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Leading Causes of the 2010 Destructive Earthquake in Haiti

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Abstract

On Tuesday afternoon, 12 January 2010 at 16:53 local time, Haiti faced the most disastrous earthquake in its history since the 1842 Cap-Haïtien (north coast of Haiti) Earthquake. Occurred with a moment magnitude (M_w) of 7.0, the 2010 Haiti earthquake devastated Port-au-Prince, Léogâne, and Jacmel. Despite some progress in rebuilding infrastructure, the high cost of living due, in particular, to political instability and unemployment forces people to rebuild in worse condition than before the 2010 earthquake. Based on an independent investigation and experience of the country's reality in the domain of construction, this paper highlights the main causes of the 2010 Haiti earthquake to alert the need for better rebuilding the country. Therefore, some suggestions are given to boost the construction practice in Haiti to circumvent the loss of life and property in future catastrophic events notably earthquakes.

***Keywords*:** country's reality; earthquake; Haiti; loss of life and property; main causes; pounding; slums.

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1. Introduction

The 2010 Haiti earthquake was the most injurious that ever happened in Haiti since the 1842 Cap-Haïtien earthquake. It occurred on Tuesday afternoon, 12 January 2010 at 16:53 local time with a moment magnitude (M_w) of 7.0 and a focal depth of 13 km (8.1 miles). The epicenter (18°27′25″N 72°31′59″W) of the earthquake was roughly 25 kilometers west of Port-au-Prince [1]. The recorded peak ground acceleration (PGA) of the earthquake and the Modified Mercalli Intensity (MMI) were respectively 0.5g and X [1]. The earthquake was felt across the Republic of Haiti and nearby countries such as Dominican Republic, Cuba, Jamaica, Venezuela and Puerto Rico. Particular cities affected by the quake included Port-au-Prince, Léogâne, and Jacmel. Government officials reported that 316,000 people killed, 300,000 injured, 1.3 million displaced, 97,294 houses totally destroyed and 183, 383 severely damaged [2]. Nevertheless, there is little evidence to support that the estimate was correct.

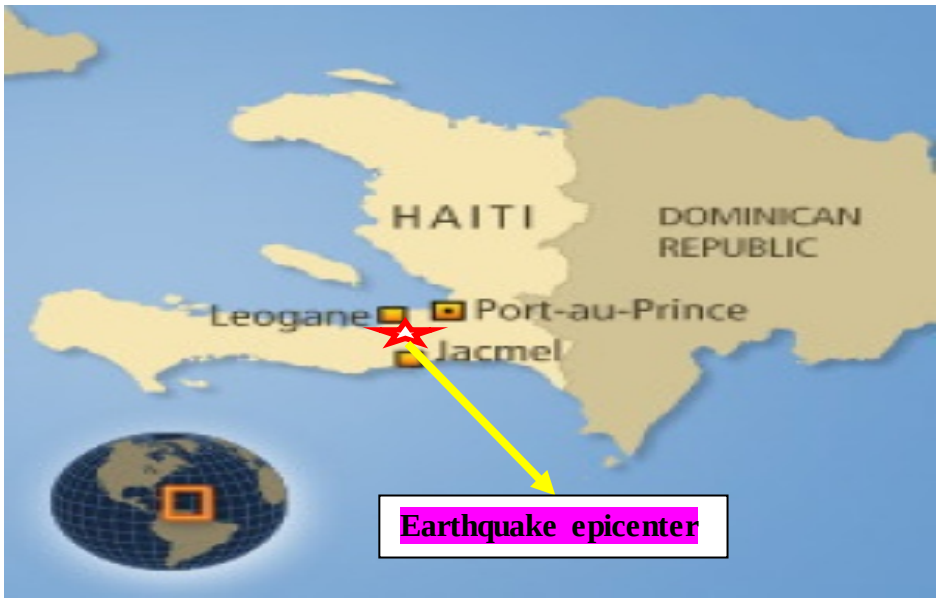

Figure 1: epicenter and the cities most affected by the 12 January 2010 Haiti Earthquake

Many papers about the 12 January 2010 Haiti earthquake are mostly written by foreign experts, media, and organizations. Only a few papers have been presented by national experts who have a better understanding of the construction practice in Haiti including in particular the Technical Unit of Seismology (TUS) which was created one year after the earthquake [3]. It may be true that there is no official evidence to support that in-depth investigations were carried out by the Haitian government to evaluate the level and nature of destruction caused by the 12 January 2010 Haiti earthquake. Essential infrastructures including hospitals, communication systems, and air, sea, and land transport facilities, necessary to respond to the catastrophe were severely damaged or destroyed. To achieve the goal of making Haiti an emerging country by 2030 [4], it is imperative to build new infrastructures such as schools, hospitals, roads, bridges, and airports to mention a few. These structures have to be designed to remain safe, stable and secure throughout their use. This paper, based on independent reconnaissance survey and experience of Haiti's reality in the construction field, presents the major causes of the 2010 disastrous earthquake in Haiti. Some recommendations are also provided to tackle the problems so that, in

future earthquakes in Haiti, the built environment can be controlled in order to minimize the seismic risks to socio-economically acceptable levels.

2. Haiti and previous earthquakes

Located on the west of Hispaniola with an estimated population of 10.6 million people, Haiti is the second biggest island in the Greater Antilles and the third largest Caribbean country after Cuba and Dominican Republic.

Haiti lies on fault planes able to end before they arrive at the Earth's surface known as blind thrust faults. There are two major problems associated with the thrust blind faults: they are neither easy to discern until they rupture nor to appreciate in mapping due respectively to the insufficiency of surface evidence and their low dip. They are related to the Enriquillo-Plantain Garden Fault system (EPGFZ or EPGZ). According to a published paper entitled "Complex rupture during the 12 January 2010 Haiti earthquake"; seismological, geological and ground deformation data revealed no evidence of surface rupture after the 2010 earthquake in Haiti [5]. In figure 2, the topography along the Enriquillo-Plantain Garden Fault is shown.

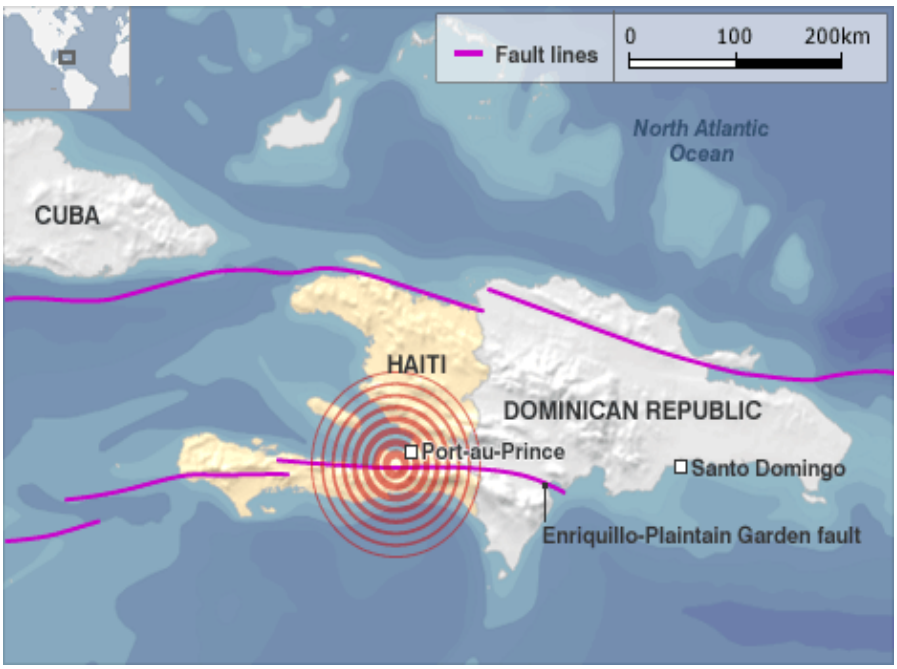

Figure 2: Enriquillo-Plantain Garden Fault, Haiti [6]

The northern part of Haiti, Cap-Haïtien, has in the past experienced a devastating earthquake known as the 1842 Cap-Haitian earthquake. With epicenter 19°45′N 72°12′W, it occurred on 7 May 1842 at 17:00 local time with an estimated magnitude, on the surface wave magnitude (M_s) scale, of 8.1 and provoked a cataclysmic tsunami [7]. In addition to Cap-Haitian, Port-de-Paix and Dominican Republic have been affected but Port-de-Paix city was the most damaged. The casualties have been estimated to 5,300 including 5,000 killed by the earthquake and the remaining by the tsunami. One of the landmark buildings that has gravely damaged was the Henri Christophe's Sans Souci Palace and till now never rebuilt.

Figure 3: the ruins of the Sans-Souci Palace. Constructed from 1810 to 1813, the palace was known as the Versailles of the Caribbean

Two other major earthquakes occurred in Port-au-Prince on November 21, 1751 (epicenter: 18°30′N 72°18′W) and on June 3, 1770 (epicenter: 18°25′N 72°47′W) and had respectively a surface wave magnitude ($_{Ms}$) of 8.0 and a moment magnitude (M_w) of 7.5 [9]. No casualties have been reported for the 1751 earthquake but the 1770 earthquake killed more than 250 people and dropped down the local economy which, in turn, caused the death of 30,000 people [8].

Conclusion was drawn by Calais and Hayes (2010) that the 12 January 2010 earthquake has occurred on a highly dipping fault located just north of the main trace of the Enriquillo-Plantain Garden Fault [9]. Having a sharp inclination to the North, this fault has named the Léogâne fault. The following figure illustrates the seismicity of the Hispaniola region over a period of more than one century.

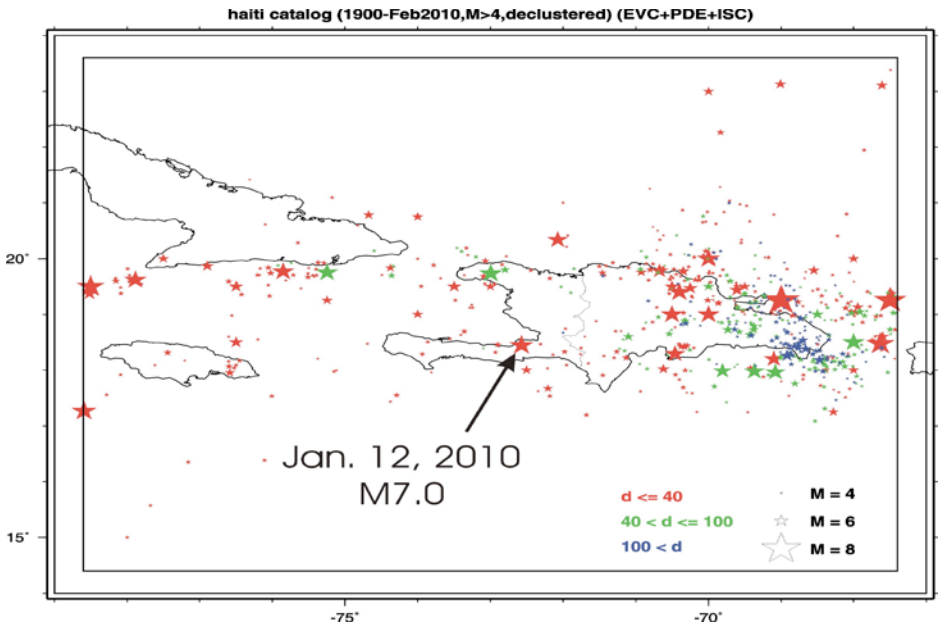

Figure 4: seismicity for the Hispaniola region from 1900 to 2010 [10]

3. Major causes of the 2010 Haiti earthquake

Haiti was not the only country where occurred earthquake in 2010 but the most affected among all the countries suffered from earthquake that year. Before relating the main causes of the 2010 Haiti earthquake, the following table presents the countries where earthquake happened in 2010 to better understand the reason why it was so destructive in Haiti.

Table 1: ranking by magnitude of all 2010 earthquakes of magnitude 7 or above [11]

Rank	Magnitude	Death toll	Location	Date
1	8.8	525	Maule region, Chile	February 27
2	7.8	0	Sumatra, Indonesia	April 6
3	7.7	711	Sumatra, Indonesia	October 25
4	7.6	0	Mindanao, Philippines	July 24
5	7.5	0	Nicobar Islands, India	June 13
5	7.5	0	Port Vila, Vanuatu	August 10
7	7.4	0	Mindanao, Philippines	July 24
7	7.4	0	Bonin Islands, Japan	December 21
9	7.3	0	New Britain , Papua New Guinea	July 18
9	7.3	0	Mindanao, Philippines	July 24
9	7.3	0	Coast of Vanuatu	December 25
12	7.2	4	Baja California, Mexico	April 4
12	7.2	0	Sumatra, Indonesia	May 9
12	7.2	0	Vanuatu	May 27
12	7.2	0	Papua (province), Indonesia	September 29
16	7.1	0	Solomon Islands	January 3
16	7.1	1	Pastaza Province, Ecuador	August 12
16	7.1	0	Canterbury, New Zealand	September 4
19	7.0	316,000	Léogâne, Haiti	January 12
19	7.0	0	Ryukyu Islands, Japan	February 26
19	7.0	17	Papua (province), Indonesia	June 16
19	7.0	0	New Britain , Papua New Guinea	August 4

From table 1, in terms of magnitude, it can be clearly seen that the strongest earthquake has occurred in Maule region, Chile whereas regions such as Léogâne (Haiti), Ryukyu Islands (Japan), Papua province (Indonesia) and New Britain (Papua New Guinea) have recorded the weakest earthquake with a moment magnitude of 7.0. However, considering the number of deaths, Haiti is largely ranked top one with an estimated figure of 316,000 people killed. This estimated figure represents more than 600 hundred times higher than the number of deaths in

Chile where the most intense earthquake has happened with a moment magnitude of 8.8. Moreover, no one has been killed by the 6 April 2010 Sumatra (Indonesia) earthquake which occurred with a moment magnitude of 7.8. It was the same case in many other countries such as India, Philippines, Papua New Guinea, and Indonesia etc…where have occurred earthquakes with stronger magnitudes than Haiti. **So, why the 2010 Haiti earthquake was so devastating**?

It may be true that identification of the unmapped Léogâne fault was the main cause of 12 January 2010 Haiti earthquake, however, the casualties arise mostly from structural collapses.The fundamental causes are the following: **lack of national experts**, **lack of coordination in government bureaucracy**, **urbanization**, **abundance of non-engineered buildings**, **inadequate engineered buildings**, **structural pounding,** and **absence of codes and standards**.

3.1. Lack of national experts

One of the major problems encountered by Haiti is a lack of national experts in several fields. This is the case in the domain of engineering for instance (Civil Engineering, Structural Engineering, Earthquake Engineering, and Geotechnical Engineering). The inefficiency of the education system in Haiti is a key factor leading to the lack of experts. There are only two public universities (the State University of Haiti: one in Port-au-Prince and one in Limonade) for the whole population and the number of students admitted per year per faculty is up to 150. There are a few private universities but they are too expensive for the majority of the family. The academic environment in Haiti is extremely poor with almost no facilities, no laboratories, poor library resources etc… In many remote zones in Haiti (most often populous), there is not even one Civil engineer. How can they build at least a low-cost engineered building? Moreover, the fact that most of the buildings destroyed by the 2010 earthquake are being rebuilt largely by foreign companies is a good example that Haiti suffers a lack of experts. Obviously, the majority of the 550,000 buildings destroyed or damaged were not designed to face the earthquake.

Figure 5: the Haitian Supreme Court destroyed by the quake and rebuilt by Overseas Engineering Construction Companies: a Taiwanese Company

3.2. Lack of coordination in government bureaucracy

There are absolutely no regulation controls in the construction of buildings in Haiti. Haitian people construct where and how they want. With the high levels of illiteracy, people from Haiti do not care about the construction materials, and they do not get any help from local authorities in selecting the construction materials. Government officials in Haiti are so irresponsible that they do not mind if people are constructing housing accessible only by foot even within the Haiti's capital, Port-au-Prince. There are local authorities in all the communal sections (remote zones also) of Haiti including ASEC and CASEC but the majority of them can only sign their names. They are not able to control the construction of buildings in their zones. No construction supervision is provided. Most important, there is no notice about the high risk areas, usually on slopes. Most of buildings totally destroyed in Port-au-Prince by the 2010 Haiti earthquake were built on slopes.

Figure 6: buildings built on slopes totally destroyed or damaged during the quake

3.3. Urbanization

Another factor that contributed to increasing the number of deaths during the earthquake was urbanization. In seeking a better life, a large proportion of the Haitian population moved from the countryside to urban areas particularly Port-au-Prince, which in turn creates slums. When the migrant workers are coming to Port-au-Prince, difficult to find a place to live in, reside in slums. This population density, living in informal housing, around the earthquake's epicenter, meant that several of the country's residents were directly exposed to the quake.

Figure 7: slums in Port-au-Prince with poor-quality construction affected by the quake

3.4. Abundance of non-engineered buildings

Arya (1994), defined "non-engineered buildings" as those that are unconsciously and commonly built in several countries in the long-established manner without any or little intervention by qualified architects and engineers in their design. Counted for 90% of the buildings built in Haiti [12], the non-engineering buildings are proportioned based on experience only with walls mostly made of concrete blocks, earth, stone and brick, clisse (thin pieces of wood used to make walls of several residential buildings in Haiti, especially in the countryside) as well as combinations of these locally available materials. Frequently built on unstable soil foundations, several of these buildings are found in slums in Cité Soleil, Bel Air, Grand Ravine, Martissant and also on mountainside in Pétion-Ville, Carrefour, and Carrefour Feuilles etc...

Consisted of two or three storeys, the highest percentage of non-engineering buildings found in urban areas are built with confined masonry walls and concrete slabs. Due to low seismic resistance, this type of construction caused the majority of deaths during the 2010 Haiti earthquake. The vital elements explaining the poor quality of non-engineering buildings in Haiti can be summarized as followed:

- Use of heavy hollow block slabs
- Inadequate detailed reinforcement in beams and columns
- Bad connections (beam-column joint, column base)
- Poor concrete quality

Figure 8: non-engineered concrete block walls buildings in Port-au-Prince destroyed by the quake

3.5. Inadequate engineered buildings

Only 10% of the buildings in Haiti are built by civil engineers [12]. A large portion of these buildings (mostly reinforced concrete structures) are public buildings (government buildings, churches, schools, hospitals…..), commercial buildings (warehouses, shopping malls….), private entreprise buildings (banks, hotels….) and

residential buildings (only a few).

Many facts reveal that most of the engineered buildings were not designed to resist lateral forces or loads due to earthquakes or wind but only vertical loads. The key explanation behind this is a lack of experts in earthquake engineering in Haiti. Frequent problems associated with engineered buildings in Haiti include:

- Irregularity in plan and elevation
- Inadequate foundation
- Weak/soft first storey
- Light reinforced concrete columns
- Flat slabs supported by columns and infill walls
- Poor quality of concrete, segregation in concrete
- Bad connections

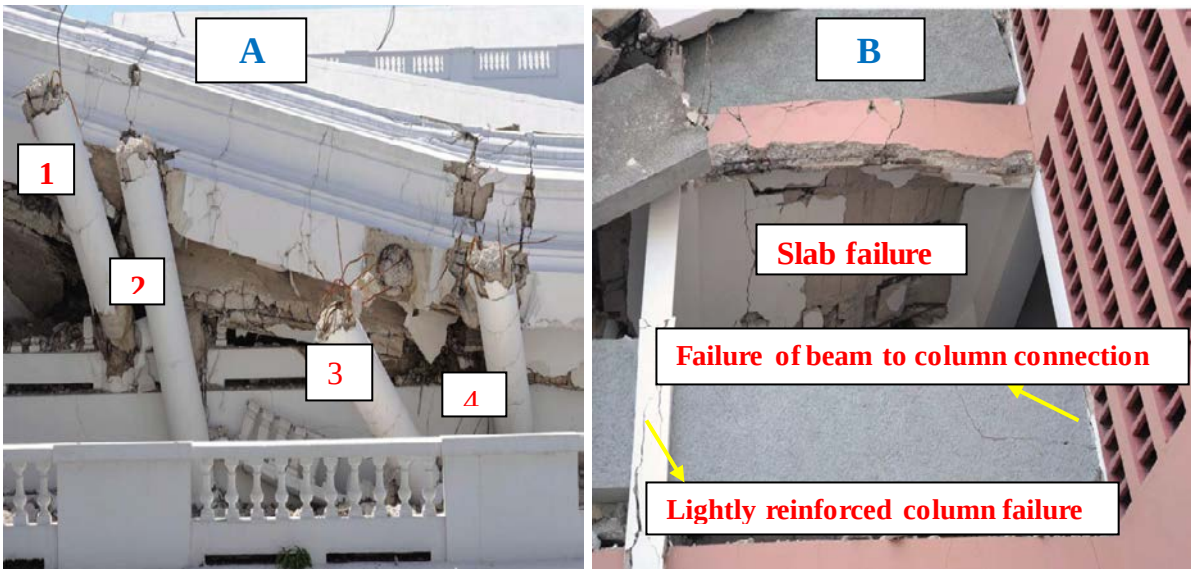

Figure 9: Image "A" shows softly reinforced concrete columns of the Presidential palace unable to withstand the quake and "B" Canado-Haitien High School destroyed by the quake

3.6. Structural pounding

Ignored in many papers about the 2010 Haiti earthquake, pounding was one of the main causes of severe damage of buildings and deaths during the quake. Seismic pounding occurs when the gap between adjacent buildings is not enough. In congested areas of Port-au-Prince, adjacent buildings are constructed with little or no gap providing separation. They are most often built with unequal floor heights which increase considerably the effects of pounding. Many people were not able to get out during the 2010 Haiti earthquake because of inadequacy of separation between adjacent buildings, and the probability of occupants to survive is quasi-null in such case. Many buildings have been destroyed or were severely damaged by adjacent buildings because they are built with insufficient separation.

Figure 10: Image "I" shows adjacent buildings with no gap and unequal heights and "II" illustrates adjacent buildings built so close that they have been destroyed each other

3.7. Absence of codes and standards

No Haitan Society of Civil Engineers (or any other association) is existed till now. It means that technical guidelines to encourage safety, reliability, production, and efficiency in the field of Civil Engineering in Haiti are rare. Structural design within the Haitian society was based on various codes and standards creating disorder before the quake. For instance, Engineers educated in Haiti conventionally studied the French BAEL (Reinforced Concrete Limit State Design) code (BAEL 91) or the ACI code (ACI 1995), concentrating on gravity load design, without consideration for earthquake loads [12]. Those educated abroad are most likely to use the codes and standards of the country where they got their degrees. The codes and standards of these countries are often updated. There is no seismic design in the BAEL 91. They are few researchers in Haiti.

After the 2010 Haiti earthquake, the director of the Department of Sustainable Development, Organization of American States, Cletus Springer, declared on CNN: "You could tell very easily that these buildings were not going to withstand even a [magnitude] 2 earthquake" [13]. Only a small proportion of the buildings were designed to withstand earthquakes. Surprisingly, most of the government buildings were completely destroyed by the quake.

4. Recommendations

According to a group of researchers, Haiti and the Dominican Republic should plan for future devastating earthquakes because the entire Enriquillo fault system appears to be seismically active [9]. Definitely, it is difficult to design a structure that is utterly safe, one that will never fail to be more precise. Nevertheless, we can undoubtedly lessen the risks so that, for instance, if a major earthquake or any other hazard does occur, occupants can have enough time to leave or be rescued. Following recommendations are provided to raise the seismic safety of civil infrastructure in Haiti.

- Considering the lack of local experts, government officials should invest more in higher education to

encourage professors as well as to have more students. It is true that the State University of Haiti is free but the academic environment is too poor.

- Civil infrastructures will always need to build in any country. Haiti needs more Civil engineers than ever before. Therefore, government officials should create opportunities so that more young students can study Civil engineering with a focus on structural engineering, earthquake engineering, geotechnical engineering etc… Many scholarships are offered to young Haitian annually. Authorities can arrange so that a number of admitted students into the scholarship programs mainly educate in Civil Engineering based on the fact that the Haitian education system is relatively poor compared to many countries offering scholarships to young Haitian each year (USA, France, Canada, Taiwan, Japan, etc…)
- Haiti needs the help of foreign expertise but cannot rely on it eternally. Government officials should invest on research relative to the earthquake so that local experts can come up with new ideas aiming at providing engineers with practical tools to build the structures safer and more reliable.
- Constructions should be imperatively controlled because of the high rate of illiteracy in Haiti. Due to the abundance of non-engineering buildings, authorities should employ qualified engineers to supervise the sites, materials used for buildings construction as well as the gap between adjacent buildings in particular in urban areas.
- Because of the vulnerability of Haiti to the earthquake, regular maintenance (at least every 5 years) of existing engineered buildings should be compulsory.
- Considering the volume of non-engineered buildings and the availability of local materials, it would be a good idea that officials encourage retrofitting under the supervision of competent experts. It would be an excellent and low-cost social project that would particularly allow poorest people passing from extremely poor housing to a better place to live.
- To achieve the goal of being an emerging country by 2030, it is mandatory that new civil infrastructures are built. In this case, government authorities should establish rules so that new buildings including hospitals, schools, bridges, public offices etc… are properly designed and constructed to withstand the seismic effects.
- If not yet started, it is time that Haitian experts in civil engineering and sub-disciplines in collaboration with government authorities open "true discussions" aiming at elaborating Haitian codes and standards.

5. Conclusion

The 2010 Haiti earthquake, which occurred with a moment magnitude of 7.0, has taken the life of hundred thousands of people including children, students, parents, and professional in various fields. The quake has also affected many public, residential and commercial buildings. Compared to the earthquake that took place in Chile the same year with a magnitude (8.8) stronger than the 2010 Haiti earthquake (7.0) and that however considerably made fewer injuries, it can be concluded that civil infrastructures in Haiti were not seismic-resistant. A seismic-resistant structure is not always costly or highly strong. Even if there is little progress in the reconstruction, many residential, public and landmark buildings still imperatively need to be rebuilt.

The goal of this paper was first to present the key reasons behind the 2010 Haiti earthquake and then to provide

some recommendations so that key resolutions can be taken to considerably lower the level of loss of life and property in future earthquakes in Haiti. To make Haiti an emerging country by 2030, it is imperative that more civil infrastructures are built and they have to be seismic-resistant. Low-cost housing projects have to be created also to alleviate the living conditions of hundred thousands of poor Haitian people residing in remote zones, in slums in Port-au-Prince and other cities.

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