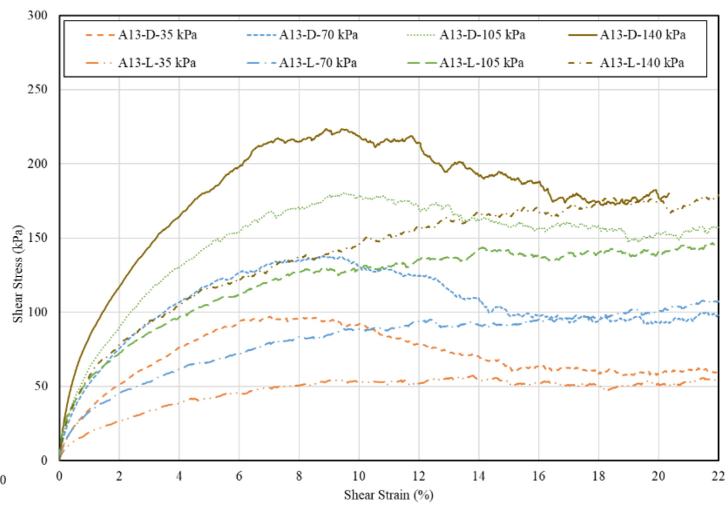

Figure 4. Shear strain versus shear stress relationship.

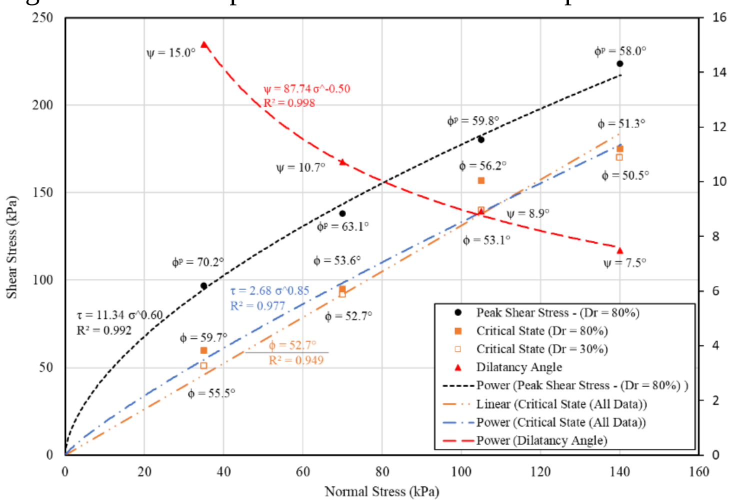

Figure 5. Linear and nonlinear Mohr Coulomb envelopes.

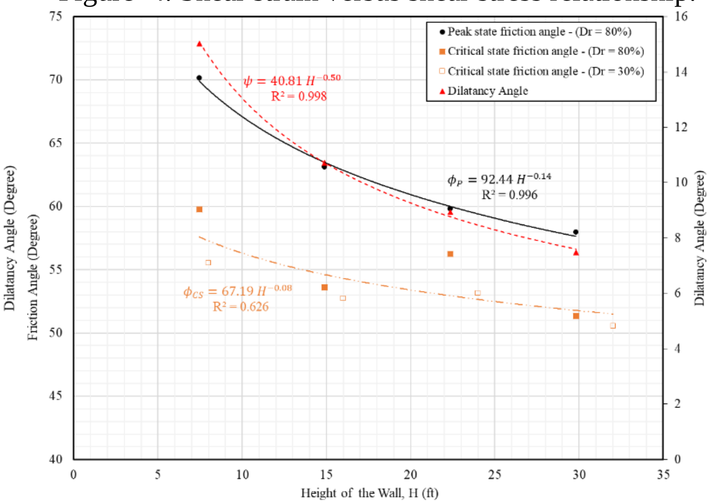

Figure 6. Friction and dilatancy angles versus wall height.

Table 3. Summary of measured friction and dilatancy angles and the power model that relates normal stress (σ) to shear stress (τ).

<table>
<tr><td colspan="4">Peak state friction angle (Power model)
(ϕ_p)</td><td colspan="4">Critical state friction angle (Power model)
(ϕ_{cs})</td><td>Linear Mohr Coulomb for Critical state friction angle</td><td colspan="4">Dilatancy angle (Power Fitting)
(ψ)</td></tr>
<tr><td colspan="4">$\tau = 11.34\ \sigma^{0.60}$, $R^2 = 0.992$</td><td colspan="4">$\tau = 2.68\ \sigma^{0.85}$, $R^2 = 0.977$</td><td rowspan="4">ϕ = 52.7°
$R^2 = 0.949$</td><td colspan="4">$\psi = 87.74\ \sigma^{-0.50}$, $R^2 = 0.998$</td></tr>
<tr><td>σ = 35 kPa</td><td>70</td><td>105</td><td>140</td><td>35</td><td>70</td><td>105</td><td>140</td><td>35</td><td>70</td><td>105</td><td>140</td></tr>
<tr><td rowspan="2">70.2°</td><td rowspan="2">63.1°</td><td rowspan="2">59.8°</td><td rowspan="2">58.0°</td><td>59.7°</td><td>53.6°</td><td>56.2°</td><td>51.3°</td><td rowspan="2">15.0°</td><td rowspan="2">10.7°</td><td rowspan="2">8.9°</td><td rowspan="2">7.5°</td></tr>
<tr><td>55.5°</td><td>52.7°</td><td>53.1°</td><td>50.5°</td></tr>
</table>

Table 4. Values of recommended friction and dilatancy angles for different wall heights.

Wall Height (ft)	Recommended Friction Angle	Recommended Dilatancy Angle
< 10 ft	56	13
15 ft	54	10
20 ft	53	9
25 ft	52	8
30 ft	51	7

For more information check https://alshibli.utk.edu/research/ or contact Professor Khalid Alshibli, Email: Alshibli@utk.edu