DAMAGE AND IMPACTS FROM THE 2018 M5.9 PORT-DE-PAIX, HAITI EARTHQUAKE

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Abstract

On October 6, 2018 at 8:11 pm local time, a M5.9 earthquake struck offshore, approximately 20 km north-northwest of Port-de-Paix, Haiti [1]. The shaking was felt throughout much of the country, including in Port-au-Prince. According to figures provided by the Direction de Protection Civil (DPC – Directorate of Civil Protection), 18 people were killed and 548 were injured. 2102 houses were destroyed, and a further 15,932 were damaged [2]. This earthquake is the most significant to strike Haiti since the 2010 earthquake, and is the largest earthquake in northwest Haiti since 1887 [3].

Despite its moderate magnitude, the earthquake caused significant damage to schools (79 damaged), hospitals, police stations, other government buildings, and homes. Most damage occurred to stone masonry, weak concrete frame, or concrete block buildings. The affected area has numerous older institutional buildings constructed of stone masonry. Some vernacular colombage buildings were damaged, but the damage primarily consisted of shedding exterior masonry and did not typically affect structural stability. Damage was concentrated in Port-de-Paix, Saint-Louis-du-Nord, Gros Morne, Pilate, and Bassin-Bleu. The level of damage in Gros Morne and Pilate, which were over 50 km away from the epicenter, was unexpected. Though no strong motion instruments were present in the epicentral region at the time of the mainshock to provide data, the highly uneven geographic distribution of damage to similarly vulnerable building types indicates that the strength of shaking varied widely. Based on mapped surficial geology, site effects are thought to have played a role. The level of damage from this moderate earthquake provides a clear warning that many buildings in northern Haiti lack earthquake resistance, and are very vulnerable to damage in future, larger earthquakes such as the one scientists expect will occur on the Septentrional fault located just offshore of much of northern Haiti.

Keywords: structural damage; site effects; masonry; concrete

1. Introduction

A M5.9 earthquake struck offshore of Haiti's northwest coast, approximately 20 km north-northwest of Port-de-Paix on October 6, 2018 at 8:11 pm local time [1]. Figure 1 shows the location of the affected area, the epicenter, and areas of notable damage. This earthquake is the most significant to strike Haiti since the devastating January 12, 2010 M7 earthquake, and is the largest earthquake in northwest Haiti since 1887 [3]. Along with the rest of Hispaniola, northern Haiti has experienced a number of damaging earthquakes in over 500 years of recorded history. The largest of these was the 1842 earthquake and ensuing tsunami that killed half of Cap Haitien's population at the time and caused damage in Port-de-Paix and other locations in along the northern coast [4]. The most recent deadly earthquake in the area, prior to the 2018 event, was a 1994 M5.4 earthquake that collapsed houses and killed four people in Saint-Louis-du-Nord, near Port-de-Paix [5].

Northern Haiti continues to face a high level of seismic hazard, primarily from the western portion of the Septentrional Fault Zone [6], a major left-lateral strike-slip fault zone offshore that approximately parallels Haiti's northern coast between Port-de-Paix and Fort Liberte, and then comes onshore in the Dominican Republic and continues through the Cibão Valley. The Septentrional Fault Zone accommodates part of the displacement of the North America-Caribbean plate boundary, with a slip rate of 10 mm/year [7]. Significant earthquakes have been attributed to this fault by several authors (e.g., [8], [9], [10] and [11]) and it is the most studied fault system within Hispaniola. Further offshore, the North Hispaniola Fault is a continuation of the Puerto Rico trench subduction zone [6]. Northern Hispaniola also has other less-studied, smaller crustal faults. While the studies on the complex tectonics of the region are limited, its unique geology is a concern when assessing the seismic risk of northwestern Haiti.

Figure 1 – Affected area, with locations of more significant building damage, including Port-de-Paix, Saint-Louis-du-Nord, Bassin-Bleu, Gros Morne, Pilate, and Plaisance. Damage in Bassin-Bleu was in rural areas off the road system. Red star indicates the epicenter of the 2018 M5.9 Port-de-Paix earthquake. Image source Google Earth; satellite imagery Landsat/Copernicus; Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Inset map: ESRI.

2. Event Description

The M5.9 Port-de-Paix earthquake occurred on Saturday October 6, at 8:11:50 pm local time (October 7, 00:11:50 UTC). The epicenter was reported by Haiti's Bureau des Mines et de l'énergie (BME – Bureau of Mines and Energy) as 20.013°N, 73.006°W, with a depth of 15.3 km [1]. The epicenter was offshore of the northern Haiti coast, in the channel between Hispaniola and the Île de la Tortue (Tortuga Island), approximately 20.5 km from Port-de-Paix, and 31.5 km from Saint-Louis-du-Nord. Moment tensors from USGS [12] show dip slip with nodal planes oriented 135° N with a fairly flat dip (<20°), and nearly vertical dip with strike subparallel to the Septentrional Fault Zone. It is not yet clear whether a secondary fault associated with the Septentrional Fault produced this earthquake.

Shaking from the October 6, 2018 event was felt throughout much of the country, including in Port-au-Prince. According to figures provided by the Direction de Protection Civil (DPC – Directorate of Civil Protection), 18 people were killed and 548 were injured. 2102 houses were destroyed, and a further 15,932 were damaged [2]. Damage occurred in several locations to the south that are 50 km or more from the epicenter, while closer areas with similarly vulnerable buildings experienced far less damage. Gros Morne and Pilate, shown in Figure 1 and which are both over 50 km away, experienced significant damage to local buildings including collapse of a school in Gros Morne. It appears likely that site amplification played a significant role in this damage pattern as discussed in the next section, though there were no strong motion instruments in these areas to measure shaking.

3. Geotechnical Effects

Port-de-Paix is characterized by its predominant geologic formation, La Crête, which consists mainly of clay and silt turbidites, locally identified at the edge of the rivers. Closer to the hills, the soft turbidites erode easily, and result in friable clay soil that is locally very clayey. During heavy rainfall these soils can be unstable, causing landslides. The second most important formation in the area is the Villa Trina formation, mainly composed of yellowish friable marls and overlaid by the La Isabella formation, slightly weathered coralline limestone. In the northern part of the commune, these formations are covered by alluvial fans (Qa). The geology of Saint-Louis du Nord is similar to Port-de-Paix, also characterized by clay and silt turbidites from the La Crête formation.

Geologic conditions can affect ground response, causing variations in the level of amplification that can directly increase structural and non-structural damage. Though the authors did not carry out geotechnical borings or geophysical studies following the earthquake, increased building damage was observed in Chemin Desgranges, Deux Mélisses and Charlesmagne Péralte Street which are characterized by the La Crête formation, thick layers of clay and silt where site amplification is expected [13]. Also, damage was observed in La Coupe Street, located on the alluvial plains consisting of interbedded layers of silts and sands. Significant structural damage was observed in Gros Morne, 55 km from the epicenter, located in a sedimentary basin, as well as in Pilate. This reported damage provides a rough estimation of the soil behavior in the affected region. Available Vs30 maps developed for the area [14], agree with the geology described for the cities of Port-de-Paix and Saint-Louis-du-Nord, with Vs30 ranging from 300 m/s in areas of Qa consisting of alluvium and sedimentary deposits to stiffer areas with Vs30 of 600 m/s corresponding to limestone formations. In addition, according to Frankel et al. [6], the peak ground acceleration expected in the Port-de-Paix area with a probability of exceedance of 10% in 50 years is 0.3 to 0.4 g. Based on the geologic and geotechnical characteristics of the cities where damage was reported, site amplification is expected for these types of soils.

At least one landslide in the La Crête Formation in Port-de-Paix and one in Pilate were reported, shown in Figure 2. It is unknown if these landslides were caused by the earthquake alone; slopes may have been saturated by rain from Tropical Storm Isaac, which hit the northwest coast of Haiti in September 2018, causing floods in the area until the end of the month. This multi-hazard environment may have been responsible for triggering these landslides.

Figure 2 – Landslides in La Crete formation (left); and Pilate (right). Photos: BME (left) and DPC (right).

4. Building Damage

Structural damage to buildings and damage to stiff architectural elements were the primary types of damage observed in this earthquake.

4.1 Masonry

4.1.1 Unreinforced Masonry

The affected areas have three main types of unreinforced masonry buildings: (a) older stone and brick masonry buildings, colonial-style architecture and some perhaps dating from the colonial era; (b) stone, brick or concrete block masonry government and institutional buildings including schools and hospitals; and (c) concrete block private residences.

Cities in the affected areas have a modest number of historic stone and brick masonry bearing wall buildings with timber floors and roof framing. Many of these buildings are more than a hundred years old, and a number in the downtown area of Port-de-Paix have colonial-style architecture. Because this area was affected by the 1842 earthquake, many colonial-era or colonial-style stone and brick masonry buildings in Port-de-Paix at that time would have been damaged or destroyed, and subsequently rebuilt or repaired. In many of these Port-de-Paix buildings, the walls in both stories are tied together with wrought iron horizontal tie rods (“chains”) that pass through the exterior walls and are fixed with wrought iron end plates. Relatively few colonial-style buildings, even those with additions, suffered significant damage in Port-de-Paix, though damage in Port-de-Paix appeared lighter, as a proportion of total buildings, than in Gros Morne or Saint-Louis-du-Nord.

The area also has a number of newer stone masonry buildings; institutional buildings such as police commissariats continued to be built in stone masonry in the affected areas into the 1970s. As expected, two-story stone masonry buildings suffered more damage than their single-story counterparts. Damage consisted of pier cracking, corner cracking, and delamination of the inner and outer wythes. Because the shaking is thought to have been light to moderate in most areas, relatively few collapses occurred despite significant damage to these buildings. Please see later sections on hospitals, schools and government buildings for further discussion.

As in much of the rest of the country, the typical vernacular building material in the affected area is now concrete block. Weak, poorly manufactured concrete blocks are common in the affected areas. The team observed weak blocks continuing to be made in Port-de-Paix during their visit. However, many concrete block residences have some concrete columns, and could be considered semi-confined masonry; damage to these buildings is discussed in the next section. Few buildings were observed to be entirely unreinforced concrete block without some concrete frame members.

4.1.2 Semi-confined and Confined Masonry

In northern Haiti, truly confined masonry with all recommended elements is rare. Reconstruction programs following the 2010 earthquake, which trained builders and promoted its use, were necessarily confined to earthquake-affected areas near Port-au-Prince. Construction practices in the north vary widely, from buildings with many recommended features to those that are only "wall first" but nearly unreinforced [15]. Many of the vulnerabilities of semi-confined masonry buildings observed following the 2010 earthquake such as weak and poorly cured blocks, and limited toothing/staggering of block adjacent to columns are present in buildings in the north as well. These buildings suffered a variety of damage, and as expected, two story buildings had more damage than single-story buildings. Shear cracking in ground story confined masonry panels in two story buildings was the most common type of observed damage. This type of damage was especially prevalent in Saint-Louis-du-Nord, shown in Figure 3, and Gros Morne, with some examples in Port-de-Paix. Some buildings with severe ground story cracking had been vertically shored and remained occupied, though they were not also laterally braced, pointing to the need for education on safer shoring.

Figure 3 – Damaged concrete block residence in Saint-Louis-du-Nord (left) with some small tie columns (white circle) only in certain locations and not around all openings (right). Photos: Janise Rodgers, GHI.

4.2 Reinforced Concrete

As discussed above, few buildings in the area have true reinforced concrete lateral force-resisting systems. Many buildings with some concrete members, especially residential buildings, function more like wall buildings of semi-confined or confined masonry. Exceptions are recently built government buildings, such as the Port-de-Paix municipal administration building, which is less than 10 years old. This building had minor infill wall cracking in the ground story and was open at the time of the team's visit. It is located next to several more vulnerable buildings that were red-tagged by MPTPC. Please see the subsequent government buildings section for further discussion.

4.3 Vernacular Colombage

In many rural parts of Haiti, as well as in towns and to some extent in cities such as Port-de-Paix, many people still live in traditional vernacular houses of a construction type called *colombage*. These houses typically have a timber post-and-beam structural system with timber sheathing on the inside of the exterior walls, and rubble stone masonry infill covered by plaster on the exterior. Due to the small size of the timber used, these walls are thin—typically 100 mm (4 inches) or less—and as a result the stone infill has a single wythe of mostly small, often rounded stones with significant amounts of mortar between. Traditionally, the mortar was mud, though some buildings may have lime or cement mortar. Infill with cement mortar is much stiffer and may dissipate less energy [16]. The stone infill panels are quite weak and fail easily. The timber sheathing on the inside of the wall prevents the stone infill from falling inside the building during an earthquake, and provides lateral resistance. Not all buildings have complete timber sheathing, and in some cases it appears to have been removed over time. Where present, the wall sheathing is often 4-6 inch wide sawn lumber, but in other cases may consist of any available pieces of wood. Interior partitions can be either timber or stone infill that typically does not have timber on one side. The latter are similar in dimension to the exterior stone masonry panels, or event thinner, which makes them quite vulnerable to the stone falling out of the panel frame during shaking. As expected, buildings with interior timber sheathing performed better in this earthquake than buildings without. Buildings with condition problems still appeared to perform reasonably well.

4.4 Timber and Steel Buildings

The team also observed a modest number of entirely timber buildings in Port-de-Paix. These appeared undamaged. As discussed in earlier sections, in some cases the second story of a building will be timber, constructed atop a masonry ground story. Very few steel framed buildings exist in the affected areas. The hospital in Saint-Louis-du-Nord, a prefabricated steel building that was structurally undamaged, was one of the few observed.

4.5 Hospitals

In Port-de-Paix, the main hospital's buildings suffered varying degrees of damage. The surgery building in Figure 4 suffered wall damage at both ends and was red-tagged by MPTPC. Several other buildings had lesser damage and were yellow-tagged. Patients from the surgery building and the internal medicine department were evacuated at the time of the visit, and being treated in a tent in the hospital courtyard. The internal medicine department was in a yellow tagged building, and patients were fearful of remaining inside due to aftershocks.

Figure 4 – Damage to surgery building in Port-de-Paix (left) and pediatrics building in Gros Morne (right). Photos: Janise Rodgers, GHI.

The Gros Morne hospital contains a number of buildings of varying ages and construction types. The apparent oldest, a stone masonry building built in perhaps the 1960s, suffered severe damage and was cordoned off with caution tape, as Figure 4 shows. It had not been officially red-tagged, but the building was not in use. The hospital has a range of single story buildings of varying ages and construction types ranging from stone masonry with some concrete members, to concrete block, to confined masonry. Many of these buildings had cracks in their masonry gables, often across the base, but the gables had not fallen. Some buildings also had minor cracking elsewhere. A new two-story reinforced concrete building, still under construction but structurally complete, was undamaged. Per the hospital staff, nonstructural damage appeared to be limited to finishes damage. Contents damage was limited: oxygen cylinders fell down, and hospital staff did not report other contents damage. The hospital did not lose power or water. The hospital did run short of supplies, because they had not been resupplied as usual the week before the earthquake.

4.6 Schools

According to the Ministry of National Education and Vocational Training (MENFP) [17], a total of 79 schools were affected by the earthquake: in Nord-Ouest (Northwest) Department, 26 government and 29 private schools; in Nord (North) Department, 7 government and 3 private schools; and in Artibonite Department, 3 government and 11 private schools. Of these, several were severely damaged, and one school building in Gros Morne collapsed in an aftershock. The level of school damage in this moderately sized event raises significant concerns about the earthquake vulnerabilities of both government and private schools in Haiti.

In Port-de-Paix, we observed significant damage at two private schools, and moderate damage to the government high school. In Pilate, the DPC team observed significant damage at schools. Rubble stone masonry piers in both a two story building and a single story building experienced severe cracking, and some walls experienced partial collapse. At the private Ecole Evangel Emmanuel, a concrete block demising wall between classrooms partially collapsed, and other walls were severely cracked. Figure 5 shows typical damage to both schools. In Saint-Louis-du-Nord, the GHI team visited the high school. The older building had suffered some modest cracking in few walls, in a newer part of the building. Other buildings appeared undamaged.

Figure 5 – Collapsed exterior stone masonry school wall in Pilate (left); damaged interior walls at Ecole Evangel Emmanuel in Pilate (right). Photos: Jean-Henri Petit, DPC.

In Gros Morne, the government high school, Lycee Jacques Roumain, had some wall cracking, particularly in the block masonry piers between windows, but remained in operation. No damage to the reinforced concrete frame was observed. The nearby government primary school appeared undamaged and was also in use. Two private schools in Gros Morne operated by the Catholic Church, the Ecole Sant Gabriel, and the Ecole Notre Dame de Sacre Coeur had older masonry buildings that suffered severe damage and were red-tagged by MPTPC, including a two-story stone masonry building at Ecole Saint Gabriel constructed in 1888 that experienced significant wall cracking. Also at Ecole Saint Gabriel, a newer two-story block masonry 10-classroom building, which normally contains 320 pupils, was severely damaged in the mainshock and was leaning afterward, according to local residents. It collapsed in the aftershock the next day, Sunday. A smaller concrete block building with a concrete roof had wall cracking and was yellow-tagged by MPTPC. Other small, newer buildings at the site appeared undamaged.

4.7 Government Buildings

The GHI team visited the police stations in Port-de-Paix and Gros Morne, both of which had buildings that suffered significant damage and were red-tagged by MPTPC. The Port-de-Paix Police Commissariat is a two-story stone masonry building built in 1976, with reinforced concrete floors and *galeries* (exterior corridors). Walls throughout the building suffered shear cracking. The second story was especially badly damaged, with piers severely cracked and in some cases having the two stone wythes partially delaminated. One corner of a second-story room partially collapsed. An adjoining two-story concrete frame and block prison building constructed in 2004 experienced wall cracking in the ground story, and was yellow-tagged by MPTPC. A nearby courthouse and municipal administration building appeared undamaged. A fairly recently built semi-confined masonry education office also nearby was badly damaged and red-tagged. In Gros Morne, the single story stone masonry police station suffered significant shear cracking, and was red-tagged by MPTPC. A new building constructed in the 2000s was undamaged, as was the recently built court building several blocks away.

Figure 6 – Second-story stone masonry pier with shear cracking and partial delamination of the inner and outer wythes, Police Commissariat, Port-de-Paix (left); Severely damaged semi-confined masonry education office, Port-de-Paix (right). Photos: Janise Rodgers, GHI.

4.8 Damage to Architectural Elements, Other Nonstructural Components, and Contents

Most observed nonstructural damage was to architectural elements, with some instances of contents damage. Numerous architectural elements constructed of unreinforced masonry, including parapets, gables, cupolas, bell towers, and interior partitions suffered damage. A number of churches, including the cathedrals in Plaisance and Gros Morne, suffered façade damage. In the otherwise undamaged hospital in Saint Louis, some contents fell from shelving.

5. Lifelines and Transportation

5.1 Utilities

In Port-de-Paix, there were no reported failures of water or electricity due to the earthquake. Reports indicate that the water system in Pilate was damaged in the earthquake, reducing water availability by about 20% (UNICEF, 2018). In Saint-Louis-du-Nord, water is supplied by individual wells rather than a municipal system. A municipal electricity system is under construction, and there was no reported damage.

5.2 Roads and Bridges

Roads in the affected area are typically unpaved, and did not appear to have been damaged by the earthquake. Bridges along the routes traveled were open and undamaged. Along the highway from Gonaives to Port-de-Paix, there are several multispan simply supported bridges of different types, including prestressed concrete girder and steel plate girder bridges. In addition, there were a number of single-span simply supported prestressed concrete girder bridges. All bridges appeared to have been recently built, were in good condition, and most appeared to have some seismic design, with elements such as shear keys present. All were undamaged.

6. Key Findings and Recommendations

Key findings from this earthquake, and resulting recommendations, include the following:

- Significant damage was concentrated in certain areas rather than being widespread near the causative fault. Heavy structural damage, including collapses, also occurred at a sizeable distance (more than 50 km) from the epicenter, for reasons that are not yet apparent. Seismic instrumentation and further studies are needed in order to understand the reasons and to indicate whether the same patterns are likely to repeat for larger earthquake on the Septentrional Fault.
- Older schools and some newer, vulnerable schools suffered heavy to severe damage, and a school building collapsed in an aftershock. Had the earthquake been stronger, and occurred during school hours, many young lives could have been lost. This earthquake was a close call, and a reminder that retrofitting or replacing seismically vulnerable schools with earthquake-resistant schools is an urgent need.
- Older hospital buildings and police stations suffered heavy damage. In a stronger earthquake, damage to or collapse of these essential facilities could severely impede the response. Older buildings throughout the country, particularly unreinforced masonry buildings, should be replaced over time with new ones that will provide the desired level of earthquake performance and meet modern functionality needs. Many buildings are over 40 years old, and medical care in particular has advanced substantially since they were built.
- Vernacular concrete block housing and some vernacular semi-confined masonry housing suffered significant damage. Large numbers of these popular house types exist across Haiti's areas of highest seismic hazard, presenting a serious threat to residents' lives in a future large earthquake. In contrast, vernacular colombage housing with interior timber wall sheathing performed significantly better, and did not typically suffer life-threatening damage. Vernacular timber and masonry houses with only timber vertical posts and unreinforced masonry walls suffered significantly more damage than houses with interior timber sheathing. Programs to provide builders with training and owner-builders with education on the need for earthquake- and hurricane-resistant construction are necessary to reduce the number of seismically vulnerable buildings.

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8. Disclaimer

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