Designing a Zero-Waste Concrete Mix Testing Lab

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Abstract – A zero waste laboratory to mix and test the engineering and performance properties of **concrete** was designed and tested at Wentworth Institute of Technology. To achieve the design, **recycling** and reuse opportunities were developed for both plastic and hardened concrete used from testing as well as other residual **aggregate** solids. Processed water waste was minimized by the design of a settling and filtration recycling system. Both reductions in raw material consumption and economic savings realized by avoiding waste streams were measured in the study. The laboratory is used extensively by students preparing for careers in the design and construction of the built environment, including civil engineering and construction management. As the concept of **sustainable** design continues to hold greater significance in engineering and related professional disciplines, the laboratory also provides the opportunity to reinforce principles of sustainability, including embodied energy, life cycle assessment, waste management and minimization. In addition, the design project has and continues to provide undergraduate research opportunities in the area of concrete design. Some aspects of this work will also be presented in this paper.

Keywords: Concrete; Recycling; Aggregates; Wastewater; Sustainability

BACKGROUND

Industry Need for Sustainability

The estimated volume of concrete produced in 2011 in the U.S. was 500 million cubic yards. In terms of raw materials, this volume represents the consumption of 900 million lbs. of stone, 600 million lbs. of sand, 300 million lbs. of cement and 18 million gallons of water. The Portland Cement Association, (PCA), estimates that the cement industry is responsible for 1% of mankind's carbon footprint, while others claim it is as high as 5%. As a teaching institution that has numerous degree programs preparing graduates in construction and related built environment careers, it is necessary to both teach and practice principles of sustainability in regard to construction materials. While an academic laboratory consumes very small amounts of raw materials, the means and methods of conservation of natural resources, waste minimization, and recycling and reuse of materials can be effectively practiced and serve as an example for similar practices that can be implemented on a larger scale in industry.

Laboratory and Material Demand

A required course for the Construction Management (CM) and Civil Engineering Technology (CET) programs at Wentworth is Material Testing and Quality Control. One learning objective of this course is for students to understand the "design, proportioning and testing of Portland Cement Concrete (PCC) mixtures to satisfy specific performance criteria." To accomplish this objective, three laboratory sessions, which closely follow American Society of Testing and Materials, (ASTM), and American Concrete Institute, (ACI), methods for aggregate and concrete testing, are included in the course. These sessions emphasize proper testing and quality control. Students are also taught the effects of water/cement ratio, temperature and admixtures. In the last lab session students replace cement with Supplemental Cementitious Materials (SCM), to understand the economics of concrete and benefits of SCM.

To perform these labs, as much as two hundred fifty five (255) 1 – ½ cubic foot batches or 14.2 cubic yards of concrete per year is mixed. This volume of concrete consumes a great deal of raw materials (i.e., natural resources).

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An average cubic yard of concrete requires 1800 pounds of stone, 1200 pounds of sand, 600 pounds of cement and 300 pounds of water. In summary, the laboratory is using 25,560 pounds of stone; 17,040 pounds of sand; 8,460 pounds of cement and 4,230 pounds of water, (507 gal.), for mixing concrete annually.

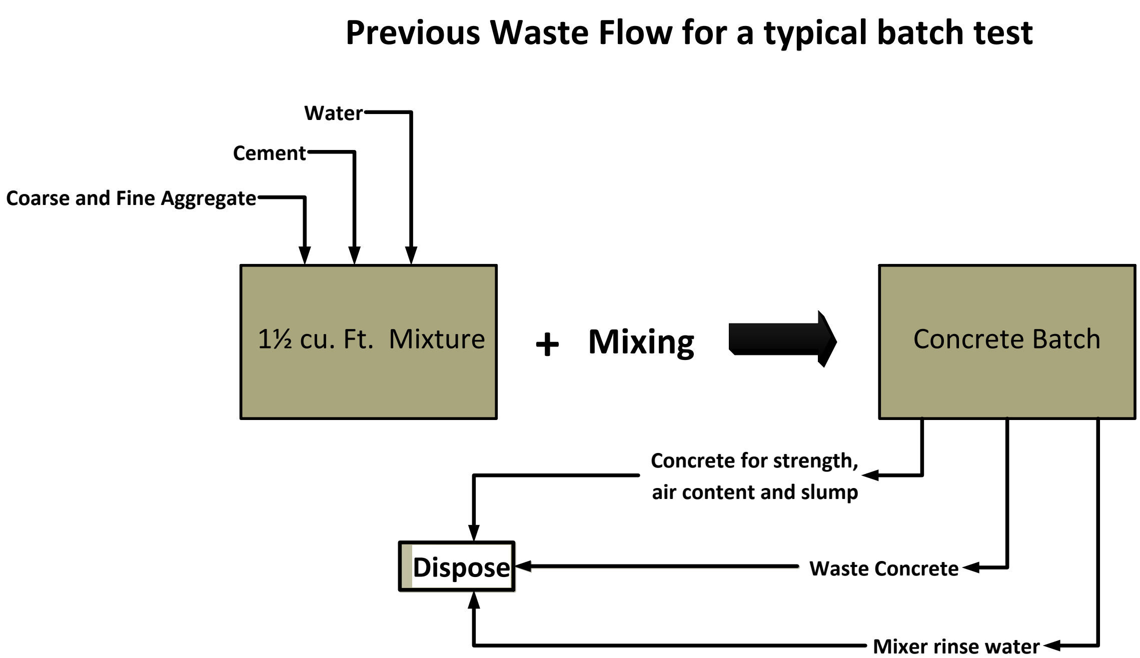
Former Practices

Each batch fabricated for testing weighs approximately 144 pounds per cubic foot, (216 pounds per batch). From this concrete, eight 4” x 8” cylindrical specimens are cast in accordance with ASTM C31. These specimens are used for compressive strength tests at 1, 7, and 28 days. However, these specimens only require 68 pounds of material, leaving 148 pounds of concrete for waste. This waste, (37,740 pounds total) had been disposed of in an all-purpose dumpster prior to the new zero-waste design.

Other materials also became waste when fabricating these trial batches. In the mixing and testing of concrete, all tools and equipment are routinely rinsed after each batch to keep them in working condition and clean. On average, this rinsing requires 2 minutes: one minute for tools; and one minute for the mixer. At a metered flow rate (Q) of 0.1426 gallons/second this represents 17.11 gallons of water per batch or 4,363 gallons of wash water annually. Furthermore the excess stone, sand and cement paste is typically washed into a wheelbarrow and this material had also been disposed of in the all-purpose dumpster.

Finally, all 8 cylindrical specimens from each batch made, an additional 17,340 pounds of concrete, had been disposed of after compression. In all, 55,080 pounds of solid material and 4,363 gallons of water are disposed of annually. Figure 1 provides a process flow diagram of the former concrete mixing process.

Figure 1



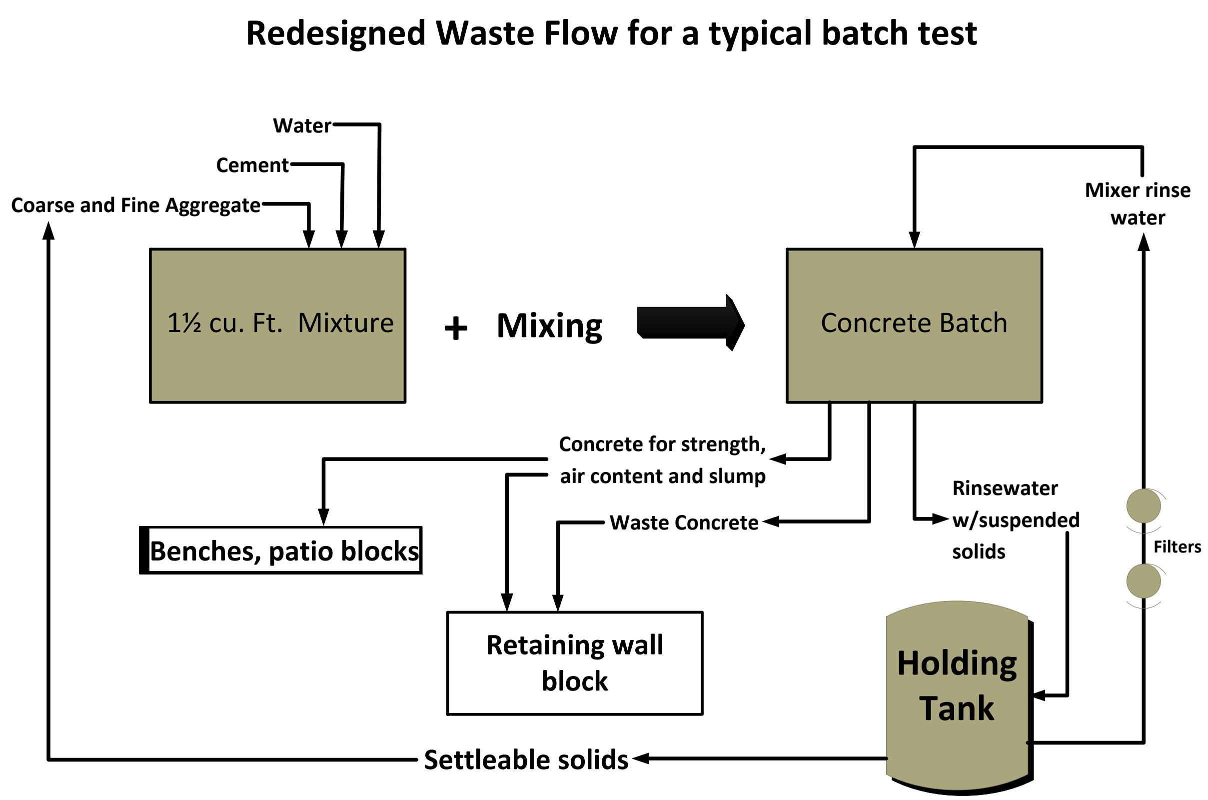
Previous Waste Stream Flow Chart

ZERO WASTE DESIGN

Elimination of Waste Streams

Under the new laboratory concrete system all solid waste and wash water is diverted to useful products and through recycling process streams. The overall process is summarized in Figure 2, (see below). The fresh concrete that remains after the fabrication of the cylindrical specimens is now molded into pavers, stepping-stones and other forms of garden statuary. All wash water is separated from the aggregates and cement and reused for washout in a completely closed-loop system. The aggregates that are separated from the wash-water are dried, separated into coarse or fine aggregate and reused in future concrete batches, thereby offsetting the consumption of virgin aggregate material. The last material to recycle is the cylindrical specimens. These specimens are crushed during compression and added to a 3'x3'x2 ½' concrete retaining block as large aggregate filler.

Figure 2



Redesigned Waste Stream Flow Chart

Water Recycle

To reduce wastewater an innovative separation and washout system was designed, built and installed. This system began with the rinsing of the tools and the equipment. To capture all the water and solids, a plastic four part separation system was installed. The system has an initial collection pit, with a 30" x 24" base and 13h". Attached to this collection pit is a runoff plate where students rinse excess concrete from tools and equipment. The mouth of the mixer is also lined up beside the runoff plate, directly over the collection pit where it too is rinsed of excess concrete. All of the excess water and solids are discharged into this initial collection pit. As the larger materials sink, the water rises. When the water rises to a height of approximately 4 inches it overflows through a ¼ inch hole to a second separation pit. This section is 26”x30”x16h”. Here, the water must rise over a 14 inch baffle before it runs off to a third and finally a fourth basin. When the water has reached the final chamber all of the larger solids have been separated and only the wastewater with fines remains. This water is pumped via a 0.3 HP submersible sump pump into a 200 gallon tank.

As the tank fills, the water is pulled into a 2” PVC pipe via a Flo-Tech ½ HP shallow-well jet pump. When the water exits the well pump it is further cleansed of the very fine material through 100- and 50- micron filters in series. Line pressure is monitored and filters are periodically changed when filter clogging is revealed based on pressure build-up. After this filtration process, water is then available for reuse in the cleaning and rinsing stage of the process. In effect, the water rinsing system is closed-loop. Therefore, no water is added to the system. This system is shown in Figure 3.

Figure 3

Closed Loop, Water Filtrations System

Aggregate Recovery and Recycle

The aggregates that are separated from the water are reclaimed. After each PCC mix is completed the mixer is scraped clean and rinsed. Then, after plastic concrete testing, tools are also rinsed into the initial collection pit. This rinsed material is allowed to settle for 24 hours and then removed. It is then dried and sieved in accordance with ASTM C136, Sieve Analysis of Concrete Aggregates. Aggregate finer than number 4 (4.75 mm) sieve are treated as fine aggregate while those particles passing the ¾ inch (19 mm) sieve and retained on the number 4 sieve are treated as coarse aggregate. This analysis showed that the reclaimed material is comprised of 7% coarse aggregate and 93% fine aggregate. All the reclaimed material is then added, at 10% total replacement, proportionally to future concrete mixes. An analysis of eight virgin aggregate mixes were compared to eight mixes using 10% reclaimed aggregate.

RESULTS

The new system has eliminated almost 100% of the waste generated. The wastewater system isolates all wash water in a closed loop system. The water in the system is neutralized and disposed of as waste only once a year. The total water disposed of annually is 100 gallons - a reduction in water use of 97.7% or 4,263 gallons annually.

Each concrete batch fabricated nets 2% reclaimed aggregate. This aggregate is used in future batches with no effect on the concrete performance. The result is a reduction in coarse aggregate use of 178.5 lbs. per year and a reduction in fine aggregate of 1,585 lbs. per year.

The plastic and hardened concrete waste has been completely eliminated. This concrete is turned into product and sold to generate much needed funds for the American Society of Civil Engineers and Construction Management student chapters.

Wentworth Institute of Technology has also realized economic savings. The initial set up costs for the waste water treatment center was $673.48. This included the well pump, submersible pump, micron water filters, and miscellaneous fittings and piping. The concrete molds to produce stepping stones and other garden statuary, see figure 4 below), had a cost of $25 per mold. Wentworth purchased ten of these molds for the first semester's trial and another ten in the second semester. The retaining wall mold was fabricated on site by work-study students, therefore, the cost was for materials only; $59.87. Finally the 200 gallon tank was on-site, surplus equipment and its use represented no cost. The total cost of this initiative was $1,233.35.

The savings per year included the material costs which totaled $30.71 and tipping fees at the landfills. Tipping fees are currently $120 per ton. The total weight of materials that were being disposed of was 55,080 or 27.54 tons and had cost $3,304.80 annually. The total annual savings, due to the elimination of waste streams, is $3,335.51. The net savings for the first year was $2,102.16. This savings will rise as initial costs are depreciated in years hence.

Figure 4

Concrete Bench Patio Block

Garden Products made from Waste Concrete

CONCLUSIONS

The zero waste laboratory saw a total reduction in waste of 99.1%. The only material that was disposed of after the lab was fully functional was the 100 gallons of water that is neutralized and disposed of annually. All plastic concrete has been transformed into aesthetically pleasing garden products and statuary, while hardened concrete waste is now large aggregate for retaining block. 14.2 cubic yards of material is no longer going into landfills. Wentworth Institute has to date realized a net savings of $2,102.16. The new system has been implemented without compromising any course learning objectives. The new system enhances concepts of sustainability. Also, the system creates valuable concrete products that have provided new entrepreneurial opportunities to support student clubs via the sale of these items.

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