Thesis Project Portfolio

Concrete Canoe Design Competition

(Technical Report)

Recycled Materials in Design and Construction; Perception of "Most Sustainable" in the Built Environment

(STS Research Paper)

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Executive Summary

"Construction is destruction", as previously stated by an undergraduate civil engineering student at the University of Virginia. The Concrete Canoe team at the University of Virginia started back up in fall of 2022, with a blank slate of knowledge and experience. As stated in the 2024 ASCE Concrete Canoe Competition Request for Proposal (RFP), the objectives of the competition includes the opportunity for civil-engineering students to gain hands-on practical and leadership experiences through concrete mix designs and project management, promoting awareness of concrete technology and versatility as a construction material, providing recognition of ASCE, national sponsors, benefits of an ASCE membership, and the innovative profession of civil engineering. The Concrete Canoe team has implemented sustainable measures in their mix and construction methods with the use of a reusable modular wooden mold and less carbon intensive aggregates and cementitious materials. While the final mix used consists of virgin materials, there are options for recycled steel for rebar in the canoe or recycled concrete aggregates that can further lessen the environmental impact and project waste. Concrete, steel, and timber are the main structural materials used around the world. With the reduction in natural building materials and increase in climate change due to the environmental impacts from production of virgin materials, sustainable practices should be enforced to choose more environmentally-conscious materials suitable for the project through the use of recycled materials and reducing waste generated from project sites. The future in sustainable structural design consists of recycled steel and concrete aggregates.

The Concrete Canoe team is further divided into three sub-team that have centralized focuses and goals: Hull Design, Mix Design, and Construction. The hull design team defined characteristics of an ideal canoe: wide-bottomed and stable. Hull began by developing curve equations for a flat-bottom versus shallow vee shape, and testing properties of each shape using 3-D printed models and a flume machine, with a general focus on qualitative analysis of how canoe shapes impact stability, speed, maneuverability, tracking, and other hydrodynamic properties. The construction team outlined tools needed and researched techniques and ideas for constructing various mold methods and its advantages towards the team's ideal canoe. The mix design team implemented ASTM standards in analyzing materials, setting targets for strength and density. Various tests were conducted to determine the optimal combination of materials including the slump, compressive strength, and tensile strength of the mix. The research and analysis done by the mix, hull, and construction teams produces a final canoe that is easily reproducible, has a low environmental impact, and has excellent performance in lakes.

This year, the team aimed to achieve a high strength, low weight, medium slump mix that allowed for easy application to the reusable wooden female mold. The team's sustainable efforts include using hydrated lime to reduce the carbon footprint of our primary cementitious material and the consideration of Poraver expanded glass and natural aggregates. The final mix composition included Type IL Portland Limestone Cement, Type S Hydrated Lime , grade 120 GGBFS, Poraver® expanded glass microspheres, and Arcosa Riverlite® Alabama expanded clay

lightweight aggregate. The final mix design yielded an average 7-day compressive strength of roughly 2,690 psi and a density of 73 lb/ft3. The hull design came up with a hydrodynamic yet stable shallow vee shape that is 16 feet in length and 3⁄4 inch in thickness. The width is symmetrical and varies, with the interior width peaking at 28 inches. The structural calculations prove the product's passing of the swamp test with a maximum buoyant force of 1,686 lbf without air pockets, and a total weight of 330 lbs. The final product applies a sustainable application that prioritizes quality, minimizes waste, and optimizes production. The high-strength mix produced connects with the stable and hydrodynamic hull design, and reproducibility construction method of a female mold.

Structural engineers have an integral role of advocating for sustainable, low-energy projects as well as understanding sustainable design elements and their effects of carbon emissions, cost efficiency, and user's comfort. Literature review would dive into the topics of recycled concrete aggregates and steel and biophilic elements to understand the technical concepts behind these research topics and a comparison would be held on the properties and methods between recycled versus new material. Case studies will analyze the sustainable efforts of building made from recycled compositions and its social, environmental, and economical impact. Interviews with upcoming civil engineers will further represent the perception of sustainability in the current industry and if structural engineers play a key role in making this change. Using this combination of research methods would allow perceptions of sustainability from various sources and roles of engineers to determine if there is potential for change in the industry, engineers willing to change the current standards and use the research into real-world projects, and upcoming engineers. Design professionals should begin to investigate the influential effects of perceived sustainable material and choose the material that is best for the project to achieve all five categories of the sustainability instrument- quality, functionality, user appeal, resourcefulness, and purchasability. What are the factors to consider to make a sustainable design without compromising the structural integrity? It is the role of the structural engineer to consider all relevant factors of the structure to find a balance of biophilic solutions and sustainable materials that work to create a structurally-sound and healthy structure.

Steel recycling has high energy saving levels, efficient water usage rates and low carbon emissions. Additionally, the circular flow of steel does not reduce any of its metallurgical properties, with the quality and properties of recycled steel being comparable to those of virgin steel. Having early involvement with the steel fabricator and engineer can provide optimizations for the structure without using additional steel through using higher strength metals and taking advantage of the structural framing load path and material attributes. Common recycled C&D materials used in structural and infrastructure applications include recycled concrete aggregates (RCA), recycled masonry aggregates (RMA), mixed recycled aggregates (MRA), and reclaimed asphalt pavement (RAP). Recycled aggregates can be used in pavement applications in substitute for virgin materials. To be suitable for structural use, the recycled aggregate must hold suitable

shear strength, drainage, chemical resistance to environmental or chemical degradation agents, anti-freeze-thaw characteristics, and good hydraulic behavior to ensure appropriate durability.

The Concrete Canoe team has conducted great strides in the advancement of sustainability in their mix design and construction methods. However, due to the high percentages of waste accumulation from the construction industry and lack of resource preservation, alternatives such as recycled steel and concrete aggregates are ideal substitutes that should be considered. Each material has varying levels of sustainability, not one can be said to be better, the engineer's goal should be to select the most applicable material that fits the design and then continue to optimize the use of materials environmentally. To gain the maximum benefit of a sustainable building, the engineer must choose the appropriate material for the project and gain proper and accurate information and properties on the material. Through the analysis of performance of recycled steel and concrete aggregates, the materials exhibit properties comparable to those of virgin materials and would serve as a sustainable alternative with the verification by structural calculations and the judgment of a licensed structural engineer.