Analyzing the Extensive Landslide History of Riverside Avenue

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Figure 1: Historical photograph of the 1955 slide slightly down the slope from Riverside Aven

Abstract

Riverside Avenue, located in Burlington, Vermont, has encountered numerous landslides over the past century. In order to better understand these landslides and why they occur, we analyzed multiple geomorphic processes including the how and why of landslides, the influence of human activity, role of hydrology, and the glacial history of the area. There is not one sole cause of these landslides, but instead a combination of these factors come together to shape the area that we see today. The fill of the previous slides has impacted the stability of the area with future decisions impacting the probability of the reoccurrence of landslides along Riverside Avenue. The usage of multiple mitigation strategies could decrease the risk of future landslides whereas continuing to use the methods of the past could result in semi-frequent future slides.

Introduction

Approximately 20 years after the addition of fill on the north side of Riverside Avenue, the area began to experience frequent landslides. The topography combined with the fill material are thought to be significant contributors to the reoccurrence of these landslides. The slope has a steep angle near 30˚ and is 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 that were buried under Riverside Avenue contribute to the saturation of the slope, decreasing the shear strength. The unstable combination of topography, fill composition, and slope saturation set up the area for disasters.

Discussion

Looking back at the history, we know that between August and November of 1955, three landslides occurred, followed by several more in 1972, 1976, 1981, and most recently 2019. Considering the spatial distribution, it is likely that these landslides were caused mainly by heavy rainfall events. However, there are other underlying factors including rock and soil type, slope angle, topography, surface hydrology, glacial history and human interference that allow the heavy precipitation to have that much influence.

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

The landslides on Riverside Avenue likely result from a combination of the underlying factors stated above, although some factors have a greater influence than others. Following the addition of fill and immediate decrease in slope stability paired with an increase in the driving shear stress, we can use the infinite slope model to help predict whether a landslide will occur given the conditions of the slope. Using an example model to interpret the driving and resisting forces of the Riverside Avenue slope, changing the slope saturation given the slope angle and cohesion of the material significantly influences slope failure. Changing slope angle or slab thickness only have so much influence, but the saturation depth is what really triggers these landslides to occur.

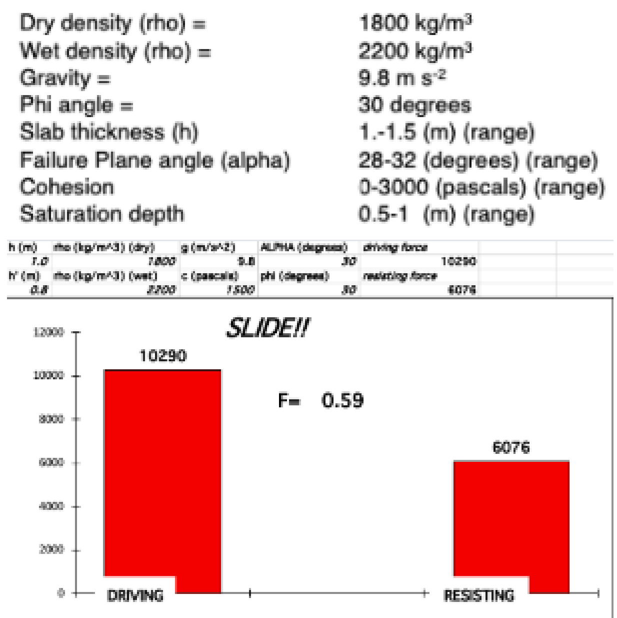

Figure 3: Using an example model to calculate F, the factor of safety, helps determine whether a landslide will occur. In this model, the slope and cohesion of the Riverside Ave area is set to estimates near their true values and the slab that failed is 80% saturated.

There is no doubt that the Riverside Avenue landslides are impacted by human activities. Construction is one of the major ways that humans have influenced the occurrence and frequency landslides. In 1931, the city of Burlington began to widen the road and add sidewalks. The development continued into the late 1940's when small buildings were built along the road. Several landslides occurred between then and the early 1980's when more development started to occur. The steep slope along Riverside Avenue would not support the amount of development occurring over the past 100 years, which led to several major landslides. Initial construction and filling were followed by private owners illegally dumping trash and fill down the slope, which further decreased the slope stability and made the area more vulnerable to landslides. Figure 4 is an example of one image that showed gaps forming along pavement at the top of the slope shortly before a landslide occurred.

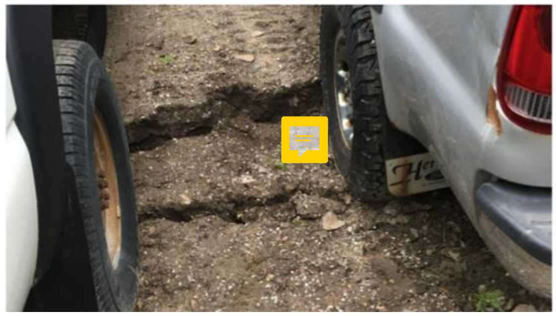

Figure 4: From Burlington Free Press showing a 6-inch gap starting to form, leading to a crack and shortly before the 2019 Halloween night landslide occurs.

While landslides in general and the landslides that have occurred along Riverside Avenue are natural geomorphic processes, the frequency and risk posed by them has been 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. Steep slopes with loose soils like those surrounding Riverside Avenue are bound to slide, especially with a quick and large increase in moisture as we saw in October of 2019. With increased human activity, the frequency and probability of these landslides will likely increase. Although these processes can be modeled and understood, changes in human activity may make future landslides less predictable and possibly more destructive.

Figure 5: Image taken in 1955 after a landslide on Riverside Avenue significantly lowered a section of the road and small buildings.

Surface and ground water hydrology are essential components that help contribute to the rich landslide history of Riverside Avenue. In Figure 6, we see a stream channel that runs under Riverside Avenue and into the Winooski River. Figure 7 shows that the stream channel and several smaller channels spread out along the length of Riverside Avenue. Because both the filled area and surrounding soils are primarily sandy and have a high permeability, most rainwater infiltrates into the soil and moves downslope. The topography directs a decent portion of groundwater north towards the filled area, which helps reduce the strength of the slope during a storm. 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 trigger shallow landslides.

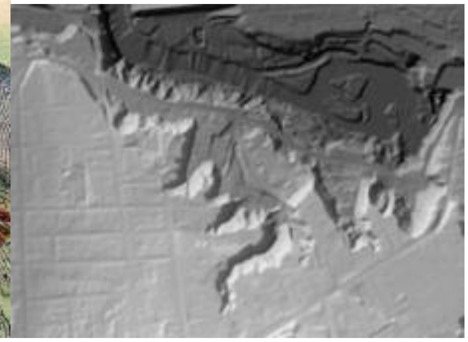

Figure 6: (Left) Topographic map of Riverside Ave from the US Coast Survey, 1872. The stream channel is clearly visible.
Figure 7: (Right) DEM of Riverside Avenue, 2004. Several landslide scars are visible between Riverside Avenue and the Winooski River.

Burlington, Vermont was impacted by glaciers with the most recent during the last Ice age when the area was covered by the Laurentide Ice Sheet. The presence of glaciation has impacted the composition of the surficial material, and a layer of glacial till composed mainly of sands and silts now underlies much of New England, including Riverside Avenue. In addition, the till does not have the same permeability as the fill material. If rainfall from a heavy precipitation event were to infiltrate into the soil, the boundary between the till and the fill would become increasingly unstable and result in more slope failures. Overall, the glacial history may have created the necessary underlying soils for landslides, but the major contributing factors are still anthropogenic.

The greatest factors in facilitating landslides on Riverside Avenue is the reduction of tree cover on steep slopes, the addition of fill behind businesses and where slides 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 trigger 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 been going on for nearly 100 years. By listening to scientists, engineers, and community advocates the cycle can be broken - businesses and individuals on Riverside Avenue can relax and we can finally stop pouring money into half-hearted attempts at solving the issue.

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Citations

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