The Keowee Creeper

By Daryl Wurster, PE and
Doug Chappell, PE
Wurster Engineering & Construction, Inc.
Lake Keowee is located in the Upstate of South Carolina and was created for power production and for recreation.
The Oconee Nuclear plant is located on Lake Keowee and as a result, water levels are held fairly constant. Much of the waterfront has residential development. Lakefront property in the lower portions of the lake is gently to moderately sloping.
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The ground movement is typically very slow moving and deep seated, often encompassing several acres of ground.

Uniquely, the surface profile of the moving areas is often rather flat, ranging from 3H:1V to 7H:1V, and the slides typically exit well below the lake surface.
Four known slides in same general area of Lake Keowee with similar characteristics
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- Slope of ground is flatter than might be expected for a slide to occur in this general area. Site grades are typically 3H:1V or flatter
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- Areas with borings and slope inclinometers indicate movement near the soft soil/weathered rock interface
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- Failure plane is about 30 to 60 ft deep near the shoreline extending out into Lake Keowee
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- Slope of ground is flatter than might be expected for a slide to occur in this general area. Site grades are typically 3H:1V or flatter
- Areas with borings and slope inclinometers indicate movement near the soft soil/weathered rock interface
- Failure plane is about 30 to 60 ft deep near the shoreline extending out into Lake Keowee
- Two of the sites experienced ruptured water lines. We are not sure if the ground movement caused the water lines to break or if broken water lines broke on their own and induced ground movement.
Where are these slides located
Does geology have anything to do with the location of these slides?
Walhalla Thrust Sheet consisting of gneisses and schists

Oconee Nuclear Plant
Let's look at each of the four slides

Property owners' names left off for privacy and one of these slides is in litigation.
Site 1
Site 1

- Site 1 slide was repaired by others using patterned ground anchors.
Site 1

- Site 1 slide was repaired by others using patterned ground anchors.
- Slide was deep seated and extended into lake.
Site 1

- Site 1 slide was repaired by others using patterned ground anchors.
- Slide was deep seated and extended into lake.
- Ground movement showed up as separation cracks in house.
Site 1

- Site 1 slide was repaired by others using patterned ground anchors.
- Slide was deep seated and extended into lake.
- Ground movement showed up as separation cracks in house.
- Ground was gently sloping.
Site 2
Site 2

- Site 2 slide was repaired by others by regrading slope.
Site 2

- Site 2 slide was repaired by others by regrading slope.
- Effectiveness of repair unknown.
Site 2

- Site 2 slide was repaired by others by regrading slope.
- Effectiveness of repair unknown.
- Slide was deep seated and extended into lake.
Site 2

- Site 2 slide was repaired by others by regrading slope.
- Effectiveness of repair unknown.
- Slide was deep seated and extended into lake.
- Ground movement did not extend as far as house.
Site 2

- Site 2 slide was repaired by others by regrading slope.
- Effectiveness of repair unknown.
- Slide was deep seated and extended into lake.
- Ground movement did not extend as far as house.
- Ground was moderately sloping.
Site 2

- Site 2 slide was repaired by others by regrading slope.
- Effectiveness of repair unknown.
- Slide was deep seated and extended into lake.
- Ground movement did not extend as far as house.
- Ground was moderately sloping.
- Slide is the edge of a larger slide that encompasses most of the adjacent lot and a third lot.
Site 2

- Site 2 slide was repaired by others by regrading slope.
- Effectiveness of repair unknown.
- Slide was deep seated and extended into lake.
- Ground movement did not extend as far as house.
- Ground was moderately sloping.
- Slide is the edge of a larger slide that encompasses most of the adjacent lot and a third lot.
- Adjacent lot was abandoned.
Site 2

• Site 2 slide was repaired by others by regrading slope.
• Effectiveness of repair unknown.
• Slide was deep seated and extended into lake.
• Ground movement did not extend as far as house.
• Ground was moderately sloping.
• Slide is the edge of a larger slide that encompasses most of the adjacent lot and a third lot.
• Adjacent lot was abandoned.
• The third lot has a house on it and repairs were reportedly made by regrading the lot.
Site 3
Site 3

- Site 3 slide has not been repaired at this time.
Site 3

- Site 3 slide has not been repaired at this time.
- Slide is deep seated and extends into lake.
Site 3

- Site 3 slide has not been repaired at this time.
- Slide is deep seated and extends into lake.
- Ground movement showed up as small to large tension cracks.
Site 3

- Site 3 slide has not been repaired at this time.
- Slide is deep seated and extends into lake.
- Ground movement showed up as small to large tension cracks.
- Large tension cracks at first appear to be ditches and old roads.
Site 3

- Site 3 slide has not been repaired at this time.
- Slide is deep seated and extends into lake.
- Ground movement showed up as small to large tension cracks.
- Large tension cracks at first appear to be ditches and old roads.
- Ground was gently sloping (i.e. 7H:1V), however, ground offshore is as steep as 1H:1V.
Site 3

- Site 3 slide has not been repaired at this time.
- Slide is deep seated and extends into lake.
- Ground movement showed up as small to large tension cracks.
- Large tension cracks at first appear to be ditches and old roads.
- Ground was gently sloping (i.e., 6H:1V), however, ground offshore is as steep as 1H:1V.
- Initial repairs were made by others to a new house located in the middle of the slide area included helical piers. Piers could be tightened up, then would loose. WEC was then asked to look at site.
<table>
<thead>
<tr>
<th>ELEVATION/DEPTH (FT)</th>
<th>SOIL DESCRIPTION</th>
<th>SOIL TYPE</th>
<th>STANDARD PENETRATION RESULTS</th>
<th>BLOW/FOOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2-INCHES OF TOPSOIL: Very firm, yellowish-red with pink and white, silty, fine to coarse SAND with gravel (residuum)</td>
<td>4</td>
<td>5</td>
<td>7</td>
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<tr>
<td>4</td>
<td></td>
<td>3</td>
<td>11</td>
<td>12</td>
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<tr>
<td>44</td>
<td></td>
<td>2</td>
<td>11</td>
<td>12</td>
</tr>
</tbody>
</table>

**NOTES:**
- Slope inclinometer set at 37 feet.
- Ager refusal at 37.5 feet. Groundwater encountered at 31.5 feet at time of drilling and at 29 feet after 24 hours.
Jasmin Sl-3, A-Axis

Depth in feet

Cumulative Displacement (in) from 02/28/2010

7/30/2010
8/30/2010
10/1/2010
4/8/2011

Jasmin Sl-3, B-Axis

Depth in feet

Cumulative Displacement (in) from 02/28/2010

7/30/2010
8/30/2010
10/1/2010
4/8/2011

Jasmine Point

BLE Project No. J10-7112-01

Cliffs at Keowee Falls South
Jasmin SI-4, A-Axis

Depth in feet

Cumulative Displacement (in) from 6/25/2010

Jasmin SI-4, B-Axis

Depth in feet

Cumulative Displacement (in) from 8/25/2010

Jasmine Point

BLE Project No. J10-7112-01

Cliffs at Keowee Falls South
Jasmin SI-5, A-Axis

Jasmin SI-5, B-Axis

Cumulative Displacement (in) from 6/25/2010

Cumulative Displacement (in) from 5/25/2010

Jasmine Point

BLE Project No. J10-7112-01

Cliffs at Kecwee Falls South
Reticulated/Battered Micropiles

Ground Surface

Potential Failure Plane

Micropiles
Site 4
Site 4

- Site 4 slide was repaired by WEC using battered micropiles with a concrete cap beam and tieback anchors.
Site 4

- Site 4 slide was repaired by WEC using battered micropiles with a concrete cap beam and tieback anchors.
- Site is being monitored with slope inclinometers.
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- Site 4 slide was repaired by WEC using battered micropiles with a concrete cap beam and tieback anchors.
- Site is being monitored with slope inclinometers.
- If movement continues, patterned ground anchors will additionally be installed.
Site 4

• Site 4 slide was repaired by WEC using battered micropiles with a concrete cap beam and tieback anchors.
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• If movement continues, patterned ground anchors will additionally be installed.
• Slide was deep seated and extended into lake.
Site 4

• Site 4 slide was repaired by WEC using battered micropiles with a concrete cap beam and tieback anchors.
• Site is being monitored with slope inclinometers.
• If movement continues, patterned ground anchors will additionally be installed.
• Slide was deep seated and extended into lake.
• Ground movement showed up as separation cracks in house.
Site 4

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- Site is being monitored with slope inclinometers.
- If movement continues, patterned ground anchors will additionally be installed.
- Slide was deep seated and extended into lake.
- Ground movement showed up as separation cracks in house.
- Ground was gently sloping.
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- Site 4 slide was repaired by WEC using battered micropiles with a concrete cap beam and tieback anchors.
- Site is being monitored with slope inclinometers.
- If movement continues, patterned ground anchors will additionally be installed.
- Slide was deep seated and extended into lake.
- Ground movement showed up as separation cracks in house.
- Ground was gently sloping.
- Slide encompasses adjacent lot where house was demolished.
LAKE KEOWEE

PROPERTY LINE FOLLOWS 804 MSL CONTOUR.
### BORING LOG

**Project No:** 65M0144  
**Client:** Roger Keranen  
**Project:** Keranen Residence Distress Evaluation  
**City/State:** Lake Keowee, SC

**Elevation:** Total Depth: 41.0’

**Drilling Method:** HSA  
**Hammer Type:**

**Date Drilled:**

**Driller:** Richmond, Va

<table>
<thead>
<tr>
<th>Elevation</th>
<th>Depth</th>
<th>Description of Materials (Classification)</th>
<th>Sample Blows</th>
<th>Sample Depth (feet)</th>
<th>N-Value (Blow/ft)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>4.0</td>
<td>FILL - Soft to firm, moist, dark red clayey Silt (MH) with little sand</td>
<td>1-2-1</td>
<td>0.0</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3-3-3</td>
<td>1.5</td>
<td>6</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>W01-2-2</td>
<td>3.0</td>
<td>4</td>
<td></td>
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<tr>
<td></td>
<td>7.0</td>
<td>APPARENT RESIDUAL - Firm, moist, dark reddish brown clayey Silt (MH)</td>
<td>3-3-3</td>
<td>4.5</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2-3-4</td>
<td>6.0</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15.0</td>
<td>Firm, moist to wet, reddish brown to light tan sandy Silt (ML)</td>
<td>2-3-5</td>
<td>8.5</td>
<td>7</td>
<td></td>
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<tr>
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<td>2-3-6</td>
<td>10.0</td>
<td>7</td>
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<tr>
<td></td>
<td></td>
<td>Loose to medium dense, moist, dark brown and red silty fine to medium SAND (SM) with trace mica flakes</td>
<td>2-3-3</td>
<td>13.5</td>
<td>8</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>2-3-3</td>
<td>15.0</td>
<td>8</td>
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<td></td>
<td>6-6-7</td>
<td>18.5</td>
<td>6</td>
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<td></td>
<td></td>
<td>3-3-3</td>
<td>20.0</td>
<td>6</td>
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<td></td>
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<td></td>
<td>2-2-2-3</td>
<td>23.5</td>
<td>5</td>
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<td></td>
<td></td>
<td></td>
<td>6-6-7</td>
<td>25.0</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>32.0</td>
<td>Medium dense, moist white, tan, orange and gray silty fine to medium SAND (SM) with mica</td>
<td>8-9-10</td>
<td>28.5</td>
<td>13</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>3-3-3</td>
<td>30.0</td>
<td>13</td>
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<td></td>
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<td></td>
<td>6-6-7</td>
<td>33.5</td>
<td>19</td>
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<tr>
<td></td>
<td>38.5</td>
<td>SOFT WEATHERED ROCK - Sampled as white, tan, orange and gray silty fine to medium SAND (SM)</td>
<td>50/4&quot;</td>
<td>35.0</td>
<td>19</td>
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<td></td>
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<td></td>
<td>50/2.5&quot;</td>
<td>40.0</td>
<td>19</td>
<td></td>
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<tr>
<td></td>
<td>40.5</td>
<td>Auger refusal encountered at approximately 41 feet below the existing site grades</td>
<td></td>
<td></td>
<td>100+</td>
<td></td>
</tr>
</tbody>
</table>

*Number of Blows required for a 340 lb hammer dropping 10’ to drive 2” O.D., 1.375” I.D. sampler a total of 18 inches in three 6” increments. The sum of the second and third increments of penetration is termed the standard penetration resistance, N-Value.*
Keranen Residence, Inclinometer K-2

Roger Keranen

Sets marked * include zero shift and/or rotation corrections.
Keranen Residence, Inclinometer K-3
Roger Keranen

Sets marked * include zero shift and/or rotation corrections.
Keranen Residence, Inclinometer K-5

Roger Keranen

Sets marked * include zero shift and/or rotation corrections.
SILTY SAND
γ = 120 psf
C = 0
φ = 22°

HOUSE
σ = 500 psf

β = arcsin \( \frac{y}{y} = 18.4° \)

APPROX. SCALE:
1" = 20'

PWR

LAKE
KISWAZ FLOODPOOL @ 640'

BY: D.S.
Date: 11/1/2012

Checked by: TCS
\[ W_x \]

\[ W_x = W \sin \beta = 248.6 \sin 18.9^\circ \]

\[ W_x = 78.5 \text{ lbf/ft} \]

\[ F = \frac{N \tan \phi}{\text{tan} 22^\circ} \]

\[ F = 95.3 \text{ lbf/ft} \]

**FS with House Load**

\[ FS = \frac{P_{Rx} + F}{P_{Rx} + P_a} = \frac{40.9 \text{ lbf/ft} + 78.5 \text{ lbf/ft}}{78.5 \text{ lbf/ft} + 95.3 \text{ lbf/ft}} = 136.2 \]

\[ FS = 1.00 \]

**FS without House Load**

\[ FS = \frac{P_{Rx} + F}{W_x + P_a} = \frac{126.2}{134.1} = 1.24 \]

\[ FS = 1.09 \]

The results of the block analyses support that the existing factor-of-safety is near 1 assuming that the friction angle along the slide interface is 22 degrees.
Conclusions/Additional Questions
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• Does geology have anything to do with location of slides?
Conclusions/Additional Questions

- Does geology have anything to do with location of slides?
- What effect does the lake have on these slides?
Conclusions/Additional Questions

• Does geology have anything to do with location of slides?
• What effect does the lake have on these slides?
• Apparent similarities between these slides?
Conclusions/Additional Questions

- Does geology have anything to do with location of slides?
- What effect does the lake have on these slides?
- Apparent similarities between these slides?
- Could the susceptibility of these sites to landslide movement be assessed?
THANK YOU