TRANSPORTATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

Lead Agency (FHWA or State DOT): Kansas DOT

INSTRUCTIONS:
Lead Agency contacts should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.

Transportation Pooled Fund Program Project #	**Transportation Pooled Fund Program - Report Period:**
TPF-5(503)	☐Quarter 1 (January 1 – March 31) ☐Quarter 2 (April 1 – June 30) ☐Quarter 3 (July 1 – September 30) ☒Quarter 4 (October 1 – December 31)

TPF Study Number and Title:
TPF-5(503) and Standardizing Rigid Inclusions For Transportation Projects: Phase I

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Lead Agency Project ID: Click or tap here to enter text.	**Other Project ID (i.e., contract #):** Click or tap here to enter text.	**Project Start Date:** **7/1/2023**
Original Project Start Date: Click or tap to enter a date.	**Original Project End Date:** **6/30/2025**	**If Extension has been requested, updated project End Date:** Click or tap to enter a date.

Project schedule status:

☒On schedule	☐On revised schedule	☐Ahead of schedule	☐ Behind schedule

Overall Project Statistics:

Total Project Budget	**Total Funds Expended This Quarter**	**Percentage of Work Completed to Date**
$240,000	$14,703	75%

Project Description:

Rigid inclusions are grouted or cemented columns used to improve loose or soft soils. They have been increasingly used in practice in the United States, mostly for embankment, retaining walls, and box culvert support in transportation applications. Several types of equipment and methods are available in the practice to install rigid inclusions with different trade names. Installation of rigid inclusions may cause full or partial displacement of their surrounding soils that disturb soils, neighboring rigid inclusions, and/or existing structures, depending on the type of equipment and method used, installation procedure, and type of soil. Rigid inclusions are often installed under a load transfer platform to support embankment or structure loads. The methodology and equipment-driven installation has been closely guarded and much is proprietary (commercial competitive advantage), which has left the DOTs dependent on and obligated to the contractor. No well-accepted design methods and construction specifications are available to assess and consider installation effects on their surrounding soils, neighboring rigid inclusions, and nearby existing structures, down drag forces in rigid inclusions under embankment or structure loads, and stability of embankments with side slopes supported by rigid inclusions. Research, including the state of the practice (Phase I) and full-scale field tests (Phase II), is needed to quantify rigid inclusion installation effects, develop design methods considering their effects on load transfer analysis, axial load capacity, and displacement calculations for vertical loads and evaluating the stability of rigid inclusion-supported embankments, and develop construction specifications for minimizing installation effects and improving long-term performance.

The main objectives of the Phase I study are to assess the state of the practice of rigid inclusions used for embankment and structure support, analyze existing data and design methods available in the literature or agencies, identify knowledge gaps and missing data and procedures, and develop a plan for full-scale field tests to be carried out in the Phase II study.

Tasks for this study include:

1) Literature Review and Assessment of Current Practices
2) Evaluating design methodologies
3) Developing a Full-scale Field Test Program

Progress this Quarter
(includes meetings, work plan status, contract status, significant progress, etc.):

The research team continued evaluating design methods for load efficacies, settlement, and reinforcement tension, conducted two-dimensional numerical analyses for evaluating analytical methods for stability, and reviewed papers related to installation effects about the current practice of rigid inclusions in projects. The research team selected 26 case studies in the USA and in the world with instrumentation data, which were used to evaluate four design methods commonly used in the literature and practices including the British method (BS8006), the German method (EBGEO), the Netherlands method (CUR226), and the FHWA strain compatibility method. The research team has also conducted two-dimensional numerical analyses to evaluate the British method and the US practice using the stress reduction concept for analyzing the stability of RI-supported embankments. The research team further reviewed a three-dimensional numerical analysis of installation sequence effects on RI displacements. The research team organized a virtual meeting with the steering committee to give them updates on the above evaluations and seek their inputs about the findings and future research activities. The research team proposed continuing the stability analyses of embankments on rigid inclusions and developing a plan for the Phase II project.

Task 1: Literature Review and Assessment of Current Practices
The literature review work has been completed.

100% COMPLETE

Task 2: Evaluating Design Methodologies
The research team has performed the numerical model calibration and verification for two case studies and evaluated four design methods with measured data available in the literature. The research team has also performed two-dimensional numerical analyses to evaluate two methods available in the literature and used in the practice for analyzing the stability of RI-supported embankments. The research team further reviewed a three-dimensional numerical analysis of installation sequence effects on RI displacements

90% COMPLETE

Anticipated work next quarter:

The research team will continue performing numerical analyses to evaluate the stability of embankments on rigid inclusions and review previous studies about installation effects and QC/QA procedures. The research team will also develop a plan for the Phase II study including layout of rigid inclusions, instrumentation, construction of a test embankment, budget, and schedule. The research team will share and discuss the numerical results, these evaluations, and the plan for the Phase II study with the consultants. The research team will also meet with KDOT to develop this plan including funding for the Phase II study. After the meeting with the consultants and KDOT, the research team will organize a virtual meeting with the steering committee to go over the numerical results, the evaluations, and the plan for the Phase II study.

Significant Results:

The literature review shows that different types of rigid inclusions have been used in the practice. Rigid inclusions (RIs) are typically designed as a system, which includes rigid inclusion elements and a load transfer platform. Much research has been done on load transfer mechanisms (soil arching and tensioned membrane) and critical heights above rigid inclusions to prevent differential settlement. A large number of methods including analytical and numerical methods are available to design load transfer platforms above rigid inclusions but these methods often yield significantly different results. Several studies examined the accuracy and differences of these design methods. However, limited research has been done on installation effects and slope stability of embankments supported by rigid inclusions. Recent projects have used a small area replacement ratio (less than 5%) for rigid inclusion elements. Rigid inclusion elements subjected to lateral loads and need for steel reinforcement have become a concern for some projects. How to consider lateral loads in design still requires further research.

According to the survey, the majority of the respondents indicate that (1) embankments are the most common application of RIs, (2) drilled displacement columns are the most common type of RIs, (3) reducing settlement is the main objective of RIs, (4) clay is the soil type where RIs are commonly used, (5) design-build is the most common contracting methods for RIs in projects, and (6) the conditions for using steel reinforcement in RIs are: slope stability, seismic load, and horizontal loads.

The numerical analysis shows that both unit cell and global models could reasonably model embankments over soft soils, rigid inclusions, and rigid inclusions with geosynthetic reinforcement. The commonly-used design methods in the literature gave a wide range of predictions of the performance of rigid inclusions under embankments. All these four commonly-used design methods evaluated in this study are overall conservative. The FHWA strain compatibility method gave better prediction of load efficacies while the Netherlands method (CUR226) gave better prediction of differential settlement and reinforcement tension in the load transfer platform. Both the British method and the stress reduction method overestimated the factor of safety as compared with the numerical method.

Installation sequence of rigid inclusions affects the displacements of pre-installed rigid inclusions, which may affect their integrity and quality.

Circumstance affecting project or budget. (Please describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope and fiscal constraints set forth in the agreement, along with recommended solutions to those problems).

No challenges have been encountered so far that might affect the completion of the project within the time, scope, and fiscal constraints set forth in the agreement.

Not yet.

Potential Implementation: