Figure 6-36. Extent of slide (Photo by Curt Edwards)

Figure 6-37. Slide from below (Photo by Curt Edwards)

6.10. Major Observations and Lessons Learned

It was surprising that there was no major bridge damaged even though many were located in high-risk areas, such as coastal river crossings. Although there was some cracking, span movement, abutment settlement, and minimal repairs, the bridges were still functional. This allowed for continued movement of rescue vehicles, aid packages, and critical vehicles such as water delivery trucks. If one or more of these bridges had collapsed, the already heavy traffic would have been worse, further delaying response times.

Some of the lessons learned from this event include:

1. Reassign available heavy equipment from less important tasks to road clearing and debris removal. This will greatly improve emergency response times and improve recovery.
2. Evaluate ground conditions during highway construction. If possible, mitigate hazards such as landslides and liquefaction/lateral spreading zones to avoid road damage.

7. Ports, Marine Oil Terminals, and Airports

Port, marine oil terminal, and airport facilities were investigated during the ASCE-TCLEE post-earthquake reconnaissance following the January 2010 Haiti earthquake. Many of the waterfront facilities near Port-au-Prince suffered significant damage during the earthquake and aftershocks, with the majority of the structures damaged and many unusable for weeks or more following the earthquake due to strong ground shaking and liquefaction.

Given the large humanitarian needs, the airport underwent emergency repairs and was partially operational by January 13. The port of Port-au-Prince was heavily damaged and only partially operational with larger ships offloading to smaller, self-unloading ships and the use of temporary dock barges. Some international humanitarian aid was also routed through smaller private ports near Port-au-Prince.

7.1 Description of Systems

Port Facilities

Several port facilities (Fig. 7-1) are located near Port-au-Prince:

- **Port de Port-au-Prince (PPAP):** Terminals located in Port-au-Prince consisted of a finger pier, a marginal wharf, and two pile-supported roll-on/roll-off (Ro/Ro) berths that handled container and break bulk cargo.
- **Terminal Varreaux:** Located north of Port-au-Prince, this terminal included a marginal wharf with a finger pier extension that handled break bulk materials.
- **Cimenterie National (CINA):** CINA included facilities north of Port-au-Prince at a cement plant to handle break bulk materials for the cement plant consisting of a finger pier and a bulkhead Ro/Ro berth.
- **Moulins d'Haiti:** This included facilities at a flour mill north of Port-au-Prince to handle break bulk materials for the flour mill. It consisted of two bulkheads, one serving as a Ro/Ro berth.
- **Terminal Abraham:** This terminal included a finger pier located west of Port-au-Prince for break bulk cargo.

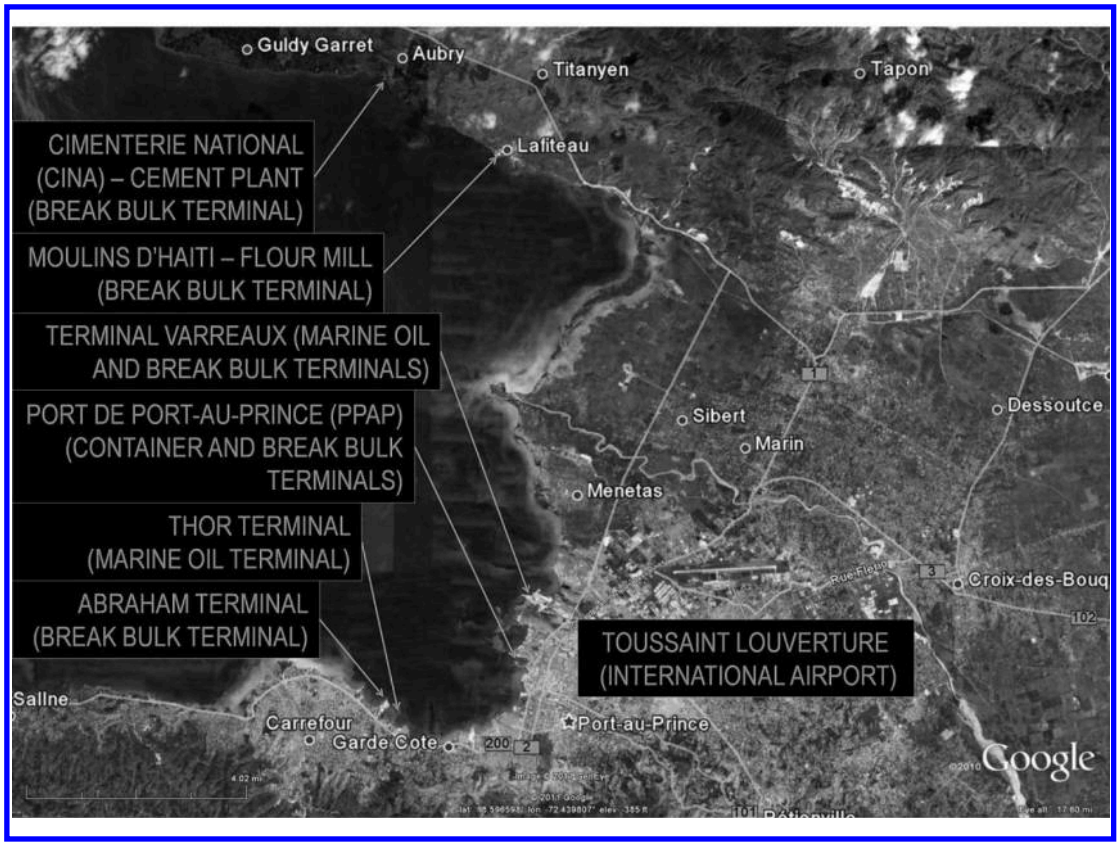

Figure 7-1. Overview of investigated facilities in the Port-au-Prince area (Image © 2011 Google, GeoEye, with permission from GeoEye)

Marine Oil Terminals

Two marine oil terminals near Port-au-Prince that handled the majority of the country's petroleum imports (Fig. 7-1):

- **Terminal Varreaux Marine Oil Terminal:** This terminal was located north of Port-au-Prince and adjacent to the break bulk facilities at the same terminal. The facilities consisted of a finger pier, pipeline system, storage tanks, and a distribution system.
- **Thor Marine Oil Terminal:** Located west of Port-au-Prince, this terminal consisted of an earth mole with a finger pier extension, pipeline system, storage tanks, and a distribution facility.

Airports

There was one major airport near Port-au-Prince:

- **Toussaint Louverture International** (Fig. 7-1) is one of two international airports in Haiti; the other is located in Cap Haitian on the north side of the country. The airport included a single runway about 3 km (10,000 ft.) long.

7.2 Overview of System Performance

The waterfront facilities (ports and marine oil terminals) and the airport facility were significantly damaged during the earthquake. The airport damage was mostly structural due to the strong ground shaking. The waterfront facilities were damaged primarily due to liquefaction of the foundation and backfill soils, although there were also indications that many of the facilities were not designed to current seismic standards or were corroded or damaged before the earthquake and may have suffered significant damage due to inertial loading. There was also damage to backland storage tanks and pipeline systems at the marine oil terminals.

The loss of both the airport and waterfront facilities greatly hampered the humanitarian and post-recovery efforts. The functionality of the airport was partially restored within about 1 day; however, air transportation was not able to accommodate the large volumes of cargo necessary for the large-scale humanitarian and post-earthquake recovery efforts needed after such a large disaster. It was necessary to restore the waterfront facilities to provide this needed capacity.

Port Facilities

Port de Port-au-Prince (PPAP)

Haiti's main seaport is located in the capital of city of Port-au-Prince about 1 mile south of the city of La Saline and 1 mile west of Croix des Bossales. The port is centered at a latitude of 18.5561 degrees and longitude of about -72.3487 degrees, which is about 22 km (13.5 miles) from the earthquake epicenter. There was no direct measurement of ground shaking at the port. Based on the preponderance of liquefaction, however, it is estimated the peak ground acceleration was about 0.2 g or greater.

The port is operated by the government's Authorite Portuaire National (APN). APN is a landlord port, whose current functions are both regulatory and operational. It was the largest and busiest container port in Haiti, handling about 1200 containers per day and 170,000 TEU's[5] per year before the earthquake, according to APN officials. The port primarily consists of two separate facilities designated as the north wharf and the south pier (Fig. 7-2), both built between1978 and 1980. There were seven berths including two Ro/Ro berths before the earthquake.

Port Entrance

The main port entrance was significantly damaged during the earthquake and became unusable afterwards. Liquefaction evidence and lateral spreading were observed along the port entrance road (Fig. 7-3).

[5] A TEU is a standard shipping unit of measure, and refers to a standard 6-m (20-ft.) equivalent unit (TEU) shipping container.

Figure 7-2. PPAP Facilities prior to the Earthquake
(Image © 2011 Google, GeoEye, with permission from GeoEye)

North Wharf

The North Wharf was a marginal wharf constructed in 1979 approximately 457 m (1,500 ft.) long and 12 m (70 ft.) wide supported by 45 cm (18 in.) square pre-stressed concrete piles with plumb and two batter piles per bent (Fig. 7-4, 7-5). There were five plumb piles and two batter piles per bent (NAVFAC 1994). The wharf supported a rail-mounted gantry container crane and two mobile harbor cranes. The water depths along the berth line ranged from 10 to 12 m (33 to 39 ft.) before the earthquake. A Ro/Ro ramp was located adjacent to the wharf on the east end.

The north wharf and Ro/Ro ramp collapsed during the earthquake (Fig. 7-4), and two of the three cranes were submerged in the water. During the earthquake, two vessels were moored to the north wharf, and a crew member from one vessel took several photographs of the immediate post-earthquake damage. Figures 7-6 through 7-9 are photographs taken from the moored ship following the earthquake. The photographs provide evidence that the wharf did not initially collapse completely: After strong shaking the wharf was still above water and gradually collapsed into the bay. Figure 7-6 provides an aerial view of the North Wharf several days after the earthquake and shows complete collapse of the wharf into the bay.

Figure 7-3. PPAP port entrance damage
(Photo courtesy of Nason McCullough)

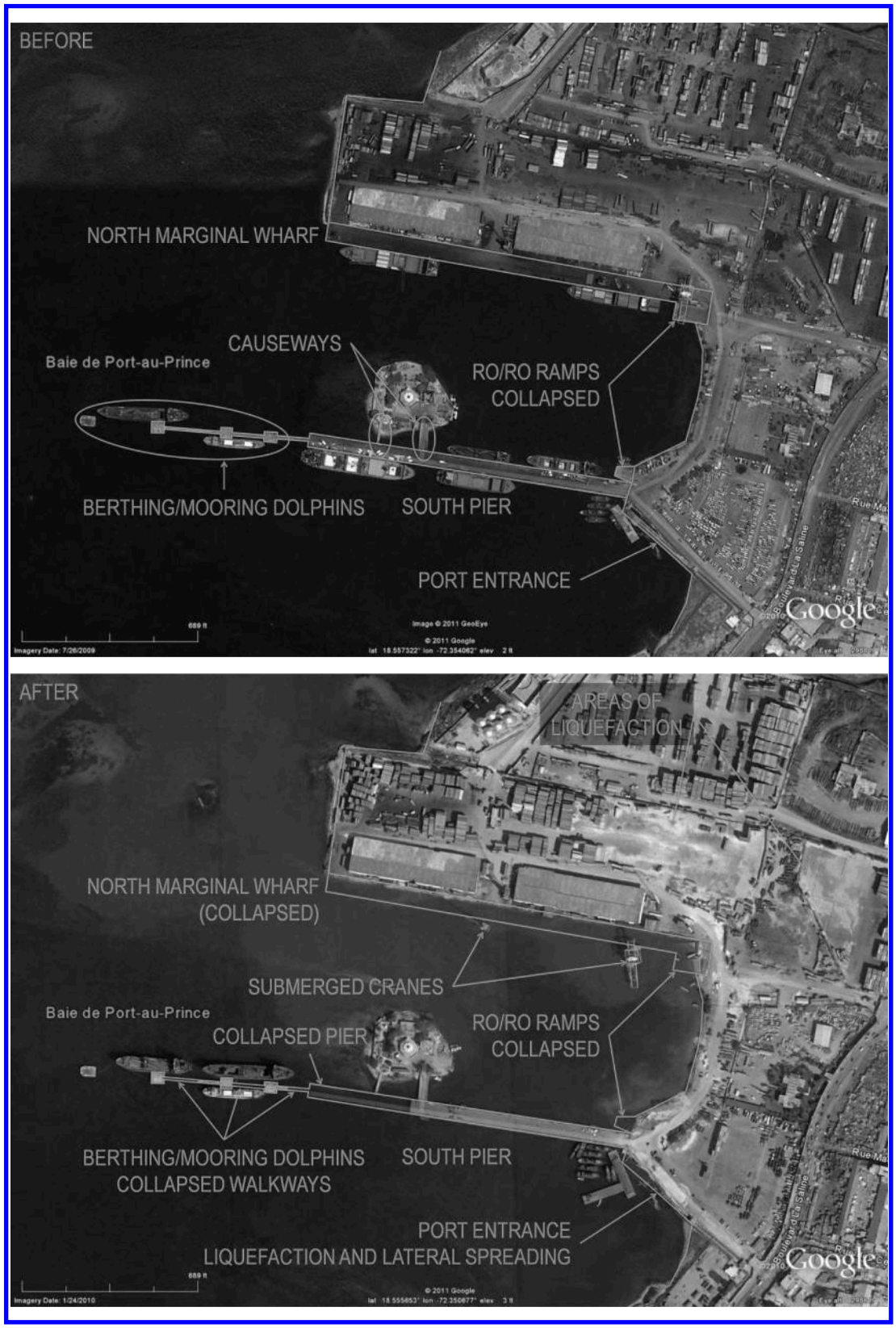

Figure 7-4. PPAP North Wharf and South Pier before and after the earthquake (Image © 2011 Google, GeoEye, with permission from GeoEye)

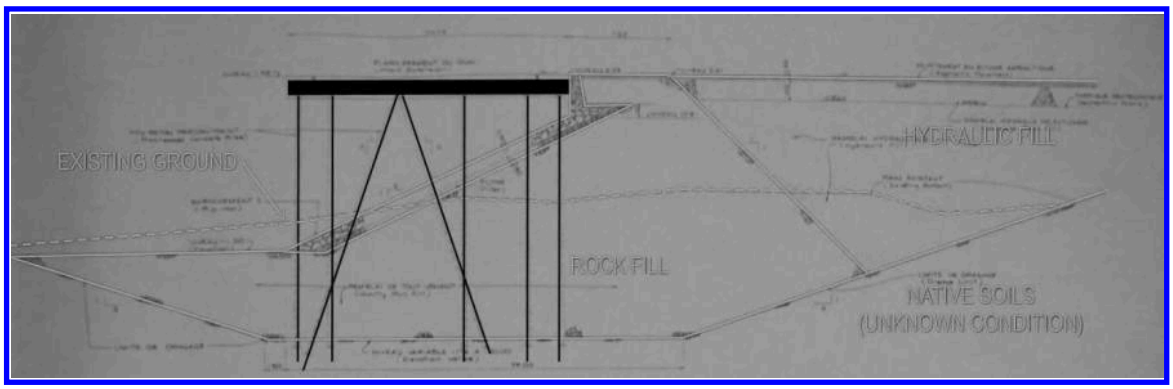

Figure 7-5. PPAP North Wharf as-designed geometry

Figure 7-6. PPAP North Wharf damage 4 days after the earthquake (Photo courtesy of the Department of Defense)

There was evidence of liquefaction in the backland areas (Fig. 7-4). Large ground cracks were also observed along and near the edge of the waterline (Fig. 7-7 through 7-8), presumed to be caused by the significant liquefaction.

Two steel-frame warehouses suffered significant damage, but did not collapse (Fig. 7-9). The steel trusses were severely buckled in several locations, and the foundation supports were also severely damaged or separated (Fig. 7-10) from the columns in several locations. Figure 7-11 shows the significant internal damage to the warehouse.

South Pier

The South Pier was a pile-supported finger pier constructed in 1979 about 380 m (1250 ft.) long and 18 m (60 ft.) wide (Fig. 7-4). The pier was pile supported with two plumb and four interior batter piles per bent (Fig. 7-12). Two pile-supported causeways, a vehicular bridge, and a pedestrian bridge connected the pier to an island where port security was located. The western end of the pier was connected to four dolphins by walkways.

Figure 7-7. PPAP North Wharf damage and ground cracks (looking west) (Photo courtesy of Alex Augustin)