Riverside Avenue Landslides

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<u>Abstract (120 words)</u>

The purpose of this paper is to evaluate both the human and natural causes of Riverside Avenue landslides, and to find possible ways to prevent them in the future. The study area is under specific concern due to human impact over time and the failure repeatability of these slopes. This study looks at the science behind slope morphology as well as historical records that document landscape change over time. Data was collected in the field and then calculated as it was analyzed against models. The conclusion of this study is that these landslides are natural and human induced, and a variety of preventative steps need to be accounted for when looking to the future in order to reduce the hazard.

(1644 words)

What controls landslide spatial distribution along Riverside Avenue?

The spatial distribution of landslides along Riverside Avenue is controlled by a variety of factors. One example of this is soil composition. As seen in figure 4, a diagram of a soil pit displaying each of the soil horizons, most of the soil in this area is generally sandy in composition, and this was proven by the digging of a soil pit in the woods behind Delehanty hall, only around 300 meters from Riverside Avenue. The sandy composition of the soil in this area most likely makes it more susceptible to landslides. Land use changes have also had a significant effect on where landslides occur. Throughout the last century, Riverside Avenue has become much more developed, and it has led to an increase in landslides. Changes in land use such as the widening of the road and an increased number of buildings on the side facing the river bank have all contributed to this issue.

Why are there landslides along Riverside Avenue?

The reason why landslides occur along Riverside Avenue is that many conditions, some human-caused and others natural, that allow landslides to occur coincide with each other in the area. However, they occur so frequently here primarily due to human activity. Efforts to improve the aesthetic quality of the road and surrounding area in the 1930s inadvertently made it more susceptible to landslides. In the decades to come, the recurring landslides were continuously ignored as the area became more and more urbanized despite the slides, further exacerbating the problem. For example, the removal of trees led to a loss in root cohesion, which allowed for even more landslides to occur. The geomorphic and glacial history of Riverside Avenue also plays a significant role in explaining why landslides are so frequent here. The advance and retreat of the Laurentide ice sheet caused most of the soil to consist of sandy till and glacial clay, which are both very low in cohesion. While the presence of vegetation made up for that lack of cohesion, human deforestation has undone that effect.

What triggers them?

Landslides are earth hazards that have multiple possible triggers. These triggers ultimately disturb the slope stability so much so that the driving shear stress exceeds that of the resisting shear stress, resulting in material traveling down the hill slope (as seen in Figure 3). Slope stability can be disturbed by decreasing soil cohesion, excessive and sudden influx of water, and gravity's force over time. Soil cohesion is compromised by deforestation, soil removal, and excessive filling of loose material. Deforestation rids soil of tree roots, which act as a stabilizer and provide cohesion. Soil removal makes the soil less compact, and filling those holes with loose sediment perpetuates the instability. Loose sediment fill does not have the porosity or cohesive ability to sustain a hill slope with strong soils. A sudden influx of water can occur with heavy rainfalls and snow melt, which can decrease infiltration rates and increase the runoff down the slope. This water can bring other material down the slope and could potentially trigger a landslide. Gravity causes soil creep over time, which is the slow, episodic movement of material down slope. Falling trees can carry other materials with them, eventually accumulating to an amount that allows the driving force to exceed the resisting force. Landslides can be triggered by many different things in many different ways, and always involve an unstable hill slope.

Are they natural?

Landslides are naturally occurring events that can be triggered with the aid of human development. There are naturally occurring processes, both internal and external, that affect slope stability and the likelihood of a landslide. The primary reason for the occurrence of landslides is gravity, for the gravitational force pulls materials down slope, with varying rates depending on the cause. Soil creep is a result of Earth's gravity, which is prevalent on Riverside

Avenue due to the steep inclines of the landslide locations. However, human development has a drastic impact on the rate of landslides and their magnitude. The increase of soil removal and installation of impermeable material throughout Burlington decreases infiltration rates and increases run off, which allows for more water to run down the slope and pick up other materials with it. The human response to landslides on Riverside Avenue has historically been to add artificial fill, which exacerbates slope instability and further increases the likelihood of another landslide occurring. Landslides are natural disasters that have both natural and artificial causes.

Are they human-induced? (timeline figure)

The continual deforestation and expansion of urbanization has caused a wide array of problems that promote proper conditions for landslides to occur. The landslides of Riverside Avenue are human-instigated and exacerbated. This area of Burlington is underlain by glacial till and sand deposits. The Winooski River cuts through the land, incising and eroding the river banks. While sand has very little cohesion, vegetation plays a large role in maintaining cohesion in the soil. Instability of the land is further perpetuated through human activities; since as early as 1931, there has been extensive road work done on Riverside Avenue, including deforestation and construction of concrete roads, curbs, sidewalks, and sewage systems. Deforestation contributes to the decrease in cohesion of the soil, as the roots rot away, root cohesion is lost and the root cavities open. The construction on the land at top of the slope for the construction of streets and buildings, puts a larger pressure load on the slope and increases the amount of impermeable surfaces. The increase of impermeable surfaces, causes and increase in quantity and velocity of runoff, which helps to further erode the slope more quickly. The excavation for sewer system and implementation of culverts, has disturbed the land and increased the vulnerability to erosion. In 1932, the streets were widened and new ornamental lighting with underground cables were added. In August and September 1955, the first two washouts occurred - an unused culvert was said to be the blame; reconstruction began shortly after. In November 1955, the third landslide broke out while construction on the area underwent. This washout sent fill and pine trees down into the Winooski River. A repair job quickly began to patch the road.

We observe decades of evidence of this repeated cycle with at least five landslide events and reconstruction attempts. At the banks of the river, there are still old appliances, large boulders, sand, silt, gravel, as well as debris, from the illegal dumping in June 1981. The execution of these attempts to fight the crumbling slope have largely proved to be insufficient. The addition of sediment without compaction, induces infiltration and during a rainfall event, pore pressure would build up, sediment is likely to be transported downslope.

What is the role of surface and ground water hydrology?

Water is the most active force of erosion. The work on Riverside Avenue has effectively disturbed the natural systems of the surface and ground water hydrology and decreased the infiltration rate of ground. The infiltration rate is how quickly water absorbs into the soils rather than runs off. The infiltration rate is dependent on the porosity and permeability of the surface. Surfaces with low permeability will promote faster run-off, more erosion, and more transportation of sediments downslope. The addition of paved roads and buildings turned once permeable land into impermeable surfaces, causing less water to infiltrate into the ground and more water to run-off the surface. Vegetation plays an important role in absorbing groundwater and increasing infiltration rates. The removal of vegetation reduces the infiltration rate, as well as impacts secondary porosity of the soil, leaving vacant root cavities for water to fill. During high intensity rainfall events, like in 2019, the ground can reach maximum infiltration capacity and the rainfall will run-off the surface, this process is called Horton's Overland Flow. There is a lag time between the peak rainfall and the peak run-off. The time it takes for an event to reach peak discharge, typically occurs quite rapidly in saturated ground, steep narrow watersheds, and areas of urbanization.

What is the role of glacial history on landslide location and frequency?

The recession of the Laurentide ice sheet over the last 100 kya deposited glacial till along the surface of the Northeast,and the formation of glacial lake Vermont which deposited glacial sand/clays throughout the Winooski floodplain. The apparent cohesion of this sandy till is little to no KPa, while glacial clays have a higher cohesion value. (Bierman et al, 2020) (Fig. 5.) Landslides were most likely very active right after deposition of this material due to the absence of apparent root cohesion from vegetation along slopes, mainly of uncompacted sandy till origin. (Bierman et al, 2020) These landslides occurred as normal stress decreased due to precipitation events and pore pressures were filled, saturating the slope. Over time, the landslide activity most likely decreased, and more cohesion was implemented naturally, and the normal stress was increased. This was the narrative until the slopes were clear cut during colonial domination. Which started a whole new era of filling and sliding along the street which fueled many landslide events, such as the 2019 slide.

What should be done to reduce risk from future slides and how can science help inform these management decisions.

In order to reduce risk from future slides along Riverside avenue, businesses that are situated northeast of the road adjacent to the slope need to be reevaluated on proximity, compaction of permeable surfaces, and unauthorized filling near/on the slope. (Fig. 1) Ground and surface water assessment should be done on runoff from the impermeable road above and the unknown culverted drainage pipes which have unknown effects on the filled slopes pore pressure. Preventive strategies that are backed by science that can help support the anthropogenic filled slopes of riverside avenue are planting vegetation, which adds root cohesion. Areas of previous slide disturbance might need enforcement with large half meter to meter blocks, which have a shallow theta angle and allow for mass drainage, which reduces saturation of the slope. Due to widening of the road with fill, removal of permeable surfaces and trees, these slopes will continue to fail during certain weather events with the constraints the slopes are applied to in present day.

Figure 1.

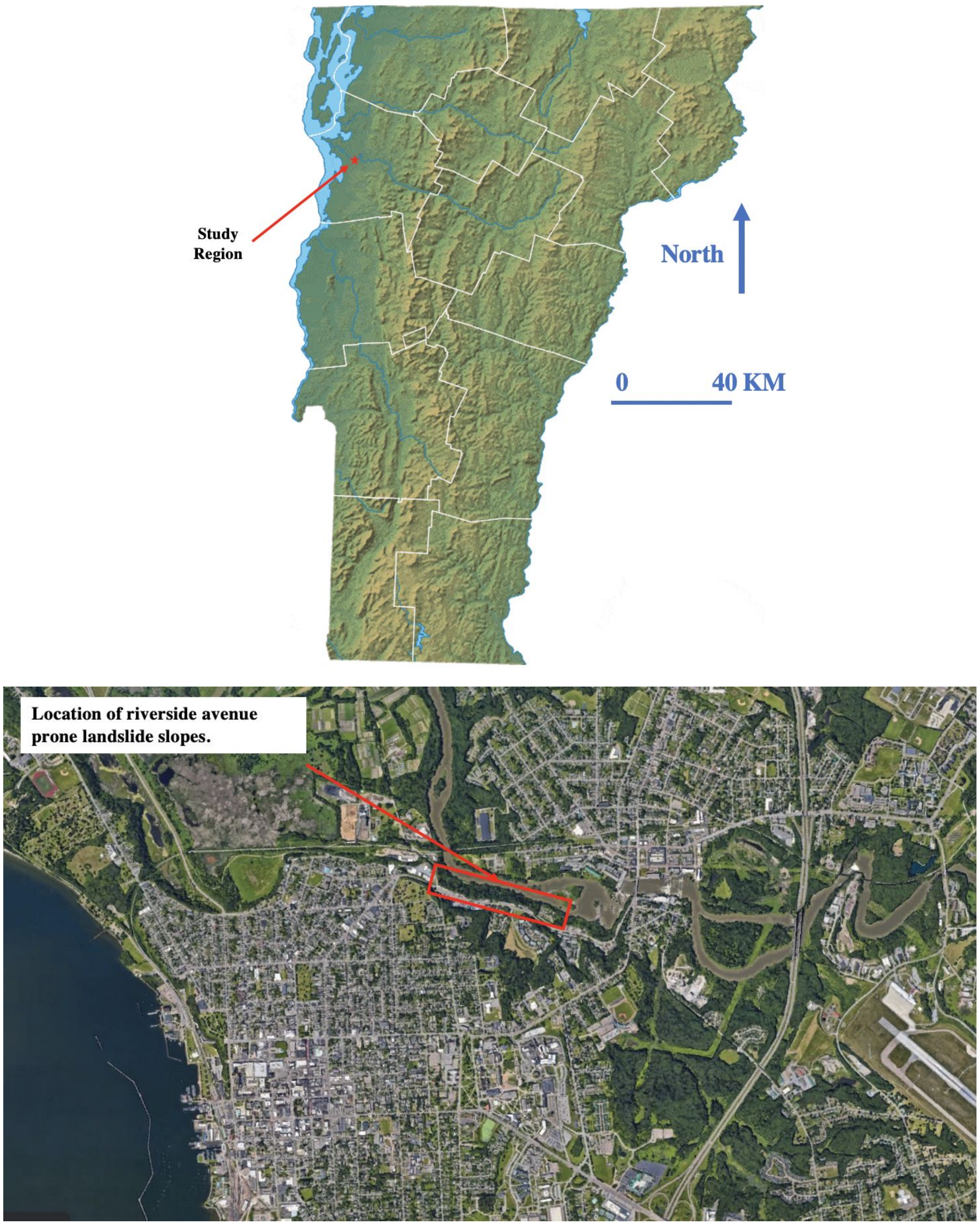


Figure above shows a map of Vermont, the red star indicates the study region within the state. The aerial photo below shows the city of Burlington and Winooski VT, with the narrow slope between Riverside Avenue and the Winooski river indicated. The red indication shows the area of past and active landslides alongside the busy street.

Figure 3.

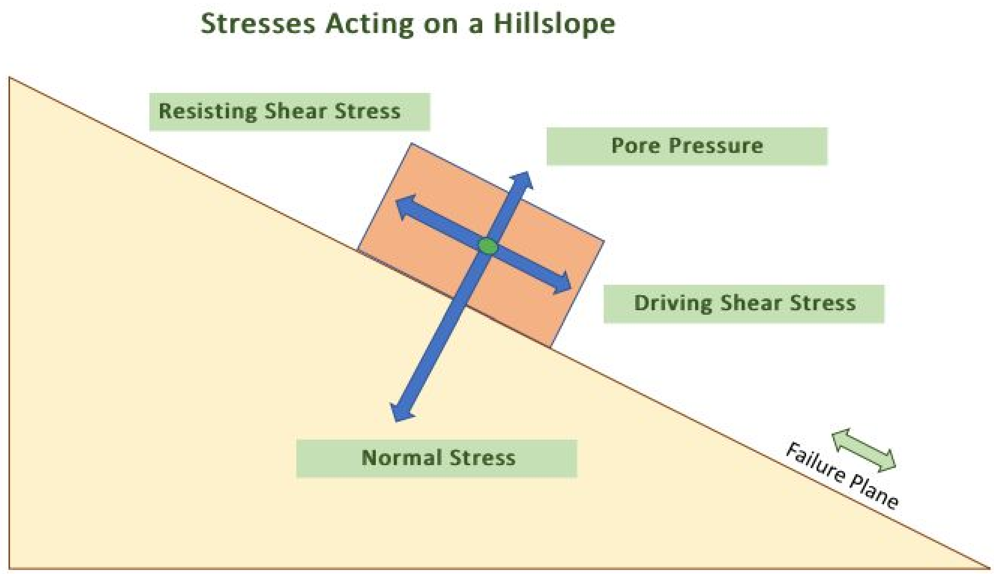
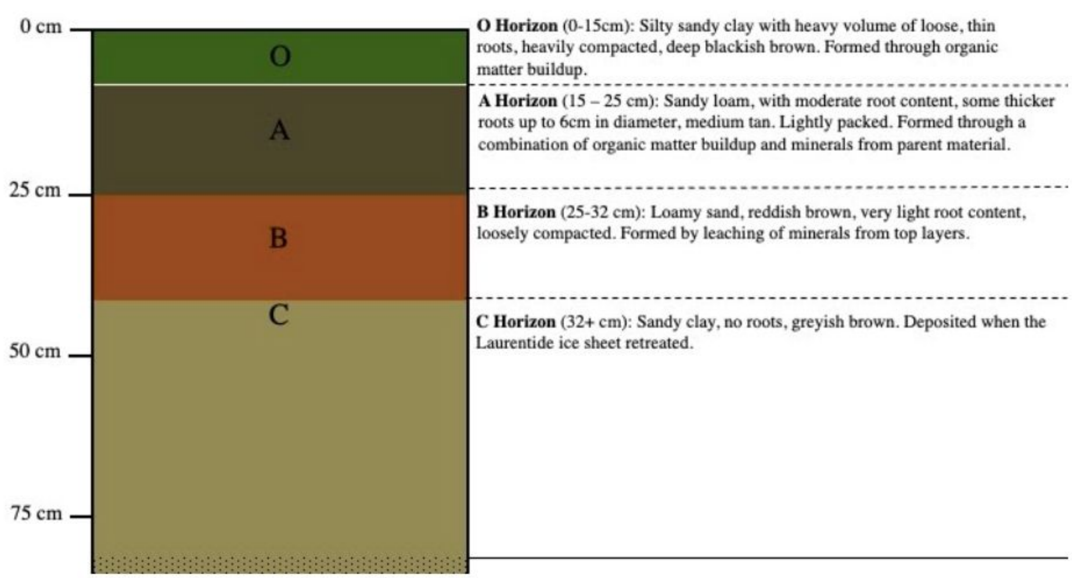


Figure 3.

The figure above depicts the relationship between resisting shear stress, driving shear stress, pore pressure, and normal stress. These active stresses and their relationship with one another determine the likelihood of a landslide occurring. Landslides occur when the driving shear stress exceeds the resisting shear stress, which can be triggered by many factors.

Figure 4.



Riverside Ave Timeline

1931

Riverside Avenue and South Willard Street Get Improvements — South Prospect Street to Be Widened

Last year, a concrete walk was constructed from the bridge to the curve near the garage on Riverside avenue.

1932

Electric Light and Street Departments to Make Riverside Ave. Attractive Boulevard

The department is to install an underground cable the ornamental lights.

It is the aim of the city to make Riverside avenue from Winooski avenue to the bridge an attractive boulevard, and the new lighting will be a part of this improvement.

The street department did considerable road and sidewalk, curbing and gutter work last year, and has already started to do a lot more this year. There will be a walk from Winooski avenue to the bridge, and the roadway will be widened.

Sept 13, 1955

Rebuild Street

A section of Riverside avenue was washed out. Street department officials blame an unused culvert about 65 feet below the level of the road. Water from the culvert eroded the road foundation.

Sept 19, 1955

EMERGENCY ROAD BY-PASSES RIVERSIDE AVENUE WASHOUT—Sunday traffic uses new asphalt road laid down by city to by-pass construction work on Riverside avenue where washout forced street to be blocked off. New pavement was built in a loop through the city land-fill dump property and enables almost normal flow of traffic along Riverside avenue. Reconstruction of the main road is expected to cost about $35,000

Nov 22, 1955

Washout Rips Riverside Ave. Third Time

Thousands of yards of fill, carrying along a half-dozen big pine trees, plunged into the Winooski River, as still another washout struck Riverside Avenue... workmen were excavating for a culvert with two bulldozers... [they were] working nearby to repair the damages of a big washout last September... they had been pushing dirt from around the old culvert and storing it along the bank to the west of the old washout. The first washout on Riverside avenue came near the end of August. The street deparment patched it. About a week later, a big washout broke a water main and took away many yards of dirt. A repair job, including replacing of a culvert, then was launched.

Nov 16, 1959

Driving Rain Causes Landslide, Topples Trees

Tons of earth, shrubbery and trees were sent sliding down a bank off Manhattan drive and almost every Burlington street was flooded over curb level by a driving thunderstorm Saturday afternoon.

May 24, 1968

Land Ho . . .

Vermont Highway Department personnel conduct test soil borings Thursday at scene of recent landslide off Riverside Avenue. Street Supt. Edward J. Crowley asked for special engineering aid to determine best way of permanently preventing future slides.

Mudslide Cleanup Funds Sought

The slide, which spilled about 4,000 yards of earth, trees and junk vehicles into the Winooski River, occurred about 35 feet from Riverside Avenue near B.J.'s Variety Market following heavy rains which hit Vermont in August and September.

Ogden earlier reported that the slide was diverting the normal waterflow toward the Winooski side of the river and was causing increased scouring of the banks. Winooski officials have been concerned that a long-term partial blockage of the channel could damage the city's sewage treatment plant outfall pipe which enters the river across from the slide area.

Jan 13, 1977

June 27, 1981

Illegal Dump Nets Charges

Clayton Norton, who owns the land across Riverside Avenue from the Koffee Kup bakery, asked workmen to deposit the debris on his land to serve as fill. The material caused the bank to give way, sending trees, dirt and garbage into the river.

Sept 30, 1983

City Looking for Method To Starch Riverside Avenue

Goodkind said Riverside Avenue is in danger of collapse because of a landslide on property owned by Clayton Norton across from the Koffee Kup Bakery. The land was the site of a landslide two years ago caused by illegal dumping.

The contractor he hired built a road across the face of the bank and the road quickly fell in, causing further erosion of the land near the road, Goodkind said.

Oct 18, 1983

The slides have been occurring on private property because some property owners have tried to extend their property lines by filling in land that is too steep, some of it along the banks of the Winooski River, according to Goodkind.

Dec 8, 1983

State to Help City Fix Sagging Road

The embankment between the Winooski River and Riverside Avenue, a major artery linking Winooski and Burlington, has been plagued by slides for years. Across from the Koffee Kup Bakery, the cliff has crept to within several feet of the roadway, leaving officials concerned that the road might tumble into the river.

Steven Goodkind, the city's public health and safety administrator, told the board that site needs immediate work. If the bank should freeze, Goodkind said, the water table behind it could build up and a sudden thaw could cause a major washout of the road.

Dec 29, 1983

Workers Begin To Brace Bank Along Riverside

Work finally began Wednesday to shore up a bank alongside Riverside Avenue that Burlington officials had considered in danger of sliding into the Winooski River.

The plan is to remove clay muck from the tumbling bank and replace it with a combination of stone and fill, while making the bank less steep.

a new drainage system will run from the top of the bank to the river to keep the new surface as dry as possible. He said the hill will be reduced to a "two-on-one" slope — it will go two feet horizontally for every foot of vertical drop.

The bank will be resurfaced with 2,000 cubic yards of sand and 3,000 cubic yards of stone, Pidgeon

"If all goes well, this will take care of it" permanently, said Steven Goodkind, city public health and safety administrator. "It's always possible something could happen out there to cause more erosion," he said. "If somebody else does something stupid out there," another landslide could occur, he said.

Figure 5.

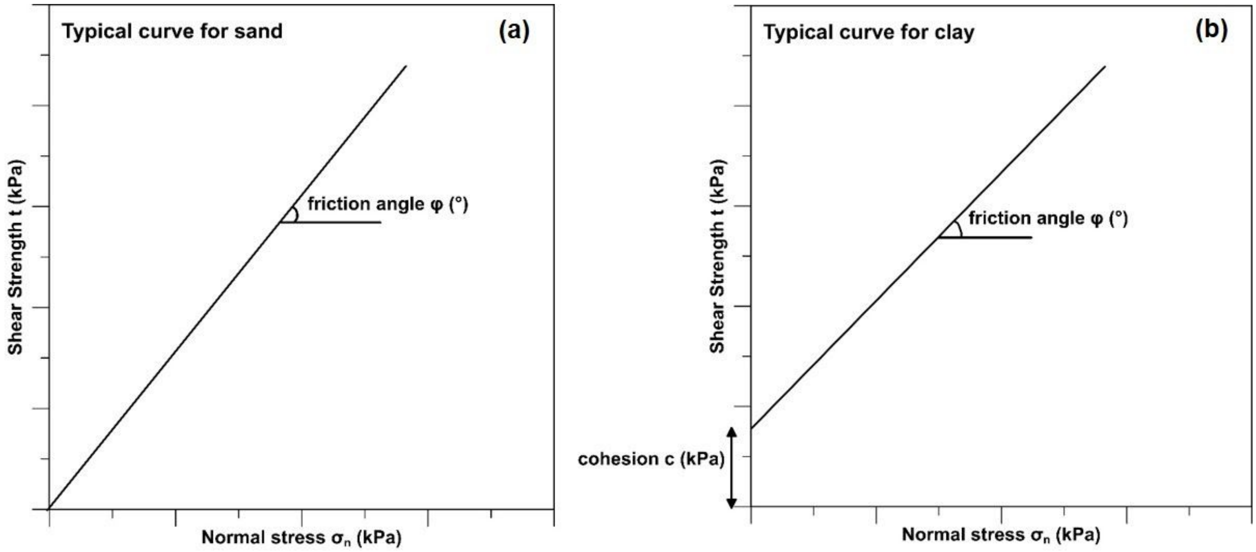


Figure above shows two plots (a) which is the curve for sand giving a shear strength t (kPa) plotted against the normal stress (kPa) and (b) the curve for clay with the same variables plotted. Notice the cohesion c (kPa) value for clays, which has an internal shear strength t at 0.

References:

Bierman, P. R., & Montgomery, D. R. (2020). Hillslopes. In *Key concepts in geomorphology.* New York: Macmillan Learning.

https://www.geoengineer.org/education/laboratory-testing/direct-shear-test