2019-2020 Awardee

Thomas Germain *is currently completing his master's degree in civil engineering at Université Laval in Québec City, QC, Canada. Originally from France, where he trained as a mechanical engineer at the Arts & Métiers school, Germain decided to pursue his education in Québec City in the field of civil engineering. His research project focuses on the reduction of rebound in shotcrete by better controlling the placement parameters of fresh concrete. This project is part of a larger project developed by Marc Jolin's Shotcrete Research Team, pursuing the objective of "Zero Rebound."*

MASTER'S RESEARCH PROJECT

Automation and Optimization of Shotcrete Placement Using a Robotic Arm

Shotcrete is an outstanding concrete placement technique and has seen, in recent decades, a number of improvements in mixture designs and equipment that have made it more popular than ever in fields such as mining, tunneling, repairs, and new construction. However, there is one drawback that is sometimes reported regarding the amount of rebound observed, whether it has to do with the mixture design, the shotcrete process, or difficult placement conditions. Building on the earlier work of graduates from the Shotcrete Laboratory at Université Laval, our knowledge of the composition, the properties, and the behavior of the spray of material has led us to believe rebound can be much better controlled and that equipment and placement techniques to achieve this need to be further explored.

The rebound reduction effort can roughly be put into three groups: shotcreting equipment, mixture design, and placement techniques. Indeed, most projects in the past have focused, with success, on mixture design and more recently on the behavior or description of the spray pattern.[1] However, very little attention has been given to the placement technique itself since the early publication from Crom in the 1980s.[2] This lack of research on the influence of placement methods on rebound has led us to take an active interest in it. Moreover, all can appreciate how placement technique is critical in obtaining high-quality shotcrete. Good materials placed poorly will produce an unsatisfactory final product.

Over the last few years, shotcrete placement has turned toward mechanically assisted applications: more hydraulic manipulators are used to prevent worker's exposure to potentially unstable shotcrete, unsupported ground, rebound, or dust. They can also help to increase productivity.

In parallel, the concrete industry has seen the development of ultra-high-performance concrete (UHPC) and some special fiber-reinforced concretes that along with some other high-performance materials can create resource efficient building elements.[3] Unfortunately, these materials are often developed for standard form-and-pour placement methods that are not always efficient and cost effective. Shotcrete placement opens up new possibilities to apply these special materials and use them to their full potential.

Keeping in mind these new high-performance materials, the need to further understand and control rebound, and the promising improvements to placement technique, the objective of this project was developed: To improve and optimize placement techniques through automation.

The first step of this project was to choose a way to automate shotcrete placement. By studying how other fields proceed, such as in the paint industry, the best and most exciting way to automatize shotcrete is by using fully controlled six-axis-robots. To come up with the most suitable solution, a specification chart was prepared to assure the robot would be compatible and able to handle the shotcrete placing equipment selected.

To operate the robot correctly, a suitable environment was essential. Different steps and system requirements had to be considered such as power supply, transportable mounting support, ground anchors, the tool to hold the nozzle, protective covers for high dust and wet environments, robot programming software, safety barriers, and sensors. This automated application of shotcrete must be transferable for use on future projects, so the design of the whole setup had to be reliable, flexible, and user-friendly. This portion of the project is completed. Sparo (Shotcrete Placement Automated by Robot) is now in the Shotcrete Laboratory; setup and initial programming is under way.

The second portion of the project is to create an automated shotcrete placement program to reduce rebound. For this, it has been decided to study separately the influence on the rebound of each parameter in nozzle movement: the spraying distance, the spray angle, the deposition rate, and the nozzle path. ACI 506, Guide to Shotcrete, recommends standard nozzle distances, angle, and placement techniques such as bench shooting or vertical layers.[4] The objective is to incorporate and optimize all this data into the research program to have an optimized shotcrete deposition efficiency.

This master's project intends to reduce rebound by optimizing placement parameters during fresh shotcrete deposition. In the future, it opens the possibility of a fully automated and smart application of shotcrete to create resource-efficient building structures with high-performance materials.

References

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4. ACI Committee 506, "Guide to Shotcrete (ACI 506R-16)," American Concrete Institute, Farmington Hills, MI, 2016, 52 pp.