Oct 4, 2016 – Hurricane Matthew, HAITI
Surveyed Oct 25-28, 2016
Build Change Post-Disaster
Reconnaissance Report

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1. BACKGROUND

1.1. HURRICANE MATTHEW

Hurricane Matthew was a Category 4 hurricane on the Saffir-Simpson Scale, with sustained winds of 230 kilometer per hour. Hurricane Matthew made landfall on the southwestern tip of the Haitian peninsula near Les Anglais, Haiti, around 6:00 am local time (7:00 am EDT) on October 4, 2016.

Hurricane Matthew resulted in significant damage, including heavy wind damage, storm surge and extensive flooding, in southern Haiti. Storm surge that was 7–10 feet high hit Haiti's Southern Coast and there was also 300-500mm rainfall in Southern Haiti with isolated higher amounts. [1]

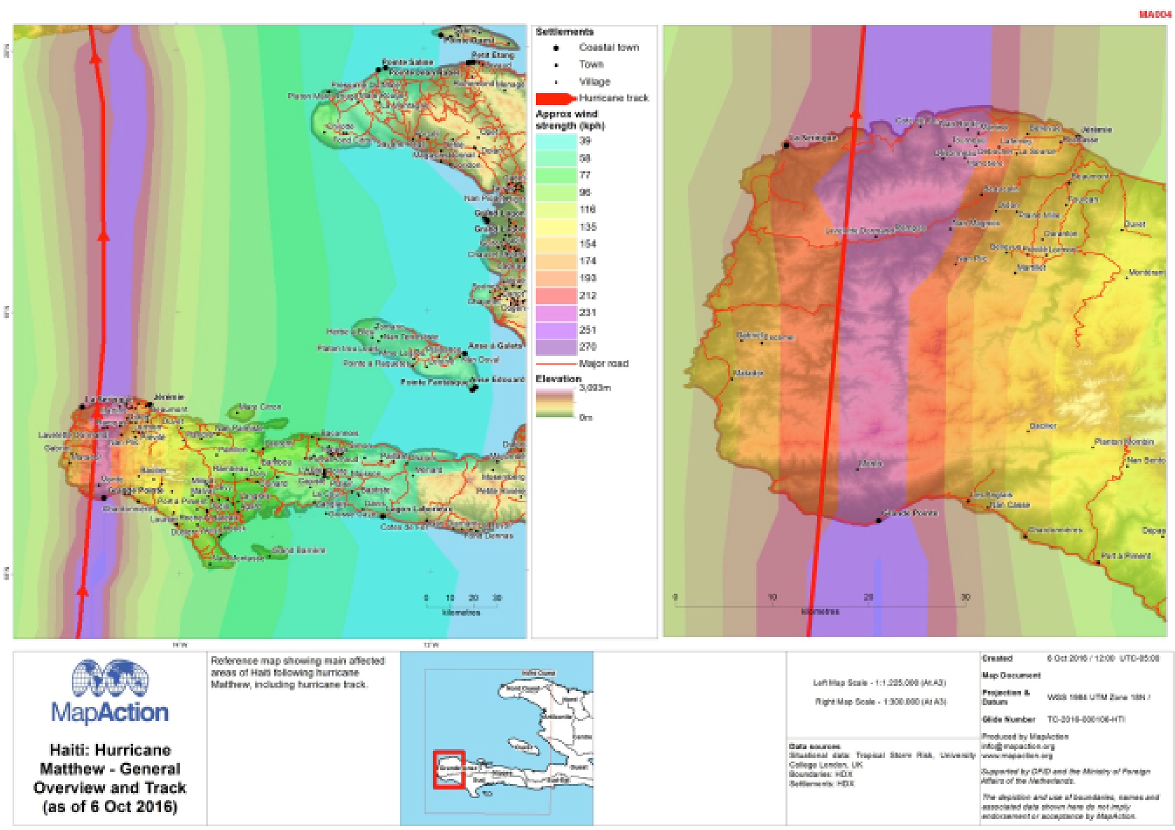

Figure 1 Hurricane Matthew track and estimated wind speeds (Source: Mapaction, University College London)

The hurricane affected mainly the three departments located in the southwestern peninsula: Grand'Anse, Sud and Nippes, but caused significant damage in the Nord-Ouest department and the Gonave Island. See Figure *2* for a map of the departments.

[1] USAID Fact Sheet #1 to #10, Oct. 2016

Figure 2 Map of the Haitian departments

USAID estimated 2.1 million Haitians people were affected by the hurricane resulting in 1.4 million requiring humanitarian assistance. The Haitian government assessed the death toll at 546 people.

UNDP agency reported that 220,000 houses have been damaged or destroyed due to the hurricane.

Hurricane Matthew was the most powerful hurricane in the Caribbean since hurricane Felix in 2007. It was the strongest hurricane to hit Haiti since 1964 Category 4 Hurricane Cleo, and caused more damages than the devastating 1980 Category 4 Hurricane Allen.

1.2. DESIGN WIND PARAMETERS

The National Haitian Building Code (CNBH 2012) defines four wind zones in Haiti as shown in Figure *3*.

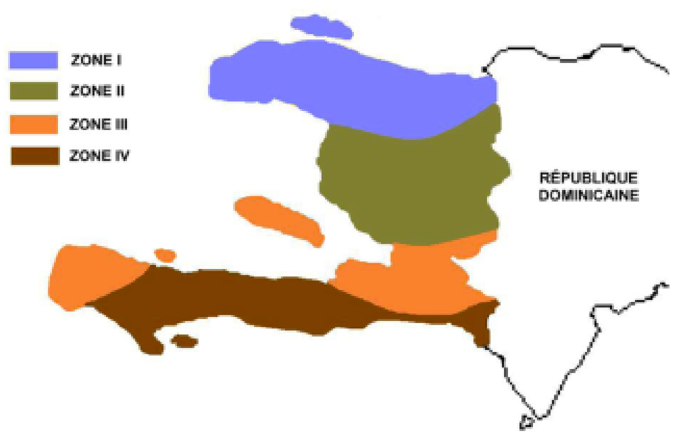

Figure 3 Wind zones to consider in Haiti (Source: CNBH 2012)

The corresponding reference wind speeds are defined in Table 1 on the next page.

WIND ZONES	I	II	III	IV
Reference Wind Speed (MPH)	100	110	120	130
Reference Wind Speed (m/s)	45	49	54	58
Reference Wind Speed (KPH)	161	177	193	209

Table 1 Reference wind speeds compatible with ASCE 7-98 to 7-05 and IBC 2009 (Source: CNBH 2012)

The maximum sustained winds of Hurricane Matthew in Haiti were 10% higher than the reference winds specified in the CNBH (209kph vs. 230kph) for the South department. For the Grand'Anse department the winds speed were 20% higher than the reference wind speed (193kph vs. 230kph).

1.3. VISIT OBJECTIVES

Following the hurricane, Build Change Haiti, based in Port au Prince, deployed a small team in the affected zone three weeks after the hurricane made landfall with the following objectives:

1. Visit several of the main cities and towns affected by Hurricane Matthew in the South and Grand'Anse departments: Les Cayes, Beaumont, Moron, Jérémie, Port-Salut, Saint-Jean du Sud.

2. Identify the main types of existing structures for housing and schools, especially those that suffered damages.

3. Compare the performance of engineered vs. non-engineered buildings.

4. Identify the most common damages and failure modes that appeared in the building structures in order to improve understanding of the high wind vulnerability of the common building types.

5. Gain understanding of the distribution of damages throughout the affected region (concentrated or dispersed).

6. Survey homeowners and builders within the affected areas, in order to identify common construction practices and preferences.

7. Survey material shops and block manufacturers to understand the material quality and availability throughout the region.

1.4. SURVEY TEAM

Build Change's reconnaissance team included the following members:

- Clement Davy (Civil/Structural Engineer): Build Change Project Engineer for retrofit program in Port-au-Prince, houses and schools.

- Junior Macié (Civil Engineer): Build Change Team Leader for housing retrofit program.

- Herode Nazaire (Civil and Geotechnical Engineer): Build Change Senior Trainer for the block department.

- Gaspard Pierristal: (Civil Engineer/Master in Earthquake Engineering): Build Change Program Manager for the AREMA project (Housing retrofit and new construction project in Port-au-Prince).

2. VISITS TO AFFECTED AREAS AND METHODOLOGY

The survey team visited several towns within the southwestern peninsula, in order to observe buildings, particularly houses and schools but also other engineered buildings. See Figure *4* to locate the towns visited: Cavaillon (B), Les Cayes (C), Camp Perrin (D), Roseaux (E), Jérémie (F), Moron (G), Beaumont (H), Port-Salut (I) and Saint-Jean du Sud (J).

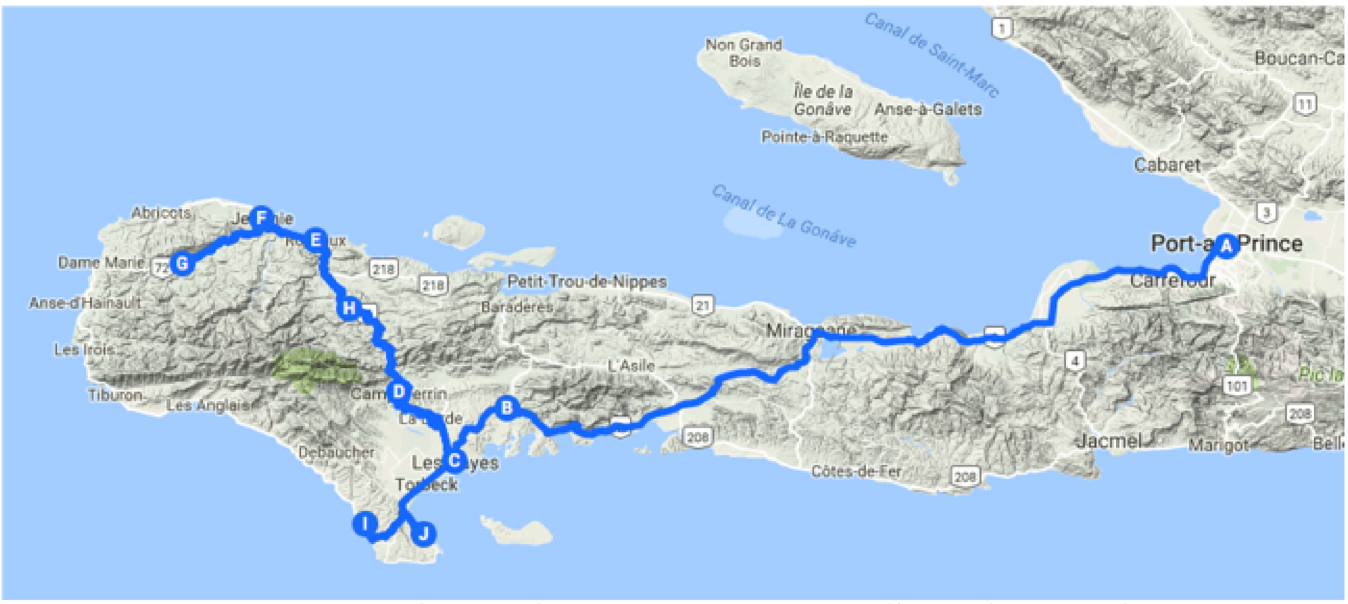

Figure 4 Itinerary of the Build Change reconnaissance mission (Source: Google Maps)

2.1. METHODOLOGY

The methodology we adopted for this reconnaissance mission was:

- Carrying out windshield surveys in the villages and cities we drove through in order to estimate the extent of damages and typology of structures.
- Carrying out ATC 45 – Safety Evaluation of Buildings After Wind Storms and Floods – rapid evaluations (adapted to the Haitian construction context) on groups of houses in Moron, Jeremie, Beaumont, Port-Salut and Les Cayes. We evaluated all buildings within a representative sample of houses to collect quantitative data. We classified the houses for internal use - see Figure *5* for the distribution in each location. We used tablet-based technology to collect the data and produced a database to provide the percentages included in this report.
- Carrying out specific evaluations for particular buildings: schools, town halls, police stations, fire station, and offices.

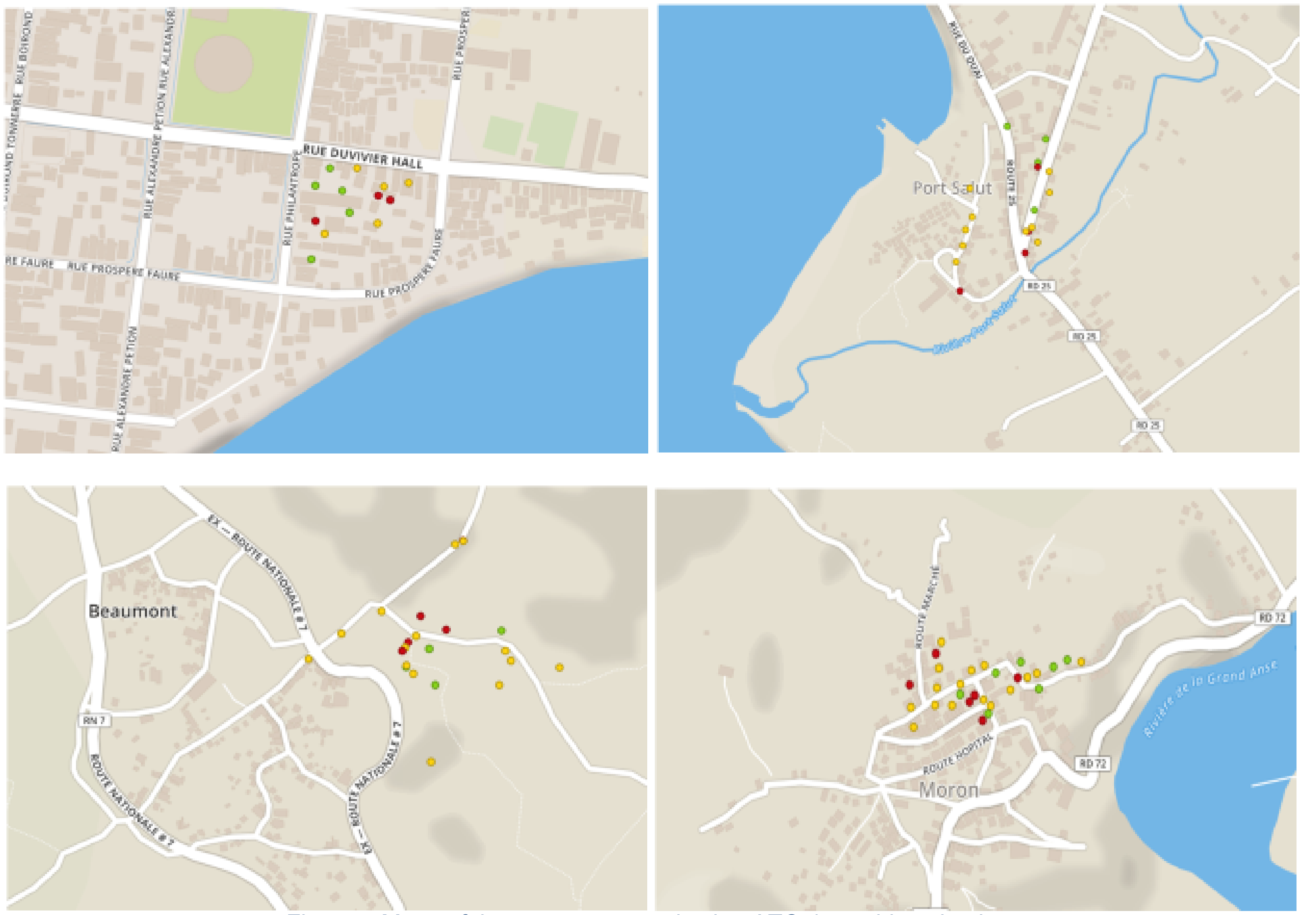

Figure 5 Maps of the areas assessed using ATC-45 rapid evaluation.
Green, Yellow and Red Tagging can be seen on the maps.
Note the GPS location are approximate due to poor reception.

We used several survey forms depending on the type of evaluation, for the South and Grand'Anse departments we did:

- 115 Rapid evaluations, based on ATC 45.
- 13 Homeowner surveys to understand their current situation, knowledge about disaster resistant construction, and their plans for future work.
- 6 Material surveys to assess the price of materials per zone, and the availability.
- 6 Mason surveys to assess their level of knowledge on material quality selection, earthquake resistant and hurricane resistant good practices.
- 5 Open site surveys to observe practices implanted in ongoing construction sites.

2.2. PORT AU PRINCE TO JÉRÉMIE – OCTOBER 25TH, 2016

The team traveled from Port-au-Prince to Jérémie, performing quick "windshield" surveys of the towns. More detailed information about the building types and damages observed can be found in the corresponding blog post for the day at http://www.buildchange.org/2016/10/26/hurricane-matthew-into-southwestern-haiti-to-asses-damages-in-Jérémie/

2.3. MARFRANC, MORON, JÉRÉMIE – OCTOBER 26TH, 2016

The team traveled to the mountainous region west of Jérémie visiting Marfranc and Moron. The team met with the town representative and did more detailed surveys of the town of Moron. Additional information about the activities and observations of the day can be found in the blog post at http://www.buildchange.org/2016/10/27/after-hurricane-matthew-assessing-damages-in-moron/

2.4. BEAUMONT AND CAYES – OCTOBER 27TH, 2016

The team traveled from Jérémie to Les Cayes stopping in Beaumont to a more detailed evaluation of the houses and schools. See the blog post of the day for more detailed information:
http://www.buildchange.org/2016/10/28/after-hurricane-matthew-investigating-housing-and-school-damages-in-beaumont-les-cayes/

2.5. PORT-SALUT AND SAINT-JEAN DU SUD – OCTOBER 28TH, 2016

The team traveled to the city of Port-Salut and Saint-Jean du Sud located on the seashore on the southern coast of Haiti to evaluate damages on houses and schools. More detailed evaluations were made in Port Salut.

3. SITUATION AND ANALYSIS OF AREAS VISITED

3.1. CITIES (JEREMIE, LES CAYES, PORT SALUT)

Figure 6 Left: Main road of Jérémie
Right: City center of Les Cayes

Type of disaster: All the cities we visited suffered from extremely high winds. The storm surge affected the shores greatly as well. Floods due to rain greatly affected Les Cayes in the aftermath of the hurricane. Slope instability in areas on the outskirts of Jérémie was also of great concern.

Roof: The extreme winds recorded severely affected about 95% of lightweight roofs due to various reasons such as:

- Deteriorated state of metal sheets used for covering
- Substandard metal sheet (0.35mm or thinner)
- Insufficient number of roof nails and type of nails to fasten the sheets to the frame below
- Insufficient connection between roof element and to the walls (no strap, no gusset)
- Type of materials used of the structure of the roof
- Non standardized form of the truss

The damages affected all shapes of roof whether it was a monoslope, gable or hipped roof.

Structures: Unreinforced masonry and wood frame with stone masonry infill are the two main typologies encountered in cities. Makeshift structures were also very common in the outskirts of Jérémie and les Cayes and by the sea front. Wood frame structures were extremely affected by the hurricane winds, and the floods soaked the wood and infill, which further deteriorated the integrity of the structure. In the informal neighborhood of Les Cayes, 75% of the structures we visited suffered moderate to severe damage. Unreinforced masonry damage varies greatly depending on the construction quality. About 70% of unreinforced masonry houses we visited suffered no or minor damage. Additional discussion on specific damages is presented later in this report.

Material availability and quality: Based on the material shop owner we surveyed, it appears that construction materials are widely available in the cities. Even if some particular material, such as hurricane straps or sawn lumber, were not immediately available the shops stated that it is possible to order additional materials from Port au Prince if the demand is sufficient. The concrete block quality is generally low. Blocks were typically manufactured manually, but some vibrated blocks were observed in Les Cayes. The sand used for construction was poor quality. Sands were sourced from either from the sea or from the river with a lot of fine sediments.

Local masons/carpenters: In the cities we visited, homeowners generally hire masons to build/repair their houses. They are generally not trained and typically lack knowledge on good disaster-resistant construction practices.

Ongoing reconstruction: In the city centers of Les Cayes, Jérémie and Port Salut, three weeks after Hurricane Matthew, roof repairs were moving fast. However, in surrounding poorer areas and areas that suffered storm surge, the whole structure of the houses often had higher levels of damage that are difficult to address quickly due to lack of means.

Possible reconstruction strategies: As block masonry is the preferred structural option for most city inhabitants, and also as there is material availability and a market for masons, technical support for reconstruction in confined masonry buildings should be developed by:

- Training of block makers
- Training of local masons
- Training of local carpenters
- Training of homeowner on confined masonry and good quality material selection

This technical support should include the repair and reconstruction of a light-weight hurricane-resistant roof that is adequately secured to the structure, as well as integrate key aspects of earthquake-resistant construction, especially for homeowners who may be considering a conversion to a concrete slab roof.

Relocation planning of the population who are living in the storm surge zone or flood zone should be addressed.

3.2. VILLAGES (MORON, BEAUMONT)

Figure 7 Left: View of Beaumont
Right: View of Moron

Type of disaster: Villages in the mountains suffered from the extreme wind forces. Even though slopes can be significant in these areas, no landslide or slope instability issues were observed in the area visited. It is worth noting that these areas were covered with forest before the hurricane, which could have helped with retaining the soil.

Roof: The extreme winds recorded severely affected about 90% of the lightweight roofs we evaluated. The shape of the roof did not have a great impact on the extent of the damage. The main explanation for the damages appeared to commonly be due to the insufficient connections and the low quality of the metal sheets.

Structures: Wood frame with stone masonry infill was the main structural typology for the houses we encountered in villages. It is the structural system of approximately 70% of houses compared to approximately 30% for unreinforced masonry. Unreinforced stone masonry houses were observed, but remain marginal.

The increase in frequency of wood frame structures in the villages explains the greater number of houses severely damaged as compared to the cities. About 80% suffered moderate or severe damage to primary structural members and walls. This type of damage varied from cracks in the infill to total collapse of the structure. One homeowner described the structure during the hurricane as being shaken by the wind forces, which dismantled the structure completely to collapse.

Material availability and quality: The villages we visited were accessible by road and therefore construction materials were available, although the price of transport varied greatly between locations. The concrete block quality observed was extremely low, as the blocks were typically manufactured manually and the mixes incorporated unwashed sand and even clay, giving a brown color to the blocks. Use of lime plaster was observed, however this is an old technique that is rarely made anymore. Lime and mud were used mainly as mortar in villages of Beaumont and Moron, and in the cities they used mostly unwashed sand and cement.

Local masons/carpenters: The situation regarding construction labor varies between villages, but we observed more homeowners rebuilding their own roof and houses by themselves than with hired labor. These homeowners displayed a lack of basic knowledge on good disaster-resistant construction practices. It is worth noting that the roof frame with stone infill house type is typically an old typology. The average construction date of this house type was 1983 for the wood frame houses evaluated, compared to 1997 for the block masonry houses surveyed. The knowledge and skills for these vernacular structures may have been lost recently in some of these regions.

Reconstruction: Tarps had been distributed in the areas we visited and makeshift structures are being rebuilt next to collapsed houses as temporary shelters. We saw construction sites starting, but homeowners typically expressed concern about their lack of capital to rebuild.

Possible reconstruction strategies in villages:
Even if block masonry may be the preferred option for village inhabitants, the extremely low block quality will be a great challenge to overcome in order to build safe confined masonry houses. Low incomes and increased transport prices can prevent homeowners from buying enough cement and reinforcing as necessary to build safe disaster-resistant houses.

The vernacular wood and stone masonry infill option for structures can also be challenging as in some areas they have not been built recently and thus the knowledge and skill has been lost. The reconstruction strategy for villages should consider the skills and material availability in each particular village on a case-by-case basis.

3.3. RURAL AREAS

Figure 8 Landscapes with rural houses near Moron, mountains on the right photo does not have road access and were cut off due to the floods

The Build Change team did not visit remote rural areas due to the difficult access. However, the team discussed the situation in the surrounding rural communal sections with the mayors of Beaumont and

Moron. Some areas are still cut off due to the fall of trees on pedestrian, horse and mule trails. The cable bridge spanning above the Grand'Anse River was destroyed by the hurricane. The people of section 2 and 3 of Moron had to cross the 40m wide River by foot.

Type of disaster: Rural areas suffered from the extreme wind forces. A significant amount of the rural population lost their houses and did not have any place to shelter during the hurricane and lay on the ground, waiting for the hurricane to pass.

Roof/Structure: The mayors we met described these areas as suffering 100% destruction to buildings, including the wall and roof. The wattle or reed structures or wattle-and-daub structures common to these areas did not resist the hurricane winds.

Material availability and quality: Construction materials need to be transported by foot or by mule, or collected very locally from natural resources, such as timber and mud.

Local masons/carpenters: In remote rural areas, homeowners usually build their houses by themselves, or with the assistance of family members and sometimes with some untrained masons or carpenters.

Possible reconstruction strategies in remote rural areas:
No road access prevents the transport of good quality material at an affordable price. The dispersion of the population on the territory makes it hard to train and replicate good practice. Wattle or reed or wattle-and-daub house are the structures most likely to be rebuilt. And it seems difficult to make hurricane resistant for such high winds. Nevertheless safe emergency shelter should be addressed to ensure these populations have a safe shelter during disasters.

3.4. COASTAL AREAS (SAINT JEAN DU SUD, ROSEAUX, PORT-SALUT)

Figure 9 Left: Houses on the sea shore in Port Salut
Right: Tents put up by fishermen who lost their houses by the sea

Type of disaster: Extensive damage was caused by storm surge in numerous cities and villages along the coast. Notably we visited Roseaux, Port Salut and Saint Jean du Sud. In many cases, waves damaged retaining or foundation walls causing the collapse of entire structures. Villages along the seashore were greatly affected by the storm surge; a settlement of fishermen between Jérémie and

Roseaux was completely washed away. In Jérémie the bulwark resisted the storm surge, but the houses close to the sea were flooded.

Structure/Roof: The majority of buildings on the shore were reinforced concrete frame hotels or partially confined block masonry houses. The storm surge affected all type of structures. The extremely high winds destroyed nearly all the lightweight roofs immediately along the coast, even for engineered buildings.

Material availability and quality: Construction materials were typically available along the coasts because most roads run along these areas, where is it is relatively flat. The concrete block quality observed is low; the blocks were typically fabricated manually and the mix incorporated unwashed sand.

Local masons/carpenters: Similar to the situation in the villages or cities, depending on the size of the settlement and level of development.

Reconstructions strategies: An awareness campaign could be implemented to deter people from building by the sea. Local municipalities should consider enforcing No-build coastal zones.

4. BUILDING TYPES AND CONSTRUCTION OBSERVED

4.1. HOUSING TYPES

4.1.1. HOUSING CONSTRUCTION SYSTEMS

For housing there were several types of construction systems observed:

- Unreinforced block masonry
- Confined/partially confined block masonry
- Wood frame with stone masonry infill with, mud mortar, mud andlime mortar or unwashed sand and cement mortar
- Wattle or Reed House[2]
- Wattle-and-Daub House[2]
- Timber frames, with timber or lath panels
- Dry joint stone masonry
- Combined systems

Below, each system is described and examples are presented.

Unreinforced Block Masonry
Unreinforced block masonry structures are a popular option in the cities and villages, as it appeared modern. The walls are typically made out of non-vibrated block (done manually in a mold) sitting on a stone masonry foundation. The block concrete mix generally includes clay that gives a brownish color to the block. They are assembled with cement and sand or mud mortar and are typically not confined either vertically nor horizontally. The structure can be cover with reinforced concrete roof slab, but more often covered by a lightweight roof made out of round natural timber and covered by metal sheets. The roof is typically connected to the top of the wall by a piece of rebar embedded in the last row of block and bent around the rafter.

[2] Improvement of Rural Housing in Haiti to Withstand Hurricanes, F.C. Cuny, September 1982

Figure 10 Unreinforced block masonry houses

Confined/partially confined block masonry
Partially confined block masonry is a common typology similar to unreinforced masonry. The level of confinement varies between the houses evaluated, but is generally insufficient to consider the house fully confined. It is common to see columns but much rarer to see reinforced opening or intermediate tie beams.

Figure 11 Two-story partially confined block masonry house in Moron

Wood frame with stone masonry infill with mud or lime mortar
Wood frame with stone masonry infill is the most common type of housing structure in the villages of the Southwestern peninsula of Haiti. This typology was very common in the 70s and 80s according to the interviews carried out by the team.

The walls sit on a stone masonry foundation. The wood poles with round irregular section of approximately 10cm are embedded in the foundation generally without any wood preservative treatment.

The bays are typically 1m wide and infilled with stone masonry; generally the walls are not braced with wood diagonals – like can be observed in historic columbage buildings in Port au Prince.
The masonry is made out of unworked small stones (10-20cm diameter) placed with mud or lime mortar. The walls are plastered with lime or cement mortar to waterproof and protect the masonry and the wood from the elements. A wood ring beam sits on top of the wall and is nailed to the top of the poles, which are notched and flattened to improve the connection interface. The roofs are typically hipped roofs, made of round natural timber nailed to the top to ring beam and aligned with the post. No hurricane straps or plywood gussets were typically used for theses existing housing structures. The roofs are covered with substandard (gauge 29 and higher) metal sheets, which were generally rusted and in bad condition.

Figure 12 Wood frame with stone masonry infill house

Wattle or Reed Houses:
Typical wattle or reed houses are present in remote rural areas, where there is no direct road access. They are made of natural round timber pole frames with cane or sticks woven between the vertical posts. The creole name for this housing type is Kay Ajoupa.

Figure 13 Wattle or Reed House

Wattle-and-Daub House:

Wattle-and-Daub houses can also be found in remote rural areas. They have the same structure as wattle and reed houses, but the walls are covered with mud stucco to make them more durable and resistant. The creole name for this housing type is Kay Klise.

Timber frames, with timber or metal sheet panels:

Timber frame houses are common in the cities of Jérémie or Les Cayes. They are typically old historical one or two story houses. Due to deforestation, there are very few new houses made of wood only.

Figure 14 Timber frame vertical expansion with metal sheet panel walls

Dry joint stone masonry:

Stone masonry houses were a minor typology in the rural areas. The stone masonry is assembled without mortar; the walls are generally 30cm thick. The roof is typically made of wood and metal sheets connected with piece of rebar embedded in the top of the wall.

Figure 15 Dry joint stone masonry house in Moron

Combined systems:

Combined systems are common in the cities with wood additions to first floors constructed in masonry. In rural areas, newer expansions of wood frame houses are sometimes made out of block masonry.

4.1.2. HOUSING ROOF SYSTEMS

For housing there were several types of roof systems observed:

- Light weight wood hipped roof covered with metal sheets or straw
- Light weight wood gable roof covered with metal sheets
- Light weight wood monoslope roof covered with metal sheets
- Reinforced concrete slab roof

Lightweight wood hipped roof covered with metal sheets or straw
Lightweight wood hipped roof is one of the most common typologies (50% in villages, but less in dense city neighborhoods).

Figure 16 Left: Hipped roof covered of vetiver straw
Right: Hipped roof covered of metal sheet

The wood structure is made out of natural round wood nailed together and sitting on a top plate.

Figure 17 Structure of a hipped roof

Lightweight wood gable roof covered with metal sheets
Lightweight wood gable roofs covered with metal sheets are a common option too (approximately 40% in villages, 70% in cities). The gable end walls were either built with light materials, or in masonry (see Figure 18).

Figure 18 Left: house with a lightweight gable roof
Right: Masonry gable wall not confined

Lightweight wood monoslope roof covered with metal sheets
Lightweight wood monoslope roofs are not very common in the Great South (Around 10% of the roofs observed). They are made of round natural wood and cross planks, to which the metal sheets are nailed.

Reinforced concrete slab roof
Reinforced concrete slab roofs are not very common (less than 10% of the roofs observed). They are typically 15cm-thick flat slabs with rebars in both directions at 20-30cm. In urban areas the slabs are made mostly of blocks and ribbed beams.

Figure 19 Reinforced concrete slab roof

4.3. SCHOOLS TYPES

For schools, there were two main types of construction systems observed:

- Concrete frames, typically with masonry infill
- Unreinforced block masonry

Reinforced Concrete frame with block masonry infill walls:
The most common type of structure for schools observed in cities was reinforced concrete frames with infill walls. These were typically two or three story buildings. The floor system was usually a reinforced concrete slab or blocks and ribbed beams. The roof systems were typically either metal or wood trusses covered with metal sheets.

Figure 20 Reinforced concrete frame with block masonry infill schools in Port-Salut (left) and Jérémie (right)

Partially confined block masonry:
In villages, the schools we evaluated were made of unreinforced block masonry with partial confining elements. The roofs were mainly gable roofs with wood trusses or rafters only. The quality of the connections varied between the schools, but generally the roof is made with sawn lumber and plywood gusset connections are used.

Figure 21 Unreinforced masonry school in Beaumont

4.4. CONSTRUCTION MATERIALS

There are several material types identified for common construction of housing and schools

Sand: Generally unwashed river sand. In the towns or cities close to the shores it is not rare to see beach sand used.

Figure 22 Left: River sand extracted from the riverbed, generally used unwashed.
Right: Beach sand used for block manufacturing in Jérémie

Gravel: Round river gravel extracted from riverbed. Generally no crusher is used. No angular gravel was encountered during the visit.

Concrete Masonry Units, CMU: Typically 15cmx20cmx40cm in dimension. Although no sampling and testing was performed during the visits, a visual assessment of the blocks quality was carried out. In Les Cayes, some block manufacturers are vibrating the blocks, but in the rest of the South and Grand'Anse departments, the great majority of blocks are manually made. The quality of the blocks is generally low due to use of poor quality material: unwashed sand, insufficient use of cement in the mix, and the addition of clay in the mix. The low quality was also due to a lack of training and knowledge of good manufacturing practices such as: insufficient curing, curing under the sun, and insufficient vibration.

Figure 23 Blocks curing in Jérémie

Lime: Lime mixed with clay, mud and sand was used as a mortar to lay the rocks or plaster to protect the masonry from the elements. During our visit we did not encounter limekiln, instead people prefer the use of cement when there is road access. Lime calcination is an old practice requiring a significant amount of wood for the calcination of the limestone. More investigation is required to understand if the lime is still used in some remote areas.

Wood: The wood used for housing is generally round natural timber with irregular section. The wood is typically not treated and can be protected from the element with lime or cement plaster. The wood was often deteriorated by insects, typically termites.
Homeowners and carpenters typically use the more resistant wood they find in the area. The names vary depending on the location. In the South the wood used is typically, bois de Campêche, bois d'Acacia or bwaple. In the Grand'Anse it is typically bois de cèdre, bois fwenn, bois fè. (names are in French or Creole as the scientific name was not investigated).

Rocks: Rocks generally comes from the soil around the construction sites or found during excavations. The stone use is typically limestone or basaltic stone or tuff depending on the geological layer of the location. Some quarries exist too. Rocks are generally 10-25cm diameter unworked.

Figure 24 Tuff rocks assembled with mud mortar

Timber: For schools, sawn lumber is used typically for the roof trusses. It is imported Southern Pine 2x4 or 2x6 elements.

Mortar and concrete: Round gravel and unwashed sand is used in the concrete or mortar mix. Mud, lime and mud are also used in some villages. There is also a lack of training in the placement of the concrete and problems with concrete cover, segregation etc. were observed.

Figure 25 Reinforced concrete beam in Les Cayes

Steel reinforcing: In reinforced concrete frame elements, the rebar for longitudinal reinforcing was usually ½" diameter ribbed bars, and for transverse reinforcing, like stirrups and ties, it was usually ¼" diameter smooth bars.

5. General Recommendations

If earthquakes and typhoons cannot be prevented, they don't have to be disasters. Building safe houses in an appropriate location can prevent damage and save lives. The Haitian Ministry of Public Work has issued recommendations for building/retrofitting safe houses in the past.

For the new construction of small confined masonry buildings:
Guide de Bonnes Pratiques pour la Construction de Petits Bâtiments en Maçonnerie Chaînée en Haiti, MTPTC, 2010

For the retrofitting of block masonry buildings and light weight roofs:
Guide de Renforcement Parasismique et Paracyclonique des Bâtiments, MTPTC

The CNBH Part 1 also covers construction and design requirements for residential buildings in Haiti.

Based on the damages observed, the key recommendations from these resources that should be emphasized during reconstruction include the following:

General Recommendations
- Build on a safe site not close to the sea, river, not on steep slope.
- Build a simple, symmetric layout.
- Ensure wall spacing between parallel walls is not more than 3.5m (wood frame) or 4.5m (block masonry) maximum.
- Choose good quality materials.
- Hire a skilled mason/carpenter.
- Maintain the house.

Recommendations for Masonry Structures
- Build a strong foundation with rocks and cement mortar or reinforced concrete strip footing
- Use good quality concrete blocks. Don't use blocks that have brown color. Use blocks that do not break when dropped on the flat side on hard earth from chest height.
- Don't use unwashed river sand or beach sand as aggregates to make concrete or concrete blocks.
- Use 1:2:3 mix for concrete and 1:5 mix for mortar
- Use confining columns and beam in reinforced concrete.
- Connect the roof to the ring beam with straps or brackets.
- Connect the masonry structure using a ring beam on top of walls, a plinth beam at the foundation, and tie columns between them.
- Use 40cm overlaps to connect rebar, not short laps or short hooks.
- Connect beams and columns together by continuing rebar through the joints. Use rebar stirrups with rotated hooks around column and beam rebar.
- Use rebar dowels or masonry toothing to connect masonry walls to columns. Build the walls before pouring the columns and ring beam.
- Use reinforced concrete lintels above windows and doors.
- Plaster the house to make itmore resistant, more durable and protect the blocks from deterioration.
- Don't use masonry in the gable wall. It can fall on resident. Build a hipped roof or a lightweight gable instead.

Recommendations for wood frame and stone masonry infill structures

- Use diagonal wood bracing to strengthen every masonry wall panel.
- Keep masonry panels small, with posts at every 1m to 1.5m on center.
- Connect bracing members with straps or gusset plates.
- Connect all wood-framing members to each other.
- Connect the roof to the walls with straps or brackets.
- Anchor timber posts to the foundation with post brackets and a positive/fastened connection.
- Ensure the foundation is deep and heavy enough to counteract the uplift force of wind.
- Use cement mortar for the infill masonry or good quality lime mortar.
- Treat the wood to slow decay and infestation.
- Plaster the house to make it stronger, more durable and protect the infill from deterioration

Recommendations for roofs

(Good practices observed to continue)

- Use of hipped roof more than gable or monoslope roof
- 20-40 degrees roof angle
- Roof overhang no longer than 30cm

Improvements needed

- Disconnect veranda roof from the house roof.
- Use trusses to build the roof structure.
- Brace the trusses.
- Provide sufficient rafter-to-rafter splice connections, such as two stitched side members
- Connect the truss elements with plywood gussets and sufficient nails
- Connect the trusses to the walls with hurricane straps
- Use 0.35mm or thicker roof metal sheets
- Maintain the roof sheet and add rustproof paint to increase the durability
- Use roofing nails every two waves typically (approx. 15cm on center) at each purlin, and at every wave (approx. 7.5cm on center) along the roof edges and ridge
- Use Vetiver straw or Palmis leaves as roofing cover when available and accepted by the homeowners (Note, these coverings are not resistant to wind-born debris, so although use of them could reduce the loads imparted to the structure during a storm, residents housed should be advised to evacuate the structure during a storm to avoid potential impact from flying debris).

6. DAMAGES OBSERVED AND DISCUSSION

6.1. HOUSE DAMAGES

6.1.1. UNREINFORCED OR PARTIALLY CONFINED BLOCK MASONRY

Overall block masonry structures better withstood the hurricane winds compared to other housing structure typologies, although in some cases structural deficiencies did lead to the failure of certain buildings. No damage or minor damage to primary structural members, such as cracking of walls, was observed in 70% of structures evaluated.

It is worth noting the roofs were generally poorly connected to the top of the wall. Thus the wind loads were not properly transfer to the walls, reducing the demand on the walls. The reconstruction of roofs should carefully address the capacity of the wall to transfer the load from the roof to the ground. A strong roof well connected to a poor masonry wall (Insufficient confining element or poor block quality) can result in greater damage in the event of high winds.
Even if it is hard to understand the exact cause of the collapse we observe severely damaged unreinforced houses possibly due to the failure of the walls prior to roof failure.

Figure 26 House totally destroyed possibly because of wall failure prior to roof failure

From an earthquake resistant point of view, the quality of the buildings observed was very poor and improvements need to be done to make them disaster-resistant.

Out of plane failure:

- Description:
  Out of plane failure of masonry wall was observed in many unreinforced masonry building. The damage varies from a couple blocks falling from the top of the wall to total collapse of the wall panel.

Figure 27 Left: Wall collapse due to lack of toothing and intermediate beam
Right: Tall wall collapsed

Figure 28 Blocks placed back after the hurricane to replace the roof as the previous ones fell

- Possible causes:
  Out of plane failure can be attributed in certain cases to the excessive length of the wall panels or the excessive height of the wall. The lack of confining elements to brace the wall out-of-plane and prevent the fall of concrete blocks is a common cause of failure. The insufficient connection between the block wall and the reinforced concrete tie are also a cause of out of plane failure. Typically there is no toothing at vertical columns. We can add also the poor quality of the materials.
- Possible measures for improvement:
  Limit the span of wall panels to 4.5m long to comply with MTPTC seismic good practices[3].
  Limit the height of the wall to 2.7m high (MTPTC recommendations).
  Enforce toothing techniques.
  Provide ring beams at the top of walls, particularly where light roofs are used.
  Used good quality of blocks and mortar.

[3] Guide de Bonnes Pratiques pour la Construction de Petits Bâtiments en Maçonnerie Chaînée en Haiti, MTPTC, 2010

Deterioration of blocks

- Description:
  Deterioration of blocks by weather was a common structural deficiency. Plastered walls generally better resisted the hurricane.
- Possible Causes:
  The poor quality of the block can explain the rapid deterioration of the blocks.
- Possible Improvements:
  Improve the block quality throughout the region.
  Recommend cement plaster on the exterior wall.
  For retrofits of existing structures, deteriorated walls should be replaced, as application of plaster would likely be an insufficient retrofit method.

6.1.2. WOOD FRAME WITH STONE MASONRY INFILL WITH MUD OR LIME MORTAR

Wood frame with stone masonry infill houses suffered major damage. About 80% of structures evaluated had moderate (37%) to severe (42%) damage to primary structural members and cracking of walls.

Infill and pole connection failure

- Description:
  Cracks at the joint between the top of the wood pole and the masonry were observed. It is the top of the wall that generally suffered the most damage.

Figure 29 Visible cracks at corner of the masonry

- Possible Causes:
  The wind forces visibly shook and racked the structure, provoking the cracks in the infill masonry.
- Possible Improvements:
  Use of diagonal cross bracing to better connect the infill with the frame and reduce racking.

In plane cracking of infill

- Description:
  Diagonal cracking of the stone masonry infill due to in-plane shear loading was observed. Very occasionally we observed diagonal wood bracing in the infill and the wall panel withstand better the wind forces.

Figure 30 Left: Cracking of the infill
Right: Partial wood diagonal bracing in masonry wall infill

- Possible Causes:
  The stone masonry walls are not able to transfer the lateral loads and tend to crack easily and be disconnected from the wood post.
- Possible Improvements:
  Install diagonal bracing in the wall panel with planks to help transfer the lateral loads to the foundations.

Out of plane failure of wall infill

- Description:
  The stone masonry infill often collapsed during the hurricane, the damage varies from partial collapse of the top part to total collapse of the walls.

Figure 31 Out of plane failure of masonry infill

- Possible Causes:
  Lack of connection between the confining wood element and the masonry infill and large masonry panels
- Possible Improvements:
  Nails on the wood elements to create a better adherence between the wood and the masonry, and installation of diagonal wood member to reduce the masonry panel size.
  Uses good quality of mortar to make better adherence with the stone.

Out of plane failure of the wall panels

- Description:
  In some houses that collapsed completely the homeowner described an intense shaking of the structure, roof and wall, and the whole structure went down when the roof was blown away. In some sites, piles of stones and mud are visible as the only element remaining of the wall infill.

Figure 32 Out-of-plane failure of wall panels

Figure 33 Total collapsed of a wood frame building

- Possible Causes:
  Possibly the length of the wall between perpendicular walls was too long and the top plate was not able to resist the lateral loads.
  Insufficient connection with perpendicular structure.
- Possible Improvements:
  Reduce the wall span between shear walls. Calculations are needed to determine the appropriate length.

Rupture of post-to-beam connection

- Description:
  Failure of the connection between the wood pole and ring beam was observed in some houses. The connection quality varies between the structures; it can be the pole sticking into a notch in the ring beam (Figure *34*) or just the ring beam nailed to the top of the wall. The connection failure was rarely directly observed as the infill is likely to collapse after the frame opened up.

Figure 34 Connection between the ring beam and the top of the wood pole

- Possible Causes:
  The weight of the infill masonry can explain high forces on the wood connection which are likely to fail if under designed.
- Possible Improvements:
  Use metal straps to strengthen the connection between wood elements.
  Train carpenters to use good notching techniques.

Plan configuration irregularities

- Description:
  Even though the house plans are generally regular and have a square shape we observed horizontal additions to houses which were badly damaged.
- Possible Causes:
  The irregularities in house plans can lead to a concentration of wind forces on the small part sticking out of the regular plan, causing greater damage to this areas.
- Possible Improvements:
  Avoid plan irregularities.

Water infiltration and saturation of mortar

- Description:
  The infill, when cracked or not plastered, is directly exposed to the rain. The rain water soaked the mud mortar, which caused a loss of strength and led to the collapse of the infill walls.

Figure 35 Wall totally collapse due to water infiltration and saturation of mud mortar

- Possible Causes:
  The infill, when cracked or not plastered, is directly exposed to the rain. The water soaked the mud mortar, which lose strength and lead to the collapse of the infill walls.
- Possible Improvements:
  Recommend cement plaster on the exterior wall to protect the mortar from the elements.

Deterioration of wood elements

- Description:
  Insect infestation and the resulting deterioration of wood elements was often observed both in villages and in the cities. Rotten wood due to water was not observed often.

Figure 36 Infested wood poles

- Possible Causes:
  The wood is not treated and the plaster hides the decay of the wood to the homeowner.

The wood type used by the homeowners appears to be rather water resistant, as we did not observe many wood elements with moisture decay or dry rot.

- Possible Improvements:
  Treat the wood before using it with Zincomat (Usually available in towns and cities we visited). Maintain the house to prevent insect infestation.

6.1.3. LIGHTWEIGHT WOOD ROOF COVERED WITH METAL SHEETS OR STRAW

95% of lightweight roof were damaged by the hurricane. The damages affected all shapes of roof whether it was monoslope, gable or hipped roof.

Failure of roof metal sheets

- Description:
  Failure of the roof metal sheets is probably the most typical damage we observed during the evaluation. Metal sheets were blown away by the high winds leaving the structure and its inhabitant unprotected from the hurricane. Metal sheets became high speed flying hazards when untied from the roofs. Roof nails are widely used but we also observed screw and washer connections that seems to be less resistant. The spacing of the nails is generally every 3 to 5 waves on the ondulated sheet and does not vary at edges or ridge.

Figure 37 Rusted metal sheet insufficiently nailed to the roof structure

Figure 38 Left: Screw and washer hole on a metal sheet
Right: metal sheet torn apart due to insufficient thickness of the sheet

- Possible Causes:
  Most of the metal sheets we observed were too thin to resist the high wind of the hurricane. The metal sheets looked torn apart and the roof nails sometimes ripped the sheet, called pull through or pull over failure.
  Rusted metal sheets were more likely to be damaged and are more fragile.
  The insufficient nailing of the metal sheets to the rafter can explain also the extent of roof sheet failure.
- Possible Improvements:
  Use thicker metal sheets that are galvanized or painted and maintained.
  Use roofing nails with adequate spacing.

Failure of roof-to-wall connections

- Description:
  Failure of roof-to-wall connection was often observed. For wood frame structures, the connection type is typically the rafter nailed down to the top plate with a flat interface between the rafter and the top plate. For masonry structures, the roof-to-wall connection is typically a bent rebar wrapped around the rafter or top plate. As the block masonry structures rarely have a ring beam, the rebar is typically embedded in the last row of block at wall corners and wrapped around the wood structure.


Figure 39 Left: Roof system-to-top plate connection
Right: Column-to-top plate connection

- Possible Causes:
  The nailed connections may be undersized insufficient for the hurricane-level demands.
  The spacing of the connections to the building are too large and insufficient (typically only at corners)
- Possible Improvements:
  Use metal straps to strength the positive connection.
  Provide connections between the roof and wall at each truss, not only at wall corners and ends.
  Use a reinforced concrete ring beam at the top of masonry walls, with straps embedded into the beam and connected directly to each truss.

Failure of gallery roof

- Description:
  Even though the majority of lightweight roofs were completely gone, we observed failure of the cover was sometimes initiated at the gallery roof.


Figure 40 Gallery roof damaged

- Possible Causes:
  The wind blowing below the gallery roof creates a local increase of pressure where the roof is more likely to fail.
- Possible Improvements:
  Disconnect gallery roof from the rest of the building, so that if it does fail, it does not impact the rest of the house roof.

Discussion on Vetiver straw or Palmis leaves roof
Natural cover better withstood the hurricane winds for possibly several reasons:

- The difference of pressure created by the wind blowing on a sloped surface is the cause of high uplift loads on roof structure when it is sealed with metal sheets. In the case of straw, the cover is permeable allowing the pressure to equilibrate and avoid a high uplift load.
- The rain soaked the straw and made the cover more heavy, helping to compensate against the uplift load

Additionally, metal sheets are an extremely dangerous flying object during high winds and can cause injury or death if they strike a person or animal. While natural covers are less likely to be a wind-borne hazard, they also do not protect well against wind-borne debris impact and therefore, inhabitants of houses with natural covers should evacuate to secured buildings in the event of high winds.

6.1.4. REINFORCED CONCRETE SLAB ROOF

- Description:
  They are typically 15cm thick integral slabs with rebars in both directions at 20-30cm. The rebars are often exposed due to insufficient cover and rusted in some locations. The concrete is made of round gravel and unwashed sand. Generally, the slabs resisted the hurricane well, but in case of an earthquake they can potentially be extremely dangerous for the people living in the house.


Figure 41 Exposed rebars and insufficient thickness of two slabs

- Possible Causes:
  The lack of training in good construction practices and money can explain the poor quality of the slabs.
- Possible Improvements:
  Retrofit the houses and replace hazardous slabs.
  Train masons and carry out an awareness campaign to the homeowners to explain the risks of a poor quality slab and a slab on a house which could not support it in an earthquake.

6.2. SCHOOL DAMAGE

The team did an ATC-45 rapid evaluation of one school in Jérémie, two schools in Beaumont, and three schools in Port Salut.

6.2.1. REINFORCED CONCRETE FRAME SCHOOL

We did not assess any schools in reinforced concrete frame that had damaged walls or concrete frames, but the lightweight roofs did have some damage. See the lightweight roofs section below.

6.2.2. PARTIALLY CONFINED SCHOOL

Flash floods damage

- Description:
  The Ecole Communautaire de Port-Salut was completely destroyed by a flash flood affecting the building foundation retaining wall and the building's masonry block walls.

Figure 42 Ecole Communautaire de Port-Salut located close to the ravine

- Possible Improvements:
  Building close to ravine should be avoided. An awareness campaign should be done for the population along ravines with the support of the mayor's office.

Failure of windows

- Description:
  Wood shutters and metal louvers failure was observed and let the wind blow inside the classrooms.

Figure 43 Left: Wood shutters failure
Right: Metal louver failure

- Possible Causes:
  For the wood shutters, the connection to the frame might have been insufficient to resist the wind loads. For the metal louvers, the frame was just placed in the opening and was not positively connected to the structure.
- Possible improvement:
  Use hurricane shutters or plywood sheets to protect openings when there is a hurricane warning. Positively connect the frame of metal louver windows to the structure.

Masonry gable wall failure

- Description:
  The masonry gable walls of two schools evaluated collapsed, causing the failure of the roof structure and enabling the wind to blow inside the structure.

Figure 44 Left: Total collapse of masonry gable.
Right: Partial collapse of masonry gable element due to the load from the roof structure.

- Possible Causes:
  High winds perpendicular to the gable wall in addition to the loads transferred from the roof structure can shake the wall out of plane and lead to the partial or total collapse of the normally unbraced panel.
- Possible Improvements:
  Replace masonry gable by lightweight material such as plank sheathing that is adequately connected to the roof and wall structure.
  Brace the gable with masonry shear walls.

6.2.3. WOOD-FRAMED LIGHTWEIGHT ROOFS

Wood trusses

Figure 45 Left: Wood truss with simple nailed connection
Right: Wood truss with gusset plate connection

Failure of connection

- Description:
  Rafter-to-rafter connection failure was observed in the Ecole Nationale de Beaumont. Truss-to-top of the wall connections made of bent rebar were observed in the school. Even though the connection did not fail, it is worth noting that the failure of the metal sheet cover of the roof may have reduced the loads on the connection.

Figure 46 Left: Failure of rafter-to-rafter connection
Right: Truss-to-top of the wall connection

- Possible Causes:
  The rafter splice detail was not sufficient and the cut of the lumber can explain why the wood was split apart by bending in the rafter under the wind loads. Additionally, the nails were insufficient.
- Possible Improvements:
  Avoid having the connection at mid-span, which is usually where bending loads are highest.
  Use nailed side plates for splice connections.
  Use metal straps for truss-to-top of the wall connection.

6.2.4. METAL-FRAMED LIGHTWEIGHT ROOFS

Similar to the houses, the most common failure observed was the metal sheets being blown away by the winds.

Roof trusses

- Description:
  The roof trusses we observed were made out of angles and connected with metal gussets, or made of 2”x2” tubes welded together at joints. The trusses are typically spaced every 3 to 4 meters and metal purlins span between the trusses with a spacing of 1m typically. The trusses were connected to the top of the wall with straps, or directly welded to rebars protruding from the walls. We observed failure of this last type of connection in the Sainte Dominique Congreganist school in Port-Salut (See Figure *48*).

Figure 47 Left: metal sheets blown away
right: Roof truss made of angles and metal gusset plates

Figure 48 Failure of the welded connection of the masonry gable

- Possible Causes:
  Truss-to-rebar welded connections were probably not sufficient to resist wind loads.
- Possible Improvements:
  Prefer strap connections. Welding in Haiti is typically not performed by certified welders and therefore not very reliable.

6.3. ENGINEERED BUILDINGS

We assessed several engineered buildings in Jérémie, Les Cayes and Port Salut.

Metal frame structures:

We evaluated the fire station of Jérémie, the structure did not suffer any damage.


Figure 49 Jérémie fire station

Figure 50 Undamaged steel frame water tower

In Port Salut a new hotel made of metal frame located on the top of the mountain exposed directly to the sea suffered extensive damaged to the windows and infill but the primary structure resisted.

Figure 51 Metal frame hotel in Port Salut

Reinforced concrete frame structures:
The police stations we visited suffered little damage to the wall structure. Nevertheless the lightweight roof of the Jérémie police station was blown away. The roof structure failed due to several reasons: poor connection to the reinforced concrete frame, failure of the metal sheet and failure of the some structural elements.


Figure 52 Left: Facade of Jérémie police station
Right: Light weight roof of a part of the police station

We visited a covered garage in Jérémie; the reinforced concrete frame did not suffer damage but the secondary structure of the roof failed. The top part of the gable wall was damaged too. See Figure *53*.
See below a reinforced concrete vetiver factory in Les Cayes that did not have structural damage, but some windows were broken.


Figure 53 Left: Covered garage in Jérémie
Right: Undamaged reinforced concrete factory in Les Cayes

The town halls - made of reinforced concrete frame with masonry infill and heavy roof - we visited in Port Salut, Jérémie and Beaumont did not suffer damage from the hurricane.

Partially reinforced building:
We visited offices between Roseaux and Jérémie, where the partially reinforced wall structural system resisted the hurricane well, but the lightweight wood roofs were blown away due to poor connection to the wall.

Figure 54 Wood top plate embedded in mortar to connect the roof rafters

Storm surge type of damage:
The coast of Port Salut is a tourist destination; along the beach numerous hotels are located close to the sea. Most of them suffered extensive damage, mainly due to the storm surge. The waves damaged the retaining walls of some hotels, causing the collapse of building walls, whereas hotels far enough from the shore were flooded but not destroyed (See Figure 55). The lightweight roofs were almost all gone for the hotels facing the sea.

Figure 55 Left: Collapsed hotel in Port Salut due to the storm surge
Right: Hotel not damaged but flooded up to the 1m above the first level

Combined RC and Steel frame structure
We visited a church in Les Cayes, which had a reinforced concrete (RC) structure for the level 1 and a combined steel frame and RC frame structure for the second level. The second level was completely destroyed by the hurricane winds. The concrete column failed at the base. The gable wall partially collapsed in the church. We observed very poor quality concrete (round gravel, brittle concrete) and blocks used for the structure.


Figure 56 RC and steel frame Church in Les Cayes

Roads and bridges:
Even if infrastructure was not the primary purpose of the reconnaissance mission we assessed some critical points. The flooded river in Grand'Anse eroded the banks and the foundations of the suspended bridge are now at risk. The road of Pointe Sable in Port Salut was heavily damaged by the storm surge. 3x1m pieces of concrete pavement were moved dozen meters inside the land.


Figure 57 Left: Jérémie suspended bridge
Right: Damaged Point Sable road in Port Salut

7. CONCLUSIONS

Technical and financial support for the affected areas is critical to the safe reconstruction, repair and retrofit of damaged buildings to be disaster-resistant, not only to future hurricanes, but also to earthquakes. The strategy for assistance may need to vary based on the region as accessibility and building type varied depending on whether the area was in a city, village or remote rural zone. Technical assistance should be provided in accordance with the applicable standards in order to aim for structures that will be safe in future disasters.

Considering the very high incidence of damage to roofs, technical support for ongoing or soon-to-be started roof repair should be prioritized. However, it cannot be blindly applied. Structures with other key structural deficiencies or built in risk-prone areas may not be better off in the next disaster if only the roof is rebuilt, and assistance should be provided to homeowners to better understand all elements of a disaster-resistant house so that additional key improvements can be made along with the roof reconstruction or repair.

Schools should be designed and constructed according to modern building codes and standards so that they can perform at a higher level in the next disaster, as required by the CNBH. It was apparent that resources, such as sawn lumber, steel framing, etc. were brought to the areas and applied specially to school buildings, however other deficiencies in the design or construction did not help the additional investment in these materials prove worthwhile as the building still suffered damage.

Shifting school construction types to multi-story reinforced concrete frames with infill because they performed well in the hurricane should be approached with caution. These buildings have a higher potential to incur injuries and death in the event of an earthquake if not constructed to the required standards for ductile earthquake-resistant construction.

Recently built and engineered structures, such as the fire station in Jérémie performed extremely well, whereas engineered structures that still may not have conformed to code required construction practices and material standards did not perform well, such as the church in Les Cayes. Construction quality supervision implemented in accordance with applicable buildings codes, such as the International Building Code is equally as critical as ensuring the design meets code requirements.

The location of buildings immediately along the coast or adjacent to ravines proved highly destructive for those structures. Careful site selection should be followed for reconstruction, paired with awareness materials for those that may tend to rebuild in these hazardous locations.

The rapid building evaluations, the materials used for construction, and the interviews with homeowners and builders reveal various quality gaps in the value chain of construction. These shall be tackled with an integrated approach combining technical and financial assistance to builders, homeowners and construction material producers. Training and awareness initiatives will be key to the amelioration of construction practices in the long term and to improved population safety.

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