Overview of the 2010 Haiti Earthquake

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The 12 January 2010 M_w 7.0 earthquake in the Republic of Haiti caused an estimated 300,000 deaths, displaced more than a million people, and damaged nearly half of all structures in the epicentral area. We provide an overview of the historical, seismological, geotechnical, structural, lifeline-related, and socioeconomic factors that contributed to the catastrophe. We also describe some of the many challenges that must be overcome to enable Haiti to recover from this event. Detailed analyses of these issues are presented in other papers in this volume. [DOI: 10.1193/1.3630129]

INTRODUCTION

On 12 January 2010, at 4:53 p.m. local time, a magnitude 7.0 earthquake struck the Republic of Haiti, with an epicenter located approximately 25 km south and west of the capital city of Port-au-Prince. Near the epicenter of the earthquake, in the city of Léogâne, it is estimated that 80%–90% of the buildings were critically damaged or destroyed. The metropolitan Port-au-Prince region, which includes the cities of Carrefour, Pétion-Ville, Delmas, Tabarre, Cite Soleil, and Kenscoff, was also severely affected. According to the Government of Haiti, the earthquake left more than 316,000 dead or missing, 300,000[1] injured, and over 1.3 million homeless (GOH 2010). According to the Inter-American Development Bank (IDB) the earthquake was the most destructive event any country has experienced in modern times when measured in terms of the number of people killed as a percentage of the country's population (Cavallo et al. 2010).

The Republic of Haiti occupies the western third (27,750 km^2) of the island of Hispaniola, located in the northeast Caribbean between Puerto Rico to the east and Jamaica and Cuba to the west (Figure 1), and had a population of approximately 9.6 million prior to the earthquake. The metropolitan area surrounding its largest city, Port-au-Prince, has an estimated population of 3 million. Haiti has been impacted by other natural disasters in recent years. In 2008, more than 800 people were killed by a series of four hurricanes and tropical storms that struck Haiti during a two-month period.

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[1] The number of casualties is a highly debated issue, with estimates ranging from 70,000 to 316,000. At the time of this publication, the official number from the Government of Haiti is 316,000.

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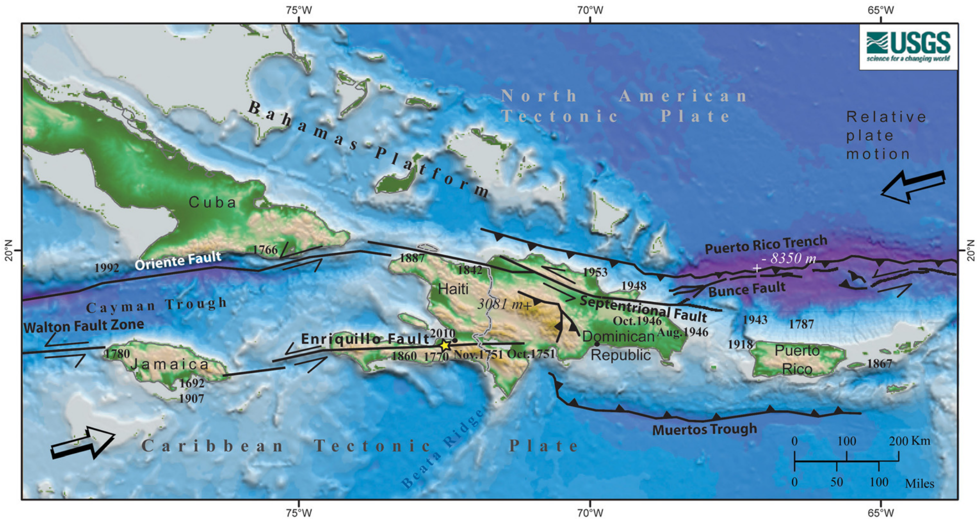

Figure 1. Geographic and tectonic setting of the island of Hispaniola, of which Haiti occupies the western third. The 2010 earthquake occurred on or near the Enriquillo-Plantain Garden fault zone and was preceded by earthquakes in southern Haiti in 1751 (two events, in October and November), 1770, and 1860. The location of the main shock of 12 January 2010 and aftershocks are shown in Figure 2.

The damage to the infrastructure from the earthquake in Haiti was staggering. More than 300,000 homes collapsed or were critically damaged. It is estimated that 60% of the nation's administrative and economic infrastructure was lost, and 80% of the schools and more than 50% of the hospitals were destroyed or damaged (GOH 2010). More than 180 government buildings and 13 out of 15 key government offices collapsed, including the presidential palace and parliament. The partial destruction of the main port of Port-au-Prince and blockage of roads from debris hampered the response and recovery for many months after the earthquake. Even nine months after the earthquake, the destruction continued to disrupt the lives of many Haitians. The Interim Haitian Reconstruction Commission estimated that as of 12 October, 1.3 million people were still displaced—either in one of the more than 1,300 camps and other settlements registered by the International Organization for Migration (IOM) or in temporary housing situations in both the quake-affected zone and in non-affected regions (IHRC 2010).

Overall losses and damages from the earthquake are estimated to be between US$7 billion and US$14 billion (approximately 100%–200% of Haiti's gross domestic product), making this the most costly earthquake event in terms of the percentage of a country's gross domestic product (Cavallo et al. 2010).

PRE-EARTHQUAKE HAITI: SETTING THE CONTEXT

It is difficult to quantify the impact of pre-earthquake conditions on the devastation resulting from the earthquake in Haiti. However, there is no doubt that the dire socioeconomic conditions that existed prior to the earthquake were a major contributor to the resulting damage. Following a slave rebellion in 1804, Haiti became the first free black nation in the world. It was subsequently forced to pay France a massive indemnity for properties lost in that rebellion, and was ostracized socially and economically by countries all around the world. Haiti subsequently became entrapped in a cycle of poverty and misgovernment from which it has never emerged (Heinl 1996).

Haiti is the poorest country in the Western Hemisphere, ranking 145 out of 169 on the UN Human Development Index (UNDP 2010). Less than 10% of the population has access to potable tap water and less than one-third has access to electricity, even intermittently (UNSD 2010), which are the lowest respective percentages in the Western Hemisphere. More than half of Haiti's population lives on less than US$1 per day, and more than three-quarters live on less than US$2 per day. Haiti has the highest rate of mortality among infants, children under 5, and during maternity of any country in the Western Hemisphere (UNSD 2010). Haiti's exports are small: 10% of the gross domestic product. Haiti's poor economic performance is, in part, the result of the decline of its agricultural sector, which in turn is due in large part to the degradation of the environment. Haiti ranks 155 out of 163 countries when it comes to general environmental degradation. For years, Haitians have cut down trees to use as cooking fuel, resulting in less than 3% of Haiti being covered by forest, a stark contrast to the lush forests of its neighbor, the Dominican Republic. The environmental degradation only increases Haiti's vulnerability to natural hazards.

In addition to its poor socioeconomic standing, Haiti's limited recent history of large earthquakes (Figure 1) left it unprepared for the 12 January 2010, earthquake. Haiti had few seismologists and no seismic network in the country. It only had one seismic hazard map, which was outdated and lacked sufficient detail to be useful. The best geological map dated to 1987 (Lambert et al. 1987). The building code was outdated, rarely used, and not enforced (CUBiC 1985). There was no earthquake preparedness program and no contingency plan for earthquakes. The typical university curriculum did not include seismic design, seismology, or the geosciences.

SEISMOLOGICAL ASPECTS

GEOLOGY AND TECTONICS

The geologic evolution of Hispaniola can be traced to the Mesozoic breakup of Pangea and the creation of the Atlantic Ocean. This process resulted in the formation of the Caribbean microplate, with subduction zones forming around the margins (Garcia-Casco et al. 2008). The geology of Hispaniola, including Haiti, consists of igneous rocks formed within a volcanic island arc, as well as abundant marine sedimentary rocks that have accreted at the oceanic subduction margin (Woodring et al. 1924, Maurrasse 1982).

The 12 January 2010 earthquake occurred on or near the Enriquillo-Plantain Garden Fault, a prominent strike-slip fault that is clearly evident in high-resolution relief maps of the Southern Peninsula of Haiti. Field studies confirmed that the mapped Enriquillo-Plantain Garden Fault in the epicentral region separates basaltic rocks south of the fault from marine sedimentary rocks (chalk, sandstone, and limestone) to the north. Thus, the fault can be easily discerned by its morphology and geology. However, detailed field and geophysical studies indicate that the fault rupture was a complex event that involved slip on more than just the Enriquillo-Plantain Garden Fault (Nettles and Hjörleifsdóttir 2010, Prentice et al. 2010, Calais et al. 2010, Hayes et al. 2010).

SEISMICITY

For several decades prior to the 12 January 2010 earthquake, seismic activity within the island of Hispaniola had been heavily concentrated in the eastern two-thirds of the island in the Dominican Republic, and Haiti had been relatively seismically quiescent. Indeed, since the establishment of a modern global seismic network in 1964, the Port-au-Prince region of southern Haiti has experienced only one earthquake of magnitude greater than 4.0, with several additional events occurring 100 km to the west. However, studies of historical seismicity have established that large (magnitude 7.0 or greater) earthquakes have struck the Port-au-Prince region in the historic past. These earthquakes are all attributed to movement on the east–west oriented Enriquillo Fault (Figure 2). The largest earthquakes occurred in 1751 (two events), 1770, and 1860 (O'Loughlin and Lander 2003). One of the two earthquakes of 1751 occurred near the longitude of Port-au-Prince and destroyed buildings throughout the city (modified Mercalli intensity [MMI] of X). The 1770 earthquake occurred an

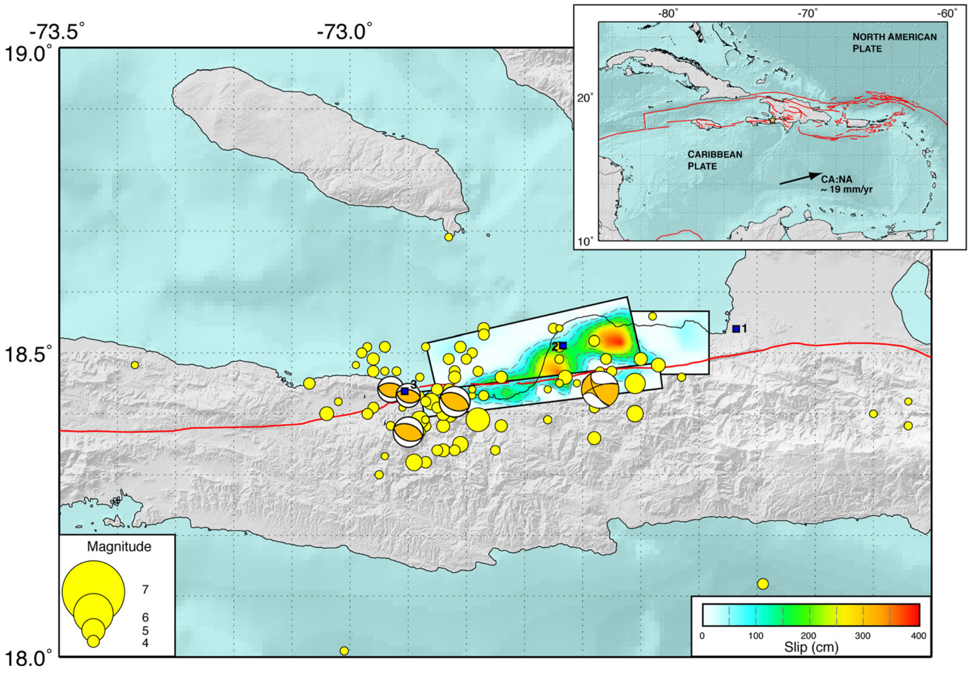

Figure 2. Topographic map of the Southern Peninsula of Haiti: (a) Port-au-Prince, (b) Léogâne, and (c) Port Royal. The east–west oriented Enriquillo Fault (red line) passes the main shock epicenter (single larger focal mechanism SE of Léogâne). The Enriquillo Fault is a left-lateral fault that accommodates 7+/−2 mm/yr of strain (Manaker et al. 2008). Aftershocks (yellow circles) are concentrated to the west of the main shock, and their focal mechanisms (orange) indicate reverse faulting. Panels centered on Léogâne indicate the extent and magnitude of fault slip on three rupture planes (Figure 3).

estimated 30–50 km further to the west on the Enriquillo Fault, and once again resulted in the widespread destruction of buildings in Port-au-Prince and Léogâne (O'Loughlin and Lander 2003). The 1860 earthquake was located still further to the west of Port-au-Prince and was observed to cause uplift of the sea floor. This uplift is significant because it indicates that crustal strain accommodation and release is partitioned between pure strike-slip and reverse-faulting structures (Nettles and Hjörleifsdóttir 2010, Hayes et al. 2010, Calais et al. 2010).

THE MAIN SHOCK AND AFTERSHOCKS

The 12 January 2010 event occurred at 04:53:10 p.m. local time. The U.S. Geological Survey (USGS) located the epicenter at 18.44° N, 72.57° W, which placed the event 25 km WSW of Port-au-Prince, on or near the Enriquillo Fault. The estimated depth was 13 km, but the lack of local seismic data made the precise depth uncertain. The USGS assigned a horizontal uncertainty of $+/-$ 3.4 km. The first-motion focal mechanism (ref) for the main shock indicated left-lateral oblique-slip on an east–west oriented fault. However, there was clear evidence of coastal uplift north of the Enriquillo Fault (Hayes et al. 2010) as well as vertical ground deformation imaged by interferometric synthetic aperture radar (InSAR) data. These observations require significant slip on a nearby reverse fault (Figure 2). The finite fault model by Hayes et al. (2010) showed slip on three fault planes and satisfies seismologic, geodetic, and geological observations. This model showed a maximum slip of 3.5 m on the reverse fault (Figure 3). The earthquake source zone (i.e., the surface area of the fault that slipped) was quite compact, with a down-dip dimension of approximately 15 km and an along-strike dimension of close to 40 km. This source dimension is about two-thirds the size of a typical M_w 7.0 earthquake. The earthquake rupture was very abrupt and sharp; maximum moment release occurred in the first 4–8 seconds of the fault slip, and 80% of the moment release occurred in 12–14 seconds (Hayes et al. 2010).

The main shock was followed within 20 minutes by two large aftershocks with moment magnitudes of 6.0 and 5.7, respectively. Eight days after the main shock, on 20 January 2010, a M_w 5.9 aftershock occurred. Overall, the early aftershock sequence from this earthquake was three times more productive than a typical aftershock sequence in California.

SEISMOLOGICAL AND GEODETIC FIELD ACTIVITIES DURING 2010

The first accelerometer to measure aftershocks was installed on the grounds of the U.S. Embassy in Port-au-Prince on the evening of 27 January 2010 (Eberhard et al. 2010). In March 2010, additional temporary seismographs were deployed by the USGS and French and Canadian research groups and these data were being interpreted at the time of this writing. GPS and InSar data have been collected (Calais et al. 2010, and references therein), and Coulomb stress changes imparted by the 12 January 2010 event have been calculated (Lin et al. 2010). These data and additional analytical models will be used to guide the next generation of seismic hazard maps (Frankel et al. 2010).

GEOTECHNICAL

The earthquake-affected region is a physiographically diverse area with a complex geologic history. The topography within the study area is relatively rugged, with steep mountain

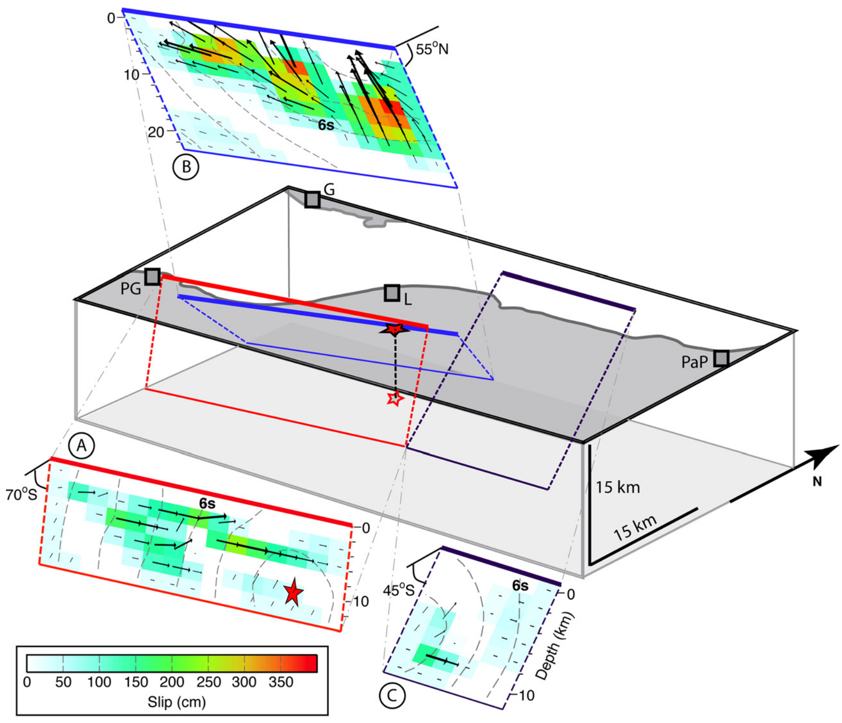

Figure 3. Geometry of fault ruptures for the January 2010 Haiti earthquake. Fault plane A (red outline) contains the earthquake hypocenter (locus of slip initiation; red star) and is a steeply-dipping (70°) left-lateral strike-slip fault. Fault plane B (blue outline, top) is a blind thrust fault (55° dip), shows the largest slip displacement (up to ca. 350 cm) and is responsible for approx. 80% of the seismic moment released during the earthquake. Fault plane C (black outline, bottom) is a reverse fault with a modest amount (ca. 100–200 cm) of slip (from Hayes et al. 2010).

ranges and hillfronts, deeply incised streams and narrow intermountain stream valleys, and broad coastal delta fans and valleys. Quaternary deposits in the epicentral zone include Holocene to late Pleistocene fluvial alluvium (channel, terrace, floodplain overbank deposits) deposited in the Port-au-Prince valley and interior incised river valleys, alluvial fan and colluvial wedge deposits along the margins of larger valleys, coastal delta fan complexes where larger streams discharge into the sea along the coast, localized organic sediments within marshes and swamps, and beach sands along protected portions of the coast. Port-au-Prince spans a broad region from the relatively level floor of a large alluvial valley underlain by Holocene to Pleistocene deposits, southward to low hills underlain by Mio-Pliocene deposits. Léogâne and Carrefour are located on large delta fans and are underlain by Holocene to Pleistocene alluvium. Coastal areas adjacent to Port-au-Prince are mostly composed of artificial fill placed during westward expansions of the city during the past 200 years. Post-earthquake reconnaissance visits to Haiti have provided opportunities to acquire detailed information on geologic and geotechnical conditions throughout the affected area (Cox et al. 2011, Green et al. 2011, Rathje et al. 2011, Hough et al. 2011, Lekkas and Carydis 2011).

The observed structural damage from the earthquake correlates well with these geologic conditions. Ground-motion amplification was a primary factor in alluvial soils in the north-central and coastal region of Port-au-Prince, Carrefour, and Léogâne. Hough et al. (2010) used weak-motion data from aftershock recordings at seismograph stations deployed following the earthquake to determine that the mean amplification ratio of peak ground acceleration (PGA) for stations on alluvium was 1.78 +/− 0.58 compared to a reference station on hard rock. Rathje et al. (2011) documented that the largest concentrations of damage occurred in areas underlain by Holocene alluvium with average shear wave velocities in the upper 30 m (V_{S30}) of approximately 350 m/s, which corresponds to National Earthquake Hazards Reduction Program (NEHRP) Site Class D.

Large concentrated zones of damage also occurred in the southern portion of Port-au-Prince that extends into the hills underlain by Mio-Pliocene, weakly cemented deposits. In these areas, both topographic amplification and site effects contributed to higher levels of shaking. Hough et al. (2010) compared weak-motion recordings at sites located in the foothills of Port-au-Prince with a hard-rock reference station and found that the PGA was amplified by a factor of 2.94 +/− 1.06; amplification ratios as high as 5 were calculated for frequencies of several Hertz. Rathje et al. (2011) and Hough et al. (2011) have used digital elevation models to correlate observed damage patters with topographic features in the area.

Artificial fill in the port areas of Port-au-Prince and Carrefour experienced extensive liquefaction, lateral spreading, and settlement damage. At the Port de Port-au-Prince, liquefaction-induced lateral spreading (Figure 4) resulted in the collapse of the pile-supported North Wharf, damage to two steel-frame warehouses, and other port facilities (Green et al. 2011, Werner et al. 2011). Geotechnical site investigations performed after the earthquake includes soil borings with standard penetration tests (SPT), dynamic cone penetration tests (DCPT), and surface wave (MASW and SASW) tests (Green et al. 2011). Grain size analyses indicated that the coarse-grained soils were well-graded mixtures of sands and gravels

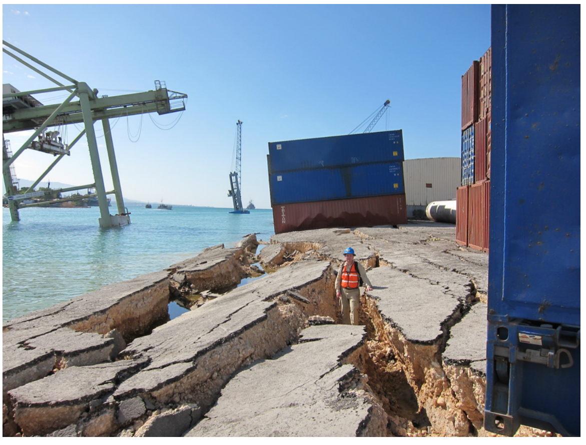

Figure 4. Liquefaction-induced lateral spreading leading to the collapse of the North Wharf at the Port de Port-au-Prince.

with median grain sizes ranging from 0.2 mm to 10 mm. The calcium carbonate ($CaCO_3$) content of the materials was 80%–90% and is attributed to the marine origin of the fill materials. Level-ground liquefaction analyses performed using the SPT and DCPT data indicated that the liquefaction potential of the soils is very high, which is consistent with the extent and severity of liquefaction-induced ground failures at the port. Green et al. (2011) also compare observed values of permanent deformation with estimates obtained from various empirical methods and found that the observed values generally exceed the estimated values. Ground-motion amplification in the soft fill soils was likely a contributing factor to the partial collapse of and extensive damage to the remaining portion of the South Pier at the Port de Port-au-Prince (Werner et al. 2011).

Many of the road failures observed along the coast west of Carrefour occurred where the road crosses marshy ground and the distal ends of small alluvial valleys. Settlement and localized creep/slumping of sediments underlying the roadbed appear to be responsible for many of the road failures, rather than lateral spread failure, because cracking typically was confined to the roadbeds and fill and did not extend through natural soils shoreward of the roadways. Localized liquefaction of loose, saturated sediments in these areas may have contributed to the road failures, but was not the major factor.

Numerous landslides and rockfalls occurred within the Mio-Pliocene and older limestone bedrock in steep slopes and roadcuts within the epicentral zone. In some cases these failures appear to have been restricted to colluvial soil and fractured/dilated rock within a weathered zone that extends about 1–3 m deep into the slopes. However, some deeper-seated slumps and debris avalanche/slide failures occurred in less-weathered, deeper bedrock in steep mountainous slopes. These failures appear in part to be influenced or controlled by bedrock joints or weak zones. In places, developments on steep slopes appear to have been impacted by slope raveling or foundation sliding/slumping. Additional analyses of landslides in the epicentral zone are described in Liu et al. (2011).

PERFORMANCE OF BUILDINGS

The earthquake caused extensive damage to buildings throughout the Port-au-Prince metropolitan area, and in the rural areas and towns to the west and south of the city. Nearly all of the severe damage and collapses appeared to occur in buildings that were constructed without considering the effects of earthquakes. The majority of buildings that were designed for earthquakes and that were well constructed did not collapse in the earthquake.

BUILDING INVENTORY

A nationwide census conducted in 2003 documented many characteristics of Haitian society, including the frequency of common building types, as well as the materials used to construct the walls, roofs, and floors. The percentage of each type of building is reported for urban and rural areas in Table 1, which was compiled with data from the Haitian Ministry of Statistics and Informatics (IHSI). Within urban areas, 78% of the buildings were classified as one-story houses and another 14% were classified as multistory houses or apartments (IHSI 2010). The remaining 8% of the buildings consisted of slum housing or traditional forms of construction (two common types are *kay atè*, buildings with a combined roof and walls, and *ajoupas*, rural homes with thatch, straw, or palm leaf roofs). Within rural areas,

Table 1. Distribution of building types in urban and rural areas (IHSI 2010)

	Location		
Type of Building	Urban Areas (%)	Rural Areas (%)	Combined (%)
Kay atè (combined roof and walls)	0.5	1.9	1.4
Taudis (slum housing)	3.2	2.5	2.8
Ajoupas (rural home with roof made of thatch, straw, or palm leaves)	3.7	25.3	17.6
One-Story House	78.3	69.2	72.5
Multistory House/Apartment	13.7	0.8	5.4
Others	0.6	0.3	0.4

ordinary one-story houses were again most common (69%), multistory structures were rare (<1 percent), and *ajoupas* made up 25% of the building inventory.

The wall materials for each building type in urban areas are summarized in Table 2, which was also developed from the IHSI data. In urban areas, concrete block walls predominated (79%), particularly in multistory houses and apartments (97%). In rural areas, the most common wall material was earth (33%), followed by concrete block (22%), and clissage (19%), consisting of intertwined sticks, twigs, and branches. Considering all building types and regions, approximately two-thirds (69%) of the structures had metal roofs, but for multistory houses and apartments, 89% had roofs made of concrete (IHSI 2010).

Typical reinforced concrete frame buildings with concrete block infill had numerous vulnerabilities known to cause seismic damage. Figure 5 shows a typical low-rise reinforced concrete frame building with infill concrete block walls that was under construction at the time of the earthquake. Columns were slender with depths in the range of 200 mm to 250 mm. Such columns were often reinforced with 4 #4 bars, sometimes deformed and sometimes smooth. Column and joint transverse reinforcement was minimal (e.g., #2 smooth ties) and spaced at a distance roughly equal to the column depth. Concrete and mortar

Table 2. Distribution of wall materials for each building type in urban areas (IHSI 2010)

	Wall Material				
Type of Building	Concrete Block (%)	Earth (%)	Wood/ Planks (%)	Clissage (%)	Other (%)
Kay atè (combined roof and walls)	0.0	91.3	0.0	7.6	1.1
Taudis (slum housing)	11.3	8.3	15.3	8.5	56.6
Ajoupas (rural home with roof made of thatch, straw, or palm leaves)	0.0	54.6	9.6	28.2	7.6
One-Story House	82.4	3.8	2.9	3.0	8.0
Multistory House/Apartment	97.4	0.0	0.6	0.0	1.9
Others	67.0	0.4	6.2	0.7	25.7
All	78.7	5.7	3.2	3.7	8.8

Figure 5. Residential concrete block slab construction.

quality appeared to vary significantly. In the building shown Figure 5, concrete blocks were placed outside the frame lines. More typically, the concrete block walls were used as infill. In some structures, column steel splices were placed directly above the elevation of the floors.

BUILDING PERFORMANCE

Damage to residences and commercial buildings was widespread. According to Figure 11 (USAID 2010), approximately 40%–50% of buildings were “destroyed” in Carrefour and Gressier, communes near Port-au-Prince. In downtown Port-au-Prince, Eberhard et al. (2010) found that 28% of the 107 buildings surveyed had collapsed partially or totally, and an additional 33% were damaged enough to require repairs. The damage was even higher in Léogâne, the city nearest the epicenter. According to Figure 11, 80%–90% of buildings there were destroyed.

Two adjacent structures in downtown Port-au-Prince illustrate the consequences of poor seismic proportioning and detailing. Figure 6 shows the collapse of the multistory Turgeau Hospital, constructed in 2008. The building’s lateral-force resistance was provided by a reinforced concrete frame with masonry infill. As with the residence shown in Figure 5, the columns were slender, and the columns and joints had little transverse reinforcement. In contrast, the Digicel building (Figure 7) across the street had only minor structural damage, consisting mainly of concrete spalling at the base of the columns. The building had been designed to resist earthquakes; it had much larger columns with closely spaced ties and included shear walls.

It appears that some buildings performed better than their neighbors because of their low mass. For example, the wood-frame building shown in Figure 8a was adjacent to a collapsed reinforced concrete structure. Similarly, the one-story church shown in Figure 8b had a light-metal roof supported by masonry walls. Although it appeared to be constructed with materials of poorer quality than those used in a neighboring concrete bearing-wall house, the masonry church structure suffered less damage.

(a) (b)

Figure 6. Turgeau hospital in downtown Port-au-Prince: (a) Before the earthquake (Simon Young CaribRM), and (b) collapsed structure after the earthquake.

PERFORMANCE OF LIFELINES

BRIDGES

There are very few bridges in Haiti, and most are short, single-span bridges or culverts. We did not learn of any bridge collapses attributable to the earthquake. Within Port-au-Prince, most of the crossings over streams were accommodated by box culverts, which did not appear to be damaged. Along the Route Nationale No. 2, small streams were also spanned by culverts. The culverts themselves were not damaged, but in at least one case, the approaches to the culvert settled relative to the culvert itself.

The main river crossings on Nationale No. 2 were spanned by bridges with precast girders resting on cast-in-place reinforced concrete bents and supporting a cast-in-place deck. We observed damage to two such bridges. The bridge over the Momance River had minor pounding damage at one of the intermediate supports. In the Carrefour section of Port-au-Prince the external shear keys (Figure 9) of a similar bridge were damaged at both intermediate supports. This failure was apparently caused by the lack of hook anchorage at the end of the top beam reinforcement.

WATER AND WASTEWATER

The main public water system in Port-au-Prince is supplied by a series of springs located in the nearby mountains. The water is chlorinated in the spring boxes and sent to the distribution system, which serves 1,000,000 people (Edwards 2010). Prior to the earthquake, this supply was unreliable, and the water was not drinkable without further treatment. There were relatively few water main breaks, which is unusual for a system this large. Most of the breaks were repaired within one to two weeks of the earthquake.

There were no working wastewater treatment plants in Haiti. In the metropolitan areas, wastewater was discharged in open drainage channels and directed to Port-au-Prince Bay. Many of the drainage channels were blocked by debris and trash.

(a)

(b)

Figure 7. Damage to two structures across the street from one another in Port-au-Prince: (a) Reinforced concrete frame with masonry infill, and (b) new Digicel building under construction appears to be nearly undamaged.

(a) (b)

Figure 8. Light buildings that were damaged but did not collapse: (a) Wood-frame building, and (b) church with masonry walls and light-metal roof.

Figure 9. Damage to shear key at intermediate support.

TELECOMMUNICATION SYSTEMS

The telecommunication system in Haiti is comprised of a single wireline carrier (Teleco), and three wireless mobile vendors (Edwards 2010). Teleco is a wireless-based utility providing service through a network similar to those operators throughout the United States. The earthquake caused the collapse of the Teleco building in Port-au-Prince. At several locations throughout the Port-au-Prince metropolitan region, the placement of COWS (Cells on Wheels or Mobile Cellular System and Telescoping Antenna Array) outside of several telephone central offices was a temporary solution to enable inter-exchange traffic.

Digicel, one of Haiti's largest wireless cellular providers, had significant damage due to the collapse of buildings onto antennas. According to Digicel officials, it was estimated that 20% of the company's network was damaged beyond repair and unable to return to service. By 27 January 2010, the company had restored 92% of radio frequency capability with the regulator's grant of additional spectrum for a period of 12 months.

SOCIOECONOMIC IMPACT

Researchers distinguish between emergencies, disasters, and catastrophes (Comerio 1998, Teirney 2008), and by all measures, the earthquake in Haiti can certainly be classified as a major catastrophe—perhaps the worst in modern history. Not only were the physical and social impacts extremely large relative to the population of the affected areas, but also relative to the country as a whole. Given the extent of the damage, the government was paralyzed and an international response faced massive challenges—with limited access to the damaged port and airport, and uncertainty over who could or should take charge. The United Nations (UN), which had a peacekeeping mission in Haiti prior to the earthquake, lost a significant number of their own staff, as did the numerous International Non-Government Organizations (INGOs) that provided a wide variety of health care, housing assistance, training, and other social services. With every segment of civil society impacted—the government, schools, universities, businesses, health clinics, orphanages, INGOs, and churches—it was often difficult to understand who could provide relief and assistance to the earthquake victims.

The U.S. Armed Forces initially took over airport operations. UN and World Bank representatives, in partnership with Haitian officials, became key leaders in managing relief services, damage data collection, and shelter planning. Meetings of various groups were coordinated daily at the Hotel Caribe (where the lobby and meeting rooms were undamaged) and at the UN peacekeeping base near the airport. The initial weeks were driven by the dual purposes of providing food and shelter to victims on one hand, and collecting sound data for recovery planning on the other. At that time, it was already clear that the government of Haiti would not fully be in charge of the recovery, in part because the international organizations would control the funding and in part because the already weak Haitian government was weakened further by the disaster, leaving a leadership vacuum. Of the US$1.8 billion in earthquake relief that has been sent to Haiti (as of July 2010), less than 2.9% has gone directly to the Haitian government (Farmer 2010).

Tents and tarps were provided by a variety of international groups, but many Haitians formed informal tent camps with materials salvaged from the rubble, as shown in Figure 10. Of the 1.3 million homeless, UN Habitat and USAID estimated that over 500,000 left Port-

(a) (b)

Figure 10. (a) Salvaging materials from damaged buildings, and (b) tent camps created by earthquake victims.

au-Prince for outlying provinces: 163,000 to Artibonite, 91,000 to Centre, 120,000 to Grand Anse, and the remainder to the other six provinces (USAID 2010, see Figure 11). Haitian architect and planner Leslie Voltaire was involved in planning operations that argued for aid supply to the outlying provinces so that the displaced could stay in and be supported by those regions, thus limiting the need within Port-au-Prince.

An early return and resettlement plan by UN Habitat assumed that approximately 240,000 households needed resettlement and that ideally, it was best if people could return to a safe house in their community of origin, and only be settled elsewhere if that return was not possible. Transitional camps with temporary shelters were used for those with no other options (see Table 3) (UN Habitat 2010).

Almost one year after the disaster, this plan has been difficult to implement for a variety of complicated reasons. People remain fearful of returning to existing buildings and prefer to sleep in the tents. Although it has been documented that families do return to their homes in the daytime, they generally do not stay there overnight. The camps continue to be a source of free food, clean water, and sanitation facilities. In a testimony to the U.S. Congressional Black Caucus on 27 July 2010, Dr. Paul Farmer noted that diarrheal diseases dropped 12% after the earthquake because disaster aid agencies provided clean bottled water to the displaced population. He went on to acknowledge that while a burst of attention can make some improvements, the overall lack of food security, sanitation, clean water sources, jobs, education, health care, and other basic services are all critical issues which highlight the need for a functioning government public sector, not simply short-term aid from INGOs (Farmer 2010).

Nearly one year after the earthquake, there are hopeful signs that coordination is taking place between the Haitian government, INGOs, and religious organizations, and progress is being made on a number of fronts. The UN has been testing the concept of a humanitarian coordination hub. The leaders from all of the UN cluster groups convene to coordinate their own activities as well as those of the more than 10,000 NGOs that are working in Haiti. USAID has contributed one of its officers to assist with information sharing, which means that most of the major funders are well-represented in the coordination efforts.

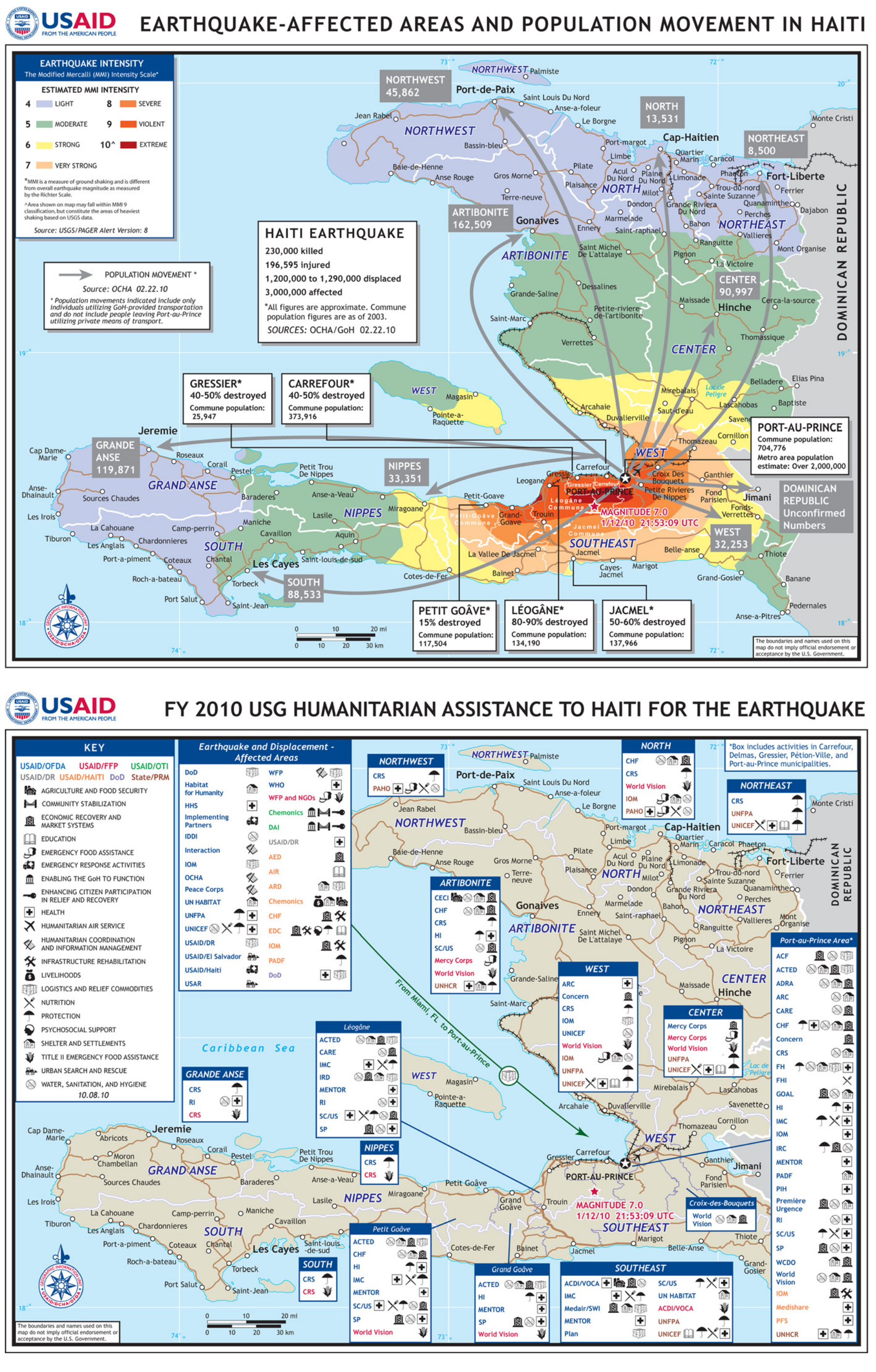

Figure 11. Earthquake-affected areas and population movement in Haiti following 12 January 2010 earthquake.

Table 3. UN Habitat estimates of sheltering options

Shelter Options	Percent	No. Households
Return to Safe House	40%	96,000
Return to Safe Plot + Temp Shelter	20%	48,000
Resettlement in proximity: Lot + T. Shelter	20%	48,000
Resettlement in new neighborhoods + T. Shelter	10%	24,000
Host Family support	10%	24,000

Some 220,000 temporary shelters are expected to be completed by August 2011, up from the original estimate of 125,000. This increase may be partially due to the ever-increasing number of people returning from the countryside. It is estimated that 40% of those who left Port-au-Prince after the earthquake have returned (as of October 2010). Two critical issues affect all the shelter efforts: rubble removal and land tenure. A year after the earthquake, piles of rubble still block Port-au-Prince's traffic-choked streets. Clearing the debris is crucial for rebuilding, but rubble removal is not a priority for donors, so funds are not readily available for this primary task. Less than 5% of the rubble has been removed, and the disposal of the estimated 20 million cubic meters of rubble lacks a dumpsite and the equipment to move it. It seems that the UN could "tax" donors on new construction projects in order to allow this critical task to be completed.

The longstanding problem of ill-defined property ownership and the population influx to Port-au-Prince in recent years created squatter settlements in slum areas before the earthquake. It is estimated that 60%–70% of the earthquake-displaced people were squatters and most have no funds for rent and thus will live in the camp settlements indefinitely. Less than 5% of Haiti's land is officially registered in public land records; and there is no proper land registry system. A recent UN Habitat report noted that because of an informal land tenure system (with many titles being passed through oral tradition), large numbers of now-deceased landowners, contradictory laws, and weak institutions for enforcement, there is a profound lack of land tenure security, which will significantly impede rebuilding. The state of insecure property and land rights is also stifling local enterprise. Many Haitian business leaders are struggling to obtain bank loans because they are unable to prove that they own land. It is also causing potential foreign investors to be wary (D'Amico 2010).

CONCLUSIONS

The M_w 7.0 earthquake that struck the Republic of Haiti on 12 January 2010 was among the most devastating events in recent history. The death toll is estimated at 300,000; 1.3 million people remain homeless 10 months following the earthquake; and the estimated losses of US$7 to US$14 billion exceed the gross domestic product of the country. Many factors contributed to the scale of the catastrophe. Pre-earthquake socioeconomic conditions—Haiti lacks effective government and institutions and is the poorest country in the Western Hemisphere—increased vulnerability. The absence of significant seismic activity in Haiti since the 18th and 19th centuries contributed to a lack of earthquake awareness and preparedness. The proximity of the epicenter to the capital city of Port-au-Prince exposed a dense urban area to intense ground shaking. Geological and geotechnical conditions in the epicentral area include artificial fills, soft alluvial soils, and topographic features that caused ground-motion amplification and liquefaction-induced ground failures. The lack of an effective building code, inadequate seismic proportioning and detailing, inferior construction materials, and the lack of quality control all contributed to the poor performance of structures in the earthquake-affected area. Typical reinforced concrete frame buildings with concrete block infill had numerous vulnerabilities known to cause seismic damage, including slender columns and inadequate transverse reinforcement.

The earthquake demonstrated not only the weakness of Haiti's physical infrastructure and environmental degradation, but also the more fundamental weakness of its institutions and government. This disaster, perhaps more than any other in recent history, illustrates the role of socio-vulnerability in a natural disaster. With every segment of civil society impacted—government, schools, universities, businesses, health clinics, orphanages, non-governmental organizations (NGOs), and churches—it was often difficult to understand who could provide relief and assistance to the earthquake victims. One year after the earthquake, however, there are hopeful signs of coordination between the Haitian government, NGOs, and religious organizations and progress is being made. Haiti's long-term recovery depends on providing food security, sanitation, clean water, jobs, education, property and land rights, health care, and other basic services that require a functioning government public sector, not simply short-term aid from NGOs. Building capacity at all levels—technical, institutional, and governmental—will be required to put Haiti on a new path of economic growth and social justice.

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