Prepared in cooperation with the U.S. Agency for International Development, Office of U.S. Foreign Disaster Assistance

Field Reconnaissance Report of Landslides Triggered by the January 12, 2010, Haiti Earthquake

By Randall W. Jibson and Edwin L. Harp

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Conversion Factors

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Volume	
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	1.308	cubic yard (yd^3)

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Introduction

Shaking from the January 12, 2010, Haiti earthquake (M 7.0) caused devastating structural damage and triggered many landslides that blocked roads, dammed rivers and streams, and threatened infrastructure in many parts of Haiti. The earthquake had a complex mechanism that included both thrust and left-lateral strike-slip movement. We began analysis of satellite imagery to map triggered landslides almost immediately after the earthquake. When the scope of the disaster became clear, the U.S. Agency for International Development, Office of U.S. Foreign Disaster Assistance (OFDA), requested that the U.S. Geological Survey (USGS) assess various seismic hazards, including those from landslides. Using funding provided by OFDA, we departed for Haiti on March 25, 2010, to conduct a preliminary hazard assessment; the brief mission included aerial helicopter reconnaissance of areas affected by landslides and ground inspections at some accessible landslide sites. This brief report summarizes our activities and preliminary findings.

Activities

- January 13–March 24: Searched for usable satellite imagery from before and after the earthquake. Used imagery in Google Earth to compile a preliminary map of landslides triggered by the earthquake. Assembled available topographic maps. Consulted with other teams who had been to Haiti about logistics and field conditions.
- March 25: Flew from Denver to Miami. Overnighted in Miami.
- March 26: Flew from Miami to Port-au-Prince, Haiti. Moved into quarters at U.S. embassy provided by OFDA. Finalized arrangements for helicopter support and field guide (for driving and translation).
- March 27–28: Conducted helicopter reconnaissance of areas affected by landslides. Landed at key areas to conduct field studies and assess hazards on the ground. Conducted ground reconnaissance of areas in the foothills above Port-au-Prince.
- March 29: Began compiling data and drafting preliminary report. Briefed OFDA staff at U.S. embassy in Haiti on initial findings of investigation.
- March 30: Flew from Port-au-Prince to Denver.
- March 31–April 10: Completed initial trip report.
- April 10–September 30: Continued mapping of landslides from satellite imagery.

Summary of Key Findings

Landslide numbers and distribution

Imagery acquired soon after the earthquake by Google Earth has 60-centimeter (cm) resolution; using this imagery we produced a preliminary map of the point locations of landslides triggered in areas around the Enriquillo-Plantain Garden fault zone (fig. 1). More detailed mapping of landslides as polygons is partially completed and is continuing. Based on mapping completed to date, several observations can be made regarding the number and distribution of landslides triggered by the earthquake:

- We estimate that the earthquake triggered 4,000–5,000 landslides. This is within the range predicted by empirical studies of earthquake-triggered landslides worldwide that estimate numbers of landslides as a function of earthquake magnitude. (Keefer, 2002; Malamud and others, 2004).

- The area affected by landslides extends about 60 kilometers (km) east and west from the earthquake epicenter and across the entire north-south extent of the peninsula west of Port-au-Prince (fig. 1). Studies of earthquake-triggered landslides around the world indicate that the maximum distance limit for slides from a M 7.0 earthquake is about 200 km (Keefer, 1984); thus, this earthquake appears to have produced shaking well below the maximum of similar historical earthquakes worldwide, as indicated by triggered landslides.

- Landslide concentrations are greatest south of the Enriquillo-Plantain Garden fault zone, which could indicate either (1) stronger shaking in that area, or (2) higher landslide susceptibility of slopes in the area south of the fault zone. Our initial assessment suggests abundant susceptible slopes both north and south of the fault, which would argue in favor of lower shaking to the north. The extensive building damage north of the fault, however, suggests high-level shaking there. The lack of strong-motion seismic recordings in the area limits our ability to address fully the question of the asymmetrical landslide distribution.

- Landslide densities were greatest in deeply weathered, sheared, fractured, and (or) altered limestone (fig. 2). That material tends to disaggregate as downslope movement begins, and disrupted rock fragments form most of the landslide deposits. Weathered basalt slopes produced far fewer landslides; those slopes are less steep, more rounded, and, apparently, less susceptible to landsliding (fig. 3).

Landslide types

Most of the landslides triggered by the earthquake were disrupted rock falls and rock slides in the limestone and weathered basalt that predominate in the region surrounding the Enriquillo-Plantain Garden fault (landslide terminology after Varnes, 1978). These landslides consist of partially or completely disrupted masses of rock that form on the steep slopes of deeply incised river valleys and coastal bluffs (fig. 4). Where the rock mass is harder and well-cemented, large blocks fell, slid, and (or) rolled down the slopes (fig. 5). In weaker rock, the material locally crumbled into smaller pieces and slid or flowed to the base of the slope (fig. 6). The predominance of disrupted rock falls and rock slides is consistent with observations from other earthquakes around the world (Keefer, 1984, 2002). Lateral spreads (horizontal movement of blocks of soil on nearly level ground) occurred at some port facilities in Port-au-Prince and along coastal areas to the west (fig. 7).

Landslide dams

Many of the landslides blocked stream drainages and impounded lakes. The larger landslide dams had already been breached, and streams were flowing through them in a stable state, at the time of our visit (fig. 8). Water downstream from these breached dams was running clear at the time of our investigation, which indicated that little or no upstream erosion was occurring. Some small lakes are still impounded in tributary valleys, and those likely will breach during future rainy seasons (fig. 9). Volumes of such lakes are not large enough to be of concern for downstream populations. During future rainy seasons, already-breached dams will be downcut slightly more but should not pose a significant hazard. The landslide dam blocking the Grand Goave River, 5 km south of Grand Goave, has breached and drained; no lake remains.

Ongoing landslide hazards

Several ongoing potential landslide hazards exist. These hazards will be of particular concern during future earthquakes and rainy seasons:

- The earthquake shaking created many partially detached landslide masses. These are blocks of rock that moved but did not slide all the way to the bottom of the slope (fig. 10). Such blocks can be precarious, and renewed movement could occur in future earthquakes or during rainy periods. Renewed movement could damage areas downslope and could, in some places, form new landslide dams.

- Many landslides that initiated at the tops of slopes have related cracks behind the main scarp (fig. 11). These cracks indicate a potential for more landsliding—either during future earthquakes or rainy periods—which could enlarge the initial slide.

- Earthquake-triggered landslides have moved large amounts of loose sediment into stream drainages (fig. 12); additional material has been detached from slopes but has not slid all the way to the valley bottoms. During future rainy seasons this sediment associated with earthquake-triggered landslides will move into river systems and create significant increases in downstream sedimentation. The magnitude of this effect cannot be quantified with currently available data.

Summary and Conclusion

The January 12, 2010, Haiti earthquake (M 7.0) triggered 4,000–5,000 landslides consisting mainly of disrupted slides and falls in fractured, weathered, and (or) altered limestone and basalt. The distribution of landslides suggests that the earthquake might have produced lower levels of shaking than would have been expected for a M 7.0 earthquake. It is thus possible that future earthquakes of equal or greater magnitude could trigger higher concentrations of landslides over a much broader region than did the January 2010 earthquake. The largest landslide dams have already breached; smaller landslide dams pose no serious threats. The most significant ongoing hazards include (1) partially detached landslide masses (some of which could form new landslide dams) that could remobilize in future earthquakes or rainy seasons; (2) cracks behind head scarps of landslides, which could indicate the potential for renewed and enlarged landslide movement; and (3) increased downstream sedimentation resulting from large quantities of sediment deposited in stream valleys by earthquake-triggered landslides. Continuing detailed mapping of landslides from satellite imagery should provide a clearer picture of landslide distribution and possible reasons for the relatively small area of landsliding and the asymmetrical landslide distribution.

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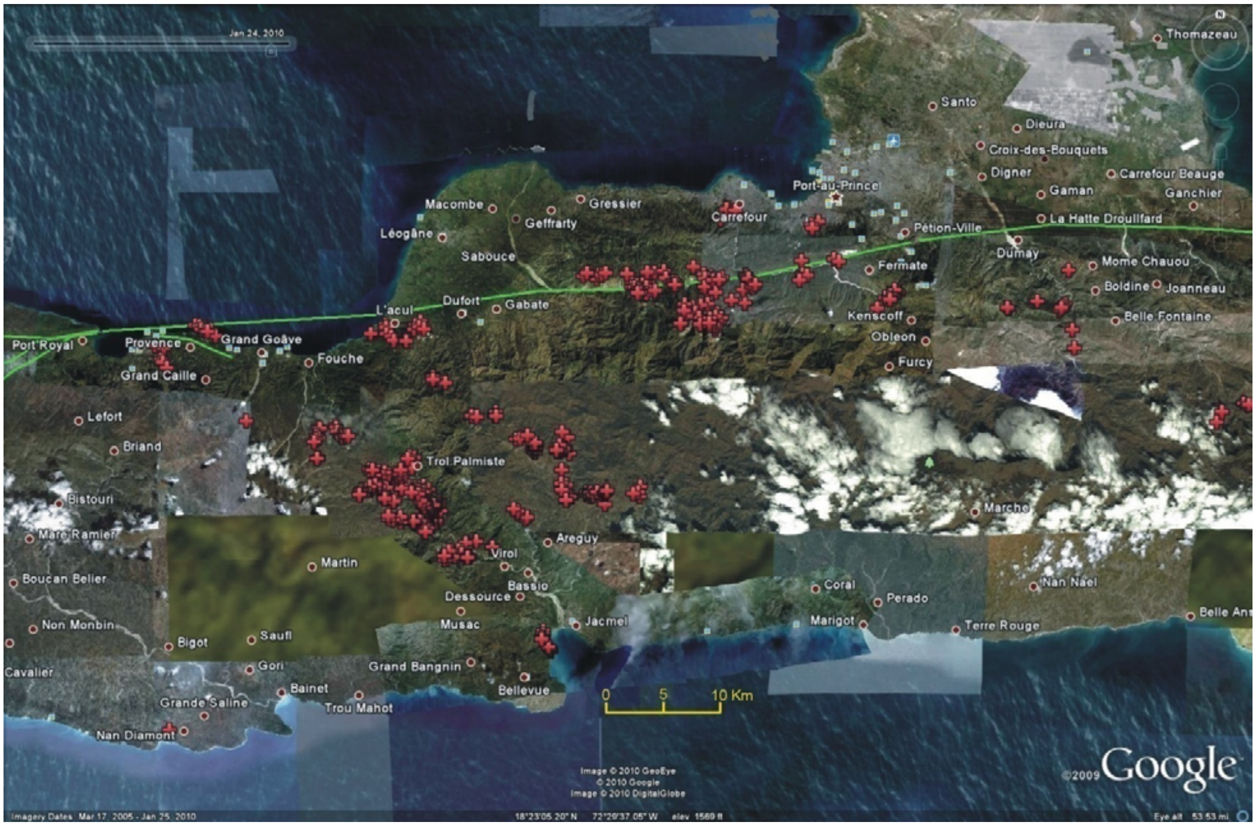

Figure 1. Preliminary map of locations of landslides triggered by the January 12, 2010, Haiti earthquake as observed from imagery in Google Earth. Red crosses denote landslide locations; Enriquillo-Plantain Garden fault shown in green; small labeled red circles are towns and cities; blue squares are photograph locations in Google Earth. This map is not complete and shows only some of the triggered landslides; more thorough mapping is continuing. (Note the misspelling on this image of the town named Nan Diamant in the southwestern corner of the view.) Base image is copyrighted by Google, Inc., GeoEye, and DigitalGlobe, all 2010.

Figure 2. Dense concentration of landslides in limestone near the Enriquillo-Plantain Garden fault zone about 10 kilometers south-southwest of Carrefour.

Figure 3. Landslide cracks in weathered basalt 12.7 kilometers southwest of Carrefour. Note the soft, rounded topography of the basalt.

Figure 4. Earthquake-triggered landslide on southern coast of Haiti near village of Nan Diamant.

Landslide is about 135 meters wide and has an estimated volume of 300,000 cubic meters.

Figure 5. Boulders of intact limestone that fell and rolled during the earthquake from cliffs along the Enriquillo-Plantain Garden fault zone.

Figure 6. Rock fall that deposited disaggregated limestone fragments in river valley. The landslide is about 200 meters wide and is 5.4 kilometers southwest of Carrefour.

Figure 7. Lateral-spread cracks along coast west of Port-au-Prince near Léogâne.

Figure 8. Landslide dam 15 kilometers northwest of Jacmel. The dam has breached, and the small amount of water impounded upstream should pose no future hazard. The landslide is about 150 meters wide.

Figure 9. Small lakes impounded by landslide dams along a 600-meter length of stream northwest of Jacmel. Yellow arrow shows general downstream direction.

Figure 10. Detached landslide blocks (arrows) about 15 km northwest of Jacmel that could move further in future earthquakes or rain storms.

Figure 11. Extensional cracks behind the main scarp of the coastal landslide shown in figure 4.

Figure 12. Landslides that deposited sediment to a river valley along the Enriquillo-Plantain Garden fault zone about 6 kilometers south-southwest of Carrefour.