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Performance of Buildings in the Haiti Earthquake

A report by Members of the Earthquake Engineering Research Institute Reconnaissance Team

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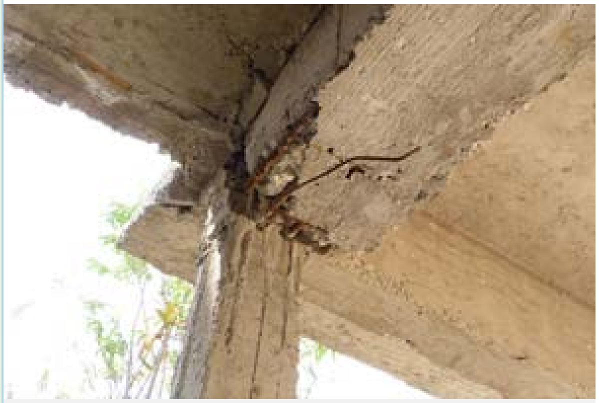


An example of poor coverage and lapping of reinforcing steel at column to beam from a building in Haiti after the earthquake. *Photo by Martin Hammer.*

On January 12, 2010 at 4:53 pm local time, a 7.0 earthquake occurred on the Enriquillo Fault 10 miles west-southwest of Port au Prince. It was the most powerful earthquake to strike the Port-au-Prince region in over 200 years.

Over 3 million people lived in the greater Port-au-Prince metropolitan area at the time of the earthquake; the earthquake directly affected half of them. Fatality estimates range between 220,000 and 250,000, and more than 300,000 were injured. This natural disaster is both the deadliest per capita and the costliest by GDP in recorded world history.[1]

The earthquake has had a devastating effect on infrastructure in Haiti. It significantly damaged or destroyed over 313,000 homes and 30,000 commercial buildings.[2] Thirteen out of 15 government buildings have been critically damaged or destroyed. More than 1,300 educational institutions and more than 50 hospitals collapsed or are unusable. According to the United Nations, between 30 and 60 percent of buildings in Port au Prince are severely damaged or collapsed.[3] In several towns closer to the epicenter, the United Nations has estimated that 80 to 100 percent of buildings are significantly damaged or destroyed.

By comparison, in 1989 a similar magnitude earthquake (6.9) struck the San Francisco region at a similar time of day (5:04pm), exposing a larger urban to sub-urban population (7.4 million), resulting in only 63 deaths, 3700 injured, and 10,000 rendered homeless.[4] This earthquake was deeper (11 mi. vs. 6 mi.), of shorter duration (15 sec. vs. 35 sec.) and further from the densest populations (60 mi. vs. 10 mi.) than the Haiti quake. Nonetheless, the extreme difference in lives lost and buildings damaged is worth noting.

Existing Building Stock

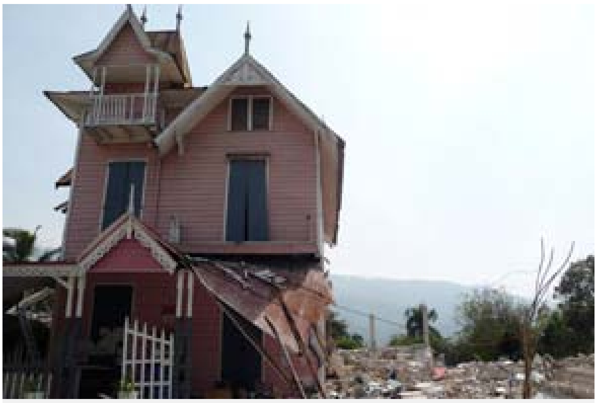
THIS ISSUE

Features

The most prevalent building type in Haiti, specifically in the Port au Prince region, consists of low-rise, non-engineered concrete block masonry structures used for single-family dwellings and small businesses. These low-rise buildings are typically one to two stories tall, though three-story buildings are not uncommon. They are constructed with unreinforced concrete masonry units framed by slender, lightly reinforced concrete columns. Fired clay brick is not used, though it was employed in historic unreinforced masonry buildings and French-styled Colombage construction in the 1800s. Floors and roofs are reinforced concrete slabs, typically 4- to 6-inches thick with a single layer of reinforcement. Lightweight sheetmetal overlayed on a sparse woodframe is also a common roofing method. Foundations are typically one meter deep and assembled with stone or rock rubble and lightly cemented mortar. When built on sloped land, foundations can be as tall as two meters above ground.

The city centers of Port-au-Prince and Petion Ville have a small number of engineered steel-framed concrete-clad and *reinforced concrete high-rise apartments*. The tallest commercial building is 12 stories and built to the ACI 318 standard. Older warehouses and newer industrial factories used by the garment industry are lightweight steel frame and truss systems with non-structural concrete block infill.

Code and Code Enforcement



Wood frame building next to site of collapsed concrete building in Haiti. *Photo by Martin Hammer.*

Most countries in the Caribbean use the Caribbean Uniform Building Code (CUBiC). However, few engineers in Haiti have used this code, and most buildings were not built to code or designed by engineers. Occasionally engineers, either within Haiti or from outside, have used U.S. or European codes, but only voluntarily, as there is no Haitian building code. Although permits are required for many buildings, plan checks commonly conducted by the Ministry of Public Works in the 1960s and 70s have been extremely rare. Construction inspections have been equally rare or nonexistent. As a result, most residential, commercial, and institutional buildings have been built without code enforcement or quality control of essential building materials, such as concrete and reinforcing steel. The lack of building maintenance also contributed to the severe dilapidation of much of the building stock in Haiti.

Common vulnerabilities that led to the collapse of structures in Haiti include the following:

Inadequate Lateral Load Resisting Systems

In recent decades, most low-rise buildings have been constructed of reinforced concrete frame with unreinforced masonry infill. This system of “confined masonry” can perform well in earthquakes if built properly. However, in Haiti the concrete frames were often under designed, and masonry walls were often not adequately integrated with the reinforced columns and beams, and therefore did not act as in-plane load bearing elements. During the earthquake, the masonry walls were often expelled under out-of-plane loading.

Engineered structures in Haiti were constructed primarily to withstand hurricanes. Many of these structures had heavy floor and ceiling slabs supported on undersized columns of inadequate strength and stiffness, resulting in the commonly observed soft story failure. Many of the engineered buildings also had insufficient wall area and complete lack of ductile detailing. Further, buildings were often constructed with a mix of lateral force resisting systems, resulting in a significant lack of symmetry and facilitating torsional response.

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Poor Quality of Construction

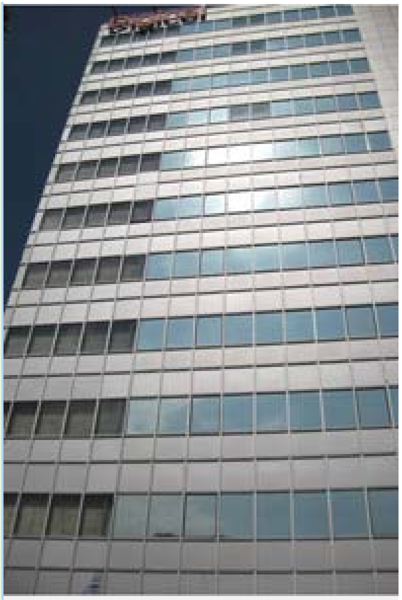
The poor quality of construction was also a major contributor to the damage observed in Haiti. This is a result of both the lack of skilled labor, the lack of construction equipment, and the lack of construction inspections. It was common to find columns and walls out-of-plumb by 5-7 degrees, and columns not aligned from one floor to the next. We commonly observed concrete with voids due to poor consolidation or lack of coverage of reinforcing steel.

Many of the non-engineered low-rise buildings constructed with concrete block infill and confined masonry techniques lack basic construction and detailing standards. Commonly walls were not load bearing, siginificantly reducing the lateral capacity of these building types. Further, floor and ceiling slabs were usually connected to the slender columns only with insufficient detailing. For the confined masonry building technique, we observed that masonry block walls did not develop a sufficient bond with the reinforced concrete columns and beams because of a lack of staggering of masonry units at the column interface.

Poor Quality of Materials

Construction materials used in Haiti are of significantly poor quality. The concrete tends to be low strength due to insufficient amounts of cement, high water content, and the use of weak aggregates. Concrete masonry units similarly lack sufficient cement content, as well as poor quality aggregates. Hydrating of concrete or concrete masonry units is not a common practice. The use of smooth reinforcement in new construction didn’t cease until approximately 2000, compared with the deformed steel bars that are critical for adequate composite performance of reinforced concrete.

The lack of adequate seismic detailing is pervasive in Haiti. Use of undersized and insufficient amounts of longitudinal reinforcement is very common in most columns, typically with a longitudinal reinforcement ratio of 0.4-0.8 percent. In addition, transverse reinforcement was frequently inadequate in size and spacing, and at times omitted altogether. We did not observe a decrease in lateral tie spacing at column ends in non-engineered structures.


Digicel headquarters in Port-au-Prince, Haiti after the earthquake. The buidling suffered some very minor damage, but is essentially intact. *Photo by Dr. Reginald Desroches.*

Some Buildings Performed Well

One example of good performance is the case of the 12-story, reinforced-concrete frame Digicel headquarters building, which is the tallest building in Port-au-Prince. The building was detailed according to ACI-318 specifications, and such detailing appeared to have been adequate. The building sustained minor damage in the form of minor concrete spalling of columns and minimal nonstructural damage to partition walls, ceiling tiles, and the curtain wall.

Many of the timber frame buildings, though sometimes suffering from termite damage or poor maintenance, performed quite well with their more flexible structural systems. It is common to see one of these structures standing next to a concrete and masonry building that collapsed.

The National Science Foundation Learning from Earthquakes Program supported this reconnaissance research.

1 Haiti Post Disaster Needs Assessment (PDNA), 2010
2 Government of Haiti
3 (PDNA), 2010
4 USGS DDS-29, and EERI Preliminary Reconnaissance Report, November 1989

Alphabetical list of contributing authors: Yves Anglandes, Susan Brink, Peter Coats, Reginald DesRoches (team leader), Amr Elnashai, Harley Etienne, Rebekah Green, Martin Hammer, Charlie Huyck, Ayhan Irfanoglu, Sylvan Jolibois, Anna Lang, Amanda Lewis, Jean Michel Michaud, Scott Miles, Rob Olshansky, Patrick Paultre.

Profiles in Safety

Send us your photos of "codes in action"

Sometimes you can spot disaster a mile away. An experienced code official might have examined certain buildings in Port au Prince and spotted issues of concern that, had they been addressed, could have prevented the disaster the January 2010 earthquake brought to that Haitian city.

The reconnaissance team from the Earthquake Engineering Research Institute (EERI) documented that poor building construction, lack of labor and appropriate materials, and most importantly, lack of building code enforcement contributed to the disaster in Haiti, resulting in lost lives and destroyed homes and property.

The Digicel building -- the tallest edifice in Port au Prince – pictured above,

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suffered only minor damage from the quake. Built to standards referenced in the IBC and ACI-218, it stands essentially intact amid surrounding structures that collapsed. Compare that to the photo at the top the previous page, demonstrating poor coverage and lapping of reinforcing steel at column to beam.

A picture is worth a thousand words, and those words speak volumes about the importance of codes and code enforcement, how they save lives as well as millions of dollars and hours of labor devoted to reconstruction.

Be our eyes. Send us your photos of "codes in action," photos that demonstrate the power of I-Codes, of how doing things right - or wrong - can make a world of difference. Send us your entries for consideration, and we'll post the most compelling ones in an upcoming issue of BSJ. Please also include a brief caption explaining how your submitted photo demonstrates good or bad code. You may email high-quality digital copies to us. Please indicate "Profiles in Safety" in the subject line. Note that we cannot return any materials sent to us. Please submit photos by May 17 for consideration for publication in the June Issue of BSJ.

Click here to read the Engineering News-Record article, U.S. Embassy Tour Shows Small Measures Pay Off Bigtime, discussing how the Embassy in Port au Prince came through the earthquake with "flying colors," one reason being that it was built according to I-Codes.