

Partnership to Improve the Quality of Local Construction Materials in Haiti's Central Plateau

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ABSTRACT: *This paper presents a successful ongoing partnership between Clemson Engineers for Developing Countries (CEDC) and a concrete masonry unit (CMU) manufacturing plant in rural Haiti. The infrastructure destruction and resulting loss of life of the 2010 earthquake in Haiti highlighted the need for improved building materials and codes. This partnership has helped to improve the strength of CMUs in the plant, both creating a safer local built environment and expanding the economic opportunities for this plant. Using samples of aggregate and cement from the site in Haiti, students in Clemson performed experiments to optimise the CMU mix design and made other suggestions to improve efficiency and quality of their product. Consistency continues to be a challenge for the CMU plant, and this paper also describes proposed procedures to help the plant implement quality control and quality assurance plans.*

KEYWORDS: Partnership, Building Codes, Concrete Block, Construction Materials, Earthquake, Haiti

1 INTRODUCTION

Clemson Engineers for Developing Countries (CEDC) is a translational research and education program at Clemson University. By utilising a unique organisational structure that includes students in the classroom and year-round student interns in Haiti, CEDC has designed, implemented, and managed several projects throughout Haiti's rural Central Plateau. These projects have ranged from village water systems to repairing schools to constructing fish hatcheries.

Since 2012, CEDC has partnered with a concrete block plant in the Central Plateau to increase the quality of their products and the efficiency of their processes. This relationship has been mutually beneficial, as bolstering the operations of the facility not only allows CEDC projects to be built with higher quality materials, but also enables

the block plant to expand their own enterprise, promoting job growth and economic development in the region. This paper describes the process by which CEDC has partnered with the block plant, the obstacles this endeavour has surmounted along the way, and the tangible results of this relationship between Clemson University and a small business in Haiti's Central Plateau.

2 PROJECT BACKGROUND

2.1 CEDC in Haiti

CEDC formed organically when a small group of undergraduate and graduate engineering students showed an interest in using their technical skills to serve in an international context. In June 2009, a group of six students travelled to the village of Cange in Haiti's Central Plateau

to perform assessments and survey a site where Clemson engineers could make an impact. This information would be used to begin a design course in Fall 2009 to begin addressing Cange’s engineering issues (Plumlee 2012). The catastrophic earthquake in January 2010 greatly increased demand for aid in Cange and the Central Plateau as refugees from Port-au-Prince flocked to the area. Since May 2011, CEDC has had a near-continual student presence in Cange, with student interns providing project oversight and serving as the liaison to the community as the scope and scale of projects began to expand. These interns have been able to manage the completion of the USD \$1.5 million Cange municipal water system, with support from donors, industry professionals in the United States, and local construction crews in Cange, in addition to several other projects.

2.2 Concrete Masonry Units in Haiti

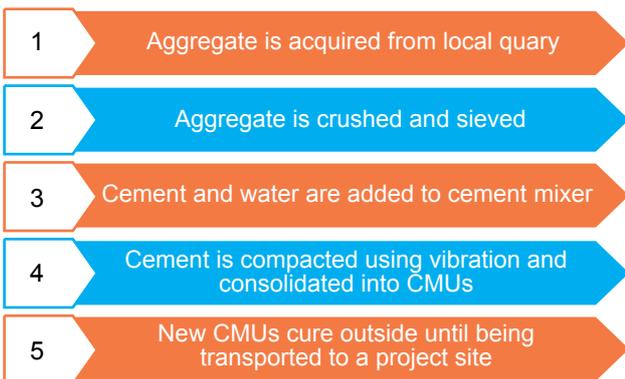
The January 2010 earthquake in Haiti was catastrophic to the people and infrastructure in Port-au-Prince. Before this event, almost 90 % of people in the capital city were living in small concrete structures made of concrete masonry units (CMUs), many of which had inadequate or no reinforcement and most of which were not held to any sort of national or international standard (Disasters Emergency Committee 2015). Building codes, such as those prescribed by the American Standards for Testing and Measurements (ASTM) in the United States or the Code National du Batiment D’Haiti (CNBH) in Haiti, are crucial to the design and construction of safe buildings and structures that can withstand loads from natural occurrences like earthquakes. It is estimated that when the 7.0 magnitude earthquake hit, nearly half a million people were killed or injured, mostly from building collapses and falling objects like CMUs (CNN Library 2015). A USGS survey of the event attributed the massive loss of human life to the “poor quality of much of the construction” and suggested that “the earthquake did not produce ground motion sufficient to severely damaged well-engineered structures” (Eberhard 2010).

A review of the 2010 earthquake damage by a team of engineers cited that shear failures in rigid and interior walls due to low-quality CMUs were responsible for a majority of structural failures (Kijewski-Correa 2012). These shear failures transferred large horizontal seismic forces to insufficiently designed or non-engineered concrete columns thereby leading to structural failure (Kijewski-Correa 2012). The exact quality of such CMUs is not known but a recent informal survey of block manufacturers around the Port-au-Prince area found that they produce CMUs at an average compressive strength of 4.45 MPa (approximately 650 psi) (Build Change 2012). For reference, the Ministère des Travaux Publics, Transports et Communication (MTPTC) guidelines in Haiti dictate that a CMU’s compressive strength should meet or

exceed 15 MPa (approximately 2,175 psi) (CNBH 2013). ASTM C90-16 dictates a minimum compressive strength of 1,800 psi (12,411 kPa) or an average of 2000 psi (13,790 kPa) for three CMUs (ASTM 2016). In the wake of the devastating earthquake, many experts and critics have therefore pointed to the lack of adherence to building codes as a major reason for the catastrophic nature of the event (Lindell 2010). Unfortunately, Haiti’s strained political state makes public oversight of building codes through proper inspection and approvals extremely difficult (Kijewski-Correa 2011). Non-governmental organisations (NGOs) and federal projects could conceivably import building codes for externally funded projects like hospitals and schools, but smaller projects such as homes and shops would still lack these life-saving construction standards (Kijewski-Correa 2011). Consequently, it is not enough to simply provide Haitian masons, contractors, and constructors with a one-time access to superior construction methods.

Since its inception, CEDC has possessed a core principle that the organisation would only design to internationally accepted construction standards such as the International Building Code (IBC) which references the ASTM standards with regards to construction materials (International Code Council 2015). In addition, many sustainable construction practices in the developing world dictate that local materials should be used whenever possible (Pocock 2016). CEDC, in an effort to follow these practices in the developing world holds the philosophy that locally available materials and labour should be utilised with projects without compromising the safety of the structure. However, no CMU products meeting ASTM or CNBH quality requirements were available in the Central Plateau. A small CMU plant was contacted near the town of Domond along National Route 3 in the Central Plateau. This particular plant was originally established in 2011 through partnerships with the Haitian government, Partners in Health/Zanmi Lasante (a large and renowned public health NGO), and a small NGO known as 1,000 Jobs for Haiti (Farmer 2012). While this plant’s ambition was large, the actual quality of the block itself was lacking in compressive strength, durability and consistency; for instance, CMU samples that students obtained from the plant during the first visit in 2011 could be broken by students using only their bare hands or by dropping it from a mere 0.5 to 1 m (2 to 3 feet).

A team of Clemson Civil Engineering students began to establish a professional relationship with the owners of the CMU plant. The idea was that such a partnership would be mutually beneficial to both parties: CEDC would be able to use higher quality CMUs for its projects, while the CMU plant would increase their marketability and production capacity. Figure 1 shows two Clemson engineering students with the block plant employees.



Top to bottom:
 Figure 1. Clemson engineering students with CMU plant employees
 Figure 2. The quarry where aggregate and sand are excavated
 Figure 3: Process flow diagram of CMU manufacturing plant in Haiti
 Figure 4: An employee sieving aggregate with a shovel

3 CONCRETE MASONRY UNIT PLANT

3.1 Plant Overview

The Domond CMU plant works on a project-by-project basis, selling various types of blocks to constructors and contractors around the Central Plateau. They have several teams of workers around their factory. One team works at a nearby quarry (see Figure 2), excavating aggregate and sand and then transporting it to their main facility.

All of the water in the plant is provided by a single hose, which is sourced from a local well. Cement is purchased from local vendors who retrieve it from the cement manufacturing facility in Port-au-Prince. Most CMUs are created for specific contracts, but the plant also creates and stores CMUs for smaller projects as well. There are approximately 20 people employed by this enterprise.

3.2 Baseline Capabilities and Operations

The following information describes the operations of the CMU plant prior to CEDC interventions and are based on the notes of the CEDC students during their first visit to Domond. Prior to the partnership with CEDC, the block plant possessed the following equipment:

- Rock crusher;
- Cement mixer;
- CMU compactor;
- Oven (to dehydrate aggregate);
- Sieve screen;
- Shipping container;
- Electronic scale; and
- Several out-of-service pieces of equipment, such as a mechanical sieve and cement mixers.

The process by which the CMU is manufactured is summarized in Figure 3. The aggregate is transported throughout the plant using wheelbarrows. Most aggregate is initially crushed using a large mechanised rock crusher. After this, an expanded metal sieve sorts the aggregate by size, which it is then stored in an outdoor, uncovered bay. If the aggregate exceeds the acceptable size, it is returned to the rock crusher to be crushed again, after which it will again be sieved. The sieving process is displayed in Figure 4.

4 RESULTS AND DISCUSSION OF CEDC PARTNERSHIP

4.1 CEDC/Block Plant Relations

During this first visit to the Domond CMU plant in 2012, CEDC students took note of the entire process summarized above and gathered several samples of coarse/fine aggregate, cement, and water to test in the Clemson Civil Engineering materials lab, while also recording the type of equipment available and the layout of the CMU manufacturing facility. During this time, the block plant had no clear mix design. The owners roughly estimated



Top to bottom:

Figure 5: Manufactured CMUs curing outside

Figure 6: A photo of CMUs prior to the partnership with CEDC

Figure 7: The mix design painted on a wall at the CMU plant

proportions of raw materials in the concrete based on visual consistency.

With this data, Clemson students in the classroom set out to test the materials acquired in Haiti and calculate a mix design that would most effectively use the available aggregate, sand, and cement. With the support of a local cement manufacturing facility in South Carolina, Clemson students identified that a water/cement ratio of approximately 0.35 would be most appropriate (Cemex 2008). This ratio is dry enough for the factory to easily work with through the manufacturing process but has a high enough slump that the mix can still be easily vibrated

into its form. The mix design was roughly converted to units of buckets and litres so that Haitian labourers could easily measure cement, sand, and water quantities with readily available five-gallon (~19 L) buckets and water bottles. This mix design was subsequently introduced to the owners of the CMU plant in March 2013 during the CEDC Spring Break trip. The block owners then painted this mix design on the side of their plant for all their labourers and workers to use as a reference, as seen in Figure 7. This mix design calls for one bag of cement, fifteen buckets of aggregate (sand and gravel), and one bucket of water for each batch of thirty-three blocks.

After the mix design was introduced and adopted, CEDC students began to address other areas of concern in the manufacturing process, such as the lack of quality assurance/quality control procedures and worker safety. Other student groups partnered with the CMU plant at this time as well in order to repair some of the derelict equipment around the facility.

4.2 Post-CEDC Intervention

In Spring 2015, after working with the Domond CMU plant for almost two years, CEDC students carried six sample CMUs from Haiti back to Clemson for official ASTM C-140 testing by Soil Consultants Incorporated (SCI), an engineering firm based out of Charleston, SC. SCI tested both gross compressive strength and net compressive strength. Gross compressive strength is the block’s maximum supportable compressive load divided by the total cross-sectional area, whereas net compressive strength is the maximum supportable compressive load divided by the total cross-sectional area minus the cross-sectional area of the hollow cores in the CMU. The ASTM standard specifies minimum net area compressive strength not gross compressive strength (ASTM 2016).

The net compressive strengths of the Haitian CMUs are reported in Table 1. Two of the three samples tested for compressive strength exceeded the ASTM C90-16 standard of 1,800 psi (12,411 kPa) in a standard compression test (ASTM 2016). The average is approximately 2,200 psi (15,168 kPa) that exceeds the ASTM C90-16 standard of 2,000 psi (13,790 kPa) for an average of three CMUs and slightly above the MTPTC standard of 2,175 psi (14,996 kPa). Full test results are located in Appendix 1.

Prior to the updated mix design, the compressive strength of the CMUs was estimated at a maximum of 1,200 psi (8274 kPa), according to compressive strength measurements by the block plant owner, using a compression machine at a local trade school. Although the pre- and post-intervention blocks were tested at different facilities, the change in compressive strength is substantial. Figure 8 provides a comparison of the averages of our testing pre- and post- CEDC intervention and also shows ASTM and MTPTC standards for CMU compressive strength.

Table 1: Net compressive strengths of sample CMUs after CEDC support

Block #	Compressive Strength	
	kPa	psi
1	17,651	2,560
2	10,204	1,480
3	17,720	2,570

While this significant increase in CMU strength is an important accomplishment, the consistency of CMU strength is just as critical. One of the CMUs brought back to the lab did not meet the strength requirement due to issues with honeycombing, indicating that the problem was likely with production techniques. Figure 9 shows CMU blocks manufactured at the plant in November 2015. These CMUs exhibit far less honeycombing and other structural integrity issues than block manufactured prior to the CEDC partnership, seen in Figure 6. Honeycombing is still a problem at the facility, but this can be attributed to the fact that the workers at the plant deviate from mix design procedure at times.

4.3 Future Plans

Now that the majority of the CMUs are meeting ASTM standards, efforts must be made to ensure a more consistent output. The CEDC team and plant management concluded that the most effective way to achieve a consistently high quality product is to simplify the production process and systemise every aspect to leave little room for error. Beginning with the aggregate, a second sieve will be added to reduce fine particles and improve the aggregate grading. This addition of another sieve will allow the plant to sort the aggregate more precisely, as well as in an

additional gradation. The additional aggregate size will enable the employees to create more accurate mixes that have less void space, rather than having to manually estimate aggregate sizes.

Next, the mixed concrete will be processed with the same machinery, but the mix design will be more accurately followed. Some workers of the plant do not recognise concrete production as a science or appreciate the importance of the mix design. In addition, many companies in Haiti reduce the amount of cement (the most expensive component in basic concrete) in the mix to make the concrete cheaper and easier to sell. This mix is aesthetically similar but much weaker. To complicate matters, clients of the block plant have indicated that the surface voids created by this weaker mix is actually preferable since it provides a more adhesive surface for the stucco finish common in Haiti. Therefore, CEDC students are now communicating with the owner of the block plant in order to devise strategies that can ensure adherence to the mix design while accounting for a block that provides the customer-requested surface texture. The next trip to Haiti will include a meeting with the owners to discuss how they can produce CMUs with consistently higher strength by following the advised mix design.

Finally, the curing process will be overhauled, as proper curing drastically improves the strength of concrete (Holliday 2011). The curing process is an essential part of the concrete mixing and strengthening process (Kosmatka 2016). CEDC hopes to work with the plant to bolster this step in their procedure by placing their CMUs in a shipping container for the initial week of curing. The enclosed environment will retain moisture, which the plant can use to artificially create a humid environment by placing bowls of water throughout the shipping container. While the temperature and humidity of the container will still vary, the overall conditions of the shipping container

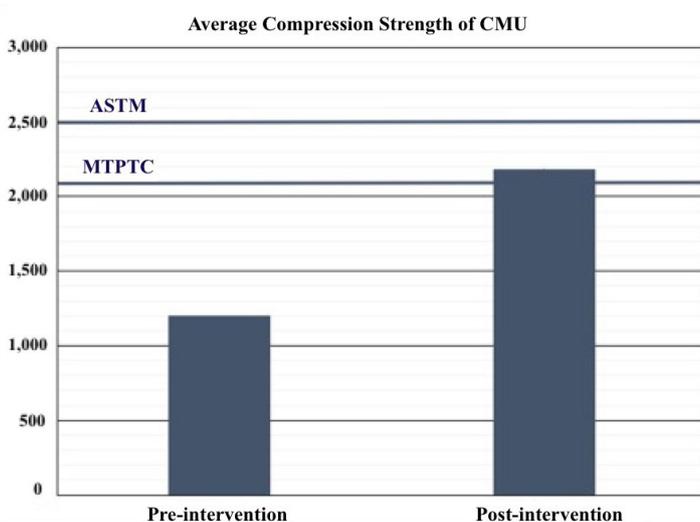


Figure 8: Average compression strength of CMU



Figure 9: A photo of CMUs currently produced by the plant

are going to be more conducive to curing than leaving the blocks outside. In addition, the higher curing temperatures in the container accelerate strength gain, expediting curing time (Kosmatka 2016). The final results should create a higher quality block with more thorough and consistent strength.

5 CONCLUSIONS AND RECOMMENDATIONS

The ramifications of such an effort highlight the impact that a student group can make on a local business, but also on the necessity for a long-term partnership. Even though the CMU consistency has yet to be established, this CMU plant is now distributing CMUs at a considerably higher quality than before partnering with CEDC. This higher quality has been noticed by local contractors and businessmen, who now purchase from the plant over other plants in the area. Since the relationship between the plant and CEDC started, the facility has greatly expanded with the addition of several pieces of equipment and trucks to transport block to various job sites.

In 2010, hundreds of thousands of people lost their lives due to structural failure of concrete buildings, in many cases stemming from poor construction materials (Marshall 2011). Now, due to collaboration of CEDC and local Haitians, buildings in the Central Plateau can be built with much stronger CMUs that are nearly to the ASTM C90 standard. These efforts can easily be replicated throughout Haiti and around the world. CMU plants litter the developing world, and in most places, their procedures can be refined to be more productive, efficient, and effective. On a broader scale, other aid groups should consider adopting more stringent standards to ensure that those in developing countries are not unnecessarily exposed to unsafe conditions.

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APPENDIX

Appendix 1: Full results from testing of post-intervention CMUs



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Date: August 21, 2015
Client: Clemson University
Clemson, S.C.

SCI Report No: GRATIS
Date: 8/21/2015
Sampling by: CLIENT
Units Received: 8/10/2015

Unit Configuration: SINGLE END

Unit Designation/Description:
6'X8"x16" Normal Weight
CLEMSON-Haiti15-1N6SE

Summary of Test Results

	Required Values	Tested Values
Net Area Compressive Strength	2000 psi	2203.333 psi
Gross Area Compressive Strength	N/A psi	1413 psi
Density	>125.0 pcf	130.60 pcf
Absorption	13 pcf	10.66 pcf
Minimum Faceshell Thickness	1.25 in	1.147 in
Minimum Web Thickness	1 in	1.116 in
Equivalent Web Thickness	2.25 in	4.17 in
Equivalent Thickness	CLIENT in	3.683 in
Max Variation from Specified Dimensions	0.125 in	0.375 in
Net Cross-Sectional Area	CLIENT in ²	56.818 in ²
Gross Cross-Sectional Area	CLIENT in ²	87.891 in ²
Percent Solid	CLIENT %	64.34 %
Moisture Content	CLIENT %	11.88 %

Individual Test Results

Block ID	Average Width (in)	Average Height (in)	Average Length (in)	Rcv'd Weight (lb)	Max Load (lb)	Cross Sectional Area		Compressive Strength	
						Gross (in ²)	Net (in ²)	Gross (psi)	Net (psi)
Unit #1	5.625	7.25	15.625	29.414	133,500	87.891	52.249	1520	2560
Unit #2	5.625	7.25	15.625	32.765	88,000	87.891	59.544	1000	1480
Unit #3	5.625	7.25	15.625	32.231	151,000	87.891	58.662	1720	2570
Avg	5.625	7.250	15.625	31.470	124,167	87.891	56.818	1413	2203.33

