Reducing Rockfall Risk in Yosemite National Park

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Yosemite National Park preserves some of the world's most spectacular geological scenery, including icons such as Half Dome and El Capitan. The glacially sculpted granite walls of Yosemite Valley attract 4 million visitors a year, but rockfalls from these cliffs pose substantial hazards (Figure 1).

Responding to new studies of rockfall hazard and risk, the National Park Service (NPS) recently took actions to reduce the risk to humans posed by rockfalls in Yosemite Valley. A rockfall in February 2014 demonstrated the merit of these actions.

A History of Rockfalls

Rockfalls are common natural events in Yosemite National Park. A rockfall inventory database for Yosemite [*Stock et al.,* 2013] documents 925 rockfalls between 1857 and 2011, resulting in 15 fatalities; 85 injuries; and extensive damage to buildings, roads, and trails. Although virtually all of Yosemite Valley is subject to rockfalls, the developed area of Curry Village, nestled among talus and large boulders, has proven particularly vulnerable. Established in 1899, Curry Village is a complex of visitor and employee accommodations, consisting mainly of rustic wooden and tent cabins. Rockfalls affected Curry Village almost from its inception, but the direct consequences became more prevalent in the past few decades [*Stock et al.,* 2013].

A rockfall in July 1996 devastated an area just east of Curry Village when the impact of about 30,000 cubic meters of rock generated an air blast that felled 1000 trees, causing one fatality and several injuries. Rockfalls from above Curry Village in 1998–1999 caused another fatality and destroyed several tent cabins. A rockfall in December 2003 caused minor injuries and damaged 14 wooden cabins, and another rockfall from the same location in June 2007 caused additional damage. These impacts culminated in October 2008, when a roughly 5700-cubic-meter rockfall damaged or destroyed 25 wooden and tent cabins (Figure 2a). Three people sustained minor injuries, and many more narrowly avoided injury or death.

Assessing Rockfall Hazard and Risk

The destructive power of rockfalls in Yosemite has long been noted [e.g., *Muir,* 1912; *Matthes,* 1930], but the associated risk was only gradually recognized. Rockfall impacts in Curry Village prompted the U.S. Geological Survey to conduct hazard assessments for select areas of Yosemite Valley in the late 1990s [*Wieczorek et al.,* 1998]. Later work used three-dimensional computer models of rockfall runout [*Guzzetti et al.,* 2003]. These studies generated important data on hazard extent but were not spatially comprehensive and did not fully quantify risk.

Following the 2008 Curry Village rockfall, the NPS took more aggressive action to evaluate risk to visitors and employees. Between 2010 and 2012, geologists and engineers assessed rockfall hazard and risk for all of Yosemite Valley. The study integrated lidar-based terrain mapping and cosmogenic exposure dating of boulders, together with computer simulations of rockfall runout, to establish a rockfall hazard zone beneath the cliffs. The hazard zone is defined probabilistically, with a 10% chance in 50 years that rockfall boulders will travel beyond this zone [*Stock et al.,* 2012]. Buildings, campsites, and other areas of congregation within the hazard zone were evaluated to assess the rate of human exposure to hazards. The position of structures within the hazard zone, coupled with their human exposure, yielded quantitative risk metrics for all structures within the hazard zone [*Stock et al.,* 2012].

Mitigating Rockfall Risk

In general, risk can be mitigated by reducing the occurrence of the hazard or by limiting exposure to the hazard. Methods for reducing rockfall hazard and risk include direct mitigations, such as scaling or stabilizing loose rocks, or indirect mitigations, such as ditches, fences, or netting designed to slow or stop falling rocks. However, such methods are generally considered incompatible with the NPS's mission to conserve natural scenery and processes. Furthermore, indirect mitigations are unlikely to stop the large and energetic rockfalls occurring in Yosemite Valley. The most effective method for mitigating rockfall risk in Yosemite is to reduce exposure by removing structures from hazardous areas and by repurposing buildings to low-occupancy uses.

About one-third of all structures in Curry Village were located within the newly established hazard zone, and many were among the highest risk identified. Accordingly, the NPS removed more than 200 buildings from Curry Village in 2013 (Figure 2b). Three other buildings were repurposed from residences to storage. Elsewhere in Yosemite Valley, campsites were relocated, and other buildings were assigned reduced use levels. These actions culminated in a 95% reduction in human occupancy–related risk compared to 2008 levels.

The success of these mitigation actions was quickly realized. In the early morning of February 2014, a rockfall sent boulders into Curry Village, but this time, there were no longer buildings there to be affected. A boulder with a volume of about 1 cubic meter impacted within the footprint of a former wooden cabin and then came to rest within the foundation of another (Figure 2c). Had these cabins been standing, they would have been extensively damaged, and had they been occupied, there almost certainly would have been injuries and perhaps even fatalities.

It is not possible to completely eliminate risk from rockfalls in Yosemite; indeed, the soaring cliffs are precisely why so many people visit the park. The probabilistic nature of

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Fig. 1. A rockfall tumbles down the face of Half Dome in Yosemite National Park on 27 July 2006.

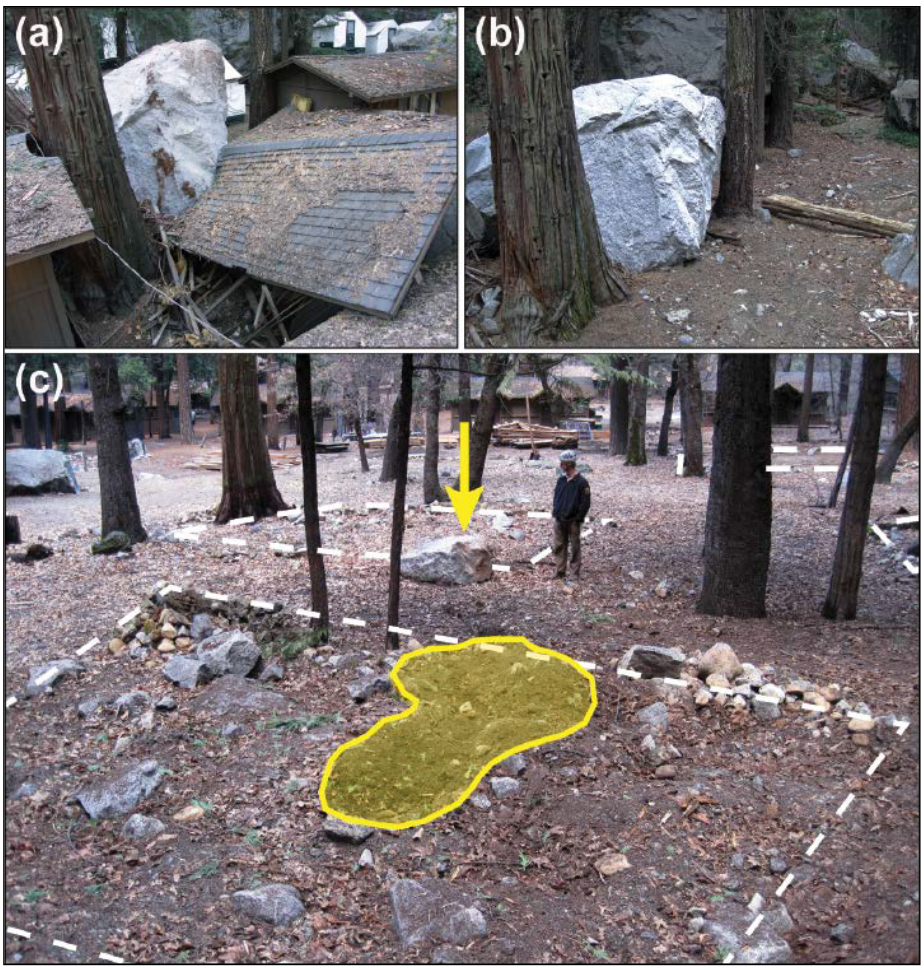

Fig. 2. Rockfall hazard and risk in Yosemite Valley's Curry Village. (a) Cabin damage resulting from an October 2008 rockfall. (b) The same area following removal of more than 200 cabins in 2013. (c) Successful mitigation of rockfall risk. Dashed white lines indicate footprints of removed cabins. The yellow arrow identifies an approximately 1-cubic-meter boulder that fell in February 2014, and the yellow shaded area shows the impact crater from this boulder within the footprint of a former cabin.

the rockfall hazard zone implies that large-magnitude, low-frequency rockfalls will eventually enter areas where structures exist. Roads and trails also remain subject to risk. Nevertheless, the recent actions have already proven effective in reducing risk in this renowned—and geologically active—park.

References

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