Analyzing the Extensive Landslide History of Riverside Avenue

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Abstract

Riverside Avenue, located in Burlington, Vermont (Figure 1), has suffered numerous landslides over the past century. To better understand these landslides and why they occur, multiple geomorphic processes were analyzed including general landslide causes, the glacial history of the area, role of hydrology, and the influence of human activity. We found that there is not one sole cause of these landslides, but rather, these factors intersect to shape the landslide-prone area that exists today. The repeated addition of sandy fill and garbage on Riverside Avenue along with human impact has negatively affected the stability of the slope and the recurrence of landslides. Several mitigation strategies including the removal of fill and planting vegetation are available to decrease the risk of future landslides, whereas continuing to use the methods of the past will result in semi-frequent landslides.

Figure 1: Riverside Avenue Location in Burlington, VT (Google Earth 2020).

Introduction

Beginning in the late 1920's, fill was added along the north side of Riverside Avenue. Within a few decades, major landslides began to occur on this slope. Between August and November of 1955, three major landslides occurred, followed by several more in 1972, 1976, 1981, and most recently October of 2019 (Newspaper Clippings). Considering the spatial distribution of these landslides, we believe that they were induced by heavy rainfall events. However, additional underlying factors including rock and soil type, slope angle, topography, surface hydrology, glacial history, and human interference allowed the heavy precipitation to be so influential.

Background

The topography of Riverside Avenue combined with the fill material are significant contributors to the reoccurrence of these landslides. At the site of the 2019 landslide (Figure 2), we observed a slope angle near 30˚ that was composed of a various aggregate of fill materials including old junk objects, sands, and gravels that impact soil properties and decrease stability. Additionally, several old streams and culverts, some of which are buried under Riverside Avenue, contribute to the saturation of the slope and decrease its shear strength. During heavy rainfall events, a large flux of groundwater is moved by the culverts to further saturate the filled slope. This combination of topography, fill composition, and slope saturation set up the area for numerous disasters.

Figure 2: Image of the steep slope where the 2019 landslide occurred. Various debris including trash and concrete are visible (Liviya Kovacevic 2020).

Glacial History

Burlington, Vermont was impacted by glaciers following the retreat of the Laurentide Ice Sheet at the conclusion of the most recent glacial period. The presence of glaciation has impacted the composition of the surficial material. A layer of glacial till composed mainly of sands and silts now underlies much of New England, including Riverside Avenue. While we were unable to directly see this in the field, we know that the historical presence of glaciers in the area has affected the surficial geology. In addition, the till does not have the same permeability as the fill material. When rainfall from a heavy precipitation event infiltrates into the soil, the boundary between the till and the fill becomes increasingly unstable and results in slope failures. While the glacial history has helped create the necessary underlying soils for landslides, the major contributing factors are anthropogenic.

Landslide Causes

The slope angle, slope material, and heavy precipitation are most important in determining whether a landslide will occur. Translational landslides, such as those on Riverside Avenue, often occur in areas where groundwater converges and raises pore pressure, which reduces the normal stress and therefore decreases the frictional strength of the slope material (Bierman & Montgomery 2020), illustrated in Figure 3. Following the addition of fill, there was an immediate decrease in slope stability and increase in driving stress. The cohesion of the fill was lower than that of the underlying soil, therefore rain that occurred after

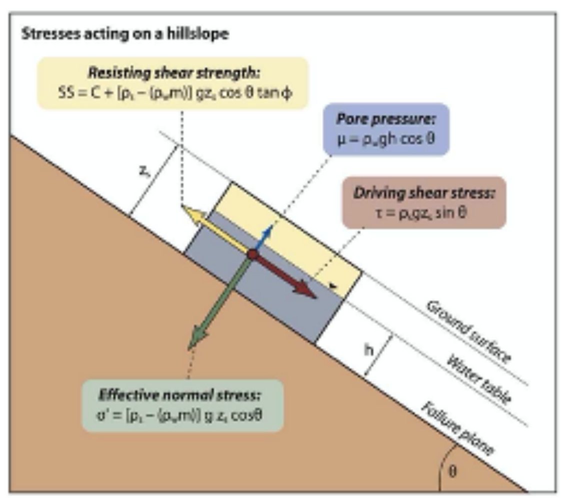

Figure 3: Stresses acting on a hillslope (Bierman & Montgomery 2020). A combination of the resisting shear stress, driving shear stress, pore pressure, and effective normal stress determine whether a slope will fail.

the addition of fill had a greater ability to decrease the frictional strength of the slope material and cause landslides.

Vegetation tends to increase the cohesion of a slope by anchoring material with its roots (Bierman & Montgomery 2020). At or upslope of multiple landslide sites on Riverside Avenue, vegetation was removed, which decreased the slope cohesion. Though the lack of vegetation does not directly cause landslides, it influences the strength and stability of the slope and therefore the probability of landslide occurrences.

Most of the Riverside Avenue landslides resulted from heavy rains that quickly saturated and decreased the strength of the slope (Newspaper Clippings). Using the infinite slope model as an example, increasing the slope saturation given the slope angle and cohesion of the material significantly influences slope failure. These given conditions resulted in the Riverside Avenue landslides to be induced mainly by heavy precipitation.

Hydrology

Surface and ground water hydrology are essential components involved in the landslide history of Riverside Avenue. In Figure 4a, we see a stream channel that runs under Riverside Avenue and into the Winooski River. Figure 4b shows that the stream channel and several smaller channel basins spread out along the length of Riverside Avenue. Because both the filled area and surrounding soils are primarily sandy very permeable, most rainwater infiltrates into the soil and moves downslope. The topography directs a significant volume of groundwater north towards the filled area, decreasing the strength of the slope during a storm by reducing the cohesive strength between the fill material. Since the soil is very permeable, water from heavier storms infiltrates deeper into the soil in a short time period compared to more clay rich soils. A higher saturation depth will decrease the stability of a slope to a greater extent and help drive shallow landslides.

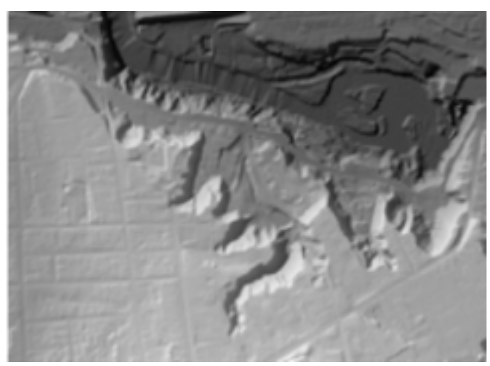

Figure 4a: (Left) Topographic map of Riverside Avenue from the US Coast Survey, 1872. The stream channel is clearly visible (Riverside Avenue Imagery, Maps, and Elevation).
Figure 4b: (Right) DEM of Riverside Avenue, 2004. Several landslide scars are visible between Riverside Avenue and the Winooski River (Riverside Avenue Imagery, Maps, and Elevation).

Natural vs. Human Impact on Landslides

There is no doubt that the occurrence and frequency of Riverside Avenue landslides are impacted by human activities, as seen by an increase in landslides after construction begun in the area. In the 1920's, the city of Burlington widened the road and added sidewalks. The development continued into the late 1940's when small buildings were built along the road. Several landslides occurred between the completion of the construction and the early 1980's when additional development began. Eventually, the steep slope along Riverside Avenue could not support the amount of development occurring, leading to several major landslides. Initial construction and filling were followed by private owners illegally dumping trash and fill down the slope (Newspaper Clippings), which further decreased the slope stability and made the area more vulnerable to landslides. Figure 5 is an example of a precursor to landslides, taken shortly before the 2019 landslide.

Figure 5: A 6-inch gap begins to form, cracking shortly before the 2019 landslide occurred (Paul Bierman 2019).

Figure 6: Image taken in 1955 after a landslide on Riverside Avenue significantly lowered a section of the road and small buildings. (UVM Landscape Change Program).

While landslides in general and the landslides that have occurred along Riverside Avenue are natural geomorphic processes, the frequency and risk posed by them have increased by human interaction and development along the road. The addition of fill and dumping of debris, as well as removal of trees throughout the areas surrounding Riverside Avenue have undoubtedly contributed to a greater risk of landslides, due to decreased cohesion and soil density. The sandy fill has less cohesive strength than the glacial till, and the loss of vegetation allows more water to flow down the slope. Steep slopes with loose soils such as those surrounding Riverside Avenue are bound to slide, especially with a quick and large increase in groundwater as we saw in 2019 landslide that was caused by hours of heavy precipitation. With further human activity, the frequency and probability of these landslides will increase, especially as our changing climate increases the occurrence rates of heavy rainstorms. Although these processes can be modeled and understood, changes in human activity and climate will make future landslides less predictable.

Conclusion

The greatest factors in facilitating landslides on Riverside Avenue are the reduction of tree cover on steep slopes, the addition of fill behind businesses and where landslides have occurred, and finally the dumping of waste and debris along Riverside. The removal of trees reduces the overall cohesion and normal force of the soil, while the dumping of fill and debris increase shearing force and reduces soil cohesion, allowing landslides to occur with less force needed to drive them. By removing fill and debris responsibly, replanting trees, and using some of the many methods designed to mitigate risk of landslides (rerouting debris and groundwater, constructing structures to strengthen soil cohesion, etc.), Riverside Avenue could experience significantly fewer landslides. As we have seen, the cycle of destructive landslides on Riverside Avenue has continued for nearly 100 years, but by implementing effective mitigation strategies we have the possibility of decreasing the number of future landslides and keeping the community safer.

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