The Gabion House Approach

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Abstract

A gabion is a wire cage that is filled with rocks and then stacked usually in retaining wall situations. However, in the case of the Gabion House reported in this paper their use and design was modified to allow them to be stacked to form a load-bearing “masonry” type walls. This shelter/building approach was developed in the post earthquake situation in Port au Prince, Haiti to use the extensive amounts of rubble generated by the January 12 2010 earthquake. The costs and the logistics to remove the rubble were a significant challenge to shelter agencies working in the ravines and valleys typical of the Port au Prince typography. The lack of access meant that the rubble would have to be removed manually and the costs of clearing and dumping were between US$30 to $60 per cubic metre. This approach also included the use of hand crushers that allowed further re-use of the rubble for footings, plasterwork and concrete aggregate.

Post disaster reconstruction approaches often attempt to reverse the impacts of a disaster by trying to simply rebuild back what was there originally. In a sense it tries to “reverse” the process caused by or resulting from the disaster. However, in many situations where this “reversing” is simply not possible requires instead an innovative approach to get back to where you were previously; to allow any build back better. And this paper presents a possible “operational” example of that in the post earthquake context of Haiti. There are nearly 250+ of these houses in the planning stage as at December 2010 with a proof of principle house constructed and 4 further prototypes testing a 2 storey option currently under construction.

Keywords: Housing, seismic, recycling, gabions

1. Background

A Richter scale 7 earthquake struck Haiti on January 12, 2010 at around 5pm. It was shallow and located 22 kilometres from the capital city of Port au Prince and resulted in 230,000 fatalities and extensive building damage that only became evident the next morning.

In the following days after the emergency response a clearer understanding of the extent of the building damage developed. Haiti does not have any seismic building standards and hence the impact of the seismic event cut across all sectors of Haitian society. However, as the disaster response moved into the recovery phase there developed a time lag between the rural and the urban transitional shelter responses with the rural one leading. This was due to the terrain, housing density and building typology of the urban setting and was particularly noted in Carrefour and Port au Prince. A study by UN Habitat the year before in 2009 on informal settlements in Port au Prince showed the following[1]:

- Metropolitan Port au Prince was home to 2.7 million inhabitants with most living in “informal” settlements which are areas where access to land and services are not secure. For example, land title is usually legally vague or more often non-existant (thus people could be thought of as “squatting”); they had limited or no access to safe drinking water, sanitation and waste collection through mazes of narrow lanes and alley ways. Roads are under sized and hence traffic grid lock was the norm.

- Nonetheless, most of the houses were built of “durable” materials and typically included concrete floors, concrete frames with concrete block infil walls and solid timber doors.

- Haiti is the poorest country in the western hemisphere and is ranked amongst the least developed countries with 76% earning under the $2US/day poverty line with the average income for a poor family being $0.44US/day (many of these families were living in rural areas).

- Haiti is one of the most densely populated countries in Latin America with 310 inhabitants per square kilometer

- In metropolitan Port au Prince 53% of informal settlements live in ravines and 38% live on hill sides.

[1] Strategic Citywide spatial planning: A situational analysis of metropolitan Port au Prince, Haiti UN Habitat 2009

And for these reasons perhaps it was not unexpected for such a lag to occur?

The media (and to some extent the humanitarian response) focused on the issue of land tenure as being the key to moving forward but it became increasing apparent that a more practical and innovative approaches were needed given the apparent long timelines for any legal resolution. The typical transitional shelter developed by aid agencies worked in rural areas where land was seemingly more available, but was problematic in the cities where land was scarce. Pressure was also applied by the large camp population (around 1.3 million people at the time of this work) living in difficult circumstances and exposed to any potential hurricane event; and then there was a cholera outbreak if that was not enough. But it was the practicalities of rubble removal that was first estimated as 20 million cubic metres (later revised to 10 million) that would need to be manually removed from these ravines and hillsides and it's replacement essentially with the same amount to build back that was the "driver" for this alternative approach. Approximate figures suggested that it would take 27.4 years for the local quarry sector working 24/7 to produce the necessary 10 million cubic metres of materials. Moreover, the cost of mechanically clearing and dumping the rubble was estimated at between US$32.50-$58 per cubic yard[2] by one source and US$26-$80/tonne by a second source[3] with a cost of between US$20-25/tonne[4] (all things being equal) to bring in new material washed aggregates and sand. Thus, it was going to cost in the order of US$500 million and take 27+ years just to get ready to reconstruct the houses lost in the earthquake.

Hence, simply stated the idea was to re-use the rubble on site to rebuild using local labour and manual crushing machines to additionally produce road and alleyway hard fill, concrete aggregates and plaster sand.

2. The Principles

A gabion is a wire cage that can be stacked vertically in a wall and then packed with various materials Normally they are used as retaining walls, but in the case of the Gabion House their design has been modified to allow them to be stacked to form a load bearing, masonry wall capable of carrying both vertical and horizontal (lateral wind or seismic) loads.

To enable the gabions to effectively perform as a load bearing wall required they should:

- Be laid in stretcher bond.
- Be wired together, both vertically and horizontally.

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[2] NY times, Oct 17th,2010. "Weary of Debris, Haiti Finally Sees Some Vanish"
[3] Private Sector Participation in Municipal Solid waste Management; part iii by Sandra Cointreau-Levine pub by SKAT 2000 pg 5; prices adjusted for inflation.
[4] Based on local costs to a "typical" site.

- The gabion tops are open to further enhance “meshing” and load transfer.

Figure 1: The construction, placement and layout of gabions

- The masonry material packed tightly to minimize compaction.

- Be protected from the weather by the application of a plaster skin both inside and outside made with sand from crushed rubble.

- Be restrained and compressed at the top of the gabion wall. This is achieved by 12 mm vertical rods at approximately 2 metre centres around the perimeter that clamp a timber top plate to which the bottom chord of the trusses are attached. This ensures that the top section of wall can develop adequate shear friction for in plane loads and transfer of out of plane loads via the trusses to resisting walls.

- Plan dimensions of maximum 3:1 and vertical for walls of 1:1 with only 2-3 stand windows and 2 standard door openings.

3. The Benefits

The technical advantages of gabion cages are that they provide a matrix of wire mesh throughout the body of the wall which offers confinement of the masonry, both horizontally and vertically together with the wall compression provided by the tie down rods produces a thick, robust, redundant and resilient structure. In addition, the mass of the walls (and the concrete floor) provides a thermal buffer that smoothes out temperature variations and together with a cross ventilation approach provides better thermal comfort levels than other types of low mass buildings.

However, the approach has significant social benefits in that the construction processes are semi-skilled and will enable employment within the affected community. Moreover, there is also the possibility of setting up small enterprises to produce the gabions and the associated crushing of rubble to produce building products.

The overall costs of construction are low and depend on labour costs, proximity of rubble, and size and amenities included in the house. In the context of Haiti 2010, this represented producing a $24m^2$ house for between US$4-5,000 and between US$3-4,000 if rubble is available directly from the site (see alter cost breakdown).

4. The Architectural Design Criteria

The original pilot included elements that were appropriate to the Haitian context and climate such as a shaded verandah for the front and rear entrances. Such spaces are fundamental as "transition" zones between inside and outside where one prepares by putting shoes on or off or changing clothes. These transition areas are typical in tropical climate architecture as they ensure cooler spaces because of the increased air flow and become popular with house occupants. The gabion house is based on a "core house strategy with the option of turning the two side windows into access ways for future extensions. Personalisation is encouraged and the spaces have been designed to allow multiple uses and activities in a compressed area. A two storey "shop house" was also developed that would allow a mixed use with commercial/retail on the bottom floor and residential above (or residential on both levels).

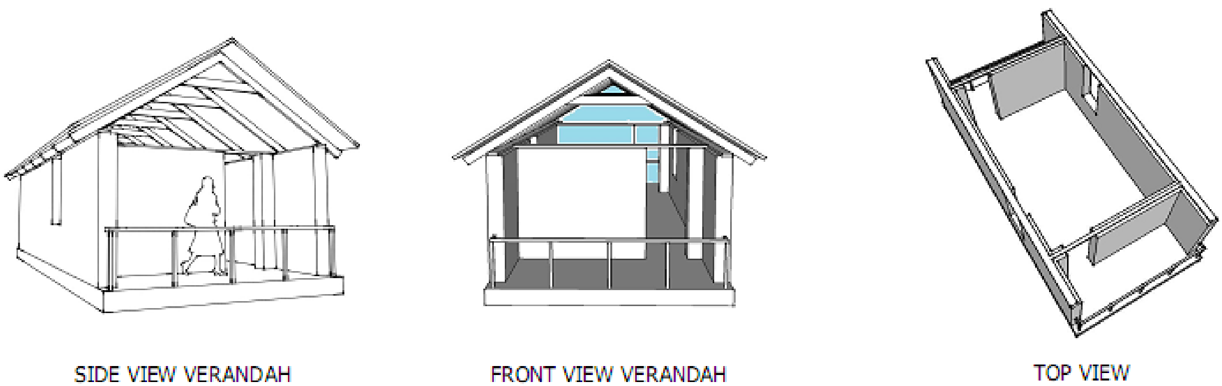

Figure 2: The Gabion House design

5. The Structure Design Criteria

Gabions are by their nature monolithic blocks. The wire cages provide a tensile capacity that holds the rock material as one block and when these blocks are stacked to form walls they achieve stability essentially by their relatively large mass compared to the remainder of the building. Hence to be effective, gabions should be used in relatively squat structural systems. However, to ease these issues threaded rods are inserted into the gabions and tensioned against the wall's top plate to achieve the following:

- To increase the load bearing on the top gabion block and hence the friction capacity of the blocks.

- Provide a tensile uplift capacity within the wall and thus mitigate the squat requirement.
- Provide a level of ductility for the structural system and hence minimize the design seismic load.

This has been the basis for the attached seismic design calculations. Lateral loads (hurricane and seismic) produce in plane and out of plane forces and buildings require systems that resist the first and transfer the second. This house uses gabion walls to resist in plane forces and diagonal ties (timber or steel to be confirmed based on costs) at ceiling level to transfer out of plane forces to these walls. Consequently, the plaster finishing is not used structurally but instead relies on good packing of gabions.

6. The Construction Process

Footings: The foundations are designed as a continuous strip. In stable soil conditions, the trench dug is twice the width(w) of the wall and (2w - 150mm) deep. In this instance the gabion wall is 300mm wide so the foundation trench is 600wide and 450 deep. The trench is filled with rubble which has been broken down using a sledge hammer to a maximum size of 100mm and is then compacted by hand using a tamping rod and finally leveled using 20mm aggregate from crushed rubble.

Bond Beam: A 150mm thick reinforced bond or tie beam is cast on top of the rubble foundation formed above. The concrete is mixed using one part ordinary Portland cement, 2 parts sand crushed from concrete block rubble and 4 parts aggregate using 20 mm crushed concrete rubble; a 1:2:4 mix.

Threaded Steel Bars: In order to ensure that the top of the wall can resist seismic shears, threaded steel rods are screwed into 100 x 200mm rectangular steel plates 6mm thick cast into or placed directly under the bond beam. These are spaced at an average of two metres intervals and protrude 900mm above the bond beam. As the wall construction proceeds additional rods are connected using threaded couplers ultimately to the top of the wall.

Gabions: The gabion baskets are made using (A52) steel reinforcing mesh lined with additional chicken wire infil mesh. They are 600mm long x 300mm wide x 300mm high to minimize sheet wastage. The mesh is cut into the appropriate shape using bolt cutters which is then lined with chicken wire and the sides and ends are bent into the required “box” shape and fastened together with tie wire. The first course of gabion baskets are placed on the bond beam and fastened together using tie wire. They are then filled with rubble manually ensuring minimizing voids are kept to a minimum and that only rubble with one flat side is used on the two exposed faces of the gabion basket; this is important as it minimises the amount of sand/cement render used and ensures that there are a minimum of voids next to the sides of the baskets. The second course is then laid in 'Stretcher' bond and subsequently tied to the first maintaining both vertical and horizontal aspects. Half gabions are placed wherever necessary to maintain the stretcher bond. A timber fixing block is placed in every 2nd course adjacent to the joinery frames and secured in place by 2 screws. Work continues in this manner until 4 courses have been laid. After the 4th course, a bed of leveling mortar is placed and the next course of gabions is embedded in this while still moist. The next three courses are placed as before until the seventh course has been laid. We are now at the top of the windows and need to place 2 x 1.5m lengths of 100x100x6mm angle iron on top of the window surround and spanning 300mm on to the adjoining gabions. The supporting gabions and the supported gabions are tied to the angle iron with tie wire. When the eighth and final course is in place the top of the gabions are covered with a lid made from the gabion mesh and a leveling bed of mortar is placed on top of the final course. A 200mm x 50mm timber wall-plate is then bedded in the mortar so that the threaded steel rods protrude through the wall-plate and through a 100mm x100mm steel plate which is secured on top of the wall-plate and the entire fixed in place with a 12mm hex nut & washer - tightened to the engineer's specification.

Joinery: The door and window openings are framed with 18mm plywood and 100mm x 50mm timber is fixed to the plywood as window & door frames. The doors are traditional sheeted timber and bracing fixed with heavy T hinges to the frames, to resist strong winds. The windows are traditional shutters made from planks with bracing and also fixed with strong hinges to the frame.

Plastering: A minimum of two coats of sand/cement render are applied to the exposed wall surfaces both inside and outside, the final coat being floated to give a nap finish. The plaster is a 4:1 sand/cement mix; the sand is produced on site from crushed concrete block rubble using a hand operated crusher

Figure 3: Joinery and plastering

7. The Production of Building Materials from Rubble

The composition of the rubble varies from site to site, and as such, a selection process would be required to ensure appropriate material selection. Earlier investigations indicated that concrete from the slabs and columns were suitable for the gabions and that the concrete infill could be used for plastering. In addition, the rubble can be processed into hardfill, aggregate and sand by hammer milling and screening. A local supplier had procured 20 manual rock crushing machines and these were included as part of the overall gabion house strategy. It is envisaged that plastering sand (2mm down), fine aggregate (10mm down) and coarse aggregate (20mm down) can be produced from selected rubble for use in the gabion houses. Currently, concrete slabs produce the best aggregate while concrete blocks can be used to produce plastering sand and it may be possible to value add by producing products such as concrete roofing tiles. Feasibility tests were planned using a tile machine and style developed in Cuba. Because selection and quality control are paramount to the success of both the buildings and the businesses supplying the products, training programs are being developed.

8. Enterprises

The following small scale enterprises could be developed to supply an active Gabion House construction sector. While many of these operations could be relocated, there are considerable economies to be achieved by a well established permanent site if transport costs are not too expensive. Operation of hand or mechanically powered jaw crushers could be combined with screening and a hammer mill to more efficiently produce graded sand products. One owner/operator would need to employ at least 5 persons for a continuous production operation for one of these products as a multi-pass crushing process would be anticipated. The production of gabions could be a mobile operation, and could also be done by women. On the other hand the production of concrete roof tiles would require a permanent site. And if products were standardised in terms of dimensions and together with quality control could allow excess production to be sold to other to other construction sites.

9. Training

Currently, training programs for the operation of the crushers and the selection of rubble are being developed by a private consortium. (HayTrac, Cemex, Unibank) while training for the construction of the gabion houses would be part of any housing programne. Training manuals, combined with a video, will outline the process of construction. These will be adapted to suit the local labour force.

10. Cost Breakdown

The projected cost based on a 24 sq. m2 Gabion Core House is nearly US$4,000 (as at December 2010 see table below). This cost compares favourably with some of the costs for transitional shelters particularly if the labour costs which are going back into the community are taken off.

Table 1: Gabion House Costs (US$ as at Dec 2010)

ITEM	PROJECTED COST
GABIONS 5 Rolls of square mesh 6 Rolls of chicken wire	 $900.00 $500.00
CEMENT 35 bags @ $7.50	$262.50
JOINERY 3 sheets of 18mm ply @34 ea.	$102.00
Doors & Windows	$250.00
RUBBLE Cost of collection & transport.	$200.00
LABOUR Making of gabions Filling gabions Crushing rubble	 $130.00 $130.00 $480.00
THREADED ROD	$160.00
PLASTERING	$250.00
ROOF	$600.00
TOTAL	**$3,964.50**

11. Conclusion

The gabion house has unique features relevant to the Haitian situation such as the access to re-useable rubble and consequently maybe specific to the urban context of Haiti. Nonetheless, where there are adequate supplies of rocks could mean that this housing alternative is viable. Moreover, the development of a more economic basketing material would also be beneficial.