Debris Flow Monitoring in Forest Falls, California

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I. Acknowledgements

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Thank you to Ting-Chi Tsao from Sinotech Engineering Consultants Corp, Taiwan for sharing information which helped me understand the purpose and operation of several instruments. Lastly, thank you to Joel Smith from U.S. Geological Survey (USGS), Golden, CO for sharing information on how the USGS is using instrumentation to remotely monitor and detect debris flows at the Chalk Cliffs, near Buena Vista, CO.

II. Executive Summary

This project occurred from April to September 2019 and the purpose was to research different types of instrumentation that can be used to monitor and, thus, help to understand the occurrence of debris flows in the community of Forest Falls, California.

The community of Forest Falls is located within a canyon in the San Bernardino Mountain range of Southern California (Figure 1). The community sits approximately 3,000 feet below the steep north slope of Yucaipa Ridge. Most of the homes are built upon coalescing alluvial fans that have formed along the base of Yucaipa Ridge. About five canyons flow out from the mountain front and through the town. Many historic debris flows have occurred along these creeks with Snow Creek being the most prominent drainage. Snow Creek stream flows occur several times during the year with only some of the flows containing significant amounts of sediment.

A debris flow is defined as a moving mass of water, loose unconsolidated mud, sand, boulders of rock, and air that travels down slope under the influence of gravity in a fluid-like behavior (Yin and Huang, 2018). Particle sizes of sediment deposited throughout the alluvium range from sands to boulders. Since 1950, eleven (11) damaging debris flows have been documented to occur along Snow Creek and two adjacent creeks (Morton and Hauser, 2001). Snow Creek sediment flows, within the last two years, have periodically closed the only road in and out of the valley (Valley of the Falls Drive), but have not otherwise damaged property. Research by Cato and Goforth (2019) indicates that linear hydraulic loading does not define the debris flow initiation thresholds or explain the complex debris flow storage (within bedrock channels), or the depositional processes that occur on the alluvial fans.

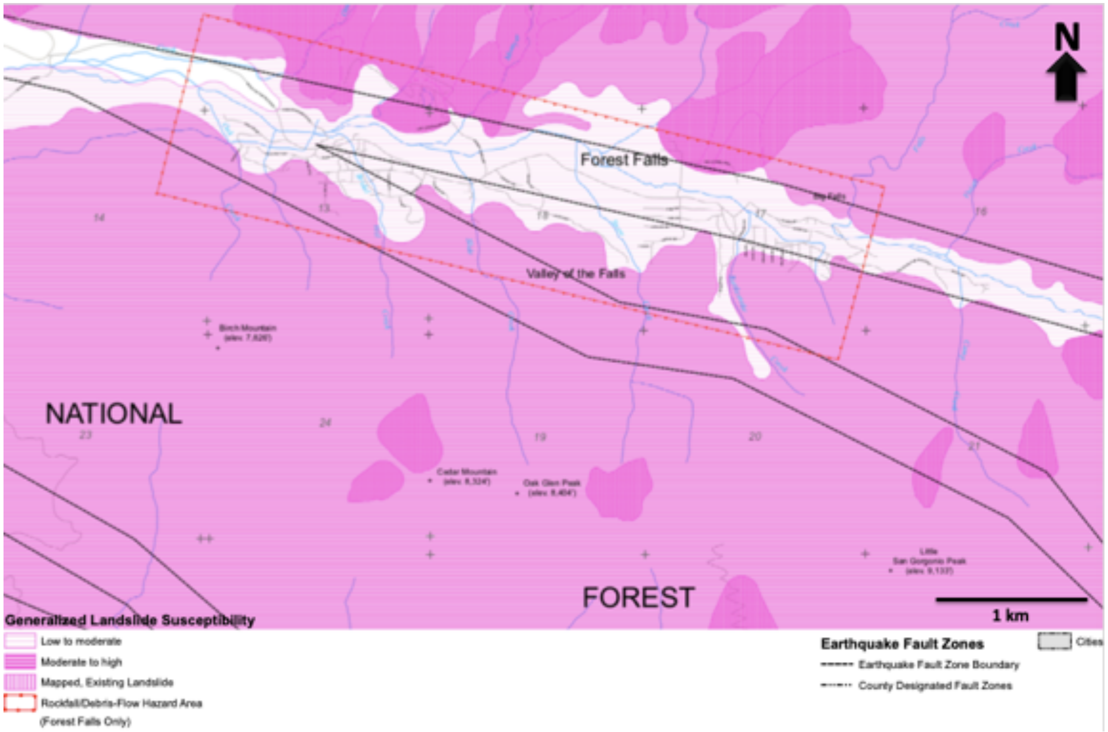

Figure 1. Moderate landslide susceptibility shown (light magenta color) across the steeper topography of the valley walls (light magenta color) along with mapped landslides (darker magenta) (San Bernardino County General Plan Geologic Hazard map (San Bernardino County, 2013).

Knowing which storm events produce only predominate water flow versus flows that produce muddy sediment and debris is very difficult to predict based only on knowledge of precipitation from weather station data. Using instrumentation to monitor the actual flow as it comes down the channel is a critical element to understanding the continuum from debris-flow initiation to sediment flow.

The monitoring instruments investigated during this study have the promise of providing an assemblage of data from the debris-flow data, but it also provides information that allows researchers to connect flow information with geomorphic observations about the amount of sediment, erosion and channel morphological changes across the alluvial fan. Monitoring data can inform of approaching disasters and endorse understanding of debris flow characteristics as well as technologies or system models to predict future hazards.

III. Project Objective

The objective of this project was to determine if: monitoring instrumentation can be feasibly used to monitor Snow Creek debris flows in Forest Falls; and, if so, then to determine which specific instruments should be considered; and we needed to see which other sites monitor debris flows, discuss these instruments with site personnel, and determine how successful the monitoring has been at these sites. Specifically, we need to determine if the conditions at Snow Creek are similar to conditions at these other monitored sites and, thus, determine which instruments can be used at our site.

It was important to look at different possible instrumentation suites that can be applied in the debris-flow channels. We needed to analyze the pros and cons of each instrument and decide which instrument suite could best be applied at Forest Falls. Specifically, we looked at ultrasonic sensors, radar sensors, laser sensors, geophones, wire sensors, video cameras, and LIDAR (light detection and ranging) sensors, and rain gauge triggering mechanisms to automatically turn the system on.

IV. Project Approach

To begin, the hazard effect of debris flows and how they can cause significant damage to the town of Forest Falls had to be understood. This consisted of visiting the town and seeing historic debris flow evidence (Figure 2). Debris flows, especially from Snow Creek have impacted the town many times, sometimes multiple times during a calendar year. One thing that would help residents and first responders would be to better predict when flows might occur and what volume of debris can be expected.

To answer these questions, we researched different types of instrumentation being used at other sites to monitor debris flows. Also, websites of multiple companies were researched to understand how certain instruments work and to compare their pros and cons.

Figure 2. Photo of Valley of the Falls Drive showing recent debris flow deposits that line both sides of the only road in and out of the town for residents. Car is approximately 1.5 m high and deposits are up to 3 m high.

Contacts made by my advisor during his attendance at DFHM7 were revisited for this study (Dr. Kerry Cato, Personal Communication, July 2019),.At the 7th Debris Flow Hazards Mitigation Conference (DFHM7), held in Golden, CO in June 2019, debris flow researchers from around the world discussed their research. Based on his recommendation and review of the Conference

Proceedings (DFHM7, 2019), two attendees from the conference were contacted. Ting-Chi Tsao from Sinotech Engineering Consultants Corp in Taiwan was contacted to discuss his company's deployment of instruments at their sites. He provided information on how certain instruments operate as well as the purpose of that instrument regarding debris flow monitoring. Joel Smith, a civil engineer with the U.S. Geological Survey (USGS) was contacted and provided information on how the USGS has placed monitoring instrumentation on the mass wasting occurrence in Chalk Cliff, Colorado.

V. Review of Instrumentation at Other Sites

There are several types of instruments that can be used to monitor debris-flows. Monitoring debris-flows can be implemented as an early warning system as a defense against a debris flow hazard. Examples include: video cameras (Figure 3) (Coe et al., 2010; McCoy et al., 2010), still cameras/video imagery (Coe et al., 2010; McCoy et al., 2010), seismometers (Arattano and Marchi, 2008), geophones (McArdell et al., 2007; Graf and McArdell, 2011; Arattano and Marchi, 2008), LIDAR (Light Detection and Ranging) (Coe et al., 2010; Barnhart et al., 2019; McCoy et al., 2010), ultrasonic sensors (McCoy et al., 2010; Arattano and Marchi, 2008), a terrestrial laser scanner (Coe et al., 2010) and solar panels for providing power to these remotely deployed instruments (Coe et al., 2010; McCoy et al., 2010; Graf and McArdell, 2011). There are several other methods and instruments that can provide monitoring of debris-flow and receive data, but these instruments detailed above are the most common methods being used by researchers at present. These instruments can provide an assemblage of data from a debris-flow, as well as provide a link with geomorphic observations concerning the amount of sediment, erosion and channel deformation.

Figure 3. Joel Smith of the USGS describes Chalk Cliff monitoring instrumentation that consists of solar panel for power (right), long distance video camera (top), and controls in other boxes. Camera is monitoring station shown in Figure 4A and 4B.

The Colorado Rocky Mountains contain locations prone to debris-flow occurrances which originate from rainfall and one of these is at the Chalk Cliffs, southwest of Buena Vista, CO. Monitoring instruments in the Chalk Cliffs basin consisted of rain gauge (Figures 4A & 4B) and soil-moisture sensors in the hillslope and channel (Coe et al., 2010). Success with the original monitoring system was expanded to include ultrasonic sensors, pressure transducers, a force plate, video cameras, and still cameras. These methods helped determine the amount of sediment being transported through the channel as well as the amount of water that triggers the initiation of debris flow.

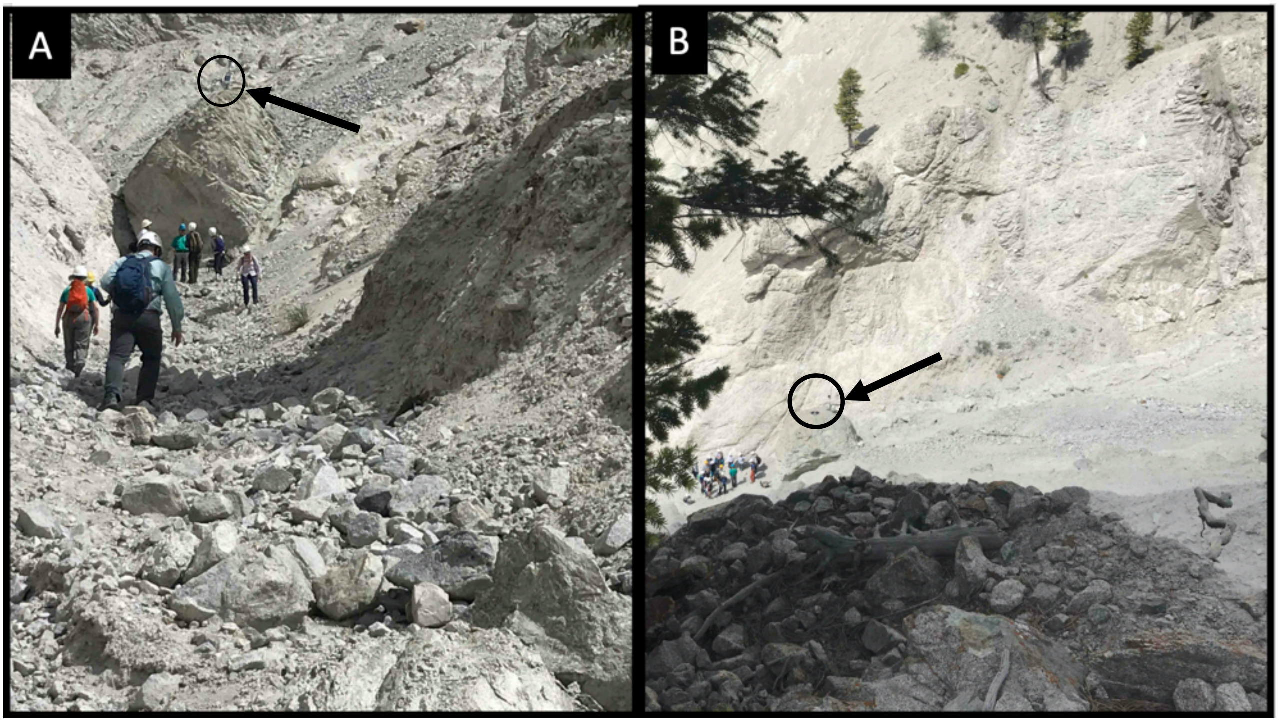

Figure 4A. Rain gauge trigger and solar panel mounted on a large boulder in the Chalk Cliffs debris channel. **Figure 4B.** View of the rain guage trigger and solar panel from hilltop video station shown in Figure 3. In both 4A & 4B, instrument denoted by arrow.

McCoy et al. (2010) used a certain method that includes a video camera, still camera, ultrasonic sensor, rain gauges, force plate, and pore pressure sensors. These combination of single instrument placed along the channel length provides real-time record of the flow as it is occurring, as well as documentation of about the cumulative sediment volume and its flow characteristic (i.e., liquid flow to hyperconcentrated flow to debris flow). At this site, each flow surge appeared to be composed of large-diameter coarse-grained (5-35 cm) rocks, as compared to the water-rich tails that were composed of fine-grained materials (McCoy et al. 2010). Researchers were able to observe about 15 distinct surge fronts which made up the total deposit thickness, but it revealed little about the mechanics or magnitude of each individual surge (McCoy et al. 2010).

In southwestern Switzerland the Illgraben channel is a site where debris flows occur from May through October from rainstorms (McArdell et al., 2007). Instrumentation includes a geophone sensor (which measures the front velocity), a laser distance-measuring device (which measures the flow depth), and a force plate on the base of the channel (which measure the normal and shear forces as well as fluid pressure) (McArdell et al., 2007). These instruments were able to provide quantitative values of basal forces and fluid pore pressure.

Chalk Cliffs, Colorado located in the Sawatch Range of central Colorado and the range itself is a hydrothermally altered and fractured quartz monzonite (Kean et al., 2013). Videos that were captured indicate that the initiation of debris flow occurs from water runoff with sediment transport also occurring during these events. The idea is to observe the frequency on the debris flow initiation and monitor the resulting sediment surges (Kean et al., 2013). To do this, researchers used rain gauges to measure rainfall that was set up at each station, laser distance meters to measure the flow stage (Figure 5), and force plate to measure the change during a surge.

Figure 5. Rain gauge (top), solar panel, control box, and laser scanner (left) at Chalk Cliffs. Laser used to determine stage (depth) of flow and, hence, sediment volume that passes station per time increment.

Frana di Roscero which is located in the southern Swiss Alps near Preonzo, Canton of Ticino (Graf and McArdell, 2011). This site is an active debris flow location as well as site where rock avalanche and rockfall commonly occurs. Deflection dams were built in 2007 to re-direct potential debris flows back into the old channel. Instrumentation used included geophones (assessing front velocity), video cameras (real-time perceptive) and a radar sensor (measuring flow depth). By the use of RAMMS (Rapid Mass Movements) software combined with the use of the shallow water equation and the Voellmy relationship for the flow friction, workers were able to describe the flow character of the debris (Graf and McArdell, 2011). The propose was to evaluate whether the new deflection dams would adequately mitigate the debris flows.

Barnhart et al., (2019) used airborne LIDAR and UAS (Unmanned Aerial System) to identify topographic deformation at Chalk Cliffs, Colorado. With the use of the instruments, they were able to demonstrate the topographic deformation over a 10-year period by the active debris flow location and the deformation of the basin are controlled by the erosion of colluvial surfaces. This research determined that the average yearly erosion rate is 0.002 m per year and 750 m^3 per year for sediment distribute rate (Barnhart et al., 2019).

Arattano and Marchi, (2008) studied the most common monitoring and warning system for an event of debris flow. The monitoring of debris flows contributed to further understanding of these hazard events. In that case, Arattano and Marchi, (2008) made a listing of monitoring instruments that pertain to advance warning systems and event warning systems. The purpose of thier study was to understand the effectiveness and drawback use of these instruments and how it can play a role as a defensive system that allows near communities to be alerted.

VI. Project Outcomes

During the 5-month duration of this project, it was concluded that having a rain gauge such as a tipping-bucket style gauge on the apex of the channel will help understand the amount of rainfall that triggers or initiates the sedimentation flow. It is also important to have an instrument that measures the ground vibrations, for it could measure the transition speed of the flow; a geophone would be placed on the channel bank, away from the flow, to measure the front velocity. For a real-time perceptive, multiple video cameras would be needed to obtain a visual perceptive of an occurring debris-flow and the visualization of the mass and speed of the flow. Lastly, the use of airborne LIDAR and UAS (Unmanned Aircraft Surveying) will help identify topographic deformation in Forest Falls.

VII. Conclusion

This project illustrates the debris flow hazard occurrence in Forest Falls and how monitoring instrumentation can possibly help mitigate the occurrence of these catastrophe events. This research shows the pros and cons of each instrumentation and shows which instruments are the best to use. The instruments best suited for monitoring debris flow in Forest Fall are rain gauge (amount of rainfall), geophone (assessing front velocity), video camera (real-time perceptive) and LIDAR (light detection and ranging).

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