MPC- 411

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**Project Title:**

Re-Use of Mine Waste Materials Amended with Fly Ash in Transportation Earthwork Projects

**University:**

Colorado State University

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**Research Needs:**

Environmental sustainability and land stewardship are challenging but laudable constraints for all infrastructure development in the United States. Our nation’s prevalent energy concerns, which include the desire for energy independence coupled with a growing population requiring additional energy capacity, constrain energy available to repair and build new infrastructure. The Colorado Department of Transportation (CDOT) has identified the maintenance and improvement of roadways in addition to increased construction of local road systems as strategic goals in the statewide transportation plan (CDOT 2008). These goals will support an overarching objective in Colorado to enhance transportation safety while meeting future needs of increased transportation capacity.

Improving roadway construction and initiating new transportation-related construction projects throughout Colorado will require a broad array of earthwork constructions, such as road subbase and subgrade, un-paved roadways, embankments, and fills. Each of these earthwork projects requires earthen materials (e.g., soil or crushed rock) that are constructed in a manner to obtain optimal performance. The use of recycled materials, such as mine waste (mine waste rock and tailings) and coal combustion residuals (CCRs), has the potential to aid transportation-related construction needs while decreasing energy consumption, raw material use, and greenhouse gas emissions.

Mine waste materials include waste rock discarded from mining operations and fine-grained tailings produced during ore extraction processes (Wickland et al. 2006). Coal combustion residuals include fly ash, bottom ash, boiler slag, and flue-gas desulpherization, which are all by-products generated at coal-fired power plants (ACAA 2012). Recent studies on innovative mine waste management practices have demonstrated the applicability of mine waste rock and tailing co-disposal (i.e., mine waste and tailings mixtures) that can mitigate acid rock drainage from mine waste rock and low shear strength in tailings (Wickland et al. 2006). Additionally, the re-use of CCRs, in particular fly ash, in transportation-related earthworks has been reported to enhance soil strength and durability with negligible environmental effects from introducing CCRs into natural environments (e.g., Lee et al. 2010). The proposed study will evaluate the efficacy of creating a sustainable earthen material from mixtures of mine waste rock and tailings, stabilized with fly ash, which meets performance and environmental constraints for use as a construction material in transportation-related earthwork projects.

**Research Objectives:**

The following objectives will be completed as part of the proposed project to evaluate the hypothesis that mixtures of mine waste rock, tailings, and fly ash have satisfactory performance to warrant re-use as a sustainable geomaterial in transportation-related earthwork projects.

1. Evaluate and summarize the current state-of-practice and state-of-art in re-use of mine waste materials and fly ash in geotechnical projects related to transportation construction, with particular emphasis on projects in Colorado.
2. Assess the efficacy of creating mixtures of mine waste rock and tailings with and without fly ash that have adequate geotechnical and geoenvironmental properties (i.e., shear strength, compressibility, hydraulic properties) for use in transportation-related projects.
3. Optimize the mine waste mixture ratio, amount of fly ash addition, and specimen preparation method that produces a material with geotechnical and geoenvironmental characteristics ideal for field implementation and evaluation.
4. Data analysis and report writing combined with preparation of peer-reviewed conference and journal papers for dissemination of research results.

**Research Methods:**

*Materials.* To assess the feasibility of mixing mine waste rock and tailings, a single waste rock and single tailings source will be selected that are representative of high production-volume materials in Colorado mines. Maximum particle size for the mine waste rock will be constrained to maximum particle sizes used in CDOT earthwork projects. Alternatively, an upper bound maximum particle size may be required to adhere to laboratory testing constraints, whereupon a representative waste rock will be prepared with parallel gradation to the material scalped for use in CDOT earthwork projects. The parallel gradation technique has been reported to yield comparable shear strength parameters for mine waste rock (e.g., Stoeber et al 2012).

Fly ash will be obtained from Colorado coal-fired power plants (e.g., Platte River Power Authority, Fort Collins, CO). Specific fly ashes will be identified that have potential to enhance geotechnical and geoenvironmental behavior of the mine waste mixtures. For example, Class C fly ash has cementitious characteristics and has been shown to enhance the strength of fine-grained soils (e.g., Edil et al. 2006). Behavior of the fine-grained tailings in the mine waste mixtures is believed to be a critical component towards enhanced performance of the mixture material, and thus, will be a key consideration for soil stabilization via fly ash.

*Methods.* Mixtures of mine waste rock and tailing will be hand-mixed following procedures in Khalili et al. (2010) to create homogenous materials where tailings “just fill” void space of a compacted mine waste rock. This mixture method has been shown to yield reproducible results, which will be necessary for evaluating enhanced performance via fly ash amendment. The geotechnical and geoenvironmental behavior of the fly ash- and non-fly ash-amended mixtures will be evaluated for compaction, permeability, shear strength, stiffness, compressibility, and leaching potential.

Compaction characteristics will be assessed via standard and modified Proctor compaction. Permeability of compacted specimens will be conducted in flexible-wall permeameters to minimize the potential for side-wall flow while evaluating hydraulic behavior on as-compacted specimens. Strength and stiffness of the mixture specimens will be evaluated via unconfined compression tests, with additional consolidated undrained triaxial compression tests conducted as needed. Compressibility will be conducted in one-dimensional consolidometers. All tests will be conducted on large-diameter specimens (approximately 150-mm-diameter) such that a broad range of mine waste rock particle sizes can be included. Leaching of contaminants (i.e., heavy metals) from mixtures will be assessed via batch tests to identify an upper-bound of leachability as well as column tests to determine leaching characteristics more applicable to field scenarios.

Large diameter testing equipment is available for compaction, permeability, and shear strength assessment at Colorado State University. Compression equipment that can accommodate the proposed specimen size will be developed as part of the proposed research program. Implementation of the proposed laboratory tests will be conducted in accordance with American Society of Testing and Materials (ASTM) standards as well as with current research (e.g., Arora and Aydilek 2005; Kim et al. 2005; Edil et al. 2006; Tastan et al. 2011; Sauer et al. 2012).

**Expected Outcomes:**

A key deliverable from the proposed project will be a preliminary geotechnical and geoenvironmental assessment on the re-use potential of mine waste materials amended with fly ash in earthwork projects. This preliminary investigation will support a feasibility assessment of incorporating mine waste materials in transportation infrastructure. Subsequent research from the proposed study will include the following: (1) field-scale evaluation of fly-ash and non fly-ash amended mine waste mixtures via construction and evaluation of field test sections; and (2) long-term performance of fly ash and non fly-ash amended mine waste mixtures via evaluation of freeze-thaw and desiccation effects on geotechnical and geoenvironmental performance.

Research results from this project will be disseminated to CDOT as well as Department of Transportations from neighboring states affiliated with the Mountain Plains Consortium. The evaluation of additional mine waste materials and CCRs will be encouraged to evaluate broader geographic and infrastructure implications of the proposed research. A long-term deliverable from this project and follow-up research studies will be guidelines for incorporating mine waste materials in transportation earthwork projects. This long-term vision has the potential to re-use mine waste and energy industry by-products to enhance transportation sustainability.

**Relevance to Strategic Goals:**

*Safety.* Enhancing durability of earthen materials used in transportation infrastructure will improve the performance of these materials, thereby decreasing the propensity for roadway degradation that can lead to unsafe transportation conditions.

*State of Good Repair.* Incorporating mine waste and CCRs into transportation earthworks will enhance the management of our natural resources, promoting good land stewardship practices.

*Economic Competitiveness.* Past research has shown that incorporating CCRs into transportation earthworks improves mechanical performance of the materials, which leads to increased longevity and durability. The use of CCRs and mine waste provides an economic advantage in offsetting raw material requirements and improving infrastructure performance.

*Environmental Sustainability.* The use of mine waste materials and CCRs reduces the quantity of raw earthen materials required for a given earthwork construction, which decreases energy consumption and reduces greenhouse gas emissions.

**Educational Benefits:**

This project will support a graduate student to lead the proposed laboratory research as well as an undergraduate student to assist in preparing materials and conducting experiments. With successful implementation of the project plan, the graduate student will acquire sufficient laboratory data to prepare and defend a graduate thesis. The undergraduate student, having been trained in experimental laboratory research pertaining to geotechnical engineering, will be recruited to participate in one of the proposed follow-up studies as a graduate student. Integrating graduate and undergraduate students into the research efforts will provide mentoring opportunities at the graduate-level and enhance recruitment and retention of undergraduates for subsequent research studies.

The proposed project will provide an opportunity for the Principal Investigator (PI), Dr. Bareither, to enhance his understanding of the current and future role of geotechnical engineering in transportation infrastructure as well as the sustainable re-use of mine waste materials and CCRs. This knowledge will be used in both undergraduate and graduate courses. Dr. Bareither will integrate an overview of transportation-related earthworks and sustainable re-use of mine waste materials and CCRs at the undergraduate-level to inform students of current challenges facing geotechnical engineers. At the graduate-level, Dr. Bareither will integrate research findings and background literature from the proposed project into a course he is creating entitled “Waste Mechanics”. This course will include a module on the sustainable re-use of mine waste and CCRs in geotechnical engineering, with particular emphasis on transportation earthworks.

**Work Plan:**

The primary tasks for the proposed project are outlined in Fig. 1 (Tasks 1, 2, 3, and 4), and correspond to each of the research objectives discussed previously. Initial efforts will focus on compiling available literature on re-use of mine waste materials and fly ash in transportation earthwork projects, and identifying needs for executing the laboratory research program (i.e., equipment and materials). The experimental phase (Tasks 2 and 3) will be implemented throughout the project duration. Preliminary testing in Task 2 will evaluate the effects of varying tailings solids content in mine waste mixtures with and without fly ash amendment on geo-behavior. Results from Task 2 will be coupled with an evaluation of recommended field design and performance criteria for transportation earthworks (Task 1) to identify practical material mixtures for use in Task 3. Subsequently, the effect of fly ash content will be evaluated in Task 3 using the relevant mine waste and tailings mixture identified from Tasks 1 and 2. A preliminary report will be prepared prior to the end of Year 1 to document progress of the project. A final report as well as a graduate student thesis and peer-reviewed manuscripts (conference and journal) will be prepared at the end of Year 2.



Fig. 1. Estimate timeline of the primary tasks for completing the proposed project.

**Project Cost:**

Total Project Costs: $130,000

MPC Funds Requested: $65,000

Matching Funds: $ 65,000

Source of Matching Funds: soft match = one month PI salary in Years 1 and 2 of the project; hard match = Bareither start-up funds from Colorado State University.

**TRB Keywords:** coal combustion residuals, geotechnical, geoenvironmental, mine waste

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