Structural Design of AguaClara Plants

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Abstract

The AguaClara team at Cornell has focused on the unit process and hydraulic design of municipal drinking water treatment plants and has left the structural design to the Honduran engineers who are also responsible for site surveys and construction supervision. There are many opportunities for structural design work and research at Cornell that could significantly improve the design and reduce the construction costs. Although the structural design based on locally manufactured brick, re-bar, mortar and poured concrete columns is a common construction technique in Honduras, there may be opportunities to further optimize this construction technique and there may be alternate construction techniques that would be more cost effective. As a first step it would be beneficial to evaluate the current construction techniques using modern tools of structural analysis. A second opportunity is to design a more cost effective foundation for the plants. A third opportunity is to begin to automate the structural design. A fourth opportunity for research would be to develop a set of material strength tests that could be used at AguaClara construction sites for quality control.

Students	4
Skills	Structural engineering (preferably senior level or M.Eng.)

1 Geotech-Structure interactions and the slab design

The design for AguaClara tanks begins with a 60 cm rock/concrete layer (See Figure 1). The rock/concrete layer is created by first carefully placing large rocks and then pouring a thin mixture of concrete into the voids. The purpose of this layer is apparently to provide a thick slab that acts like a beam and that will be strong enough to resist cracking from moments or shear due to uneven settling of the soil. It is not clear if this layer is necessary for AguaClara plants. Elimination of this layer would significantly reduce excavation and the labor of placing the rocks. The rock layer might be more necessary for water storage tanks that don't contain interior walls. In the case of the AguaClara plant, the reinforced walls that are connected with rear to the slab form a monolithic

Figure 1: Construction technique for the slab at a 12 L/s plant at Alauca, El Paraiso, Honduras during the summer of 2011. The section of the slab with few vertical re-bars will support the sedimentation tanks. The vertical re-bars will support the channel walls for the flocculator.

unit. The reinforced walls act like very large beams that prevent the slab from bending. Analyze the effects of shear and loading conditions for the slab. What happens if floc tank is full and the sedimentation tank is empty? Does the rock base provide any advantage? What alternative foundation designs could be used to reduce construction costs?

The structural engineer designs the plant assuming the soil supports 0.5 $\frac{kg}{cm^2}$ (49 kPa). This is equivalent to a column of water 5 m deep. Thus it appears that the pressure applied by AguaClara plants is smaller than even a relatively low strength soil. Some soils resist up to 3-4 $\frac{kg}{cm^2}$.

2 Structural Analysis of AguaClara Tank Walls

AguaClara plants use a poured concrete slab and stacks of bricks (see Figure2) with both horizontal and vertical re-bar for reinforcement. The relatively shallow tanks are approximately 1.6 m to 2 m deep and thus the hydrostatic forces are relatively small. This has made it possible to construct walls that are only 15 cm thick when finished.

Figure 2: Poured slab reinforced foundation and bricks with both horizontal and vertical re-bar at the Agalteca water treatment plant.

The structural analysis of AguaClara plants should begin with an overview of structural analysis methods that could be applied to these tank walls. The methods should include both approximate analytical approaches and more sophisticated analytical methods that facilitate analysis of the entire structure. After the available tools are identified the structural design should be evaluated using one or more approaches. The failure modes need to be characterized with special attention to the need of the tanks to be waterproof and thus to have minimal cracking. After the structural design is evaluated, opportunities for improving the current design can be explored. For example, could the addition of a steel mesh on the outside of the brick that would be embedded in the plaster improve the strength of the walls? Could the amount of re-bar used in the walls be safely reduced?

There is some indication that reinforced masonry unit walls are sufficiently complex that they are beyond the computational scope of commercial structural design software. This assessment needs to be corroborated and if it is the case, then a strategy for design needs to be developed.

Another strategy would be to propose a different construction technique.

3 Automate Structural Design

A key innovation of the Cornell AguaClara team is the online AguaClara design tool that creates the unit process and hydraulic design for AguaClara facilities. The same scalable design approach could be used for the structural design as well. It is not yet clear if it is appropriate for the Cornell AguaClara team to design the structure. We will need to carefully address issues of liability if we provide structural design guidance. It should be possible to have the structural design reviewed by professional engineers prior to inclusion in the design tool to ensure that the structural designs are robust. The rational for adding structural design to the online design tool is that it will further reduce implementation costs.

The structural design will need to be varied based on the availability of materials. This added complexity needs to be carefully assessed to create a design methodology that can scale globally.

4 Site Evaluation of Material Properties

The use of locally available materials often means that the strength of the materials is unknown or poorly characterized. This leads to uncertainty in the structural design and a need to include large factors of safety. It would be very useful to develop test methods that could be implemented at the construction site to evaluate the strength of the material as well as to maintain quality control of construction. The test methods could be evaluated relative to laboratory test methods used in the Bovay test facility at Cornell.

5 Alternative Construction Methods

Scaling up AguaClara implementation would benefit significantly from improved construction methodologies. The construction techniques that rely on bricks/re-bar/mortar are time consuming to assemble. Are there alternative construction methods that would be consistent with the AguaClara philosophies (local labor, locally available materials) that could reduce construction costs and construction time? Possibilities include using

1. reusable forms
2. prefabricated wall panels
3. bricks that are perforated so that the bricks can be interlaced and have re-bar connecting them

6 Stacked Rapid Sand Filter Construction

The stacked rapid sand filter (SRSF) at Tamara, Honduras is approximately 3.8 m deep, 1 m wide, and 1.4 m long (see Figure 3). The SRSF box experiences significantly higher hydrostatic pressure than the sedimentation and flocculation tanks. The SRSF box at Tamara was constructed using stacks of bricks oriented the long way to make thick walls. The 25 to 30 cm thick walls may be over designed given the dimensions of the filter box. The wall design for the filter box must account for this pressure and the foundation must accommodate the higher loading on the soil. The relatively short walls of the filter box suggest that the moments from the hydrostatic pressure can be transferred to the adjoining walls and that the walls must be designed to withstand the bending moment at the corners. Alternately, the bending moment could be transferred to the slab, but this is inefficient given the much larger moment that would need to be resisted.

The SRSF includes a rock base similar to the foundation at Alauca (see figure 1). Evaluate the function of the rock slab and the possibility of eliminating it in future construction projects.

Devise improved structural designs for the filter.

It is very likely that the filter design will be included in new plants beginning in October of 2011. The filter box location in the plant is an important design consideration. We are currently assuming that the filter box will go next to the sedimentation tank (see figure 4). From a structural perspective it might be easier to build the filter as a separate unit from the sedimentation tank. We need to evaluate the optimal layout of the filter relative to the rest of the plant from both a structural and a hydraulics perspective.

Figure 3: Re-bar and brick placement for the first stacked rapid sand filter at Tamara, Honduras. The concrete ledger is also visible.

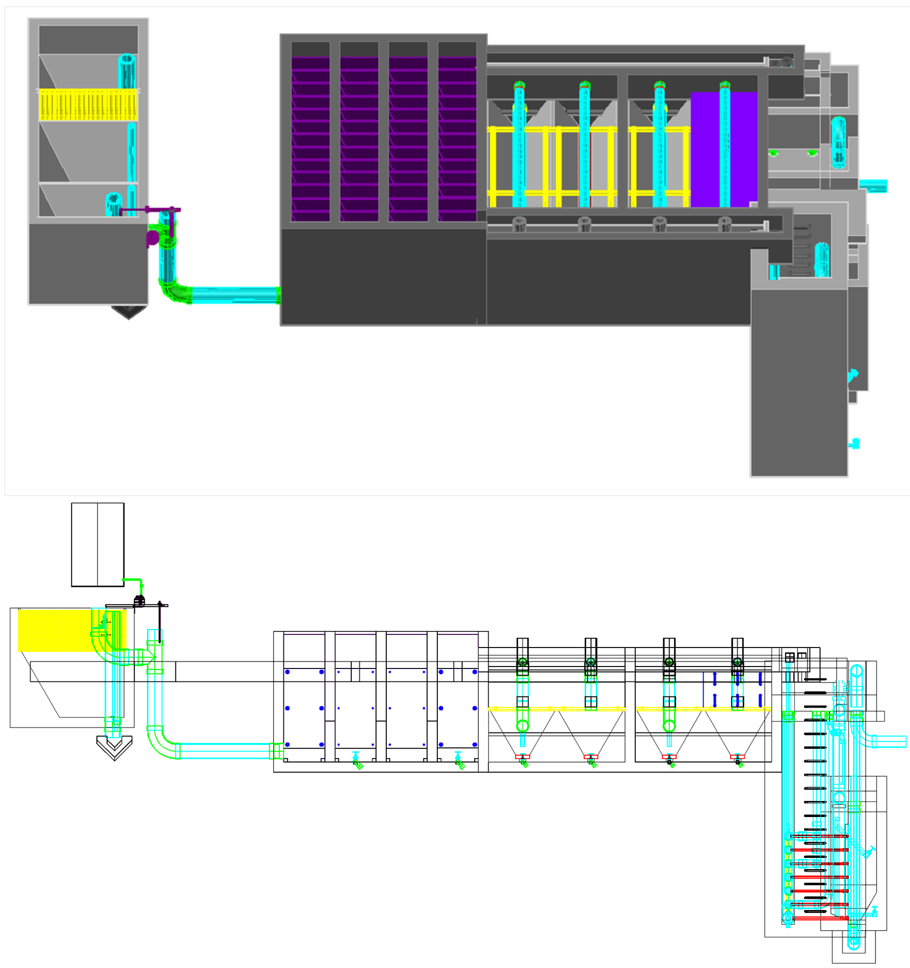

Figure 4: AguaClara plant cross section showing the much deeper filter box.