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| **Project Name:** | Improving Track Substructure Designs and Settlement due to Complex Dynamic Loads from High Speed Passenger and Freight Trains (Phase 2) |

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| **Project ID:** | NURail2013-UIUC-R10 | | **Funding Year:** | 2012 | 2013 | | 2014 | | 2015 | |
|  | | Is this the continuation of a prior year project? | | | | YES | | NO | |
| **Project Type:** | | Research | Education | Tech Transfer | | SDP | | Other | |

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| **Project Team:** |  |  |  |
| **Name** | **Role** | **Institution** | **Department** |
| Erol Tutumluer | Principal Investigator | UIUC | CEE |

**Project Summary:** *(Include objectives, scope & method. 300 words maximum or 1/2 page)*

Railroad track substructures that have traditionally supported heavy freight trains are undergoing rehabilitation as they are developed into shared corridors capable of supporting higher-speed passenger service, generating more complex dynamic loading. These substructures consist of mostly ballasted track, which must be durable, stable, and able to withstand repetitive dynamic loading without excessive deformation or ride quality degradation. There is an increasing need to (i) better understand effects of different qualities of aggregate types, degradation trends, tie-ballast gap and tie support conditions as well as effects of moisture on subgrade and ballast layer performance under such demanding dynamic loading scenarios anticipated in shared corridors and (ii) develop engineered/optimized ballast specifications and subgrade preparation guidelines for improved track performance and hence increased network safety and reliability. This project aims to improve track substructure designs by properly evaluating effects of mixed-traffic on track performance through the use of an integrated approach to dynamic analysis of the railway track behavior from field instrumentation, analytical modeling, as well as numerical simulations using the Discrete Element Method (DEM). A discretely supported tie, ballast and subgrade track model will be used to study complex dynamic loading patterns, tie-ballast gap and tie support conditions and the related substructure deformations measured under both high speed passenger and heavy freight trains. Associated track settlement, vibration and deterioration trends due to these moving wheel loads will be realistically evaluated using the field-validated ballast numerical model developed at UIUC based on the DEM utilizing an imaging based ballast aggregate particle size/shape characterization. The results from the dynamic, repeated train loading DEM simulations are expected to improve ballasted track substructure designs including railway transitions which often experience differential movement due to differences in track system stiffness, foundation type, ballast settlement from fouling and/or degradation, as well as subgrade settlement.

. **Strategic Goals / Research or Educational Areas Addressed:**

*(Check at least one under both USDOT Strategic Goals and NURail Center Topic Areas)*

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| **U.S. DOT Strategic Goals** | **NURail Center Topic Areas** | |
| Safety | Infrastructure | Passenger/Public Transport |
| State of Good Repair | Rolling Stock / Equipment | Freight |
| Economic Competitiveness | Safety & Risk | Multimodal |
| Livable Communities | Operations | Institutional |
| Environmental Sustainability | Capacity | Education |
|  | Reliability | Workforce Development |
|  | Planning | Technology Transfer |
|  | Economics | Other |

**Detailed Scope of Work:** *(Include a description of the project, a list of tasks and associated deliverables and how students will be involved. 600 words maximum or 1 page)*

High speed passenger and heavy freight trains jointly operating in shared tracks/corridors generate complex dynamic loading patterns of varying pulse magnitudes/shapes with different dynamic amplifications and rest periods. There is an imminent need to develop proper track models to evaluate effects of mixed traffic as well as varying tie-ballast support conditions on track settlement, vibration and deterioration trends.

A discretely supported tie, ballast and subgrade track model was recently proposed as a “sandwich” type structure, i.e., “beam (rail) on discrete support (ballast) on beam (trackbed, or bridge deck/approach) on Winkler foundation (subgrade)” combination, by research efforts of the principal investigator. Further, with the objective to provide better engineering insight into the designs of ballasted track, current ongoing research at the University of Illinois has also developed a ballast performance model based on the Discrete Element Method (DEM) to realistically simulate interactions of angular ballast aggregate particles. The ballast DEM model requires as input the imaging based aggregate shape, texture and angularity quantifications to precisely create three-dimensional (3D) aggregate shapes as individual “polyhedron” type discrete elements. The ballast DEM model, calibrated with laboratory direct shear (shear box) strength test results and validated with settlement measurements from full-scale test track, is a quantitative track performance prediction tool.

This project will consider an integrated approach to dynamic analysis of the railway track substructure behavior using field instrumentation, analytical modeling, as well as numerical simulations of ballast using the DEM. Track response data from field instrumented crossties and rail will be used to determine track substructure layer properties and calibrate the discretely supported track dynamic model. Loading profiles generated from this model will be used as input for the DEM model to predict tie vibrations and individual particle accelerations within the ballast layer. The importance of modeling the ballast as a particulate medium will be highlighted, and the particle contact based on load transfer within the ballast will be demonstrated.

The proposed NURail research in infrastructure renewal and track substructure designs for mixed traffic loading considerations will therefore consist of the following project tasks:

Task 1 – Analyzing Dynamic Load-deformation Data from the Northeast Corridor: Concrete ties and rail were instrumented at three bridge approaches on Amtrak’s North East Corridor (NEC) near Chester, PA with multidepth deflectometers (MDDs) and strain gages, respectively. The MDD systems were successful in recording both the permanent (plastic) and transient deformations of individual track substructure layers subjected to dynamic wheel loading. Analyses of the track settlement (or permanent deformation) data at the instrumented sites established the ballast layer to be a primary source of recurrent settlement and geometry problems in the track. Strain gauges mounted on the rail to measure the applied vertical wheel loads were successfully used to quantify tie support conditions. The full dynamic oscillation patterns of the instrumented ties due to gaps and tie seating disturbances under the ties and movements in the ballast aggregate will be studied due to the passages of high speed passenger and heavy freight trains.

Task 2 – Dynamic Track Model Simulations: The discretely supported dynamic track model will be fully developed to study different combinations of dynamic loading patterns due to high speed passenger and freight trains operating jointly in shared tracks/corridors. The pulsed stresses acting on various track substructure layers, i.e., ballast, subballast and subgrade, due to such mixed traffic patterns will be studied for different tie-ballast contact as well as trackbed and railway transition conditions.

Task 3 – Performance Prediction using the DEM Methodology: The ballast DEM model will be provided with the mixed traffic loading profiles generated from the dynamic track model considering different dynamic load amplifications and rest periods experienced under different train combinations and speeds. By applying accurately the pulsed field stresses and the realistic tie-ballast support conditions, the effects of vibration and ballast degradation, i.e., crushing and changes in particle shape and size distributions at different load levels, will be evaluated. Associated track settlement, vibration and deterioration trends due to moving wheel loads under mixed traffic will be realistically predicted from the DEM track simulations.

**How Project Relates to U.S. DOT Strategic and NURail Center Goals:** *(Provide an explanation of how the stated goals will be addressed in the project. 300 words maximum or 1/2 page)*

Track Substructure, Mixed Traffic from High Speed Passenger and Freight Trains, Track Settlement, Safety

supp Supported Dynamic Track Model, Ballast Discrete Element Model

The proposed research deals with “Infrastructure” topic area. The project will develop appropriate models to properly define and analyze the most critical track substructure loading considerations due to mixed traffic. Such complex dynamic loading scenarios anticipated in joint passenger and freight corridors will be investigated for developing rapid deterioration of track to cause inadequate tie support and hanging tie type conditions as recently observed with data collected in the field. Major insights will be gained into the safety and performance evaluations of current track designs under both freight or/and high speed passenger train traffic. Accordingly, the project will determine conditions for “Safety” of operation, which can in turn be used to define the “State of Good Repair” of rail infrastructure to ultimately bring “Economic Competitiveness” through adoption of improved track substructure designs. The quantitative track performance simulation capability for settlement and lateral movement under realistic dynamic train loads, from both freight lines and combined freight and passenger mixed traffic conditions, will help to engineer/optimize ballast material properties, evaluate ballast deformation trends to improve tie-ballast support conditions, accordingly recommend development of new specifications, and as a result, improve ballasted track designs for different trackbed and railway transition (bridge deck/approach, turnout, grade crossing, etc.) conditions.

**Index Terms / Keywords:**

**Estimated Number of Students Involved:** *(by academic level)*

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| --- | --- | --- | --- | --- | --- | --- |
| **Primary** | **Secondary** | **Bachelors** | **Masters** | **Doctoral** | **Post-Doc** | **Total** |
|  |  |  |  | 1 |  |  |

**Type of Student Involvement:** *(e.g. Research Assistant, Teaching Assistant, Other, etc.)*

Ms. Wenting Hou will be supported 50% time as the PhD student and graduate research assistant in this project.

Research Assistant

**Proposed Project Schedule:**

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| --- | --- | --- |
| **Project Start** | **Project Complete** | **Duration (months)** |
| May 16, 2015 | May 15, 2016 | 12 |

**Estimated Project Budget:** *(Note: Verify Cost Share requirements for Funding Year at Institutional Level)*

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| --- | --- | --- | --- |
| **Source** | **Status** | **Amount** | **% Total Cost** |
| **NURail Funds** | Proposed | 65,000 | 65,000 |
| **Cost Share:** |  |  |  |
| Source 1 | Available | 100,000 | 100,000 |
| Source 2 |  |  |  |
| Source 3 |  |  |  |
| **Subtotal Cost Share:** |  | 100,000 | 100,000 |
| **Total Estimated Project Cost:** |  | 165,000 | 165,000 |

Source 1:

Project title: Track Substructure Strategic Research Initiative University Partner

Project funded by: Association of American Railroads

Project funding amount: $100,000 (1/2015-12/2016)