ATTENTION: Mr. David Cutter, ASLA, LEED AP

RE: Geotechnical Overview
    Cascadilla Glen and Fall Creek Gorge
    #210009

Dear Mr. Cutter;

Pursuant to your request for a geotechnical engineering overview of the Cornell gorges, we have pieced together the following reports that our office prepared for Cornell University over the past 3 years. We believe this report will provide useful background for your current project.

The Fall Creek Gorge and Cascadilla Glen are beautiful, deep canyons with prominent bedrock exposures. From a geologic viewpoint, continual erosion by the creeks causes frequent changes to the gorges that yield fresh exposures of the earth and rock. The exposures have yielded alluring landforms and ecosystems.

1. Geologic History

The conventional geologic interpretation is that the two gorges developed essentially simultaneously since the last ice age that ended about 10,000 years ago. The streams eroded their steep-sided gorges through layers of bedrock. The soil cover over the bedrock forms the sloping top portions of the gorge rims. The slopes at the base of the rock faces are debris piles that fell in from above.

The writer judges that the rock throughout the two gorges, and beneath the campus in between, is similar in many respects. It consists of various layers of the Genesee Group shales. The rock exposed in the gorges consists mostly of fractured and
thinly bedded indurated siltstone, with occasional thin beds of sandstone and shale.

2. Engineering Properties of the Rock and Soil

Recent tests for Cornell University determined unconfined compressive strengths of over 10,000 psi for unweathered intact rock for the recently constructed Physical Sciences Building and the proposed CIS Building. This value is 2 to 3 times that of concrete used for buildings. For a 150 ft deep gorge, the vertical pressure at the sidewall would be on the order of 180 psi, or about 3 percent of ultimate strength of the intact rock.

The bedrock is not solid and intact, though. It contains many fractures and discontinuities. The most significant regional discontinuities are nearly horizontal bedding planes and planar vertical fractures that extend over tens or hundreds of feet. Occasionally odd fractures have been observed at an incline. The orientations of the discontinuities are mostly favorable for stability of steep sides, since the rock pieces are essentially stacked orderly, like slabs and blocks. Where vertical discontinuities are close together, however, a vertical slope may behave like a tall stack of teetering blocks. With so much rock exposed, and so many discontinuities, there are many areas where pieces of rock are at risk of popping out of the side slopes.

The soil covering the bedrock is exposed near the gorge rims. Typically, the soils are relatively impermeable so there is not a large volume of water seeping out of the hillsides below the rim, but there are a few small springs and wet spots on the south side of Fall Creek north of University Avenue and there must be others.

In most places, fill appears to have been placed to raise low spots next to the gorges for roads and other facilities. The fill typically lies over several feet of lacustrine soil consisting of medium silt, clay and sand. The lacustine soils lie over dense silty glacial till. Thickness of soil overlying the bedrock exceeds 60 ft on the north side of University Avenue opposite Tjaden Hall and rises to just a few feet near Thurston Avenue.
The steepest natural slopes are on the order of 34 degrees, indicating that the angle of repose of the soil is about 34 degrees. Flatter slopes have formed where there is persistent seepage and steeper slopes have formed where dense glacial till is exposed and there is no persistent seepage.

3. Active Processes

The exposed rock faces continually weather by mechanical and chemical means that cause small, random, fractures. These weathered zones unravel gradually and the small pieces fall into the gorge below.

The constant weathering causes four specific types of rock fall susceptibility: Spalling, differential weathering, toppling, and block or wedge sliding.

The first, spalling, occurs when water, frost, chemical deterioration and weathering, cause small pieces of rock to loosen and slip out of the gorge sides. This process occurs slowly throughout the year, but accelerates during wet weather and in the spring when groundwater is most plentiful and frost leaves the ground. Each piece that spalls off increases the vulnerability of similar fate to the pieces behind, so there is a slow, continual unraveling. The spalls accumulate as talus at the base of the gorge sides in many places, similar to those shown on Figure 1. The rock falls and talus in many areas of the gorges, however, are washed away by the streams.

The second mode is differential weathering that gives rise to larger falls. Larger pieces may fall where weathering-resistant harder layers are underlain by less resistant layers, as shown in Figure 2. As the weaker layers deteriorate, larger blocks of the stronger rock are undermined and left overhanging until they eventually fall.

The third failure mode is toppling of tall narrow columns of rock. Toppling can occur where vertical discontinuities in the rock mass intersect near the face of the gorge to create a narrow column of rock that behaves independently of the rock mass. Tall narrow columns have lower stability against toppling than short wide ones. Erosion or dissolution undermining of the toe of the column by the stream can eventually undermine the block base past its tipping point. Tall narrow columns may also be at risk of buckling. The
writer believes that the prismatic hollow spots common in both gorges, as shown in Figures 3a and 3b, may have formed by toppling of blocks of rock. The relatively strong rock with well-developed vertical discontinuities means that relatively tall and narrow rock columns can develop, as shown in Figure 4.

The fourth failure mode is Block sliding. This occurs where discontinuities of the rock align and/or intersect such that block masses so determined are unstable with respect to the frictional resistance required to hold them in place. Erosion or unraveling of the rock face or weathering along a discontinuity may tip the balance of resistance in favor of the destabilizing forces. Water pressure within discontinuities also may have a great destabilizing effect. The relatively high side slopes and narrow discontinuities are vulnerable to sudden buildup of water pressure during wet periods.

Evaluation of the topography of the soil slopes indicates that they have been left behind after the overlying soil has slid or been washed or eroded into the gorges. The old scars from this process indicate that the slides are typically shallow-seated slides that are on the order of 100 ft wide.

4. Evaluation of Features

There are many “slots” in the rock faces in both gorges. These slots may have been formed from combination of erosion by small or intermittent tributary streams and rock block slides or topples. Examples of these slots are shown in Figure 5. In several places the slots extend to the gorge rim where a retaining structure was built to retain old fill. An example is north of Eddy Gate at the south rim of Cascadilla Glen.

5. History of Rock Falls and Slides

An accepted method of evaluating rock fall risk considers the frequency of previous falls in the area. We understand that there are no records of rock falls in either gorge. Community recollections of significant rock falls appear to be far and few between. Maintenance workers report that rock spalls are frequent in the spring and after heavy rains, but not as frequent in the summer and fall. We know of no reports of large rock falls or block slides in Cascadilla Glen or Fall Creek Gorge, so they do not appear to happen “often,” but they
have occurred undoubtedly within geologic time, and should be expected in the future. We observed the small recent rock fall in Cascadilla Glen in early December 2008 that is shown in Figure 6.

6. Geologic Time Frame

Over a geologic time frame, the gorge is active. This perspective, however, is not our common frame of reference. Based on the estimated 10,000 yr age of Cascadilla Glen, the 250-ft-wide gorge between Central Ave and Stewart Ave has widened at an average rate of $250 \text{ ft} / 10,000 \text{ yrs} = 0.025 \text{ ft} / \text{ yr}$. This is equivalent to each rim receding about 0.15 inch (4 mm) per year. Based on parallel reasoning, the gorge volume of 10,000 cu ft per ft would indicate that each linear ft of the gorge has increased at an average rate of 1 cu ft per year. The values for Fall Creek are slightly greater.

The average yearly rates of 0.15 inches of rim recession and 1 cu ft per ft of enlargement are so small that they are essentially imperceptible according to our normal frame of reference. Nevertheless, the campus that was founded almost 150 years ago, should take a long term perspective on this. Over 100 years, the gorge rim would recede 15 inches on each side, on the average, and the volume would increase at 100 cu ft per ft. at this rate, over a 100 year period, the 1100 lin ft of Cascadilla Glen from College Avenue to Stewart Avenue would lose 110,000 cu ft or over 4000 CY, which is almost 350 large dump truck loads of material.

If the geologic processes at work in the gorge can be viewed as proceeding at steady rates, it is only over a very long term. The erosion and mass wasting that have formed the gorges occur in fits and starts. Large falls may occur infrequently that account for much of the activity. Areas of greatly concentrated activity compensate for the areas that are more stable. But in the big picture, the gorge is changing and the rim is naturally expanding at a rate that should be of concern to facilities near the rim.

7. Potential for Large Rock Falls and Rock Slides

The geologic background indicates there is a risk of frequent small rock falls and less frequent large rock slides. The gorge itself formed this way and the process has not stopped.
Although large rock falls have not been recorded, they will eventually occur where the stream impinges on the toe of the bedrock or talus slopes. The constant washing away of minerals or the eroding of the rock at stream level acts to undermine the slope above. The strong rock will continue to cantilever out over the hollow spot below until the tipping point is reached. This tipping point depends on how wide the rock column is and how far back from the face a critical rock discontinuity occurs. Vertical discontinuities are common in the rock, so significant overhangs are not likely to exist for long. The few overhangs that are apparent in the gorges can be suspected of having short remaining lifetimes.

8. General Shape of Gorges

The gorges have a characteristic shape shown in Figure 7. The top portion slopes on the order of 1-v:2-h with vegetation and little rock exposure. The middle portion is significantly steeper with persistent rock exposure and sheer faces. The bottom portions are either covered with talus piles inclined at nearly 45 degrees or the rock face extends to the stream bed.

The bedrock at the gorge rims is covered by natural soil deposits and old fill. Since the soil is weaker than the bedrock and is more susceptible to erosion, the rim areas slope at a flatter angle than the rock below. Due to thin soil cover, the sloping rim is relatively narrow in Cascadilla Glen between Stewart Ave and Central Ave, whereas the sloping rim is much wider next to Oak Street, where the soil cover over the bedrock is greater.

9. Soil Slopes Below Rims

As a consequence of the processes that formed the gorges, the soil side slopes can be presumed to be at their angle of repose. Further deepening or widening of the rock gorge increases the steepness of these slopes, causing the surficial soil to unravel. Changes to surface drainage will quickly erode the surface of these slopes and changes to subsurface drainage could reduce deeper stability. The rim and side slopes in the soil areas can be expected to creep from weathering, freezing and thawing. Since the gorges are typically wider in areas of thicker soil overburden, we
estimate that the rim there recedes faster than in areas of thinner soil cover.

Development of small flat areas within a slope for trails requires steepening the slope below or above the trail, or both. These new slopes will in general be steeper than the angle of repose so that the new slopes will be less stable than before. The greater the natural slopes are steepened, the greater and more rapid the potential instability will be. Thus, one should expect that trails in many of the sloping areas below the gorge rims would require frequent maintenance and perhaps periodic re-building or re-routing.

Please contact me if we can be of further service in this matter.

Sincerely,

JOHN P. STOPEN ENGINEERING PARTNERSHIP

James P. Stewart, Ph.D., P.E.
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attachments