Staircase Falls Rockfall on December 26, 2003, and Geologic Hazards at Curry Village, Yosemite National Park, California

By Gerald F. Wieczorek, James B. Snyder, James W. Borchers, and Paola Reichenbach

Open-File Report 2007–1378

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia 2007
Revised and reprinted: 2007

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS—the Federal source for science about the Earth,
its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

Suggested citation:
Wieczorek, G.F., Snyder, J.B., Borchers, J.W., and Reichenbach, Paola, 2007, Staircase Falls rockfall on December 26, 2003, and geologic hazards at Curry Village, Yosemite National Park, California: U.S. Geological Survey Open-File Report 2007-1378, available online only at http://pubs.usgs.gov/of/2007/1378

Contents

Abstract....................4
Introduction....................4
December 26, 2003, Staircase Falls Rockfall....................6
Glaciation and Weathering....................7
Jointing and Weathering....................7
Hydrology and Weathering....................8
Hazard and Risk Assessment....................9
Conclusions....................12
Acknowledgments....................13
References Cited....................13

Figures

Figure 1. Topographic map of Glacier Point-Curry Village in Yosemite Valley, California, with two rockfalls from Staircase Falls into Curry Village....................5
Figure 2. Glacier Point with Staircase Falls and abandoned Ledge Trail along eastward-dipping J2 joint sets and site of December 26, 2003, and November 12, 2001, rockfalls....................6
Figure 3. December 26, 2003, Staircase Falls rockfall release site with fresh light-colored joints and impact area and large ledge covered with snow at the top of Staircase Falls....................9
Figure 4. Sketch of rockfall talus at base of slope and outlying boulders illustrating the limit of the rockfall shadow angle....................11
Figure 5. Comparison between the mapped landslides and the simulated rockfalls for the November 12, 2001, event and the December 26, 2003, event....................12

Tables

Table 1. Joint systems in the Glacier Point region....................8

Staircase Falls Rockfall on December 26, 2003, and Geologic Hazards at Curry Village, Yosemite National Park, California

Gerald F. Wieczorek,[1] James B. Snyder,[2] James W. Borchers,[3] and Paola Reichenbach[4]

[1]*U.S. Geological Survey (email: gwieczor@usgs.gov)*
[2]*National Park Service, Yosemite National Park (email: jimsnyder@sbcglobal.net)*
[3]*U.S. Geological Survey (email: jborcher@usgs.gov)*
[4]*Consiglio Nazionale delle Ricerche, Istituto di Ricerca per la Protezione Idrogeologica (email: Paola.Reichenbach@irpi.cnr.it)*

Abstract

Since 1857, several hundred rockfalls, rockslides, and debris flows have been observed in Yosemite National Park. At 12:45 a.m. on December 26, 2003, a severe winter storm triggered a rockfall west of Glacier Point in Yosemite Valley. Rock debris moved quickly eastward down Staircase Falls toward Curry Village. As the rapidly moving rock mass reached talus at the bottom of Staircase Falls, smaller pieces of flying rock penetrated occupied cabins. Physical characterization of the rockfall site included rockfall volume, joint patterns affecting initial release of rock and the travel path of rockfall, factors affecting weathering and weakening of bedrock, and hydrology affecting slope stability within joints. Although time return intervals are not predictable, a three-dimensional rockfall model was used to assess future rockfall potential and risk. Predictive rockfall and debris-flow methods suggest that landslide hazards beneath these steep cliffs extend farther than impact ranges defined from surface talus in Yosemite Valley, leaving some park facilities vulnerable.

Introduction

Since 1857, various types of landslides, particularly rockfalls, rockslides, and debris flows have been observed in Yosemite Valley by many visitors, including Josiah Whitney, the first State Geologist of California; James Hutchings, author and hotel owner in Yosemite; John Muir, noted naturalist; and Joseph LeConte, Professor of Geology at the University of California. More systematic recording of both small and large rockfalls and other types of landslides affecting facilities began after 1916 in the monthly National Park Service (NPS) Superintendent's reports. The level of rockfall documentation increased beginning in the 1980s with the involvement of the U.S. Geological Survey (USGS) with the NPS (Wieczorek and others, 1992). Between 1857

Glaciation and Weathering

The eastern portion of Yosemite Valley was deepened and broadened during several episodes of glacial erosion (Huber, 1987). The latest (Tioga) glacial advance peaked between about 28,000 and 17,000 years before present and did not fill the valley (Bursik and Gillespie, 1993). The December 26, 2003, Staircase Falls rockfall originated at about 1768 m elevation on the edge of LeConte Gully and on the upper northeast side of a small weathered fin around which Staircase Creek has to turn sharply out of the gully to reach the top of its falls. Bedrock at the release site, upslope from the maximum level of the Tioga glaciation (Matthes, 1930, pl. 29; Wieczorek and others, 1999), has been weathering since the Sherwin glaciation overtopped Yosemite Valley's walls 1 million years ago (Smith and others, 1983). Above the Tioga glacial trimline, the cliffs have weathered and joints have opened allowing water to infiltrate and ice to wedge open near surface joints. Weathering is accelerated, and weathered rock zones are thickest where granitic rocks are most frequently wet.

The bedrock geology of the Yosemite Valley consists of several different types and ages of granitic materials, principally including Cretaceous granite, granodiorite, quartz monzodiorite, and quartz diorite (Huber and others, 1989). The rocks in the mountainous area of Glacier Point and Staircase Falls are primarily Late Cretaceous Sentinel or Glacier Point Granodiorite and Half Dome Granodiorite. Resting on these units at the base of Curry Village are Quaternary alluvium and talus (Calkins, 1985; Peck, 2002). Even though there is a contact between Glacier Point and Half Dome Granodiorites in the Staircase release area, there is no clear correlation between rock type, jointing, or weathering patterns.

Jointing and Weathering

As many as 13 joint sets (J1-J13) have been identified in the Glacier Point region (table 1) and labeled following the methodology used to describe joint sets near the 1998-99 Curry Village rockfall release (Wieczorek and Snyder, 1999). Regional-scale joints (J3, J7, J10, J11), visible on satellite imagery (U.S. Geological Survey, 1986), may dominate the ground-water-flow system near Glacier Point. Glacier Point and Half Dome cliff faces as well as LeConte Gully are controlled by these joints, which intersect nearly all others. Joint J2 is a pervasive ledge-forming discontinuity with steep dips of about 30° to the east below Glacier Point. This orientation is similar to the set of discontinuities that form the stair treads of Staircase Falls and the broad ledge carrying the abandoned "Ledge Trail" (fig. 2), which begins above Curry Village and extends westward toward LeConte Gully. The third kind of joints are exfoliation joints (J1), parallel to topographic surfaces, which have influenced erosion back from the original controlling joint surfaces exposing the inclined steps of Staircase Falls (Huber, 1987).

The intersection of joints along a slope can be analyzed to determine whether rockfalls, slides, or topples are likely. A joint or exfoliation sheet parallel to the cliff also can be responsible for a collapse. For example, the release area for a rockfall of 563 m^3 that occurred on November 16, 1998, above the eastern part of Curry Village contained intersecting joints J2 through J6, but none of these joint planes or joint plane intersections formed plane or wedge conditions favorable for sliding or toppling because the direction and inclination of the cliff face was not optimally oriented for sliding or toppling. The joints and their intersections at the release points define the top and lateral boundaries of an exfoliation sheet section that released the rockfall. Thus, although joint sets J2 through J6 did not form the surface along which sliding occurred,

little subsurface geological investigation has been done in Yosemite Valley, rockfall potential was mapped on the basis of recorded rockfall deposits and surface evidence of talus and scattered outlying boulders beyond the talus slopes at the base of cliffs. To compensate for the lack of subsurface data on the valleyward extent of rockfall, the angle extending horizontally from the apex of the talus slope to the farthest outlying boulder (fig. 4) was used to determine the limits of rockfall shadow where infrequent rockfall events may stop (Evans and Hungr, 1993). The map has one line along the foot of visible talus at the base of the talus slopes and a shadow line drawn from a minimum shadow angle of 22° beyond the talus (fig. 4). This line did not apply to some large debris flows, large rock avalanche runout distances, potential airblast areas, or potential flyrock ranges (Wieczorek and others, 1999). Rockfall impact areas including flyrock were mapped not only for safety around facilities but to see how actual events of different sizes and characters correlated with the map of potential failures.

The extent of areas potentially subject to rockfall hazards was also assessed by using STONE, a topographically based rockfall simulation computer program using digital elevation model (DEM) (Guzzetti and others, 2002). Whereas other models typically generate two-dimensional rockfall trajectories, STONE can generate the three-dimensional rockfall trajectories over a range of rock volumes. The STONE model has previously been used to investigate rockfalls in Yosemite Valley (Guzzetti and others, 2003). Applying the STONE model to two rockfalls near Staircase Falls-Curry Village, November 12, 2001, and December 26, 2003, the simulated and actual rockfall trajectories can be compared (fig. 5). Although the predicted travel direction for the smaller November 12, 2001, rockfall did not exactly match the mapped rockfall, the trajectory simulated for the larger December 26, 2003, rockfall was close to the field mapping. Although flyrock is not included in the STONE model, the model indicates the potential for rocks to travel even farther than recorded from these specific releases. The STONE model suggests that travel distance is directly related to rockfall volume; that is, larger volumes may travel farther.

The STONE model does not evaluate debris flows, and the map of rockfall potential did not address the area directly beneath the Staircase release in enough detail when new dormitories were planned and built. Furthermore, there were few recorded rockfalls or debris flows in the inventory for the west Curry Village area before the Christmas 2003 events. Simultaneous with the December 26, Staircase rockfall, a small debris flow from LeConte Gully entered the proposed dorm area. Although there are notable exceptions, most debris flows occur between late fall and early spring because that is the time of greatest ground saturation. Debris flows can be initiated by heavy storms but also by rockfall or avalanche onto saturated slopes. The December 1937 flood initiated debris flows from both Staircase Falls and LeConte Gully. The Staircase Falls debris flow filled the Staircase creek channel with “huge boulders,” piled rock and debris against cabin walls, and broke through into the cabins. In February 18, 1986, a debris flow of rock and mud extended through Curry Village burying one residence and the uppermost Curry Village shower house with up to 4 feet of debris (Wieczorek and Snyder, 2004). The shower house was rebuilt, and a diversion wall of large rock was built in the channel behind the new shower house to protect it.

Subsurface trenching in the proposed dormitory area indicated that unrecorded debris flows and flyrock from rockfall reached the dorm area (fig. 2) and noted that a stream channel mapped in 1934 had been filled by a debris flow (Norman and Gates, 2005). Other evidence of rockfall into the shadow zone appeared when excavations for dorm building foundations encountered a 15-foot-long boulder, 2 feet under the surface and again when tons of flyrock and rockfall boulders were removed for building foundations. On October 25, 2005, a rockfall from the cliffs above sent flyrock well into the new dorm during construction with only one minor injury.

Acknowledgments

Jim Snyder conducted the major field examination of the December 26, 2003, Staircase Falls rockfall. Jim Borchers examined the conditions of water influence on joints in the Glacier Point region. Paola Reichenbach conducted the STONE models of rockfall from specific release points below Glacier Point. David Jones of the USGS modified and improved the detailed figures. Greg Stock of the NPS and Tom Holzer of the USGS conducted a preliminary review of the document.

References Cited

Bertolo, P., and Wieczorek, G.F., 2005, Calibration of numerical models for small debris flows in Yosemite Valley, California, USA: European Geophysical Union-Natural Hazards and Earth System Sciences, v. 5, p. 993-1001.

Borchers, J.W., 1996, Ground-water resources and water-supply alternatives in the Wawona area of Yosemite National Park, California: U.S. Geological Survey Water-Resources Investigations Report 95-4229, 77 p.

Bursik, M.I., and Gillespie, A.R., 1993, Late Pleistocene glaciation of Mono Basin, California: Quaternary Research, v. 39, p. 24-35.

Calkins, F.C., 1985, Bedrock geologic map of Yosemite Valley, Yosemite National Park, California, with accompanying pamphlet by Huber, N.K., and Roller, J.A.: U.S. Geological Survey Miscellaneous Investigations Series Map I-1639, scale 1:24,000.

Evans, S.G., and Hungr, O., 1993, The assessment of rockfall hazard at the base of talus slopes: Canadian Geotechnical Journal, v. 30, p. 620-636.

Guzzetti, F., Crosta, G., Detti, R., and Agliardi, F., 2002, STONE; A computer program for the three-dimensional simulation of rock-falls: Computers and Geosciences, v. 28, no. 9, p. 1079–1093.

Guzzetti, F., Reichenbach, P., and Wieczorek, G.F., 2003, Rockfall hazard and risk assessment in the Yosemite Valley, California, USA: Natural Hazards and Earth System Sciences, European Geophysics Union, v. 3, p. 491-503.

Huber, N.K., 1987, The geologic story of Yosemite National Park: U.S. Geological Survey Bulletin 1595, 64 p.

Huber, N.K., Bateman, P.C., and Wahrhaftig, C., 1989, Geologic map of Yosemite National Park and vicinity, California: U.S. Geological Survey Miscellaneous Investigations Series Map I-1874, scale 1:125,000.

LeConte, J., 1875, A journal of ramblings through the High Sierras of California: San Francisco, Francis and Valentine.

Matthes, F.E., 1930, Geologic history of the Yosemite Valley: U.S. Geological Survey Professional Paper 160, 137 p.

Norman, D., and Gates, W.C.B., 2005, Limited debris flow assessment at the proposed employee housing, Curry Village, Yosemite National Park: Kleinfelder, Inc. for NPS, Yosemite National Park, Job. no. 47022.

Peck, D.L., 2002, Geologic map of the Yosemite quadrangle, central Sierra Nevada, California: U.S. Geological Survey Geologic Investigations Series Map I-2751, scale 1:62,500.

Smith, G.I., Barczak, V.J., Moulton, G.F., and Liddicoat, J.D., 1983, Core Km-3, a surface-to-bedrock record of Late Cretaceous sedimentation in Searles Valley, California: U.S. Geological Survey Professional Paper 1256, 24 p., 1 pl. in pocket.

U.S. Geological Survey, 1986, Satellite orthoimage of Yosemite Valley, Yosemite National Park, California: Mariposa County, Experimental Edition, scale 1:24,000.

Wieczorek, G.F., and Jäger, S., 1996, Triggering mechanisms and depositional rates of postglacial slope-movement processes in the Yosemite Valley, California: Geomorphology, v. 15, p. 17-31.

Wieczorek, G.F., and Snyder, J.B., 1999, Rock falls from Glacier Point above Camp Curry, Yosemite National Park, California: U.S. Geological Survey Open-File Report 99-385, 22 p.

Wieczorek, G.F., and Snyder, J.B., 2004, Historical rock falls in Yosemite National Park: U.S. Geological Survey Open-File Report 03-491, 11 p.

Wieczorek, G.F., Snyder, J.B., Alger, C.S., and Isaacson, K.A., 1992, Rock falls in Yosemite Valley, California: U.S. Geological Survey Open-File Report 92-387, 191 p.

Wieczorek, G.F., Morrissey, M.M., Iovine, G., and Godt, J., 1999, Rock-fall potential in the Yosemite Valley, California: U.S. Geological Survey Open-File Report 99-578, available online at http://pubs.usgs.gov/of/1999/ofr-99-0578/.