Was the 2014 Oso Landslide Predictable?

Michael Raiwet

Introduction

The Oso landslide occurred on March 22, 2014 and inundated Steelhead Haven, a small rural neighbourhood located 6 km east of Oso, Washington. The high-mobility landslide destroyed over 40 structures and is responsible for the deaths of 43 people (Henn *et al.*, 2015). Capital losses are estimated to be at least $50 million (Wartman *et al.*, 2014). A better understanding of events of this magnitude, as well as their frequency is of great importance in preventing similar disasters in the future. Was the the 2014 Oso landslide predictable? And if so, what may have been done to mitigate such severe losses. This paper will attempt to comprehend the Oso landslide, the geography of the region in which it occurred, its geomorphology, and the local history of comparable events. It will examine the landslide in greater detail and it will offer possible recommendations that may have helped to prevent or lessen the effects of the Oso landslide and those events to come. Finally, this paper will conclude by evaluating all the factors involved in the 2014 Oso landslide and assess what

Geomorphological Context

The geography surrounding the Oso landslide is largely defined by glacial sediments that were deposited as glaciers retreated 14,000 years ago (Stone *et al.*, 2014). These glacially derived sediments occur in a 100 m thick deposit which contain interbedded layers of clay, silt, sand, gravel, cobbles and pebbles (Wartman *et al.*, 2014). A valley formed sometime after glacial retreat by incisions made by the Stillaguamish River which created conditions that are conducive to mass wasting (Wartman *et al.*, 2014). Nearly the entire valley bottom, especially in surrounding area of the Oso landslide, consists of previous landslide deposits or areas where these deposits were reworked by in the Holocene by active channel migration and floodplain forming alluvium deposition (Wartman *et al.*, 2014).

Historic Context of Regional Landslides

The history of mass wasting in the surrounding area of the Oso landslide is relatively well understood (Wartman *et al.*, 2014; Wayman, 2014). Evidence for other large landslides reveals multiple generations of mass wasting in the region, that reoccur with a frequency of about 400 to 1,500 years (Wartman *et al.*, 2014). Based on carbon dating, a total of 15 mapped large landslides are known to have occurred over four generations over a period of 6,000 years

(Wartman *et al.*, 2014). Historic data reveals numerous dates of renewed activity of sliding in portions of the slope in the vicinity of the Oso landslide. The most recent took place in 2006, when a landslide (known as the "Hazel Landslide") travelled 100 m which partially obstructed the North Folk Stillaguamish River but terminated before reaching the Steelhead Haven community (Wartman *et al.*, 2014). Types of failures associated with these events include: rotational slumps, debris flows, and transverse sliding of blocks where the forest predominately remained intact (Wartman *et al.*, 2014).

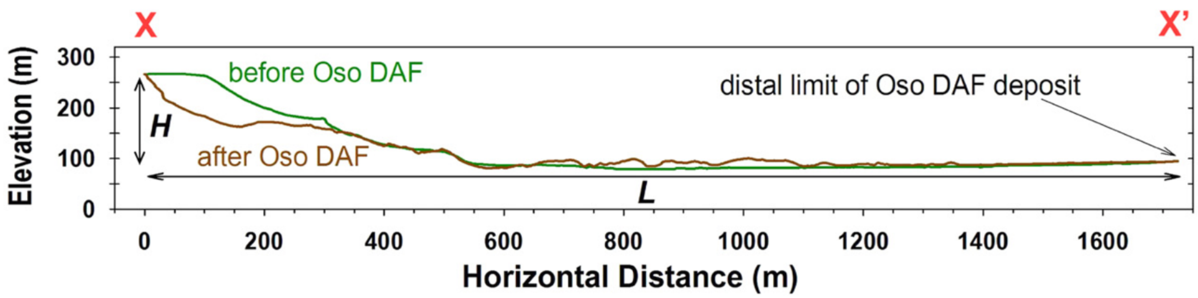

Figure 1 – Longitudinal topographic profiles from before and after the Oso debris avalanche flow (DAF); H = maximum height; L = length (Iverson *et al.*, 2015)

Landslide Projections and Risk Management in the Oso Landslide Region

There does not appear to have been any formal assessments of the probability of landslide hazards in the valley prior to the March 2014 event (Wartman *et al.*, 2014). However, earlier geological and geotechnical studies by Shannon and Associates (1952) and Miller (1999) do express the likelihood of mass wasting events with potential to cause damage to property and human lives to occur at some point in the future (Wartman *et al.*, 2014). The Miller (2009) study also predicts the estimated run-out distance of a potential slide. These estimates were based on comparable landslide volumes from previous events and expected to be less than 275 m (Wartman *et al.*, 2014).

In terms of risk management, there were two measures in place to reduce the risks associated with the slope (Wartman *et al.*, 2014). The first being land use restrictions which confronted the problem in several ways including: vegetation management; prohibiting development in locations deemed unsafe; ensuring that the factor of safety for landslides exceed 1.5 for static conditions and 1.1 for dynamic conditions; construction of retaining walls to allow that maintenance of natural slopes; as well as others not listed (Wartman *et al.*, 2014). The second strategy involved evaluating river bank stabilization (Wartman *et al.*, 2014).

The 2014 Oso Landslide

The 2014 Oso landslide occurred on clear and sunny Saturday morning that brilliantly marked the first weekend of spring after an exceptionally rainy March. Had the event had occurred one day earlier, it would be very likely that many of the casualties would have been away at school or work and this tragedy would have been largely property loss. Instead, along with the devastation of over 40 structures in the entire Steelhead Haven community, 43 people lost their lives and 10 others suffered significant injuries, making this the most fatal landslide event in continental United States history (Wartman *et al.*, 2014).

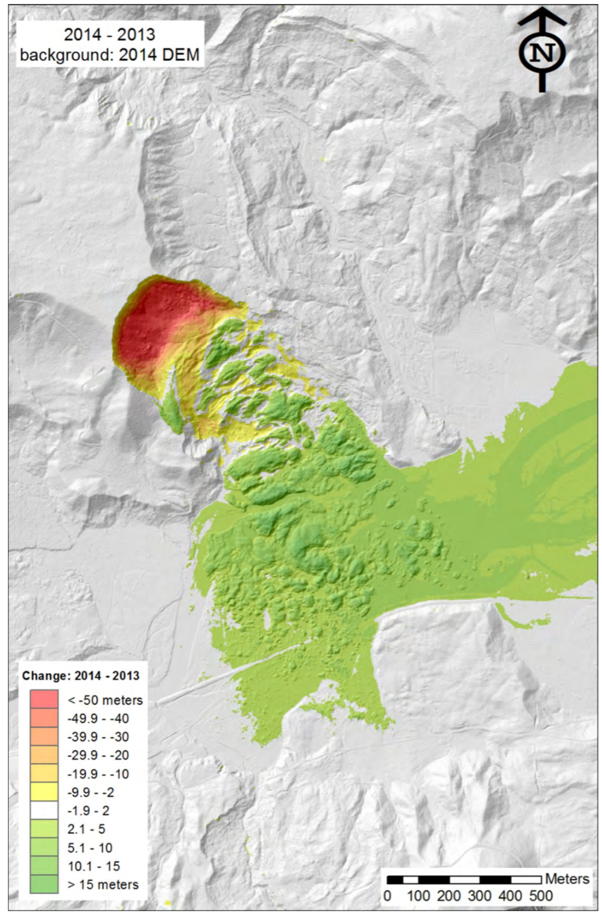

Figure 2 – Differences in elevation between 2013 and 2014 using lidar data (Wartman *et al.*, 2014).

The landslide was initiated from a 190 m hill slope with an average slope less than 20º that was composed of unconsolidated glacial till and outwash (Henn *et al., 2015)*. Based on seismic data, detectable landslide motion began at 10:36:33 AM local time (Iverson *et al.*, 2015). The initial slide is believed to involve remobilization of remnants of the 2006 Hazel landslide. Movement was moderate and is believed to have come to a rest before reaching the river (Iverson *et al.*, 2015). However, as this initial movement decelerated, retrogressive collapse of the upslope bluff took place at approximately 50 seconds after the event initiated. From here, the slope quickly accelerated, due to a number of factors but likely the most significant being liquefaction of water-saturated sediment at its base (Iverson *et al.*, 2015). Seismic data indicates another prominent seismic event 310 seconds after the initial detection (Iverson *et al.*, 2015). This is believed to be caused by secondary debris fall (Iverson *et al.*, 2015). An estimated volume of 7.6 cubic metres flowed for about 1.13 km in the brief time that elapsed during the 2014 Oso landslide.

Potential Causes

Prior to the landslide event, precipitation was unusually heavy for March (Henn *et al.,* 2015). The precipitation totals were at least 229 mm in the week preceding the event and the total precipitation for March may have been more than 760 mm (Wartman *et al.*, 2014). However, although precipitation was heavy during this time, based on 21 to 42 day precipitation accumulations, this would be expected to occur as often as every 3 years or no rarer than 5 to 6 years (Henn *et al.,* 2015). Henn and Associates do acknowledge that the timing of this precipitation occurred near the end of the seasonal wet period, when soil moisture would already be exceptionally high. They indicate that soil moisture is a better indicator of hazard than precipitation alone (Henn *et al.,* 2015).

Geology and porosity also played a role in increasing fluid pressures (Wartman *et al.*, 2014). Wartman and Associates provide three additional factors for the slope failure. The first factor involves the alteration of the local groundwater recharge and hydrogeological regime that is due to previous land sliding and potentially land use practices. The second factor regards the weakening and alteration of the landslide mass due to previous landslides and other natural geologic processes. The third factor mentioned suggests that changes in stress distribution resulting from the removal and deposition of material from earlier landslides (Wartman *et al.*, 2014). Further considering land use practices, the region directly above the landslide area is a relatively heavily wooded area. Throughout the twentieth century and into the last decade, logging and clearcutting practices appear to be a continual practice in the photographs provided by Wartman and Associates. It does seem reasonable to suggest that aggressive logging will alter water drainage, which in could potentially lead to slope failure. However, in their research Wartman and Associates do not find any correlations between increased logging and land slides based on aerial photography (Wartman *et al.*, 2014).

Destabilization caused by the Stillaguamish River cutting into the toe of the hill slope's debris pile may have also reduced slope stability (Wayman, 2014). Figure 2 shows evidence of river movement towards the base of the hill slope in the bottom left portion of the image.

Most likely, a number of the factors described above coupled with a trigger such as the increased precipitation were components of the resultant slope failure and land slide event.

Future recommendations

On the basis of further reducing the possibilities of similar events as those experienced at the 2014 Oso landslide, several authors in my research provide recommendations which will be discussed in the following section.

Sun and Associates recommend the increased usage of geomorphological monitoring technologies capable of detecting slope movement (Sun *et al.*, 2014). They further advocate improvements in accuracy in these systems (Sun *et al.*, 2014).

Wartman and Associates provides several suggestions involving the study of landslides, and the zoning of communities adjacent to sloping ground and potentially unsafe slopes and include: consideration for history and behaviour of past landslides and colluvial soil masses when mapping areas for zoning purposes; better awareness and communication to the public about possible risks landslides pose to property and safety; advancement in monitoring systems and imaging technologies such as lidar imagery; new methods to identify potential landslide run-out zones; the influence of precipitation on both short and cumulative duration intensities when assessing the likelihood of initial or renewed slope movement; and finally, doppler weather radar utilization in providing data regarding precipitation intensity, amount and variability in locations of interest (Wartman *et al.*, 2014).

Conclusion

The likelihood of a slope failure and resulting landslide along the Stillaguamish River not only appears to be predictable, but it also seems inevitable. When all factors, such as geology, porosity, or alteration of water drainage are coupled with triggers such as relatively heavy periods of precipitation, it is all the likely that mass wasting is to occur at some point. The only component that does not seem predictable regarding the 2014 Oso landslide event appears to be its magnitude; which by all accounts, the predicted outcome should have been much less insignificant.

References

Iverson, R. M., George, D. L., Allstadt, K., Reid, M. E., Collins, B. D., Vallance, J. W., et al. (2015). Landslide mobility and hazards: implications of the 2014 Oso disaster. *Earth and Planetary Science Letters*, *412*(C), 197–208.

Penn, B., Cao, Q., Lettenmaier, D. P., Magirl, C. S., Mass, C., Bower, J. B., St. Laurent, M., Mao, Y., Perica, S. (2015). Hydroclimatic Conditions Preceding the March 2014 Oso Landslide. *Journal of Hydrometeorology,* 1–24.

Stone, R., & Service, R. F. (2014). Even for Slide-Prone Region, Landslide Was Off the Chart. *Science*, *344*, 16–17.

Sun, Q., Zhang, L., Ding, X., Hu, J., & Liang, H. 2014. Investigation of Slow-Moving Landslides from ALOS/PALSAR Images with TCPInSAR: A Case Study of Oso, USA. *Remote Sensing*, *7*(1), 72–88.

Wartman, J., Keaton, J. R., Anderson, S., Benoît, J., DeLaChapelle, J., Gilbert, R., & Montgomery, D. R. 2014. The 22 March 2014 Oso Landslide, Snohomish County, Washington. *Geotechnical Extreme Events Reconnaissance*, 1–186.

Wayman, E. (2014). Seismic signals chronicle deadly landslide. *Science News*, *185*, 1–2.