Impactful Resilient Infrastructure Science and Engineering (IRISE)

-Project Scope of Work-

(FY 2021-22 Annual Work Program)

SUMMARY PAGE

Project Title: Three-dimensional micro-mechanical characterization of the effect of vibration and compaction in concrete pavements

Person Submitting Proposal: Alessandro Fascetti

Proposed Funding Period: 10/01/2021 - 09/30/2023

Project Duration: 24 months

Project Cost: $ 253,787.58

Project Title: Three-dimensional micro-mechanical characterization of the effect of vibration and compaction in concrete pavements.

Problem Statement: The definition of the correct paving process to be used in different projects and conditions is a complex task that is severely influenced by environmental conditions (e.g., temperature and humidity), the type of concrete mix and layout of reinforcement and the manipulations performed during construction (i.e., vibration and compaction). The construction operations are generally performed based on established practices that do not take into account the specific conditions of the pavement. To this extent, advances in the description of the effects of vibration and compaction procedures could lead to the definition of practical rules to perform optimized paving in different conditions. The effect of each of the influencing factors needs to be accurately defined, in order to provide comprehensive guidelines and operational control for the optimization of the paving process in variable conditions and environments.

Project Objectives: 1) Build novel experimental tools to enable optimized design and construction of concrete pavements, 2) Experimentally investigate the effect of vibration and compaction in paving processes under different environmental conditions, 3) Build and validate novel computational tools to perform accurate parametrization of the solution space and identify best practices and optimal results, 4) Create a set of guidelines based on the results from the previous objectives to provide more efficient construction of new pavements.

Project Scope: In this project, an experimental characterization of concrete paving will be combined with computer vision techniques to reconstruct the spatial and temporal arrangement of coarse aggregate in the mix during the paving process. We will first experimentally test several pavement specimens constructed using artificially manufactured aggregates (e.g., glass or polymer-based beads). After this stage, 2D slicing techniques will be used to reconstruct the three-dimensional arrangement of the aggregate after proper curing of the specimens in different environmental conditions (i.e., temperature, humidity, workability of the mix). The 3D reconstruction of the position of each aggregate piece will be used for the quantification of the spatial gradients of the density of the hardened mix, to evaluate effectiveness of the vibration and compaction operations. To this extent, the use of manufactured aggregates will not influence the applicability of the obtained results to real-life cases, as the main goal is to be able to digitally reproduce the spatial arrangement of coarse aggregate pieces. Once the digital reconstructions are obtained, the effective resulting strength of the pavement will be tested using traditional limestone aggregates, on specimens that are statistically representative of the measured conditions. Following the experimental tests, the experimental database will be used to train semi-unsupervised Machine Learning algorithms, to establish the cause-effect relationship (i.e., the *hidden physics*) between duration and intensity of vibration and/or compaction operations and the effective spatial density of the pavement. These results will then be used to validate a numerical model to simulate interactions between aggregate pieces and mortar under the effect of the mechanical manipulations performed during the paving process. This will allow for the evaluation of the viscous effects and transport properties within the fresh mix. The novel computational models defined in the work will allow to investigate the influence of different parameters on the final quality of the paving process. With this work, we will formally quantify the effect of vibration and compaction as a function of the mix workability and the ambient temperature and humidity on the overall paving process. Our findings will serve as the base for the definition of novel guidelines to allow for the optimized construction of concrete pavements in different conditions.

Task Statements:

The objectives of this project will be realized through the completion of the following tasks:

Task A: Review current practices in paving processes and identify current knowledge gaps. The experimental design (Task B) will leverage such information to define a meaningful parametrization of the design space. Design and develop a novel methodology to conduct such investigations and quantify results in a meaningful manner. This will consist of: 1) definition of the experimental test set-up to quantify input (i.e., initial conditions for the fresh mixture and spatio-temporal distribution of the vibration forces) and output (measurement of density and 3-D reconstruction of the cured pavement sections).2) development of the manufactured aggregate, with particular emphasis on the density and size of the aggregates to be produced including the possibility of embedding sensors inside the aggregate, 3) definition of the size/shape of the specimens to be tested and method of fabrication, 4.) Develop fabrication and test protocols to be executed under Task B

Task B: Design and conduct an experimental campaign on specimens constructed by means of artificially manufactured aggregates, to evaluate the three-dimensional arrangement of the aggregate after vibration, compacting and curing. We will investigate both laboratory and field conditions. Particularly, the field experiments will be conducted in close collaboration with PennDOT and contractors. The main design parameters will be: 1) mixture design and aggregate composition, 2) vibration energy and duration, 3) Pavement structure. This campaign will provide the data used in the subsequent numerical simulation of vibration (Tasks C and D).

Task C: Development and validation of a numerical model capable of predicting the final spatial arrangement of coarse aggregate as a result of vibration and compaction in different environmental conditions. The numerical model will leverage extensive background of the PI in the development of discrete models to simulate transport and mechanical problems for Civil Engineering applications.

Task D: Sensitivity analysis and parametrization of the relevant variables by means of semi-unsupervised Machine Learning, to identify relationships between duration and intensity of vibration and effective spatial density of the pavement. The models will be informed by both the experimental data (obtained on small-scale lab tests as well as field measurements), which will be augmented by the results obtained from the numerical model developed during Task C.

Task E: Final Report containing suggestions and guidelines for optimal paving processes. Such guidelines will define the optimal levels of vibration and compaction to be employed as a function of the on-site environmental conditions (i.e., temperature, humidity and mix workability), effectively allowing for more efficient paving processes in a practical yet formal fashion.

Deliverables:

1. Experimental data on specimens cast under different vibration and compaction levels (11 months from notice to proceed).
2. Three-dimensional reconstructions of the spatial arrangement of coarse aggregate in the cured specimens (13 months from notice to proceed).
3. Numerical model based on a Random Lattice Modeling approach for the simulation of vibration effects in fresh concrete mixtures (18 months from notice to proceed).
4. Reduced order model based on Machine Learning algorithms to allow for fast predictions and meaningful model parametrization (22 months from notice to proceed).
5. Final report and guidelines (24 months from notice to proceed).

Key Personnel:

Principal Investigator:

Alessandro Fascetti

Other Key Staff:

Julie Vandenbossche

Other Personnel:

Grad Students:

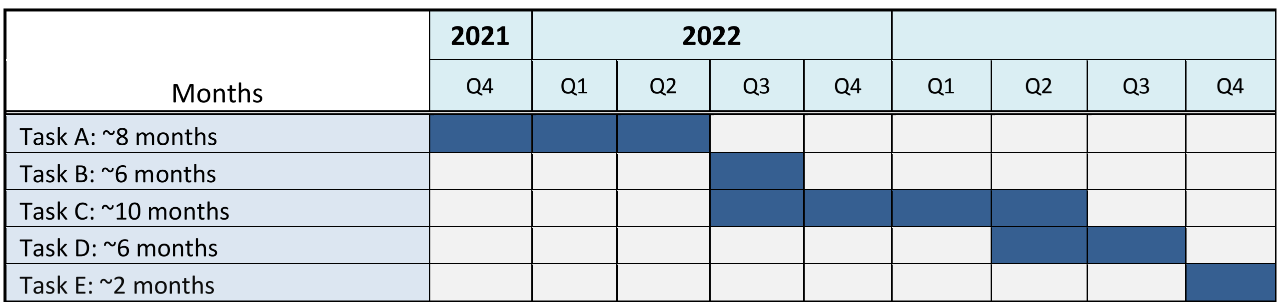
1x Graduate Student (Tasks A, B, E)

1x Graduate Student (Tasks A, B, C, D, E)

Proposed Person-Hours by Task:

Team Member	Task A	Task B	Task C	Task D	Task E	Total
Key Project Team Members, Estimated Hours Per Task						
Alessandro Fascetti	50	60	130	80	27	347
Julie Vandenbossche	105	45	-	100	34	284
Graduate Student 1	766	320	-	-	300	1386
Graduate Student 2	100	176	530	280	300	1386
Total	1021	601	660	460	661	3403

Schedule:



Budget: The total project cost is $253,787.58.

Acknowledged By:

Alessandro Fascetti, Ph.D.
Principal Investigator