Reconstructing Landslide Plane Areas From Sesimic Refraction Tomography and Ground Penetrating Radar

Camarena, G., Mookerjee, M., and Anfinson, O.A.

Department of Geology, Sonoma State University, Rohnert Park, CA

Abstract

The Sonoma County area and its neighboring communities are prone to the natural mass wasting phenomena known as landslides. Landslides are defined as movement of rock and/or debris down a slope, and can be caused by earthquake activity, over saturation of the ground, and intense rain/snow fall, among other things. Large areas in Sonoma county have high landslide risk because of their weak bed rock and steep slope. Cities like Rohnert Park, Santa Rosa, and Petaluma are at a higher risk because of their proximity to the Roger's Creek fault. Our aim with this project is to reconstruct a landslide plane area using ground penetrating radar, hammer seismic and refraction tomography. By being able to reconstruct the plane area of a landslide, we can get a better understanding of the depth to bedrock, and a better understanding of how at risk a landslide is. Understanding this can help determine the weak points and aid in landslide stabilization in the future.

Geologic Background

Sonoma County has a complex geology that is a result of tectonic, erosional, volcanic, and sedimentary processes. The land the county is on forms part of the Franciscan complex and has heavy influences from the Sonoma Volcanics. The Franciscan complex came to be after the Farallon plate subducted into the North American plate and caused the rocks on the Farallon plate to be "scraped" up and accredited onto the ledge of the North American plate. Most of the rocks accredited include many clays, sandstones and basalts, among other volcanic and metamorphic types. Additionally, and more recently, the area has been under influence of the Sonoma Volcanics. This processes are responsible for most of the mountains surrounding the area, like Sonoma Mountain and the Mayacamas Mountains. A lot of the volcanic rock types found in the area can be traced back to the Sonoma Volcanics. The types often found include rhyolite, andesite, volcanic ash tuff, and other combinations. The area also includes 4 faults, the San Andreas fault on the western edge of the county, and the Healdsburg, Roger's Creek, and Maacama faults on the eastern side. Because of the relatively weak bedrock, lose sediments, steep slopes, and a lot of potential seismic activity, Sonoma County is very susceptible to the mass wasting phenomenon known as landslides.

Field Area

The Fairfield Osborn Preserve (FOP) is a nature preserve found in the foothills of the Sonoma Mountains, located in Sonoma County. It is located approximately 9.98 Km East of Sonoma State University(Image 1). It is estimated that FOP was formed 200 to 60 Ma years ago (Beach, et. al., 2012). Like most of the county, FOP sits on the Franciscan Complex and is part of the Sonoma Volcanics. It is largely composed of bedrock, sandstone, clays, and loam (Beach, et. al., 2012). The most abundant and weakest rocks found at the preserve are Rhyolite and Healdsburg Tuff. Because most of the preserve is composed of these rock types, it also experiances a lot of mass wasting. The biggest mass wasting site on the preserve, and the landslide used for this research, being the 1986 Valentine's Day landslide.

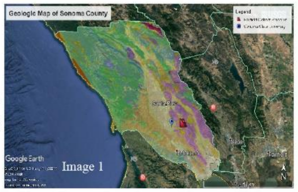

Image 1

Methods

To aquire the seismic data, hammer seismics was used. Image 2, shows the general setup and equipment used for hammer seismics. Image 3 shows how seismic refraction works. Additionally, Ground Penetrating Radar was used as a second geophysical method to compare the tomographic profile to.

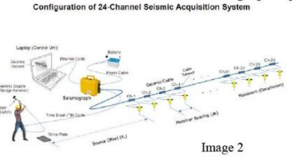

Image 2

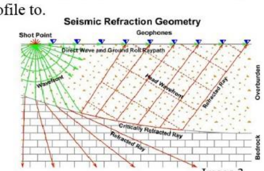

Image 3

Results

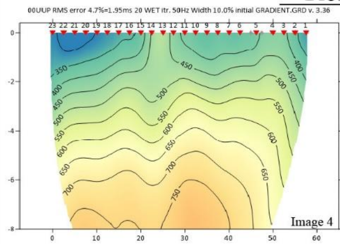

Image 4


Image 5

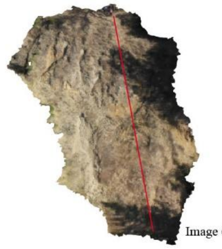
Image 6

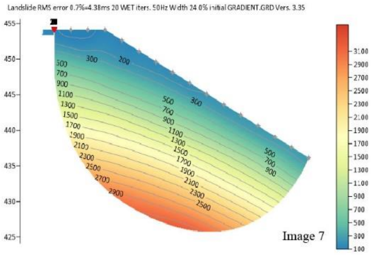

Image 7

Material	V_p (m/s)	ρ_{dry} (mg/m^3)	ν
Air	330		
Damp loam	300-750		
Dry sand	450-900	1.6-2.0	0.3-0.35
Clay	900-1,800	1.3-1.8	~0.5
Fresh, shallow water	1,430-1,490	1.0	
Saturated, loose sand	1,500		
Basal/lodgement till	1,700-2,300	2.3	
Rock			0.15-0.25
Weathered igneous and metamorphic rock	450-3,500		
Weathered sedimentary Rock	600-3,000		
Shale	800-3,700		
Sandstone	2,200-4,000	1.9-2.7	
Metamorphic rock	2,400-6,000		
Unweathered basalt	2,800-4,300	2.2-3.0	
Dolostone and limestone	4,300-6,700	2.3-3.0	
Unweathered granite	4,800-6,700	2.6-3.1	
Steel	6,000		

Image 8

Image 4 shows our first tomographic profile and image 5 shows the approximate location of the seimic line that correlates to it. Using the chart (image 8) we can start to correlate our velocities with what we could possibly looking at. Based on the velocities of the first line, we could be looking at a composition of anything from damp loam to weathered igneoues rock. Image 7 is our second profile, and image 6 shows the approximate location of the seismic line. This line was placed over the actual slope of the landslide. This profile contains higher velocities then the first one, particularly towards the bottom. Once again, using image 8, we can begin to speculate what composition we could be looking at. With what we know about the geology of FOP, it makes more sense that these higher velocites correlate with the presence of sedimentary and more igneous rocks.

Ground Penetrating Radar

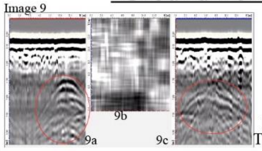

Image 9

As a method of comparison, we used ground penetrating radar (GPR). Image 9 shows a section of our findings. 9a shows our horizontal profiles and 9c shows our vertical profiles. 9b shows a top view of both. The profiles in this image are set at our starting point. What we can see in this section of our profiles is that there appears to be a hyberbola about 11m in on our x-profile and 7m in on our y-profile, at about a depth of 2m. This area is circled in red on 9a and 9c. This could potentially mean that there is something buried in that area, such as a boulder or some other type of rock.

Landslide Movement

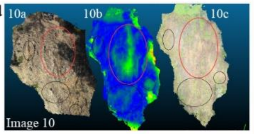

Image 10

After a rainy winter season, we hoped to see movement on the landslide. Using drone images we constructed two 3D models, one before the start of the winter season (10a), and one after (10c). Using CloudCompare, a software that compares 3D dense clouds and meshes, we were able to visually show the movement on the plane area (10b). Of particular interest is the area circled by red, where most of the movement took place. Areas circled by black appear to have had movement, but not as prominent. Because of the images used to generate the 3D models, we are unable to confirm if the edges are real movement.

Conclusion

- While we failed to precisely image the landslide's slide plane, what we do see within the tomographic profiles seems to align with what we know about the geology of Fairfield Osborn Preserve.

- While some visualization methods (i.e., GPR, refraction tomography, and point cloud comparison from SfM derived topographic models) worked better than others, overall, we were able to document that there has been movement on the landslide after the winter season.

- Because Sonoma county is very susceptible to landslides, continued study of these structures is highly valuable. Their impact on the community has the potential to be devastating. Studies like this one can help understand them better and potential mitigate loss of life and property in the future.

Acknowledgements

Thank you - To **David Fowler** for his donation of the seismic data aquistion equipment. To **Dr. Robin Glas** and **Siegfried Rohdewald** for their assistance in data analyzing.

Funding - Provided by **Center for Environmental Inquiry and WATERS Collaborative** for the purchase of Mavric 2 Pro drone.